The influence of lithology on physical, chemical, and biological characteristics of headwater streams in the Feniak Lake region, Noatak National Preserve, Alaska.

Michael B. Flinn[1]
William, B. Bowden[2]
Bruce J. Peterson[3]
Julia R. Larouche[2]
and
Angella R. Allen[4]

[1]Biological Sciences, Murray State University, Murray, KY, U.S.A.
email:michael.flinn@murraystate.edu

[2]Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT, U.S.A. email:breck.bowden@uvm.edu

[3]The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, U.S.A.
email:peterson@mbl.edu

[4]Department of Biological Sciences, University of Alabama, Tuscaloosa, AL, U.S.A.
email:arallen3@bama.ua.edu

Final Report to the National Park Service
Arctic Network
Fairbanks, Alaska

31 December 2009

Abstract

In 2006, we sampled a set of 16 streams in the central Noatak River Basin in northwest Alaska, USA as part of an effort to develop a freshwater monitoring program for the Arctic Network (ARCN) in the National Park Service (NPS). Our sampling framework used lithology as a basis to stratify the sampling effort, on the premise that lithology would introduce variation in measured indicators that might obscure real trends detected in a future monitoring program. The Feniak Lake area of the Noatak National Preserve is characterized by contrasting lithologies including ultramafic (UM), non-carbonate (NC), and complex sedimentary (CS) formations. Important physical, chemical, and biological characteristics of streams arising on these lithologies differed significantly, consistent with *a priori* hypotheses. Chlorophyll *a* concentrations were variable within and between lithologies and not significantly different, but patterns suggested highest production in NC watersheds. Concentrations of N and P were very low across all streams. Total dissolved P (TDP) was not significantly different among streams but total dissolved N (TDN) was 2x higher in NC streams than in the other stream types. Significantly higher (P<0.05) amounts of metals (Fe, Ni, Si (3x)), base cations (Mg^{++}, Ca^{++}), dissolved organic carbon (4x), and benthic organic matter (~2x) were found in NC versus UM streams. Analysis of macroinvertebrate communities revealed similar trends with significantly (P<0.01) higher abundance (2x), biomass (5x), taxa richness (4/3x), Shannon's diversity (2x) and ratios of collector-filterer (3/2) and scraper (4x) functional feeding groups in NC streams versus those streams of ultramafic origin. Streams arising from complex sedimentary watersheds had variable characteristics that were intermediate with respect to the other two lithologies. These data (and similar data from 2005) suggest that lithology is an important variable that can be used to direct future surveys of freshwater resources in the Noatak River basin and may provide guidance for sampling in other high latitude stream ecosystem studies.

Keywords: arctic streams, lithology, organic matter, macroinvertebrates, chlorophyll *a*, algae, watershed, functional groups

Introduction

Wide-scale patterns of climate and geology influence the physical structure of streams and their associated chemical characteristics and biological communities. It is widely accepted that the variation in stream structure and function depends on the interaction of these processes and the spatial and temporal scale being studied (Frissell et al 1986, Rosgen 1994, Richards et al 95, Huryn et al. 2005). Thus, we thought that differences in landscape-scale geology – expressed as surficial lithology – might be a logical framework to underpin a long-term aquatic monitoring program for the Inventory and Monitoring Program of the Arctic Network in the National Park Service (NPS).

Several models have been developed to conceptualize how lotic systems are organized (Vannote et al. 1980, Ward and Stanford 1983, Junk et al. 1993, Poff et al. 1997). These models, in conjunction with theories that address species interactions and diversity (Connell 1978, Huston 1979, Lake 2000) provide a framework for the structure and function of streams within a network. The role of lithology as a driver of physical and biological conditions has received more attention over the last 20 years, although, the number of studies are few. However, studies conducted in pristine high-latitude streams that examine the influence of landscape level parameters are limited. Huryn et al. (2005) showed that arctic stream-community structure is influenced significantly by stream type (e.g., mountain, tundra, spring) with specific regard to substratum freezing and instability. In areas where permafrost dominates the landscape, differences in water chemistry and hyporheic exchange have been shown to be influenced by stream geomorphology (Greenwald et al. 2008). And streams with different water sources (glacial vs non-glacial) have been shown to differ in invertebrate community composition (Milner and Oswood 1997, Lodz-Crozet et al. 2007). Thus, we thought that lithology could provide a useful framework to describe the structure and function of streams across stream networks within a geologically complex terrain.

The purpose of this paper was to develop and provide background data for a framework to detect changes in freshwater resources within the Arctic Network of parks in the NPS. There is growing evidence that the arctic landscape is undergoing change at an unprecedented rate (Chapin et al. 2000, IPCC 2001, US/ARC 2003, Serreze 2004, ACIA 2004) and so the selection of an aquatic monitoring framework that is based on a stratification scheme (lithology) that is inherently static will allow repeated sampling with the most inference on long temporal scales (10-100 yrs) while controlling for a key landscape factor that may introduce inherent variation or bias. The choice of lithology as a static reference is particularly important because other background layers traditionally used as sample frameworks are also changing rapidly (e.g., vegetation (Magnusson et al 2000,Tape et al. 2006), permafrost (Osterkamp and Romanovsky 1999, Pollack 2003, Frauenfield 2004)).

We examined 16 low-order streams in the Feniak Lake area of the Noatak National Preserve, Alaska, USA that were distributed over contrasting lithologies. Three lithologies were selected for the study: non-carbonate (NC), ultramafic (UM), and complex sedimentary (CS) based on findings of Jorgenson et al. (2002). The same study showed that the vegetation communities among these lithologies differ and are likely influenced by phytotoxic effects of soluble minerals and differences in soil pH. The two lithologies with the greatest contrasts are the NC and UM lithologies. The NC lithology is characterized by higher amounts of shales, organic-rich soils, and has lower pHs that support shrub birch, willow and ericaceous plants. The

UM lithology is comprised of higher amounts of basalt, gabbro, peridotite, pyroxenite and dunite, which are high in iron and magnesium and support little vegetation. The CS lithology is intermediate between the NC and UM lithologies and is comprised of shales, limestones, and mafic rocks.

We hypothesized that the differences in lithology and terrestrial primary productivity outlined above would be reflected in stream structure. Further, in the short period of time we had to work in this remote location we could not adequately assess biological functions, but assume that biological structure strongly influenced basic functions such as production, decomposition, and nutrient cycling. Specifically, differences in lithology would influence the geochemical signature, primary producer abundance (algae, bryophytes), and invertebrate community characteristics. We further hypothesized that we expected strong autochthonous influences in the UM streams, strong allochthonous influences in the NC streams and something intermediate in the CS steams.

Methods

Study Sites

The Noatak Arctic Preserve is located in northwest Alaska, USA (Figure 1). The Noatak River was internationally recognized as a Biosphere Reserve in 1976 by UNESCO and is included in the National Wild and Scenic River System. The area we sampled was located ~250 km east of Kotzebue and ~350 km northwest of Bettles, AK around Feniak Lake. The Noatak Basin is regarded as one of the last truly remote wilderness areas of its size (30352 km^2, Young 1974). Long, cold winters (February avg. 11°C) and short, cool summers (July avg. 25°) typify the Noatak Basin. Streams in the Noatak Basin are characterized by extreme conditions which exert strong abiotic control over the ecosystem. Since the first crude survey of the Noatak Basin in 1889 (Smith 1912), only a few studies have contributed additional understanding about the ecology of freshwater resources in this area (Young 1974, O'Brien 1975, Oswald et al. 1999).

Over the period July 7-13, 2006 we sampled 16 low-order streams that arose entirely within a single lithology (based on mapping of Jorgenson et al. 2002) of either ultramafic (UM), non-carbonate (NC), or complex sedimentary (CS). To minimize gross inter-site differences we selected stream reaches of approximately the same size and with no influences from nearby lakes or glaciers. To minimize day to day variations among streams, on each sampling day 3 field teams simultaneously sampled 1 reach from each of the 3 lithologies using exactly the same methods and equipment. Because the study area is very remote and our objective was to advise the NPS on methods that could be easily used by agency staff to characterize the condition of the streams in a limited amount of time and perhaps only one visit every few years, we selected simple metrics that could provide a reasonably integrated assessment of the streams.

Physical Characteristics

Weather conditions were noted to help interpret the effects of storm events on sampling effort. Each stream reach was ~100 to 300 m long (with longer reaches on wider streams) and was characterized at least 10 even-spaced locations (i.e.; 10-30 m apart). The true left and true right bank (facing downstream) were characterized separately. Stream morphology was recorded at each location as 1 of 7 classes based on the water surface and flow conditions (e.g., riffle, pool, chute, cascade, etc.). We recorded bank condition (eroding or not) and the dominant vegetation community type (1 of 7 types; e.g., shrubs, mosses, grasses, etc.) and noted the dominant benthic substrate type (1 of 7 classes; e.g., boulder, cobble, gravel, etc.) and vegetation type (1 of 6 classes; e.g., epilithic algae, filamentous algae, bryophytes, etc.). The general topography and vegetation community of the stream corridor and floodplain were recorded.

At each of the ~10 assessment points within each reach we estimated average water depth with a meter stick based on 5-6 measurements along a transect across the channel. We assessed water velocity qualitatively as slow (<0.12 m/sec), moderate (0.12-0.6 m/sec) or fast (>0.6 m/sec). We measured stream width for wetted and bankfull discharges with a meter-tape or laser range finder. Substrate embeddedness was estimated by visual inspection of the stream reach and recorded as to the nearest 10%.

Substrate composition was determined by a standard pebble count using a gravelometer (Wolmen 1954, Bevenger and King 1995, Harrelson et al. 1994). Over a zig-zag transect from bank-to-bank we collected the first substrate particle encountered by touch at 100 locations spaced at every other pace. We measured the intermediate axis of each particle and then returned it to the stream. We recorded the size of the median particle as the D50 class for that reach.

Field sample collection and processing

We measured pH, specific conductance, dissolved oxygen, and temperature using a WTW-350i multi-meter probe. The pH and dissolved oxygen probes were calibrated daily prior to each use.

At each stream reach we collected samples for later analysis of nitrate, total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), dissolved organic carbon (DOC), cations, and heavy metals samples. Water samples were collected using 60-cc syringes fitted with cellulose acetate filters (25 mm diameter, 0.45 µm pore size). Syringes were rinsed 3x with stream water immediately before samples were taken and each sample bottle was rinsed with a few mls of filtered stream-water. Care was taken to keep samples cool by placing them in ziplock bags and stored out of the sunlight or under moss at streamside. Samples were pre-processed at base camp as soon as possible after collection following standard procedures (Hauer and Lamberti 2006). Samples of TDN, TDP, DOC, cations and heavy metals were acidified with 100-µl of 6N HCl for every 50-ml of sample.

At each stream, composite rock samples were scrubbed for analysis of epilithic total chlorophyll pigments (tCHL) and to obtain samples for algal species composition, epilithic total particulate carbon (TPC), total particulate nitrogen (TPN), and total particulate phosphorus (TPP). A total of 12 rocks were collected from riffles (6 for each composite replicate). A small area on each rock defined by an empty 5-cm x 5-cm slide (film) holder was scrubbed with a small metal brush. The resulting slurry from each set of scrubs was filtered onto pre-ashed 25 mm GF/F filters. For each sample, a minimum of 100-ml sample replicates (2) were made for TPC/TPN, TPP, and 10-ml for tCHL. For algal composition, a few drops of Lugol's solution were added to ~50-mls of the slurry for preservation and later identification. A final inspection of the reach was made and any visible macrophytes, algae, bryophytes were sampled and stored in Whirlpaks for later identification based on Crum and Anderson (1981), Crum (1983), Grout (1928), Lawton (1971), Ireland (1982). The determinations for bryophytes were based on the identification of species that composed >5% of the sample. The total species count did not take into consideration smaller fragments of bryophyte litter present in many packets. All bryophyte identifications were compared to voucher specimens located in the Bryological Laboratory at Michigan Technological University before final determinations were assigned.

Within a few hours after returning to base camp, tCHL extractions were performed using standard procedures. The tCHL filters were placed into 15-ml centrifuge tubes using forceps and immersed in 10-mls of 100% acetone. After 16-18 hours of extraction the tCHL content was analyzed using a Turner Designs Aquaflor field spectrophotometer. We did not attempt to estimate phaeopigments or other chlorophyll pigments and so report these values as total chlorophyll (tCHL). In similar streams in the Toolik Lake region (100 miles to the west) we have found that chlorophyll *a* is the dominant pigment type.

A surber sampler (area = 0.9-m^2, 243-µm mesh) was used to collect quantitative macroinvertebrate samples. Five samples were taken from at least two separate riffles in each stream. Substrate was scrubbed with a brush to dislodge macrophytes and detritus. Samples were preserved in 5% formalin in whirl-packs for further examination in the lab.

Post-field work sample processing and analysis

Standard methods were used to analyze all preserved samples for chemical analyses. Nitrate was converted to nitrite by cadmium reduction (EPA method 353.2) followed by spectrophotometric analysis. Typically we find no nitrite in these types of samples and so have expressed our results as nitrate alone. The detection limit for this method is ~3.6 µM NO_3 ($\pm$12% relative standard deviation, RSD). TDP and TDN were analyzed by alkaline persulfate digestion (slightly modified from method 4500-Norg-D) followed by spectrophotometric analysis. The detection limits for this methods are ~0.2 µM P ($\pm$8% RSD) and ~1.1 µM N (+8% RSD). DOC was analyzed on a Schimadzu TOC analyzer by high temperature combustion at 720ºC. Base cations and selected metals were analyzed by inductively coupled plasma (ICP) emission spectroscopy (EPA method 200.7) with detection limits and precision as noted in the method documentation.

Macroinvertebrates were removed from preserved field samples by hand under magnification. Invertebrates were identified to the lowest practical taxonomic level, usually genus, and assigned to functional-feeding groups based on Merritt and Cummins (1996), Epler (2001), and Smith (2001). Biomass was estimated from measurements of body length using family-level length-mass relationships (Benke et al. 1999). Density and biomass/m^2 for each taxon present was estimated for each stream. Organic matter obtained during sampling was oven dried for 48 hr at 60 ^oC. Dry mass was measured and then the sample was ignited in a muffle furnace (500 ^oC) for 1-h. The remaining ash mass was measured and subtracted from dry mass to estimate ash-free dry mass (AFDM).

Statistical Analyses

Differences between lithologies were compared using analysis of variance (ANOVA) with JMP statistical software (V6.0.3, SAS Institute 2001) and tests between individual means were analyzed using the Student's t-test. Values were transformed (log [x+1] or arcsine where appropriate) to normalize data and reduce heteroscedasticity. We considered *p*-values less than or equal to 0.05 to be significant. We conducted additional analyses to examine spatial patterns in stream communities using non-metric multidimensional scaling analysis (NMDS) from DECODA© software (Minchin 2005) and Sorensen distance as the dissimilarity measure (Faith et al. 1987). We overlaid vectors representing physical habitat data to aid interpretation of macroinvertebrate ordinations. We tested for community differences among lithologies using analysis of similarity (ANOSIM, Clarke and Green 1988, Clarke 1993) from DECODA© (Minchin 2005).

Results

Physical and water quality parameters

In general, physical characteristics of streams were similar across all three lithologies. There were no significant differences between substrate size (D50 range 61-69cm) and many of the basic water quality parameters. Water temperature ranged from 5.5° - 12°C, but mean temperatures across all lithologies varied by less than 1°C. The pH across all lithologies was circumneutral with means that ranged from 7.3-7.8. Electrical conductivity ($\mu S/cm^2$) was relatively low in the UM (40 ± 5) and NC (168 ± 26) lithologies but significantly higher in the CS lithology (502 ± 153, $P<0.05$).

The concentrations of heavy metals in streams were generally very low across all lithologies and in some cases below detection limits (Table 1). Streams draining the NC lithology had the highest concentrations (all $P<0.05$) of Al, Cu, Ni, and Si (Table 1) compared to CS and UM streams. Iron was highest in NC and UM streams compared to CS streams ($P<0.05$). Chromium concentrations were higher in CS streams, but levels were at or near detection limits. There were no significant differences in Zn or Pb concentrations across all streams.

The pattern of dissolved cation concentrations differed from heavy metals. The concentrations of Ca^+, K^+, Mg^+ and Na^+ were higher (all $P<0.05$) in CS streams than in UM or NC streams. Non-carbonate streams, although not statistically different, had ~3-4x higher concentrations of Ca^+ and Mg^+ but differed little in K^+ and Na^+ concentrations (Table 1).

The streams in the central Noatak River Basin were ultraoligotrophic. The patterns of nutrient concentrations were variable across stream types. Total dissolved phosphorus was at or below the detection limits (range 0.14-0.15 µM) and had similar levels across all streams (Table 1). The concentrations of nitrate in UM streams was nearly 2x that found in CS streams and nearly 4x that found in NC streams, although no statistical differences were found. However, concentrations of TDN in NC streams were more than 2x ($P<0.05$) the concentrations found in either the UM or CS streams (Table 1). Thus, the proportion of NO_3/TDN in NC streams was about 1/6th that found in the CS streams and only 1/10th that found in UM ($P<0.05$) (Table 1). The ratio TDN/TDP was over 50:1 in the CS and UM streams and well over 100:1 in the NC streams ($P<0.05$).

Primary Producers

The tCHL concentration in each lithology showed a similar pattern to nutrient concentrations. The mean density of epilithic tCHL in NC streams was ~4x higher than UM streams, and CS streams were intermediate. The density of epilithic tCHL in UM streams was uniformly low. The density of tCHL in one NC stream (SNC08) was an order-of-magnitude higher than the densities found in the two other NC reaches. However this high measurement was found in both replicates from this reach and was corroborated by field observations and pictures of the substrate.

Algal communities were similar at all sites and had moderate diversity, with 7 to 28 taxa per site. Dominant species varied between sites with one of the following typically observed as dominant or co-dominant: *Achnanthidium minutissima, Achnanthes* cf. *microcephala, Cymbella minuta, Diatoma tenue, Fragilaria vaucheriae, Gomphonema angustatum, Hannea arcus, Meridion circulare,* or *Tabellaria flocculosa*. The diatoms *Cocconeis placentula* and *Diatoma hiemale* which are common elsewhere in the Noatak headwaters (Bowden, unpublished data) were not commonly observed at these sites. Elevated levels of *Achnanthidium minutissima*, were found primarily at sites with median pebble counts below 100 mm.

Bryophytes were not abundant in these streams. We collected 11 bryophyte species and 1 liverwort specimen. *Bryum pseudotriquetrum* was present in 7 samples, *Hygrohypnum alpestre* was present in 8 samples, and *Hypnum lindbergii* was present in 5 samples. The abundance of *Bryum pseudotriquetrum* in the samples is not surprising as it is a common and widely distributed moss. *Schistidium agassizii* which is common in streams on the North Slope of Alaska (Bowden refs) was found in only 3 collections. Other bryophytes encountered included *Drepanocladus revolvens, Calliergon sarmentosum*, *Bryum muehlenbeckii, Campylium stellatum*, and *Didymodon rigidulus* with the liverwort *Philonotis fontana* in one sample.

Dissolved Organic Carbon and Particulate Organic matter

The concentration of dissolved organic carbon DOC was ~4x higher (P<0.01) in NC streams compared to UM and CS streams (Table 1). Benthic organic matter followed the same patterns as DOC. Total particulate organic matter in NC streams was ~1.6x higher (P<0.01) than UM and CS streams. The coarse fraction was over 1.5x more abundant in NC streams compared to both CS and UM streams (Table 1) though not statistically significant. The fine particulate organic matter in NC streams was 2x (P<0.01) more abundant compared to UM streams and 1.6x (P<0.05) CS streams (Table 1). The proportion of coarse particulate organic matter was over 2x greater than fine fractions across all lithologies.

Macroinvertebrates

The patterns of aquatic macroinvertebrates generally mirrored that of nutrients and primary producer abundance. Over 40 different taxa were collected, not including Chironomidae genera. Most stream communities contained Oligochaeta, chironomids (mostly genus *Diamesa*), and the mayfly *Capnia* (Capniidae). The NC and CS streams had relatively higher densities compared to UM streams (Figure 2) and ranges were typical of arctic tundra and mountain streams. Differences were more apparent in community biomass where NC streams had 1.5x higher biomass compared to CS streams and over 7x higher than UM streams (P<0.01, Figure 2b). Taxa diversity was low with means that ranged from ~13 taxa in NC streams to ~9 taxa in the UM streams. The collector-gatherer functional feeding group dominated all streams representing over 60% (Figure 3). Shredders represented significantly more (P<0.02) of the community in CS streams (30%) than NC streams and were similar to UM streams (23%) (Figure 3). Collector-filter feeding groups were similar across the all lithologies and represented about 5% (Simuliidae and *Brachycentrus* (Brachycentridae) (Figure 3). The biggest differences were represented by the scraper group (Figure 3) where NC streams had a significantly higher ratio (p<0.01) than CS and UM streams mostly because of the presence of three taxa in NC streams (i.e. mayflys *Cinygmula sp.* (Heptageniidae) and *Baetis sp.* (Baetidae), and chironomid *Orthocladius sp.* (Orthocladiinae)).

NMDS and associated analyses confirmed differences in macroinvertebrate communities between each lithology (Figure 4). Vector analysis indicated that higher concentrations of DOC and TDN were correlated with the NC streams (Figure 4). The ratio of TDN:TDP had the highest correlation with the communities in NC streams. In contrast, UM stream communities had high correlations with NO_3 and the proportion of NO_3/TDN. Anosim analysis showed that all lithologies were statistically different from one another. However, the largest differences in macroinvertebrate communities (ANOSIM R=0.78) were between NC and UM streams (Figure 4) which was consistent with our *a priori* hypotheses.

Discussion

The freshwater resources of high-latitude regions contain some of the most pristine systems on the planet. Recently the nature and condition these resources have received more attention in light of increasing anthropogenic influences, including climate change, and the resulting effects on high-latitude landscapes (ACIA 2004). The freshwater resources in the Arctic Network of parks are particularly poorly characterized and so the NPS has a mandate through its Inventory and Monitoring program to establish a baseline and develop a monitoring program for these under-studied areas (Oswood 1989, NPS I&M 2002). The primary purpose of this study was to provide preliminary information that could inform the development of a future monitoring framework for the Arctic Network parks. To this end we developed a sampling strategy that stratified stream types on the basis of the lithology from which the streams arose. We hypothesized that inherent lithological differences would introduce variation that would have to be quantified to understand whether and how streams in the Arctic Network of parks had changed at some future point in time. Furthermore, stratification on the basis of lithology could provide a means to extrapolate stream characteristics over space to areas of the park lands that could not be sampled but for which lithology is known.

Physical Characteristics of the Streams

The streams we chose for this study did not differ across the three selected lithologies with respect to simple morphological characteristics (width and depth) and the physiochemical variables of temperature, pH, and dissolved oxygen. However, electrical conductivity (Ec) differed significantly among the streams by lithology. As Ec is a proxy for the ionic concentration of water it is a strong indicator that streams arising on different lithologies have different biogeochemical characteristics that may in turn influence biological community structure and functions.

Heavy Metals and Cations

Several studies have shown that high concentrations of heavy metals in soils can influence the concentrations found in riparian and aquatic invertebrates (Notten et al. 2005, Corbi et al. 2008, Schipper et al. 2008). However, in our study, the concentrations of heavy metals in the stream water were several orders of magnitude lower than studies evaluating anthropogenic impacts. The patterns of heavy metal concentrations of the central Noatak streams were consistent with *a priori* hypotheses. The highest concentrations of metals (Al, Fe, Ni, Si) were typically in NC streams (Table 1). Initially this finding seemed to conflict with our hypotheses. However, when we compared the concentrations of metals to soil concentrations (Jorgenson unpublished), it was apparent that high concentrations of Al, Mg, and Ni, were present in UM lithologies but these metals were not reaching the stream. Overall, the concentrations of heavy metals in these streams were very low and likely had little direct influence on primary producers and consumers.

Although we found no significant differences in the concentrations of base cations between UM and NC streams the concentration of Mg^+ and Ca^+ in NC streams was always ~4x higher (Table 1). This observation, along with the heavy metals results, suggests that weathering in ultramafic lithologies is relatively low compared to NC and CS streams. The CS streams had 3-4x higher concentrations of all base cations and are likely why Ec was higher in these streams. Biggs et al (2002) showed that lithology had a significant influence on the concentration of base cations across forested and deforested watersheds of Brazil. The differences in base cations among lithologies may be especially important in detecting the impact of future changes in vegetation (Tape et al 2006), precipitation forms (McNamara et al 1998, ACIA 2004), and weathering on the landscape (Goosseff et al. 2002, Maurice et al 2002) and might be a potentially useful metric for long term monitoring of remote locations in the Arctic.

Nutrients

The streams in the Central Noatak Basin were sampled for NO_3, TDN, and TDP. We did not sample NH_4 or PO_4 because these analyses have to be done immediately and we did not have the facilities at this remote location to do these analyses reliably at the very low concentrations we expected we would encounter. Based on the analyses, these streams were ultraoligotrophic even compared to the North Slope of Alaska (Table 3). The ranges of NO_3 in the central Noatak Basin were similar to concentrations measured in the Kuparuk River and tundra streams on the North Slope. However, the average TDN was only 50% that of tundra streams on the North Slope. The more productive streams on NC lithologies had similar NO_3 and a relatively lower ratio of NO_3 as a proportion of TDN indicating that vegetation and interactions with soils may influence inorganic nitrogen availability. The catchments with the greatest development of vegetation and soils have the lowest nitrate levels as a proportion of TDN. Sine ammonium levels are normally very low in all these streams, this indicates that DON dominates the TDN pool in streams of productive catchments. The UM streams were more comparable to mountain streams of the North Slope than any other stream type.

The TDP varied little across lithology and was very low. Only a few mountain and spring streams on the North Slope and twenty tributary streams in the Upper Noatak had lower average TDP. The TDN:TDP ratios ranged from 55 to 130 (Table 3) suggesting that if production and decomposition are nutrient limited, phosphorus is in shortest supply. Studies have shown that several streams on the North Slope are phosphorus limited (Peterson et al 1993, Bowden et al 1994) and even small increases in phosphorus supply can greatly increase production in these oligotrophic streams (Slavik et al 2004). The UM streams of the central Noatak Basin had similar levels of TDP compared to other lithologies but had a much higher NO_3 as % of TDN. Furthermore, Jorgenson (unpublished) showed that UM soils were low in P compared to other lithologies. Taken together these observations suggest that the streams in the central Noatak River region are severely P-limited.

Primary Producers and Dissolved Organic Carbon

The concentrations of tCHL were highly variable, even within a single lithology. The tCHL in NC streams were the most variable and had the highest (0.68 μg/cm^2) and lowest concentrations (0.02 μg/cm^2) we sampled. Even though no statistical differences were detected between lithologies, the general pattern we observed suggested that NC streams were more productive than either CS or UM streams (Table 1), which was consistent with measurements of dissolved and particulate organic carbon. The UM streams were less variable (0.12-0.38 μg/cm^2) and had the lowest mean tCHL density. Though not significant this result was consistent with our qualitative observations that the epilithic biofilm was least well developed in the UM streams compared to the other lithologies.

The concentrations of tCHL we observed were similar to those measured on the North Slope and similar to levels of the Upper Noatak. Most dissolved organic matter in these streams is derived from terrestrial vegetation and soils as is clear from the concentrations being far higher than could be attributed to autochthonous production.

The primary producers we encountered (algae and bryophytes) were common and widely distributed species. We did not find any rare or endangered species. However, our sampling design was not optimized to discover new species.

Low nutrient conditions, freezing temperatures, low radiation, and high substrate disturbance typically limit primary production in arctic streams during parts of the year. Of these factors, the very low nutrient conditions are probably the most important in limiting the abundance and distribution of aquatic bryophytes in these streams (Stream Bryophyte Group 1999, Huryn et al. 2005). Although we did not collect data on substrate instability, it is noteworthy that the bryophyte specimens we collected were all on the NC and UM lithologies; we did not encounter bryophytes in the CS streams. This may indicate a greater degree of substrate instability in this lithology in addition to the low nutrient conditions.

The pattern of DOC showed that organic carbon export from NC streams was 4x higher than in CS and UM catchments. This agrees with the pattern of DON concentration in these stream types.

Benthic Organic Matter and Macroinvertebrates

The distribution of benthic organic matter (BOM) influences patterns of macroinvertebrate diversity and productivity (e.g., Egglishaw 1964, Brussock 1985, Whiles and Wallace 1995, Baer et al. 2001, Flinn et al. 2005). The pattern we observed was that coarse (> 1mm) organic matter comprised 2 to 3 times more mass in each stream type than fine organic matter (Table 1). Even though this pattern is typical of other systems (Wallace et al. 1987, Flinn et al. 2008, Stagliano and Whiles 2002, Colón-Gaud et al. 2008), the difference is interesting in this context. The low autochthonous production in UM streams ultimately increases the relative importance of allochthonous inputs in those streams and increases the importance of shredders. Cross et al. (2003) showed that nutrient content of different size fractions of BOM varied significantly and that FPOM was more enriched due to higher surface area to volume ratio and the colonization of bacteria and fungi. The energy and nutrient cycling in UM streams may be tightly connected to the comminution of particles by shredders (Eggert and Wallace 2003) and consequent acceleration in export of fine organic matter from the headwater reaches.

The lack of shading from streamside vegetation in these arctic tundra streams should increase the importance of autochthonous production and create a system more similar to prairie (e.g., Dodds et al 1996, Stagliano and Whiles 2002) and desert systems (e.g., Fisher and Gray 1983, Jackson and Fisher 1986). Allen et al. (in review) found that isotope analysis of macroinvertebrates in these same streams show a strong dependence on autochthonous production. These isotope data are supported by the patterns in tCHL, DOC, BOM (allochthonous mainly), and macroinvertebrates sampled in NC streams. However, UM streams were characterized by extreme nutrient limitation, low primary production, low DOC, and a relatively small percentage of fine particulate organic matter (from isotope analysis), evidence supports a system driven by allochthonous detritus.

Determining the effects of resource limitation and habitat complexity or stability on macroinvertebrate communities is difficult (Richardson 1992, Lee and Hershey, 2000, Parker and Huryn 2006). Macroinvertebrate communities of the central Noatak River basin reflect differences in lithology, but distinguishing between causal mechanisms is difficult without additional data. Although these communities were simple compared to more temperate counterparts (Oswood 1989), the patterns in density, biomass, and functional group were consistent within each lithology.

It was clear that the macroinvertebrate communities in NC streams reached higher densities, had higher community biomass, and each individual was larger compared to UM streams. Several studies have shown that macroinvertebrate communities have a quantitative response to food availability (Wallace et al. 1982, 1991, Petersen et al. 1989, Hershey et al. 1993) and important patterns were evident during our study. The differences in density between each lithology were mostly due to different abundances of the same dominant taxa. There were differences in the scrapers mentioned above and higher densities of predaceous chironomids, the stonefly *Alaskaperla*, and blackfly *Simulium*. But only the scrapers and blackflies were likely responding to bottom up control of food resources and increased periphyton and FPOM in NC and CS streams. Community biomass in NC streams was a good indicator of better food resources in the NC streams. These streams had more benthic organic matter and higher tCHL density, both of which have been shown to be important for macroinvertebrate production (Petersen et al. 1989).

Although the similar substrate size among the streams might indicate that streams in all lithologies are subject to similar potentials for bed movement, several lines of evidence indicate otherwise. The presence of macroinvertebrates indicative of lower disturbance (Irons et al. 2003, Parker and Huryn 20006), including the relatively long-lived stonefly predator *Alaskaperla*, were exclusively collected in NC streams and indicate these streams freeze less frequently and less severely. Further, bryophytes were only collected in NC and UM streams. Another notable algal taxon, *Achnanthes* cf. *microcephala* was observed at high relative density mainly in UM streams. As noted previously, systems with smaller bed material likely suffer periodic disturbance, which favors small adnate growth forms (Biggs et al. 1999). However, *Tabellaria flocculosa* was often observed in concert with *Achnanthidium*; as a colonial form, it suggests a period of stream stability before the collection was made. Along with this lithologic preference, it is also likely to be another indicator of disturbance. This diatom is not adequately described in common taxonomic references, and merits further inquiry. Relatively longer periods of substrate stability, increased algal and bryophyte density, and organic matter accumulation likely increased macroinvertebrate densities and biomass in NC streams.

The dominant taxa (Oligochaeta and chironomids) along with most of the other groups were similar to the Upper Noatak (2005) communities. In the Upper Noatak study, some unique taxa were observed in spring habitats, which were not sampled in 2006. As well, the taxonomic resolution of Chironomidae was higher in the 2005 study which increased the number of unique taxa. The relative percent of functional feeding groups were consistent with findings in other studies conducted on the North Slope (Huryn et al 2005, Parker and Huryn 2006) and several of these relationships were strong indicators of differences between lithologies and the best indicator of ecosystem function in these streams. A nearly 4-fold increase of scrapers in NC streams compared to UM streams and 2-fold increase compared to CS streams indicates a significant difference in function of those streams. Studies have shown that geomorphology influences the distribution of stream benthos on fine (e.g., Huryn and Wallace 1987, Brussock and Brown 1991) and large scales (Richards et al. 1996); however, few studies have shown the influence of lithology on an undisturbed ecosystem. Considering that the fine scale geomorphology in this study was similar, macroinvertebrate communities were significantly influenced by wide scale differences in lithology..

In summary, we found that important chemical and biological characteristics of the streams in the Feniak Lake region of the Noatak National Preserve could be related to differences in the lithology of the area in which the streams arose. As we hypothesized, streams arising on the more enriched and diverse NC lithologies had greater primary producer abundance, higher concentrations of DOC and TDN (though lower concentrations of NO3), and greater biomass of macroinvertebrates than was the case for the harsher UM lithology. The CS lithology had, as we expected, intermediate properties. These data provide a useful benchmark for future monitoring. More importantly, they show that lithology could and perhaps should be used as a means to stratify future stream sampling to isolate the variance that can be attributed to lithology alone from that contributed by anthropogenic drivers, including climate change. This information should be used to help inform the sampling program that is developed as part of the Inventory and Monitoring program for the Arctic Network in the National Park Service.

Acknowledgements

We thank Kumi Rattenbury, Tara Whitesell, Scott Miller, Suzie Mauro, Greta Burkart, and Jim Lawler of the National Park Service for field and administrative help, as well as Diane Sanzone who originally supported this project. We thank George Helfrich, Superintendent of the Western Arctic Parks including the Noatak National Preserve, for his support and encouragement. We thank our helicopter pilot Stan Herman and the staff of Bettles Air for their expert logistics support. This project was funded by the National Park Service Arctic Network (ARCN) Inventory and Monitoring Program. The conclusions and opinions expressed in this report are those of the authors and are not necessarily shared or endorsed by the National Park Service.

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Table 1. Physical, chemical and biological characteristics of 16 low-order stream reaches of the Central Noatak Basin, Alaska during 2006.

	Lithology					
	Complex Sedimentary ±1 SE		Non-carbonate ±1 SE		Ultramafic ±1 SE	
Parameters						
Sample size(n)	6		5		5	
Substrate(D50 mm)	69.50	7.14	61.60	12.98	65.75	9.24
Conductivity (uS/cm^2)	502.24	153.53	168.68	26.11	38.26	4.41
pH	7.71	0.16	7.54	0.12	7.34	0.15
Temp ºC	8.78	0.64	8.50	1.19	7.88	0.33
DO (mg/L)	10.90	0.37	10.89	0.71	10.93	0.23
Metals (ug/L)						
[Al]	92.25	1.37	102.08	1.83	95.72	2.73
[Cr]	1.85	0.12	1.17	0.19	1.30	0.20
[Cu]	0.51	0.04	1.44	0.12	0.48	0.13
[Fe]	12.32	1.10	42.34	6.83	33.02	10.40
[Pb]	0.05	0.01	0.05	0.00	0.06	0.01
[Ni]	0.65	0.11	5.20	2.44	0.92	0.08
[Si]	1703.33	72.88	3176.00	607.87	2278.00	134.51
[Zn]	14.22	11.80	2.82	0.31	1.94	0.42
Cations (mg/L)						
[Ca++)	38.01	8.96	14.00	2.41	3.80	0.80
[K+]	1.14	0.05	0.93	0.01	0.89	0.00
[Mg++]	27.40	4.88	9.06	1.82	1.92	0.56
[Na+]	5.08	1.50	1.57	0.04	1.30	0.03
Nutrients						
[NO3]	2.62	0.89	1.08	0.15	4.27	1.42
[TDN]	7.69	0.73	17.88	2.61	7.28	1.18
[NO3/TDN]	0.34	0.10	0.06	0.01	0.56	0.13
[TDN-NO3]	5.07	1.02	16.80	2.62	3.01	0.77
[TDP]	0.15	0.01	0.14	0.01	0.15	0.02
[TDN/TDP]	54.77	5.93	128.58	18.95	53.78	11.36
Primary Producers						
tCHL (*u*g/cm^2)	0.32	0.26	0.80	1.10	0.20	0.13
Organic Matter						
DOC(mg/L)	2.79	0.20	8.33	0.93	2.13	0.15
Benthic (total g AFDM/m^2)	6.96	1.21	10.69	1.96	6.51	1.79
(0.25mm>fine<1mm)	2.27	0.51	3.38	0.18	1.46	0.40
(coarse >1mm)	4.69	0.97	7.31	0.78	5.05	1.07

Table 2. Bryophyte distribution and occurrence in 16 low order stream reaches sampled on contrasting lithologies of the Central Noatak Basin, Alaska during 2006.

Lithology	Site	Frequency of occurrence	Taxa
Non-Carbonate			
	SNC10	1 of 1	*Hygrohypnum alpestre*
	SNC05	1 of 1	*Bryum pseudotriquetrum*
	SNC08	1 of 7	*Bryum pseudotriquetrum*
			Hypnum lindbergii
	SNC08	2 of 7	*Hypnum lindbergii*
			Lophozia sp.
			Bryum pseudotriquetrum
			Philonotis fontana
	SNC08	3 of 7	*Hypnum lindbergii*
			Bryum pseudotriquetrum
	SNC08	4 of 7	*Schistidium agassizii*
	SNC08	5 of 7	*Philonotis fontana*
			Bryum pseudotriquetrum
			Hypnum lindbergii
	SNC08	6 of 7	*Didymodon rigidulus*
			Bryum pseudotriquetrum
			Drepanocladus revolvens
	SNC08	7 of 7	*Drepanocladus revolvens*
Ultramafic			
	SUM01	1 of 5	*Bryum pseudotriquetrum*
	SUM01	2 of 5	*Hygrohypnum alpestre*
	SUM01	3 of 5	*Hygrohypnum alpestre*
	SUM01	4 of 5	*Drepanocladus revolvens*
	SUM01	5 of 5	*Drepanocladus revolvens*
	SUM07	1 of 3	*Bryum muehlenbeckii*
	SUM07	2 of 3	*Hygrohypnum alpestre*

Table 3. Comparisons of the stream nutrient chemistry of the Upper Noatak 2005, the Central Noatak Basin 2006, and selected North Slope streams (Arctic LTER data 1997-2000 and 2004-2005. 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
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	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	10%	0.29	81
Upper Noatak 2005 n= 20	7.1	2.9	10.6	66%	0.07	315
Central Noatak 2006						
6 complex sedimentary	1.1 ± 0.9	6.6	7.7 ± 0.7	14%	0.15 ± 0.01	55
5 non-carbonate	2.6 ± 1.9	15.3	17.9 ± 2.6	15%	0.14 ± 0.01	129
5 ultramafic	3.3 ± 1.4	4.0	7.3 ± 1.2	45%	0.15 ± 0.02	54

Figure 1. Map of the central Noatak River Basin in Northwest Alaska, USA. Map shows study streams across non-carbonate (prefix SNC-), complex sedimentary (prefix SCS-), and ultramafic (prefix SUM-) lithologies sampled during July of 2006.

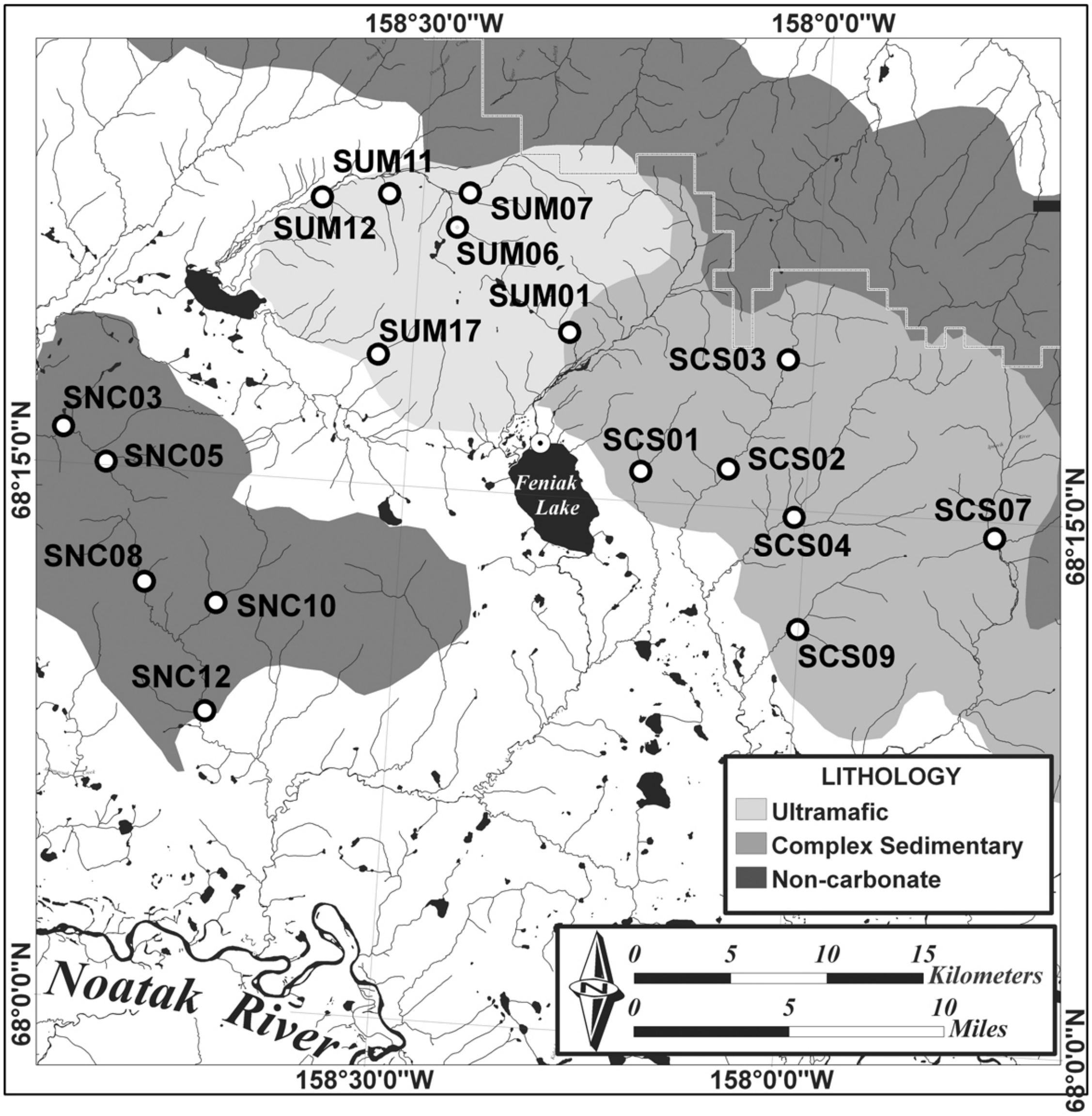


FIGURE 2. Total abundance (a) and biomass (b) of macroinvertebrates in contrasting lithologies (complex sedimentary (CS), non-carbonate (NC), and ultramafic (UM) of the Noatak Basin during 2006. Bars represent mean abundance (individuals m-2) and dry mass (DM m-2) ± 1 S.E.

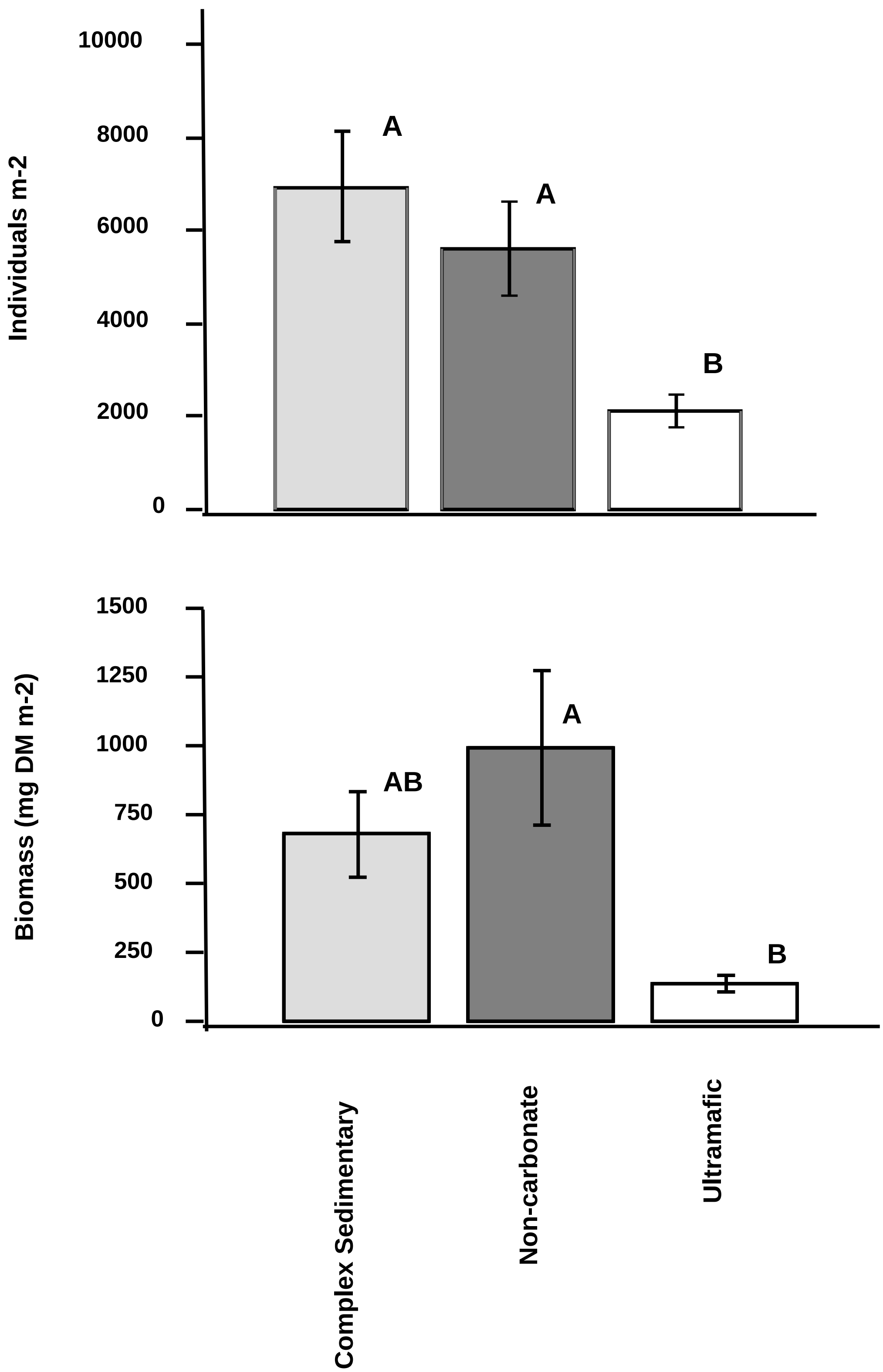


Figure 3. Relative percent of macroinvertebrate functional feeding groups of complex sedimentary, non-carbonate, and ultramafic lithologies of the Central Noatak Basin, Alaska during 2006.

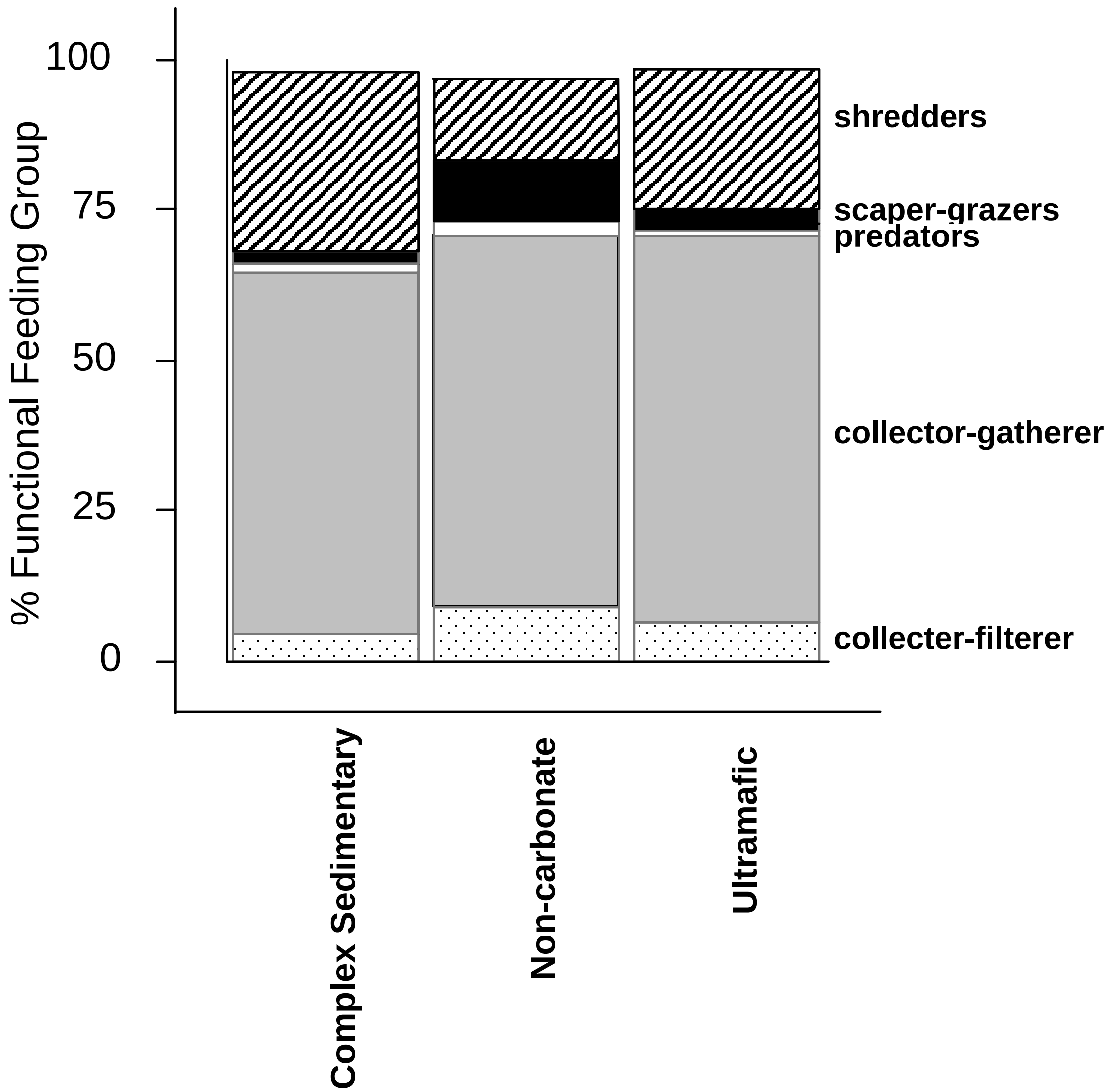
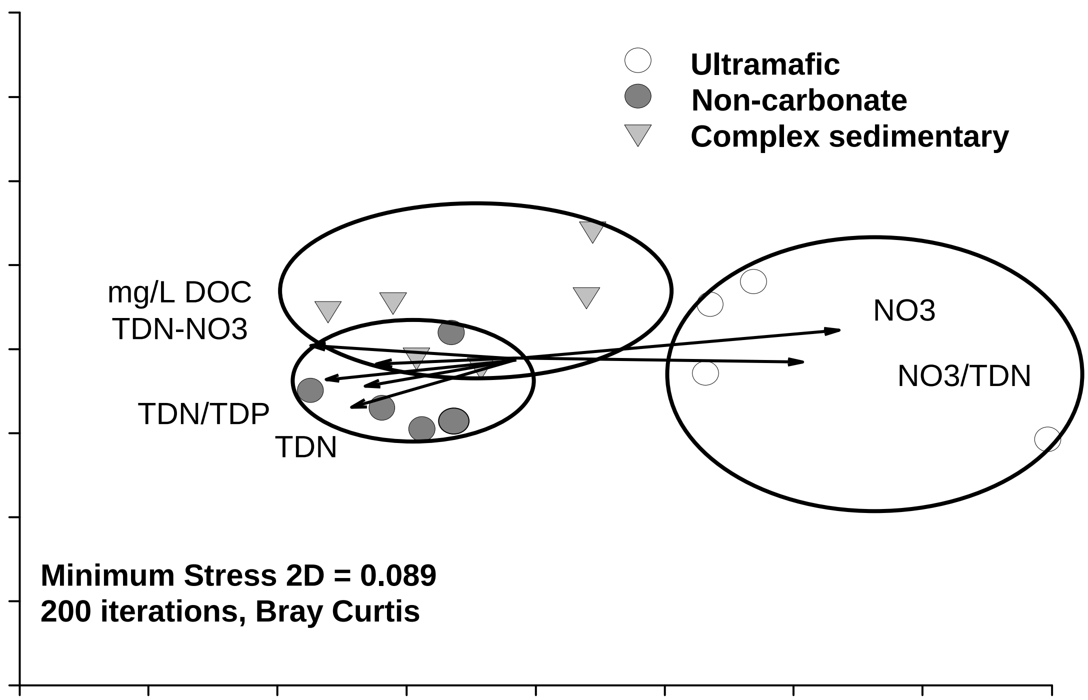


Figure 4. Non-metric multidimensional scaling analysis of macroinvertebrate community biomass in 16 streams located on contrasting lithologies of the central Noatak River Basin, Alaska, 2006. Significantly correlated environmental variables are shown as vectors.



<u>ANOSIM Analysis</u>
Non-Carbonate vs Ultramafic R = 0.78 *P*< 0.006
Complex Sed. vs Ultramafic R = 0.62 *P*< 0.004
Non-Carbonate vs Complex Sed. R= 0.34 *P*< 0.02