Condition of streams in the Arctic Coastal Plain of Alaska: water quality, physical habitat, and biological communities





A report prepared for the Alaska Department of Environmental Conservation

May 31, 2018

Rebecca Shaftel, Dan Bogan, Dustin Merrigan, and Leslie Jones

Alaska Center for Conservation Science, University of Alaska Anchorage, 3211 Providence Dr., Anchorage, AK, 99508

Table of Contents

Tables

Figures

Appendices

Introduction

The Arctic Coastal Plain ecoregion is bounded on the west and north by the Arctic Ocean and extends south to the foothills of the Brooks Range. The coastal plain is underlain by continuous permafrost and has low topographic relief that inhibits drainage. This results in a landscape dominated by thaw lakes, wetlands, and low gradient stream and rivers. The stream network on the Arctic Coastal Plain is comprised of rivers that originate in the foothills of the Brooks Range (e.g. the Meade and Ikpikpuk rivers) or within the coastal plain (e.g. the Miguakiak and Ublutuoch rivers, BLM 2012). Stream types within the river network include beaded streams, consisting of a series of narrow channels connecting deep pools; alluvial streams, which meander and have banks, bars, and floodplains; and colluvial streams, which are steeper confined streams that originate on hillslopes (Figure 1, Arp et al. 2012). Flow regimes in streams of the coastal plain are driven by snowmelt, precipitation, and connected lakes. Baseflows in summer and winter are low due to shallow active layers limiting subsurface water storage. Higher lake volumes within watersheds increases stream baseflow and decreases recessions from peakflows (Arp et al. 2012). The majority of discharge occurs during spring break-up in late May or early June and episodic rainfall events later in the summer and fall that contribute minor increases in discharge, but rarely cause flooding (BLM 2012). Rivers and streams provide important spawning, rearing, migration, and overwintering habitats for both resident and anadromous fish species. Climate change effects on streams are anticipated to be earlier break-up and later freeze-up leading to a longer open water season (Hinzman et al. 2005), increased base flows from melting permafrost (Brabets and Walvoord 2009), and increased water temperatures and nutrients (Frey and McClelland 2009).

Human activities on the Arctic Coastal Plain, such as military installations and oil and gas exploration and development, can impact stream habitats by alterations to hydrology and pollution from point and nonpoint sources. Existing military installations include the Distant Early Warning (DEW) radar stations along the Arctic Coast, constructed in the 1950s, which were converted to the Northern Warning System (NWS) sites of today. The Arctic Coastal Plain has some of the largest oil and gas reserves in the world. Production in Prudhoe Bay, the largest oil field in North America, began in 1969. Other major potential oil developments include the National Petroleum Reserve-Alaska (NPR-A) in the western coastal plain and the 1002 area of the Arctic National Wildlife Refuge on the eastern coastal plain. Annual lease sales have been held for parts of NPR-A since 1999 and the 1002 area has been recently opened by congress to oil and gas leasing.

Figure 1. Example of most common stream types on the Arctic Coastal Plain of NPR-A. Small beaded stream on top and large alluvial stream on bottom.

The objective of this project was to assess the condition of freshwater resources in the Arctic Coastal Plain ecoregion of the National Petroleum Reserve of Alaska (NPR-A). Probabilistic sampling of freshwater resources provides an opportunity to assess the status of and changes in quality to these valuable habitats. These habitats and resources are intrinsically dynamic and could be affected by direct and indirect anthropogenic activities. Changes in habitats are expected to continue and potentially accelerate due to increasing temperatures attributed to climate change and oil and gas development. Information garnered from these surveys will establish a clear benchmark of the reference condition for NPR-A habitats as there are currently minimal human disturbances (Stoddard et al. 2006).

The project was conducted as part of the National Aquatic Resource Surveys (NARS), which is a program designed to monitor the condition of fresh and coastal waters across the country. In Alaska, NARS is implemented through a collaboration between the U.S. Environmental Protection Agency (EPA), the Alaska Department of Environmental Conservation (ADEC), and the University of Alaska Anchorage (UAA). This report summarizes physical habitat measurements, water chemistry, and diatom and macroinvertebrate communities collected from streams sampled in 2015.

Methods

Study Area

The Arctic Coastal Plain ecoregion of NPR-A extends over 10.8 million acres from the Arctic Ocean on its western and northern boundaries to the foothills of the Brooks Range along its southern edge. Average monthly air temperatures on the coastal plain are below freezing for approximately eight months of the year (October through May) with the coldest temperatures in January (-25.2˚C at Utquiaġvik and -29.6˚C at Umiat) and the warmest temperatures in July (4.9˚C at Utquiaġvik and 12.8˚C at Umiat, Western Regional Climate Center, https://wrcc.dri.edu/summary/Climsmak.html). Temperatures are moderated along the coast throughout the year. Annual precipitation is low, totaling 115 mm at Utquiaġvik and 122 mm at Umiat, with a little over half falling as rain during the summer months.

Study Design

A generalized random tessellation survey design (GRTS, Stevens and Olsen 2004) was used to select sample locations. Sample weights were used to estimate the sampled population extent and generate the statistical summaries for water quality parameters using the spsurvey package and the R statistical computing software (Kincaid and Olsen 2016, R Core Team 2017). Weights were initially calculated by dividing the target population extent (length) by the study design sample size. Weights were adjusted after implementation of the study design to account for sites not sampled due to weather, landowner denial, or not meeting the target population criteria. The study design results include the total number of sites sampled, information on sites that were not sampled, the ability of the sample frame to represent the target population, and the extent of the sampled population.

The target population was wadeable streams and rivers that have flowing water during the study index period excluding portions of tidal rivers up to the head of salt. The sample frame was created by modifying the USGS National Hydrography Dataset flowlines and calculating stream order. Modifications to improve the flowlines dataset were conducted by staff at the University of Utah and are described in the survey design document (Courtwright and Miller 2015).

Fifty base sample and 200 oversample sites were selected by unequal probability selection for two stream sizes (small and large streams defined by stream order) and three logistical areas (east, west, and central), which resulted in six categories. Sites were evaluated in the office prior to sampling and again during site visits resulting in a total of 102 sites evaluated. There were several reasons evaluated sites were not sampled. Over half of the sites (56) did not meet the definition of the target population, as determined during the desktop evaluation or in the field (non-target - NT). Large streams were considered non-target during the desktop evaluation if the wetted width, as measured on aerial imagery, was greater than 20 meters. Two sites were not accessible due to their proximity to native allotments (landowner denied - LD). Nineteen sites were sampled by BLM in 2016, but are not included in this analysis (target, not sampled - TNS). Sites determined to be non-target, inaccessible, or reserved for sampling in 2016 were replaced by sites in the same stream size and logistical area category. Every effort was made to sample sites in numerical order to achieve spatial balance within each unequal probability category.

A total of 26 sites were sampled in 2015 by ADEC and UAA staff, ten large streams and 16 small streams (Figure 2). One small stream site was dropped (167) because it was sampled out of order. This site was also likely disturbed because of its proximity to Utqiaġvik. Sample weights were adjusted for all evaluated sites and used to estimate population extent and statistics for response variables. Approximately 63% of the sampling frame for small streams was not actually a stream channel, 95% CI [53, 72]. Approximately 22% of the large streams sample frame was considered non-wadeable because wetted widths were greater than 20 m, 95% CI [9, 34]. The sampled population represents 31% of all NPR-A streams in the sample frame, 95% CI [20, 42]. This proportion of the sample frame equals 5,096 km of streams in NPR-A, 95% CI [2,892, 7,300].

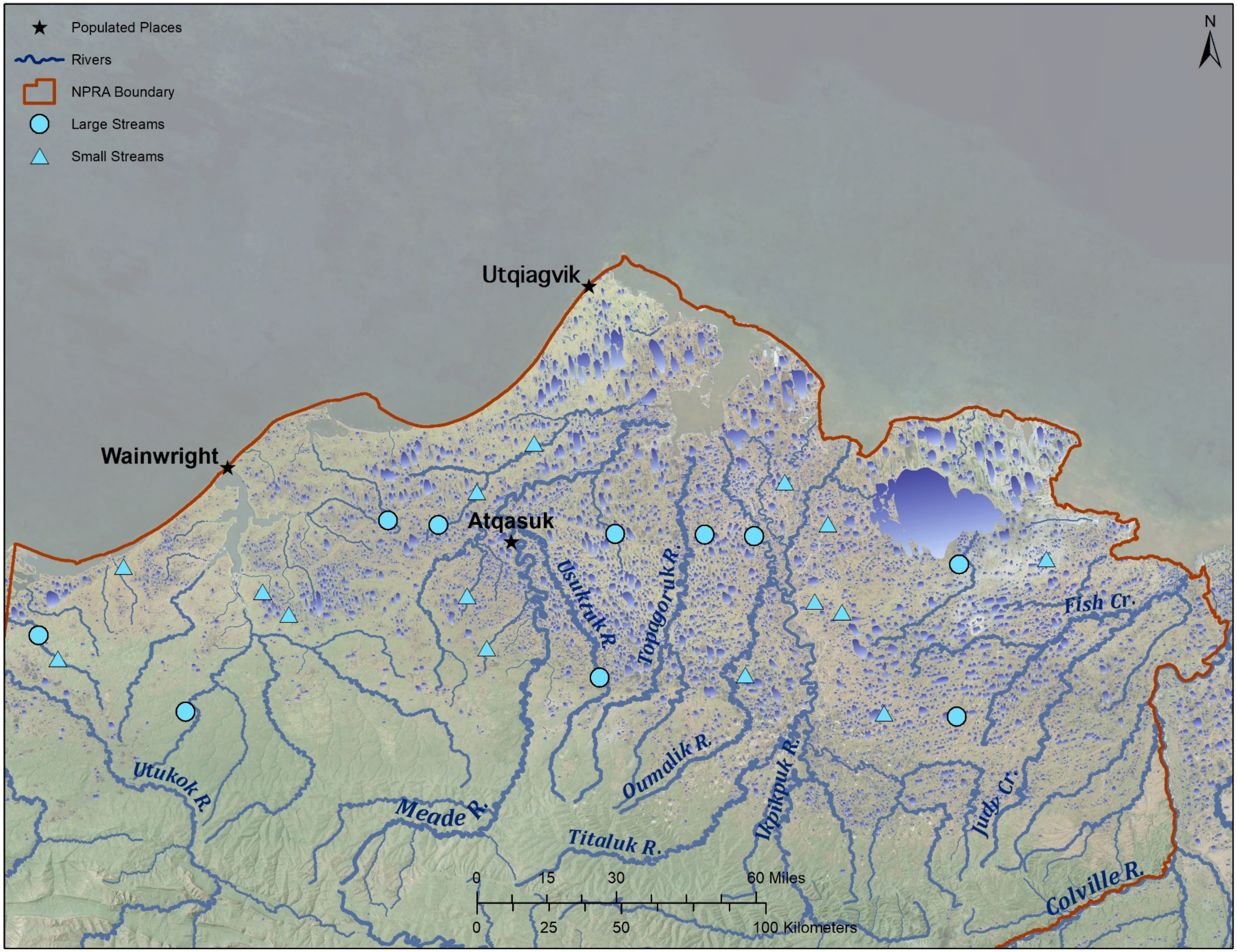

Figure 2. Stream sampling locations in the Arctic Coastal Plain of NPR-A.

Field Sampling

Field work was conducted from July 10th to July 25th, 2015. The index period was selected to capture base flow conditions. Water quality was characterized using in-situ field measurements in addition to laboratory samples of major ions, nutrients, suspended solids, and chlorophyll *a*. Physical habitat measurements included water depth, wetted and bankfull width, substrate, height and angle of streambanks, and percent cover of several fish habitat types. Physical habitat measurements were collected at 11 transects within a stream reach and summarized into metrics for individual sites.

Biological communities sampled included diatoms and macroinvertebrates. Diatoms and macroinvertebrates were sampled in one habitat at each of 11 transects and composited. Habitats were selected randomly at the left, center, or right sampling point (25%, 50%, and 75% of the wetted width) at each transect. Diatoms were sampled by collecting rock or wood substrate from the sampling point, placing an area delimiter over the substrate (12-cm^2), scrubbing with a toothbrush for 30 seconds, and rinsing the biofilm with a squirt bottle into a funnel placed inside a sample bottle, which was later preserved with Lugol's solution. Macroinvertebrates were sampled by placing a D-frame net on the bottom of the stream and disturbing all substrate in a one square foot area upstream so that it washed into the net. Net contents were composited into a bucket for elutriation as needed before placing into sample bottles and preserving with 70% ethanol.

Diatom and macroinvertebrate samples were processed and identified at UAA. Detailed field operations and lab methods manuals are provided on the U.S. EPA National Aquatic Resource Survey website (https://www.epa.gov/national-aquatic-resource-surveys/manuals-used-national-aquatic-resource-surveys).

Results and Discussion

Physical Habitat

Continuous habitat measurements were summarized using boxplots for three different groups: small streams, large streams, and all streams (Figure 3). There were ten large and 15 small streams, which summed to a total of 25 streams.

Physical habitat measurements, except for discharge, were collected at all sites. Six of the small streams were very narrow and had negligible flow preventing our ability to accurately measure discharge. After spring snowmelt, flow in beaded streams decreases by almost two orders of magnitude to ~ 0.01 m^3/s (Oswood et al. 1989, Arp et al. 2015). The dominant substrate in the majority of both small and large streams was sand (7 large and 8 small streams), followed by silt and clay in six small streams and gravel in two large streams. The median substrate size (D50) was 0.2 cm for small streams (sand) and 0.3

cm for large streams (fine gravel, Figure 3). Two large streams had coarse gravel substrates (D50 values of 4.2 and 5.3 mm).

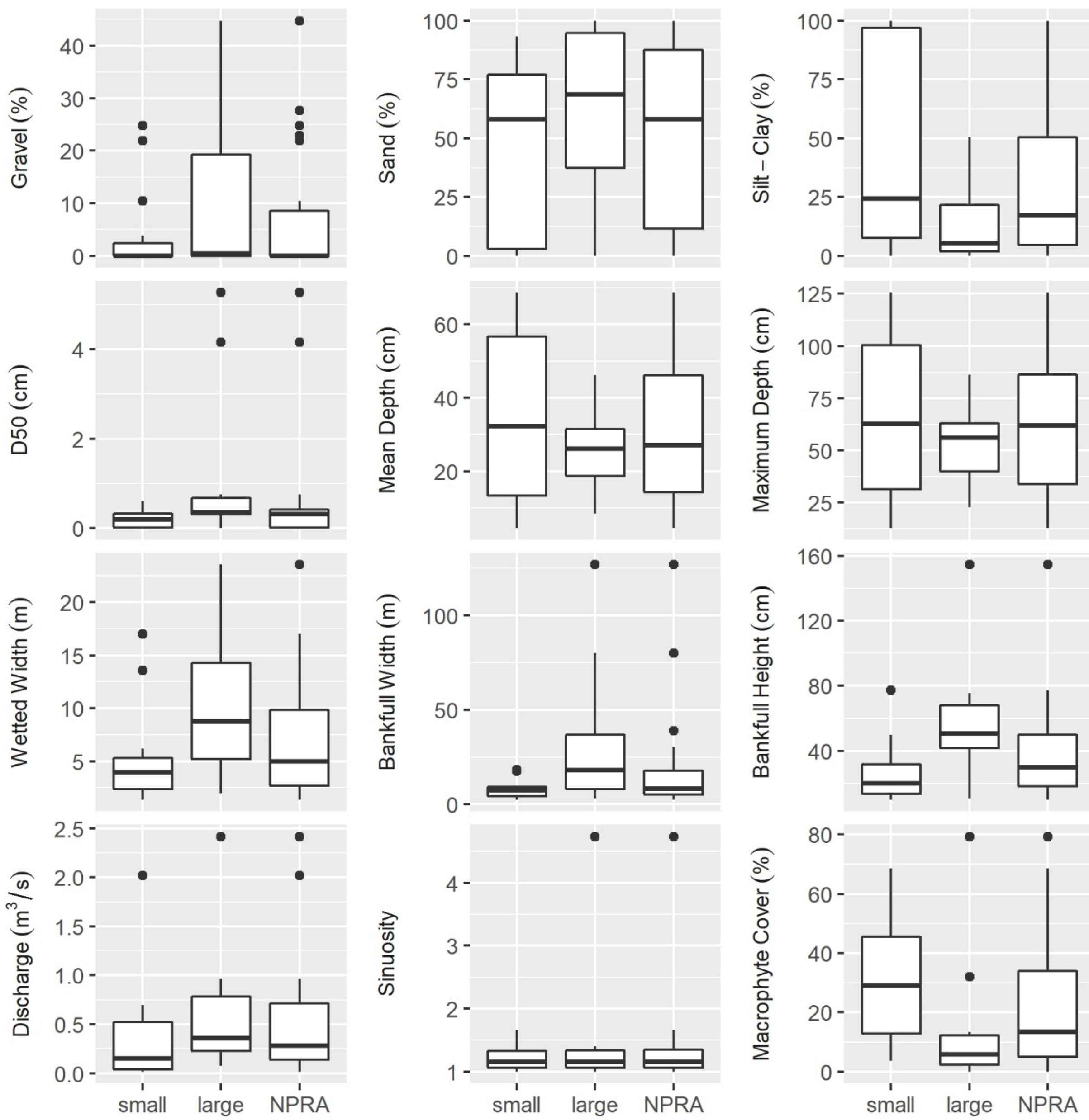

Figure 3. Boxplots for stream physical habitat variables for small streams, large streams, and all sites combined (NPR-A). Boxes include the 25th – 75th percentiles of the data, whiskers extend to 1.5 times the interquartile range, and individual points are outliers.

Both mean and maximum stream depths in NPR-A were well under a meter (median mean depth = 27 cm and median maximum depth = 62 cm). Small streams had more variable depth profiles than large streams. Small streams were much narrower than the large streams (median wetted width of 3.9 m as compared to 8.7 m). Bankfull widths were approximately twice as wide for both stream types, indicating the large volumes of water that discharge during spring snowmelt (Arp et al. 2015). Discharge during the index period varied widely across small and large streams and was generally low, ranging from 0.02 to 2.42 m^3/s. Stream sinuosity (stream reach length divided by the shortest distance between the top and bottom of the reach) did not vary by stream size and median sinuosity across all streams was 1.2 indicating relatively straight reaches. An anomalously high sinuosity measurement in a large alluvial stream was due to the stream reach extending around a large bend in the river. Aquatic vegetation cover was six times higher in small streams than in large streams.

Water Quality

Water quality samples collected at all 25 streams included nutrients, major ions, and in-situ parameters. Adjusted weights were used to plot continuous distribution functions (CDFs) for all water chemistry parameters, except those parameters with high percentages of non-detect samples (Appendix A). Raw values were summarized using boxplots for three groups: small streams, large streams, and all streams in NPR-A (Figure 4).

Stream water quality was characterized using calcium, chloride, magnesium, potassium, sodium, dissolved organic carbon (DOC), ammonia, nitrate + nitrite, Kjeldahl nitrogen, phosphorus, total suspended solids and chlorophyll *a*. Temperature, specific conductivity, pH, and dissolved oxygen were measured using an in-situ water quality probe. The majority of results were below method detection limits for nitrate-nitrite (92% non-detect, ND), Kjeldahl nitrogen (77% ND), ammonia (65% ND), and potassium (62% ND). Total suspended solids and total phosphorus had eight and two samples with concentrations below detection limits, respectively, which were replaced with one half the detection limit for CDFs and boxplots. Results were compared to lotic water chemistry from other studies in Arctic Alaska and Canada (Oswood et al. 1989, Vonk et al. 2015, Dean et al. 2016).

Nutrient concentrations in streams of NPR-A were very low (Figure 4). Median total phosphorus concentrations were 0.017 mg/L across NPR-A and the majority of results were below 0.040 mg/L except for one outlier with a concentration of 0.104 mg/L. Median DOC concentrations for NPR-A streams were 7.4 mg/L and were more variable in small streams, which ranged from 4 to 16 mg/L. Concentrations for the nitrogen parameters were mostly below method detection limits, which were 0.10 mg/L for ammonia and nitrate-nitrite and 1.0 mg/L for Kjeldahl nitrogen. The maximum concentrations were 2.39 mg/L for ammonia, 0.37 mg/L for nitrate-nitrite and 1.61 mg/L for Kjeldahl nitrogen. The maximum ammonia concentration is suspect as the Kjeldahl nitrogen at the same site was below the detection limit. Kjeldahl nitrogen includes both ammonia and organic nitrogen and should be higher than the ammonia concentration. The next highest ammonia concentration in the dataset was 0.87 mg/L. Chlorophyll *a* concentrations for all streams were below 8 μg/L, except for one small stream with a concentration of 33 μg/L.

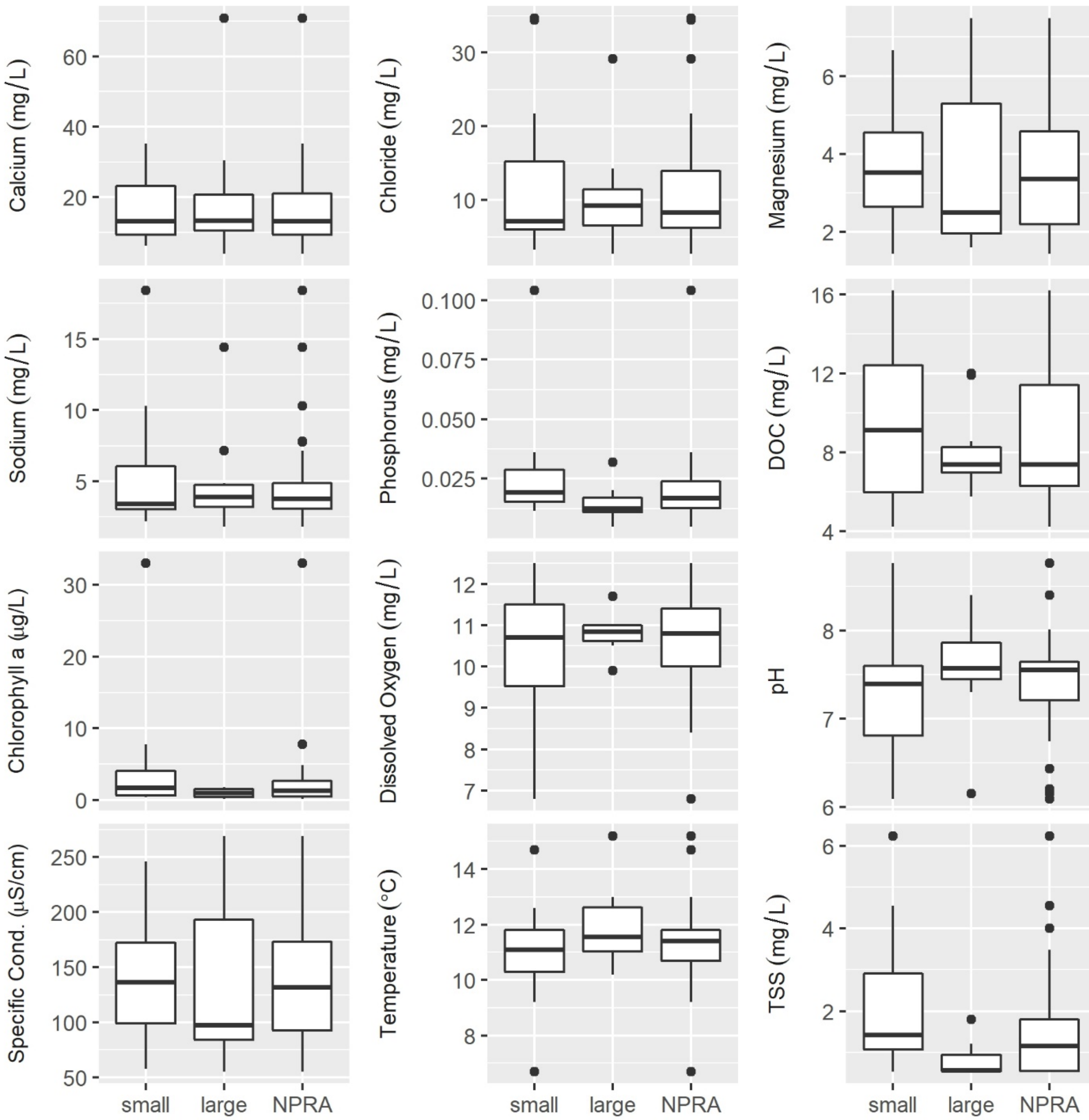

Figure 4. Boxplots for stream water quality parameters for small streams, large streams, and all sites combined (NPR-A). Boxes include the 25th – 75th percentiles of the data, whiskers extend to 1.5 times the interquartile range, and individual points are outliers.

The Kjeldahl nitrogen method detection limit was above the boundary for eutrophic conditions (0.714 mg/L), but total phosphorus concentrations indicate that the majority of streams are oligotrophic, four streams are mesotrophic, and one stream is eutrophic

(Dodds 2006). After removal of the two extreme values for chlorophyll a and total phosphorus, there was a weak positive relationship (r = 0.58), potentially indicating phosphorus limitation of primary productivity.

DOC and total suspended solid (TSS) concentrations were much more variable in small than large streams and, on average, tended to be higher in small streams. The mean DOC concentration for small streams was 9.4 mg/L, which was very similar to the average summer DOC for Imnavait Creek, a beaded stream (9.6 mg/L, Oswood et al. 1989). DOC concentrations for 134 streams in the western Canadian Arctic were much higher, averaging 23.0 mg/L (Dean et al. 2016), possibly due to deepening of the active layer and thermokarsting in this region. Average TSS in small and large streams were 2.1 and 0.6 mg/L, respectively and the maximum TSS of 6.3 mg/L was in a small stream. The low TSS values match patterns observed in Imnavait Creek, where TSS concentrations decreased over the summer from 6.3 mg/L in June to 1.6 mg/L in September (Oswood et al. 1989).

Small streams of NPR-A had highly variable concentrations of dissolved oxygen (6.8 – 12.5 mg/L) and pH (6.1 – 8.8), whereas the large streams were more similar and generally had high dissolved oxygen concentrations and neutral to slightly alkaline pH. Specific conductance values spanned a large range (55 to 269 µS/cm) across both stream types and averaged 138 µS/cm across all streams. Specific conductance was most strongly related to concentrations of magnesium and calcium (r = 0.83 and r = 0.76, respectively). Sodium and chloride were strongly correlated (r = 0.92) and were highest in streams close to the coast (r = -0.65 for distance to coast and sodium). Shifts from sodium-chloride to calcium-magnesium dominated waters from the coast inland were also observed in a study of lakes and rivers sampled from Prudhoe Bay to the Brooks Range. Sea salt in precipitation was a major contributor to water chemistry along the coast, while weathering of bedrock and glacial drift and inputs of wind-blown sediments controlled chemistry further inland (Kling et al. 1992).

Biological Communities

For each of the biological community datasets, we used several measures to investigate patterns in diversity for each study. We calculated gamma, alpha, and beta diversity to investigate differences across communities and studies at different scales (Table 1). Gamma diversity is the total number of taxa identified. Alpha diversity is the mean number of taxa for all sites. Beta diversity was calculated as the gamma diversity divided by the alpha diversity and reflects the number of distinct communities in a dataset; a beta diversity of one indicates that every site shares the same taxa. Shannon and Simpson diversity indices include information on taxa abundances and were calculated for each site and averaged for each study. Shannon's index was calculated as

$$H' = \sum_{i=1}^{S} p_i * \ln(p_i),$$

where p_i is the proportion of taxa i and S is the total number of taxa. Shannon's index is the log of the number of taxa of equal abundance. Simpson's index was calculated as

$$Diversity = 1 - \sum_{i=1}^{S} p_i^2,$$

where p_i is the proportion of taxa i and S is the total number of taxa. Simpson's index represents the likelihood that two randomly chosen individuals will be different taxa. For both indices, higher values indicate higher diversity. Frequencies and abundances for all taxa are provided in Appendix B.

At some sites sampled for macroinvertebrates, not all final taxonomic identifications were made to the lowest possible rank (e.g. genus for Ephemeroptera) because some organisms were either early instars, pupae, or lacking diagnostic characteristics. Taxonomic identifications left at a higher rank than other organisms at the same site (e.g. Baetidae and *Baetis sp*.) were removed for biodiversity calculations to avoid double-counting.

Tables of all taxa from each of the biological communities are provided in Appendix B. For each taxa, average abundances, maximum abundances, and frequencies are provided. All analyses were run in the R statistical computing software using the tidyverse and vegan packages (Oksanen et al. 2017, R Core Team 2017, Wickham 2017).

Table 1. Biodiversity indices for stream biological communities.

Community	Gamma	Alpha	Beta	Shannon	Simpson
Diatoms	451	61	7.4	3.3	0.92
Macroinvertebrates	150	34	4.4	2.5	0.85

Diatoms

Diatoms had higher diversity than macroinvertebrates with three times the number of taxa identified (Table 1). On average, 61 different taxa were observed at each site. There were 22 common taxa that occurred in at least half of the sampled streams (Table 2) and an additional 209 rare taxa that only occurred in one stream. There were four taxa found in 90% or more of the streams: *Achnanthidium minutissimum*, *Nitzschia perminuta*, *Navicula cryptocephala*, and *Rossithidium pusillum* (frequencies of 23 to 25). Two of these were also very abundant taxa. Five taxa had mean relative abundances greater than 4% across all sites: *Achnanthidium minutissimum*, *Staurosirella pinnata*, *Eunotia incisa*, *Rossithidium pusillum*, and *Diatoma tenuis*.

The diversity of diatoms in Arctic Alaska streams is considerably higher than the diatom diversity in streams in other parts of the state. A probabilistic study of 30 wadeable steams sampled in the Bristol Bay region yielded a diatom alpha diversity of 43 (D. Bogan, unpublished data) and a study of diatoms in 55 wadeable streams of the Cook Inlet Basin had an alpha diversity of 37 (Rinella and Bogan 2007). Arctic Alaska may be a hot spot for freshwater diatom diversity and therefore an important biological assemblage for monitoring environmental change.

Table 2. Diatom taxa that occurred in 50% or more of all streams.

Taxa Name	Frequency (%)	Mean Relative Abundance (%)
Achnanthidium minutissimum (Kützing) Czarnecki	100	12.0
Nitzschia perminuta (Grunow) Peragallo	100	2.8
Navicula cryptocephala Kützing	96	1.6
Rossithidium pusillum (Grunow) Round & Bukhtiyarova	92	4.9
Diatoma tenuis Agardh	88	4.0
Staurosirella pinnata (Ehrenberg) Williams & Round	88	8.5
Fragilaria capucina var. *gracilis* (Østrup) Hustedt	84	1.2
Tabellaria flocculosa (strain IV) sensu Koppen	84	3.6
Rossithidium petersennii (Hustedt) Round & Bukhtiyarova	80	1.2
Eunotia bilunaris (Ehrenberg) Schaarschmidt	76	0.9
Encyonema silesiacum (Bleisch) Mann	72	1.1
Eunotia incisa Gregory	72	5.1
Navicula radiosa Kützing	72	1.7
Rossithidium anastasiae (Kaczmarska) Potapova	60	2.8
Fragilaria tenera (W. Smith) Lange-Bertalot	60	0.6
Encyonema obscurum (Krasske) Mann	56	0.6
Caloneis cf. *silicula* (Ehrenberg) Cleve	52	0.6
Navicula sp. 5 Antoniades et al 2008	52	0.6
Psammothidium subatomoides (Hustedt) Bukhtiyarova & Round	52	0.4
Sellaphora pupula (Kützing) Meresckowsky	52	0.3
Sellaphora pupula var. *capitata* Skvortzvow & Meyer	52	0.3
Stauroneis amphicephala Kützing	52	0.5

Macroinvertebrates

A total of 150 macroinvertebrate taxa were identified across all streams and average site richness was 34 (Table 1). There were 24 common taxa found in 50% or more of all sites (Table 3) and 47 rare taxa observed at only one site. There were eight taxa that occurred in 90% or more of the sites: three chironomids (*Corynoneura* sp., *Tanytarsus* sp., and *Procladius* (Holotanypus) sp.), worms (Oligochaeta), seed shrimp (Ostracoda), roundworms (Nematoda), freshwater snails (*Valvata* sp.), and water mites (*Lebertia* sp.). Dipterans comprised the majority of all macroinvertebrate diversity and specifically the family Chironomidae (non-biting midges), which had almost half of all identified taxa (66 unique taxa). Of the other insect orders, caddisflies (Trichoptera) had the next highest number of unique taxa (14). The mayflies (Ephemeroptera), beetles (Coleoptera), and stoneflies (Plecoptera) had few taxa in NPR-A streams (five, four, and two, respectively). Stream macroinvertebrate densities ranged from 567 to 16,424 organisms/m^2 across all sites. Average densities were almost two times higher in small streams than large streams: 6,594 versus 3,404 organisms/m^2.

Table 3. Macroinvertebrate taxa that occurred in 50% or more of all streams.

Order	Family	Taxa Name	Mean Density (no./m^2)	Freq. (%)
Diptera	Chironomidae	*Corynoneura* sp.	444	100
-	-	Oligochaeta	426	100
-	-	Ostracoda	624	100
Diptera	Chironomidae	*Tanytarsus* sp.	221	96
-	-	Nematoda	268	96
Diptera	Chironomidae	*Procladius* (*Holotanypus*) sp.	159	92
Heterostropha	Valvatidae	*Valvata* sp.	605	92
Trombidiformes	Lebertiidae	*Lebertia* sp.	42	92
Diptera	Chironomidae	*Cladotanytarsus* sp.	174	84
Diptera	Chironomidae	*Constempellina* sp.	78	84
Diptera	Chironomidae	*Zalutschia* sp.	250	80
Diptera	Chironomidae	*Sergentia* sp.	180	76
Veneroida	Pisidiidae	Pisidiidae	48	76
Diptera	Simuliidae	*Simulium* sp.	27	64
Diptera	Chironomidae	*Cryptochironomus* sp.	25	60
Sabellida	Fabriciidae	*Manayunkia speciosa*	229	60
Trombidiformes	Sperchonidae	*Sperchon* sp.	11	60
Basommatophora	Planorbidae	Planorbidae	83	56
Diptera	Chironomidae	*Polypedilum* sp.	30	56
Diptera	Chironomidae	*Potthastia longimanus* group	18	56
Diptera	Chironomidae	*Ablabesmyia* (*Karelia*) sp.	31	52
Diptera	Chironomidae	*Conchapelopia* sp.	60	52
Diptera	Chironomidae	*Stictochironomus* sp.	18	52
Trichoptera	Limnephilidae	*Grensia praeterita*	11	52

Summary

Wadeable stream habitats in the Arctic Coastal Plain of NPR-A include small beaded streams and large alluvial streams. During our July sampling period, average water depths along stream reaches were all well under a meter and discharge was minimal (< 2.5 m^3/s). The dominant substrate was sand across both stream types, although coarse gravel substrates dominated two large streams in the western portion of the study area. Aquatic vegetation was much more common in small streams.

Stream water chemistry indicated that nutrient concentrations were very low and most streams in NPR-A are oligotrophic. Almost all nitrogen results were below method detection limits, total phosphorus results were below 0.04 mg/L except for one outlier, and chlorophyll a results were below 8 µg/L except for one outlier. Small streams were much more variable than large streams for pH, dissolved oxygen, and TSS. On average, both small and large streams were cold and had neutral pH, high dissolved oxygen and low specific conductance and TSS. Specific conductance was most strongly correlated to calcium and magnesium concentrations, which were variable across the study area. Sodium and chloride were highest in four streams close to the Arctic coast.

Over 600 different taxa were identified in the stream diatom and macroinvertebrate communities across the entire dataset. Diatoms had higher diversity than macroinvertebrates, which may be partly explained by taxonomic resolution as diatoms are identified to species. Macroinvertebrate diversity was dominated by taxa in the family Chironomidae (non-biting midges), although several other insect orders with several to a few taxa each were also present.

Overall, this study provides a critical baseline of habitat, water chemistry, and biological communities from randomly selected streams across NPR-A. This survey was conducted in collaboration with BLM and, when combined with their results from 2016, will create a larger baseline that captures two different years. The statistically-valid reference conditions captured in this study have increased our ability to detect future changes from climate and human development that are expected to occur in this region.

Literature Cited

Arp, A. C. D., M. S. Whitman, B. M. Jones, R. Kemnitz, G. Grosse, and F. E. Urban. 2012. Drainage network structure and hydrologic behavior of three lake-rich watersheds on the Arctic Coastal Plain, Alaska. Arctic Antarctic and Alpine Research 44:385–398.

Arp, C. D., M. S. Whitman, B. M. Jones, G. Grosse, B. V. Gaglioti, and K. C. Heim. 2015. Distribution and biophysical processes of beaded streams in Arctic permafrost landscapes. Biogeosciences 12:29–47.

BLM. 2012. National Petroleum Reserve - Alaska Final Integrated Activity Plan / Environmental Impact Statement. Anchorage, AK.

Brabets, T. P., and M. a. Walvoord. 2009. Trends in streamflow in the Yukon River Basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. Journal of Hydrology 371:108–119.

Courtwright, J., and S. Miller. 2015. 2015 Arctic Coastal Plain NPR-A Rivers and Streams Survey Design. Alaska Monitoring and Assessment Program (AKMAP), Anchorage, AK.

Dean, J. F., M. F. Billett, R. Baxter, K. J. Dinsmore, J. S. Lessels, L. E. Street, J. A. Subke, D. Tetzlaff, I. Washbourne, and P. A. Wookey. 2016. Biogeochemistry of “pristine” freshwater stream and lake systems in the western Canadian Arctic. Biogeochemistry 130:191–213.

Dodds, W. K. 2006. Eutrophication and trophic state in rivers and streams. Limnology and Oceanography 51:671–680.

Frey, K. E., and J. W. McClelland. 2009. Impacts of permafrost degradation on arctic river biogeochemistry. Hydrological Processes 23:169–182.

Hinzman, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G. L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. M. Welker, K. S. Winker, and K. Yoshikawa. 2005. Evidence and implications of recent climate change in Northern Alaska and other Arctic regions. Climatic Change 72:251–298.

Kincaid, T. M., and A. R. Olsen. 2016. spsurvey: Spatial Survey Design and Analysis.

Kling, G. W., W. J. O’Brien, M. C. Miller, and A. E. Hershey. 1992. The biogeochemistry and zoogeography of lakes and rivers in arctic Alaska. Hydrobiologia 240:1–14.

Oksanen, J., F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs, and H. Wagner. 2017. vegan: Community Ecology Package.

Oswood, M. W., K. R. Everett, and D. M. Schell. 1989. Some physical and chemical characteristics of an arctic beaded stream. Holarctic Ecology 12:290–295.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rinella, D. J., and D. L. Bogan. 2007. Development of Macroinvertebrate and Diatom Biological Assessment Indices for Cook Inlet Basin Streams - Final Report. Anchorage, AK.

Stevens, D. L., and A. R. Olsen. 2004. Spatially Balanced Sampling of Natural Resources. Journal of the American Statistical Association 99:262–278.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: The concept of reference condition. Ecological Applications 16:1267–1276.

Vonk, J. E., S. E. Tank, W. B. Bowden, I. Laurion, W. F. Vincent, P. Alekseychik, M. Amyot, M. F. Billet, J. Canário, R. M. Cory, B. N. Deshpande, M. Helbig, M. Jammet, J. Karlsson, J. Larouche, G. Macmillan, M. Rautio, K. M. Walter Anthony, and K. P. Wickland. 2015. Reviews and syntheses: Effects of permafrost thaw on Arctic aquatic ecosystems. Biogeosciences 12:7129–7167.

Wickham, H. 2017. tidyverse: Easily Install and Load the "Tidyverse."