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Central Alaska Network Flowing Waters Monitoring Program

2008 Annual Report

Natural Resource Technical Report NPS/CAKN/NRTR—2010/310

ON THE COVER
View of the upper Snag Creek valley, Wrangell-St. Elias National Park and Preserve
Photograph by: Trey Simmons

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Trey Simmons
National Park Service
4175 Geist Road
Fairbanks, Alaska 99709

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Abstract

The 2008 field season marked the third year of development of the flowing waters portion of the Central Alaska Network (CAKN) Inventory and Monitoring Program, also known as the Vital Signs Program. Data collection occurred in both Wrangell-St. Elias National Park and Preserve (WRST) and in Denali National Park and Preserve (DENA). The purposes of the study were to: 1) continue to refine field protocols and logistics related to the collection of relevant data in DENA and WRST streams and rivers; 2) evaluate the feasibility of using the generalized random tessellation stratified survey design to select synoptic sampling sites in WRST; and 3) implement the long-term flowing water monitoring program. The data collected included biological (benthic macroinvertebrate and diatom samples, fish identity and size, riparian vegetation type), physical (extensive channel geometry, substrate, *etc*.) and chemical (collected *in situ* as well as in water samples for later analysis) information. Data were collected during a total of 40 site visits across the two park units. Continuously recording temperature data loggers were deployed at 18 sites, and a continuously recording pressure transducer was deployed at one site, with data collected from early June to late September. In DENA, another sixteen previously unreported macroinvertebrate taxa were documented, bringing the two-year total to 31 taxa. Network-wide, the program has now documented 147 unique macroinvertebrate taxa and 360 unique diatom species. Of the 400 potential sampling sites selected using GRTS, 95 were rejected using remotely sensed data. 116 of the remaining 305 potential sampling sites selected were evaluated in the field in 2008, most by helicopter overflights. Of these, 33 (28%) were either sampled or deemed to be probably sampleable.

Acknowledgements

I would like to thank the staff of Wrangell-St. Elias National Park and Preserve, in particular Eric Veach, Geoff Bleakley, Beth Betts, Tom Betts and Thelma Schrank for their invaluable assistance with field logistics, and for many discussions about the park and the monitoring program. Thanks also to Pam Sousanes and Linda Stromquist for sharing helicopter time. I'd also like to thank the staff of Denali National Park and Preserve, in particular Lucy Tyrell, for lots of cheerful assistance. Finally, I'd like to thank Maggie MacCluskie for her unflagging support, intellectual, financial and moral, as I struggled through my third field season. And a very special thanks to Greta Burkart for invaluable contributions to the scientific development of the CAKN stream monitoring program

Introduction

This study is part of the National Park Service Vital Signs (Inventory and Monitoring) Program for the Central Alaska Network (CAKN; MacCluskie and Oakley 2005). Climate change and other anthropogenic impacts can be expected to have a dramatic effect on freshwater ecosystems in Alaskan National Parks; the streams and rivers portion of the Vital Signs program has been designed to detect trends in the status of important components of lotic ecosystems. These include hydrologic regime, geomorphology, temperature, water quality and the distribution and abundance of freshwater fish, benthic macroinvertebrate and diatom species. Fundamentally, the goal is to develop a logistically feasible, repeatable and scientifically robust monitoring program that will detect change in these systems. To the extent possible, we are incorporating indicators, data and methods developed as part of the Denali National Park and Preserve (DENA) Long Term Ecological Monitoring (LTEM) program, as well as utilizing other relevant data collected in network parks for a variety of purposes.

In 2008, the purposes of the program were to continue to evaluate and refine the existing field methods, maintain the continuity of existing data streams by sampling sites along the DENA park road that were part of the LTEM program, and collect data from a variety of sites in Wrangell-St. Elias National Park and Preserve (WRST) to continue characterization of the natural variability of stream ecosystems in that park unit. 2008 also marked the first year of evaluation of the generalized random tessellation stratified (GRTS) survey design in WRST. As part of the evaluation, we used helicopter overflights to evaluate the suitability of 116 potential sampling sites; we also successfully sampled seven of the GRTS sites. We sampled a total of 40 sites in 2008, 20 in DENA and 20 in WRST, although the full suite of data was not collected at all sites. Three sites in WRST and one site in DENA were visited twice during the year, once in the summer and once in the fall. We initiated the collection of continuous temperature and water depth data in 2008. Eighteen temperature loggers and one pressure transducer were installed in streams in both DENA and WRST in May; most of the units were retrieved in late September (Table 2).

The ultimate scope of inference for the CAKN stream program is all flowing waters in the network. The survey design, while not finalized, will be similar to the following. Parkwide inference will be established for each park unit using a set of synoptic sites selected using a GRTS survey design, which generates a spatially-balanced, probabilistic sample (Overton and Stehman 1993, Stevens and Olsen 2004). We used an unequal-weighting approach to specifically target wadeable streams and stratified the sample to account for differences in the cost of access. Although the spatial variation in site characteristics and responses inherent in such designs can substantially reduce overall sensitivity to trends, explicitly incorporating revisits can effectively eliminate this effect (Urquhart *et al*. 1998, Urquhart and Kincaid 1999), assuming reasonable coherence in regional response. For this reason, we will use a panel rotation approach, in which sites are revisited periodically according to a master schedule. The goal for WRST is to sample 10 synoptic sites per year, on an approximately 10-year return interval, for a total of 100 sites; the return intervals and sample panels are still being evaluated for DENA and YUCH. In addition to the synoptic site panels, we are establishing a set of “sentinel sites” that will be sampled annually. Sentinel sites are being selected for ease of access, and will be distributed as much as possible among representative stream types. Annual visitation will maximize our ability to detect

trends at these sites, although inference to unsampled sites will be limited. The DENA sentinel sites will include at least some of the LTEM sites along the park road. The WRST sentinel sites will be located along the Nabesna and McCarthy Roads, and will include most of the sites in these areas that have been sampled regularly over the last several years. Finally, we eventually will establish a very small number of "intensively monitored sites". These sites will be subject to a more intensive sampling regime than those in the other two categories, and will ideally be instrumented with continuously-recording sensors of various types (temperature, precipitation, water chemistry, stage height, soil moisture, etc.). These sites will be visited more than once per year, allowing the seasonal component of variance in the values of ecological metrics to be estimated and taken into account (*e.g*., Larsen *et al*. 2004). The results obtained at these sites will allow us to model relevant ecological and hydrological processes that may be occurring, and thus provide a conceptual framework for interpreting the data we collect at other sites.

In 2008, the feasibility of using GRTS to select a probabilistic sample of synoptic sites was tested in WRST. After editing the National Hydrography Dataset to develop a workable base dataset, a list of 400 potential sampling sites was generated using the GRTS algorithm. This list of sites was stratified into "accessible" and "inaccessible" strata using a relatively simple cost surface approach. Unequal weighting was applied to the list to overrepresent wadeable stream segments using Strahler stream order as a surrogate for stream size. Remotely sensed data were used to evaluate each of the 400 sites to determine whether it was part of the target population (*e.g*., was it actually a stream), and whether it was likely to be sampleable. Of the 305 sites that remained on the list after this step, 116 were evaluated in the field, primarily by helicopter overflight.

Methods

Study Area

Data were collected from a total of 40 site visits in 2008, 20 in DENA and another 20 in WRST (Table 1). Three sites in WRST and one in DENA were revisited in the fall. The full suite of data was only collected from a subset of these sites, however. The locations of the sites sampled are shown in Figures 1 and 2. All of the DENA sites were located along or near the park road, with the exception of Cantwell Creek on the south side of the Alaska Range. These sites included eight sites that have been sampled since 1994 as part of the LTEM program. The DENA sites also included four sampling sites spread along the length of Moose Creek from its upper basin to the Kantishna airstrip, a stream characterized by extensive deposits of travertine, the Wonder Lake outlet stream, two springfed streams on the McKinley Bar and Igloo Creek above the location of the 2007 road construction. In WRST, eight sites along the road system were sampled; the other remote sites were accessed by fixed-wing aircraft or helicopter. Three remote sites that had been sampled in previous years were revisited.

GRTS site selection

The National Hydrography Dataset (NHD, see Simley and Carswell Jr. 2009) was used as the base data for selection of the synoptic sites using the GRTS design algorithm (Stevens and Olsen 2004). The NHD for Alaska has not been edited extensively for either topological consistency or accuracy to reality; as such it is not currently appropriate to use as a basis for site selection. Accordingly, the first step was to edit the NHD for WRST to ensure topological consistency; editing for accuracy was not possible at the park scale. A Geographic Information System (GIS) was used to edit the NHD as follows. GIS datalayers for the three 4-digit hydrographic units that encompass WRST (1901, 1902 and 1904) were first merged, and then clipped to the park boundary using ArcGIS Desktop 9.3 (ESRI, Redlands, CA). The RivEX network analysis tool (Hornby 2009) was used to evaluate the NHD for topological errors (*e.g.*, disconnected polylines). Corrections to the network were effected using tools available in ArcGIS. The RivEX tool was then used with the edited and corrected NHD layer to attribute each stream segment with Strahler stream order (Strahler 1952). Stream order can be used as a surrogate for stream size; because the program is largely limited to sampling wadeable streams, it was important to over-represent stream segments likely to wadeable in the final site list. Although catchment area (upstream contributing area) is generally a better surrogate, it is not feasible to calculate the catchment area for every potential sampling site in even a small portion of a stream network.

WRST contains over 1,000,000 acres of inholdings, mostly owned by local native corporations. Following the recommendation of WRST staff, I eliminated all stream segments that were contained within inholdings from consideration for inclusion on the list of potential sampling sites. Because the cost of accessing remote sites imposes a major limitation on the monitoring program, I attempted to stratify the sampling population by accessibility. The plan was to select 50% “accessible” sites and 50% “inaccessible” sites, as defined by the likelihood of needing a helicopter to get to the site. If trends in key indicators were coherent between the two strata, we could be confident in the future that an emphasis on accessible sites would not detract from our ability to draw conclusions about sites across the entire park or network.

I used several data layers in ArcGIS to generate an approximate "accessibility surface". Layers delineating the locations of roads, ATV trails, major river corridors, landing strips and floatplane-accessible lakes were merged to create a layer representing potential points of access. The access point layer was then buffered at 1.0 miles to create a layer representing "accessible" sites. In retrospect, the inclusion of major river corridors was a miscalculation. The idea was that these corridors would provide access either by boat or by fixed-wing aircraft (due to the likely presence of large gravel bars that might serve as landing strips); however, in most cases it turned out that use of a helicopter would be required to access these sites.

Once the WRST NHD layer had been attributed with Strahler stream order and accessibility, I used the spsurvey package (Kincaid 2008) in the R statistical software environment (R version 2.8.1, the R Foundation for Statistical Computing, 2008) to generate the GRTS sample. I set the algorithm to select a 50-site accessible stratum with a 150-site oversample, and a 50-site inaccessible stratum with a 150-site oversample. The large oversample was chosen because it was deemed likely that the majority of sites would not be sampleable, making it difficult to identify a set of 100 sampleable sites without a substantially longer starting list of possibilities. The unequal weighting function was used to over-represent 2nd and 3rd order stream segments in the site list. All 400 sites were then examined using a variety of remotely sensed and GIS data to determine whether they were part of the target population.

Reach definition

Sampling reaches were defined using guidelines from the EPA's EMAP Wadeable Streams Assessment (USEPA 2004), and modified as necessary. A sampling reach was defined as 40 times the mean wetted width of the stream, based on five equally spaced measurements at the bottom of the proposed reach. Although this length was initially chosen as the minimum sufficient to adequately capture fish community composition in wadeable streams (Reynolds *et al.* 2003), it is also generally long enough to include a complete meander bend, which is a fundamental unit of stream geomorphology. Hence, a reach sufficiently long to encompass a meander bend should adequately capture the habitat complexity of that section of stream (Kaufmann *et al*. 1999). The minimum sampling reach length was set at 150 meters, and the maximum at 500 meters (the latter for feasibility and safety reasons). Reaches were selected to be as representative as possible of the stream section in which they were embedded; in addition, major tributary junctions were avoided and reaches near road crossings were located so as to begin at least 50 meters upstream. Once defined, the reach was subdivided into ten equally spaced sections by the placement of 11 cross-sectional transects (A – K). These transects formed the framework around which the bulk of biological and physical sampling occurred. For 2007, we dispensed with the requirement to measure and flag the transects. This procedure can take upwards of 30 minutes, which is a substantial portion of the time spent at each site. Instead, I elected to estimate the inter-transect distance by stepping it off in approximately 1-meter intervals. Although this results in some variability in transect location between different sampling efforts (*e.g.*, macroinvertebrates *vs*. channel geometry), the loss of accuracy is minimal because the goal of the program is to characterize the reach, rather than to establish monumented cross sections; therefore, the exact locations at which data are collected should not matter.

Table 1. List of sites sampled in 2008 with location and brief description. A * indicates sites that have been sampled at least once in previous years

Site	Park	Description
Travertine stream*	DENA	small travertine-like stream near Stony Creek
Sanctuary River*	DENA	large glacially-influenced river (LTEM site)
Moose Creek at bridge*	DENA	large clearwater river in Kantishna Hills (LTEM site)
Moose Creek at airstrip	DENA	large clearwater river in Kantishna Hills
Moose Creek at crossing	DENA	large clearwater river in Kantishna Hills
Upper Moose Creek	DENA	large clearwater river in Kantishna Hills
Little Stony Creek*	DENA	high-elevation tundra stream (LTEM site)
Gorge Creek spring*	DENA	small spring-fed tundra stream below Gorge Creek overlook
Gorge Creek	DENA	braided clearwater tributary of Thorofare River
Lake Creek	DENA	Wonder Lake outlet stream
McKinley Bar spring*	DENA	springfed stream on terrace at end of McKinley Bar trail
McKinley Bar trail creek*	DENA	groundwater stream on McKinley Bar trail
Igloo Creek*	DENA	large forested stream (LTEM site)
Tattler Creek*	DENA	small steep braided stream (LTEM site)
Igloo Cr. above Tattler*	DENA	Igloo Creek sampled above the 2007 road construction
E.F. Toklat River*	DENA	Large turbid braided glacial river (LTEM site; summer and fall)
E.F. Toklat tributary*	DENA	clearwater tributary to E.F. Toklat River (LTEM site)
Hogan Creek*	DENA	small groundwater-fed stream (LTEM site)
Cantwell Creek	DENA	glacially-influenced stream south of the Alaska Range
Chalk Creek*	WRST	clearwater stream along Nabesna Road (summer and fall)
Rock Creek*	WRST	clearwater stream along Nabesna Road (summer and fall)
Little Jack Creek*	WRST	clearwater stream along Nabesna Road
Jack Creek*	WRST	large lake outlet along Nabesna Road (summer and fall)
Rufus Creek	WRST	stable groundwater stream along Nabesna Road
Caribou Creek	WRST	intermittent stream along Nabesna Road
Strelna Creek	WRST	clearwater stream along McCarthy Road
Chokosna River	WRST	clearwater stream along McCarthy Road
Lake Creek*	WRST	clearwater tributary to Nizina River
Willow Creek*	WRST	clearwater tributary to the Tana River
Beaver Creek*	WRST	small lake outlet stream east of Chisana
Notch Creek tributary	WRST	small high-gradient stream west of Chisana
Bryan Creek	WRST	deep clearwater stream near Chisana
Chavolda Creek	WRST	large glacial stream north of Chisana
Solo Creek tributary	WRST	small clearwater stream at edge of Solo Flats
N.F. White River	WRST	small clearwater stream at edge of Solo Flats
Horsfeld Creek	WRST	high gradient clearwater stream near Horsfeld airstrip

Biological sampling

Biological sampling protocols were largely adopted from the EMAP WSA Field Protocols (USEPA 2004) and from methods developed at the Western Center for Monitoring and Assessment of Freshwater Ecosystems at Utah State University (Hawkins *et al*. 2003).

Macroinvertebrate samples were collected as follows: a modified net that combines elements of Surber and D-net samplers with a 500 μm mesh was used. At each transect, the net was placed in the left 1/3, center 1/3 or right 1/3 of the stream width (within these broadly defined areas, the exact sampling locations were haphazard), 1 meter upstream of the first transect. The position of the first placement was determined by rolling a die, and net placements at subsequent transects followed the pattern left-center-right-left…*etc*. An area of 0.09 m^2 in front of the net opening

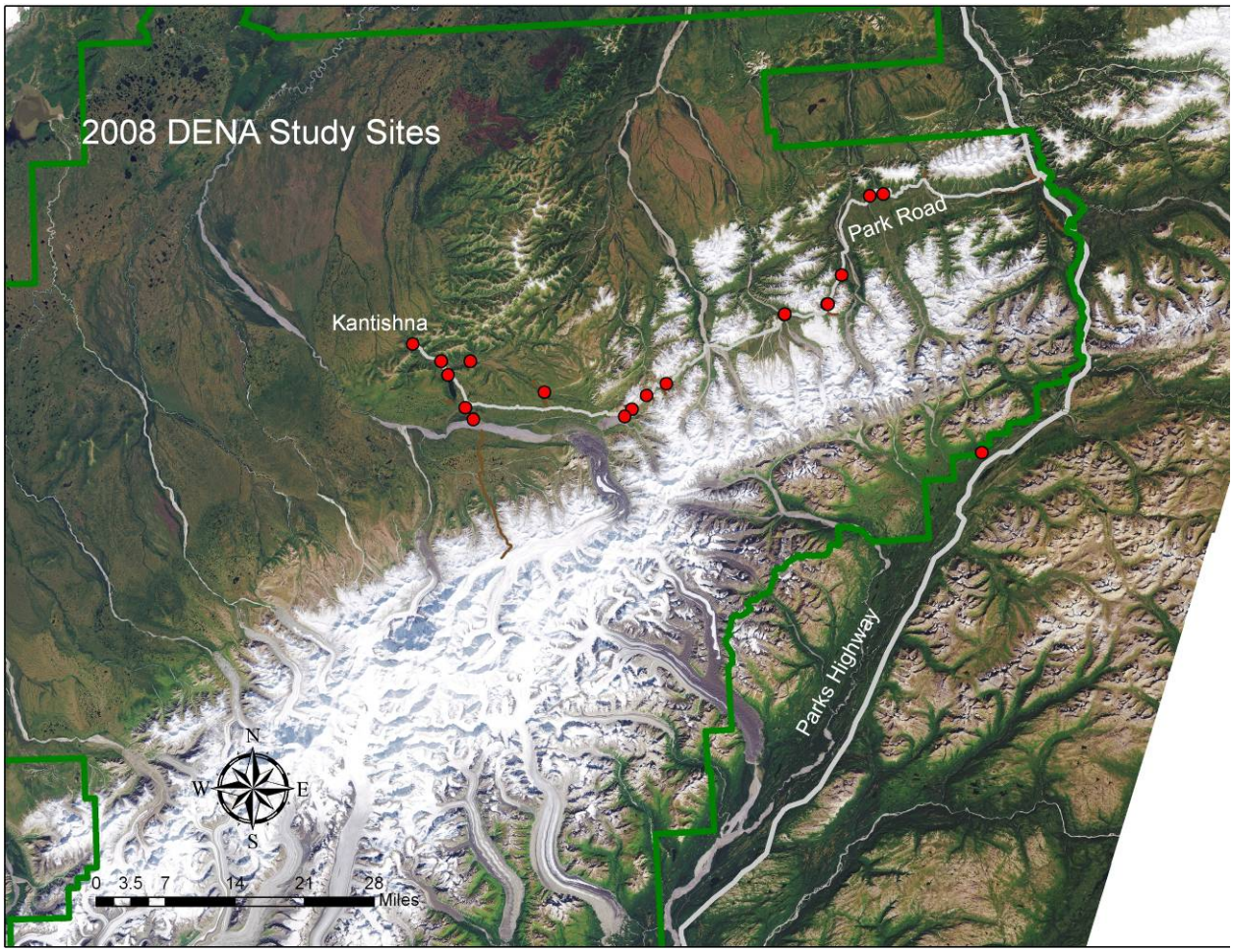

Figure 1. Locations of 2008 study sites in DENA. The easternmost site is Cantwell Creek; the westernmost is Moose Creek at the Kantishna airstrip

(as defined by a hinged frame that could be lowered to the stream bed) was thoroughly searched for macroinvertebrates by individually rubbing cobbles in front of the net opening and subsequently disturbing the remaining substrate by raking to a depth of approximately 10 cm. A total of eight macroinvertebrate samples were collected and composited into a single reachwide sample. This sample represents a total of 0.72 m^2 of streambed. Macroinvertebrates and organic detritus were separated from cobble and gravel and preserved in 70% ethanol. Macroinvertebrates were sorted and identified to the lowest practical taxonomic level, generally genus, by Mike Cole, a taxonomist for ABR, Inc. Due to variability within and among samples in the taxonomic resolution that could be achieved, I established a set of Operational Taxonomic Units (OTU) to assure that taxa are not double (or triple) counted. In some cases this required deleting coarse-resolution data (generally family level); in other cases, higher-resolution data (species or genus) were collapsed back to coarser resolution (genus, sub-family or family). The net result, often referred to as OTU richness, is therefore a conservative estimate of the true richness at a given site.

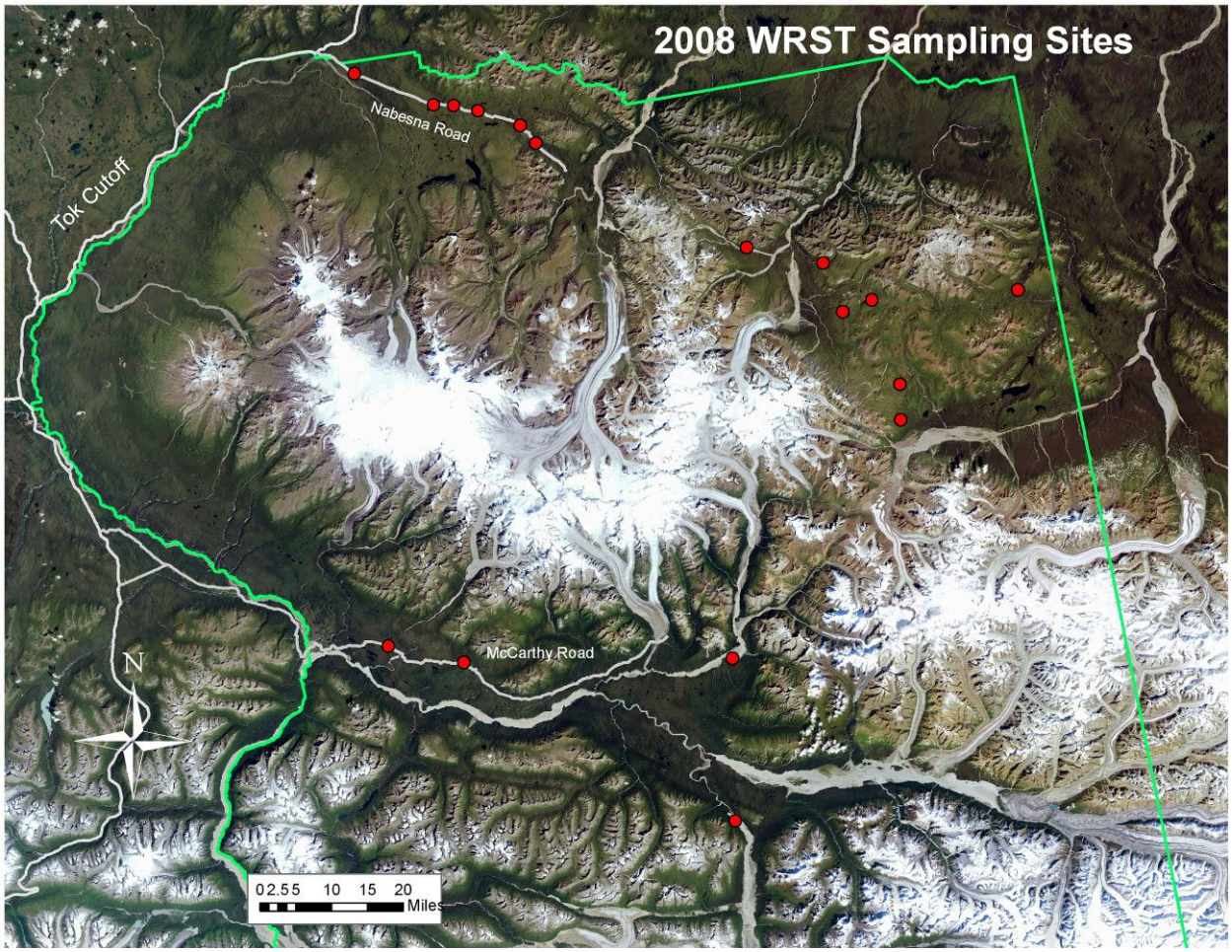

Figure 2. Location of 2008 study sites in WRST. The easternmost site is Horsfeld Creek near the airstrip; the southernmost site is Willow Creek, a tributary of the Tana River.

Benthic diatoms were collected as follows. At each of the eight transects where macroinvertebrates were collected, an appropriate cobble was haphazardly selected along the same cross section used for macroinvertebrate sampling (1 meter upstream of the transect itself). Cobble selection was shifted one "unit" to the right (*i.e.*, if macroinvertebrates were collected in the center of a given transect, a cobble was selected on the right). A defined area (12 cm^2) of each cobble was scrubbed and scraped to remove diatoms and the material collected was composited into a single reachwide sample. The total volume (diatoms plus rinse water) was recorded and a 40 mL subsample was removed and preserved with 2 mL Lugol's solution. Benthic diatoms were identified to the lowest practical taxonomic level, generally species, by Julia Eichmann, a diatom taxonomist for Ecoanalysts, Inc.

Fish were captured by a combination of electrofishing, minnow trapping and angling (fly fishing). We used a Smith-Root Model LR-24 backpack electrofisher. When electrofishing, crews worked upstream through the reach. All likely habitats were fished, and we generally had two netters attempting to collect stunned fish. When minnow trapping, we deployed 6 traps in likely habitats (log jams, backwaters, undercut banks) immediately upon arriving at the sampling reach. Traps were baited with a small amount of treated salmon eggs in small perforated plastic

bags, which were attached with twisty-ties to the midpoint of the trap. Traps were left in place for a minimum of 2 hours; whenever possible, they were deployed for longer periods, up to 16 hours (overnight). Captured fish were anesthetized with a mixture of clove oil and ethanol, identified and fork lengths were recorded. After completing identification and measurements, fish were allowed to recover in a bucket of fresh water before being released. Sampling by angling consisted of fly fishing the reach using a combination of wet and dry flies. The time spent angling was generally short (less than 30 minutes). Fish caught by angling were identified to species, their length was estimated and they were released immediately.

Physical and chemical data collection

We used a YSI QS650 sonde to collect temperature, specific conductivity, pH and dissolved oxygen *in situ*. Data were collected in riffles or runs and generally in midstream at the bottom of the reach. In addition, water chemistry samples were collected for later laboratory analysis. The samples were collected at the same location as the *in situ* water chemistry. A 1-liter bottle was rinsed 3 times with stream water, and then used to collect the main sample. A 500 mL unfiltered sample for total nitrogen and total phosphorous was transferred into an acid-washed Nalgene sample bottle and placed in a cooler with dry ice to freeze. The other 500 mL was filtered through a 0.45 μm filter. A 250 mL aliquot (for nitrate, ammonium, phosphate and common ions) was transferred to an acid-washed Nalgene bottle and placed in a cooler with dry ice to freeze. A 125 mL aliquot of filtrate (for dissolved organic carbon and silicon analysis) was transferred to an acid-washed Nalgene bottle and kept on ice. In some cases it was not possible to freeze the samples in the field; in these cases, the samples were kept cool in stream water and frozen as rapidly as possible (generally within an hour or two). Analytical water chemistry data were provided by the Cooperative Chemical Analytical Laboratory, established by memorandum of understanding no. PNW-82-187 between the U.S. Forest Service Pacific Northwest Research Station and the Department of Forest Ecosystems and Society, Oregon State University. This laboratory specializes in low-level detection of ambient stream water solutes.

Physical data collection protocols were largely based on EMAP WSA protocols (USEPA 2004). At each transect, we measured depth (five measurements), width (wetted and bankfull), channel height (bankfull and incised), undercut banks, canopy cover (six measurements) and substrate size class (using a gravelometer – five measurements at depth locations). In intertransect segments, we measured thalweg depth and habitat type (ten measurements), width (one measurement), substrate (five cobbles along width measurement cross-section), woody debris (by size class) and fish cover (macrophytes, filamentous algae, boulders and undercut banks (qualitative estimate of extent). We measured reach slope using a transit level at some sites. We also measured discharge at a subset of sites using a Marsh-McBirney flowmeter and a topsetting wading rod.

Continuous data collection

Temperature-recording dataloggers were installed in 18 streams in May and early June (Table 2). In addition, a continuously recording pressure transducer was installed in Jack Creek (WRST). Dataloggers were generally secured using vinyl-coated steel cable to attach them to riparian trees. Loggers were additionally wired to the underside of large anchor rocks to keep them in place. Where possible, loggers were placed in relatively deep, fast–flowing water (*e.g.*, in a run). Care was taken to minimize the visibility of both the logger and the anchoring system. Two

dataloggers were lost over the course of the summer. One was lost when the cable apparently wore through the plastic attachment grommet on the logger, although it was later recovered downstream on the stream bank. A second logger was lost in a dynamic aggrading stream in WRST (Lost Creek), when the channel shifted and buried the attachment site under a large amount of cobble. Two other temperature loggers, both installed at remote sites, could not be retrieved before the end of the field season, and remain in place. Loggers were set to record temperature every 8 minutes. This resulted in approximately a 5 month maximum lifespan for the data record. A 5-month record is adequate when loggers are installed and retrieved each field season; however, in cases where loggers are left over the winter, there is no possibility of recording additional data the following season. In future years, loggers will be set to record temperature once per hour – this should provide enough detail regarding diurnal variation while allowing over 2 years of data to be collected.

Table 2. List of sites where temperature loggers were installed in 2008, along with brief site descriptions

Site	Park	Description
Sanctuary River	DENA	large glacially-influenced river (LTEM site)
Moose Creek at bridge	DENA	large clearwater river in Kantishna Hills (LTEM site)
Little Stony Creek	DENA	high-elevation tundra stream (LTEM site)
Lake Creek	DENA	Wonder Lake outlet stream
Igloo Creek	DENA	large forested stream (LTEM site)
Hogan Creek	DENA	small groundwater-fed stream (LTEM site)
Savage River	DENA	large mostly clearwater river, some glacial influence (LTEM site)
Chalk Creek	WRST	clearwater stream along Nabesna Road
Rock Creek	WRST	clearwater stream along Nabesna Road
Little Jack Creek	WRST	clearwater stream along Nabesna Road
Jack Creek	WRST	large lake outlet stream along Nabesna Road
Caribou Creek	WRST	intermittent stream along Nabesna Road
Lakina River	WRST	large glacial stream along McCarthy Road
Gilahina River	WRST	large clearwater stream along McCarthy Road
Chokosna River	WRST	large clearwater stream along McCarthy Road
Long Lake Creek	WRST	lake outlet stream along McCarthy Road
Solo Creek	WRST	clearwater tributary to White River
Tana River tributary	WRST	Large, deep, very low-gradient stream in Tana River floodplain
Lost Creek	WRST	Dynamic aggrading intermittent stream along Nabesna Road

Results and Discussion

Water Chemistry

The water chemistry results (Table 2) revealed a very wide range of conditions across the 2 parks. The exception was pH, which normally does not vary much between unpolluted streams, and is typically in the range of 7.5 – 8.5. For example, sulfate concentrations varied some 100-fold among the sites. By far the highest sulfate levels (almost 78 mg/L) were observed in the "Travertine stream", a small, unusual-looking stream that crosses the DENA park road near Stony Creek. It is characterized by extensive deposition of a travertine-like precipitate and water with a slight yellowish cast. This stream was also quite alkaline (bicarbonate-carbon = 58 mg/L, *vs*. a mean value of 24.4 for all streams), with high levels of dissolved minerals such as calcium and magnesium. During high flows the water can actually be slightly milky (P. Brease, Denali National Park, personal communication), suggesting that very high levels of minerals may be transported. The origin of this unusual stream has yet to be fully investigated, although it appears to flow out of a spring several miles into the Alaska Range foothills. About a mile upstream of the sampling site an iron-rich tributary enters. Interestingly, the stream has an above average diversity of aquatic insects (see Macroinvertebrates section below). One possible natural source of elevated sulfate in streamwater is anoxic oxidation of FeS_2 in groundwater by denitrifying bacteria (*e.g*., Kölle *et al*. 1985), although the presence of elevated calcium and magnesium as well suggests that calcium and magnesium sulfate minerals may be contributing the bulk of the sulfate. The chemistry of this stream in 2008 was virtually identical to that observed in 2007.

Table 3. Summary water chemistry statistics from 2008 samples.

	Minimum	Mean	Median	Maximum
Temperature	1.6°C	5.8°C	5.7°C	13.5°C
Specific Conductance	75 μS/cm	339 μS/cm	312 μS/cm	860 μS/cm
pH	7.4	8.09	8.09	8.53
Alkalinity (HCO_3-C)	4.9 mg/L	24.4 mg/L	22.5 mg/L	58 mg/L
Total nitrogen	5 μg/L	192 μg/L	195 μg/L	390 μg/L
Nitrate-N	3 μg/L	95 μg/L	92 μg/L	276 μg/L
Total phosphorous	3 μg/L	26 μg/L	13 μg/L	245 μg/L
Phosphate-P	< 1 μg/L	3 μg/L*	<1 μg/L	90 μg/L
Sulfate-S	0.73 mg/L	20.5 mg/L	18.5 mg/L	77.9 mg/L
Dissolved organic carbon	0.36 mg/L	2.06 mg/L	1.46 mg/L	6.35 mg/L

*90% of samples tested in 2008 had Phosphate-P levels at or below the level of detectability reported by CCAL. I substituted values of ½ the detection limit of 1 μg/L for calculating descriptive statistics, although with the understanding that it may introduce error (Helsel 2006).

Another feature of these streams is the generally low levels of phosphate-P. The mean concentration among all streams sampled in 2008 was less than 3 μg/L, and 90% of samples had undetectable levels (<1 μg/L). Total phosphorus (TP) was also generally low, with a few exceptions. The mean TP concentration in these streams (26 μg/L) is more than three-fold lower than the comparable value (90 μg/L) for wadeable streams in the lower 48 (USEPA 2006). The median concentration for CAKN streams is in fact only 13 μg/L, which is strikingly low. In fact, only a handful of streams sampled in 2008 had a TP concentration higher than 50 μg/L – one of

these was a glacial stream with high sediment loads and undetectable levels of dissolved phosphate. This suggests that suspended sediment was the source of the high TP levels and that much of it is not biologically available. The other exceptions included a small tributary of Solo Creek. It's not clear why this stream had fairly high TP (131 μg/L) and phosphate (90 μg/L), as the geology of this area is not well studied.

An ongoing challenge for the program will be dealing with the extremely low concentrations of many important solutes in these streams. This is despite the very low detection limits of the CCAL methods for most solutes. The most problematic of these are soluble reactive phosphorous (SRP, aka soluble phosphate-phosphorous) and ammonium-nitrogen. Of the 88 samples so far analyzed, 56% are below the level of detection for SRP (1μg/L) and a full 69% are below the level of detection for ammonium nitrogen (10 μg/L). Statistical methods based on survival analysis exist for dealing with these so-called "non-detects", generally by selecting values from a modeled distribution using maximum likelihood estimation techniques; however, they do not generally perform well for small data sets (less than 30-50 detected values), where there is insufficient evidence to determine whether the assumed distribution fits the data adequately (Helsel 2006). In these cases, we may have to use non-parametric procedures designed for censored data, the software algorithms for which are currently not adapted to deal with environmental data (Helsel 2005, 2006).

Macroinvertebrates

Macroinvertebrates were collected from 19 DENA streams (20 site visits) and 14 WRST streams (16 site visits) in 2008. As was the case in 2006 and 2007, observed OTU taxa richness varied tremendously among the sampled sites, ranging from 3 unique taxa at the East Fork of the Toklat River in DENA to 33 at Moose Creek in Kantishna (DENA). The mean richness across all sites was 19.6 taxa, which is comparable to that observed in 2007 (17) at a different but partially overlapping set of streams. Chironomid midges accounted for approximately 29% of taxa richness across all sites, and 34% of individuals. This is substantially lower than reported by Oswood (1989), who found that chironomids constituted on average 59% of individuals in Alaskan streams, but is similar to the results observed in CAKN streams in 2006 and 2007. The highest richness was found at the two "middle" Moose Creek sites in DENA, Moose Creek at Bridge (33 unique taxa) and Moose Creek at Crossing (32 unique taxa). Densities varied from a low of 7 individuals/m^2 at East Fork Toklat River to a high of over 10,000 per m^2 at Igloo Creek above Tattler.

In 2007 a total of 15 aquatic insect taxa not reported by Milner *et al*. (2003) or by Conn (1998) were collected by the CAKN crew in DENA in 2007 (see Table 1 in Simmons 2009). In 2008 we collected an additional 12 previously unreported insect taxa (Table 1), including new families of beetles, stoneflies and true flies. As we discussed last year, the true total is likely to be substantially higher, as we were able to identify to the species or genus level a number of taxa reported by Milner *et al.* as identified only to the genus or family level, respectively. Of the taxa first reported in 2007, we have confirmed the presence of *A. lapponica*, *D. doddsii*, *Arcynopteryx sp.*, *Apatania sp.*, *Limnophora sp.*, *Micropsectra sp.*, *Pseudosmittia sp.*, and *Sympothastia sp.* The unidentified chironomid genus (subfamily Orthocladiinae) collected in 2007 in Hogan Creek was also collected in 2008 from Hogan Creek. In addition, it was collected from the so-called Travertine Stream near Stony Creek. 4 of the new taxa from 2007 were not collected in the 2008

samples. The initial identification of *Capnia sp*. from 2007 is now in question due to subtle differences between *Capnia* and *Mesocapnia/Utacapnia*. Our taxonomist is currently not willing to make a definitive call, and is consulting with expert plecopteran taxonomists before making a final determination. In any case, none of these 3 genera has been previously reported from DENA. Similarly, we reported the presence of *Prostoia sp*. in 2007. *Prostoia* has not been previously reported anywhere in Alaska. Although the specimens in question closely resemble *Prostoia*, it is possible that they represent a morphologically distinct group of the similar genus *Podmosta*, which is known to occur in Alaska. Again, we are consulting expert plecopteran taxonomists before making a final determination.

Table 4. List of aquatic insect taxa identified from 2008 CAKN samples and not reported in Milner *et al*. (2003) or Conn (1998). Milner *et al*. sampled 58 streams parkwide.

Coleoptera (beetles)
Staphylinidae – semiaquatic (family)
Ephemeroptera (mayflies)
Acentrella turbida
Plecoptera (stoneflies)
Taeniopterygidae (family)
Paraperla sp.
Nemoura sp.
Trichoptera (caddisflies)
Allomyia sp.
Diptera (true flies)
Dolichopodidae (family)
Harnischia sp.
Paraphaenocladius sp.
Stempellina sp.
Thienemannimyia sp.
Trichotanypus sp.

We also identified 4 families of freshwater molluscs (Pisidiidae, a family of bivalves, and three snail families: *Lymnaea sp.* [family Lymnaeidae], Planorbidae, and *Valvata sp*. [family Valvatidae]) from 2008 samples. As far as we are aware, these have not been formally reported in DENA. All 4 families were present in substantial numbers in Lake Creek. In addition, *Lymnaea sp*. was collected from Cantwell Creek and Pisidiidae from the McKinley Bar spring creek. This brings the 2-year total to a minimum of 31 newly reported aquatic macroinvertebrate taxa and reinforces our argument, made last year, that the streams and rivers of DENA remain woefully understudied. A similar situation no doubt entails in WRST, but there is no comparable literature available for comparison in that park unit.

A total of 147 unique macroinvertebrate taxa have now been identified in the three years of the CAKN program. 84 of these first were identified in the 2006 samples, another 41 were unique to the 2007 samples, and an additional 22 were first identified in 2008 samples. It is likely that we will continue to add to this total for a number of years given the relative paucity of stream

macroinvertebrate data from these parks, particularly from WRST. One interesting observation was made at the "Travertine Stream" in DENA, which has unusual water chemistry and extensive deposition of a travertine-like precipitate (see above in "Water Chemistry" section). As a result of the deposition, the stream contains little in the way of traditional stream habitat for invertebrates; there are only a few small areas of apparent upwelling that remain partially precipitate-free. These areas also accumulate small amounts of particulate organic matter. Despite these seemingly hostile conditions, a surprisingly diverse macroinvertebrate community inhabits the stream. A total of 20 unique taxa were collected from the Travertine Stream, including 2 stoneflies. A previously unidentified midge of the subfamily Orthocladiinae, first identified in samples from 3 sites in 2007, was collected again at 4 sites in 2008. It was collected from Hogan Creek in both years, and also collected from the Travertine Stream in 2008. In addition, a previously unidentified midge from the subfamily Tanytarsini was collected from a stream in WRST in 2008. Although it would be satisfying to identify and name these new species, the necessity of capturing live larvae and rearing them to the adult stage in the laboratory for identification means this next step is unlikely to occur soon.

In 2007, the density of macroinvertebrates in Igloo Creek below the road construction - 275/m^2 - was only 3% of that observed at the Igloo Creek site above the construction - 8,000/m^2 (Simmons 2009). In 2008, with road construction complete, the lower site appeared to have recovered somewhat, with a macroinvertebrate density that was 10 times higher than in 2007 (2807 per m^2) and nearly 28% of the observed density at the upper site. Densities at the upper site were comparable in both years (8,000 vs. 10,000 per m^2), suggesting that the road construction may have had a negative, albeit apparently temporary, effect on macroinvertebrates downstream.

Benthic Diatoms

Diatoms were also collected from the same 33 sites. As seen in previous years, observed species richness for diatoms was substantially higher than for macroinvertebrates, and varied from a low of 12 species (East Fork of the Toklat River in DENA) to a high of 79 species (Lake Creek in WRST), with a mean of 37 species per site. A total of 360 diatom species have now been identified through the CAKN program. 166 of these were first identified in samples collected in 2006, while another 68 species were identified in the 2007 samples. An additional 126 new species were collected in 2008. In general, the lowest species richness and density were found in unstable braided systems, and the highest in stable spring-fed creeks. Although the finding that species richness and densities were lowest in turbid and unstable streams was expected, species richness in some of these systems was remarkably high. For example, the East Fork of the Toklat River had 12 species of diatoms, as opposed to only three macroinvertebrate taxa. *Didymosphenia geminata*, an emerging invasive species with a number of unusual properties, is native to boreal streams, but has been observed recently to cause problematic blooms even within its native range. *D. geminata* was identified in 9 of the 33 sites sampled (2 remote sites in WRST and 7 sites along the park road in DENA), albeit at generally low densities. An apparent nuisance bloom was observed in upper Igloo Creek in DENA; unfortunately no samples of the bloom material were retained to definitively confirm this observation (although *D. geminata* was present at the site). The CAKN program will continue to monitor the distribution and abundance of this species, and we are developing a set of procedures to allow other field personnel in the parks to recognize and collect samples of suspected *D. geminata* blooms.

Fish

Fish were successfully captured at 17 sites in 2008 (listed in Table 4) using a combination of electrofishing, minnow traps and angling. Electrofishing was conducted at only a handful of sites. Because different capture methods are biased toward different species, these results are illustrative rather than definitive. For example, both slimy sculpin and arctic grayling tend to be poorly represented in minnow trap samples, whereas grayling are easily captured by angling. In contrast, juvenile salmonids are highly susceptible to minnow traps. We failed to capture any juvenile chinook salmon in Moose Creek (DENA) in 2008, where they were first documented in 2007. We were, however, able to capture juvenile coho salmon in Lake Creek (WRST), confirming our initial tentative observation from 2007. Juvenile chinook were also captured in Willow Creek, confirming our visual observation from 2007 of spawning adults. Finally, we documented the presence of coho salmon in Willow Creek as well. On the basis of these observations, I have nominated Willow Creek (for coho) and Lake Creek for additions to the Alaska Department of Fish and Game Anadromous Waters Catalogue.

Table 5. Summary of 2008 fish data.

Site name	Species identified (number)
DENA	
Sanctuary River	Slimy sculpin (16), Arctic grayling (5)
E.F. Toklat tributary	Arctic grayling (7)
Igloo Creek	Arctic grayling (3), slimy sculpin (2)
Igloo Creek above Tattler	Arctic grayling (5), slimy sculpin (4)
Little Stony Creek	Arctic grayling (5)
Moose Creek at bridge	Slimy sculpin (14), Arctic grayling (1)
Moose Creek at airstrip	Arctic grayling (2)
McKinley Bar spring	Arctic grayling (2)
McKinley Bar Trail creek	Arctic grayling (6), slimy sculpin (1)
Lake Creek	Lake trout (6), burbot (1), slimy sculpin (40)
Wonder Lake macrophyte beds	Burbot (1), slimy sculpin (11)
WRST	
Beaver Creek	Arctic grayling (4), slimy sculpin (1)
Lake Creek	Dolly Varden (4), **coho salmon (4)**, slimy sculpin (1)
Willow Creek	Dolly Varden (6), **coho salmon (6)**, chinook salmon (2), slimy sculpin (1)
Solo Creek tributary	Arctic grayling (4)
Rufus Creek	Dolly Varden (5), Arctic grayling (2)
N.F. White River	Arctic grayling (5), slimy sculpin (2)

bold indicates an extension of the Alaska Anadromous Waters Catalog for this species

Evaluation of GRTS sample list

All 400 proposed sampling sites were first evaluated using remote sensing to minimize time wasted in the field. Where available, I used Ikonos imagery; however, in many areas lower-resolution imagery had to be used. In this procedure I was attempting to eliminate sites that were clearly not part of the target population, either because there was no stream at the location, because the site was actually a lake, because the stream, or necessary access routes, overlapped private or Native Corporation land, or because the river was clearly too big to sample safely. Of the 400 sites on the original list, 95 (23.75%) were determined to be non-target based on remote

sensing data (Table 6). 116 of the remaining 305 potential sampling sites (38%) were evaluated by field visits in 2008. Most of these were assessed during helicopter overflights, although a small number were accessed by hiking. Five of the GRTS sites were sampled during this process. The results of this field reconnaissance are also shown in Table 6. Of the 116 sites I visited, 33 (28%) were either sampled (5 sites) or were determined to be both accessible and probably sampleable. Based on these figures, approximately 114 of the original 400 sites should be both accessible and sampleable, which provides a small cushion for achieving the target of 100 synoptic sites.

The distinction between the accessible and inaccessible strata did not play out as hoped initially. Although 16 of the first 50 "accessible" sites were estimated to be sampleable, only 8 of those 16 can probably be reasonably accessed without the use of helicopters. If those percentages are representative of the entire site list, then there will likely be at most 30 total "accessible" sites, and the remaining 70 sites will require helicopter access.

Table 6. Evaluation of GRTS sample sites.

Site category	Number of sites	Percent of starting site list
	Remote sensing evaluation (400 sites)	
Doesn't exist	4	1%
Lake	21	5.25%
On private/corporation land	29	7.25%
Too big to sample safely	41	10.25%
Possibly sampleable	305	76.25%
	Field evaluation (116 sites)	
Doesn't exist	9	7.7%
Lake/marsh	6	5.2%
Not landable with helicopter	9	7.7%
Dry	4	3.4%
Too big to sample safely	20	17.2%
Not accessible	7	6%
Probably too big to sample safely	28	24%
Landable or hikeable and sampleable	28	24%
Sampled in 2008	5	4.3%

Glacial river phenology

2008 marked the first year in which CAKN sampled a glacial river in both the summer and the fall. Glacially-influenced rivers are typically turbid and highly dynamic during the summer melt season, but clear up and stabilize in the fall. This clearwater phase, which occurs in both fall and spring, may provide a critical subsidy to stream consumers, including fish, as the stable hydrology and clear conditions should allow for a burst of primary productivity during the time period after the end of the glacial melt season, but before the angle of the sun, temperature and day length decrease too much (and *vice versa* in the spring). Because climate warming may alter these processes, the CAKN monitoring program is determined to include multi-season monitoring of glacial rivers as an important component. The East Fork of the Toklat River in

DENA was chosen as the first glacial river to be monitored in this way. The river was sampled in late August, when it was extremely turbid, and exhibited very dynamic hydrology, and then sampled again in late September, when the water was clear and the flow was low and stable.

The results were remarkable, and are shown in Table 5. It is not known exactly when the melt season ended for the East Fork Glacier, but given observations of other glaciers in the network, it was likely not more than a week or two before the fall sampling on September 25. Hence, most if not all of the changes discussed here as differences between "summer" and "fall" likely occurred within this short time period. With the exception of total phosphorous, there is little change in water chemistry between summer and fall. The high level of total phosphorous observed in the summer is almost certainly related to phosphorous in the sediment load carried during glacial melt. High total phosphorous accompanied by low soluble reactive phosphate is typical of the turbid glacial rivers that have been examined in the Central Alaska Network. The likely

Table 7. Summary of instream conditions at East Fork Toklat River in summer *vs*. fall

Metric	Summer value	Fall value
Temperature	8.2°C	2.2°C
Specific conductivity	369 μS/cm	387 μS/cm
Total nitrogen	160 μg/L	170 μg/L
Total phosphorous	245 μg/L	7 μg/L
pH	7.8	8.2
Nitrate-N	112 μg/L	135 μg/L
Soluble reactive phosphorous	<1 μg/L	<1 μg/L
Macroinvertebrate taxon richness	3	7
Macroinvertebrate density	7 / m^2	54 / m^2
Diatom species richness	12	18
Diatom density	5900/cm^2	350,000/cm^2

explanation for this lack of interseasonal variability is a significant contribution to the shoulder season baseflow from hyporheic flow with a substantial glacial component. Despite this minimal change in water chemistry, however, a substantial biological change occurs over this short time period. Diatom species richness increases by 50% and diatom density by nearly two orders of magnitude (Table 5). Even more remarkable is the change in the macroinvertebrate community, given the typically much longer life cycles and slower growth rates of macroinvertebrates relative to diatoms. Macroinvertebrate taxon richness more than doubles, and macroinvertebrate density increases nearly 800%, though it remains low relative to nonglacial streams. These results support the idea that the shoulder seasons are important to overall stream productivity in glacial systems, and as the timing and duration of these clearwater periods are likely to be altered by ongoing climate change, the CAKN program plans to expand its two-season monitoring of glacial streams and rivers.

Re-evaluating the comparison between LTEM and CAKN macroinvertebrate data

An important focus for the 2007 field season was to test whether legacy invertebrate data collected in Denali National Park and Preserve (DENA) as part of the Long Term Ecological

Monitoring Program (LTEM) would be compatible with data collected using the Central Alaska Network (CAKN) stream monitoring protocols. Under the direction of Sandy Milner, invertebrate samples have been collected annually since 1994 at 14 sites along the Park Road. Furthermore, the program collected macroinvertebrate data in 1994-1996 from a total of 58 streams located throughout DENA. These data should provide an invaluable starting point for the determination of long-term trends in the ecology of DENA streams; however, differences in the field methods used by Milner and the CAKN program have the potential to complicate efforts to synthesize these two data streams. Initial comparative analyses based on data collected by both groups at 10 sites along the park road in 2007 revealed substantial differences between the two programs, in both the reported taxa richness and community composition, at these 10 sites. In 2008, CAKN resampled 8 of those 10 sites to assist in the re-evaluation of these findings (Table 7).

The 2007 findings can be summarized as follows. There were two cases of obvious taxonomic disagreement; in both cases the CAKN taxonomist made a strong case that the CAKN designation was correct, and for the purposes of analysis, the assumption was made that the CAKN designation should apply to both data sets. A number of other taxonomic adjustments were also necessary to make the two datasets comparable; these were mostly the result of the higher level of taxonomic resolution in the CAKN data. After making these adjustments, it was found that both mean taxa richness and mean density were substantially higher in the CAKN samples than in the LTEM samples (mean taxa richness was 35% higher, mean density was 31% higher). The differences in reported richness were highest at large, wide rivers. The most parsimonious explanation is that differences in sampling methodology largely account for this discrepancy. The LTEM samples are collected from within a 10-meter reach regardless of stream size, whereas the CAKN samples are collected from a reach that is much longer (40 times the mean wetted width, with a minimum reach length of 150 meters), and therefore probably captures more of the diversity of the larger stream segment. This effect is more pronounced in larger streams, as would be expected. The 2008 CAKN data continue to support this idea. Comparing the 2008 CAKN data to the 2007 LTEM data shows that the difference in reported

Table 8. Streams from the 2007 comparative analysis that were sampled again in 2008 by CAKN

Stream name (reach length in meters)	Description of CAKN sampling reach
Hogan Creek (150 m)	Reach starts ~50 m above road
Sanctuary River (500 m)	Reach starts opposite pullout ~1/4 mile past bridge
Igloo Creek (250 m)	Reach starts ~100 m above bridge
Tattler Creek (150 m)	Reach starts ~50 m above road
East Fork Toklat River *	Reach starts ~50 m above tributary confluence
East Fork Toklat tributary (150 m)	Reach starts ~200 m above confluence
Little Stony Creek (150 m)	Reach starts ~50 m above road
Moose Creek (500 m)	Top of reach at Kantishna bridge

*The E.F. Toklat is a dynamic braided river. For this type of system, we use a “transverse” reach across the floodplain and sample all braids.

richness at large streams continues to hold, with difference in mean richness at large streams (21 *vs*. 14, or 50%) being greater than that at small streams (11.4 *vs.* 10, or 15%).

We also re-examined the species composition of the various samples. In 2007, the mean Bray-Curtis distance between LTEM-CAKN stream sample pairs (excluding the depauperate E.F. Toklat River) was 0.34, compared to the global between-sample distance of 0.63 (Simmons 2009). Bray-Curtis distance is a measure of the degree to which the taxa lists of two samples overlap. It varies from zero to one, with a value of zero indicating that two samples are identical, and a one indicating that they share no taxa in common. Although the mean between-sample distance from 2007 was about ½ of the mean between-stream distance, it was still higher than it should be. In 2006, the CAKN program resampled a single reach (Chalk Creek in WRST) 5 times in one day. The mean Bray-Curtis distance among these replicate macroinvertebrate samples was 0.14, meaning that they shared 86% of their taxa lists on average. The mean distance among all WRST streams sampled in 2006 was 0.66, which is comparable to the mean for these Denali streams. This distance (0.14) then represents the approximate minimum between-sample distance that can be expected, with the understanding that differences in the degree of spatial heterogeneity among streams may increase or decrease it. The remaining variability between the two data sets could result largely from taxonomic differences we have not yet identitifed (Stribling *et al*. 2003) or may stem from the differences in field methodology or from a combination of both.

For comparison, the mean between-sample distance among the Chalk Creek replicate samples was 0.33 for diatoms (compared to 0.66 among all streams). Hence, the 2 macroinvertebrate sampling methodologies are apparently approximately as comparable as replicate diatom samples, at least in this instance. However, diatoms are generally more spatially variable within habitats than macroinvertebrates. Natural variability (spatial and temporal) in macroinvertebrate community composition presents a major challenge for the detection of trends in stream ecosystems. This variability can be substantial; hence, it is critical that other sources of variability, such as those due to sampling error, be minimized.

When the data from the 8 streams CAKN resampled in 2008 were included in the analysis, it was found that the mean Bray-Curtis distance between CAKN stream-year pairs (0.30) was nearly the same as the mean distance between LTEM and CAKN samples collected at those 8 streams only a few days apart in 2007 (0.28). However, the mean distance between a given 2007 LTEM sample and its corresponding 2008 CAKN sample was substantially higher (0.38). Most of this difference was again driven by the substantial dissimilarity in samples collected in larger rivers. This suggests a systematic problem, at least with respect to sampling larger systems, in comparing data collected by the two programs.

We are currently in the process of conducting more sophisticated analyses to determine in a more quantitative way how comparable the two methodologies will be for the types of analyses we are interested in using in the CAKN monitoring program. As part of this process, we will in 2009 be maintaining each individual subsample from the composite reach sample separately at these sites (using the CAKN methodology). Milner's group already maintains subsamples separately. This will allow us to account for imperfect detectability of taxa, and generate more accurate estimates of species richness.

Initial analyses of year-to-year variability

2008 was the third year of data collection, which provides enough data to begin to look at year-to-year variability in some of the metrics collected. For water chemistry data, there are 21 sites

with data from at least 2 years, and 3 sites with data from all 3 years. Several sites have been visited multiple times in one or more years as well. Although power to detect trends depends on various factors, an estimate of the year-to-year (or visit-to-visit) variability in the value of a given metric (*e.g.*, the coefficient of variation) provides some insight into how difficult trend detection is likely to be. Table 9 shows the mean, 95% confidence intervals and coefficient of variation for some key water chemistry parameters at the 3 sites for which data are available from all 3 years of the program. All 3 sites were visited more than once in at least one of the 3 years. Chalk Creek was visited twice in 2006 and 2007 and 3 times in 2008; Rock Creek was visited twice in 2006, once in 2007 and 3 times in 2008; and Jack Creek was visited once in 2006, once in 2007 and 3 times in 2008.

Table 9. Visit-to-visit variability in water chemistry parameters at selected sites 2006-2008. For each stream/parameter combination, the sample size (N), mean, 95% confidence intervals and coefficient of variation are given.

Stream	Parameter	N	Mean	95% CI	CV
Rock Creek	Specific conductance	5	368 μS/cm	+/- 82	0.25
Chalk Creek	Specific conductance	6	403 μS/cm	+/- 69	0.21
Jack Creek	Specific conductance	5	386 μS/cm	+/- 69	0.20
Rock Creek	pH	4	7.86	+/- 0.38	0.05
Chalk Creek	pH	5	8.2	+/- 0.27	0.04
Jack Creek	pH	4	7.98	+/- 0.33	0.04
Rock Creek	Total nitrogen	5	264 μg/L	+/- 69	0.30
Chalk Creek	Total nitrogen	5	430 μg/L	+/- 255	0.68
Jack Creek	Total nitrogen	4	240 μg/L	+/- 27	0.11
Rock Creek	Dissolved organic carbon	5	5.33 mg/L	+/- 2.2	0.47
Chalk Creek	Dissolved organic carbon	4	4.35 mg/L	+/- 3.9	0.91
Jack Creek	Dissolved organic carbon	4	2.55 mg/L	+/- 1.0	0.41
Rock Creek	Total phosphorous	5	19.8 μg/L	+/- 9	0.51
Chalk Creek	Total phosphorous	5	327 μg/L	+/- 597	2.09
Jack Creek	Total phosphorous	4	25.5 μg/L	+/- 15	0.61
Rock Creek	Nitrate-nitrogen	5	74 μg/L	+/-18	0.28
Chalk Creek	Nitrate-nitrogen	4	140 μg/L	+/- 77	0.56
Jack Creek	Nitrate-nitrogen	4	130 μg/L	+/- 42	0.33
Rock Creek	Sulfate-sulfur	5	18.9 mg/L	+/- 3.5	0.21
Chalk Creek	Sulfate-sulfur	4	20.9 mg/L	+/- 4.6	0.23
Jack Creek	Sulfate-sulfur	4	23.7 mg/L	+/- 3.4	0.15

Even with just 3 streams, it is clear that there is a great deal of variation among both parameters and streams in terms of variability. Specific conductance, pH and sulfate-S all show relatively low variability at all 3 sites, whereas dissolved organic carbon and total phosphorous are quite

variable at all 3 sites. A preliminary power analysis (with $1-\beta = 0.90$, $\alpha = 0.05$) based on these data suggests that detecting a relatively moderate increase (25%) in the mean measured concentration of dissolved organic carbon or total phosphorous would require substantially more effort than detecting a similar increase in specific conductivity (4-20 times as many samples).

Note that Chalk Creek shows substantially more variability than Jack Creek or Rock Creek in nutrient measures, but not in pH, specific conductivity or sulfate. This variability is driven largely by a single event – in July 2007, Chalk Creek was sampled during a storm-related spate. Nutrient levels measured during the spate were very high compared to baseflow concentrations (*e.g.*, total phosphorous was 1,546 μg/L *vs*. a mean of 22 μg/L during base flow). Substantial changes in stream water chemistry during high flows are common, and result largely from changes in the relative importance of different hydrologic flowpaths. In the case of Chalk Creek, the concentrations of most cations and anions dropped moderately, along with conductivity, alkalinity and nitrate, whereas the levels of dissolved organic carbon, total nitrogen and phsoporous, ammonium and soluble phosphate spiked. This is consistent with a substantial increase in overland and shallow subsurface flow contributing to overall discharge.

A preliminary analysis of patterns in macroinvertebrate community composition over the 3-year sampling period was also conducted. Briefly, abundance data were converted to presence-absence, and a Bray-Curtis dissimilarity matrix was calculated. The matrix itself was examined to assess year-to-year variation in composition at sites with multiple years of data (Table 10); in addition, cluster analysis was used to look at overall patterns among sites and across years (Figure 3). The site with the most invertebrate samples is Chalk Creek, where samples have been collected in all 3 years, including both summer and fall samples. In 2006, 5 replicate macroinvertebrate samples were collected at Chalk Creek in a single day. The mean between-sample dissimilarity for these 5 samples was 0.14, meaning that, on average, any two replicates shared 86% of their taxa in common. This can be interpreted to mean that a combination of spatial heterogeneity in the distribution of macroinvertebrates and subsampling error (see *e.g*. Cao *et al*. 2002, Ostermiller and Hawkins 2004) limits the similarity between any two samples to 86%; in other words, the sampling error averages 14% (at least in this stream). Mean dissimilarity among all Chalk Creek samples was 0.36; however, samples were collected in both summer and fall so this figure includes seasonal as well as interannual variability. Dissimilarity between summer-only samples was 0.21, while dissimilarity among fall-only samples was 0.30. Given the sampling error of 0.14, this suggests that year-to-year variation in community composition is actually rather low. However, it is clearly risky to draw conclusions based on only 3 years of data.

Among all 16 streams for which summer samples were collected in multiple years the mean between-year dissimilarity (for summer samples) was 0.33. Year-to-year dissimilarity among fall samples was also relatively low at 0.33.There was a substantial degree of variation among streams, however (Table 10), with interannual dissimilarities ranging from a low of 0.20 (Hogan Creek in DENA) to a high of 0.56 (Willow Creek in WRST). Although only a limited number of fall samples have been collected, it appears that seasonal variation (mean within-year dissimilarity = 0.56) is substantially higher than interannual variation among samples collected in the same season. This clearly illustrates the important effect of sampling date on measured community composition. The monitoring program is continuing to expand the number of streams

that are sampled in multiple seasons to better assess the relative magnitudes of interannual and seasonal variation in community composition. Additionally, in 2009 the program will modify invertebrate collection procedures to allow the use of occupancy modeling methods to quantify detectability. Accounting for imperfect detectability will decrease the apparent variability between samples and improve our ability to quantify change.

Table 10. Year-to-year variation in macroinvertebrate community composition. Figures given are Bray-Curtis dissimilarities and are averages among all year pairs (*e.g.*, 2006-2007, 2006-2008 and 2007-2008 if data were available for all 3 years). The last column represents the mean within-year dissimilarity between summer and fall samples.

Stream name	summer/summer	fall/fall	summer/fall	summer/fall(within year)
Chalk Creek	0.21	0.297	0.425	0.41
Rock Creek	0.33	0.50	0.50	0.435
E.F. Toklat River	0.43	--	0.64	0.80
Willow Creek	0.56	--	0.45	0.59
Jack Creek	--	0.32	--	--
Little Jack Creek	--	--	0.58	--
Beaver Creek	0.32	--	--	--
Lake Creek	0.40	--	--	--
Sanctuary River	0.29	--	--	--
Moose Creek	0.30	--	--	--
Little Stony Creek	0.29	--	--	--
Gorge Creek Spring	0.35	--	--	--
McKinley Bar spring	0.27	--	--	--
McKinley Bar Trail creek	0.33	--	--	--
Igloo Creek	0.45	--	--	--
Upper Igloo Creek	0.32	--	--	--
Tattler Creek	0.29	--	--	--
Hogan Creek	0.20	--	--	--
E.F. Toklat tributary	0.51	--	--	--

Cluster analysis (Figure 3) provides another and in some ways more informative way to evaluate the dissimilarity matrix, because dissimilarities are considered in a relative context. Flexible-β clustering is an agglomerative hierarchical clustering algorithm, and has a number of recommended properties as an analytical method for evaluating community data (McCune and Grace 2002). For this analysis, 84 macroinvertebrate samples were included; one of the five June 2006 Chalk Creek replicate samples was chosen at random to represent that site visit. In most cases, samples from a given site collected in different years cluster together, even if the dendrogram is trimmed with most of the information remaining. At 75% information remaining, which is a stringent cutoff, 13 of 17 paired summer samples clustered together. In addition 2 of the 3 Jack Creek samples (all Jack Creek samples were collected in fall) clustered together, as did the summer 2007 and fall 2008 samples from Willow Creek. The exceptions are instructive. The failure of the McKinley Bar Trail creek samples (D15-07 and D15-08) to cluster despite a moderate dissimilarity of 0.33 is indicative of one of the potential shortcomings of agglomerative clustering techniques, in that misclassifications can occur because later group fusions depend on

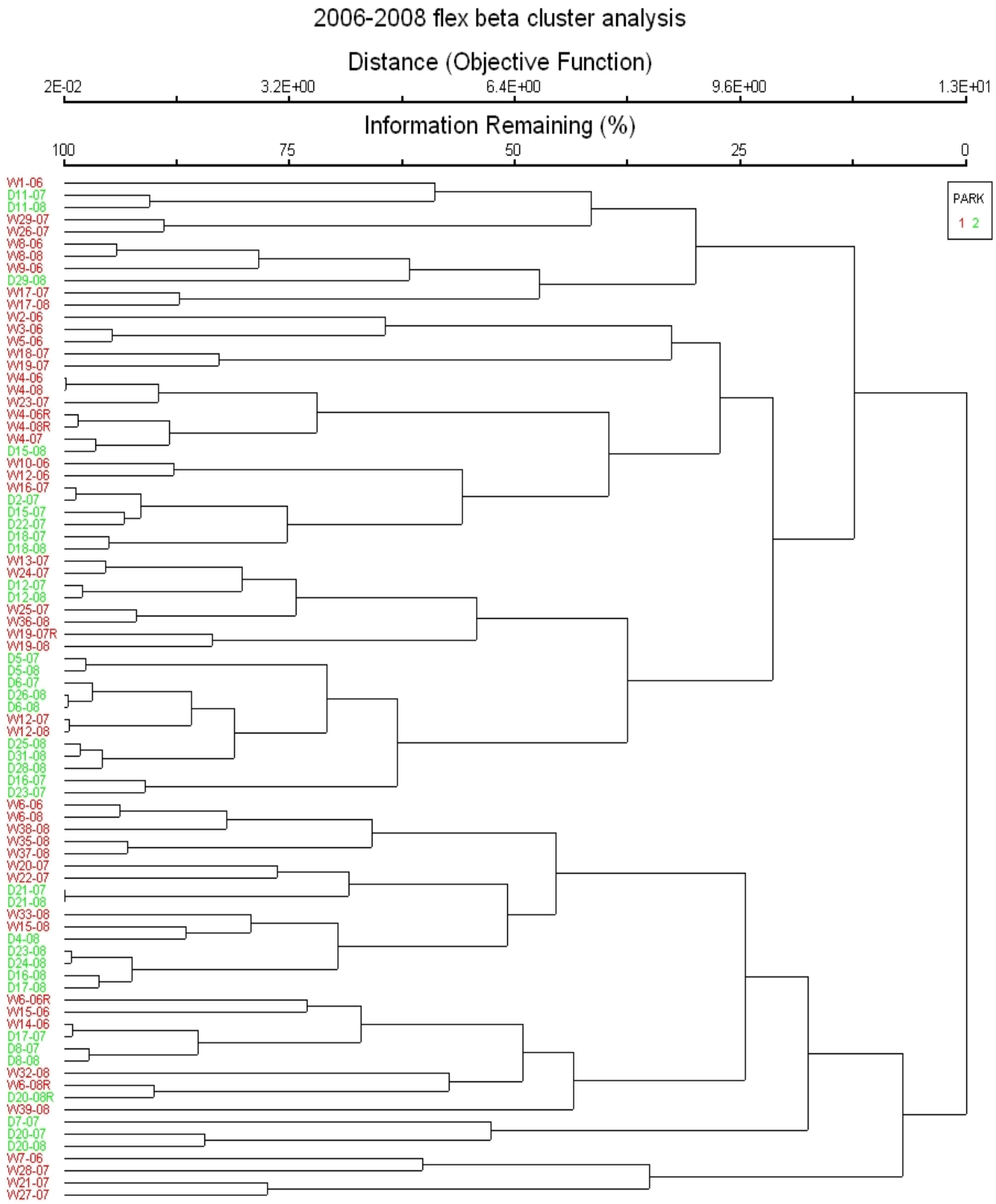

Figure 3. Flexible-β cluster analysis (β = -0.25) of all invertebrate data from 2006-2008. Abundances were transformed to presence-absence data. Bray-Curtis dissimilarity was used as the distance metric. DENA samples are in green, WRST samples are in red. Site codes (W1, D5, etc.) are listed in the Appendix. The sampling year follows the hyphen, and an "R" is included if it was a resample of that site for that year (a fall sampling event).

earlier fusions (McCune and Grace 2002). In practice such misclassifications can be corrected, either manually or through discriminant analysis. In two instances, samples from consecutive years ended up quite "far" from each other in the dendrogram; that is, on opposite sides of the major split that occurs at the very top (this split occurs at or near "0%" information remaining on the far right of Figure 3). In both cases there is a reasonable environmental explanation, though no way of confirming it. In the case of Igloo Creek (D16-07 and D16-08), the sampling site is located immediately below the extensive road construction that occurred in 2007. The 2007 sample, which had much lower density and diversity of macroinvertebrates, was collected towards the end of a summer of road construction, while the 2008 sample was collected a year later. Thus, the difference between the two samples may reflect a recovery from the impact of the road construction. Disturbance may also explain the observed difference between 2007 and 2008 in the E.F. Toklat tributary samples (D23-07 and D23-08). This stream is subject to aufeis events of varying magnitude every spring; substantial aufeis events are known to constitute a significant ecological disturbance and can lead to channel evulsions of varying duration.

The cluster dendrogram also reveals some broad ecological patterns in the distribution of stream biota that reflect underlying physical differences among streams. One important note is that there is little or no underlying geographical pattern; that is, the clusters reflect ecological similarities rather than physical proximity. This is best illustrated by considering lake outlet streams. Lake Creek, the outlet stream of Wonder Lake, is in DENA, but is most closely related in terms of species composition to 3 lake outlet streams in WRST - Beaver Creek and the Rock Lake outlet stream, which are 400 miles away on the Canadian border, and a tributary of the Nizina River, also called Lake Creek, located near McCarthy. In contrast, it is only distantly related to Moose Creek, into which it flows and which is less than a mile away.

The main division in the dendrogram (the split on the far right of Figure 3 that occurs at or near 0% information remaining) appears to reflect some measure of hydrological stability. All of the lake outlet samples cluster above this divide (and indeed tend to cluster with each other across years). Similarly, all of the larger rivers are found on this side. Most of the spring-fed streams and streams that appear hydrologically stable based on the prevalence of bryophytes also cluster with these streams. In contrast, all of the intermittent and glacial streams are found on the other side of this divide, along with all of the small, high-gradient and braided streams, as well as the high-elevation tundra streams. Mean year-to-year dissimilarity is also lower among streams in the "stable" cluster, although with so few streams with multiple samples, the difference is not statistically significant. Broadly speaking, these results are consistent with those of Milner *et al.* (2006), who found a substantial effect of stream stability on community composition and interannual variation. Inclusion of another year's worth of data after 2009 should increase the explanatory power of this and other analyses. 2009 will represent the 3rd year of data collection at the Denali sites and the 4th year for a number of sites in WRST. In addition, in 2009 the GRTS design will be formally tested for feasibility in WRST, with sampling at up to 10 probabilistically-selected sites.

Appendix

Translation of site codes from Figure 3. Sites are listed in the order shown in Figure 3, going from top to bottom of the dendrogram.

Site code	Park	Site name	Sample date	Notes
W1-06	WRST	Trib West of Tana River	June 2006	Chitna River trib
D11-07	DENA	Gorge Creek spring	August 2007	springfed
D11-08	DENA	Gorge Creek spring	August 2008	springfed
W29-07	WRST	Little Esker stream	September 2007	coastal
W26-07	WRST	Galiano West stream	September 2007	coastal
W8-06	WRST	Beaver Creek	August 2006	lake outlet
W8-08	WRST	Beaver Creek	June 2008	lake outlet
W9-06	WRST	Rock Lake outlet	August 2006	lake outlet
D29-08	DENA	Lake Creek	August 2008	lake outlet
W17-07	WRST	Lake Creek	July 2007	lake outlet
W17-08	WRST	Lake Creek	July 2008	lake outlet
W2-06	WRST	Chakina River	June 2006	Chitina River trib, large river
W3-06	WRST	Trib East of Tebay River	June 2006	Chitina River trib
W5-06	WRST	Swift Creek	July 2006	high gradient, modified?
W18-07	WRST	upper Young Creek	July 2007	tundra
W19-07	WRST	Willow Creek	July 2007	
W4-06	WRST	Chalk Creek	June 2006	lake outlet
W4-08	WRST	Chalk Creek	July 2008	lake outlet
W23-07	WRST	Bear Creek	July 2007	
W4-06R	WRST	Chalk Creek	September 2006	lake outlet
W4-08R	WRST	Chalk Creek	September 2008	lake outlet
W4-07	WRST	Chalk Creek	October 2007	lake outlet
D15-08	DENA	McKinley Bar Trail creek	August 2008	springfed
W10-06	WRST	Ptarmigan Creek	August 2006	lake outlet
W12-06	WRST	Jack Creek	September 2006	lake outlet
W16-07	WRST	Nizina River tributary	July 2007	
D2-07	DENA	East Savage River spring	August 2007	springfed
D15-07	DENA	McKinley Bar Trail creek	August 2007	springfed
D22-07	DENA	Savage River	August 2007	large clearwater river
D18-07	DENA	upper Igloo Creek	August 2007	
D18-08	DENA	upper Igloo Creek	August 2008	
W13-07	WRST	Gilahina River	July 2007	
W24-07	WRST	Amy Creek	July 2007	lake outlet
D12-07	DENA	McKinley Bar spring	August 2007	springfed
D12-08	DENA	McKinley Bar spring	August 2008	springfed
W25-07	WRST	May Creek	September 2007	stable flow - mossy
W36-08	WRST	Rufus Creek	June 2008	stable flow - mossy
W19-07R	WRST	Willow Creek	September 2007	
W19-08	WRST	Willow Creek	July 2008	
D5-07	DENA	Sanctuary River	August 2007	large clearwater river
D5-08	DENA	Sanctuary River	August 2008	large clearwater river
D6-07	DENA	Moose Creek at bridge	August 2007	large clearwater river
D26-08	DENA	Moose Creek at crossing	August 2008	large clearwater river
D6-08	DENA	Moose Creek at bridge	August 2008	large clearwater river
W12-07	WRST	Jack Creek	October 2007	lake outlet
W12-08	WRST	Jack Creek	September 2008	lake outlet

Site code	Park	Site name	Sample date	Notes
D25-08	DENA	upper Moose Creek	August 2008	large clearwater river
D31-08	DENA	Cantwell Creek	August 2008	
D28-08	DENA	Moose Creek at airstrip	August 2008	large clearwater river
D16-07	DENA	Igloo Creek	August 2007	
D23-07	DENA	East Fork Toklat tributary	August 2007	

_____MAJOR DIVISION IN COMMUNITY COMPOSITION_____

W6-06	WRST	Rock Creek	July 2006	small, lots of aufeis
W6-08	WRST	Rock Creek	August 2008	small, lots of aufeis
W38-08	WRST	Horsfeld Creek	August 2008	
W35-08	WRST	Solo Creek tributary	June 2008	small tundra stream
W37-08	WRST	North Fork White River	July 2008	small tundra stream
W20-07	WRST	Skolai Creek tributary	July 2007	small tundra stream
W22-07	WRST	4th of July Creek	July 2007	
D21-07	DENA	Hogan Creek	August 2007	stable flow - mossy
D21-08	DENA	Hogan Creek	August 2008	stable flow - mossy
W33-08	WRST	Bryan Creek	June 2008	sampled at high flow
W15-08	WRST	Little Jack Creek	August 2008	
D4-08	DENA	Travertine stream	August 2008	very small, unusual chemistry
D23-08	DENA	E.F. Toklat tributary	August 2008	
D24-08	DENA	Gorge Creek	August 2008	braided, dynamic
D16-08	DENA	Igloo Creek	August 2008	
D17-08	DENA	Tattler Creek	August 2008	small, high gradient
W6-06R	WRST	Rock Creek	September 2006	small, lots of aufeis
W15-06	WRST	Little Jack Creek	September 2006	
W14-06	WRST	Skookum Creek	September 2006	
D17-07	DENA	Tattler Creek	August 2007	braided, high gradient
D8-07	DENA	Little Stony Creek	August 2007	tundra, but spring fed
D8-08	DENA	Little Stony Creek	August 2008	tundra
W32-08	WRST	Notch Creek tributary	June 2008	small, high gradient
W6-08R	WRST	Rock Creek	September 2008	small, lots of aufeis
D20-08R	DENA	East Fork Toklat River	September 2008	glacial
W39-08	WRST	Caribou Creek	August 2008	intermittent
D7-07	DENA	Highway Pass Creek	August 2007	braided, dynamic
D20-07	DENA	East Fork Toklat River	August 2007	glacial
D20-08	DENA	East Fork Toklat River	August 2008	glacial
W7-06	WRST	Gravel Creek	August 2006	intermittent
W28-07	WRST	Independence Creek	September 2007	glacial
W21-07	WRST	Moonshine Creek	July 2007	glacial
W27-07	WRST	Icy Bay stream	September 2007	coastal

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Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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