National Park Service
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Natural Resource Stewardship and Science

Bioassessment of aquatic invertebrates along the Laramie River at Fort Laramie National Historic Site

Natural Resource Technical Report NPS/NGPN/NRTR—2013/823

ON THIS PAGE
Ken Brown collecting aquatic invertebrates in the Laramie River at Fort Laramie National Historic Site
Photograph by: Lusha Tronstad, WYNDD, University of Wyoming

ON THE COVER
The Laramie River where it flows into Fort Laramie National Historic Site
Photograph by: Lusha Tronstad, WYNDD, University of Wyoming

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Natural Resource Technical Report NPS/NGPN/NRTR—2013/823

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November 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Tronstad, L. 2013. Bioassessment of aquatic invertebrates along the Laramie River at Fort Laramie National Historic Site. Natural Resource Technical Report NPS/NGPN/NRTR—2013/823. National Park Service, Fort Collins, Colorado.

NPS 375/122848, November 2013

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Abstract

The Laramie River runs through Fort Laramie National Historic Site in eastern Wyoming and is an important source of water for the area. To estimate the ecosystem quality of the Laramie River, I collected aquatic invertebrates at three sites using a Hess sampler. Invertebrates were identified and counted under a dissecting microscope. Each taxon was assigned a functional feeding group, habit, and pollution tolerance based on published values, and I calculated 24 bioassessment metrics. Total invertebrate density in the Laramie River was 21,500 ind/m^2. I identified at least 49 taxa in the river and I collected about 21 taxa in each sample. Bioassessment metrics indicated that the ecosystem quality of the river was good and the sites were similar. The Laramie River had a high percent EPT taxa (53%), EPT richness (11), percent taxa intolerant to pollution (64%), and EPT/Chrionomidae ratio (2.6). Additionally, the Laramie River had a low percentage of tolerant individuals (tolerance value >8; 0.2%) and a percentage of tolerant taxa (2.4%). The average tolerance value of an invertebrate in the river was 4.82 on a scale of 0 (intolerant of pollution) to 10 (tolerant of pollution; Hilsenhoff's Biotic Index), showing that the invertebrate assemblage was composed of a large fraction of individuals with low tolerance to pollution. Overall, the Laramie River appears to have good ecosystem quality.

Acknowledgments

I thank Ken Brown and Kyle Hack for their assistance with field and laboratory work. Thanks to Brett Marshall who identified the invertebrates and discussed analysis of bioassessment techniques. I am grateful to Marcia Wilson, Stephen Wilson, and Mitzi Frank of the National Park Service for monetary and logistical support. Sarah Wakamiya and Marcia Wilson provided comments that improved the report.

Introduction

In his classic paper, Hynes (1975) stated that the valley rules the stream in every respect. By this statement, Hynes' was saying that what happens in the watershed affects the stream. Streams are the lowest point in the watershed, and everything in that area drains downhill into streams. Therefore, monitoring streams can provide a wealth of information about what is occurring in the watershed. Much research has focused on how different land uses can affect stream biota. Generally, land use is divided into urban, agricultural, and natural categories. Urban areas are generally a small proportion of the watershed, but they can add a high degree of stress to streams (Allan 2004). Agricultural activities can vary widely in the degree of impact they add to streams. For example, row crop agriculture can degrade streams to a much higher degree compared to rangeland (Allan 2004). However, a healthy riparian area can strongly buffer streams from land use impacts (Feld 2013).

Monitoring rivers can be done using a variety of techniques. Studies have investigated the effects of land use on fish, aquatic invertebrates, algae, and macrophytes (e.g., Hering et al. 2006, Johnson et al. 2007, Feld 2013) and these studies found that invertebrates were strongly related to land use. Samples for invertebrate bioassessment can be collected qualitatively (e.g., dip net or kick net samples) or quantitatively (e.g., Hess or Surber sampler), but research suggests that quantitative samples have higher power to detect differences (Kerans et al. 1992). Additionally, samples can be composited or analyzed separately, and data suggests that replicate samples have lower variance compared to compositing samples (Brett Marshall, personal communication). Regardless of procedures, bioassessment metrics are the most commonly used method to analyze data to understand the health of ecosystems. The metrics calculated differ depending on the approach taken. Regardless, metrics can either be analyzed individually or they can be summarized. Two methods are commonly used to summarize metrics in the United States. The multimetric approach combines several bioassessment metrics into a single measure to estimate ecosystem quality (Karr 1981, Kerans and Karr 1994). Conversely, the multivariate or predictive approach uses statistical models to predict the expected conditions at sites (e.g., Ode et al. 2008). However, others advocate for interpreting metrics individually, because individual metrics are easier to understand and can be used to interpret mechanisms (e.g., Allan 2004).

Aquatic invertebrates are excellent biota to use for monitoring rivers. First, aquatic invertebrates are extremely diverse in species richness, pollution tolerance, feeding methods, and habits (Resh and Jackson 1993). Second, invertebrates are typically abundant and easy to collect. Third, these animals are relatively long lived (weeks to 100 years). Fourth, aquatic invertebrates are fairly sedentary and thus reflect the status of the sampled site and upstream influences. Discrete discharges of pollution may be missed by periodically sampling water, but invertebrates live in the stream for most of their life and their assemblage responds to discrete and continuous changes over time. Finally, decreases in ecosystem quality impact aquatic invertebrates by reducing survival, reproduction, and fitness (Johnson et al. 1993). Thus, changes in the assemblage of aquatic invertebrates can be a sensitive measure of the ecosystem quality of a site.

Fort Laramie National Historic Site is a small park (337 hectares) that preserves the natural resources and cultural heritage of the 1800s in eastern Wyoming. The park sits among working ranches and farmland west of Torrington, Wyoming. The Laramie River flows through Fort

Laramie National Historic Site and is likely affected by activities in the watershed. To examine the ecosystem quality of the Laramie River at Fort Laramie National Historic Site, I collected aquatic invertebrates at three sites along the river. My questions were: 1) what is the ecosystem quality of the Laramie River at Fort Laramie National Historic Site according to the invertebrates, 2) how do the bioassessment metrics at the three sites compare, and 3) how do these metrics compare to other rivers in the region?

Study Area

The Laramie River is an approximately 450 km long tributary stream of the North Platte River in southeastern Wyoming. The Laramie River begins in the Roosevelt National Forest in Colorado (2800 m elevation) and flows north into Wyoming on the east side of the Medicine Bow Mountains. The Laramie River flows northeast and finally joins the North Platte River at Fort Laramie, Wyoming (1300 m elevation). Several streams flow into the Laramie River including the Little Laramie River and the North Laramie River. Impoundments along the Laramie River include Grayrocks Reservoir (above Fort Laramie, Wyoming) and Wheatland Reservoirs (above Wheatland, Wyoming). Average annual discharge of the Laramie River between 1957 and 2012 was 3.6 m^3/sec (USGS; http://waterdata.usgs.gov/usa/nwis/rt).

Under the Clean Water Act of 1972, each river in the United States is assigned a class based on the designated uses of the water (e.g., fishery, drinking water). The Laramie River is classified as a class 2AB that is designated for agriculture, aquatic life other than fish, cold water fishery, drinking water, fish consumption, industry, recreation, scenic value, and wildlife. Two sections of the Laramie River have *Escherichia coli* concentrations that exceeded the water quality standard for recreation. These reaches are located south of Woods Landing, Wyoming and south of Bosler, Wyoming (http://iaspub.epa.gov/tmdl/attains_state.control?p_state=WY&p_cycle=&p_report_type=T). No impairments are reported for the Laramie River flowing through or near Fort Laramie National Historic Site.

Approximately 6 km of the Laramie River flows through Fort Laramie National Historic Site. Fort Laramie is a 337 hectare site that was designated as a National Monument in 1938 and a National Historic Site in 1960. Fort Laramie National Historic Site is located in a short grass prairie ecosystem. The park features many historic buildings and sites, and an established riparian area. The dominant trees along the river were cottonwood (*Populus* sp.), ash (*Fraxinus* sp.) and willow (*Salix* sp.). Riparian vegetation was mainly grasses, cattails (*Typha* sp.), and rushes. I sampled three sites along the river on 8 September 2011 (Figure 1).

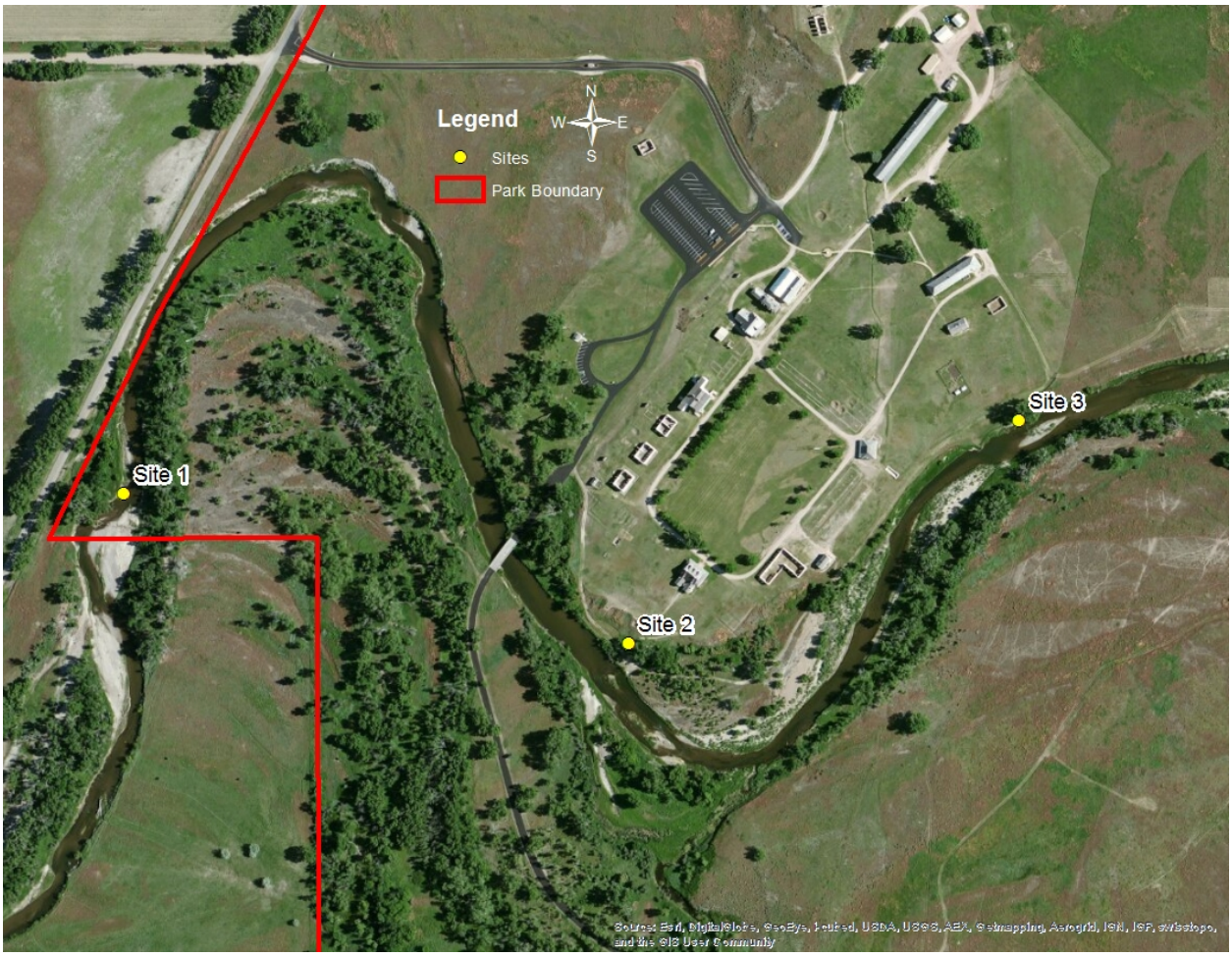

Figure 1. Map of Fort Laramie National Historic Site showing where aquatic invertebrate samples were collected.

Methods

I measured core water quality parameters and water clarity to estimate conditions at each site. I measured water quality using a Yellow Springs Instrument (YSI) Professional Plus calibrated daily. Water clarity was estimated by lowering a Secchi disk into the water until the disk disappeared from sight.

To measure the abundance and diversity of invertebrates in the Laramie River, I collected aquatic invertebrates using a Hess sampler. I collected five samples at each of three sites along the river within Fort Laramie National Historic Site (Figure 1). I placed the Hess sampler (500 µm mesh, 860 cm^2 sampling area, Wildlife Supply Company) into the substrate at five haphazardly chosen locations, scrubbed the substrate, and agitated the sediment. Samples were preserved with ~75% ethanol and transported to the laboratory where invertebrates were sorted from debris. Samples were separated into a large (>2 mm) and small (250 µm to 2 mm) fraction using sieves. The small fraction was subsampled if invertebrates were numerous using a modified record player and the entire large fraction was sorted. Each sample was checked by two qualified individuals to insure that all invertebrates were removed. Invertebrates were counted and identified under a dissecting microscope using appropriate keys (Lugo-Ortiz et al. 1994, Larson et al. 2000, Needham et al. 2000, Smith 2001, Merritt et al. 2008, Thorp and Covich 2010).

To estimate ecosystem quality at each site, I calculated several bioassessment metrics using the invertebrate data. Based on the data collected and previous studies (e.g., Resh and Jackson 1993, Kerans and Karr 1994), I selected 24 metrics to compare sites (Table 1). I chose a variety of metrics including measures of richness, abundance, community diversity, functional feeding group, habit, and pollution tolerance. Pollution tolerance values of invertebrate taxa were taken from Barbour et al. (1999) (Appendix A). Invertebrates were separated into intolerant (tolerance values of 0 to 5.0) and tolerant groups (tolerance values of 6.0 to 7.0, ≥7.0 or ≥8.0; Table 1). Functional feeding group and habit of invertebrates were from Merritt et al. (2008) and Barbour et al. (1999) (Appendix A). Invertebrate density and bioassessment metrics were calculated using R (Team 2013) with the *plyr* (Wickham 2011), *Matrix* (Bates and Maechler 2013), and *vegan* (Oksanen et al. 2013) packages. To investigate site effects, I used ANOVA to compare abundance and bioassessment metrics for each sample with R. Differences among sites were distinguished using multiple comparison tests with Bonferroni adjusted p-values where differences were significant when $p < 0.05$.

Table 1. Invertebrate bioassessment metrics used to compare sites at Fort Laramie National Historic Site.

Metric	Equation	Predicted response to impairment
% Chironomidae	$= \left(\frac{density_{Chironomidae}}{total\ density}\right) \times 100$	Increase
% clingers	$= \left(\frac{density_{clingers}}{total\ density}\right) \times 100$	Decrease
% clingers taxa	$= \left(\frac{richness_{clingers}}{taxa\ richness}\right) \times 100$	Decrease
% EPT	$= \frac{density_{EPT}}{total\ density} \times 100$	Decrease
% EPT taxa	$= \left(\frac{richness_{EPT}}{taxa\ richness}\right) \times 100$	Decrease
% filterers	$= \left(\frac{density_{filterers}}{total\ density}\right) \times 100$	Decrease
% gatherers	$= \left(\frac{density_{gatherers}}{total\ density}\right) \times 100$	Decrease
% intolerant (tolerance values 0 - 5)	$= \left(\frac{density_{tolerance0-5}}{total\ density}\right) \times 100$	Decrease
% intolerant taxa (tolerance values 0 - 5)	$= \left(\frac{richness_{tolerance0-5}}{taxa\ richness}\right) \times 100$	Decrease
% non-insects	$= \left(\frac{density_{non-insects}}{total\ density}\right) \times 100$	Increase
% predator taxa	$= \left(\frac{richness_{predators}}{taxa\ richness}\right) \times 100$	Decrease
% predators	$= \left(\frac{density_{predators}}{total\ density}\right) \times 100$	Decrease

Table 1 (continued). Invertebrate bioassessment metrics used to compare sites at Fort Laramie National Historic Site.

Metric	Equation	Predicted response to impairment
% tolerant (tolerance values 6.0 - 7.0)	$= \left(\frac{density_{tolerance6-7}}{total\ density}\right) \times 100$	Increase
% tolerant (tolerance values ≥8)	$= \left(\frac{density_{tolerance\geq 8}}{total\ density}\right) \times 100$	Increase
% tolerant taxa (tolerance values ≥8)	$= \left(\frac{richness_{tolerant\geq 8}}{taxa\ richness}\right) \times 100$	Increase
% tolerant (tolerance values ≥7)	$= \left(\frac{density_{tolerant\geq 7}}{total\ density}\right) \times 100$	Increase
% tolerant taxa (tolerance values ≥7)	$= \left(\frac{richness_{tolerant\geq 7}}{taxa\ richness}\right) \times 100$	Increase
EPT richness	Richness of mayflies, stoneflies, and caddisflies	Decrease
EPT/midge density	$= \frac{density_{EPT}}{density_{Chironomidae}}$	Decrease
HBI	$= \sum_{i=1}^{n} \frac{density_i \times tolerance_i}{total\ density}$	Increase
Taxa diversity	$= -\sum_{i=1}^{s} p_i \times \ln(p_i)$ Where p_i is the proportion of the ith taxa	Decrease
Taxa evenness	$= \frac{taxa\ diversity}{\ln(taxa\ richness)}$	Decrease
Taxa richness	Number of taxa in a sample	Decrease
Total density	Total number of individuals (ind/m^2)	Decrease

Results

Water quality was similar among sites. Water temperatures were warmest at site 1 and coolest at site 3 (Table 2). Differences in water temperatures may be due to sampling order, because I sampled site 3 in the morning and site 1 in the afternoon. Dissolved oxygen was also highest at site 1 and lowest at site 3, and patterns were probably a result of sampling order. Overall, values indicated that the water had ample dissolved oxygen to support aquatic life. Specific conductivity and pH were similar among sites. The Laramie River was basic, as is common for rivers in Wyoming. Oxidation-reduction potential was highest at site 3, but all sites were <200 mV indicating a reducing environment in the river. I could see the bottom of the river at all sites and water depth was about 45 centimeters at all sites.

Table 2. Site locations and basic water quality at each site along the Laramie River at Fort Laramie National Historic Site.

Parameter	Units	Site 1	Site 2	Site 3
Northing		42.2021	42.2009	42.2026
Easting		-104.5645	-104.5594	-104.5554
Datum		NAD83	NAD83	NAD83
Water temperature	C	18.4	16.5	15.3
Dissolved Oxygen	% saturation	119	103	92
Dissolved Oxygen	mg/L	9.7	8.7	8
Specific Conductivity	µS/cm	738	745	747
pH		8.34	8.17	8.11
Oxidation-reduction potential	mV	58.4	64.7	187.5
Secchi Disk depth	cm	Bottom	Bottom	Bottom

I identified at least 49 taxa of invertebrates in the Laramie River at Fort Laramie National Historic Site. Total invertebrate density in the Laramie River was 21,478 ind/m^2, and insects (20,908 ind/m^2) were far more abundant than non-insects (570 ind/m^2). Additionally, most of the taxa were insects (38 taxa) from 8 orders. Trichoptera (9000 ind/m^2) were the most abundant insect order followed by Diptera (6650 ind/m^2) and Ephemeroptera (4900 ind/m^2; Figure 2). I collected fewer non-insect taxa (11 taxa from 6 phyla), and Annelida (360 ind/m^2) were the most abundant followed by Nematoda (100 ind/m^2), Crustacea (50 ind/m^2), and Mollusca (30 ind/m^2).

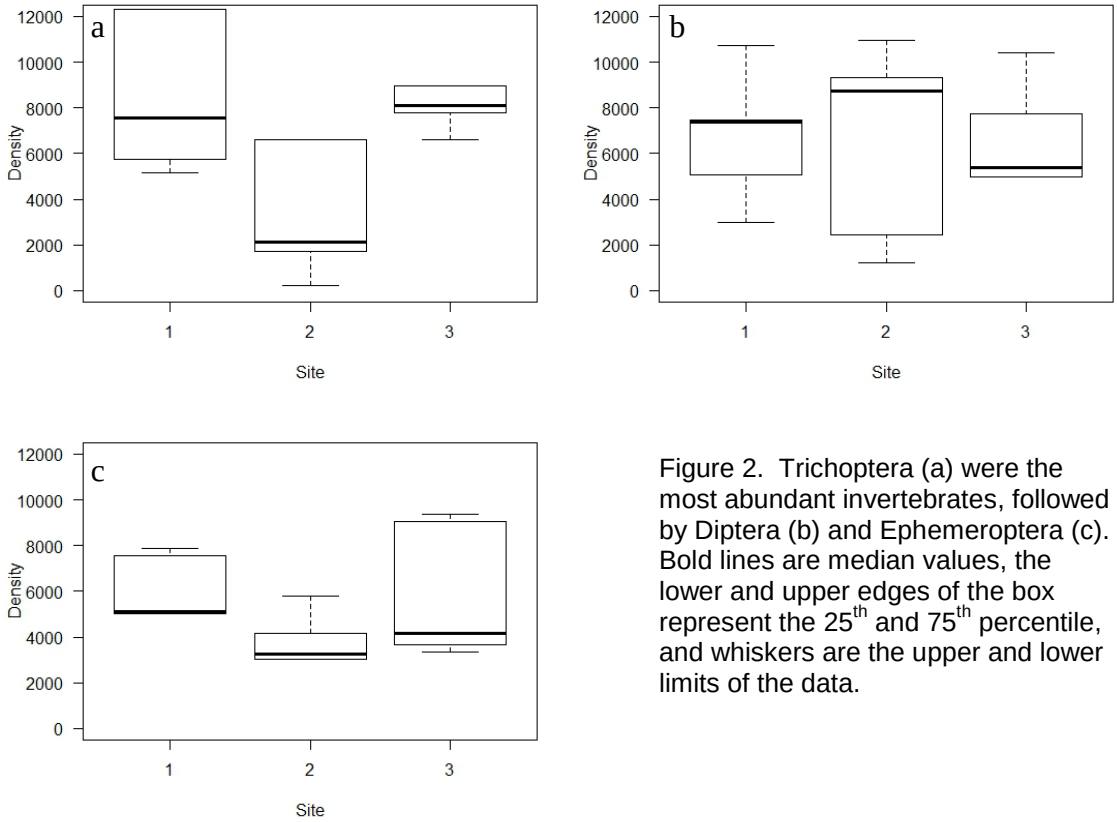

Figure 2. Trichoptera (a) were the most abundant invertebrates, followed by Diptera (b) and Ephemeroptera (c). Bold lines are median values, the lower and upper edges of the box represent the 25th and 75th percentile, and whiskers are the upper and lower limits of the data.

I collected the most invertebrates at site 3 (23,500 ind/m^2) and the fewest invertebrates at site 2 (18,000 ind/m^2; Table 3), but densities were not different among sites (F = 0.005, df = 1, P = 0.94). Diptera densities were similar among sites (Figure 2b); however, Trichoptera and Ephemeroptera densities were lowest at site 2 (Figure 2a,c). Alternatively, Coleoptera and Lepidoptera were most abundant at site 2 (Table 3). *Acentrella*, *Baetis*, *Fallceon guilleri*, and *Tricorythodes* were the most abundant (>150 ind/m^2) Ephemeroptera in the river. *Hydropsyche*, *Cheumatopsyche*, and *Oecetis* dominated the Trichoptera. Finally, non-Tanypodinae Chironomidae and *Simulium* were the most abundant Diptera in the Laramie River (Table 3). I collected other insect orders at low abundances (<10 ind/m^2; Table 3). Oligochaeta were by far the most abundant non-insect invertebrates collected (Table 4).

Collector-gatherers (11,300 ind/m^2) and collector-filterers (9400 ind/m^2) were the most common invertebrate functional feeding groups in the Laramie River at Fort Laramie National Historic Site (Figure 3). I also collected predators (370 ind/m^2), scrapers (370 ind/m^2), parasites (100 ind/m^2), and shredders (2 ind/m^2) at much lower abundances. The dominant gatherers in the Laramie River were Ephemeroptera, non-Tanypodinae Chironomidae, and Oligochaetes. The dominant filterers in the river were hydropsychid caddisflies and *Simulium*. Filterer, gatherer, scraper, shredder, and parasite densities were not different among sites (ANOVA, P >0.05); however, over 3x more predators were present at site 3 compared to the other sites (F = 9.7, df = 1, P = 0.008, Bonferroni, P <0.009) (Table 5).

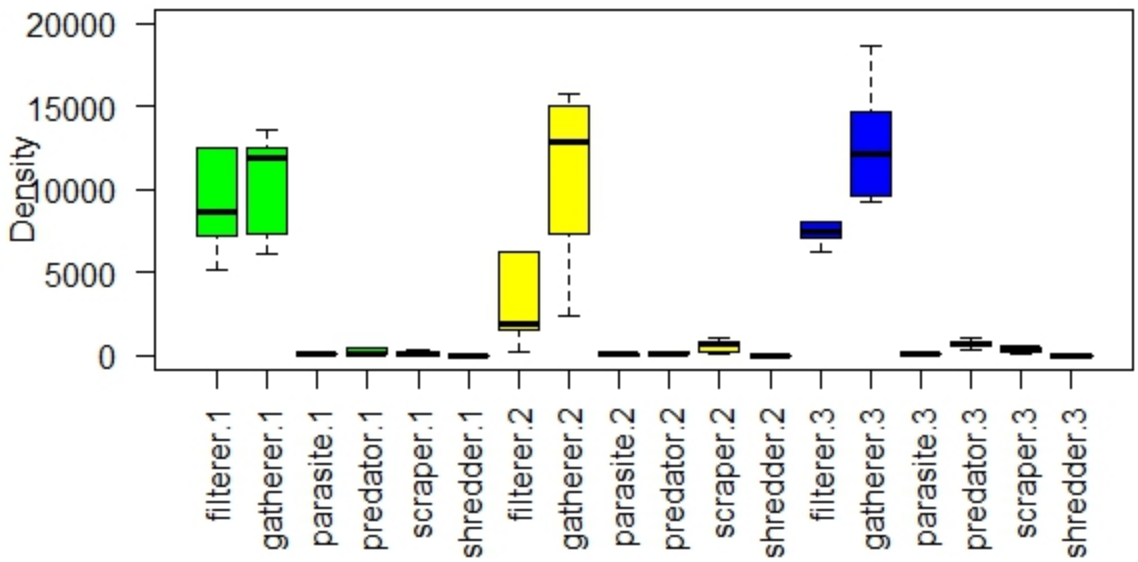

Figure 3. Density (ind/m^2) of invertebrate functional feeding groups at site 1 (green), site 2 (yellow), and site 3 (blue) in the Laramie River at Fort Laramie National Historic Site. Bold lines are median values, lower and upper edges of the boxes are the 25th and 75th percentiles, and whiskers are limits of the data.

Clinger (9810 ind/m^2) was the dominant habit of insects in the Laramie River and was mainly composed of caddisflies and *Simulium* (Figure 4). Burrowers were also abundant (6430 ind/m^2) in the river and were primarily composed of Chironomidae. Swimmers (2350 ind/m^2) and sprawlers (2380 ind/m^2) had similar abundances. Swimmers were mainly mayflies in the family Baetidae and sprawlers were primarily composed of the mayfly *Tricorythodes*. Clinger, burrower, sprawler, and swimmer densities were not different among sites (ANOVA, $P > 0.05$); however, I collected more climbers at site 3 compared to the other sites ($F = 17$, $df = 1$, $P = 0.0012$, Bonferroni, $P < 0.045$; Figure 4).

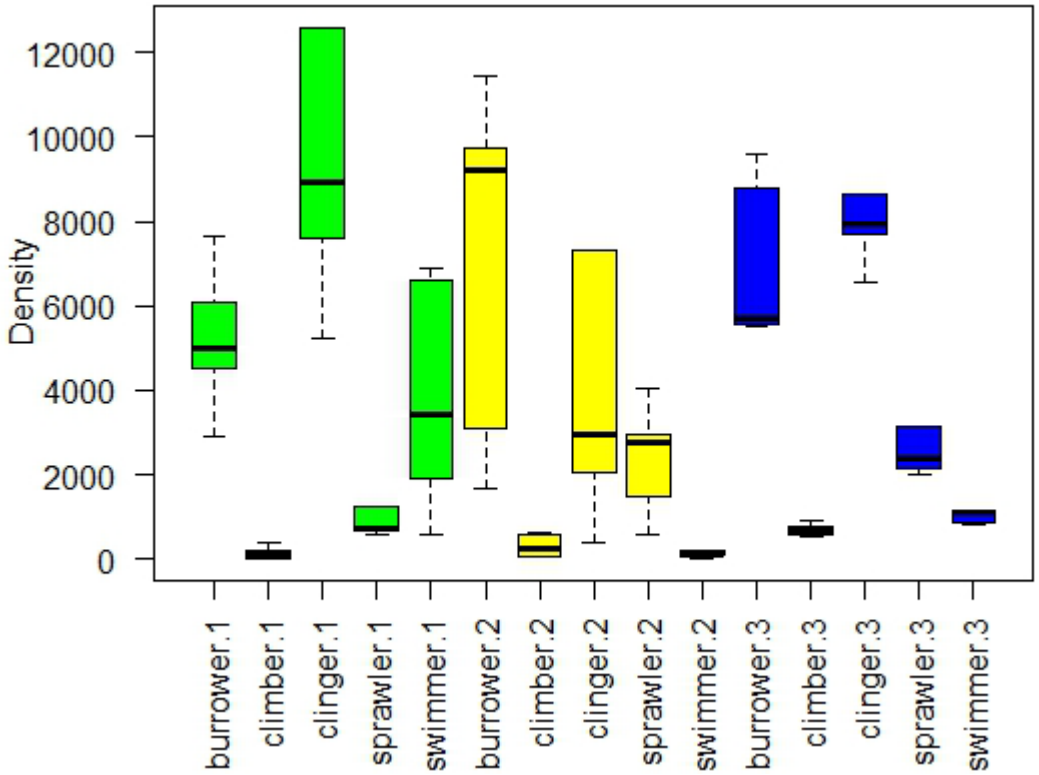

Figure 4. Density (ind/m^2) of invertebrate habits at site 1 (green), site 2 (yellow), and site 3 (blue) in the Laramie River at Fort Laramie National Historic Site. Bold lines are median values, lower and upper edges of the boxes are the 25th and 75th percentiles, and whiskers are the lower and upper limits of the data.

Table 3. Average density (ind/m^2) of insects at each site along the Laramie River at Fort Laramie National Historic Site. Variance is standard error. Higher taxonomic headings (bold) show total mean densities for the group.

Taxa	Site 1	Site 2	Site 3
Ephemeroptera	5335±344	3389±334	5924±534
Acentrella	1528±389	484±461	861±437
Baetis	900±466	232±212	441±413
Camelobaetidius	9±9	5±5	2±0
Fallceon quilleri	1360±495	235±212	768±367
Heptagenia	0±0	2±2	2±2
Rhithrogena	77±43	5±5	23±10
Isonychia	74±39	14±14	5±5
Asioplax	2±2	19±16	0±0
Tricorythodes	1209±443	2240±601	3465±1157
Leptophlebiidae (early instar)	19±19	28±19	93±93
Choroterpes	7±7	42±12	93±24
Neochoroterpes	72±31	42±28	33±27
Ephoron	77±46	42±8	137±67
Odonata	5±3	9±3	2±1
Argia	0±0	2±2	0±0
Ophiogomphus severus	0±0	2±2	2±2
Plecoptera (*Isoperla*)	0±0	0±0	2±2

Table 3 (continued). Average density (ind/m^2) of insects at each site along the Laramie River at Fort Laramie National Historic Site. Variance is standard error. Higher taxonomic headings (bold) show total mean densities for the group.

Taxa	Site 1	Site 2	Site 3
Hemiptera (*Ambrysus*)	0±0	0±0	2±2
Lepidoptera (*Petrophila*)	21±18	207±90	165±77
Trichoptera	10,600±1115	6572±922	9842±1044
Culoptila	2±2	0±0	40±37
Hydroptila	16±16	93±34	21±18
Ochrotrichia	37±18	63±57	2±2
Hydropsyche	7372±1784	3865±2490	6812±2050
Cheumatopsyche	1930±1052	1975±1187	1970±80
Nectopsyche	2±2	0±0	0±0
Oecetis	107±37	56±25	498±127
Polycentropus	0±0	5±5	0±0
Limnephilidae (early instar)	2±2	0±0	0±0
Coleoptera	56±50	409±65	233±17
Dubiraphia	2±2	35±13	7±5
Microcylloepus	26±23	195±80	133±54
Stenelmis	28±20	179±66	93±60
Diptera	6717±741	6526±968	6703±862
Probezzia	0±0	5±5	30±17
Chironomidae	5045±	6351±	6412±

Table 3 (continued). Average density (ind/m^2) of insects at each site along the Laramie River at Fort Laramie National Historic Site. Variance is standard error. Higher taxonomic headings (bold) show total mean densities for the group.

Taxa	Site 1	Site 2	Site 3
Tanypodinae	61±23	53±14	44±17
Non-Tanypodinae	4984±806	6298±1915	6367±934
Hemerodromia	2±2	2±2	37±23
Lemnophila	0±0	0±0	2±2
Simulium	1626±957	147±144	184±172
Tabanidae	2±2	0±0	0±0
Dicranota	2±2	0±0	0±0
Total Insects	22,736±706	17,113±695	22,874±743

Table 4. Average density (ind/m^2) of non-insect invertebrates at each site along the Laramie River at Fort Laramie National Historic Site. Variance is standard error. Higher taxonomic headings (bold) show total mean densities for the group.

Taxa	**Site 1**	**Site 2**	**Site 3**
Crustacea	21±13	100±40	23±15
Amphipoda	21±18	98±49	23±21
Cambaridae	0±0	2±2	0±0
Collembola	0±0	0±0	19±19
Mollusca	0±0	93±	2±2
Ferrissia	0±0	51±27	0±0
Sphaeriidae	0±0	42±42	2±2
Annelida	72±27	592±141	416±135
Helobdella stagnalis	0±0	2±2	0±0
Motobdella	0±0	2±2	2±2
Oligochaeta	72±42	588±109	414±187
Nematoda	140±43	70±25	88±31
Nemertea	0±0	2±2	56±23
Turbellaria	0±0	7±5	7±7
Total Non-Insects	233±26	863±82	610±74

Table 5. Average invertebrate bioassessment metrics for each site along the Laramie River at Fort Laramie National Historic Site. Variance is standard error. Metrics with significant site effects (ANOVA; P < 0.05) were marked with an asterisk and significant differences among sites (multiple comparison tests) were shown in the differences column. For definitions of metrics see methods.

Metric	Site 1	Site 2	Site 3	Differences
% Chironomidae	5.3±1.2	7.7±1.2	5.8±0.6	
% clingers	50±5.7	29±8.2	41±3.3	
% clingers taxa	36±2.4	45±2.8	37±1.9	
% EPT	67±5.3	49±7.8	66±4.0	
% EPT taxa	61±1.9	47±3.5	51±3.2	
% filterers	49±6.0	24±8.9	39±3.4	
% gatherers	48±5.6	70±8.1	55±3.0	
% intolerant (0-5)	68±4.9	57±7.0	68±2.8	
% intolerant taxa (0-5)	66±1.8	61±2.8	65±2.0	
% non-insects	1.3±0.40	8.2±3.3	3.0±1.2	
% predators*	1.1±0.42	1.5±0.42	3.5±0.83	1 vs. 3
% predator taxa	16±2.1	19±4.0	21±2.0	
% tolerant (6.0-7.0)	26±6.0	40±7.1	31±3.0	
% tolerant (>7)	0.34±0.14	0.94±0.40	0.45±0.17	
% tolerant taxa (>7)	7.3±1.3	7.2±1.7	8.1±0.90	
% tolerant (>8)	0.04±0.03	0.1±0.08	0.3±0.2	
% tolerant taxa (>8)	1.9±1.3	1.9±1.2	3.5±1.5	
EPT richness	12.0±1.4	10.4±0.81	11.4±0.93	
EPT/Chironomidae	3.6±1.1	1.6±0.57	2.5±0.36	
HBI	4.68±0.1	5.01±0.1	4.77±0.06	

Table 5 (continued). Average invertebrate bioassessment metrics for each site along the Laramie River at Fort Laramie National Historic Site. Variance is standard error. Metrics with significant site effects (ANOVA; P < 0.05) were marked with an asterisk and significant differences among sites (multiple comparison tests) were shown in the differences column. For definitions of metrics see methods.

Metric	**Site 1**	**Site 2**	**Site 3**	**Differences**
Taxa diversity	1.78±0.13	1.73±0.07	1.86±0.03	
Taxa evenness	0.61±0.05	0.56±0.03	0.60±0.01	
Taxa richness	19.8±2.7	22.2±1.3	22.2±1.2	
Total abundance	22,969±637	17,978±625	23,487±671	

In general, bioassessment metrics calculated using aquatic invertebrates indicated that the Laramie River at Fort Laramie National Historic Site had good ecosystem quality (Table 6). Additionally, only one metric, percent predators, differed significantly among sites (ANOVA, P <0.05) (Table 5). HBI values suggested that the average pollution tolerance of an invertebrate in the river was similar among sites and moderate in value. The percent intolerant taxa and percent intolerant were extremely high at all sites (>55%) (Table 5). Similarly, the percent EPT was high at all sites and approximately 11 EPT taxa were collected in each sample. Conversely, the percent tolerant taxa (≥8) and percent tolerant were extremely low at all sites (<5%) (Table 5). I collected about 21 invertebrate taxa in each sample. Taxa diversity (Shannon's diversity) and taxa evenness were similar among sites, and both values indicated that the invertebrate assemblage was composed of a diversity of taxa but a few taxa dominated. Chironomidae composed a relatively small proportion of the assemblage (<8%), but gathering invertebrates composed about half of individuals.

Discussion

Invertebrates in the Laramie River suggested that the ecosystem quality at Fort Laramie National Historic Site was good. The Laramie River within the park had extremely high densities of invertebrates, many of which were intolerant to pollution. Trichoptera and Ephemeroptera, insect orders known to be sensitive to pollution, were the first and third most abundant orders in the river. I collected at least 49 different taxa of aquatic invertebrates in the river and approximately 21 taxa in each sample, which represented a very diverse assemblage. Gathering, filtering, and clinging invertebrates dominated the assemblage as is predicted for healthy rivers. Bioassessment metrics suggested that the river was in good condition and that the sites differed little from one another. The average pollution tolerance of an individual in the assemblage was 4.82 which represent an excellent assemblage value (0 = intolerant and 10 = tolerant to pollution).

Compared to other rivers in the Northern Great Plains Network region, the Laramie River appeared to be in good condition (Tronstad 2013a, b, in review). Of the selected metrics, the Laramie River had the highest percent EPT, percent EPT taxa, percent intolerant taxa, taxa diversity, taxa richness, and total abundance (Table 6). All of these metrics are predicted to decrease in response to impact, so having the highest values indicated good ecosystem quality. The density of invertebrates was very high in the Laramie River, which may be due to relatively constant flow conditions and an abundant food source (Grayrocks Reservoir is ~15 km upstream). In contrast, the Laramie River had the lowest percent predators, percent tolerant taxa (≥7), and HBI value. The percent tolerant taxa and HBI values are predicted to increase with impairment; therefore, having the lowest values of these metrics indicated good ecosystem quality. However, having the lowest percent predators is not an indicator of good ecosystem quality, because percent predators is predicted to decrease in response to impact. The Laramie River had similar percent predator taxa to the Little Missouri River (Tronstad 2013a) showing that the number of predaceous taxa I collected was not exceptionally low, but that the density of these predators in the Laramie River was low. Additionally, percent predators was the only metric that differed significantly among sites. Site 3 had the highest percent predators compared to the other sites; however, 3.5% at site 3 is still a low value. Merritt et al. (2002) considered <15% predators to be a normal proportion. However, bioassessment metrics generally predict a decrease in predator abundance as impact increases (e.g., Kerans et al. 1992, Weigel et al. 2002). Compared to other streams that reported percent predators in the literatures, the Laramie River appeared low. For example, reference streams in Idaho had between 3.8% and 15% (25th and 75th percentiles) predators, while impaired streams contained 2% to 5% predators (Royer et al. 2001). Nicola et al. (2010) calculated that the density of predators in streams depended on the biomass of prey. I did not estimate biomass of invertebrates in the Laramie River; however, prey appeared to be abundant. Functional feeding groups (i.e., predators) are primarily affected by water chemistry (Nicola et al. 2010), but no known impairments exist in the studied reaches of the Laramie River. Further study is needed to understand why percent predators are low in the Laramie River at Fort Laramie National Historic Site. Calculating the biomass of invertebrates would help clarify the proportion of predators to prey taxa in the river.

Table 6. Selected invertebrate bioassessment metrics in the Laramie River at Fort Laramie National Historic Site compared to other rivers in parks within the Northern Great Plains Network region. The Belle Fourche River flows through Devils Tower National Monument (Tronstad, in review), the Little Missouri River flows through Theodore Roosevelt National Park (Tronstad 2013a), and the Knife River flows through Knife River Indian Villages National Historic Site (Tronstad 2013b).

Metric	Predicted response to impairment	Laramie River	Belle Fourche River	Little Missouri River	Knife River
% clinger taxa	Decrease	39	40	29	12
% EPT	Decrease	61	39	33	10
% EPT taxa	Decrease	53	41	40	9.7
% intolerant taxa	Decrease	64	41	25	23
% non-insects	Increase	4.1	3.6	3.4	2
% predators	Decrease	2.0	5.5	6.2	14
% predator taxa	Decrease	19	28	19	30
% tolerant taxa (>7)	Increase	7.5	25	13	38
HBI	Increase	4.82	5.42	5.90	6.08
Taxa diversity	Decrease	1.79	1.69	0.90	1.49
Taxa richness	Decrease	21	13	5.3	11
Total abundance	Decrease	21,478	3757	720	3224

Compared to other streams in southeastern Wyoming, the Laramie River at Fort Laramie National Historic Site appeared to be in good condition. I compared individual metrics used in the Wyoming Stream Integrity Index (Hargett 2011) to values measured from the Laramie River at Fort Laramie National Historic Site. The Laramie River was located in the southeastern plains bioregion of Wyoming and the multimetric index developed for this area used percent Chironomidae taxa, percent EPT taxa (excluding Baetidae, *Tricorythodes*, Hydropsychidae, and Arctopsychidae), percent gatherers, and HBI. I did not identify Chironomidae to genus; therefore, I did not calculate this metric. All sites and metrics were within the least disturbed category (Table 7) indicating that the Laramie River supported its designated uses (Hargett 2011).

Table 7. Metrics included in the Wyoming Stream Integrity Index for the southeastern plains, the expected trend in relation to stream impairment, the threshold values for least disturbed sites, and metrics calculated for three sites along the Laramie River at Fort Laramie National Historic Site. Metrics from the Laramie River were electronically composited to simulate field composite samples used to develop the metrics.

Metric	**Trend**	**Threshold**	**Site 1**	**Site 2**	**Site 3**
EPT richness (with exceptions)	-	>4	13	12	11
% Gatherers	+	<60.4	45	59	55
HBI	+	<6.8	4.5	4.8	4.7

A number of papers have been published on the biota of the Laramie River. The fish community of the Laramie River and its tributary streams have been well-studied (Hubert and O'Shea 1991, Leidy 1992, Patton and Hubert 1993, Hubert and Patton 1994, Quist et al. 2003, Quist et al. 2005, Belica and Rahel 2008, O'Connor and Rahel 2009, Dauwalter and Rahel 2011). Additionally, a new water mite was named in the Laramie River (Smith and Cook 1998) and the rare mayfly, *Baetisca bajkovi*, was reported living in the river (Edmunds 1977). However, the only information on the aquatic invertebrate assemblage in the Laramie is from Rust (2006). Rust (2006) sampled the aquatic invertebrates in the Laramie River at Fort Laramie National Historic Site and investigated ecosystem quality for her thesis work. Rust (2006) and the current study calculated similar taxa richness (18 vs. 21; Rust vs. current study), percent clingers (40% vs. 40%), percent Chironomidae (4% vs. 6.3%), percent gatherers (63% vs. 58%), and HBI values (4.52 vs. 4.82). Conversely, I collected more pollution sensitive invertebrates compared to Rust (2006) causing bioassessment metrics to differ between the studies. For example, the percent EPT (45% vs. 61%), percent EPT taxa (28% vs. 53%), percent tolerant (20% vs. 0.6%), percent tolerant taxa (31% vs. 7.5%), percent intolerant (21% vs. 64%), percent intolerant taxa (23% vs. 64%), percent clinger taxa (30% vs. 39%), and EPT richness (6 vs. 11) differed. Rust (2006) did not define tolerant or intolerant invertebrates in her thesis, but I assumed that tolerant invertebrates had tolerance values of ≥7 and intolerant invertebrates had tolerance values ≤5. Differences in the metrics may be attributed to differences in sampling methods (dip net vs. Hess sampler), sampling sites, and dates sampled. Rust (2006) sampled at 4 locations along the Laramie River from May through July during 2004 and 2005; therefore, difference may be due to inter-annual variation, sampling methods, and procedures.

The historic site has a long history of human use. Fort William was originally established in 1834 as a fur trading post. The fort was renamed Fort John when it was sold in 1841 and used by westbound travelers. The military purchased the land in 1849 and renamed the post Fort Laramie. The area was abandoned in 1890 and purchased by the National Park Service in 1938. Fort Laramie was likely positioned in its location because of the Laramie and North Platte Rivers. The Laramie River was probably an important source of fresh water for the people living at and passing by the fort.

Today, the Laramie River is still an important source of water for irrigating, livestock watering, recreation, and drinking water. The Laramie River has a large watershed with many

anthropogenic activities occurring within its boundary. Fort Laramie National Historic Site is located where the Laramie River flows into the North Platte River; therefore, the samples I collected represent an assessment for the entire watershed. How could the Laramie River have good ecosystem quality? Several factors may contribute to the good quality of the Laramie River, such as an established riparian area, low densities of livestock, and a sparse human population.

One reason the Laramie River may be in good condition is because the riparian area appears to be well-established (Figure 1 and cover photos). The riparian area within the park had a diverse assemblage of trees and understory plants that protect the river. Rivers with healthy riparian areas can buffer rivers from activities in the watershed that can degrade conditions (Feld 2013). Fort Laramie National Historic Site is a small park that preserves the ecosystem for < 1% of the river's length. The riparian area on private lands must also be in good condition to protect the river; however, the state of the riparian area in the rest of the watershed is unknown. Maintaining the riparian area along the Laramie River is probably vital to protecting the river.

Agricultural activities within a watershed can decrease the ecosystem quality of rivers. In general, land used as pasture has a lower impact on the surrounding watershed compared to land used for farming (Allan 2004). Farming, especially row crop farming, has a larger effect on rivers because of increased erosion and sedimentation from plowing, and increased inputs from fertilizers, herbicides and pesticides. Increased nutrients were the top stressor for streams in the United States (Paulsen et al. 2008) and are known to reduce ecosystem quality (Evans-White et al. 2009). Additionally, pesticides can decrease the vigor of life in streams (e.g., Van Wijngaarden et al. 2005). On the other hand, rangeland is generally managed less intensely. Livestock are typically turned out into the pasture and allowed to graze. Different grazing practices can alter the aquatic invertebrates in streams. For example, high density, short rotation grazing resulted in more riparian vegetation and more emerging aquatic invertebrates compared to long season grazing (Saunders and Fausch 2007). The Laramie River watershed is dominated by rangeland used to graze cattle. Southeastern Wyoming receives low annual rainfall (<45 cm) and the land is less productive compared to other areas. Therefore, the number of animals supported per acres is much lower in the Laramie River watershed compared to other areas such as the midwestern United States. Therefore, a low density of animals on the range may contribute to the quality of the Laramie River (Gammon et al. 2002).

Urban areas can highly impact river health (Allan 2004). Urbanization is often associated with more pollutants (concentrations and types), unpredictable flows, higher water temperatures, less riparian vegetation, increased erosion, and loss of in-stream habitat. Towns and cities exert such a large influence on streams because of the high concentration of people and activities within a relatively small area. Several studies have shown that the amount of area covered by impervious surfaces explained much of the variability in bioassessment metrics (Allan 2004). The Laramie River may have good ecosystem quality, because only two towns are located along the Laramie River. Laramie is located in the upper watershed and is home to 30,816 people. Wheatland sits in the middle of the watershed and far fewer people live here (3627 people). Therefore, the percent of urban area and area covered by impervious surfaces within the Laramie watershed is small and probably contributes to better ecosystem quality.

In contrast to agriculture and urbanization, reservoirs may increase the productivity of the Laramie River. The lotic discontinuity concept predicted differences between regulated and unregulated rivers when dams were situated at intermediate stream orders (Ward and Stanford 1983), such as Grayrocks Reservoir along the Laramie River. They predicted more fine particulate organic matter (FPOM) and less coarse particulate organic matter (CPOM) below a dam. Changes in detritus size may explain why shredders, who break down CPOM, typically have lower densities below dams (Short and Ward 1980) and why filterers, who eat FPOM, may increase in density (Ward and Stanford 1979). River discharge tends to be more predictable below dams (Ward and Stanford 1983). The density of invertebrates was eight times higher (18,000 ind/m^2) under stable discharge in the Skagit River, Washington (Gislason 1985). Ward (1976) also measured that higher flow constancy increase the biomass of invertebrates. Flow below Grayrocks Reservoir probably fluctuates little, because the reservoir is used for water storage and minimum flows are maintained for downstream wildlife. Stable flows may at least partially explain the high densities of invertebrates I measured in the Laramie River at Fort Laramie National Historic Site. Water temperatures are more constant below reservoirs (Ward and Stanford 1983) and temperatures can be higher during winter compared to unregulated stream. Short and Ward (1980) estimated that higher rates of litter breakdown occurred in a regulated river primarily because of warmer water temperatures during winter. Warmer temperatures may also increase the biomass of benthic algae during winter (Ward and Stanford 1979), which is the base of the food web. Warmer water temperatures and more benthic algae, especially in winter, may increase the secondary production in these streams. Substrate size is predicted to increase below a dam (Ward and Stanford 1983), probably because fine particles settle out in reservoirs and the released water can pick up fine material leave larger particles. Substrate size can impact the invertebrates living in the stream. For example, higher density, biomass, and diversity of invertebrates were measured on larger substrate (Williams 1977). The composition of invertebrates differed between regulated and unregulated rivers. Generally, heptageniid mayflies and stoneflies decreased below dams, and amphipods, simulids, midges, snails, and filtering invertebrates increased (Ward and Stanford 1979, Ward 1976). Diversity and biomass of aquatic invertebrates can increase or decrease below dams depending on conditions. Increases in diversity are thought to occur because of higher habitat and thermal heterogeneity (Ward and Stanford 1983). Fraley (1979) measured higher densities and biomass below Ennis Dam, Montana. The invertebrate assemblage has not been measured above Grayrocks Reservoir; therefore, I cannot compare the invertebrates above and below the dam. However, I speculate that the dam has increased invertebrate density, biomass, and diversity downstream.

Conclusions

Lands protected by the National Park Service are managed to preserve nature and culture for future generations. Fort Laramie National Historic Site preserves a reach of the Laramie River that flows through the park. However, Fort Laramie National Historic Site is a small park (337 hectares) and the Laramie River watershed (1,182,000 hectares) is large. Many anthropogenic activities occur in the watershed, such as towns, agriculture, and dams. Only two towns of significance occur in the watershed and the human population outside of town is sparse. Agriculture in the watershed is dominated by rangeland for cattle that are generally stocked at low densities and some hay production. A few dams occur along the Laramie River, including Grayrocks Reservoir above the park and Wheatland Reservoir above Wheatland. These dams dampen the hydrology of the river making the flow more predictable and likely alter food sources and thermal regimes. Stable flows may contribute to the high density of invertebrates I collected in the river at Fort Laramie National Historic Site. Many anthropogenic activities occur in the Laramie watershed; however, the low density of people and animals probably impacts the river to a much lesser degree compared to other areas that are more densely settled. These factors likely contribute to the good ecosystem quality in the Laramie River at Fort Laramie National Historic Site. In order to sustain the quality of the river, the park and land owners should work together to maintain or improve management practices in the watershed.

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Appendix A. The functional feeding group (FFG), habit, and tolerance values of taxa collected in the Laramie River at Fort Laramie National Historic Site.

Taxa	Family	Order	FFG	Habit	Tolerance
Insects					
Dubiraphia	Elmidae	Coleoptera	Gatherer	Clinger	4
Microcylloepus	Elmidae	Coleoptera	Gatherer	Clinger	4.7
Stenelmis	Elmidae	Coleoptera	Scraper	Clinger	4
Ceratopogonidae Unk	Ceratopogonidae	Diptera	Predator	Burrower	4
Probezzia	Ceratopogonidae	Diptera	Predator	Burrower	3.3
non-Tanypodinae	Chironomidae	Diptera	Gatherer	Burrower	0.4
Tanypodinae	Chironomidae	Diptera	Predator	Burrower	2.4
Empididae Unk	Empididae	Diptera	Predator	Sprawler	2
Hemerodromia	Empididae	Diptera	Predator	Sprawler	4.2
Lemnophila	Ephidridae	Diptera	Gatherer	Burrower	2
Simulium	Simuliidae	Diptera	Filterer	Clinger	4
Tabanidae	Tabanidae	Diptera	Predator	Sprawler	2
Dicranota	Tipulidae	Diptera	Predator	Sprawler	2
Hexatoma	Tipulidae	Diptera	Predator	Burrower	2.7
Acentrella	Baetidae	Ephemeroptera	Gatherer	Swimmer	8
Baetis	Baetidae	Ephemeroptera	Gatherer	Swimmer	6
Camelobaetidius	Baetidae	Ephemeroptera	Gatherer	Swimmer	2
Fallceon quilleri	Baetidae	Ephemeroptera	Gatherer	Swimmer	5
Heptagenia	Heptageniidae	Ephemeroptera	Scraper	Swimmer	3.9
Rhithrogena	Heptageniidae	Ephemeroptera	Scraper	Clinger	0
Isonychia	Isonychidae	Ephemeroptera	Filterer	Swimmer	4
Asioplax	Leptohyphidae	Ephemeroptera	Gatherer	Clinger	5.5
Tricorythodes	Leptohyphidae	Ephemeroptera	Gatherer	Sprawler	5.6
Choroterpes	Leptophlebiidae	Ephemeroptera	Gatherer	Clinger	4
Leptophlebiidae Unk	Leptophlebiidae	Ephemeroptera	Gatherer	Swimmer	4
Neochoroterpes	Leptophlebiidae	Ephemeroptera	Gatherer	Clinger	4.9
Ephoron	Polymitarcidae	Ephemeroptera	Gatherer	Burrower	2.8
Ambrysus	Naucoridae	Hemiptera	Predator	Clinger	6.5
Petrophila	Crambidae	Lepidoptera	Scraper	Climber	4
Argia	Coenagrionidae	Odonata	Predator	Climber	4.8
Coenagrionidae Unk	Coenagrionidae	Odonata	Predator	Climber	5.4
Ophiogomphus severus	Gomphidae	Odonata	Predator	Burrower	4
Isoperla	Perlodidae	Plecoptera	Predator	Clinger	5.1
Culoptila	Glossosomatidae	Trichoptera	Scraper	Clinger	5.9
Cheumatopsyche	Hydropsychidae	Trichoptera	Filterer	Clinger	6
Hydropsyche	Hydropsychidae	Trichoptera	Filterer	Clinger	7

Taxa	Family	Order	FFG	Habit	Tolerance
Hydropsychidae Unk	Hydropsychidae	Trichoptera	Filterer	Clinger	6
Hydroptila	Hydroptilidae	Trichoptera	Scraper	Clinger	5.9
Hydroptilidae Unk	Hydroptilidae	Trichoptera	Scraper	Climber	6
Orchrotrichia	Hydroptilidae	Trichoptera	Gatherer	Clinger	6
Nectopsyche	Leptoceridae	Trichoptera	Shredder	Climber	5.3
Oecetis	Leptoceridae	Trichoptera	Predator	Climber	8
Limnephilidae Unk	Limnephilidae	Trichoptera	Shredder	Climber	2
Polycentropus	Polycentropodidae	Trichoptera	Predator	Clinger	2.6
Non-Insects					
Motobdella	Erpobdellidae	Annelida	Predator	Clinger	7
Helobdella stagnalis	Glossiphoniidae	Annelida	Predator	Clinger	6.7
Oligochaeta	Oligochaeta	Annelida	Gatherer	Burrower	5
Collembola	Collembola	Collembola	Gatherer	Sprawler	10
Amphipoda	Amphipoda	Crustacean	Gatherer	Sprawler	4
Cambaridae	Decapoda	Crustacean	Gatherer	Sprawler	6
Ferrissia	Ancylidae	Mollusk	Scraper	Clinger	5.2
Sphaeriidae	Sphaeriidae	Mollusk	Filterer	Burrower	7.25
Nematoda	Nematoda	Nematoda	Parasite	NA	5
Nemertea	Nemertea	Nemertea	Predator	NA	8
Turbellaria	Turbellaria	Turbellaria	Predator	Clinger	4

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NPS 375/122848, November 2013

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