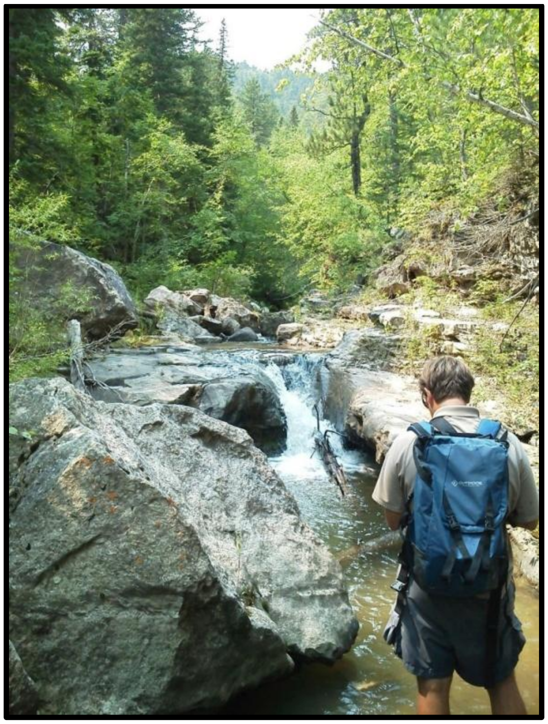
A survey for the aquatic invasive species New Zealand mudsnail *Potamopyrgus antipodarum* in the Black Hills of South Dakota



Prepared for the Aquatic Nuisance Species Coordinator, U.S. Fish and Wildlife Service – Region 6, 134 Union Boulevard, Lakewood, Colorado 80228

Prepared by:

Daniel A. James
U.S. Fish and Wildlife Service
Great Plains Fish and Wildlife Conservation Office
Pierre, SD 57501
daniel_james@fws.gov

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Executive Summary

The Black Hills of South Dakota support a large, recreational fishery and several native species populations, but are susceptible to aquatic invasive species (AIS) introductions similar to those experienced in many other North American locations. The New Zealand mudsnail (NZMS) *Potamopyrgus antipodarum* is one such AIS in the United States. To date, NZMS have not been reported from the Black Hills although efforts to look for their presence have been limited. Early detection and prevention of the spread of the NZMS is crucial to management because eradication is costly and difficult, if not impossible once populations are established. The objective of this study was to survey selected streams in the Black Hills for the presence of NZMS during the summer of 2012. I focused our search in three watersheds that contain critical habitat for an important native fish species in the Black Hills, the mountain sucker *Catostomus platyrhynchus*. In addition to documenting the presence or absence of NZMS, the community composition and abundance of native macroinvertebrates was also described.

I did not find any New Zealand mudsnails from more than 34,000 individually identified macroinvertebrates from the three streams in our survey. The presence of at least three orders of gastropods in our survey indicated that adequate habitat is likely available for NZMS to establish a population, which suggests the Black Hills are at risk to invasion and establishment if preventative measures are not exercised. Due to the potential negative impacts that NZMS have on fisheries resources, it should be considered important to periodically screen streams for its presence and proactively initiate measures to prevent introductions to the Black Hills. Prevention measures could include periodic surveys to screen for NZMS presence and outreach education. Recreational users need to be informed of the negative impacts NZMS could impose on aquatic resources and become engaged in the prevention of their range expansion. Informative signs and cleaning stations to disinfect outdoor gear could be constructed and placed in strategic locations for recreationists to use. Additionally, recreational users should be informed of simple methods to kill NZMS, such as thoroughly drying or freezing outdoor gear.

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Introduction

The Black Hills of South Dakota contain hundreds of kilometers of perennial, coldwater streams and numerous reservoirs that support a large, recreational fishery and several native fish populations. Due to popularity of the Black Hills as a tourism destination, waters in the Black Hills are unfortunately susceptible to aquatic invasive species (AIS) introductions, similar to those experienced in many other North American locations. The New Zealand mudsnail (NZMS) *Potamopyrgus antipodarum* is one such AIS in the U.S. that was first observed in Idaho in 1987 (Benson et al. 2013). Since then, the NZMS has spread throughout the western U.S. including Arizona, California, Colorado, Montana, Oregon, Utah, Washington, and Wyoming (Benson et al. 2013). Additionally, the NZMS was discovered in Lake Ontario in 1991 (Zaranko et al. 1997) and has since spread to other locations in the Great Lakes region (Benson et al. 2013). To date, NZMS have not been reported from the Black Hills although efforts to look for their presence have been limited.

The NZMS is a small (< 7 mm), freshwater gastropod (snail) native to New Zealand. Because the NZMS is parthenogenic (i.e., individuals reproduce by cloning themselves), only one individual is required to initiate a population in a new system (Wallace 1992). In systems where the NZMS has become established, abundance tends to reach high densities, which reduces space and food for native fauna through competition (Hall et al. 2003). Additionally, abundance of the NZMS can increase to such an extent that it becomes the main source of invertebrate prey for consumers (Vinson and Baker 2008).

If introduced, the potential for NZMS to spread throughout the Black Hills is large. Streams in the Black Hills are located within close proximity to one another, are easily accessible by vehicle, and represent popular fishing destinations for anglers. Once present, the NZMS can move upstream at an estimated rate of 1 $km \cdot yr^{-1}$ (Lassen 1975). The NZMS is thought to be spread by recreationists and other stream users because live NZMS have been observed in crevices of wading shoe laces, waders, and other angling gear (Richards et al. 2004). Felt soles of wading shoes retain moisture and provide conditions that allow NZMS to survive for weeks (OSG 2010) and thus act as a transportation vector. Additionally, because a large percentage (> 50%) of consumed NZMS are often undigested by fish and pass through the digestive track alive, fish themselves serve as transport mechanisms within interconnected watersheds (Vinson and Baker 2008).

Early detection and prevention of the spread of the NZMS is crucial to management because eradication is costly and difficult, if not impossible once populations are established (Simberloff 2003). The objective of this study was to survey selected streams in the Black Hills for the presence of NZMS. We focused our search in three watersheds that contain critical habitat for an important native fish species in the Black Hills, the mountain sucker *Catostomus platyrhynchus*. In addition to documenting the presence or absence of NZMS, the community composition and abundance of native macroinvertebrates was also described.

Methods

Study area

The Black Hills of South Dakota are approximately 97 km wide, 193 km long, and reach elevations of >2,100 m (Koth 2007). More than 1,200 km of streams and 22 reservoirs support fish in the Black Hills (Erickson and Koth 2000). We conducted our surveys in portions of Bear Butte Creek, Elk Creek, and Rapid Creek upstream of Pactola Reservoir (Figure 1). Bear Butte Creek is an unregulated, headwater stream maintained through springs and precipitation that drains approximately 41 km^2; mean annual discharge from 1989 to 2012 was 0.22 $m^3 \cdot s^{-1}$ (USGS 2013). Elk Creek is an unregulated, headwater stream maintained through springs and precipitation that drains approximately 56 km^2; mean annual discharge from 1992 to 2012 was 0.30 $m^3 \cdot s^{-1}$ (USGS 2013). The headwaters section of Rapid Creek drains approximately 762 km^2 into Pactola Reservoir (USGS 2013). Mean annual discharge above the reservoir averaged 1.36 $m^3 \cdot s^{-1}$ from 1954 to 2012 (USGS 2013).

Macroinvertebrate sample collection

We assessed the community composition and abundance of benthic macroinvertebrates in 13 stream km of Bear Butte, 16 stream km of Elk, and 23 stream km of Rapid creeks. I used a stratified, randomized block sampling design to select 30% of each stream section; I randomly selected three, 100-m stream reaches within each stream km of each stream section to sample. At each sample site, we collected two macroinvertebrate subsamples (i.e., one at the upstream end and one at the downstream end) using a Hess sampler (Wildco Supply Company, Yulee, FL). The Hess sampler had 500 µm mesh, was 33.0 cm in diameter, 40.6 cm high, and had an 858 cm^2 sampling area. To collect a sample, the Hess sampler was pressed into the stream substrate and oriented upstream. The substrate within the sampler was hand-rubbed for 30 s and then lifted from the stream. The collection net was rinsed down into the collection bucket from the outside with stream water. Samples were placed into individual containers, labeled, and preserved with 90% ethanol. In the laboratory, macroinvertebrates were sorted, enumerated, and identified (Merritt at al. 2008, Smith 2001, Voshell 2002). For high-density samples (i.e., > 1 hr processing time), a random 25-50% subsample was examined.

Analyses

The two macroinvertebrate samples from each sampling reach were treated as replicate samples and the quantitative variables (i.e., number, density) were averaged prior to further analysis. In addition to screening samples for the presence of NZMS, four indices to describe the macroinvertebrate community were calculated; these included richness (S), the estimated total richness (S_{total}), diversity (H), and evenness (J). Richness was determined simply as the total count of the number of taxonomic groups collected in the Hess sampler. To estimate the total number of taxonomic groups, including those I did not detect, total richness (S_{total}) was estimated using a nonparametric estimator developed by Chao (1984; cited in Kwak and Peterson 2007) as,

$$S_{total} = S_{obs} + (a^2 / 2b),$$

where, S_{obs} is the number of taxonomic groups observed, *a* is the number of groups where exactly one individual of that group was collected, and *b* is the number of groups where exactly two individuals of that group were collected. Diversity, which provides information that combines richness and relative abundance, was calculated using Shannon's index (H) as,

$$H' = -\sum_{i=1}^{S} (p_i)(\log_e p_i)$$

where *S* is the number of groups and p_i is the proportion of the total sample represented by the *i*th group (Shannon and Weaver 1949; cited in Kwak and Peterson 2007). Evenness (*J*), defined as the equitability of relative abundance among groups was calculated as,

$$J' = H' / \log_e s,$$

where *H´* is Shannon's diversity index and *S* is the number of groups (Kwak and Peterson 2007). The macroinvertebrate indices and metrics were calculated using Microsoft Excel and the program PAST 2.17 (Paleontological Statistics; Hammer et al. 2001).

Results

Overall, we collected 299 subsamples from 152, 100-m stream reaches from June-September of 2012 (Figure 1). We sampled 36 reaches in Bear Butte Creek (72 subsamples), 47 reaches in Elk Creek (94 subsamples), and 69 reaches in Rapid Creek (133 subsamples). A total of 34,476 macroinvertebrates were collected, enumerated, and identified; 4,833 were from Bear Butte Creek, 20,263 were from Elk Creek, and 9,380 were from Rapid Creek. Representatives from 16 major taxonomic groups (e.g., Class, Order) and 53 minor taxonomic groups (e.g., Family, unidentified adult) were identified.

I did not identify any NZMS in the samples we collected. Three families of Gastropoda were identified, which included Lymnaeidae, Physidae, and Planorbidae (Table 1). Macroinvertebrate richness, diversity, and evenness were greatest in Bear Butte Creek and least in Rapid Creek (Table 2). The largest macroinvertebrate abundance and densities were represented by Coleoptera: Elmidae larva in Bear Butte Creek (N=1,355; mean density=$219 \cdot m^{-2}$; SE=36), Coleoptera: Elmidae larva in Elk Creek (N=7,246; mean density=$898 \cdot m^{-2}$; SE=189) and Diptera: Chironomidae in Rapid Creek (N=4,966; mean density=$435 \cdot m^{-2}$; SE=77; Appendix 1 and 2).

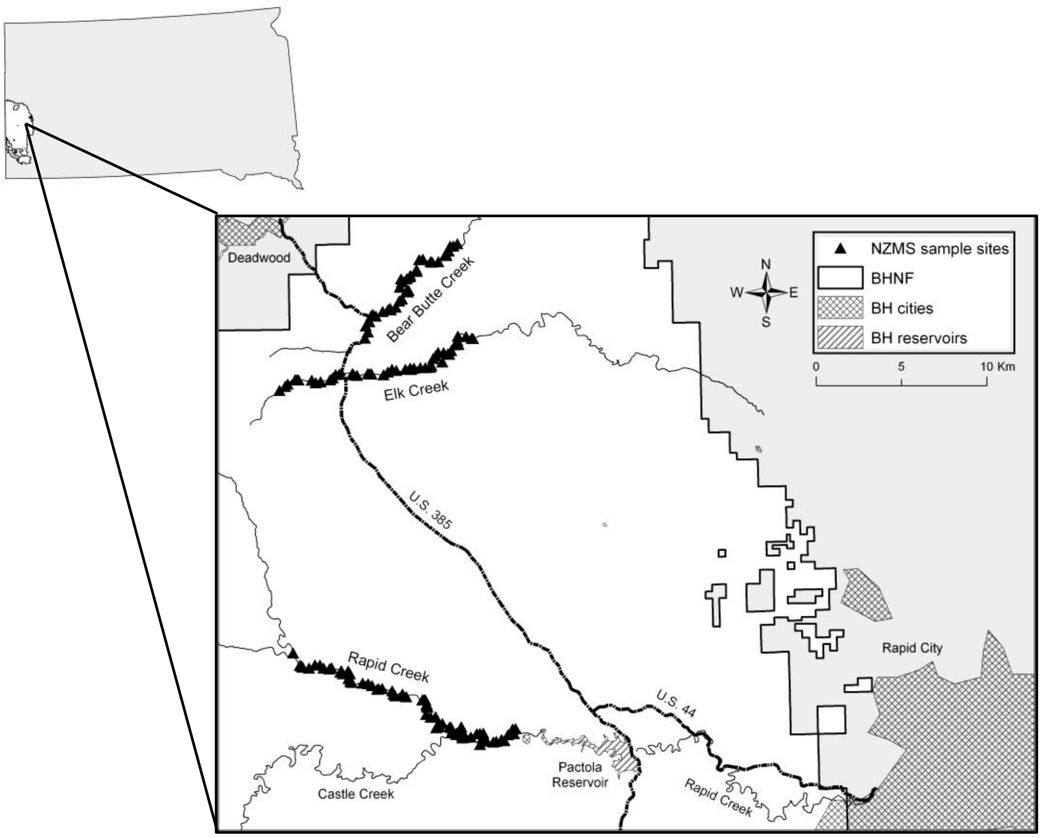

Figure 1. Stream reach locations (N=152) in Bear Butte, Elk, and Rapid creeks in the Black Hills National Forest (BHNF), South Dakota where macroinvertebrate benthic subsamples (N=299) were collected during 2012.

Table 1. Number of individuals (N) and mean density ($N{\cdot}m^{-2}$ ± one SE) of families in the Order Gastropoda collected in Hess samplers from three Black Hills, South Dakota streams in 2012.

	Stream					
	Bear Butte		Elk		Rapid	
Family	N	Density ($N{\cdot}m^{-2}$)	N	Density ($N{\cdot}m^{-2}$)	N	Density ($N{\cdot}m^{-2}$)
Lymnaeidae	0	0.0	0	0.0	2	0.18 (0.1)
Physidae	441	71.0 (11.1)	122	15.0 (11.0)	1	0.09 (0.1)
Planorbidae	21	3.0 (1.3)	4	0.5 (0.3)	4	0.35 (0.2)

Table 2. Community indices for benthic macroinvertebrates collected in a Hess sampler from three streams in the Black Hills, South Dakota during 2012. Indices are richness (*S*), estimated total richness (S_{total}), Shannon's diversity (*H*), and Eveness (*J*).

	Stream		
Index	Bear Butte	Elk	Rapid
S	43	43	38
S_{total}	53	50	49
H	2.25	2.10	1.88
J	0.22	0.19	0.17

Discussion

I did not find any New Zealand mudsnails from more than 34,000 individually identified macroinvertebrates from the three streams in our survey. Although our surveys were extensive, the estimated total taxonomic group richness was 7-11 groups more than I identified, which suggests several less common (i.e., rare) taxonomic groups were undetected by our sampling efforts. It is unlikely however, for one of these groups to be NZMS as they are typically found in large abundance unless newly established. Also, given that the mesh size of the Hess sampler we used to collect macroinvertebrates was 500 µm (0.5 mm), that NZMS grow to lengths of ~7 mm, and that we commonly collected macroinvertebrates (e.g. Chironomidae, Elmidae) of small sizes (< 7 mm), the potential that NZMS could have been overlooked during our sampling was small.

The potential negative impacts of NZMS are large in the Black Hills. The mountain sucker is designated as a species of greatest concern by the South Dakota Department of Game, Fish and Parks (SDGFP 2006) and a sensitive species by the U.S. Forest Service (USDA Forest Service 2005). Furthermore, it was recently determined that mountain sucker in the Black Hills have been potentially extirpated from two streams and 14 stream reaches and that overall, populations have significantly declined since the 1960s (Schultz and Bertrand 2012). The mountain sucker is an algal scraper (i.e., relies on algae for food) and because NZMS have been documented to consume 75% of gross primary production (i.e., algae) in streams (Hall et al. 2003), introduction of the NZMS could lead to competition with mountain sucker for food resources. Aside from mountain sucker, naturalized brook trout *Salvelinus fontinalis*, naturalized brown trout *Salmo trutta*, and stocked rainbow trout *Oncorhynchus mykiss* are an important component of the recreational fisheries in the Black Hills; anglers fish approximately 500,000 days a year in the Black Hills (Erickson and Koth 2000). Rainbow trout have been observed to lose up to 0.48% of their initial weight per day on a diet of NZMS in controlled feeding studies (Vinson and Baker 2008). Also, rainbow trout that consumed NZMS in infected streams were observed to have significantly lower body condition than rainbow trout in NZMS-free streams that did not consume the invasive snails (Vinson and Baker 2008). Thus, prey resources would likely be adversely diminished for trout species should NZMS become established, thus negatively affecting angling opportunities in the Black Hills.

Due to the potential negative impacts that NZMS have on fisheries resources, it should be considered of high importance to periodically screen streams for the presence of NZMS and proactively initiate measures to prevent introductions to the Black Hills. The NZMS is thought to be able to thrive in a variety of habitats across a wide range of ecological conditions (Benson et al. 2013) and given predictions based on ecological modeling, the habitat availability for NZMS is suitable for a large range expansion across North America, including the Black Hills (Loo et al. 2007). The presence of at least three orders of gastropods in our survey indicates that adequate habitat is likely available for NZMS to establish a population, which suggests the Black Hills are at risk to invasion and establishment if preventative measures are not exercised.

Prevention measures, for example, could include frequent surveys to screen for NZMS presence (i.e., early detection) and outreach education. Early detection of newly introduced individuals is crucial to curtail their spread because eradication after populations are established is costly and difficult, if not impossible (Simberloff 2003). Recreational users need to be well informed of the negative impacts NZMS could impose on aquatic resources and become engaged in the prevention of their range expansion. Informative signs and cleaning stations to disinfect outdoor gear could be constructed and placed in strategic locations for recreationists to use. Alternatively, recreational users should be informed of simple methods to kill NZMS, such as thoroughly drying or freezing outdoor gear (Richards et al. 2004).

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Appendices

Appendix 1. Number of individuals (N) and mean density ($N \cdot m^{-2}$ ± one SE) of major macroinvertebrate taxonomic groups collected in Hess samplers in selected Black Hills, South Dakota streams during 2012.

	Stream					
	Bear Butte		Elk		Rapid	
Taxonomic group	N	Density ($N \cdot m^{-2}$)	N	Density ($N \cdot m^{-2}$)	N	Density ($N \cdot m^{-2}$)
Amphipoda	0	0.0	63	9.0 (6.9)	0	0.0
Arachnida	13	1.1 (0.4)	27	1.6 (0.6)	8	0.4 (0.1)
Coleoptera	1,725	93.1 (14.4)	9,500	392.6 (67.5)	407	11.9 (1.1)
Diptera	1,241	18.3 (3.3)	4,090	46.1 (17.0)	5,447	43.4 (7.7)
Ephemeroptera	325	10.5 (2.3)	3,239	80.3 (9.9)	1,382	24.2 (3.0)
Gastropoda	462	24.9 (4.3)	126	5.2 (3.7)	7	0.2 (0.1)
Hemiptera	28	1.1 (0.4)	35	1.1 (0.3)	13	0.3 (0.1)
Hirudinea	31	5.0 (1.6)	2	0.2 (0.2)	1	0.1 (0.1)
Hymenoptera	2	0.2 (0.1)	9	0.6 (0.2)	2	0.1 (0.1)
Lepidoptera	1	0.1 (0.1)	19	1.2 (0.5)	0	0.0
Megaloptera	0	0.0	3	0.4 (0.2)	0	0.0
Odonata	10	0.8 (0.8)	75	4.6 (0.9)	98	4.3 (0.7)
Oligachaeta	98	15.9 (5.0)	21	2.6 (1.3)	9	0.8 (0.4)
Pelecypoda	22	3.6 (1.4)	27	3.3 (1.3)	1	0.1 (0.1)
Plecoptera	131	5.3 (1.3)	305	9.5 (1.7)	1,074	23.5 (3.1)
Trichoptera	744	8.6 (1.8)	2,724	24.1 (2.4)	931	5.8 (0.8)

Appendix 2. Number of individuals (N) and mean density ($N \cdot m^{-2}$ ± one SE) of minor macroinvertebrate taxonomic groups collected in Hess samplers in selected Black Hills, South Dakota streams during 2012.

Taxonomic group	Stream: Bear Butte N	Bear Butte Density ($N \cdot m^{-2}$)	Elk N	Elk Density ($N \cdot m^{-2}$)	Rapid N	Rapid Density ($N \cdot m^{-2}$)
Amphipoda						
Gammaridae	0	0.0	63	9.0 (6.9)	0	0.0
Arachnida						
Hydracarina	11	1.8 (0.7)	26	3.2 (1.2)	5	0.4 (0.2)
terrestrial	2	0.3 (0.2)	1	0.1 (0.1)	3	0.3 (0.2)
Coleoptera						
Elmidae	1,355	219.3 (36.1)	7,246	898.5 (189.3)	351	30.8 (2.6)
Elmidae adult	369	59.7 (14.5)	2,254	279.4 (29.7)	56	4.9 (0.9)
Hydrophilidae	1	0.2 (0.2)	0	0.0	0	0.0
Diptera						
unidentified adult	12	1.9 (0.6)	5	0.6 (0.3)	27	2.4 (0.6)
Athericidae	4	0.6 (0.4)	137	16.9 (3.3)	84	7.4 (1.3)
Ceratopogonidae	2	0.3 (0.2)	17	2.1 (0.9)	12	1.1 (0.3)
Chaoboridae	2	0.3 (0.2)	0	0.0	0	0.0
Chironomidae	1,136	183.9 (29.3)	3,487	432.4 (182.5)	4,966	435.2 (77.4)
Dixidae	1	0.2 (0.2)	4	0.5 (0.3)	1	0.1 (0.1)
Empididae	0	0.0	1	0.1 (0.1)	40	3.5 (0.6)
Muscidae	1	0.2 (0.2)	0	0.0	0	0.0
Psychodidae	8	1.3 (0.6)	57	7.1 (4.5)	1	0.1 (0.1)
Simuliidae	17	2.8 (1.6)	164	20.4 (6.9)	44	3.9 (1.0)
Tipulidae	58	9.4 (1.9)	218	27.0 (5.5)	272	23.8 (2.6)
Ephemeroptera						
Baetidae	294	47.6 (10.4)	2,154	267.1 (30.1)	1,179	103.3 (12.1)
Ephemerillidae	1	0.2 (0.2)	8	1.0 (0.6)	5	0.4 (0.2)
Heptageniidae	4	0.6 (0.4)	0	0.0	0	0.0
Leptohyphidae	19	3.1 (1.2)	902	111.8 (31.7)	72	6.3 (1.1)
Leptophlebiidae	7	1.1 (0.7)	175	21.7 (3.0)	126	11.0 (3.6)
Gastropoda						
Lymnaeidae	0	0.0	0	0.0	2	0.2 (0.1)
Physidae	441	71.4 (11.1)	122	15.1 (11.0)	1	0.1 (0.1)
Planorbidae	21	3.4 (1.3)	4	0.5 (0.3)	4	0.4 (0.2)
Hemiptera						
unidentified adult	28	1.1 (0.4)	35	0.7 (0.3)	13	1.1 (0.1)

Major taxonomic groups are listed flush left; minor groups are indented beneath them.

Appendix 2. (continued)

Taxonomic group	Bear Butte		Stream Elk		Rapid	
Major Minor	N	Density ($N \cdot m^{-2}$)	N	Density ($N \cdot m^{-2}$)	N	Density ($N \cdot m^{-2}$)
Hirudinea						
unidentified adult	31	5.0 (1.6)	2	0.2 (0.2)	1	0.1 (0.1)
Hymenoptera						
unidentified adult	1	0.2 (0.2)	3	0.4 (0.2)	2	0.2 (0.1)
Formicidae	1	0.2 (0.2)	6	0.7 (0.3)	0	0.0
Lepidoptera						
Crambidae	0	0.0	19	2.4 (1.0)	0	0.0
Noctuidae	1	0.2 (0.2)	0	0.0	0	0.0
Megaloptera						
Sialidae	0	0.0	3	0.4 (0.2)	0	0.0
Odonata						
Coenagrionidae	2	0.3 (0.2)	11	1.4 (0.5)	0	0.0
Gomphidae	8	1.3 (0.5)	64	7.9 (1.8)	98	8.6 (1.3)
Oligachaeta						
unidentified adult	98	15.9 (5.0)	21	2.6 (1.3)	9	0.8 (0.4)
Pelecypoda						
unidentified adult	22	3.6 (1.4)	27	3.3 (1.3)	1	0.1 (0.1)
Plecoptera						
Chloroperlidae	99	16.0 (4.3)	128	15.9 (5.5)	391	34.3 (4.1)
Nemouridae	21	3.4 (2.5)	45	5.6 (1.8)	438	38.4 (11.1)
Perlidae	9	1.5 (0.7)	1	0.1 (0.1)	105	9.2 (1.2)
Perlodidae	2	0.3 (0.2)	131	16.2 (3.6)	140	12.3 (1.8)
Trichoptera						
unidentified adult	3	0.5 (0.4)	0	0.0	6	0.5 (0.2)
Brachycentridae	58	9.4 (3.9)	318	39.5 (13.6)	167	14.6 (3.2)
Glossosomatidae	0	0.0	3	0.4 (0.3)	57	5.0 (1.9)
Goeridae	12	1.9 (0.8)	0	0.0	0	0.0
Helicopsychidae	69	11.2 (3.6)	1,174	145.5 (16.7)	10	0.9 (0.9)
Hydropsychidae	468	75.8 (22.0)	1,035	128.3 (18.4)	587	51.4 (9.8)
Hydroptilidae	62	10.0 (3.6)	62	7.7 (2.5)	43	3.8 (0.8)
Lepidostomatidae	1	0.2 (0.2)	5	0.6 (0.4)	0	0.0
Leptoceridae	0	0.0	97	12.0 (2.0)	0	0.0
Limnephilidae	70	11.3 (6.4)	8	1.0 (0.5)	50	4.4 (0.9)
Philopotamidae	1	0.1 (0.1)	2	0.1 (0.2)	1	0.04 (0.04)

Appendix 2. (continued)

Taxonomic group	Stream					
	Bear Butte		Elk		Rapid	
Major Minor	N	Density ($N \cdot m^{-2}$)	N	Density ($N \cdot m^{-2}$)	N	Density ($N \cdot m^{-2}$)
Rhyacophilidae	0	0.0	13	1.6 (0.8)	10	0.9 (0.3)
Sericostomatidae	0	0.0	7	0.9 (0.5)	0	0.0