Assessment of biological and physical relationships of spring and seep ecosystems across a gradient of human impacts

Lusha Tronstad
Invertebrate Zoologist
Email: tronstad@uwyo.edu
Telephone: 307-766-3115

Hannah Griscom
Vertebrate Zoologist
Email: hgriscom@uwyo.edu

Wyoming Natural Diversity Database
University of Wyoming
1000 East University Ave.
Laramie, Wyoming 82071

Fax: 307-766-3026
Website: http://www.uwyo.edu/wyndd/

Suggested Citation: Tronstad, L.M. and H. Griscom. 2012. Assessment of biological and physical relationships of spring and seep ecosystems across a gradient of human impacts. Report prepared for the USDI National Park Service, Devils Tower National Monument by the Wyoming Natural Diversity Database, University of Wyoming, Laramie, Wyoming.

SUMMARY
Our report describes the ecological significance of several springs and seeps within Devils Tower National Monument. Special attention is given to the potential restoration of sites that were developed for human use in the early 20th century. Invertebrate assemblages and water quality are characterized and compared between natural and developed springs. Springs that were developed for human use were capped and boxed, essentially cutting them off from the surrounding flora and fauna. Lower taxonomic richness and density in the invertebrate assemblage at capped springs describe the isolation after development. Options for restoration are suggested with regard to minimizing site disturbance. Suggestions for monitoring after restoration are also presented.

INTRODUCTION

Springs and seeps can be hotspots for invertebrate biodiversity. These ecosystems are places where groundwater comes to the surface and either flows (springs) or forms a pool (seeps). Invertebrates living in springs and seeps are often diverse and can occur at high densities. Invertebrates may thrive in such habitats for several reasons. First, springs and seeps often have stable water temperatures, flow, dissolved gases, and dissolved solids (Meffe and Marsh 1983), and such stability can lead to higher species richness (Erman and Erman 1995). Stable water temperatures can keep a spring open during the winter, enabling algae and invertebrates to grow year round (Glazier 1991). Second, springs and seeps are interfaces or transitional zones between aquatic and terrestrial habitats, and also between surface and groundwater (Cantonati et al. 2006; Ilmonen et al. 2009). Finally, few predators typically live in springs (Glazier 1991; Cantonati et al. 2006).

Springs and seeps are sensitive ecosystems, primarily because they are small (Cantonati et al. 2006), but also because the semi-aquatic habitat surrounding springs and seeps is extremely sensitive to disturbance. Riparian habitat can support a diversity of plants and animals, but these transitional zones are quite vulnerable to sedimentation, livestock trampling, nutrient inputs, and contamination (Cantonati et al. 2006). Springs are frequently developed by people, because they provide a constant source of clean water. Developing springs can change the function and structure of the ecosystem.

Endemic and rare invertebrates often live in springs and seeps. For example, Great Artesian Basin Springs in Australia are home to at least 12 unique species of scuds (Amphipoda; Murphy et al. 2009). Springs in the Austrian Alps are home to 7 endemic hydrobiid snails (Haase 1996). Over half of the invertebrate taxa in Sonoran Desert springs are restricted to a handful of sites (Meffe and Marsh 1983). In general, water mites (Hydrachnidiae), trueflies (Diptera), hydrobiid snails, and caddisflies (Trichoptera) tend to have the highest proportion of taxa specialized for living in springs (crenobiontic; Cantonati et al. 2006).

Many non-insect invertebrates (e.g., crustaceans) live in springs, especially scuds, pill bugs (Isopoda), snails (Gastropoda), and flatworms (Turbellaria, Glazier 1991). Non-insects probably flourish in springs because of their non-emergent life cycles (non-insects do not emerge from water as winged adults). For example, the entire life cycle of a crustacean or snail occurs in water, and they can grow year-round in constant water temperatures. In contrast, the larvae or nymphs of aquatic insects live in the water, but emerge as winged adults and mate in the terrestrial ecosystem. Many aquatic insects emerge as adults using water temperature as a cue; however, annual water temperature varies little in springs. Therefore, insects in springs probably rely more on photoperiod for life history cues (e.g., emergence periods), enabling insects to emerge at the correct time and recolonize springs (Cantonati et al. 2006).

Devils Tower National Monument encompasses 5 springs and 1 seep. Three of the springs were developed in the early 1900s, probably to collect water for human use. In each case developers dug down to the source and poured a concrete box around the spring to collect and store water. Because springs are unique and important habitats, Devils Tower National Monument is interested in restoring these boxed springs to natural or semi-natural conditions.

PROJECT OBJECTIVES

To understand how encasing the springs affected these natural resources, we compared water quality, water flow, and aquatic invertebrates in boxed and natural springs. The specific questions we addressed were:

1. To what extent has the water quality of boxed springs been impacted?
2. To what extent have the macroinvertebrate assemblages and hydrology of boxed springs been affected?
3. What techniques exist for the removal of the concrete structures and the restoration of unimpeded flow to the springs?
4. What parameters need to be monitored long-term to determine the success of the spring restoration?

SPRING DESCRIPTIONS

Devel's Tower National Monument contains 2 unaltered springs (Fallen Log Spring and Graham Spring), 1 unaltered seep (Visitor Center Seep), and 3 boxed springs (Tarpot Box, Waterline Box, and Hidden Box). Figure 1 displays the location of all six sites. All sites contain water year-round with the exception of Hidden Box which was consitently dry and thus excluded from our study.

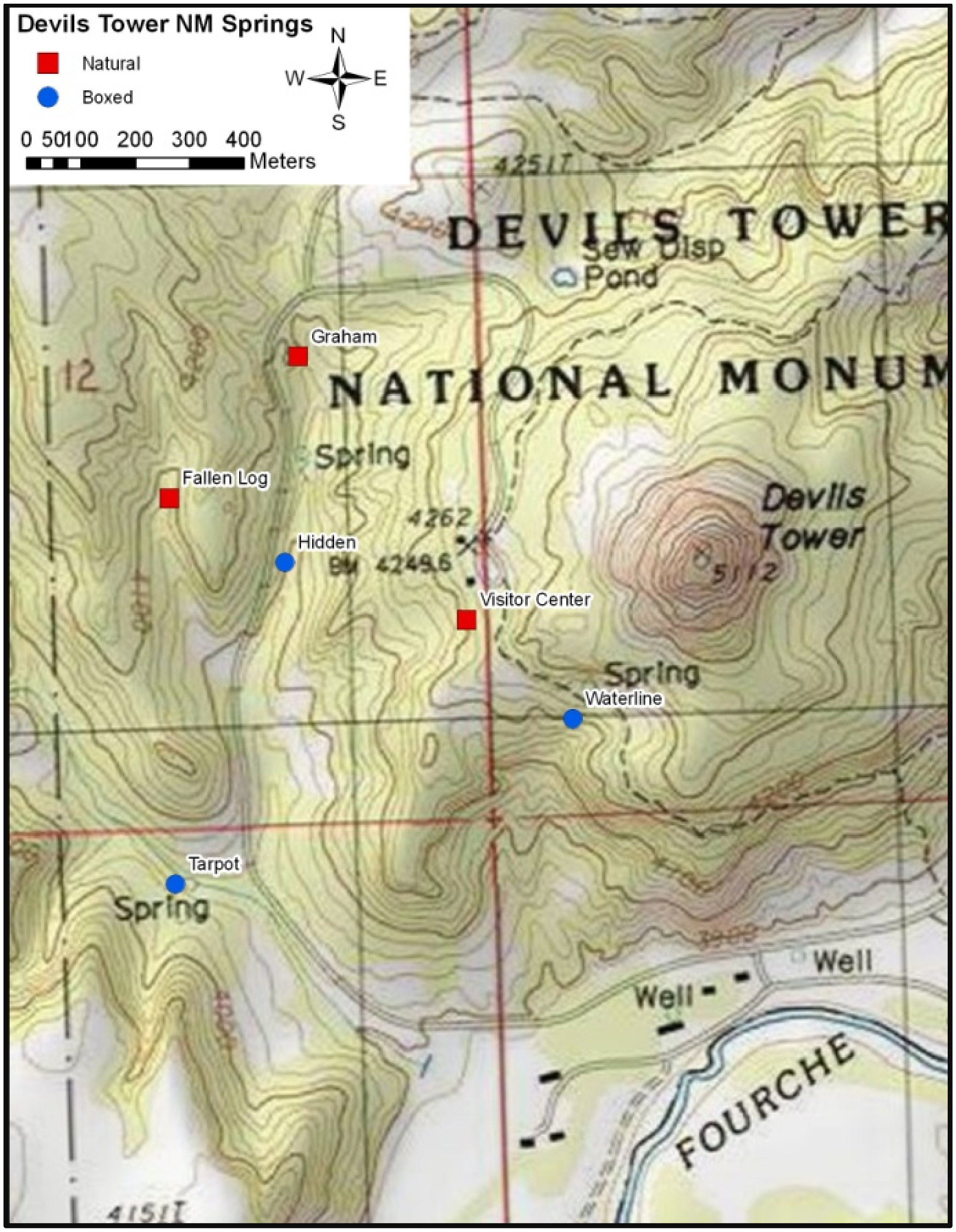

Figure 1. Map of boxed and natural springs at Devils Tower National Monument, Wyoming.

Fallen Log Spring: Zone 13 521628E 4937639N (NAD83), elevation 1260 m. Natural spring that emerges from the ground and runs down a gully before disappearing into the ground again (Fig. 2). Upper area of spring is flowing slowly, and full of filamentous and floating algae (especially in summer), but lower reaches of the spring have higher flow. Sediment is fine substrate. Spring is surrounded by grass. We observed a wildlife trail beside the spring, and an amphibian in the spring. Width = 30-46 cm. Depth = 1.2-5 cm.

Figure 2. Fallen Log Spring.

Graham Spring: Zone 13 521873E 4937893N (NAD83), elevation 1255 m. A natural spring that emerges from the ground, flows ~15 m to a pool, and flows farther down the gully before disappearing into the ground (distance depends on the time of year; Fig. 3). Pool has fine substrates and is frequently visited by wildlife. The spring is in a steep gully and is surrounded by grass. Width = ~20-30 cm. Depth = 1.2-5 cm.

Figure 3. Graham Spring.

Visitor Center Seep: Zone 13 522169E 4937399N (NAD83), elevation 1281 m. A natural seep that contained water during all visits (Fig. 4). Seep extends up to 10 m from the source but the size depends on the time of year. Spring source is near granite rocks. Seep surrounded by grass. We observed many tracks from wildlife around the seep. Width = 0.3-0.9 m. Water depth = <5 cm. Mud depth = 15 cm.

Figure 4. Visitor Center Seep.

Tarpot Box: Zone 13 521618E 4936928N (NAD83), elevation 1218 m. A spring contained in a concrete box covered by a wooden lid (Fig. 5). A little water drains from the spring box through an eroded bank and empties into the nearby stream. Spring box was previously covered with planks, and organic matter and soil accumulated in the spring box. We could not tell if the spring box had a concrete bottom or not, because there was a thick layer of soil in the bottom of the box in which we collected samples. Mice were nesting under the lid and drowning in water. Another small, natural spring located southeast of spring box. Spring box size = 2 x 2 m. Water depth = 0.8 m. Depth of the box is unknown because we could not find the bottom due to sediment filling in the box.

Figure 5. Tarpot Box with lid removed.

Waterline Boxes and Stream: Zone 13 522359E 4937211N (NAD83), elevation 1295 m. Waterline Spring consists of 3 boxes and a small stream. Box 1, the uppermost box, is a small junction box where 2 pipes come together (Fig. 6a). Box 2 is a large box (1.5 m wide x 1.8 m depth x 1.5 m height), but only contained ~15-20 cm of water in the bottom (water volume = 0.42-0.56 m^3; Fig. 6b). Box 3, the lowest box, is large (3.3 m wide x ~4.3 m depth x 1.4 m height) and was full of water (water depth = 1.2 m, water volume = 18.2 m^3; Fig. 6c). We could hear water running underground, probably in pipes, including below the 3rd box under cobble. Stream substrate was gravel (Fig. 6d). Stream width = 38-76 cm. Stream depth ~ 1.3 cm.

Figure 6. Waterline Spring consisted of 3 boxes and a stream: a.) Box 1, the upper most box, was a junction box where 2 pipes came together, b.) Box 2 contained little water, c.) Box 3, the lower box, was a large box full of water, and d.) a spring stream originated under a rock near Box 1.

METHODS

At each of the 5 sites we collected aquatic invertebrates, measured water quality, and estimated flow rate 4 times over a 2 year period. We measured water quality using a Yellow Springs Instrument Professional Plus calibrated prior to sampling. The Professional Plus measured dissolved oxygen, water temperature, specific conductivity, pH, and oxidation-reduction potential (ORP). We calculated standard error (SE) for all parameters. We estimated flow rate at the springs by collecting water in a plastic bag formed to the stream bottom for a timed interval and repeated the procedure at least 3 times at each visit. We calculated flow by dividing the volume of water (L) by time (sec). Finally, we gathered aquatic invertebrates near the source of each spring by collecting 3 samples during each visit using a hand core (16.6 cm^2 sampling area, Wildlife Supply Company; Fig. 5). We used a hand core because the device collected a small sample to minimize disturbance to these small springs. In boxed springs with concrete bottoms, we collected 2 aquatic invertebrate samples during each visit using a dip net (250 µm mesh) swept through the water for 30 seconds each (~0.3 m^3 water sampled). To calculate approximate density from sweep net samples (ind/m^2), we multiplied abundance per sweep net sample (ind/m^3) by water depth (m). We sieved all samples using 250 µm mesh, preserved them while in the field, and identified invertebrates under a dissecting microscope in the laboratory. We identified invertebrates using the following keys: aquatic insects (Merritt et al. 2008), adult aquatic predacious diving beetles (Merritt et al. 2008, Swanson 2012), and non-insect invertebrates (Thorp and Covich 2010). We calculated mean richness as the average number of taxa found in a sample and total richness as the total number of taxa found at a site.

RESULTS

Three sites at Devils Tower National Monument had flowing water (Table 1). Waterline Stream had the highest flow rate at 0.2 L/s and Graham Spring had the lowest at 0.05 L/s. Water temperatures ranged between 7 and 18°C among sites, but were consistently lower at boxed springs where they averaged 8.7°C. The natural springs and seep were warmer and averaged 11°C (Table 1). However, dissolved oxygen, specific conductivity, pH, and ORP were not different between boxed and natural springs. Dissolved oxygen was highest and varied the least at Waterline Stream and Waterline Box 3 (SE = 3.0 for % saturation; Fig. 7b, c). Dissolved oxygen was lowest at Visitor Center Seep. Specific conductivity was similar among springs (mean = 651 µS/cm) except Tarpot Box which was much higher (3100 µS/cm; Fig. 7d). The pH of all springs was basic ranging from 7.3 to 8.6 (Fig. 7e). Waterline Box 2 had the highest pH of all water sampled (Table 1). All springs appeared to be reducing environments (<200 mV; reactions where electrons are gained; Fig. 7f).

Table 1. Average water temperature, dissolved oxygen, specific conductivity (Sp conductivity), pH, oxidation-reduction potential (ORP), and flow at the springs of Devils Tower National Monument.

	Temperature	Dissolved Oxygen		Sp conductivity	pH	ORP	Flow
Site	°C	% saturation	mg/L	µS/cm		mV	L/sec
Fallen Log Spring	11.7	71	6.6	1146	7.8	74	0.092
Graham Spring	10.9	74	7.0	1063	7.9	128	0.010
Tarpot Box	8.2	78	7.9	3099	7.3	108	-
Visitors Center Seep	12.8	60	5.5	475	7.3	112	-
Waterline Box 1	8.7	97	9.7	261	7.5	237	0.077
Waterline Box 2	9.8	84	8.2	686	8.6	141	-
Waterline Box 3	8.2	96	9.7	286	7.6	155	-
Waterline Stream	8.8	99	9.9	253	7.8	144	0.042

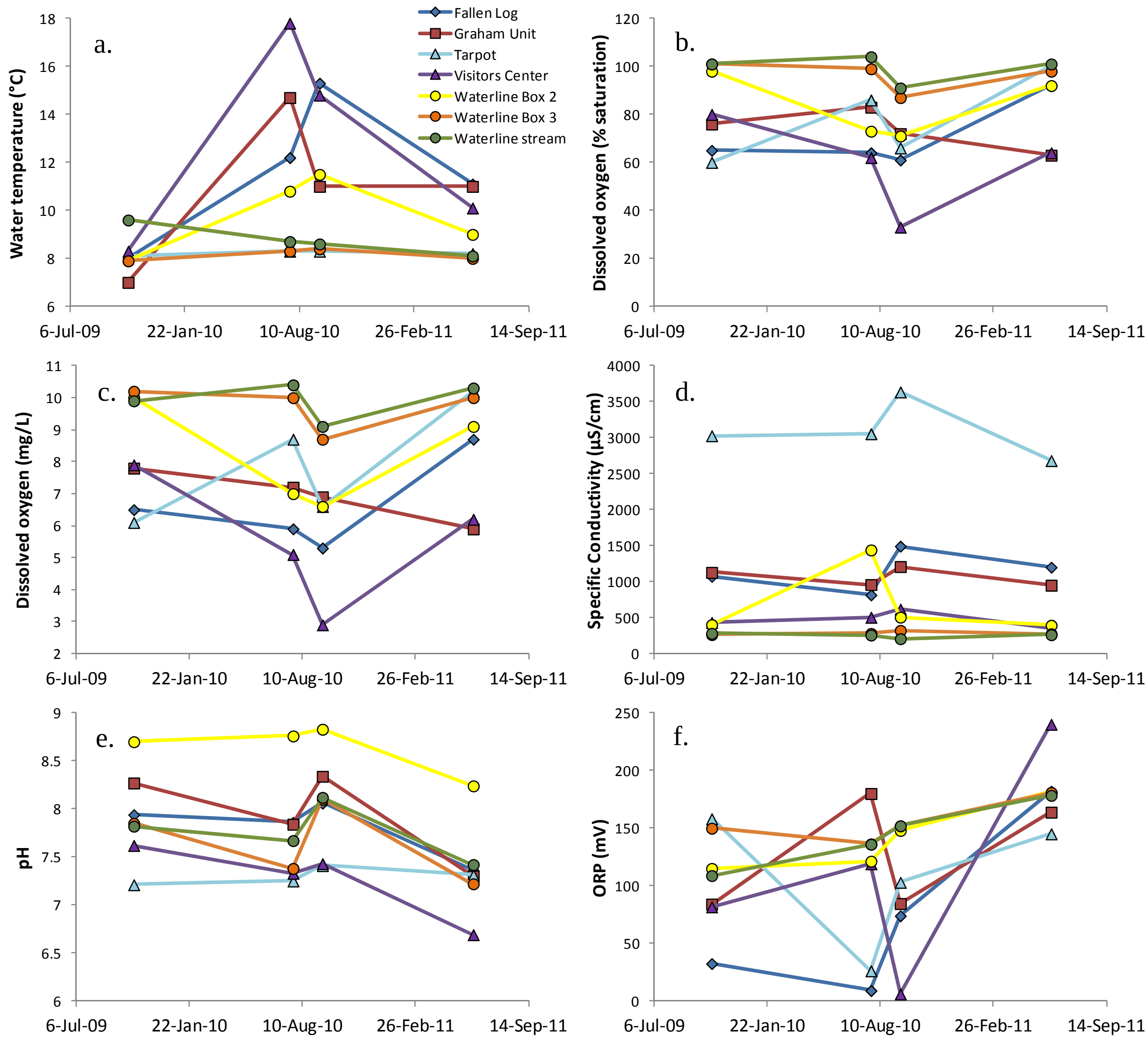

Figure 7. Basic water quality of springs at Devils Tower National Monument. We measured a.) water temperature, b.) dissolved oxygen (% saturation), c.) dissolved oxygen (mg/L), d.) specific conductivity (µS/cm), e.) pH, and f.) oxidation-reduction potential (ORP; mV).

We collected 49 invertebrate taxa in the springs at Devils Tower National Monument. Of these invertebrates, 37 taxa were insects (75%) in 24 families and 9 orders. Trueflies (Diptera) were by far the most abundant insects in springs. We collected 12 non-insect taxa including worms (Oligochaeta), flatworms (Turbellaria), water mites (Acari), crustaceans (Copepoda, Ostracoda, Amphipoda, and Isopoda), roundworms (Nematoda), and snails (Gastropoda). By abundance, insects (46%) and non-insects (54%) had similar densities. Diptera, Hemiptera, and Crustacea were collected in all springs and seeps.

In general, fewer aquatic invertebrates lived in boxed springs compared to natural springs (ANOVA: P = 0.0149, F = 6.2, df = 1; Table 2). Natural springs contained 1 order of magnitude more invertebrates (mean = 4900 ind/m^2) than boxed springs (480 ind/m^2). Mean taxa richness was also lower in boxed springs (2 taxa) compared to natural springs (5 taxa; P = 0.0004, F = 13.9, df = 1). Graham Spring, Waterline Stream, and Fallen Log Spring had the highest mean richness, and Tarpot Box had the lowest mean richness. Similarly, we collected the most taxa (total richness) from Graham Spring, Fallen Log Spring, and Waterline Stream, and the fewest taxa from Tarpot Box. Flatworms (Turbellaria) and centipedes (Symphyla) were the most common invertebrates in boxes at Waterline Spring. Curiously, we collected low densities of stoneflies, beetles, trueflies, and springtails in the boxes.

Table 2. Mean invertebrate density (ind/m^2) and standard errors (SE) from springs at Devils Tower National Monument. We collected benthic cores at springs with bottom substrate and sweep net samples in spring boxes with concrete bottoms. Natural springs and seeps are highlighted in red and boxed springs are highlighted in blue.

	Fallen Log Spring		Graham Spring		Tarpot Box		Visitor Center Seep		Waterline Box 2		Waterline Box 3		Waterline Stream	
Taxa	ind/m^2	SE	ind/m^2	SE	ind/m^2	SE	ind/m^2	SE	ind/m^2	SE	ind/m^2	SE	ind/m^2	SE
Diptera	7932	3336	3696	1288	8	5	593	205	445	172	2	1	285	76
Ephemeroptera	0	0	58	32	0	0	0	0	0	0	0	0	19	11
Odonata	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	35	21	27	20	8	5	15	12	14	10	4	2	0	0
Hemiptera	23	17	27	18	8	5	4	4	3	3	1	1	8	8
Plecoptera	0	0	0	0	0	0	0	0	0	0	2	1	96	46
Trichoptera	15	12	27	16	4	4	0	0	0	0	0	0	65	38
Collembola	216	126	31	23	23	11	0	0	0	0	7	3	50	27
Crustacea	2907	1429	1063	608	4	4	1097	719	947	612	2	2	751	460
Nematoda	0	0	4	4	0	0	131	89	115	76	0	0	19	11
Gastropoda	0	0	0	0	12	12	0	0	0	0	0	0	0	0
Turbellaria	0	0	0	0	0	0	0	0	3	3	11	3	0	0
Oligochaeta	8	5	85	65	0	0	35	20	7	7	0	0	92	36
Acari	19	13	23	12	4	4	0	0	0	0	1	1	15	12
Total	**11216**	**4269**	**5048**	**1739**	**69**	**28**	**1883**	**933**	**1540**	**785**	**44**	**8**	**1575**	**549**
Total Non-insects	**2957**	**1443**	**1174**	**607**	**19**	**12**	**1263**	**803**	**1071**	**685**	**29**	**6**	**1040**	**473**
Total Insects	**8259**	**3377**	**3874**	**1351**	**50**	**18**	**620**	**211**	**142**	**53**	**15**	**4**	**535**	**134**
Mean Richness	**5**	**1.0**	**6**	**1.5**	**1**	**0.3**	**4**	**0.6**	**3**	**0.8**	**4**	**0.5**	**6**	**0.7**
Total Richness	**23**	**-**	**25**	**-**	**8**	**-**	**15**	**-**	**14**	**-**	**14**	**-**	**23**	**-**

Invertebrate density varied with season and by site. Invertebrates tended to have higher densities in the summer than in the fall (Fig. 8a). For example, Fallen Log Spring had the highest density of invertebrates during July 2010 (33,500 ind/m^2), and much lower densities during fall months (1300 ind/m^2). Overall, Fallen Log Spring had the highest density of invertebrates followed by Graham Spring, Visitor Center Seep, Waterline Stream, and Waterline Box 2, Tarpot Box, and Waterline Box 3 in decreasing order. Diptera were the most abundant invertebrates in Fallen Log Spring and Graham Spring (Fig 8b), but crustaceans were the most common invertebrates in Visitor Center Seep and Waterline Stream (Fig. 8c). Collembola (Tarpot Box) and Turbellaria (Waterline Boxes) were the most common invertebrates in boxed springs.

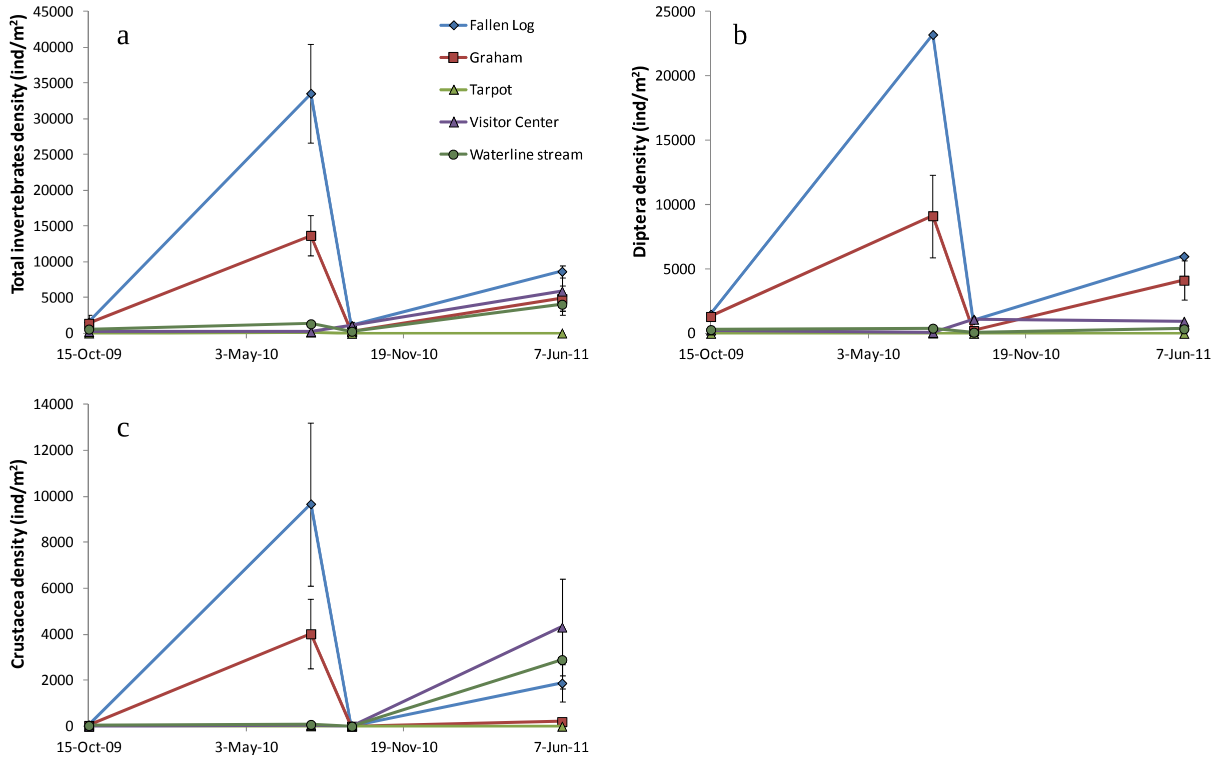

Figure 8. Density (ind/m^2) of a.) all invertebrates, b.) Diptera (trueflies), and c.) Crustaceans over the sampling period. Bars are standard errors.

DISCUSSION

Springs and seeps are vital habitats for wildlife and vegetation, especially in semi-arid environments such as Wyoming. Natural springs can be heavily used by wildlife, as we observed at Devils Tower National Monument. We noted wildlife tracks, trails, footprints, and deer bedding adjacent to springs and seeps on most visits. We also collected numerous and diverse land snails near springs at the Monument (Tronstad 2011). Griscom and Keinath (2011) captured and recorded more bats drinking from Graham Spring than at any other of the 31 sites they surveyed in Devils Tower National Monument. Most of the bats they captured were forest-obligate species which rarely forage outside the tree canopy but drink water at least once a day. They concluded that springs and seeps probably provide important habitat for bats at Devils Tower National Monument. Deer were also observed drinking from the springs and seeps on several occasions, as well as other mammals and birds. One amphibian was observed at Fallen Log Spring during our study indicating that these springs provide habitat for amphibians outside the Belle Fourche River.

1. To what extent has the water quality of the boxed springs been impacted?

The basic water quality of boxed springs at Devils Tower National Monument appears to be impacted little by development. One exception is water temperature which was lower in boxed springs compared to natural springs. Cooler water temperatures are not surprising given that boxed springs hold large amounts of water collected as groundwater emerges. Water has a high specific heat meaning that a large amount of energy is required to increase temperature. Therefore, springs or boxes with larger volumes of water would require more energy to change the temperature. For example, Waterline Box 3 held the largest volume of water, and had the least variation in water temperature. Specific conductivity, or the concentration of salts dissolved in the water, was significantly higher at Tarpot Box than at the other springs and seep. We feel that the higher specific conductivity at Tarpot Box is because of the geology and groundwater source rather than an effect of being boxed (Cantonati et al. 2006).

Groundwater often contains low dissolved oxygen and high carbon dioxide concentrations, because decomposition and respiration dominate processes underground (Cantonati et al. 2006); however, water quickly became oxygenated above ground. Therefore, we did not observe a difference between dissolved oxygen in boxed and natural springs. We did observe that Visitor Center Seep had the lowest dissolved oxygen, probably because the seep contained little standing water and no flow.

Curiously, the pH at Waterline Box 2 was nearly 10 fold higher than at Waterline Boxes 1 and 3, and Waterline Stream. A higher pH in Waterline Box 2 may be the result of the concrete boxes, degassing of carbon dioxide (CO_2) from groundwater, or geology around the water source. First, concrete can increase the pH of water by releasing OH^- ions; however, these concrete boxes were made nearly 100 years ago and we assume that the concrete has sealed itself. Furthermore, the pH of water in Waterline Box 3 was much lower. Second, we would expect the pH of water to increase as it flows away from the spring source, because, carbon dioxide degassing from groundwater increases pH. Therefore, degassing of CO_2 does not explain the trend we observed, because Waterline Box 3 and Waterline Stream had a much lower pH. Finally, the water filling Box 2 at Waterline Spring may come from a different source than the other boxes and stream. Unfortunately, we do not know how these boxes are connected, what kind of infrastructure lies underground, or how many springs water is collected from at this site. Understanding the connections between the boxes and springs would help explain differences in water quality.

2. To what extent have the macroinvertebrate assemblages and hydrology of these springs been affected?

Without prior data, we cannot say how the hydrology of the springs changed after being boxed; however, we estimate that the flow has either remained constant or increased after digging down to the spring source. Conversely, the flow at Hidden Box has ceased over time. The largest effect of encasing springs is probably water availability to flora and fauna. Spring water was available to vegetation and wildlife before being boxed, but much less water is currently available. The boxes at Waterline Spring are completely enclosed with tight lids, making the water unavailable; however, a small stream is available for wildlife and vegetation. Currently some stream flow, presumably originating from the springs, emerges to the surface below Waterline Box 1; however, more water would undoubtedly be available if the boxes and associated infrastructure were removed (see below for details). Tarpot Box is also covered with a solid lid making the water unavailable. Restoration of the boxed springs would allow terrestrial plants and animals to have access to a reliable and larger quantity of water. More water at springs may attract more wildlife and the vegetation community may change to water or spring adapted plants.

Boxed springs had fewer invertebrates and lower taxa richness compared to natural springs. Several features of spring boxes limit the aquatic invertebrates that can live there. Because most aquatic insects colonize by winged adults laying eggs in the water, the closed boxes prohibited aquatic invertebrates from colonizing these waters. We did find a few invertebrates in spring boxes, especially in the boxes at Waterline Spring. These invertebrates, such as stoneflies, probably entered the boxes by flowing in through pipes, but they likely could not sustain a population inside the box due to life history and food constraints. We did collect numerous flatworms living only in the boxes at Waterline Spring. Flatworms are typically predacious, feeding on microscopic animals (e.g., rotifers) and algae, and some are hyporheic (living under the streambed). The flatworms we collected in boxes at Waterline Spring may be hyporheic, which would explain why we did not collect them in Waterline Stream.

Tarpot Box was only partially covered by boards for years, thus invertebrates were likely able to colonize the spring box. However, a solid cover was recently placed over the box when the boards rotted (~2008). We suspect that more invertebrates lived in Tarpot Box when the lid was partially open. Covering Tarpot Box with a solid lid probably reduced the density and diversity of aquatic invertebrates we sampled there. However, we collected low densities of snails (Gastropoda), beetles (Coleoptera), springtails (Collembola), and caddisflies (Trichoptera) in Tarpot Box (Table 2). Soil from the adjacent hillside accumulated in the spring box over time adding substrate, protection, and food for invertebrates. We could never feel the bottom of the box at Tarpot, but we assumed the bottom is concrete based on the other spring boxes at the Monument. In addition, high specific conductivity may have also limited the number of invertebrates living there. High dissolved solids, such as salts, can limit the number and diversity of invertebrates inhabiting springs (Meffe and Marsh 1983).

Some springs and seeps are home to endemic or rare invertebrates (e.g., Haase 1996; Murphy et al. 2009). The springs at Devils Tower National Monument may be home to such invertebrates as well. While identifying invertebrates from the springs, we identified several taxa that are not commonly collected in aquatic habitats, such as *Atrichopogon* (Diptera, Ceratopogonidae) and *Dixa* (Diptera, Dixidae). Thus, the springs at Devils Tower National Monument are home to a different invertebrate assemblage than the Belle Fourche River (L. Tronstad, personal observation). We collected an interesting invertebrate that appears to be in the class Symphyla (garden centipedes; Fig. 9). We collected numerous Symphyla from Fallen Log Spring and Waterline Spring (Box 2, Box 3, and stream) on several dates. Symphyla are terrestrial invertebrates that inhabit the soil, thus we were surprised to find them in the springs, including in the spring boxes. We plan to send specimens to a Symphyla taxonomist for further identification. We suspect that restoration of the spring boxes at Waterline will not harm these invertebrates if Waterline Stream is minimally impacted.

Figure 9. Photo of an invertebrate (Class Symphala) found in Fallen Log and Waterline Springs.

3. What techniques exist for the removal of the concrete structures and the restoration of unimpeded flow to the springs?

Tarpot and Waterline Springs were encased in concrete boxes early in the 20th century and are the focus of our restoration discussion. Barring the existence of historic photos, we do not know what the springs looked like before they were encased; however, they probably welled up into small, boggy areas and flowed slowly downstream. The installed concrete boxes have probably not drastically changed the amount of water coming to the surface at these springs. In fact, by digging down to the source, the amount of water welling up from the springs has possibly increased. However, covering these boxes has lessened the amount of surface water available to wildlife and vegetation, reduced the invertebrate taxa living in the springs, and probably decreased the temperature of the water downstream. Given the observed use of springs and seeps by wildlife, we anticipate that the restoration of the springs to an uncovered state would provide a valuable freshwater source for a variety of species living within and around the spring.

After extensive searches in the peer-review and grey literature, we found little to no information regarding methods for restoring encased springs to their natural hydrologic and ecological function. Therefore, the restoration suggestions we make here are based exclusively on what we have observed at the springs and informed opinion based on our backgrounds in Zoology, Ecology, and Watershed Hydrology. We can only provide general guidelines here, and leave the actual details of project implementation to restoration engineers. Permits may be needed to restore the springs and we recommend that Devils Tower National Monument check with the Wyoming Department of Environmental Quality prior to restoration.

Tarpot Box: Tarpot Box emerges 150 m west of the main road in Tarpot drainage (Fig. 1). The source has been encased by a sunken concrete box and covered with wooden planks (recently replaced with a solid lid). We do not know if the spring was piped previously, but we did not observe any water transportation infrastructure associated with the spring. The apparent lack of piping suggests that the capped spring serves no current human purpose and could easily and inexpensively be restored. We consider Tarpot Box a lower priority than Waterline Boxes, because Tarpot Box is already hydrologically connected to the stream channel (a small stream emerges 20 m downstream of the spring). Also, replacing the covered concrete box with an exposed surface upwelling would provide some benefit to wildlife and vegetation. For example, Tronstad (2011) observed a colony of land snails living at a nearby seep.

There are some basic tenants of spring restoration that will minimize site disturbance and ensure ongoing flow of the spring. From an ecological restoration perspective, the spring box may not need to be removed. Simply removing the lid and filling the inside of the box with local streambed material may create spring habitat if the water comes to the surface. Filling the box would minimize disturbance to the biota and spring source. If the National Park Service chooses to dismantle and remove the box, we recommend removing as little soil as possible from around the box and spring source. The soil removed should be placed aside for later infill. Pains should be taken to avoid disturbance to the source of the spring (hillside) as any major shifts in substrate could harm the flow rate. If possible, small tools that can be carried to the site, such as sledgehammers or gas-powered jackhammers, should be used instead of backhoes or other large machinery. Once the concrete box is removed, placing coarse material, such as pieces of concrete and large rocks filled in with gravel and sand, around the water source will help preserve flow. The remaining hole may be filled in with local material from the stream bed if needed. Reseeding is probably not necessary along the stream bottom as plant recruitment will be swift. However, reseeding with a certified native grass mix is recommended if the hillsides adjacent to the spring become disturbed.

Waterline Boxes: The Waterline Boxes produce a substantial amount of water (Table 1) and were presumably developed by the National Park Service in the early 20th century to provide drinking water for staff working and living below the spring. Currently there are 3 concrete boxes possibly collecting water from different sub-springs and consolidating them into one main pipe. Each concrete box has a tight lid, but water can be heard traveling down slope in a pipe. Of the two springs, Waterline Boxes are a higher priority for restoration because the spring may yield a considerable amount of flow for wildlife and vegetation. The Waterline Boxes will probably also be more expensive and complicated to restore than Tarpot Box, because of the extent of infrastructure. We cannot estimate whether this spring, once restored, will remain above ground or infiltrate into the ground. Devils Tower National Monument could go to the extensive effort of restoring the spring only to discover that the water runs for a few meters and then plunges underground.

There are two main considerations that need to be addressed before restoration can begin on Waterline Boxes. First, a comprehensive waterworks assessment should be done. Does the current piped water serve a purpose? Where does the water currently go? Should the demolition of other associated infrastructure be considered in concert with spring restoration? Second, an important question to answer is 'where will the water go once the site is restored?' We are not sure than a proper stream channel exists to carry the water from its origins to the Belle Fourche River. One approach could be to disconnect the pipes from the boxes and simply see what the water does. When the pipe coming from Waterline Boxes was laid down, a considerable amount of rock was placed on top of the pipe for protection. We recommend in any of the following scenarios that the rock be kept in place. The rock will help reduce erosion, stabilize the channel, and the rocks will eventually fill in with soil if and when the stream runs again.

We see four **implementation options** for restoration of the spring's natural, unimpeded flow, and ecological function. The options are listed in order of relative cost below (Table 3):

***Disconnect pipes*:** Disconnect pipes from concrete boxes and possibly sources. Leave all boxes and pipes in place. Allow water to flow down slope from output of lower box (box 3) and possibly box 2 depending on connections. Make downstream channel accommodations for stream flow if needed.
***Disconnect pipes and fill in boxes*:** Disconnect pipes from concrete boxes and sources. Leave all boxes and pipes in place. Remove box lids and concrete tops, and fill in and around with sand and local material. The boxes may also be cracked so that they cannot hold water. Allow water to flow down slope from wherever it emerges. Make downstream channel accommodations for stream flow if needed.
***Remove upper infrastructure*:** Disconnect and remove pipes from concrete boxes and spring sources. Dismantle and remove boxes with gas-powered jackhammers. Fill in and re-contour water sources. Re-seed exposed ground. Leave main transport pipe in place. Allow water to flow down slope from wherever it emerges. Make downstream channel accommodations for stream flow if needed.
***Remove all infrastructure*:** Dismantle and remove boxes, upper pipes, and main transport pipe. Fill in and re-contour all exposed ground. Re-seed exposed ground. Allow water to flow down slope from wherever it emerges. Make downstream channel accommodations for stream flow if needed.

Table 3. Comparing the cost, ecological effectiveness, aesthetic appearance, and site disturbance between the different spring restoration options at Waterline Boxes at Devils Tower National Monument.

Restoration Option	Cost relative to other options	Ecological Effectiveness	Resulting Aesthetic Appearance	Site Disturbance Level
Disconnect pipes	Cheapest	Moderate	Unattractive	Low
Disconnect pipes & fill in boxes	Cheap	High	More natural-looking	Low
Remove upper infrastructure	Moderate	High	Attractive	Low
Remove all infrastructure	Expensive	High	Attractive/ Pristine	High

Because the boxes themselves have probably not altered the hydrology of the spring, destruction and removal of the concrete boxes may not be entirely necessary to return the spring to a fairly natural condition. Simply disconnecting the pipes from the boxes and sources, and allowing the water to flow downstream would be relatively easy and effective. The second option of filling in and around the concrete boxes might be an effective way to hide the boxes from view while avoiding the cost and spring head disturbance associated with their removal. The boxes may be cracked so that they can no longer hold water. The third option of removing all the concrete boxes and pipes connecting them would greatly improve the aesthetic appearance of the site but would involve greater cost. All the suggestions to avoid site disturbance at Tarpot Box above would apply for Waterline Boxes as well.

The final option of removing all the boxes and pipes including the main transportation pipe would be the most expensive and involved. Removing the main transport pipe would probably require heavy equipment which would cause much more site disturbance. There would be little hydrologic or ecological advantages beyond removing the upper infrastructure, but the site would look pristine again after a couple of years of recovery. As discussed above, if Devils Tower National Monument decides to remove the concrete boxes and associated pipes, we recommend the use of small tools (e.g., gas-powered jackhammers), and close attention to detail (e.g., replacing displaced rocks and plants to their original locations). Also, some soil stabilization, reseeding, and weed control may be needed after such a disturbance.

Hidden Box: Hidden Box is not currently collecting water, thus the box could easily be removed without harming the spring source. The box is located near the main road, so tools and fill could easily be transported to the site. We recommend removing the box using gas-powered jackhammers and filling the hole with pieces of the cement and local fill. Additionally, a pipe can be followed along the gulch that carried water to the box. Much of the time the pipe is above ground, so the pipe could probably be removed fairly easily.

4. What parameters need to be monitored long-term to determine the success of the spring restoration?

Several parameters can be measured to estimate the success of restoration. Flow should be monitored to estimate changes in spring discharge. A successfully restored spring would result in similar or higher spring flow compared to boxed measurements. For example, we expect flow to be higher at the Waterline Stream after restoration of the Waterline Boxes because spring water should no longer be collected in the boxes. Flow should be monitored at least seasonally for several years following restoration. Monitoring vegetation around the spring, especially the first few years after restoration, would be vital to ensure that native plants recolonize after the disturbance. Water quality is easily measured with a handheld probe that provides a snapshot of basic parameters in the water such as dissolved oxygen, conductivity, and pH. Invertebrates may also be monitored to ensure these animals recolonize the springs after restoration. Core samples or other small samples should be collected to minimize the number of individuals collected. Invertebrates may be collected annually during mid-summer (highest numbers and diversity) for a few years after restoration. Insects will probably colonize these habitats quickly; however, non-insect invertebrates will probably colonize more slowly because they rely on passive dispersal.

LITERATURE CITED

Cantonati, M., R. Gerecke, and E. Bertuzzi. 2006. Springs of the Alps: sensitive ecosystems to environmental change: from biodiversity assessments to long-term studies. Hydrobiologia 562:59-96.

Erman, N. A., and D. C. Erman. 1995. Spring permanence, Trichoptera species richness, and the role of drought. Journal of the Kansas Entomological Society 68:50-64.

Glazier, D. S. 1991. The fauna of North American temperate cold springs: patterns and hypotheses. Freshwater Biology 26:527-542.

Griscom, H.R. and D.A. Keinath. 2011. Inventory and status of bats at Devils Tower National Monument. Report prepared for the USDI National Park Service by the Wyoming Natural Diversity Database, University of Wyoming, Laramie, Wyoming.

Haase, M. 1996. The radiation of spring snails of the genus *Belgrandiella* in Austria (Mollusca: Caenogastropoda: Hydrobiidae). Hydrobiologia 319:119-129.

Ilmonen, J., L. Paasivirta, R. Virtanen, and T. Muotka. 2009. Regional and local drivers of macroinvertebrate assemblages in boreal springs. Journal of Biogeography 36:822-834.

Meffe, G. K., and P. C. Marsh. 1983. Distribution of aquatic macroinvertebrates in 3 Sonoran Desert springbrooks. Journal of Arid Environments 6:363-371.

Merritt, R. W., K. W. Cummins, and M. B. Berg, editors. 2008. An Introduction to the Aquatic Insects of North America, 4th edition. Kendall Hunt Publishing, Dubuque, IA.

Murphy, N. P., M. Adams, and A. D. Austin. 2009. Independent colonization and extensive cryptic speciation of freshwater amphipods in the isolated groundwater springs of Australia's Great Artesian Basin. Molecular Ecology 18:109-122.

Swanson, K.M. 2012. Predaceous Diving Beetles (Coleoptera: Dytiscidae) of Wyoming. Thesis. Department of Ecosystem Science and Management, University of Wyoming.Thorp, J. H., and A. P. Covich, editors. 2010. Ecology and Classification of North American Freshwater Invertebrates, 3rd edition. Elsevier, New York.

Tronstad, L.M. 2011. Survey of land snails at Devils Tower National Monument. Report prepared by the Wyoming Natural Diversity Database, University of Wyoming, Laramie, Wyoming for Devils Tower National Monument, National Park Service, Wyoming.

Appendix 1. Invertebrate density (ind/m2) for Fallen Log and Graham Springs at Devils Tower National Monument.

			Fallen Log				Graham			
Order	Family	Genus	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11
Diptera	Chironomidae	Non-Tanypodinae	1309	23087	970	5714	1278	8948	185	3342
Diptera	Chironomidae	Tanypodinae	0	15	0	0	0	92	0	46
Diptera	Chironomidae	pupae	0	15	31	15	0	62	0	77
Diptera	Ceratopogonidae	Culicoides	46	0	0	123	31	31	0	447
Diptera	Ceratopogonidae	Probezzia	0	0	0	0	0	0	15	77
Diptera	Ceratopogonidae	Monohelea	0	0	0	0	0	0	0	62
Diptera	Ceratopogonidae	Atrichopogon	0	0	0	0	0	0	0	0
Diptera	Dixidae	Dixa	0	0	0	0	0	0	0	0
Diptera	Tabanidae	pupae	108	0	15	15	0	0	0	0
Diptera	Tipulidae	Ormosia	0	0	0	0	0	0	0	0
Diptera	Tipulidae	Dicranota	0	0	0	0	0	0	0	0
Diptera	Empididae	Neoplasta	0	0	0	0	0	0	0	0
Diptera	Empididae	Unknown	15	15	0	0	0	0	0	0
Diptera	Empididae	pupae	0	0	0	15	0	0	0	0
Diptera	Stratiomyidae	Caloparyphus	0	15	0	46	0	0	0	15
Diptera	Stratiomyidae	Euparyphus	0	0	0	31	0	0	0	31
Diptera	Ptychopteridae	Ptychoptera	0	15	31	0	0	0	15	31
Diptera	Psychodidae	Psychoda	0	0	0	0	0	0	0	0
Diptera	Muscidae		0	46	0	0	0	0	0	0
Diptera	Unknown		0	0	0	30	0	0	0	0
Ephemeroptera	Baetidae	Fallceon	0	0	0	0	15	200	0	15
Odonata		Early instar	15	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Neoporus (larvae)	0	62	0	0	0	0	0	0
Coleoptera	Dytiscidae	Agabus (larvae)	0	46	0	0	0	0	0	0
Coleoptera	Dytiscidae	Oreodytes (larvae)	0	0	0	0	0	15	0	0
Coleoptera	Dytiscidae	Ilybius (larvae)	0	0	0	0	0	0	0	15
Coleoptera	Dytiscidae	Hydroporus appalachius (adult)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Hydroporus (adult)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Neoclypeodytes (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae	Laccobius (adult)	0	0	0	0	0	0	0	15
Coleoptera	Hydrophilidae	Hydrobius (adult)	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae	Hydrochus	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae		0	15	0	0	0	15	0	0
Coleoptera	Haliplidae	Peltodytes	0	15	0	0	0	0	0	0
Coleoptera	Ptiliidae	(adult)	0	0	0	0	0	0	0	46
Coleoptera	Chrysomelidae	(adult)	0	0	0	0	0	0	0	0
Coleoptera		early instar	0	0	0	0	0	0	0	0
Hemiptera	Gerridae	Trepobates	0	0	0	0	0	46	0	62
Hemiptera		Early instar	0	62	0	31	0	0	0	0
Plecoptera	Nemouridae	Malenka	0	0	0	0	0	0	0	0
Plecoptera	Nemouridae	Zapada (Adult)	0	0	0	0	0	0	0	0
Trichoptera	Hydroptilidae	Early instar	0	62	0	0	0	0	0	0
Trichoptera	Limnephilidae	Hesperophylax	0	0	0	0	0	77	15	15
Collembola			0	123	0	739	0	92	0	31
Thysanoptera			0	139	0	0	0	15	0	15
Oligochaeta			15	15	0	0	46	0	0	293
Turbellaria			0	0	0	0	0	0	0	0
Acari			0	77	0	0	0	77	0	15
Symphyla			0	62	0	31	0	0	0	0
Crustacea	Copepoda	Cyclopoid	0	0	0	15	0	1463	0	46
Crustacea	Copepoda	Harpacticoid	0	0	0	0	0	0	0	15
Crustacea	Copepoda	Calanoid	0	0	0	0	0	0	0	31
Crustacea	Amphipoda	Hyallela	0	0	0	0	0	0	0	0
Crustacea	Ostracoda		62	9672	15	1864	31	2557	0	108
Crustacea	Isopoda		0	0	0	0	0	0	0	0
Nematoda			0	0	0	0	0	0	0	15
Gastropoda	Physidae		0	0	0	0	0	0	0	0

Appendix 2. Invertebrate density (ind/m2) for Tarpot Box and Visitor Center Seep at Devils Tower National Monument.

			Tarpot				Visitor Center			
Order	Family	Genus	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11
Diptera	Chironomidae	Non-Tanypodinae	0	15	0	0	0	62	708	785
Diptera	Chironomidae	Tanypodinae	0	0	0	0	0	0	0	0
Diptera	Chironomidae	pupae	0	0	0	0	0	0	15	0
Diptera	Ceratopogonidae	Culicoides	0	0	0	0	200	15	0	0
Diptera	Ceratopogonidae	Probezzia	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	Monohelea	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	Atrichopogon	0	0	0	0	15	0	0	0
Diptera	Dixidae	Dixa	0	0	0	0	0	0	0	0
Diptera	Tabanidae	pupae	0	0	0	0	0	0	0	0
Diptera	Tipulidae	Ormosia	0	0	0	0	31	0	31	0
Diptera	Tipulidae	Dicranota	0	0	0	0	0	0	0	0
Diptera	Empididae	Neoplasta	0	0	0	0	15	0	0	0
Diptera	Empididae	Unknown	0	0	0	0	0	0	0	0
Diptera	Empididae	pupae	0	0	0	0	0	0	0	0
Diptera	Stratiomyidae	Caloparyphus	0	0	0	0	0	0	0	0
Diptera	Stratiomyidae	Euparyphus	0	0	0	0	0	0	0	0
Diptera	Ptychopteridae	Ptychoptera	0	0	0	0	0	0	323	154
Diptera	Psychodidae	Psychoda	0	0	0	0	0	0	15	0
Diptera	Muscidae		0	0	0	0	0	0	0	0
Diptera	Unknown		0	15	0	0	0	0	0	0
Ephemeroptera	Baetidae	Fallceon	0	0	0	0	0	0	0	0
Odonata		Early instar	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Neoporus (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Agabus (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Oreodytes (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Ilybius (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Hydroporus appalachius (adult)	0	0	0	0	0	0	0	46
Coleoptera	Dytiscidae	Hydroporus (adult)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Neoclypeodytes (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae	Laccobius (adult)	0	15	0	0	0	0	0	0
Coleoptera	Hydrophilidae	Hydrobius (adult)	0	0	0	0	0	0	0	15
Coleoptera	Hydrophilidae	Hydrochus	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae		0	0	0	0	0	0	0	0
Coleoptera	Haliplidae	Peltodytes	0	0	0	0	0	0	0	0
Coleoptera	Ptiliidae	(adult)	0	0	0	0	0	0	0	0
Coleoptera	Chrysomelidae	(adult)	0	0	0	0	0	0	0	0
Coleoptera		early instar	0	15	0	0	0	0	0	0
Hemiptera	Gerridae	Trepobates	0	0	0	0	0	0	0	0
Hemiptera		Early instar	15	15	0	0	0	0	0	15
Plecoptera	Nemouridae	Malenka	0	0	0	0	0	0	0	0
Plecoptera	Nemouridae	Zapada (Adult)	0	0	0	0	0	0	0	0
Trichoptera	Hydroptilidae	Early instar	0	0	0	0	0	0	0	0
Trichoptera	Limnephilidae	Hesperophylax	0	15	0	0	0	0	0	0
Collembola			31	31	0	31	0	0	0	0
Thysanoptera			0	0	0	0	0	0	0	31
Oligochaeta			0	0	0	0	0	108	0	31
Turbellaria			0	0	0	0	0	0	0	0
Acari			0	15	0	0	0	0	0	0
Symphyla			0	0	0	0	0	0	0	0
Crustacea	Copepoda	Cyclopoid	0	0	0	0	0	0	0	0
Crustacea	Copepoda	Harpacticoid	0	0	0	15	0	62	0	1617
Crustacea	Copepoda	Calanoid	0	0	0	0	0	0	0	0
Crustacea	Amphipoda	Hyallela	0	0	0	0	0	0	0	0
Crustacea	Ostracoda		0	0	0	0	0	0	15	2695
Crustacea	Isopoda		0	0	0	0	0	0	0	0
Nematoda			0	0	0	0	0	0	0	524
Gastropoda	Physidae		0	46	0	0	0	0	0	0

Appendix 3. Invertebrate density (ind/30 sec sweep) for Waterline Box 2 and Box 3 Springs at Devils Tower National Monument.

			Waterline Box 2				Waterline Box3			
Order	Family	Genus	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11
Diptera	Chironomidae	Non-Tanypodinae	1	1	0	0	0	1	0	0
Diptera	Chironomidae	Tanypodinae	0	0	0	0	0	0	0	1
Diptera	Chironomidae	pupae	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	Culicoides	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	Probezzia	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	Monohelea	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	Atrichopogon	0	0	0	0	0	0	0	0
Diptera	Dixidae	Dixa	0	0	0	0	0	1	0	0
Diptera	Tabanidae	pupae	0	0	0	0	0	0	0	0
Diptera	Tipulidae	Ormosia	0	0	0	0	0	0	0	0
Diptera	Tipulidae	Dicranota	0	0	0	0	0	0	0	1
Diptera	Empididae	Neoplasta	0	0	0	0	0	0	0	0
Diptera	Empididae	Unknown	0	0	0	0	0	0	0	0
Diptera	Empididae	pupae	0	0	0	0	0	0	0	0
Diptera	Stratiomyidae	Caloparyphus	0	0	0	0	0	0	0	0
Diptera	Stratiomyidae	Euparyphus	0	0	0	0	0	0	0	0
Diptera	Ptychopteridae	Ptychoptera	0	0	0	0	0	0	0	0
Diptera	Psychodidae	Psychoda	0	0	0	0	0	0	0	0
Diptera	Muscidae		0	0	0	0	0	0	0	0
Diptera	Unknown		0	0	0	0	0	0	0	0
Ephemeroptera	Baetidae	Fallceon	0	0	0	0	0	0	0	0
Odonata		Early instar	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Neoporus (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Agabus (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Oreodytes (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Ilybius (larvae)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Hydroporus appalachius (adult)	0	0	0	0	0	0	0	0
Coleoptera	Dytiscidae	Hydroporus (adult)	0	0	0	0	0	0	1	0
Coleoptera	Dytiscidae	Neoclypeodytes (larvae)	0	0	0	0	3	0	0	1
Coleoptera	Hydrophilidae	Laccobius (adult)	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae	Hydrobius (adult)	0	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae	Hydrochus	1	0	0	0	0	0	0	0
Coleoptera	Hydrophilidae		0	0	0	0	0	0	0	0
Coleoptera	Haliplidae	Peltodytes	0	0	0	0	0	0	0	0
Coleoptera	Ptiliidae	(adult)	0	0	0	0	0	0	0	0
Coleoptera	Chrysomelidae	(adult)	0	0	0	0	0	1	0	0
Coleoptera		early instar	0	0	0	0	0	0	0	0
Hemiptera	Gerridae	Trepobates	0	0	0	0	0	0	0	0
Hemiptera		Early instar	0	0	0	0	0	0	0	1
Plecoptera	Nemouridae	Malenka	0	0	0	0	1	1	0	0
Plecoptera	Nemouridae	Zapada (Adult)	0	0	0	0	0	0	0	0
Trichoptera	Hydroptilidae	Early instar	0	0	0	0	0	0	0	0
Trichoptera	Limnephilidae	Hesperophylax	0	0	0	0	0	0	0	0
Collembola			0	3	0	0	0	3	0	4
Thysanoptera			0	0	0	0	0	0	0	0
Oligochaeta			0	3	0	0	0	0	0	0
Turbellaria			22	2	93	221	3	2	5	2
Acari			0	0	0	0	1	0	0	0
Symphyla			0	12	1	0	0	6	4	7
Crustacea	Copepoda	Cyclopoid	0	0	0	0	0	0	0	0
Crustacea	Copepoda	Harpacticoid	0	0	0	0	0	0	0	0
Crustacea	Copepoda	Calanoid	0	0	1	0	0	0	0	0
Crustacea	Amphipoda	Hyallela	0	0	1	0	0	0	0	0
Crustacea	Ostracoda		0	0	0	0	0	2	0	0
Crustacea	Isopoda		0	0	0	0	0	0	0	0
Nematoda			0	0	0	0	0	0	0	0
Gastropoda	Physidae		0	0	0	0	0	0	0	0

Appendix 4. Invertebrate density (ind/m2) for Waterline Stream at Devils Tower National Monument.

			Waterline stream			
Order	Family	Genus	15-Oct-09	24-Jul-10	14-Sep-10	8-Jun-11
Diptera	Chironomidae	Non-Tanypodinae	200	308	15	246
Diptera	Chironomidae	Tanypodinae	0	0	0	0
Diptera	Chironomidae	pupae	0	15	0	0
Diptera	Ceratopogonidae	Culicoides	0	0	15	46
Diptera	Ceratopogonidae	Probezzia	0	31	15	0
Diptera	Ceratopogonidae	Monohelea	0	0	0	0
Diptera	Ceratopogonidae	Atrichopogon	15	0	0	0
Diptera	Dixidae	Dixa	15	0	0	0
Diptera	Tabanidae	pupae	0	0	0	0
Diptera	Tipulidae	Ormosia	0	0	0	0
Diptera	Tipulidae	Dicranota	31	31	46	15
Diptera	Empididae	Neoplasta	31	15	0	0
Diptera	Empididae	Unknown	0	0	0	0
Diptera	Empididae	pupae	0	0	0	0
Diptera	Stratiomyidae	Caloparyphus	0	0	0	0
Diptera	Stratiomyidae	Euparyphus	0	0	0	0
Diptera	Ptychopteridae	Ptychoptera	0	0	0	46
Diptera	Psychodidae	Psychoda	0	0	0	0
Diptera	Muscidae		0	0	0	0
Diptera	Unknown		0	0	0	0
Ephemeroptera	Baetidae	Fallceon	62	15	0	0
Odonata		Early instar	0	0	0	0
Coleoptera	Dytiscidae	Neoporus (larvae)	0	0	0	0
Coleoptera	Dytiscidae	Agabus (larvae)	0	0	0	0
Coleoptera	Dytiscidae	Oreodytes (larvae)	0	0	0	0
Coleoptera	Dytiscidae	Ilybius (larvae)	0	0	0	0
Coleoptera	Dytiscidae	Hydroporus appalachius (adult)	0	0	0	0
Coleoptera	Dytiscidae	Hydroporus (adult)	0	0	0	0
Coleoptera	Dytiscidae	Neoclypeodytes (larvae)	0	0	0	0
Coleoptera	Hydrophilidae	Laccobius (adult)	0	0	0	0
Coleoptera	Hydrophilidae	Hydrobius (adult)	0	0	0	0
Coleoptera	Hydrophilidae	Hydrochus	0	0	0	0
Coleoptera	Hydrophilidae		0	0	0	0
Coleoptera	Haliplidae	Peltodytes	0	0	0	0
Coleoptera	Ptiliidae	(adult)	0	0	0	0
Coleoptera	Chrysomelidae	(adult)	0	0	0	0
Coleoptera		early instar	0	0	0	0
Hemiptera	Gerridae	Trepobates	0	0	0	0
Hemiptera		Early instar	31	0	0	0
Plecoptera	Nemouridae	Malenka	92	77	15	185
Plecoptera	Nemouridae	Zapada (Adult)	0	0	0	15
Trichoptera	Hydroptilidae	Early instar	0	0	0	0
Trichoptera	Limnephilidae	Hesperophylax	46	169	31	15
Collembola			0	0	0	200
Thysanoptera			15	0	0	31
Oligochaeta			31	216	92	31
Turbellaria			0	0	0	0
Acari			0	62	0	0
Symphyla			0	323	62	262
Crustacea	Copepoda	Cyclopoid	0	0	0	15
Crustacea	Copepoda	Harpacticoid	0	0	0	77
Crustacea	Copepoda	Calanoid	0	0	0	0
Crustacea	Amphipoda	Hyallela	0	0	0	0
Crustacea	Ostracoda		31	62	0	2803
Crustacea	Isopoda		0	15	0	0
Nematoda			0	0	0	77
Gastropoda	Physidae		0	0	0	0