Final Report

Utah Division of Water Quality
4001 South 700 East, Ste. 700, Salt Lake City, UT 84036
phone: (801) 281-2426

Preliminary Analyses of Selenium Bioaccumulation in Benthic Food Webs of the Great Salt Lake, Utah

Dr. Wayne Wurtsbaugh
Department of Watershed Sciences
College of Natural Resources
Utah State University
Logan, Utah
wurts@cc.usu.edu

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Summary

Benthic organisms and substrates in the Great Salt Lake, Utah, were sampled during one week in June 2006 to test collection methodologies for biostromes and soft substrates and to get preliminary information on the selenium concentrations of benthic organisms. The sampling was focused on biostromes, as these solid reef-like structures cover 23% of the oxic benthic area of the lake and are the principal habitat for brine fly (*Ephydra cinerea*) larvae and pupae that are fed upon by some birds utilizing the lake. Samples were taken at depths of 1-5 m along two transects–one near Bridger Bay and another in the southern area of Gilbert Bay. The biostromes were sampled with a pumped-bucket device operated by a SCUBA diver whereas the soft sediments were sampled with a Ponar grab. Water samples and adult brine flies were also collected.

The pumped-bucket sampler effectively sampled brine flies on horizontal surfaces of the biostromes, but not on the sides of the mounded ones encountered in the southern part of Gilbert Bay. Brine fly larvae and pupae were far more abundant on the biostromes than on the soft substrates, with respective mean densities of 240/m^2, 530/m^2 and 9,140/m^2 on mud, sand and biostromes. In 2006 the mean selenium concentration in the combined organic matter-inorganic substrates in the biostromes was 1.7 ± 0.9 µg/g dry weight. Additional samples collected in 2007 yielded selenium concentrations of 0.3 ± 0.1. However, when the inorganic carbonates were removed, the remaining organic matter had selenium concentrations of 1.0 ± 0.1 µg/g dry weight. Mean Se concentrations in larvae, pupae and adult brine flies in 2006 were 1.3, 1.5 and 1.8 µg/g dry weight, respectively. A 2-way ANOVA indicated that selenium concentrations were significantly higher in Bridger Bay than in Gilbert South ($p < 0.000$), and in pupae than in larvae ($p = 0.046$), but the differences were not large. Although there was over a thousand-fold bioconcentration between Se dissolved in the water and in the periphyton of the

biostromes, the limited data suggested that there was no further bioconcentration between the periphyton and the brine flies.

Although biostromes cover only 18% of the area where phytoplankton can grow in Gilbert Bay, we estimated that the attached periphyton on them have approximately 68% of the chlorophyll contained in the lake's phytoplankton. Consequently, the biostromes represent a significant feature of primary production. The limited data from the June samplings suggests that the brine fly biomass in the lake is about 30% of that in *Artemia*. An analysis of the diets of birds collected for the selenium study, and that from the literature of saline lakes, suggests that brine fly produced on biostromes are an important diet component for American avocets (*Recurvirostra americana*), goldeneye ducks, and to a lesser extent, black-necked stilts (*Himantopus mexicanus*), California gulls (*Larus californicus*) and perhaps other species. Consequently the benthic food web may be important route for selenium uptake in these birds.

Given the importance of biostromes in the food web of the lake, more work is needed to improve sampling methodologies for the periphyton community on them and to assess how to effectively quantitatively sample brine flies from both vertical and horizontal surfaces of these unique structures. The seasonality of periphyton growth and brine fly production needs to be assessed, and the bioconcentration of other contaminants such as mercury needs to be studied.

Introduction

Brine flies are an important component of the food web in the Great Salt Lake and are important diet items of some nesting birds and consequently may serve as a vector for selenium uptake. However, only a single study has been done on the brine flies in the lake (Collins 1980). Two brine fly species have been described at the lake, *Ephydra cinerea*, and *E. hians*, with the former representing over 99% of the individuals. Adult brine flies lay their eggs on the lake surface, the eggs sink, and the 1st instar larvae hatch in benthic habitats. They proceed through three larval stages that feed on the bottom but frequently move into the water column, probably as a dispersal mechanism (Collins 1980). After growing 18-200 d the brine fly larvae attach to a solid substrate and pupate. Pupal duration varies from 37 d at 15 C, to 11 d at 25 C. The pupae release from the bottom, float to the surface and flies emerge as adults. High densities of adult flies are frequently present along the shoreline of the lake. Collins (1980) suggested that brine flies have 1–2 overlapping generations per year, although more detailed studies are needed to confirm this.

Collins (1980) found that fly larval and pupal densities were highest on the calcified biostromes (stromatolites or bioherms) in the lake that provide solid substrates. Mud substrates were secondarily important, and few flies were found on sand substrates. Based on a map by Eardley (1938), biostromes occupy 23% of Gilbert Bay's littoral zone and cover 261 km^2 (Fig. 1; Table 1). They occupy depths of ca. 1-4 m in the lake where there is sufficient light.

Parker (2005) studied the biostromes on the northern and NW sides of Antelope Island. He found that the cyanobacterium *Aphanothece* sp. represented over 99% of the cells in the biostromes, but some green algae were present. The small 1.4-µm diameter cells are embedded in a mucilaginous matrix that is partially calcified. The growing cyanobacteria change the pH of the water, causing carbonates to precipitate. Treatment with hydrochloric acid

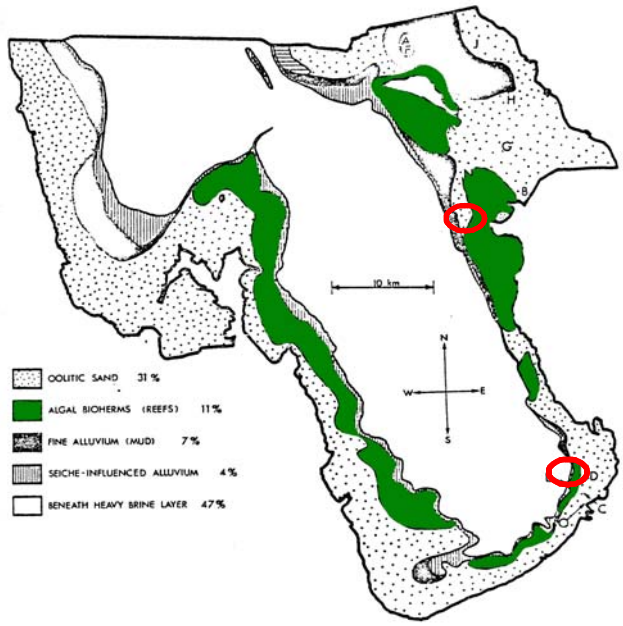


Figure 1. Map of Gilbert Bay showing the distribution of biostromes (bioherms) (green shading), oolitic sands (stippled) and mud substrates. Image taken from Collins (1980) who obtained data from Eardley (1938).

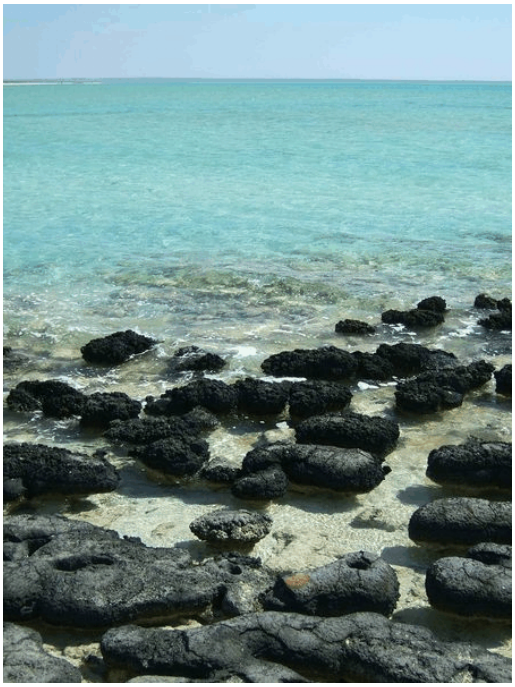
Table 1. Morphometric characteristics of Gilbert Bay of the Great Salt Lake at a lake elevation of 1280.2 m (4200 ft), which is near the mean historical elevation. The data exclude areas of the southern salt ponds and Farmington Bay. Data derived from Baskin (2005). The thickness of the mixed layer was estimated at 6.7 m (22 ft). The areas of biostromes, oolitic sand and mud were derived from the proportional areas shown in the map of Collins (1980), with an adjustment to a lake level of 1280.2 m. Hyposographic curves of the area and volume of Gilbert Bay at different lake elevations is shown in Appendix 1.

Section	Mean Depth (m)	Area of Sediments (km^2)	Volume ($m^3 \times 10^9$)
Gilbert Bay (total)	5.55	2,057	11.42
Deep-Brine Layer		912	1.73
Mixed Layer		1,145	9.69
Biostromes		261 (23%)	
Oolitic sand		712 (62%)	
Mud		172 (15%)	

dissolves the carbonates, leaving a solid, flexible mucilaginous plate ca. 1-cm thick. On the north end of Antelope Island and near Whiterock Bay in water ca. 0.8-m deep, Parker found that the circular-shaped biostromes covered a mean area of 0.70 m^2 each, and protruded 0.11 m above the sand bottom. In many places, the growing biostromes abutted each other, thus providing a completely calcified plate across the bottom. In the southern end of Gilbert Bay in 1-m of water we also have encountered the biostromes with flat-plate morphology similar to those in shallow water near Antelope Island. The plate-like structure of these biostromes is similar to the well-know growths in Shark Bay, Australia (Fig. 2a). During the sampling we found that biostromes in water about 3-m deep near the SE end of the lake had considerably different structure, with mounds that protruded ca. 0.8-1.5 m from the bottom, and that were ca. 0.5 m in diameter. These were in dense fields with limited space between mounds, although poor visibility precluded assessing them extensively. The biostromes in the 3-m-deep water were similar in morphology to those growing in the Bahamas (Fig. 2b). It is likely that stromatolites in these deeper zones have grown upward to more effectively utilize sunlight. Larval and pupal brine flies attach to the biostromes and the larvae feed on the dense cyanobacterial/algal growth (Fig. 2c, d).

The objectives of the study were two-fold. First, we needed to test methods for quantitatively sampling the periphyton and brine flies from the biostromes, mud and sand substrates. Most sampling of brine flies has relied on only semi-quantitative kick-net methods (Herbst 1988), or quantitative samples collected by wading in shallow water (Herbst 1990). Since biostromes and brine flies extend to at least 4 m of water depth (Collins 1980), methods were needed to sample effectively in the deeper water. Secondly, we sampled the periphyton and brine flies on the biostromes and sediments to provide preliminary information on whether bioaccumulation of selenium could be a problem for birds that use this prey resource.

A.



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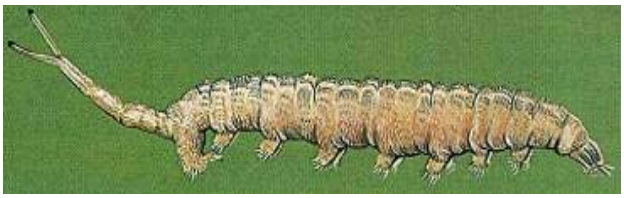

Figure 2. Biostrome structure and biota. A. Flat-plat biostromes (bioherms) similar to those observed near Bridger Bay on the NW end of Antelope Island. This photo was taken at Shark Bay, Australia. The biostromes near Bridger Bay were more closely packed and often adjoined each other. B. Dome-shaped biostromes similar to those observed at the Gilbert South site. This photo was taken in the Bahamas Islands (photo by David Liddell). C. A piece of biostrome broken from a flat-plate deposit near Bridger Bay. The dense cyanobacterial (algal) mat is obvious, as well as the brine fly pupae (light-brown protrusions). D. Drawing of a brine fly larvae (www.bioweb.lu/sapro/Ephydra.jpg).

Relevance to the Conceptual Model

Fig. 3 shows how the study of the benthic algal and brine fly populations fits in with the conceptual model developed for selenium fluxes in the Great Salt Lake. In this model dissolved selenium would be taken up by the biota in littoral sediments (including biostromes). Brine flies feed on the cyanobacteria attached to the biostromes, and they also likely feed on periphyton and perhaps detritus falling onto the loose sand and mud sediments. *Artemia fransciscana* (brine shrimp) also may feed on detrital matter in the benthic zone, as this behavior has been observed in laboratory colonies when food is limiting in the water column. The selenium accumulated in the benthic-feeding organisms could then be passed along to birds. Wading birds can feed on the attached brine flies on the biostromes and sediments. Diving birds such as goldeneye ducks (*Bucephala clangula*) can feed on the larval and pupal brine flies attached to biostromes as deep as 3-4 m (J. Vest, Utah State Univ, personal communication). Birds also have been observed feeding on the masses of brine flies that pause at the lake surface or those in flotsam slicks. Finally, birds such as gulls feed on the adult brine flies that amass along the lake's shoreline to reproduce.

In hypersaline ecosystems brine flies are often an important component of bird diets. Herbst (2006) studied bird (including black-necked stilts) use of prey in hypersaline ponds in California and concluded that nearly 90% of all feeding was on brine flies, with the remainder on *Artemia* and corixids. Brine flies (*E. hians*) also have been shown to be an important component of the diet of California gull chicks at Mono Lake, CA. In two years of study, Wrege et al. (2001) found that flies represented 15-40% of the meals given to chicks, whereas *Artemia* were 13-48% of the meals. Flies, however, have a higher nutrient value per individual prey item when compared to *Artemia* (Herbst 1986). At Mono Lake, fly larvae and pupae were the dominant forms given to chicks, with adult flies being relatively unimportant. Gull use of *Artemia*

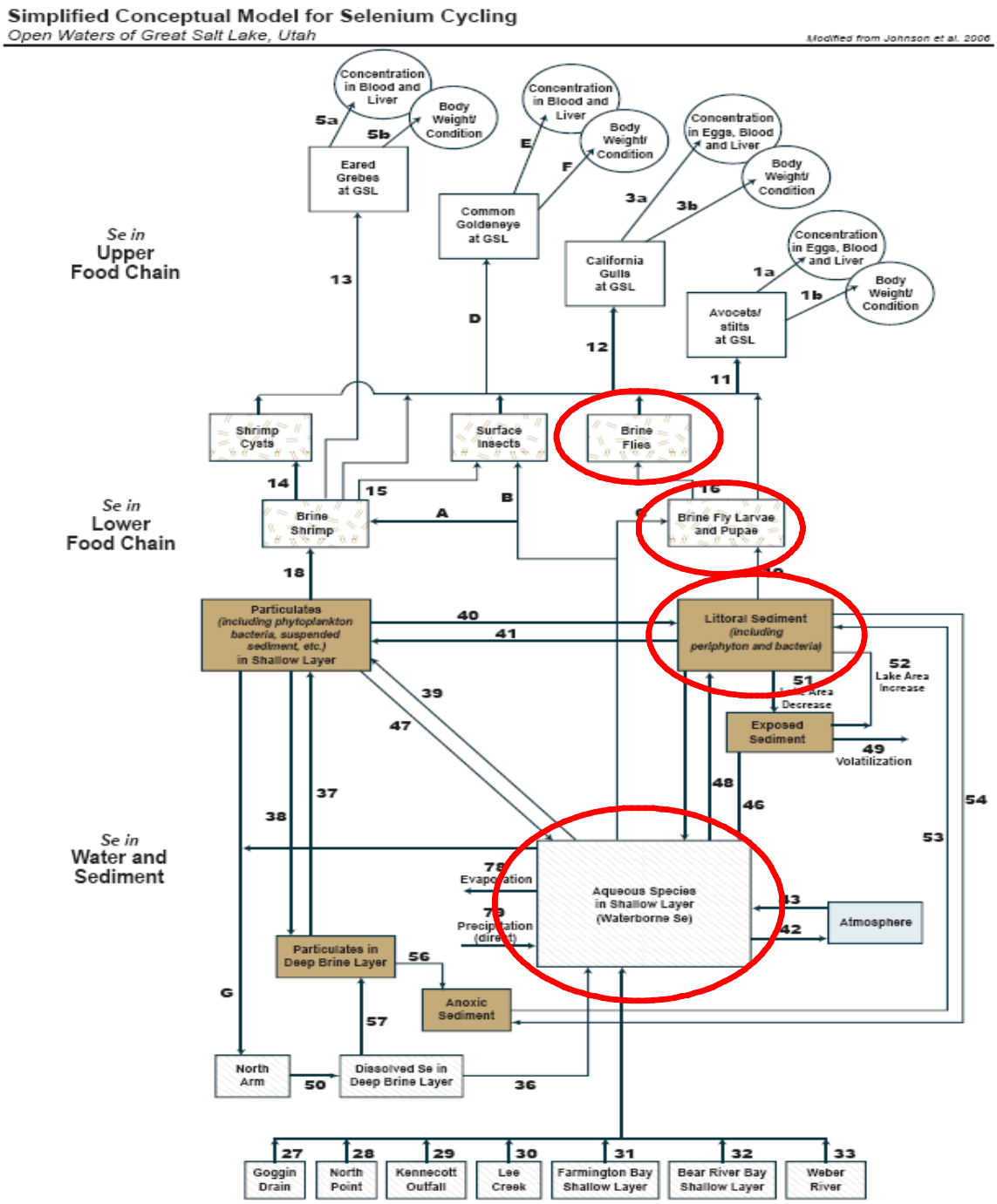

Figure 3. Conceptual model of selenium pools and transport in Gilbert Bay (Great Salt Lake) showing the pools studied in the benthic analysis (red circles). Note that "Littoral sediment" should also include the extensive calcified biostromes with cyanobacteria.

and brine flies was highly variable both within and between years, and likely reflects temporal variation of these two prey and other alternative prey. *Artemia* in the Great Salt Lake can be abundant in April and May (Wurtsbaugh and Gliwicz 2001) when bird nesting commences, but the timing is likely highly dependent on spring temperatures in the lake. The timing of brine fly abundance in the Great Salt Lake is not known. Collins (1980) studied the flies only from June through August, but based on the abundances of the larvae and pupae in June, he suggested that these forms were available in April and May. Cavitt (2007) and Conover (2007) found that brine flies were important components of the diets of wading birds, and to a lesser extent, gulls in the Great Salt Lake (see below)

The relative timing of *Artemia* and brine fly population development, as well as that of alternative terrestrial foods, could affect selenium uptake by birds, as brine fly prey may have different selenium concentrations than those present in *Artemia*. In a preliminary analysis of the Great Salt Lake, Adams (unpublished 2005) suggested that brine flies had only 36% of the selenium present in Artemia, and Herbst (2006) found that selenium was undetectable (<0.5 µg Se/g) in brine flies in saline ponds, whereas Artemia had concentrations ranging from 5-15 µg/g dry weight. For example, if brine flies are the dominant prey of birds in the early spring when egg development is occurring, reproductive impairment may be reduced as compared to a situation where the birds rely exclusively on Artemia.

Methods

Sampling Locations and dates

Brine fly pupae and larvae, periphyton, water, and sediment were sampled along two transects in Gilbert Bay of the Great Salt Lake (Fig. 4). The transect for Site 1 began at a water

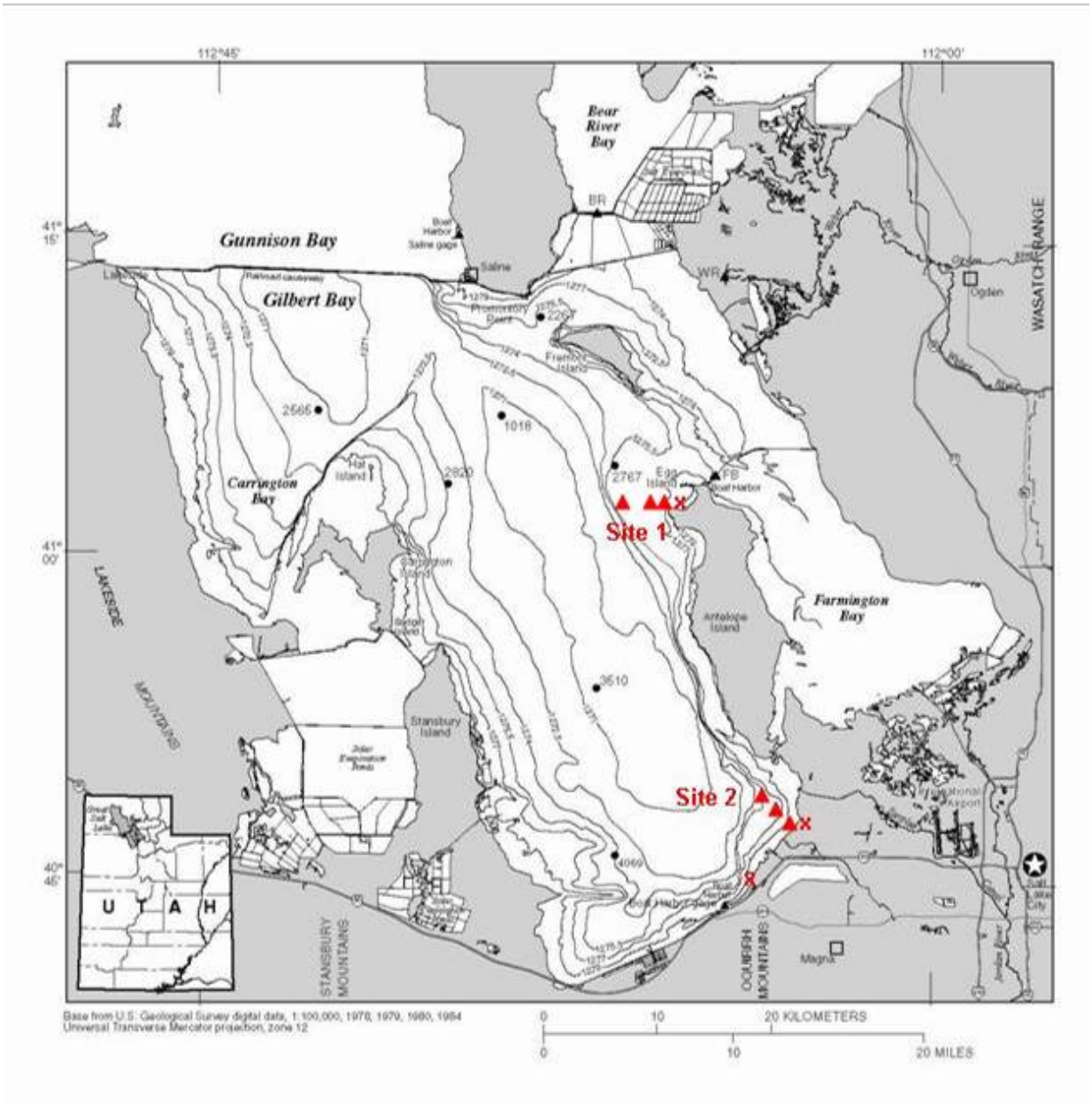

Figure 4. Map of Gilbert Bay showing benthic (▲) sampling sites for brine flies, sediments and biostromes. Sites where adult brine flies were collected on shore are shown with (**x**). Coordinates for sample sites are given in Table 2.

depth of 1 m at the SW corner of Bridger Bay on Antelope Island and proceeded westward. Site 2 (Gilbert South) was a N-S transect beginning in the SE end of Gilbert Bay. At each of these sites we sampled at nominal depths of 1, 3 and 5 m. The coordinates and actual depths sampled are shown in Table 2. We also collected adult brine flies at three shore locations: rock outcroppings at the SW corner of Bridger Bay, Saltair Beach, and at a beach just north of Kennecott mine tailings. Larval and pupal brine fly samples were collected at Site 1 on June 1, June 14 and June 16. Two additional samples were taken on September 28, 2006. Because relatively few sediment samples were collected in 2006, additional ones were collected on depths of 1-3 m on 28 April 2007, but the selenium and organic matter content of these is not yet available from the analytical laboratory. All samples at Site 2 were collected on June 15. Adult flies were collected on June 14, 15 and 16.

On June 14 Gilbert Bay's water elevation was 1279.58 m (4,198.1 ft) and it declined 0.5 m to 1279.06 m (4196.4 ft) by September 28th. At each site, salinity, oxygen and temperature profiles were measured with an InSitu sonde. Secchi disk measurements were made at each site.

Brine fly & sediment collection

Brine fly adults were captured with a fine-meshed butterfly net while running along the beach, or between rocks where brine flies were resting. Netted brine flies were placed in a cooler with dry ice to euthanize and transport them. They were kept frozen at -20°C after return to the laboratory, and then washed with de-ionized water to remove salts, counted, and weighed. A portion of the brine flies where ashed at 550°C for 2hrs, then reweighed to determine ash-free dry mass (AFDM).

Duplicate larval and pupal brine fly samples were collected at each depth. The larvae and pupae were sampled on the biostromes by SCUBA divers using a vacuum pump sampler

(Fig. 5) similar to that of Voshell et al. (1992). The sampler consists of an inverted plastic bucket with a port and glove attached to the side of the canister so that a diver can agitate the substrate. The apparatus sampled an area of 0.075 m^2. Four kilograms of dive weights were attached to the lower part of the bucket to increase stability and to keep the unit on the substrate. In order to function effectively, the sampler had to be placed on a relatively level and solid substrate. This precluded sampling on the sides of the dome-shaped biostromes in southern Gilbert Bay. Once the sampler was positioned, the diver jerked the attached pump tube so that the operators in the boat could begin bringing water to the surface with a hand-powered vacuum pump (Guzzler Model Vacuum Pump, U.S. Plastics Corp.). The diver then began scouring the substrate with a scrub brush. Pumping continued until three 20-L buckets were filled on the boat. This sample included 10.5 L of water that was in the pump tube. Samples were sieved through a 500-µm sieve and collected in an acid-washed 500-ml polyethylene bottle, and stored on ice for transport to the laboratory. To sample organic matter and chlorophyll, the diver broke off a portion of the calcified biostromes. Only edge pieces of flat biostromes, or exfoliating pieces of domed biostromes could be collected, and this could have introduced some bias. Sampled pieces were 100-300 cm^2, and usually about 3-cm thick.

On sand and mud substrates, brine flies were collected with a 0.050 m^2, 24-kg, Ponar grab (Wildco, Inc., Buffalo NY) lowered to the bottom with a rope. The Ponar dredge is weighted sufficiently to penetrate dense, sandy sediments. The samples were brought to the surface and discharged into a plastic tub, and then sieved through the 500-µm mesh. In all cases, insufficient brine flies were available from the soft sediment samples for selenium analyses because the analytical laboratory stated that they needed 1000 mg of dry weight and this required approximately 500 individual larvae or pupae. The average number of larvae recovered from the soft sediment Ponar samples was only 16 individuals.

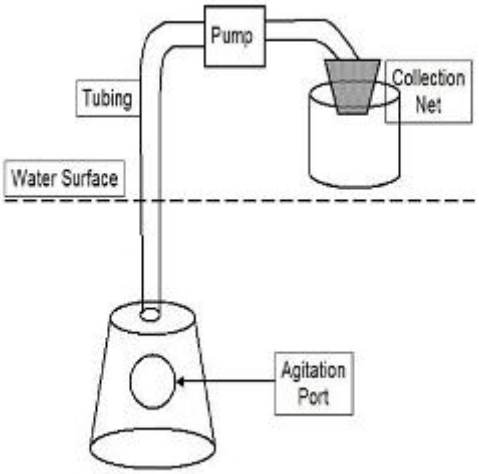

Figure 5. Left. Diagram of the bucket and pump assembly for quantitatively sampling brine fly larvae and pupae in the Great Salt Lake. Right. Photo showing the weighted bucked and the brush used to dislodge brine flies from the biostromes.

In the laboratory, larvae and pupae were counted, washed three times with de-ionized water, then weighed and frozen in polyethylene scintillation vials. Composite samples of larvae (mean, 236 individuals; range 47-500) and pupae (mean, 246 individuals; range 21-500) were analyzed for selenium. The brine fly samples were sent to LET Incorporated (Columbia, MO) for selenium analysis by hydride generation – atomic absorption spectrometry on acid-digested samples. The reporting limit for selenium was 0.1 µg Se/g. LET also measured percent solids by drying a subsample of the flies.

Pieces of biostromes of known area were frozen and subsequently placed in 95% ethanol and chlorophyll was extracted overnight at room temperature. The chlorophyll solution was then diluted with ethanol and concentrations measured in a Turner 10-AU fluorometer with

the non-acidification method (Welschmeyer 1994). Blanks and standard were analyzed at the beginning of each run. Biostrome and sediment subsamples were dried at 70°C, weighed and then ashed at 450°C for 6-8 h. Ashed samples were re-wetted using de-ionized water, dried overnight at 70ºC, and then weighed to obtain AFDM. A subsample of biostrome samples was treated with acid to remove carbonates. These samples were submerged in 1 N HCl until all CO_2 bubbling stopped. This required several hours and necessitated replacing the acid up to three times. By removing the carbonates, this procedure allowed us to determine the selenium concentration of the organic component of the stromatolites. To analyze organic matter in sediment samples, the top 3 and 3-50 mm of most grab samples was collected with a plastic spatula prior to the sample being sieved to remove brine flies. The depths and strata thicknesses are given in Table 2.

Water Samples

Water samples were taken first at all dive sites to avoid disturbed sediments. Collection of water samples occurred 2-5 cm above the sediment surface using 60-ml acid-washed syringes. Each syringe was rinsed three times with surface water, and once with water from above the sediments prior to collecting the actual sample. Water samples were taken ca. 5 m apart from each other. On the surface, water in the syringes was filtered through Whatman 47-mm GF/F filters (0.80 µm) and placed in 200-ml acid-washed polyethylene bottle. GF/F filters were used in lieu of 0.4 µm membrane filters because of the higher volume that they can filter, and because they are becoming a standard filter used in limnological and oceanographic research. The GF/F filters may allow slightly more colloids and picoplankton to pass and be considered as “dissolved” selenium. The first 40 ml of water was used to rinse the filters and bottles. Two ml of nitric acid were added to fix samples using an acid-rinsed disposable pipette.

Samples were sent to Frontier Geoscience, Seattle, WA for total dissolved selenium analysis by hydride generation and atomic fluorescence spectrometry (HG-AFS). Minimum detection limit for total Se was reported as 0.05 µg/L.

Results

Limnological Conditions

During the June 14-16 sampling, water temperatures ranged from 20.7°C at the surface to 20.4°C near the bottom and oxygen was at saturation. Surface salinities were 116 g/L (11.6%) at both sites, increasing to 126 g/L (12.6%) at 5 m. The Secchi depth (0.72 m) at Bridger Bay was influenced by the algal-laden Farmington Bay water reaching the site, as clearer water was observed farther offshore and in other areas of the lake. In the September sampling at Bridger Bay, water temperatures ranged from 20.0°C at the surface to 16.8°C at 1.8 m, and salinities ranged from 136 g/L (13.6%) at the surface to 146 g/L (14.6%) at 1.8 m, indicating an overflow of fresher water from Farmington Bay was influencing the site. The Secchi depth was 1.0 m at the Bridger Bay site. Much clearer water was observed in other parts of Gilbert Bay, but transparencies were not measured. Visibility limited our ability to assess the horizontal extent of the biostrome fields. However, at the Bridger Bay site the plate-shaped biostromes were largely continuous and interrupted by only small sand patches at perhaps 4-6 m intervals. Vertical structure was about 0.2-0.3 m. The biostromes extended from depths of <1 m to ca. 3.2 m. At 5 m, the bottom was covered in fine sand with occasional pieces of incipient biostrome material a couple of centimeters in diameter and 2-3 mm thick. At 1-m depth at the Gilbert South site there were some plate-like biostromes but these were overlain with 1-2 cm of loose, course sand, and hence did not provide solid attachment structure for brine flies. The 2.7-3.2 m sites were primarily biostrome mounds extending 0.7 to ca. 1.5 m above the bottom with some intervening patches of sand. In some cases the mounds were linked to each other. When our boat cruised over these sites the echo sounder failed to register depth because of the high depth variability. At a depth of 5 m along the transect, the bottom was all sand and mud. Diver

Table 2. Locations, substrate characteristics and brine fly abundances and selenium concentrations collected in Gilbert Bay of the Great Salt Lake during 2006.

Transect Location	Sample Date	Lat	Long	Depth (m) From Surface	Dominant Substrate	% Stromat-olite	%Sand	%Mud	Brine Fly Stage	Number m^{-2}	Wet mass ($g\ m^{-2}$)	Percent Solids	Dry Mass ($g\ m^{-2}$)	Se (ug/g dry wt)
Bridger Bay (1)	16-Jun-06	41.042	-112.276	**-1.0**	Air	-	-	-	Adult	-	-	-	-	1.9
Gilbert S. (2)	16-Jun-06	40.748	-112.193	**-1.0**	Air	-	-	-	Adult	-	-	-	-	1.8
Gilbert S. (2)	16-Jun-06	40.795	-112.150	**-1.0**	Air	-	-	-	Adult	-	-	-	-	1.8
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Larvae	198	0.6	14%	0.08	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Larvae	139	0.4	14%	0.06	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Pupae	0	0.0	9%	0.00	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Pupae	139	1.4	9%	0.12	
Bridger Bay (1)	16-Jun-06	41.036	-112.323	**3.9**	Sand	0	100	0	Larvae	1,012	3.0	14%	0.43	
Bridger Bay (1)	16-Jun-06	41.036	-112.323	**3.9**	Sand	0	100	0	Larvae	476	1.4	14%	0.20	
Bridger Bay (1)	16-Jun-06	41.036	-112.323	**3.9**	Sand	0	100	0	Pupae	0	0.0	9%	0.00	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**3.9**	Sand	0	100	0	Pupae	0	0.0	9%	0.00	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Larvae	8,930	26.6	14%	3.83	1.4
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Larvae	9,672	28.8	14%	4.15	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Pupae	3,670	36.3	9%	3.16	1.6
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Pupae	6,625	65.6	9%	5.71	
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Larvae	2,491	7.4	14%	1.07	1.5
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Larvae	3,829	11.4	14%	1.64	1.5
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Pupae	543	5.4	9%	0.47	2.0
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Pupae	278	2.8	9%	0.24	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Larvae	6,148	18.3	14%	2.64	1.5
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Larvae	11,288	33.6	14%	4.84	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Pupae	3,008	29.8	9%	2.59	1.5
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Pupae	6,227	61.6	9%	5.36	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Larvae	80	0.2	14%	0.03	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Larvae	80	0.2	14%	0.03	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Pupae	320	3.2	9%	0.28	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Pupae	80	0.8	9%	0.07	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	15	85	0	Larvae	26	0.1	14%	0.01	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	15	85	0	Pupae	0	0.0	9%	0.00	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	25	75	0	Larvae	40	0.1	14%	0.02	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	25	75	0	Pupae	0	0.0	9%	0.00	
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Sand	40	60	0	Pupae	450	4.5	9%	0.39	
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	75	25	0	Larvae	1,245	3.7	14%	0.53	
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	75	25	0	Pupae	2,045	20.2	9%	1.76	
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	100	0	0	Larvae	1,961	5.8	14%	0.84	1.0
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	100	0	0	Pupae	4,982	49.3	9%	4.29	1.1
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Stromatolite	40	60	0	Larvae	623	1.9	14%	0.27	
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Stromatolite	90	10	0	Larvae	2,054	6.1	14%	0.88	0.9
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Stromatolite	90	10	0	Pupae	14,071	139.3	9%	12.12	1.1

assessments of the approximate sediment composition are shown in Table 2. High densities of dense periphyton and larval and pupal brine flies were very visible underwater on the tops and sides of the biostromes. The sand and silt did not appear to be covered with any periphyton growths, nor were any brine flies noted on these substrates by the divers.

Brine fly densities, biomass, organic matter.

Brine fly larvae and pupae were very abundant on biostromes and scarce on sand and mud substrates (Figs. 6, 7). Total brine fly densities on biostromes averaged 9,140/m^2 and reached over 16,000/m^2 in three samples. In Bridger Bay, larvae were more abundant than pupae, but the reverse was true at the South Gilbert site. Larval brine flies were significantly more abundant in Bridger Bay than at the Gilbert South site ($p = 0.015$), but there was no significant difference for pupae ($p = 0.226$). Both larvae and pupae were significantly more abundant on biostromes than on the combined category of sand/mud ($p = 0.003$). Total brine fly biomass on biostromes averaged 5.9 g/m^2, but only 0.2 g/m^2 on sand/mud substrates (Table 2).

Our analyses suggested that organic matter content (AFDM) of the periphyton in the biostrome samples was very high, with a mean of 58% (Table 3), but these results are likely erroneous (see below). Strangely, treatment with acid to remove carbonates did not significantly influence organic matter content ($p = 0.577$). It is possible that the cyanobacteria and the mucilage matrix comprise the bulk of the upper portions of the biostromes, and the carbonates removed by acidification are insignificant. Organic matter content on the combined sand/mud substrates (6%) was significantly ($p < 0.000$) lower than on the biostromes. Chlorophyll *a* concentrations on the biostromes were very high, averaging 698 mg/m^2 ± 207. Chlorophyll was not measured on the sand/mud substrates. The AFDM and selenium content of the additional 15 samples taken in 2007 are not yet available.

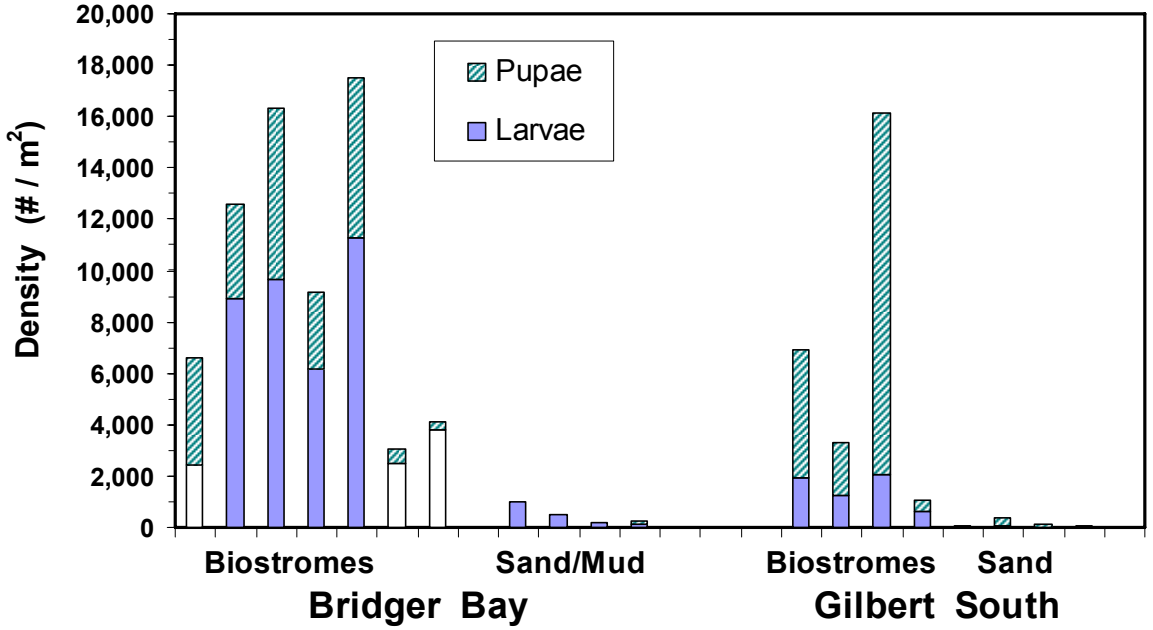

Figure 6. Cummulative abundances of brine fly (*Ephydra cinerea*) larvae and pupae on substrates that were predominantly biostromes, or on sand/mud, at either the Bridger Bay sampling site, or at the Gilbert South site of the Great Salt Lake. Most samples were collected from 14-16 June, 2006. The unfilled white bars for Bridger Bay indicate densities found on 1 June (left) or on 28 September (2 right bars). Brine fly larvae were significantly more abundant in Bridger Bay than at the Gilbert South site ($p = 0.015$), but there was no difference for pupae ($p = 0.226$). Both larvae and pupae were significantly more abundant on biostromes than on the combined category of sand/mud ($p = 0.003$).

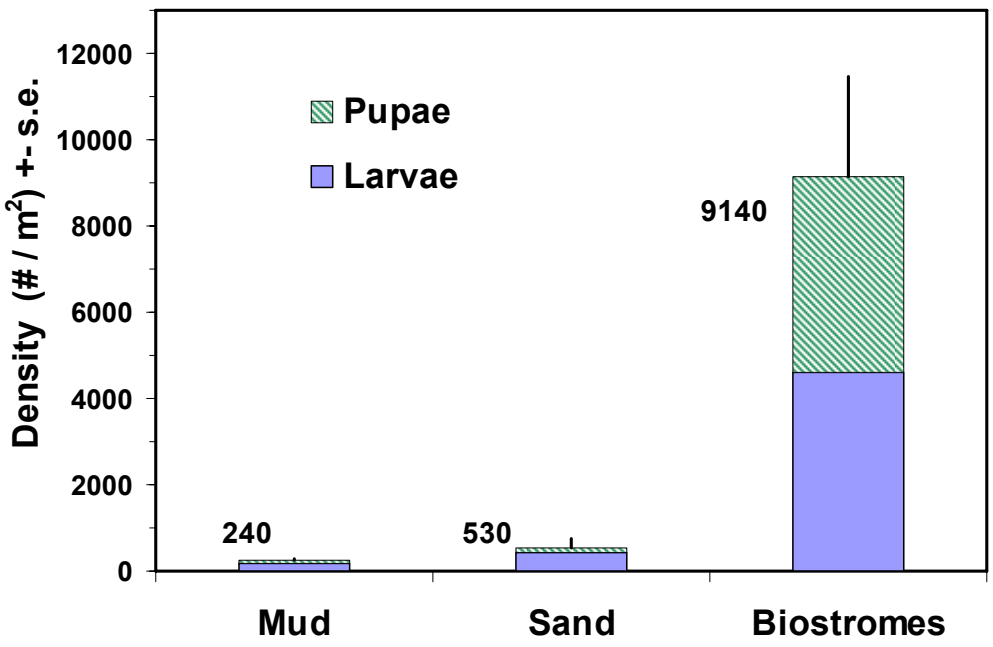

Figure 7. Summary of densities of larvae and pupae of brine flies (*Ephydra cinerea*) on three types of substrates in Gilbert Bay of the Great Salt Lake during June 2006. The Bridger Bay and Gilbert South sites were pooled.

Selenium Concentrations

Mean total dissolved selenium concentrations in the water were low (0.40 µg Se/L) and did not differ significantly between the Bridger Bay and the Gilbert South sites ($p = 0.117$). Variability in selenium concentrations in the water was very low with a range of 0.37-0.43 µg Se/L (Table 4). Mean selenium concentrations in the combined periphyton/sediment substrates (Table 4) was 1.7 µg Se/g (1.7 mg/kg; one outlier of 9.8 removed), and concentrations did not differ with respect to site ($p = 0.856$), substrate type ($p = 0.473$), or whether the samples were acidified ($p = 0.533$). However, sample sizes were small and variability was moderately high, limiting the possibility of finding differences among the different categories (Table 4). See addendum at end of report for additional measurements of sediments collected in 2007.

Selenium concentrations in the brine flies ranged from 0.9 to 2.0 µg Se/g (Table 2) and varied between groups and sites (Fig. 8). Concentrations increased from larvae (1.3 µg Se/g) to pupae (1.5 µg Se/g), and this difference was significant ($p = 0.046$). Concentrations were higher in adult flies (1.8 µg Se/g) than in pupae, but there were insufficient samples (3) to determine if this was significant or not. A two-way ANOVA indicated that the brine flies in Bridger Bay had significantly higher concentrations of selenium than did those in Gilbert South ($p < 0.000$) with a mean difference of 1.6 vs. 1.3 µg Se/g.

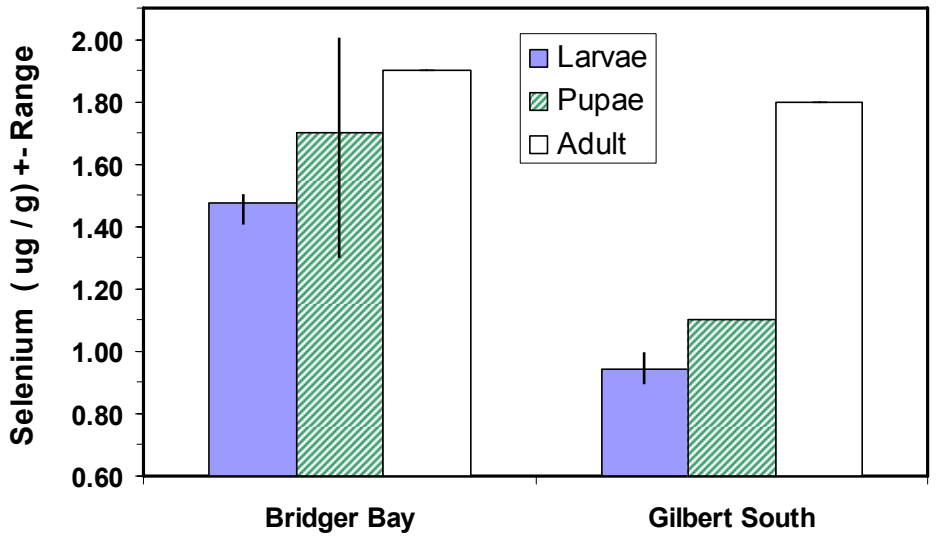

Figure 8. Concentrations of selenium in larvae, pupae and adult brine flies (Ephydra cinerea) collected near Bridger Bay, and at the south end of Gilbert Bay. A 2-way ANOVA indicated that selenium concentrations were significantly higher in Bridger Bay than in Gilbert South ($p = 0.000$), and in pupae than in larvae ($p = 0.046$). Only three samples of adult flies were measured for selenium and they were not included in the ANOVA. Note that although the results were statistically significant, the differences between stages was small.

Table 3. Samples collected for periphyton and ash free dry mass (AFDM) analyses in Gilbert Bay of the Great Salt Lake during 2006 and 2007. Most dredge samples included the upper 50 mm of material, but some samples were sectioned to determine if Se content varies with depth. Except for the acidified biostrome samples, the selenium concentrations represent that in the combined organic-inorganic matrix. The AFDM of the biostromes appears to be erroneously high. Ash-free dry weights and Se content of the samples collected in 2007 are not yet available.

Site	Sample Date	Latitude	Longit.	Depth (m)	Sediment strata (mm)	Substrate Type	% Stromatolite	% Sand	% Mud	Acidified?	AFDM %	ug Se/g dry wt
Bridger Bay (1)	14-Jun-06	41.043	112.276	1.0		Stromatolite	95	5	0	N		0.40
Bridger Bay (1)	14-Jun-06	41.043	112.276	1.0		Stromatolite	95	5	0	Y	56.0%	2.10
Bridger Bay (1)	14-Jun-06	41.043	112.276	1.0		Stromatolite	95	5	0	Y		0.90
Bridger Bay (1)	14-Jun-06	41.043	112.276	3.0		Stromatolite	95	5	0	N		0.60
Bridger Bay (1)	14-Jun-06	41.043	112.276	3.0		Stromatolite	95	5	0	Y	61.0%	2.20
Bridger Bay (1)	14-Jun-06	41.043	112.276	3.0		Stromatolite	95	5	0	Y		1.30
Bridger Bay (1)	16-Jun-06	41.036	12.323	3.9	0-50	Mud	2	98	0	Y	2.0%	*9.80*
Bridger Bay (1)	16-Jun-06	41.034	112.325	5.0	0-50	Mud	2	10	88	Y	6.0%	3.10
Bridger Bay (1)	16-Jun-06	41.034	112.325	5.0	0-3	Mud	2	10	88	Y	7.0%	3.30
Bridger Bay (1)	16-Jun-06	41.034	112.325	5.0	0-50	Mud	2	10	88	Y	10.0%	1.40
Gilbert South (2)	15-Jun-06	40.802	112.163	2.7		Stromatolite	100	0	0	N	58.0%	3.10
Gilbert South (2)	15-Jun-06	40.802	112.163	2.7		Stromatolite	90	10	0	N	59.0%	-
Gilbert South (2)	15-Jun-06	40.810	112.183	3.2		Stromatolite	90	10	0	N	52.0%	0.40
Gilbert South (2)	15-Jun-06	40.810	112.183	3.2		Stromatolite	40	60	0	Y	60.0%	1.30
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.5	3-40	Mud	0	0	100	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.5	0-3	Mud	0	5	95	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0	3-30	Mud	0	0	100	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0	0-3	Mud	0	0	100	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.271	1.0	30-50	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.274	1.0	3-50	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.274	1.0	0-3	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.271	1.0	0-3	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.275	1.0		Stromatolite	100	0	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.275	1.0		Stromatolite	100	0	0	Y	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.1		Stromatolite	100	0	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.1		Stromatolite	100	0	0	Y	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0		Stromatolite	100	0	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0		Stromatolite	100	0	0	Y	Results Pending from LET	

Table 4. Location of water samples collected of selenium analysis in Gilbert Bay of the Great Salt Lake during 2006. The water was collected by SCUBA divers utilizing 60-ml syringes. The water was taken ca. 2-5 cm above the substrate. Samples were filtered through 0.8 µm glass fiber filters.

Location	Sample Date	Lat	Long	Depth (m)	Substrate Type	Se (µg/L)	Comments
Bridger Bay	14-Jul-06	41.043	112.276	1.00	Water column	0.40	GF/F filtered
Bridger Bay	14-Jul-06	41.043	112.276	3.00	Water column	0.40	GF/F filtered
Bridger Bay	16-Jun-06	41.034	112.325	5.00	Water column	0.43	GF/F filtered
Gilbert South	15-Jun-06	40.799	112.152	1.20	Water column	0.41	GF/F filtered
Gilbert South	15-Jun-06	40.802	112.163	2.70	Water column	0.38	GF/F filtered
Gilbert South	15-Jun-06	40.810	112.183	3.20	Water column	0.38	GF/F filtered
Gilbert South	15-Jun-06	40.811	112.184	5.00	Water column	0.37	GF/F filtered

Discussion

Food web dynamics and selenium bioaccumulation

The data collected on the biostromes indicates that they are an important component of the food web in Gilbert Bay, and they may consequently have an important influence of the bioaccumulation of metals such as selenium and mercury. A relative comparison of periphyton on biostromes and the phytoplankton can be done as an approximation of how much production may come from these two sources. Primary production data are not available for the biostromes, so chlorophyll levels in the two can be compared. Biostromes are estimated to underlie an area of 261 km^2 in Gilbert Bay, which is only about 18% of the area where phytoplankton occur (Fig. 9A). However, chlorophyll concentrations are about 380% higher on the biostromes than in the integrated phytoplankton from the 6.75-m thick epilimnion (Fig. 9B). Multiplying the areal coverage of the two habitat types by the chlorophyll concentrations indicates the total amount of chlorophyll in the two habitats. This calculation suggests that the cyanobacteria and algae on the biostromes is about 70% of that in the water column (Fig. 9C). Note that this calculation does not include the contribution of chlorophyll on the muds and sands in the littoral zone of the lake. Although the cyanobacteria on (and in) the biostromes may not be as accessible to the brine flies as phytoplankton are to grazing *Artemia*, this preliminary analysis indicates that the abundant biostromes are an important component of the food web in the lake. This analysis is consistent with recent views on the importance of benthic areas for food web processes in lakes (Vadeboncoeur et al. 2002).

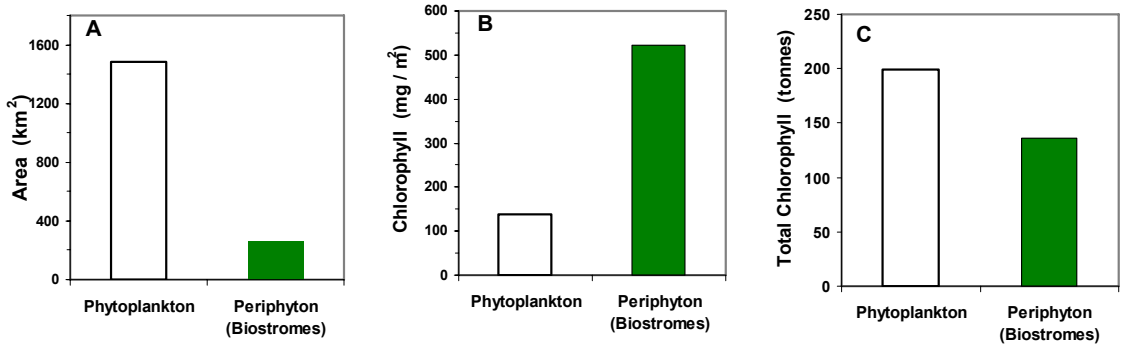

Figure 9. A. Comparison of the area covered by periphyton on biostromes (solid green) and that of the epilimnion of the Gilbert Bay where phytoplankton can grow (open). B. Concentrations of chlorophyll on biostromes (solid green) and that in phytoplankton in the water column (open). The latter was based on chlorophyll in Gilbert Bay calculated from data from 2002-2005 of W. Wurtsbaugh, and an estimated epilimnetic volume of 9.7 10^9 m^3. C: Total chlorophyll estimates (metric tones) for Gilbert Bay in periphyton attached to biostromes, and that in the phytoplankton.

The brine flies on the biostromes also represent a significant component of the invertebrates in the lake and contain a large amount of the bioavailable selenium for birds (Fig. 10). The biomass of brine flies we measured in June is about 30% of that in *Artemia* (Fig. 10A). The seasonality of brine flies is not well known, but Collins found comparable densities of pupae on biostromes from June through August. Selenium concentrations in brine flies were somewhat higher than in *Artemia* (1.5 vs. 1.2 µg/g; Fig. 10B), contrary to what others have found in the Great Salt Lake (Adams 2005 unpublished) or elsewhere (Herbst 2006) . The resulting estimate of total selenium in the benthic invertebrates suggests that brine flies contain about 38% of the total selenium that is contained in *Artemia.* These comparisons, although based on relatively few samples, indicate that brine flies could be a significant source of selenium for birds in the Great Salt Lake.

In contrast to the biostromes, the sand and mud substrates we sampled had relatively few brine flies associated with them. This is consistent with the findings of Collins (1980), although he did estimate that perhaps 18% of brine fly production could occur on mud and sand sediments. The soft sediments in much of the lake may produce little periphyton for the brine flies. It is likely that the sands in shallow waters shift so much that algae cannot become well-established. Conversely, in deeper water, periphyton may have insufficient light for photosynthesis. The photic zone at the time of our survey was estimated to be only about 2 meters deep (two Secchi depths), so photosynthesis would be negligible below this depth. Our survey sites, however, were located relatively close to discharges of nutrient-laden water (Farmington Bay and the Goggin Drain) from metropolitan Salt Lake City, and the resulting phytoplankton growth in these areas may shade-out periphyton. Sites on the western side of the lake might be expected to have periphyton growing in deeper water and more brine flies on

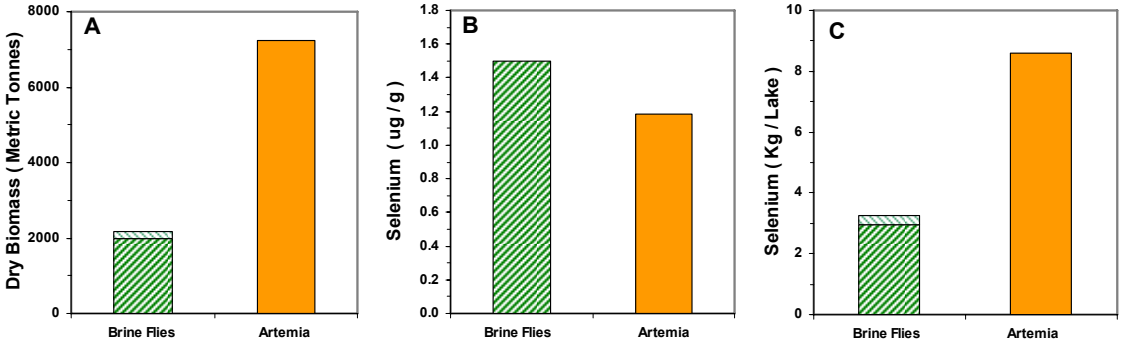

Figure 10. A. Comparison of the amount of biomass in brine flies and that in Artemia. The brine fly data are from June 2006, and represents the sum of larvae and pupae. The dark green diagonal shading shows brine flies on biostrome substrates. The light green shading represents brine flies on soft sediments. B. Mean selenium concentrations in brine fly larvae and pupae and that in adult Artemia (data of Brad Marden). Selenium concentrations were 2–4X lower in juvenile Artemia, but the data from adults was used because: (1) they are likely the main prey of birds; (2) under most circumstance they would dominate the biomass, and ; (3) with the information in the data base there was no way calculate a weighted average of selenium for the pooled plankton sample. C. Estimated total amount of selenium in brine fly larvae and pupae on biostromes (dark green shading), on soft sediments (light green shading), and in Artemia. The Artemia data are based on an April-December mean dry biomass of 0.75 mg/L (data of Brad Marden). Estimates of brine fly biomass and selenium concentrations are based on limited samples.

deep substrates. More thorough surveys of both the soft sediments and biostromes in different parts of the lake are needed to test this hypothesis.

The benthic food web is a likely route for selenium transport into birds, because more than 80% of the estimated 50 metric tones of selenium in the lake is in the bioactive benthic zone (Table 5). A comparison of data collected by Johnson et al. (2007) and that reported yields a rough estimate that 87% of the selenium is in the top 2-cm of the sediments and biostromes in the lake, 3% is in suspending particulate matter (seston) available for *Artemia* to graze on, and 10% is dissolved in the water (Table 5). Of the selenium in the benthic zone, 60% was estimated to be in the oxic sediments (46% soft sediments + 14% biostromes), and 28% in the anoxic zone. The lower amount in the anoxic sediments is due to the smaller area of this zone, and a mean selenium concentration of only 58% of that in the oxic sediments (but see addendum). It also is important to consider that the selenium in the organic material of the biostromes is potentially available to the invertebrates, whereas that beneath the deep brine layer will cycle only slowly to the oxic zone of the lake where invertebrates could take it up. The oxic sand and mud substrates, with an estimated selenium content of 1.7 µg/g and 6% organic material, could potentially be important for the transfer of selenium to invertebrates. However, the very low numbers of brine flies found on the sand and mud suggests that even the organic selenium in soft sediments would not be utilized to any significant degree. This comparison between the different lake zones is based on a small number of benthic samples from the oxic zone, and a high variability (0.4–9.8 µg Se/g) in the estimated selenium concentration, so it is clear that more work needs to be done in the oxic sediments in order to construct a true estimate of selenium in the different compartments.

Table 5. Estimates of selenium in different areas of the lake. That in the water column was based on the selenium concentrations reported by Johnson et al. (this report). Sediment estimates assume only a 2-cm thick bioactive layer, and a solids component of 76%. The solids estimate is derived from sediment core data of W. Johnson. Respective selenium concentrations in the anoxic and anoxic sediments are based on those reported by Johnson et al. (2007) and Wurtsbaugh (this report). Several of the values used to make the calculations are based on relatively few samples, so the values are only approximate.

	Se Concentration		Area/Volume	Se (Tones)	Percent
Water column (total)	0.56	ug/L	11.4×10^9 m^3	6.4	13%
Water column (dissolved)	0.42	ug/L	11.4×10^9 m^3	4.8	10%
Water column (particulate)	0.14	ug/L	11.4×10^9 m^3	1.6	3%
Sediments (total)			2057 km^2	43.4	87%
Sediments (anoxic)	1.0	ug/g	912 km^2	13.9	28%
Sediments (oxic sands & mud)	1.7	ug/g	884 km2	22.8	46%
Biostromes	1.7	ug/g	261 km2	6.7	14%
Total				49.8	

If the mean estimated selenium content in the biostrome periphyton/sediment material is correct (1.7 µg Se/g; range, 0.4-9.8 µg Se/g) there appears to be no biomagnification up the benthic food web (Fig. 11). The selenium content of organic material from biostromes measured in 2007 (Addendum) was lower (1.0 µg Se/g), but there still appears to be little, if any biomagnification. There was, however, nearly a 3,500-fold bioconcentration from the dissolved phase (0.4 ug Se/L = 0.4 ng Se/g of water) into the periphyton. However, the brine fly larvae do not increase concentrations further. This is similar to the results of Brix et al. (2004), who also did not find significant biomagnification of selenium by *Artemia*. The slight increase in selenium concentrations from larvae to pupae to adults that we found may be the result of modifications in fat content or other constituents, since feeding does not occur after the brine flies pupate. It is also possible that exoskeletons of pupae are low in selenium, so that molting into the adult stage would increase the selenium concentration in the flies.

With our limited sampling it is difficult to assess the spatial variations in selenium that may be present in the benthic zone of the lake. We did not anticipate finding higher selenium concentrations at the Bridger Bay site than at the Gilbert South site. The latter is near the discharge points of Kennecott Utah Copper Corporation and the Goggin drain where 55% of the selenium load enters the lake (Naftz et al. 2007). In contrast, the Farmington Bay discharge near the Bridger Bay site contributes only 13% of the selenium load, and concentrations of the effluent from Farmington Bay are only 56% of those from the Goggin drain (Naftz et al. 2007). The higher concentrations of selenium in the brine flies at Bridger Bay may be attributable to the very high organic content of the effluent from Farmington Bay, which is highly eutrophic (Wurtsbaugh and Marcarelli 2006). Rosetta and Knight (1995) found that brine flies bioaccumulated selenium much faster from a dissolved organic compound than they did from selenate or selenite. Indeed, most uptake of selenium by benthic invertebrates is thought to be via incorporation of organic selenium (Presser and Luoma 2006).

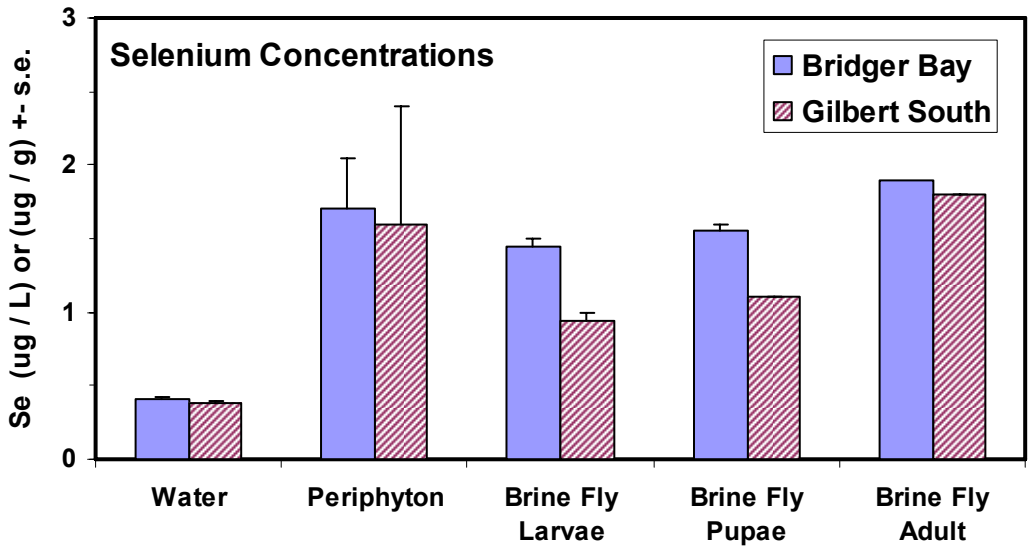

Figure. 11. Selenium concentrations in water (µg Se/L; dissolved), in periphyton (+sediment), and in brine fly larvae, pupae and adults (µg Se/g). Note that the relative scaling with these units indicates that selenium concentrations in the biota are >1000 times that dissolved in the water. Note that although this bioaccumulation is large, there is no further biomagnification from the periphyton to brine flies. Individual data are shown in Tables 2, 3, and 4. One periphyton sample concentration of 9.8 µg Se/g in a Bridger Bay mud sample was considered an outlier and was not included in the mean. Nevertheless, variability was still high in the periphyton/sediment samples. Concentrations of individual samples are shown in Tables 2-4.

The selenium content of brine flies is important because birds in the Great Salt Lake feed on them extensively. Cavitt (2007) found that brine fly larvae comprised 20-100% of the diet (by volume) of American avocets (*Recurvirostra americana*) sampled at different sites prior to or during nesting at the Great Salt Lake. The highest proportion of larvae in the diets occurred at Antelope Island where biostromes and dense brine fly populations occur close to shore. The lowest proportion of brine fly larvae in the avocet diets occurred in Ogden Bay where the mud flats are distant from biostromes and where fresher water allows other prey to be abundant. Black-necked stilts (*Himantopus mexicanus*) also ate 20% brine fly larvae at the Ogden Bay site during the nesting season. *Artemia* were absent from the diets of both of these birds. In contrast, Conover (2007) found that the diets of California gulls (*Larus californicus*) were composed of 45-83% *Artemia* at his three study sites, and brine flies represented a maximum of 25% of the diet. Curiously, at the Antelope Island sites where brine flies are very abundant, the gulls consumed no brine flies. Diet sample sizes were small for the birds, so these are only approximate proportions, and they represent only the short early or pre-nesting period when selenium in prey items can be passed to eggs.

Brine flies can be an important dietary component of other birds utilizing the Great Salt Lake (Figure 12). The diet of common goldeneye ducks is composed almost entirely of brine fly larvae and pupae (Joeseph Vest, USU, personal communication). Goldeneye have the highest concentrations of another contaminant of concern (mercury) of any birds sampled at the Great Salt Lake (J. Luft, Utah DWR, personal communication), so the potential for bioaccumulation of this toxicant through the benthic food web is likely. Mercury concentrates in lipids, and brine fly larvae have high fat levels (Herbst et al. 1984, Herbst 1986). Brine flies are also important component diets of eared grebes (*Podiceps nigricollis*) in saline lakes (Jehl 1988). Additionally,

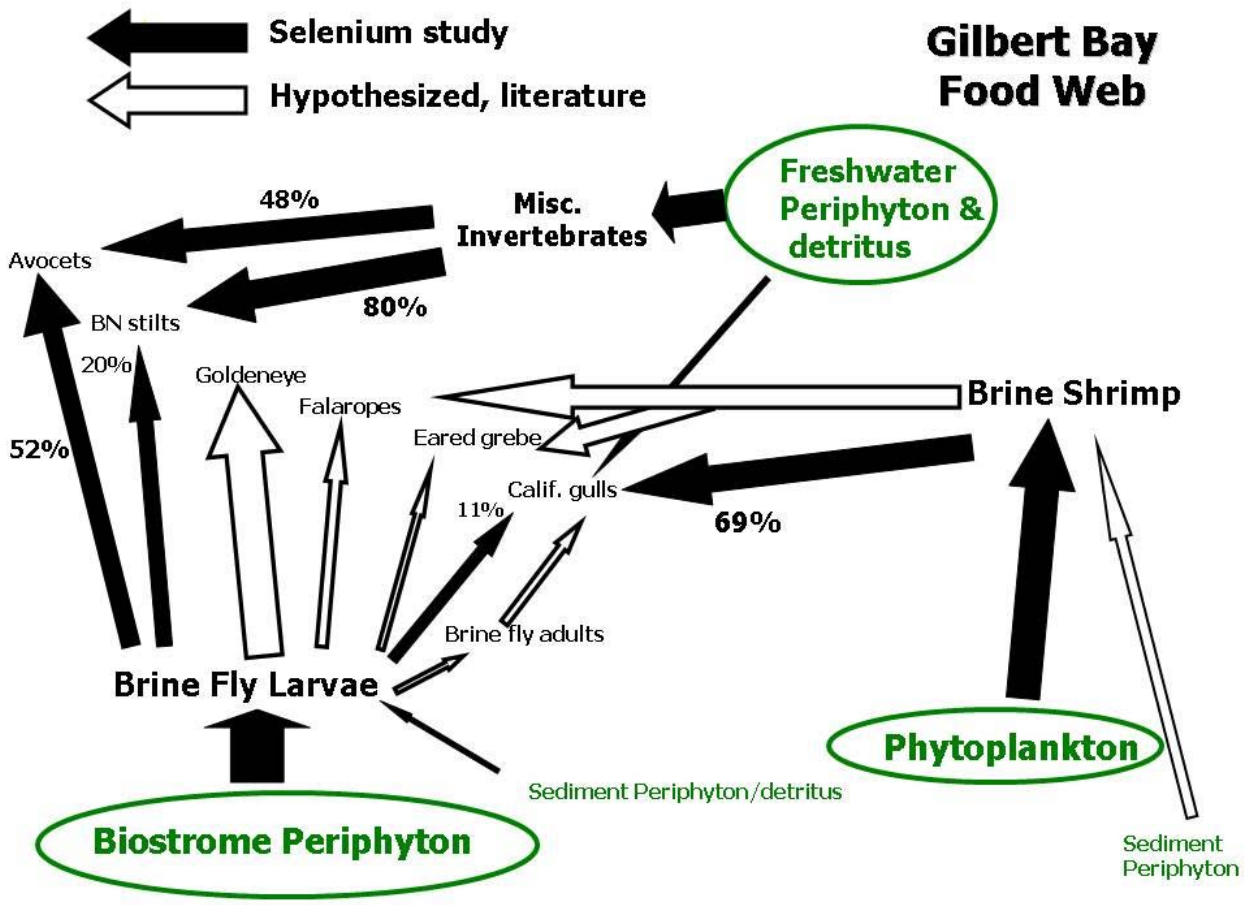

Figure 12. The food web in Gilbert Bay with an emphasis on pathways leading to birds that utilize the lake. The width of the arrows indicates the importance of a pathway. Solid arrows show data taken during the 2006 selenium study. Open arrows are hypothesized pathways based on studies in other saline lakes and ponds. The Freshwater Periphyton and Detritus pathway occurs on the mud flats of Gilbert and Farmington Bays.

red-necked phalaropes (*Phalaropus lobatus*) at Mono Lake feeding on brine flies maintained their weight, whereas those feeding only on *Artemia* lost weight (Rubega and Inouye 1994). The high fat levels and energy content of the Mono Lake brine flies makes them a good prey item for birds, but Caudell and Conover (2006) found that brine flies from the Great Salt Lake had lower caloric densities than did *Artemia*. The dominant brine fly in the Great Salt Lake (*E. cinerea*) is also considerably smaller than the *E. hians* at Mono Lake, so it is possible that the flies in the Great Salt Lake may not be utilized as extensively by birds as are the brine flies in Mono Lake.

Sampling methodology

The benthic habitat of lakes is far more difficult to sample than the open water pelagic areas, and consequently limnologists are just beginning to get good quantitative estimates of processes in this zone. The soft sand and mud sediments in Gilbert Bay were relatively easily sampled with the Ponar Grab. The only difficulty with this sampling device is that the softer sediments often mixed substantially when they were moved out of the dredge into a holding container. This made it difficult to section these types of sediments. A coring device would be better in this regard. Another drawback of the grab was that it sampled only a small area of sediments, and since brine flies were not abundant in this habitat, the variability between samples was high. Frequently, only 1–4 larvae or pupae were found in a dredge sample, so that stochastic errors become very large. The dredge also supplied insufficient numbers of brine flies for selenium analyses.

The bucket sampler was effective for quantifying the brine flies on most of the biostromes, and estimated sample sizes needed to evaluate the abundance of flies was not prohibitive. However, as presently configured, one could not effectively sample on the sides of the domed-shaped biostromes. For future work, it might be possible to attach a cam-strap to the bucket which would allow it to be cinched to the sides of biostromes. Another improvement

would be to attach the hose to the hollow hand brush so that dislodged larvae and pupae could be sucked immediately into the pump tube. This would limit their ability to float out of the bottom of the bucket when the seal is not tight. This loss, however, was not perceived to be significant. Another innovation would be to use a spherical dome instead of a bucket. This would decrease the accumulation of the pupae at the top inside of the flat bucket where they were difficult to move into the pump tube. The pupae are positively buoyant, and when their attachment to the substrate was broken, they floated upward to the top of the bucket, but not necessarily directly into the pump tube.

The periphyton/biofilm community on the biostromes proved to be the most difficult to sample. We were only able to sample by breaking off edge pieces of the biostromes or twisting off protruding pieces from irregularly-shaped domed biostromes. This undoubtedly introduced some bias in our results, although there was no obvious difference in the structure of the periphyton at the edges and in the center of the biostromes. Attempts to core a known area of the calcified material with a hole saw failed because the material crumbled after being “sawed”. Further innovation will be needed to effectively measure the biomass of periphyton and other properties of the biostromes. Additional work also is needed to verify the very high organic matter content we found during this sampling. The biostromes appear to be heavily calcified, yet nearly 60% of the material we measured was organic. Acid dissolution did not change the proportion of organic material we found. After dissolution, a thick plate of rubbery tissue is present that must compose a significant part of the total weight. However, Elser et al. (2005) found that only about 5% of the material scraped from the surface of Mexican biostromes was organic and Eardley (1938) reported that biostromes from the Great Salt Lake were only 2% organic matter, so it is likely that our high estimates are erroneous.

Predicting Sample Sizes Needed for Future Analyses

The benthic sampling in 2006 provides measures of sampling variability that allow us to conduct a power analysis to calculate the number of samples (n) required to determine mean levels at a given confidence level. Assuming normally-distributed variables, the following equation can be used to make these predictions (Prepas 1984):

$$n = \frac{t^2 s^2}{L^2}$$

Where:

n = necessary sample size

t = is the value of the Students' t-distribution for the degrees of freedom associated with the estimate of variance from the pilot survey

s^2 = variance estimate from the pilot survey

L = Allowable error in the sample mean

The power analysis of the 2006 survey data indicated that the number of samples necessary to adequately survey different parameters varied widely (Table 6). To provide a range of examples, the table includes allowable errors in the parameter estimates of 10-40%. For example, with the mean brine fly larval abundance of 5,240/m^2, and if we were able to accept an error of 30% (1570/m^2), and we wanted to be statistically confident at the 95% confidence interval, the analysis suggests that 36 replicate samples would be needed. Many more samples would be needed for Ponar samples of the sand/mud substrates, because the variability among replicates was high relative to the mean. The organic matter content on

Table 6. Input parameters for the power analysis and the estimated sample sizes needed to effectively sample Great Salt Lake biota and selenium concentrations.

					Sample Size Needed (n)			
					With Allowable Error (L) of:			
Parameter	**Mean**	**s**	**s^2**	**t_{95}**	**10%**	**20%**	**30%**	**40%**
Larval abundance - sand (#/m^2)	256	316	99811	2.37	852	213	95	53
Larval abundance - stromatolites (#/m^2)	5240	4013	16105080	2.37	328	82	36	21
Organic Matter Sand (%)	0.062	0.029	0.00082	3.18	216	54	24	13
Organic matter stromatolites (%)	0.580	0.030	0.00089	2.45	2	0.4	0.2	0.1
Chlorophyll on stromatolites (mg/m^2)	698	207	42849	2.45	53	13	6	3
Se Concentrations larvae (µg/g)	1.20	0.26	0.066	3.18	47	12	5	3
Se Concentrations pupae (µg/g)	1.33	0.23	0.052	3.18	30	7	3	2

biostromes varied little, and our data suggest that only 2 samples would be needed to estimate the mean within ± 10%. However, as mentioned previously, we are uncertain about the measurement of organic matter in these substrates, so additional work will be needed to estimate both the organic matter content and the samples sizes needed to adequately characterize this. Selenium concentrations in the brine flies were relatively uniform, so only 7-12 samples would be needed to characterize the Se with a 20% allowable error.

Note, however, that the 2006 survey included only two sites (albeit at several depths). If there is more spatial variability across the lake than that observed along our two transects, a higher number of samples would be needed. However, the two transects differed markedly with respect to biostrome morphometry and with respect to their orientation to inflows, so we may have captured a considerable amount of the actual variability in Gilbert Bay. When additional sampling is done, new power analyses should be conducted with the larger data set to compute the needed sample sizes.

Conclusions and Recommendations

Biostromes and their associated brine fly grazers are an important component of the food web in the Great Salt Lake. In contrast, the open mud and sand substrates appear to produce few brine flies, but more work in different parts of the lake is needed to confirm this. The brine flies produced on the biostromes are an important component of the diet of some birds that may be impacted by selenium, and for a number of other species that utilize the lake.

The preliminary data indicate that selenium concentrations in the organic material of the biostromes and in the brine fly larvae are higher than that in the pelagic zone. Marden (2007) found selenium concentrations of phytoplankton and *Artemia* to be 0.14 µg Se/g and 1.2 µg Se/g, respectively, suggesting that there is approximately a 9-fold bioconcentration factor

between the two trophic levels. In contrast, the preliminary data suggests that benthic periphyton in biostromes contained 1.7 µg Se/g, and larval and pupal brine flies had 1.5 µg Se/g, with a bioconcentration factor near 1. Although the limited benthic data collected so far restricts our inferences, the higher overall concentration of selenium in the benthic periphyton does not appear to pose severe risks higher in the food web due to the absence of bioconcentration.

Additional research is needed to better characterize the seasonal and spatial variability in the benthic habitats in the Great Salt Lake. Funding for this initial work constituted less than four percent of the budget of the DWQ selenium study, so only a limited number of benthic samples were collected and processed. Whereas *Artemia* and their phytoplankton food resources have been studied extensively over the past decade in support of the brine shrimp industry, very little work has been done to understand the brine flies and their biostrome habitats. Increasing eutrophication of Gilbert Bay may alter light penetration and influence the relative contribution of benthic and pelagic algae to the food web. Specific projects that need to be considered include: (1) detailed mapping of the benthic characteristics in the lake, and in particular, the distribution of different types of biostromes in the lake; (2) analysis of the spatial and temporal distribution of brine flies over at least two seasons; (3) increased effort to develop methods for sampling the periphyton and brine flies of the biostromes; (4) additional analyses of linkages between the periphyton, brine flies and the birds that feed on them; (5) studies to determine if *Artemia* utilize benthic food resources.

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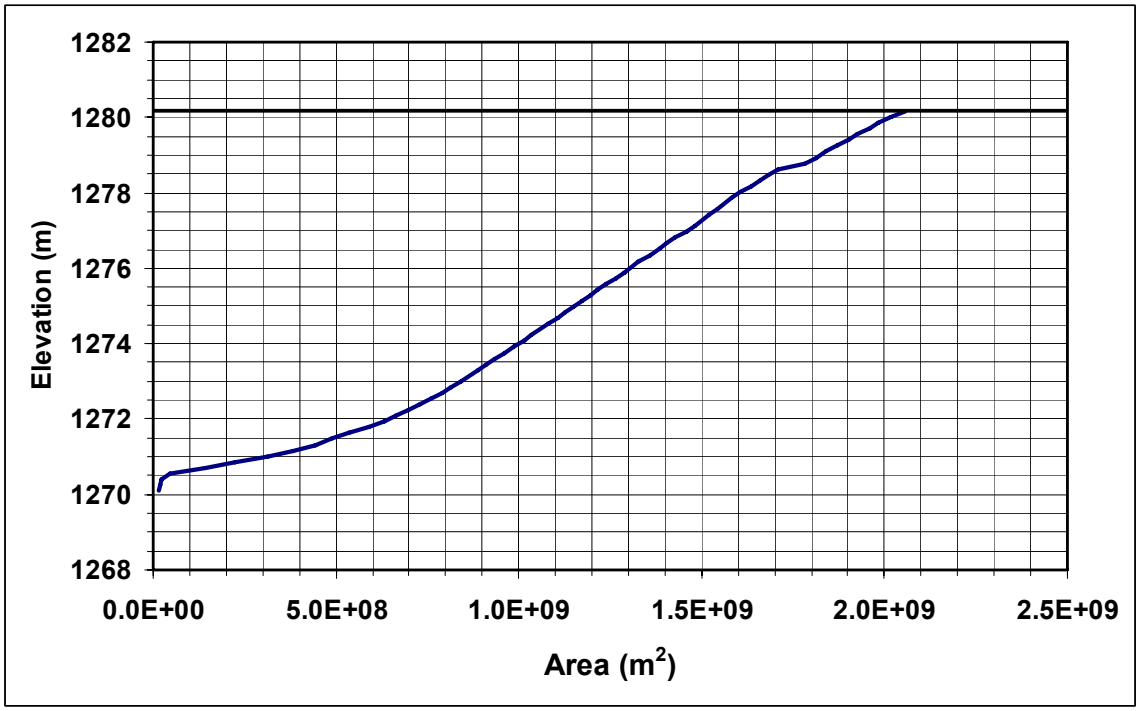
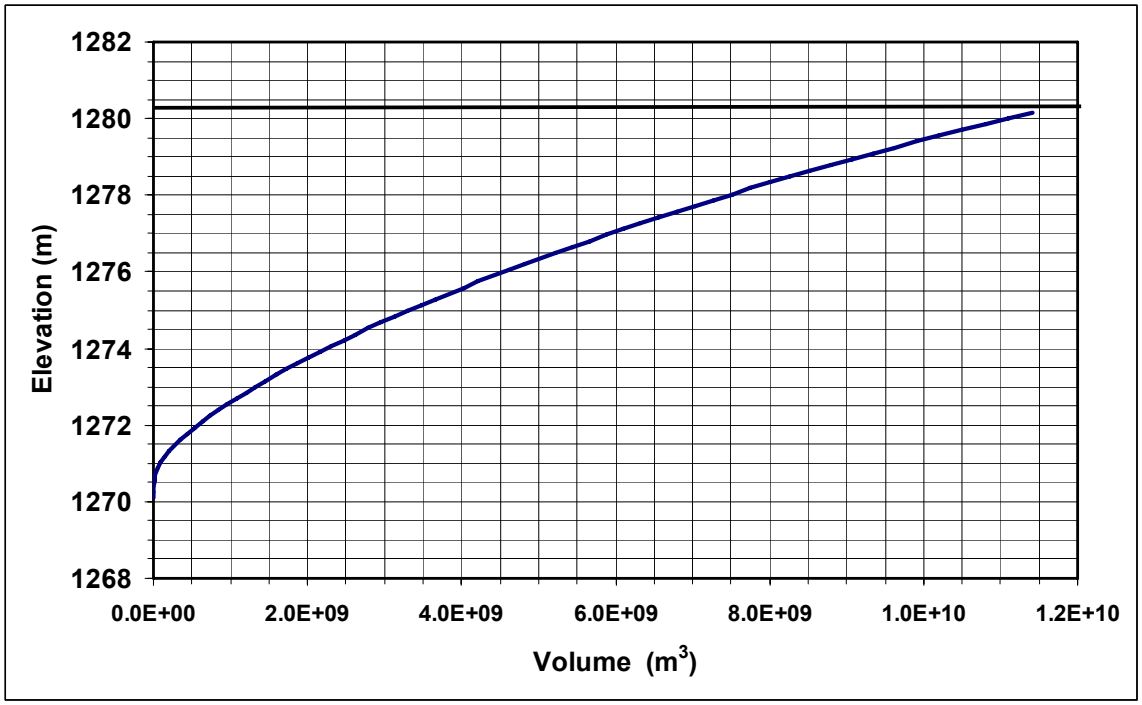
Appendix 1. Hypsographic curves showing the area and volume of Gilbert Bay (excluding Farmington Bay and salt ponds), derived from Baskin (2005). The maximum elevation plotted is 1280.2 m (4200 ft).





Addendum (2007 benthic sediment samples)

Because of the high variability in selenium concentrations found in the sediments in 2006, additional samples were collected on April 28, 2007, at the Bridger Bay site in Gilbert Bay. These were done after the funding for the benthic work had concluded, but they are presented here in the addendum. Mud and sand samples were collected with an Eckman dredge and strata of varying depths and thicknesses were scraped off for analysis. Biostrome (stromatolite) samples were broken off by a diver. Some were treated with 1-N HCl to dissolve the carbonates. Additional acid was added if necessary until all bubbling stopped (within 24 h). All samples were dried to constant weight at 70ºC and sent to LET for analysis of selenium content and organic material. Organic content was measured by combusting the samples at 450°C, adding water back, and then drying to constant weight at 70°C.

In contrast to the 2006 samples, there was a clear distinction in selenium concentrations between sediment types (Table 7; Figure 13). Both percent organic matter and selenium concentrations were significantly higher in acidified than in non-acidified biostromes (paired t-tests; $p = 0.004$ and 0.055, respectively). Selenium concentrations in mud (0.7 ug Se/g) were significantly (ANOVA, $p = 0.002$) higher than in sand (0.3 ug/g) or non-acidified biostromes (0.3 ug/g). However, when the carbonates in the biostromes were removed by acidification, the remaining organic matter (cyanobacteria and its mucilage) had significantly higher concentrations than mud. The ANOVA identified one acidified stromatolite sample (0.6 ug/g) as an outlier (Durbin-Watson D Statistic 1.633). When this value was removed from the analysis, the acidified stromatolite samples had significantly ($p = 0.002$) higher selenium concentrations (mean = 1.2 ug Se/g) than any of the other substrates.

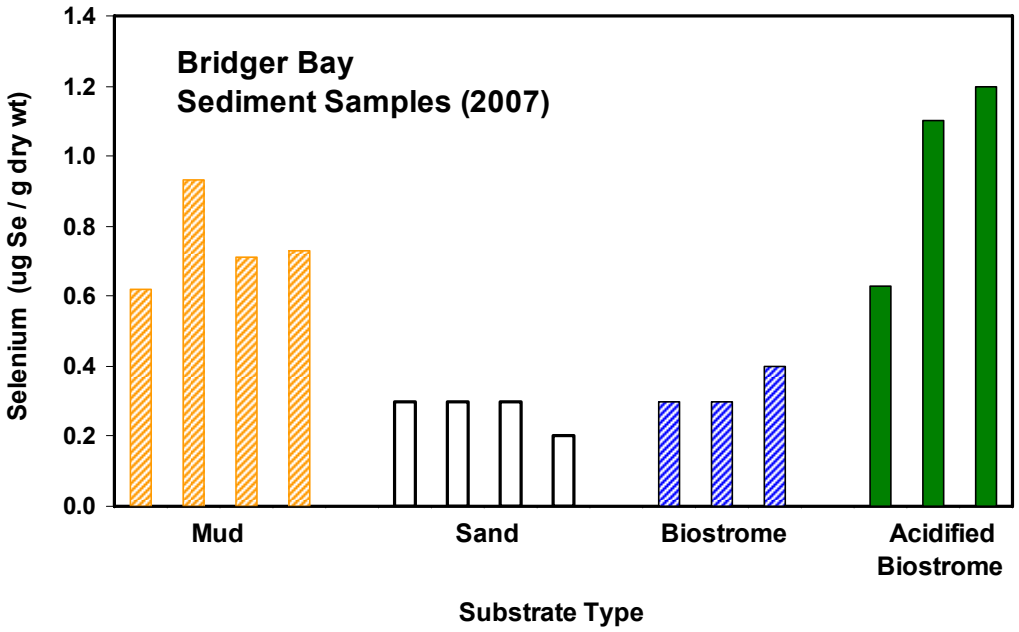


Figure 13. Selenium concentrations in sediments collected in Gilbert Bay (Bridger Bay) in 2007. Each bar represents an individual sample. Acidified biostromes were treated with HCl to remove carbonates.

The organic matter content of all substrates differed significantly ($p \leq 0.001$), with non-acidified biostromes having 27-32% organic content (Table 7). Acidification of the biostromes removed substantial amounts of carbonates, and the remaining material was 69-74% organic matter. There was a suggestion of a correlation between organic matter content in the various substrates and their selenium content (Figure 14), but the correlation was not significant ($p = 0.20$).

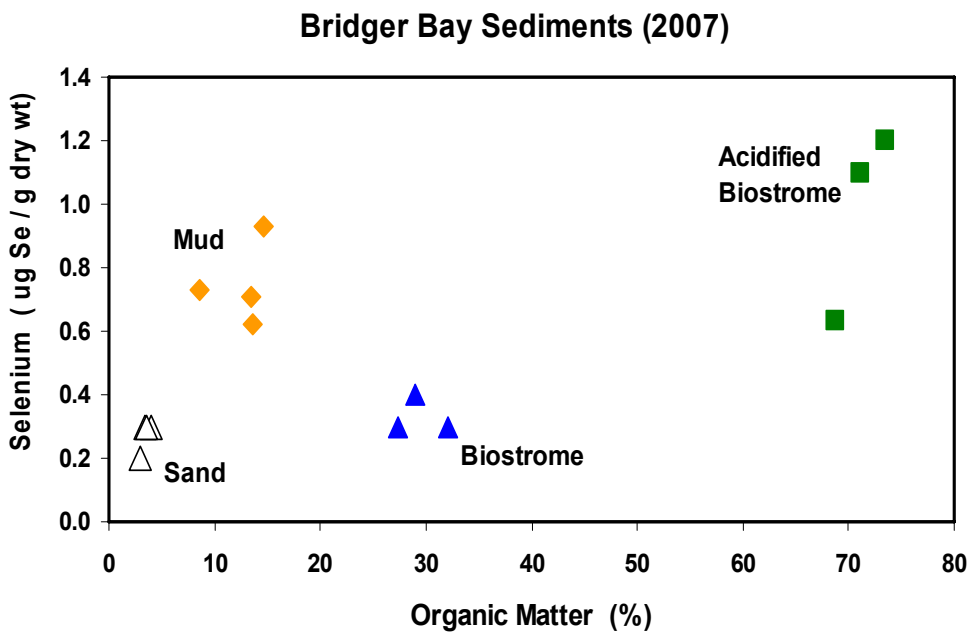


Figure 14. Relationship between the percent organic matter in the substrates from Bridger Bay in 2007 and their selenium concentration.

Table 7. Concentrations of selenium and percent organic matter (% lost on ignition) of sediment samples collected in Bridger Bay on April 28, 2007 (12:00-16:30). Mud and sand samples were collected with an Eckman dredge and strata of varying depths and thicknesses were scraped off for analysis. Biostrome (stromatolite) samples were broken off by a diver. Some were treated with 1-N HCl to dissolve the carbonates. All samples were dried to constant weight at 70ºC. Replicate concentrations of organic material content for one mud and one biostrome sample were measured, yielding very similar values.

Location	Latitude	Longitude	Depth (m)	Sediment strata (mm)	Substrate	Acidified?	% Lost to ignition	µg Se/g dry
Bridger Bay	41.0406	112.2792	2.5	0-3	Mud*	No	13.6	0.6
Bridger Bay	41.0406	112.2792	2.5	3-40	Mud	No	14.7	0.9
Bridger Bay	41.0431	112.2760	3.0	0-3	Mud	No	13.4/13.6	0.7
Bridger Bay	41.0431	112.2760	3.0	3-30	Mud	No	8.6	0.7
Bridger Bay	41.0429	112.2710	1.0	0-3	Sand	No	3.4	0.3
Bridger Bay	41.0429	112.2710	1.0	30-50	Sand	No	3.0	0.2
Bridger Bay	41.0427	112.2737	1.0	0-3	Sand	No	3.9	0.3
Bridger Bay	41.0427	112.2737	1.0	3-50	Sand	No	3.6	0.3
Bridger Bay	41.0426	112.2752	1.0		Biostrome	No	32.1/32.3	0.3
Bridger Bay	41.0426	112.2752	1.0		Biostrome	Yes	68.7	0.6
Bridger Bay	41.0407	112.2788	2.1		Biostrome	No	27.3	0.3
Bridger Bay	41.0407	112.2788	2.1		Biostrome	Yes	71.1	1.1
Bridger Bay	41.0431	112.2760	3.0		Biostrome	No	29.0	0.4
Bridger Bay	41.0431	112.2760	3.0		Biostrome	Yes	73.5	1.2

* Minute amount of sand