

Note to Reviewers: This report is submitted in draft format on currently only includes data from 2006. Review comments have been submitted to Brad Marden. He expects to finalize his report, including the 2007 data, shortly for the Science Panel's review.



**PFC: Research
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PRELIMINARY RESULTS

**GREAT SALT LAKE WATER QUALITY STUDIES
DEVELOPMENT OF A SELENIUM STANDARD FOR THE
OPEN WATERS OF THE GREAT SALT LAKE**

PROJECT 2B

**SYNOPTIC SURVEY OF THE PELAGIC ZONE:
SELENIUM IN WATER, SESTON, AND ARTEMIA**

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EXECUTIVE SUMMARY

A field study of the pelagic zone of the Great Salt Lake, Utah (GSL) was conducted from April 2006 to July 2007 to document selenium concentration in GSL water, seston, and the dominant zooplankton—brine shrimp (*Artemia franciscana*). The transfer of selenium through trophic levels (i.e., water phase, to seston, and then to brine shrimp) in the pelagic zone of the GSL was assessed. Population dynamics of brine shrimp and phytoplankton were also documented. Limnological conditions of the GSL were recorded with respect to those factors that play a key role in the growth and survival of zooplankton and phytoplankton.

The brine shrimp population displayed characteristic cyclical patterns of growth, reproduction, decline, cyst production, and terminal population collapse during the onset of winter. The population structure and size was unremarkable with respect to earlier research on the GSL. Population parameters were well within the boundaries of previously reported population cycles on the GSL (Stephens, 1997, 1998, 1999; Belovsky and Larson, 2001). Average productivity per location (5.53 cysts/L), fecundity (87 cysts/brood), biomass (0.77 mg/L dw), adult densities (1.12 adults/L), cysts in the water column (20.2 c/L), and commercial harvest yields (16.6 million pounds) indicate that this population is in a generally healthy condition (Appendices 2, 3, 4, & 5). As such, *Artemia* biomass available for foraging birds was prevalent throughout the year.

The phytoplankton population was initially composed of diverse taxa; in May there was a mixed population primarily consisting of green algae (Chlorophyceae), diatoms (Bacillariophyceae), blue-green algae (Cyanophyceae), and small numbers of dinoflagellates (Dinophyceae). Later in the summer the population was more homogenous. Chlorophytes progressively increased in relative dominance from 59% in May to 97% in August, 2006. *Dunaliella* was the most dominant genera represented in the GSL over the summer of 2006. Chlorophyll-a measurements from water column samples showed declining values at the beginning of spring (7.0 ug/L in April to 3.2 ug/L in late May 2006) (Appendix 7.1). The concentration of chlorophyll-a over the summer was between 1.3 to 16.0 ug/L. Chlorophyll-a increased steadily, as the brine shrimp population declined in October, from single digits to 20.8 ug/L. The highest chlorophyll-a concentration was measured in January 2007 (41.7 ug/L).

Total selenium concentration results for water were quite consistent spatially but not temporally. The geometric mean of selenium in water for all sample dates and locations was 0.584 ug/L (Appendix 8.5). The lowest and highest concentrations of selenium in water were 0.297 and 0.899 ug/L respectively. A net increase of 0.033 ug/L was calculated on a lakewide basis for sequential sampling dates. The cumulative net change for selenium in site-specific water samples (deep and shallow sites only) was +0.098 ug/L. These values are within one standard deviation of the mean selenium concentration in water samples and may be more a function of sample variability than a confirmation of increasing selenium loading in the GSL. Among seston selenium concentrations, the geometric mean was 0.415 ug/g and the arithmetic mean was 0.504 ug/g (Appendix 8.3).

The low and high seston values were: 0.167 ug/g and 1.408 ug/g respectively. The particulate fraction of selenium in water was determined from the seston selenium concentration reported on a per liter basis (i.e., the number of liters filtered for each seston sample). The geometric mean of selenium in seston using a per volume basis was 0.097 ug/L and the arithmetic mean was 0.105 ug/L (Appendix 8.4). The arithmetic mean concentration of selenium in adult *Artemia* tissue was 1.185 ug/g and the geometric mean was 0.984 ug/g (Appendix 8.1). Adult brine shrimp had a high selenium concentration value of 3.300 ug/g and a low value of 0.100 ug/g. Values for selenium in brine shrimp tissue were below the 5 ug/g level of concern for protection of birds.

Transformed data (Johnson transformation) were analyzed using one-way ANOVA (site, date, or geographic location) or T-tests (depth category). No significant differences in selenium concentration among water samples were found for location ($P = 0.736$, df: 2, 63) or water depth categories ($P = 0.119$, df: 1, 57). Results for water samples did show significant differences in selenium concentration across sample dates ($P < 0.01$, df: 9, 56). Results for brine shrimp were also nonsignificant for location ($P = 0.759$, df: 2, 77). They were, however, significantly different for depth categories at the $P < 0.10$ level ($P = 0.085$, df: 1, 65). There were statistically definable differences temporally in brine shrimp tissue selenium concentration ($P < 0.01$, df: 11, 68). Seston samples were uniform across sample sites ($P = 0.963$, df: 5, 51) and geographic location ($P = 0.614$; df: 2, 60), yet differed substantially across sample dates ($P < 0.01$, df: 9, 53).

The data suggest that there are temporal events that influence selenium loading into specific trophic compartments. However, when results for each biological or physical compartment are examined collectively over the course of multiple months, and evaluated spatially, they do not differ in statistical measures of central tendency. Although some putative factors that may affect the temporal pattern of selenium in biological tissues have been inferred (e.g., interaction between *Artemia* and phytoplankton population fluctuations) it is not clear from the present study which factors are most important, or mechanistically, how such factors, or biochemical processes, may function within the GSL biota.

The selenium load in brine shrimp biomass is an inconsequential factor in the overall mass balance of selenium in the GSL; the maximal load in *Artemia* biomass was 22.24 kg and the average load was 10.31 kg. The estimated amount of selenium removed from the GSL via commercial harvesting of brine shrimp cysts is similarly trivial—2.21 kg to 10.75 kg per year.

There is little evidence of biomagnification in the selenium results—as has been corroborated in the scientific literature and by other authors in the GSL Selenium Study Group (Wurtsbaugh, 2007). Regression relationships describing the transfer of selenium between trophic levels in the food web cannot be defined by the present data. This is not surprising in terms of the range of concentration (0.6 ug/L) to which brine shrimp are exposed in the water column. Similarly, brine shrimp are exposed to a small range of selenium from seston (1.24 ug/g or 0.24 ug/L). Even with a relatively large sample size it

is unlikely that GSL field data will provide meaningful regression relationships over such a small exposure concentration range.

Because of this, it has been necessary to calculate paired transfer factors between trophic compartments and to use these values to examine the relationship between the exposure concentration of selenium and tissue levels in brine shrimp. Transfer factors represent a very simplistic interpretive tool—they are in essence a snap-shot view of the relationship between brine shrimp and their environment. Transfer factors do not capture the dynamic biological, chemical, and physiological interactions that are involved in the uptake, metabolism, transport, storage, depuration and impact of selenium in biological systems. The application of transfer factors for the purposes of modeling selenium flow through the food web is therefore quite limited.

In this study we calculated transfer factors of: 3.23 for seston (ug/g) to adult *Artemia* (ug/g); 1.99 for total water (ug/L) to adult *Artemia* (ug/g); and, 0.86 for dissolved water selenium (ug/L) to seston (ug/g). Laboratory studies on the progression of selenium through each trophic level in an artificial food web are currently underway (Grosell, 2007). The data derived from such controlled studies can be used in conjunction with field generated transfer factors to more effectively model the trophic transfer of selenium through the GSL food web.

INTRODUCTION

The study was undertaken to support the State of Utah Department of Environmental Quality, Division of Water Quality in their effort to establish a site-specific water quality standard for selenium in the Great Salt Lake. This process involves an in-depth, multi-disciplinary approach for evaluating and modeling the transfer of selenium through identifiable trophic compartments of the GSL food web. The goal of which is to understand the transport, loading, loss, biogeochemical cycling, bioavailability, fate, and impact of selenium on biota within the GSL ecosystem. This information will be used to model changes that may occur as a result of increased selenium loading into the waters of the GSL. One of the simple, but very challenging, questions we are trying to address is: What impacts can be expected in the critical biota (i.e., brine shrimp, brine flies, and avifauna) found within the GSL, and its surrounding environs, if the selenium load into the GSL were increased? This is one of many questions being addressed by the GSL selenium study group, but it is the preeminent question that forms the conceptual basis for this current study on selenium in water, seston and brine shrimp (*Artemia franciscana*) in the pelagic zone of the GSL.

This preliminary report provides a summary of a detailed investigation into the trophic transfer of selenium from the water phase, to seston (suspended particulate fraction), and then to brine shrimp. Also included is an in-depth examination of the population dynamics of brine shrimp and the phytoplankton population that comprises the dietary foundation for the brine shrimp. Brine shrimp population dynamics are considered from three perspectives: 1) comparative population dynamics as a measure of population

integrity, 2) reproductive capacity, cyst production, biomass for foraging birds, and 3) as a biological conduit through which contaminants are modified and transferred to higher trophic level consumers. Phytoplankton population dynamics are studied somewhat less rigorously, but are evaluated in sufficient detail to ascertain the dominant algal taxa and general spatial and temporal patterns. Limnological conditions are examined with respect to key abiotic factors that exert a pronounced influence on the GSL biota.

Selenium in each trophic compartment is evaluated and transfer factors are described. The data are ultimately intended to be incorporated into the conceptual model of selenium in the GSL as developed by Dr. Bill Johnson (2006) and further refined by our colleagues at CH2M HILL.

It should also be acknowledged that the data presented herein are from the first year in a rather extensive field investigation. Inherent in any large scale field study there is an unavoidable element of surprise; such as irksome delays, equipment malfunctions, unanticipated logistical obstacles, weather related complications, and other challenges. During this field study there was a need for periodic refinements, improvements, and modifications in the sampling and analytical procedures. The outcome of this process is, hopefully, a better understanding the GSL ecosystem as well as the development of improved experimental methods that can help the DEQ/DWQ during future scientific inquiries into the fate and effects of contaminants within the GSL ecosystem.

METHODS

Geographic Regions of the Great Salt Lake

This study was conducted exclusively in the South Arm (Gilbert Bay and Carrington Bay) of the Great Salt Lake. Any reference to the Great Salt Lake (GSL) hereafter refers to the South Arm only and excludes the region of the GSL north of the railroad causeway, unless otherwise specified. For the purposes of this study three regions of the GSL were defined and clusters of sample sites were located in each region. The regions were based on primary sources of inflow. Ogden Bay and the northeast region of GSL receive water from Farmington Bay and Ogden, Weber, and Bear River drainage basins. In the southeast region of the GSL drainages from Tooele Valley, the Oquirrh Mountains, and overflow canals from the Jordan River provide the predominant inflow volume into the lake. This is also the region of the GSL in closest proximity to the drainage zone for Kennecott's outflow pipe. The central region of GSL (north of Hat Island) is isolated from any specific surface inflow source and is primarily a mixing zone of currents from Gilbert and Carrington bays. Deep brines from Gunnison Bay (North Arm) of the GSL are channeled along a subsurface fault ridge (Allen Ridge) in this area of the lake. Due to the known differences in lake current characteristics and tributary influences among these three regions site selection was stratified to include representative sample sites from each of these areas.

Sample Site Location and Characteristics.

Within each region further stratification of sample site designation based on depth and substrate was included (Table 1). Previous studies suggest that depth and substrate may have an influence on phytoplankton and *Artemia* population growth and abundance (Marden, unpublished). Deep sites of the GSL with an associated deep brine layer may be subjected to profoundly different geochemical cycling mechanisms than those associated with shallow or medium depth sites (Naftz, pers. com.). Light penetration and temperature factors also differ markedly between these sites and likely play an important role in biogeochemical dynamics. Depth categories included: shallow (1-3 meters in depth), medium (5-6 meters in depth), and deep sites (7-8 meters in depth). The respective elevation contours were roughly 4190, 4180, and 4170 foot contours.

The substrate differed among the depth profiles. Shallow site substrate is predominantly characterized by the presence of calcified biostromes and oolitic sand. Biostromes, also referred to as bioherms or stromatolites, are calciferous formations that markedly increase the substrate surface area and may provide a unique micro-habitat that supports microalgae and benthic invertebrates (Wurtsbaugh, 2007). Medium depth site substrate is generally mixed sands and mud. The deep site substrate is a gelatinous mud (described as “ooze” by Johnson, 2007) composed of decomposing organic matter intermixed with inorganic components. The substrate within each deep site was found below the chemocline, or deep brine layer. This layer is formed by the presence of a dense North Arm brine layer (with a salinity typically in the range of 170 to 200 parts per thousand) and characterized by an anoxic and strongly reducing hydrochemical profile (Naftz,

2007). Sample site locations, depth characteristics, and substrate composition are detailed below in Table 1.

Table 1. Sample site characteristics and geographic coordinates.

SITE ID	Max. Depth	Depth Category	Region	Substrate	Latitude	Longitude
1	2	Shallow	Northeast	Stromatolite/Mud	41.07.767	112.17.631
2	6.5	Medium	Northeast	Sand/Mud	41.05.097	112.21.145
3	8.5	Deep	Northeast	Gelatinous Mud	41.05.207	112.24.372
4	2	Shallow	Central	Stromatolite	41.05.137	112.35.437
5	6	Medium	Central	Sand/Mud	41.07.066	112.33.514
6	9	Deep	Central	Gelatinous Mud	41.06.440	112.38.260
7	1.5	Shallow	Southeast	Stromatolite	40.52.685	112.13.838
8	6	Medium	Southeast	Sand/Mud	40.49.524	112.11.431
9	8.5	Deep	Southeast	Gelatinous Mud	40.50.786	112.16.711

Sample site locations in Gilbert Bay are portrayed below in Figure 1. It is evident from the map that sample sites were clustered regionally. Bathymetric contours, along with field validation of substrate characteristics, were used to define site location according to depth category designations. A strictly randomized approach for sample site designation, along with a greater number of sample locations, was simply not feasible given the scope and financial resources for this project. A stratified-random approach was determined to be a manageable and sound approach for the experimental design.

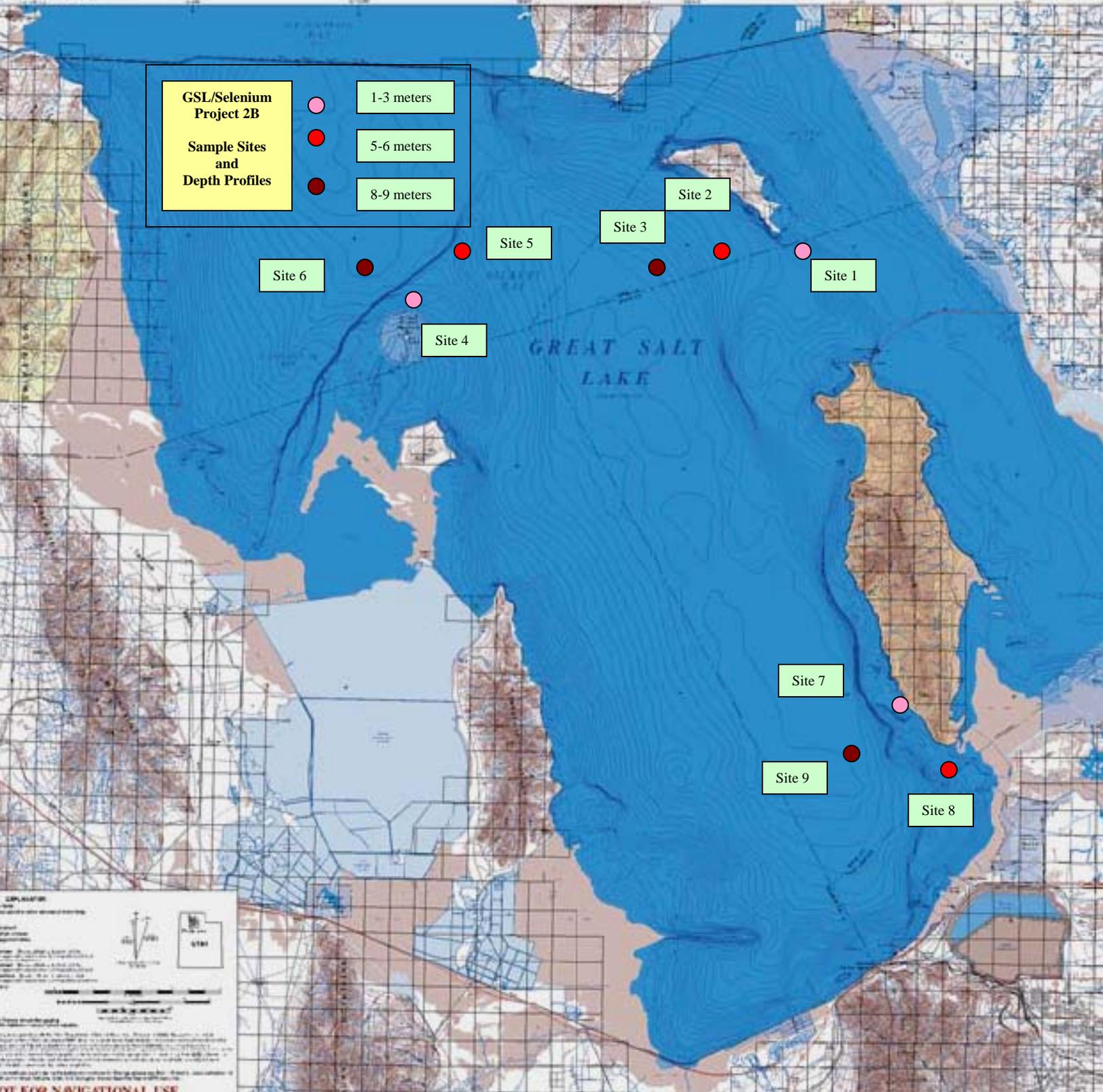


Figure 1: Great Salt Lake, Gilbert Bay. Sample site locations. Sample locations were based on a stratified random design. Substrate composition, water depth and three geographic regions of Gilbert Bay were used for sample site locations.

Sampling Schedule

Sampling of the GSL began in April 2006 and has continued through June 2007. Three more sample programs are scheduled for the summer of 2007. A total of 18 sampling programs have been completed with a final total of 21 sampling programs to be completed under current funding.

Nine sample sites were visited from April 2006 through June 2006. From July 2006 through June 2007 six sample sites were used for sample collection. This reduction in sample sizes was foreseen at the onset of the project and was implemented as a means of reducing time and analytical costs. Weather was an important consideration during the sampling programs and was a determining factor in the ability of the sampling crew to complete all sites within a sample program time period. Figure 2 depicts one of the many weather related complications encountered on the GSL. The maximum allowable time period for a sampling program was set at 7 days. The primary objective of sampling was to complete all sampling on one sample day, or as short a period as allowable by weather, equipment function, and conditions on the GSL.

Figure 2. Extensive ice formations were encountered on the GSL during January 2007. Ice extended from Promontory Point to beyond Hat Island (sample site # 6). Diverse conditions on the GSL, such as high winds or ice sheets, rendered successful sampling at predetermined times quite challenging.



Sample collection, transport, and storage.

A summary of the samples collected is shown below in Table 2. Biological and water samples were collected at each sample location. All samples were promptly stored on wet ice for transport to the laboratory. Abiotic factors were measured at each site and included temperature, dissolved oxygen, and salinity measurements at discrete intervals within the water column.

Table 2. The sampling program schedule and number of samples collected are shown. Not all samples collected have been analyzed, nor were they all intended to be analyzed. Some extra samples were collected opportunistically to expand the potential research scope of the project. Occasionally sample sizes were insufficient for analyses, or samples were not used for analysis due to budget constraints. Remaining samples are preserved by freezing (biomass), acidification and refrigeration (water samples), or with formaldehyde/Lugols iodine and refrigeration (algae samples).

Sampling Program	Sampling Dates	Artemia Biomass Samples	Water Samples	Seston Samples	Algae Samples	Chl-A Samples	Isotope Samples	Artemia Population Samples
Program 1	4/30/06	18	0	0	6	6	6	7
Program 2	5/4-12/06	42	0	0	8	8	14	14
Program 3	5/24-25/06	27	18	9	9	9	9	9
Program 4	6/12-13/06	18	0	0	6	6	6	6
Program 5	6/22-29/06	27	27	9	9	9	9	9
Program 6	7/10-13/06	18	18	6	6	6	6	6
Program 7	7/26-27/06	18	18	6	6	6	6	6
Program 8	8/18-23/06	18	18	6	6	6	6	6
Program 9	8/25-28/06	18	18	6	6	6	6	6
Program 10	9/18-24/06	18	18	6	6	6	6	6
Program 11	10/14/06	18	18	6	6	6	6	6
Program 12	11/20/06	18	18	6	6	6	6	6
Program 13	12/2/06	18	18	6	6	6	6	6
Program 14	1/26/07	18	18	6	6	6	6	6
Program 15 (Selenium Species)	3/15/07	0	0	3	3	3	0	0
Program 16	5/4-7/07	18	18	6	6	6	6	6
Program 17	5/22-23/07	18	18	6	6	6	6	6
Program 18	6/9/07	18	18	6	6	6	6	6
Program 19	6/27/07	18	18	6	6	6	6	6
Comparative Biomass Exp.	5/8/07	18	0	0	0	0	0	0
Seston Filter Exp.	9/24/06	0	0	18	0	0	0	0
GSL Water Storage Exp.	7/27/06	0	8	0	0	0	0	0
SAMPLE TOTALS		384	287	117	119	119	122	123
GRAND TOTAL	1,271							

Table 3 lists the type of sample collected at each sample location, filtration (if included), replicates, preservative used, and storage conditions. Each sampling procedure is described in greater detail below.

Table 3. Sample type or matrix, analytical procedure, filtration steps, inclusion of replicate sample, preservative, and storage conditions for biological and water samples collected.

Sample Matrix/Type	Analysis	Pre-Filtration	Collection Filter	Replicate or Pooled Sample	Preservative	Storage
GSL Water	Total Selenium	Yes 125 micron	No	Rep.	Nitric Acid	Refrigeration ¹
GSL Water	Dissolved Selenium	Yes 0.45 micron	No	No	Nitric Acid	Refrigeration ¹
Seston	Total Selenium	Yes 125 micron	Yes 0.45 micron	No	None	Freezing -25 to -30 C
<i>Artemia</i> Biomass / Adult	Total Selenium	No	Yes 850 micron	Pooled	None	Freezing -25 to -30 C
<i>Artemia</i> Biomass / Juvenile	Total Selenium	No	Yes 500 micron	Pooled	None	Freezing -25 to -30 C
<i>Artemia</i> Biomass / Nauplii-Cyst	Total Selenium	No	Yes 125 micron	Pooled	None	Freezing -25 to -30 C
<i>Artemia</i> Biomass	<i>Artemia</i> Population	No	Yes Plankton Net	Pooled	None	Refrigeration (less than 24 h)
GSL Water	Phytoplankton Population	Yes 125 micron	No	No	Lugol's/Formalin	Refrigeration
GSL Water	Chlorophyll ²	Yes 125 micron	Yes 0.45 micron	No	None	Freezing -25 to -30 C
GSL Water	Chlorophyll	Yes 125 micron	No	No	MgCO ₃	Refrigeration

1. Water samples from May 25, 2006 to July 13, 2006 were initially stored at +5C, but were stored at -25C for a period of approximately 1 month.

2. Chlorophyll samples from May 4, 2006 to Oct 18, 2006 were filtered through 0.45 micron cellulose acetate filters and then stored in freezer until analyzed. Subsequent water samples were preserved with MgCO₃ and then promptly sent to Aquatic Research Inc. laboratory for chlorophyll analysis.

Depth intervals for sample collection and abiotic measurements.

Both biological sample collection and abiotic measurements were taken at specific depth intervals. Water samples were comprised of pooled samples collected at discrete depth intervals. *Artemia* samples were collected via pooled vertical, or horizontal (for the 1 meter sites only), plankton net hauls. Abiotic measurements included temperature, dissolved oxygen, and salinity. These measurements were taken at discrete intervals within the water column. The depth intervals of each abiotic measurement and biological sample collection are listed in Table 4.

Table 4. Sampling depth profile for abiotic measurements and biological sample collection.

Sample Site Depth Category	Dissolved Oxygen (discrete intervals)	Salinity (discrete intervals)	Temperature (discrete intervals)	<i>Artemia</i> for Selenium Analysis (depth to surface)	<i>Artemia</i> for Population Assessment (depth to surface)	Seston For Selenium Analysis (pooled discrete intervals)	Water Samples For Selenium, ChlA & Algae (pooled discrete intervals)
Shallow	1 M	1 M	1 M	1 M	1 M to S	1 M	1 M
Medium	1,3,5 M	1,3,5 M	1,3,5 M	5 M	5 M to S	1,3,5 M	1,3,5 M
Deep	1,3,5,6,7 M	1,3,5,6,7,8 M	1,3,5,6,7,8 M	5 M	7 M to S	1,3,5 M	1,3,5 M

Water Samples for Selenium Analysis.

Water samples were collected by means of a GeoPump™ peristaltic pump, supplied with Teflon™ lined tubing, and Masterflex® tubing. Samples were filtered through a 125 micron stainless steel sieve and collected in a 3 liter HDPE cylinder. Equivalent volumes were collected from 1, 3, and 5 meters depth for medium and deep sites and just from 1 meter depth from the shallow sites. Pooled volumes of GSL water were mixed thoroughly and then 250 ml samples were collected in certified and pre-cleaned HDPE or glass bottles. Water samples for dissolved selenium analysis were prefiltered through a 0.45 micron, high-capacity cartridge filter. All tubing, bottles, and sample containers were pre-cleaned in the laboratory with DI water and a 2% solution of nitric acid. Field and method blanks were included in each sample program. Bottles were stored on ice for transport and then 2 ml of nitric acid were added to preserve solutions (pH < 2.0). Nitric acid was added within 12 hours of sample collection. Samples were then stored at 5C until shipment for selenium analysis. Early samples (May 25 to July 13th) were initially stored at 5C, but with delays in funding and the uncertainty of the analytical schedule were stored at -25C. All subsequent water samples were stabilized with nitric acid and stored at 5C until analysis.

Water Samples for Phytoplankton and Chlorophyll Analysis

Water samples used for chlorophyll analysis or for the identification and enumeration of phytoplankton were collected at discrete intervals using a 2.2 liter horizontal alpha bottle. Water samples were collected at 1, 3, and 5 meters for medium and deep sites and at 1 meter depth for the shallow sites. The water samples were filtered through a 125 micron sieve to remove zooplankton and large suspended particulates. Equivalent volumes were

collected at each depth interval providing a final volume of 1 liter each for phytoplankton and chlorophyll determination. Prior to preservation, all water samples were contained in amber Nalgene® bottles, stored on ice, and then transported to the laboratory. Water samples to be used for phytoplankton analysis were treated with Lugol's solution (0.5%) following which formaldehyde was added (1% formaldehyde). Water samples for chlorophyll analysis collected from May 4, 2006 to October 18, 2006 were vacuum filtered through a 0.45 micron cellulose acetate filter, wrapped in foil, placed in Whirlpak® bags and stored at -25C until being analyzed. Water samples collected after October 2006 and used for chlorophyll analysis were preserved with 1 ml per 1000 ml from a 1% stock solution of $MgCO_3$ and then refrigerated prior to shipment for analysis (usually shipped within 24-48h). Analysis of chlorophyll for these water samples was generally completed within one to two weeks of sampling.

***Artemia* Biomass for Population Assessment.**

Figure 3. Collecting brine shrimp with a plankton net.



Brine shrimp samples were collected by means of replicate vertical net hauls using a 50 cm diameter plankton net with removable collection cup (Figure 3). Duplicate net hauls were obtained from 1m, 5m, and 7m to the surface for shallow, medium, and deep sample sites respectively. The net haul contents were stored in 1 L Nalgene® bottles on ice and then transported to the laboratory. In the laboratory samples

were prepared by filtering the entire contents through 850, 500, and 125 micron sieves, resuspending in a known volume, and then replicate (n= 6 to 12) samples were obtained and counted. The volume of subsamples counted was typically 4% to 12% of the total volume. Brine shrimp were grouped according to specific age classes: the age classes defined for the purpose of this study included nauplii, meta-nauplii, juveniles, and adults. Cysts and empty shells were also identified and counted. Gender determination of adults was recorded as were the brood contents and brood sizes of gravid females. The dry weight biomass for each sample was assessed. Gravid females were randomly selected, isolated, and used for brood size and characteristics determination. Ovisacs were dissected and all brood contents were identified and counted. If possible, 10 females from each site and representing each brood type were dissected. The maximum possible

number of dissections was 270 per sampling program, but fewer were often counted due to lack of adequate numbers of gravid females for each brood type. Population enumeration was completed within 24 to 36 hours of sample collection. In one exception, the biomass was stored in formaldehyde and counted later.

***Artemia* Biomass for Selenium Analysis.**

Brine shrimp were collected via horizontal or vertical plankton net hauls. Multiple vertical net hauls were used for medium and deep sites (5 meter net hauls) whereas vertical or horizontal net hauls were employed for the 1 meter sites. The net haul contents were filtered through a sequence of three stainless steel sieves:

850, 500, and 125 micron opening size. Each fraction was rinsed with pre-filtered GSL water, collected in Whirl-pak® bags, and then stored on ice for transport. In the laboratory the brine shrimp samples were poured into pre-cleaned petri dishes where brine

Figure 4. Brine shrimp separated on the sampling vessel into three age classes (adult, juvenile, nauplii-cyst).



shrimp were carefully separated from other zooplankton or debris, water was removed via pipette, and then samples were frozen at -25C. Samples collected during 2007 were vacuum filtered as an additional measure to remove excess GSL water. All biomass samples were stored in a freezer at -25C until being shipped for analysis.

Seston Samples.

Seston samples were extracted from GSL water collected in the manner outlined above for water samples. Pooled water samples from discrete intervals in the water column were collected via peristaltic pump and filtered to remove particulates and zooplankton greater than 125 microns.

Figure 5. Seston filtration using Geotech polycarbonate housing and 0.45 μ m, 142 mm, flatstock filters.



The pre-filtered GSL water was then pumped through a 0.45 micron flatstock cellulose acetate filter housed in a 142 mm polycarbonate in-line filter holder (Geotech) (Figure 5). The volume of water filtered generally ranged from one to five liters. The 0.45 micron filter was then removed from the filter housing, folded, placed in a Whirl-pak® bag, and stored on ice for transport. The filters were immediately placed in a freezer (-25C) upon return to the laboratory and remained frozen until analysis. Dry filter weights were predetermined and were deducted from freeze-dried weights of the seston samples to allow for selenium determination on a dry weight basis. Volumes filtered were used for calculations of selenium concentration in seston on a per volume basis.

Abiotic Measurements.

Select limnological conditions were evaluated at each sample location including water transparency, dissolved oxygen, temperature, and salinity. Dissolved oxygen was determined using a YSI 550A meter calibrated to a salinity of 70 ppt (maximum possible for instrument). Dissolved oxygen was recorded at each site at depth intervals of 1 m (shallow sites), 1m, 3m, 5m, and 6m (medium depth sites), and 1m, 3m, 5m, 6m, 7m, & 8m for the “deep” sites. Because of the high salinity of the GSL dissolved oxygen is reported only as a percent of saturation. This is done due to the probable instrument error in reporting mg oxygen per liter. Calibration of the instrument and subsequent reporting of mg/l oxygen may be provided in the final project report. Temperature and salinity were also determined and recorded at these same intervals in the water column (Figure

6.0). Salinity was assessed by means of a refractometer and temperature was obtained from a temperature probe on the YSI 550 meter. Water transparency was recorded through observations of the final visible depth of a submerged 20 cm black-and-white Secchi disk.

Figure 6. Abiotic measurements.



Selenium Analysis in Water Samples.

All water samples were sent to Frontier GeoSciences Inc., Seattle, WA for determination of dissolved and total selenium. Total selenium included the dissolved and particulate

fraction in water samples. Analytical procedures included hydride generation--atomic fluorescence (HG-AF).

Selenium Analysis in *Artemia* Biomass and Seston.

All brine shrimp biomass samples and seston samples were sent to LET Inc. laboratory in Columbia, MO for analysis. Total selenium in the biological samples was carried out following acid digestion procedures and then analyzed using hydride generation coupled with atomic absorption spectrometry. The selenium instrument detection limit was 0.01 ug and the tissue detection limit was 0.1 ug/g tissue. Prior to acid digestion, LET Inc. freeze-dried samples and provided dry weight values for each sample.

Chlorophyll Analysis.

All samples used for determination of chlorophyll-a and phaeophytin concentration were sent to Aquatic Research Inc. in Seattle, WA. Chlorophyll-a was determined using fluorometric methods with a detection limit of 0.1 ug/L.

Phytoplankton Identification and Enumeration.

Preserved phytoplankton samples were sent to the Laboratory of Ichthyology and Hydrobiology, Uzbekistan Academy of Sciences (LIH-UAS), Tashkent, Uzbekistan. Microalgae were identified to the level of family, genus, and species if possible. Results were reported in abundance per unit volume as well as the biovolume of representative algal species per volume GSL water sampled. Identification was based on morphological features alone. Molecular markers were not used for confirmation of algal species identification. This laboratory was chosen because they have previously provided algae

identification for saline lake research projects funded by NATO, in cooperation with the *Artemia* Reference Center, University of Ghent, Gent, Belgium, and due to the greatly reduced analytical costs relative to laboratories in the U.S.

Samples preserved with Lugol's and formaldehyde were shipped to LIH-UAS where they were further processed and prepared for algal cell identification. Samples were vacuum filtered through Millipore brand glass fiber filters with a pore size of 0.45 microns and a 47mm diameter. Filtered algal cells and the filter disk were placed in 47 mm petri dishes and the cells were re-suspended by means of washing with 3 ml of distilled water. A minimum of 15 minutes of mixing was allowed for the cells to be washed from the filters. A 100-microliter aliquot was then introduced into a Palmer counting cell. Algal cells were examined at 400X to 1000X power using a Zeiss or Canon microscope with bright-field and phase contrast optics. A 10-mm reticle was used for the enumeration and size measurements of algal cells. Identification and characterization of algal cells was taken to the species level if possible. Cell counts and biovolume measurements were conducted according to the methods of Wetzel, Likens (2000) and Hillebrand et. al. (1999).

Additional supporting experiments.

Comparative study of *Artemia* biomass sampling methods and their influence on apparent selenium concentration.

Brine shrimp biomass was sampled concurrently using two different methods of sample collection and subsequent processing or cleaning prior to analysis. One method involved collecting brine shrimp, and any other debris or zooplankton, from the upper 1 meter of

the GSL by hand held plankton net. The sample was then placed in a ziplock bag, stored on wet ice, transported to the laboratory, frozen, and later shipped in a frozen condition to LET Inc. for analysis. No subsequent processing was included. The alternative method included the procedures defined previously for sampling and processing *Artemia* biomass for selenium analysis. Specifically, samples were collected from the water column by plankton net, filtered through tiered stainless steel sieves (850, 500, and 125 micron), placed in Whirl-pak® bags, stored on ice, and transported to the laboratory. The samples were then separated from any incidental debris or other zooplankton. The cleaned samples were then split into two fractions: those placed directly into Whirl-pak® bags and frozen, versus those that were subsequently vacuum filtered to remove excess GSL water before freezing. The resulting biomass samples were stored at -25C until analyzed by LET Inc. for total selenium.

Influence of storage conditions on selenium determination in water samples.

Replicate water samples were collected, acidified, and then stored either in a refrigerator (+5C) or in a freezer (-25C). The purpose of this small study was to determine if storage conditions exerted any influence on selenium determination in GSL water samples.

Comparative study of three different flatstock filters for the collection of seston and subsequent determination of total selenium.

Suggestions for trying alternative filter types for the collection of seston arose during the course of this study. Other researchers have tried a variety of flatstock filter types and pore sizes for the purpose of collecting seston from water samples. Three different filters

were used for the study: 0.45 and 0.8 micron cellulose acetate filters and 0.45 polycarbonate filters. All filters were 142 mm filters and were housed in a GeoTech polycarbonate filter housing. GSL water was filtered through each filter until the filter was clogged. Filters were removed, placed in pre-cleaned petri dishes then ziplock bags, and stored on wet ice for transport. The filters were promptly frozen at -25C and remained frozen until being analyzed for total selenium by LET Inc.

RESULTS and DISCUSSION

Sampling Schedule

The final sampling schedule was a result of defining sampling dates and then making every effort possible to complete a sampling program within 7 days of the target date. Although occasional equipment malfunctions caused some delays, these seldom resulted in a delay of more than one day, and were usually attributable to the complications of working in a hypersaline environment. Weather was the main factor influencing the duration of a sampling program and in the ability to complete a full sampling program on, or near, the proposed date. There were notable occasions in which the winds increased dramatically, and all sampling efforts had to be abandoned for the day. The most memorable of which occurred on July, 2006 when the wind speed increased from 10 to 15 mph to 77 mph in approximately 35 minutes near Hat Island. During the January 2007 sampling program extensive sheets of ice (sufficiently thick to support the weight of a rapidly scurrying human) were present from Promontory Point to our sampling sites north of Hat Island (Figure 2). Needless to say, sampling under these conditions was less than optimal.

Limnological Conditions.

Water Temperature.

Water temperature was monitored at discrete intervals in the water column throughout this study (Figure 7). During the earliest sampling program in April 2006 the water temperature at 1 meter was already in excess of 15°C. This is approximately 8°C to 10°C degrees above the typical threshold for the onset of *Artemia* hatching in spring. The

temperature of the GSL at one meter depth increased throughout the summer of 2006 reaching a maximum of 29.0°C on July 27th, 2006. The temperature then declined throughout the fall and into winter reaching a minimum temperature of -1.1°C on January 26, 2007. During the winter of 2007 there were extensive sections of ice on the surface of the GSL ranging from 3 to 7 cm thick. The surface temperature again warmed to over 9°C on March 14, 2007 and the most recent temperature on June 9, 2007 was 18.3°C . The deep brine layer typically responds more slowly to warming and cooling than is exhibited in the upper “mixed zone” of the GSL. The deep brine layer remained cooler than the upper mixed layers throughout the spring and summer until September 18, 2006. On this date the upper layer had cooled to 18.7°C whereas the deep brine layer remained almost two degrees warmer (20.5°C). The deep brine layer reached a minimum temperature of 3.3°C during January 2007 and continued to be warmer than the upper layer until March 2007 when the upper mixed zone had warmed to 8.9°C and the deep brine layer was still only 4.3°C .

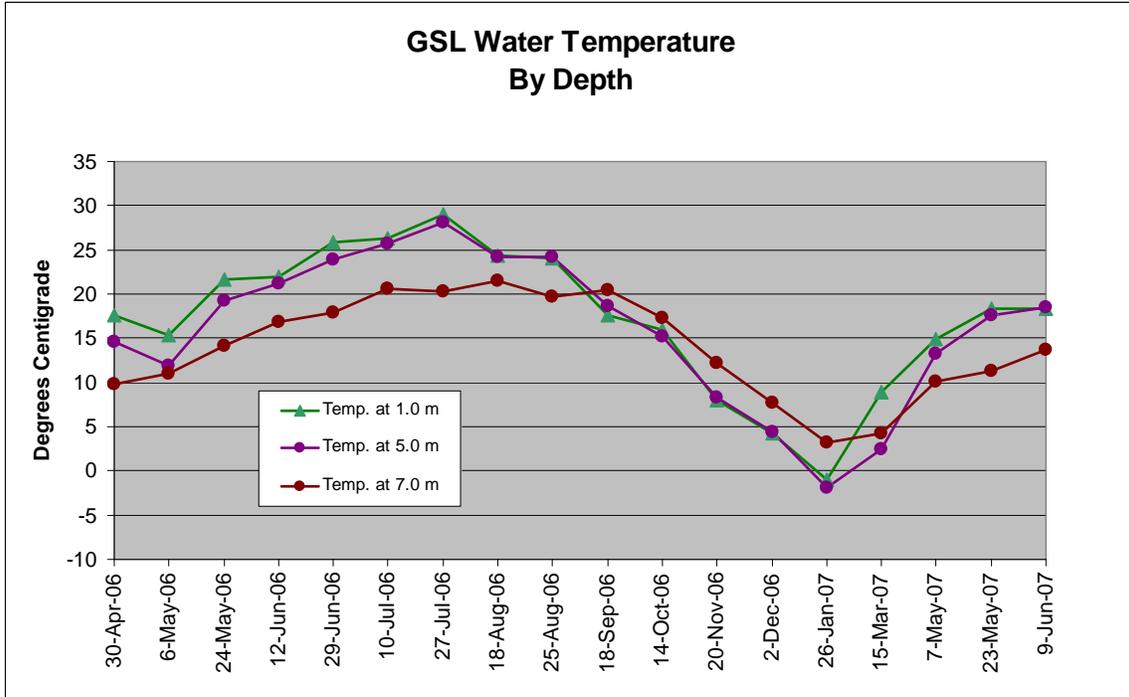


Figure 7. Water temperature of the GSL from April 2006 to June 2007. Temperature was recorded at three different depth intervals (1m, 3m, and 7m).

Water Transparency.

Water transparency varied from an average low in April 2006 of 112 cm to a maximum average depth of 324 cm in June 2006 (Figure 8). During the summer and fall of 2006 the GSL exhibited a characteristic pattern of cyclical changes in water transparency, largely attributable to the grazing pressure exerted on the algal population by the brine shrimp. Wind events and suspended particulate matter also influenced water transparency measurements. Following the brine shrimp population collapse in the winter of 2006-2007 the algal population once again flourished, obscuring visibility and resulting in a minimal water transparency of 47 cm during January 2007. As the brine shrimp population expanded in the spring of 2007 grazing pressure on the algal

population again increased dramatically and resulted in quite clear conditions with average water transparency values exceeding 440 cm.

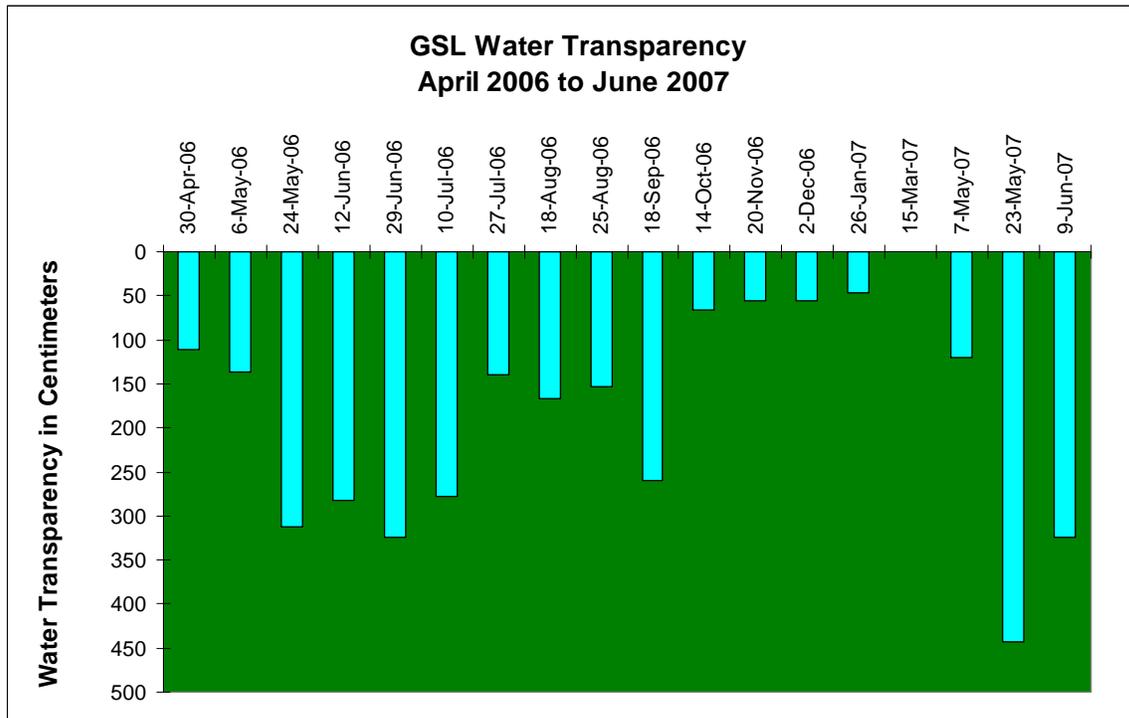


Figure 8. Water transparency of the GSL in centimeters. Measurements correspond to average transparency as measured by the final visible depth of a 20 cm Secchi disk.

Dissolved Oxygen

Dissolved oxygen followed a roughly inverse relationship to water transparency--at low Secchi disk measurements, and relatively high algal abundance, oxygen values were elevated. When the *Artemia* population expanded, algae were effectively depleted, transparency increased and dissolved oxygen was reduced. Dissolved oxygen in the upper mixed zone ranged from a high of 120% to 140% of saturation (Figure 9). Low values typically observed during May were in the range of 20% to 40% of saturation. Characteristic fluctuations during the summer and fall months were generally between

lows of 40% to highs of 80% saturation. Site-specific differences were present, the most notable of which was sample site #4 (Hat Island) which typically exhibited the highest average dissolved oxygen levels (range 55% to 216%). The deep brine layer remained anoxic throughout the study, as anticipated given the chemical composition of this layer. The transition from the upper mixed zone into the hypersaline hypolimnion was quite abrupt, occurring between 6 and 6.5 meters in depth. The average dissolved oxygen at 6m was 61.2% whereas the average at 7m was only 1.8% (Appendix 1.1).

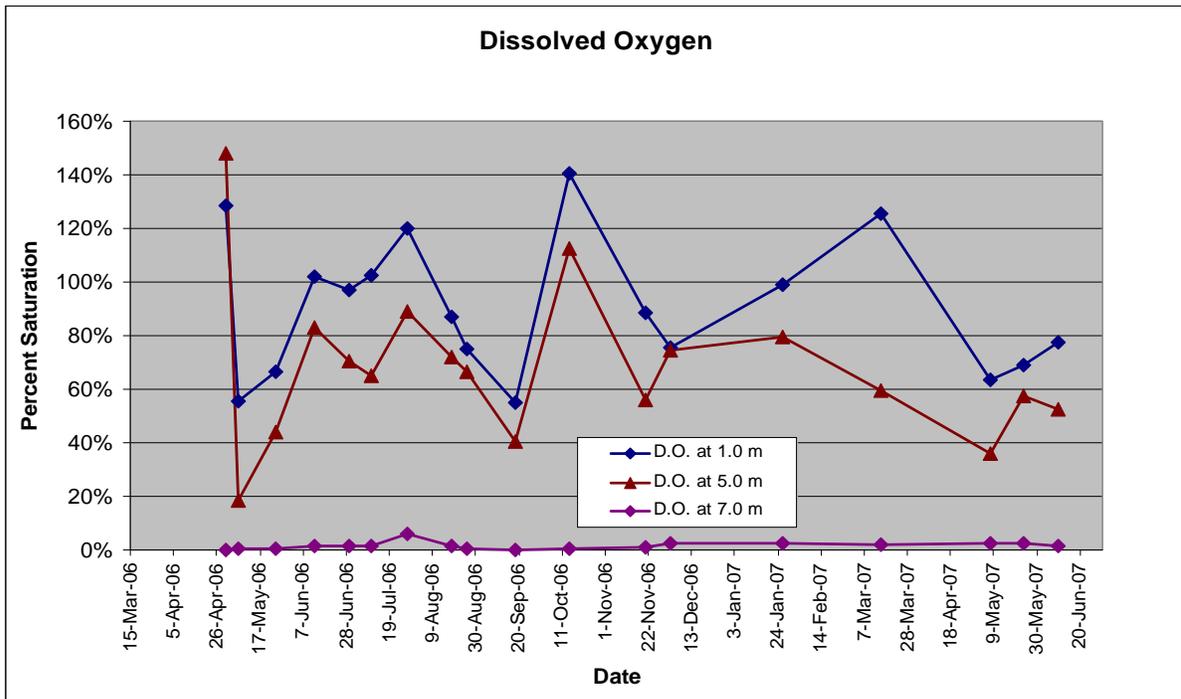


Figure 9. Dissolved oxygen in the GSL at three different depth and reported as percent saturation.

Salinity

Salinity was recorded at 6 different intervals (1m, 3m, 5m, 6m, 7m, & 8m) in the water column throughout this study. The upper 5m (surface to 5m depth) was quite uniform

spatially across the GSL within each sampling program (Figure 10 and Appendix 1.1). The data indicate effective mixing of the upper zone of the GSL. Evidence of exchange of the deep brine layer with the upper “mixing zone” begins to be apparent below 6 m depth. The average salinity for the upper 5m of the water column ranged from a minimum of 110 to a high of 150, whereas at 7m in depth the range was 120.2 to 225.0 ppt. This was a similar pattern as observed for dissolved oxygen in which the hypolimnion transition zone was usually evident below 6.5 meters in depth (Appendix 1.1).

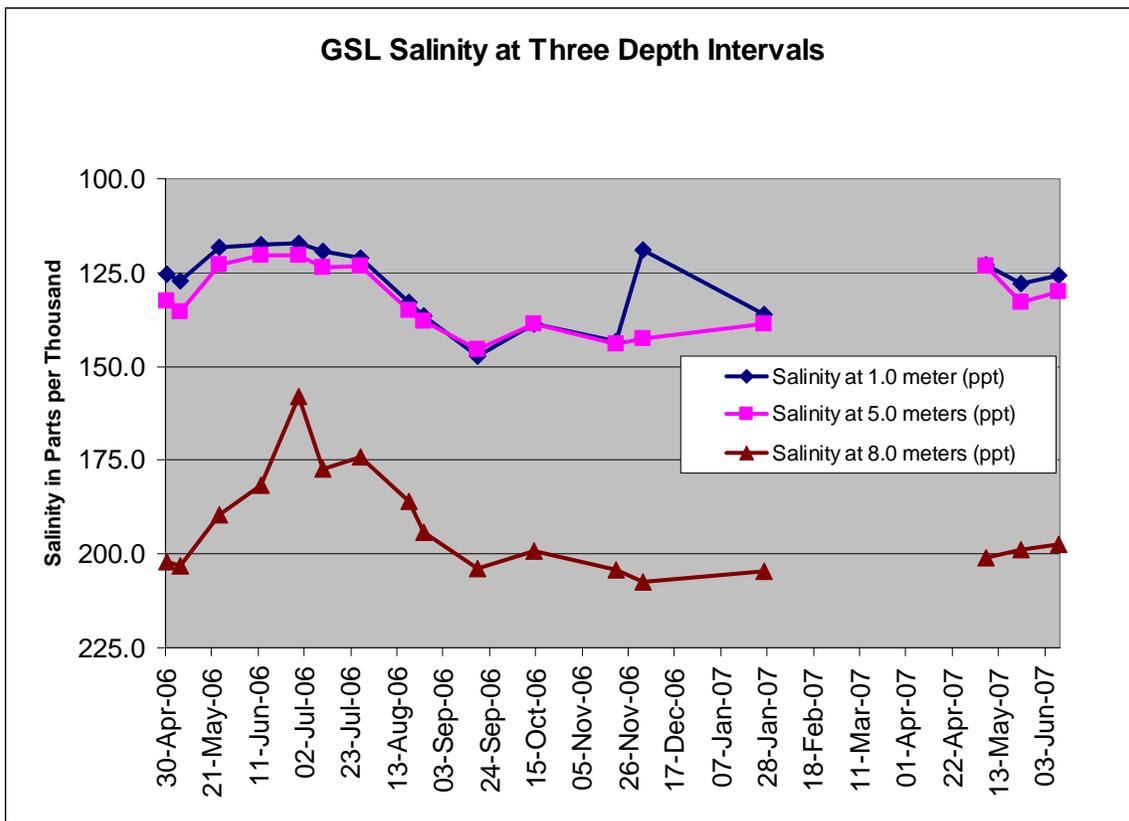


Figure 10. Salinity of GSL water samples as measured by refractometer. Three of six sampling depths are represented. The influence of inflow of hypersaline brine from the North Arm of the GSL is evident in the dramatic increase in the water column salinity at 7 and 8 meters depth.

Brine Shrimp Population Dynamics.

Detailed brine shrimp population dynamics were assessed during this study because of their importance as a critical component in the food web of the GSL and their role in the trophic transfer of selenium from the water to wildlife. Brine shrimp used for population assessments were collected from the water column extending from the surface to 7m in depth. Although the number of brine shrimp found below 6m in depth are minimal relative to those in the first 5m of the water column, the upper layers of the hypolimnion were included in the brine shrimp population assessment because previous studies have shown that cyst abundance at the chemocline between the upper mixing zone and the deep brine layer can be quite substantial (Stephens, 1997). Brine shrimp were separated by size filtration and then counted in the laboratory to determine age-specific abundance (developmental instar stages) and reproductive status (brood contents and sizes). Although filtration provided reasonably adequate separation of age classes, all samples were carefully counted under a binocular microscope to assure that age class determination was based on morphological features and not defined solely by size distribution.

In the GSL, overwintering brine shrimp typically hatch between March and April, producing the first generation of nauplii for the reproductive season. During this study the frequency and timing of sampling resulted in our inability to specifically identify the onset of hatching and the full reproductive dynamics of the first generation. Samples collected during the first sampling program for the spring of 2006 (April 30) and 2007 (May 7) revealed that the first generation of brine shrimp were already established across

all age classes and the production of a second generation was well underway (Figure 11). Adult abundance was 0.2 to 2.0 adults per liter in April, and for the remainder of the reproductive season average adult abundance was usually between of 0.2 to 2.0 individuals per liter (Appendices 2, 3, & 4).

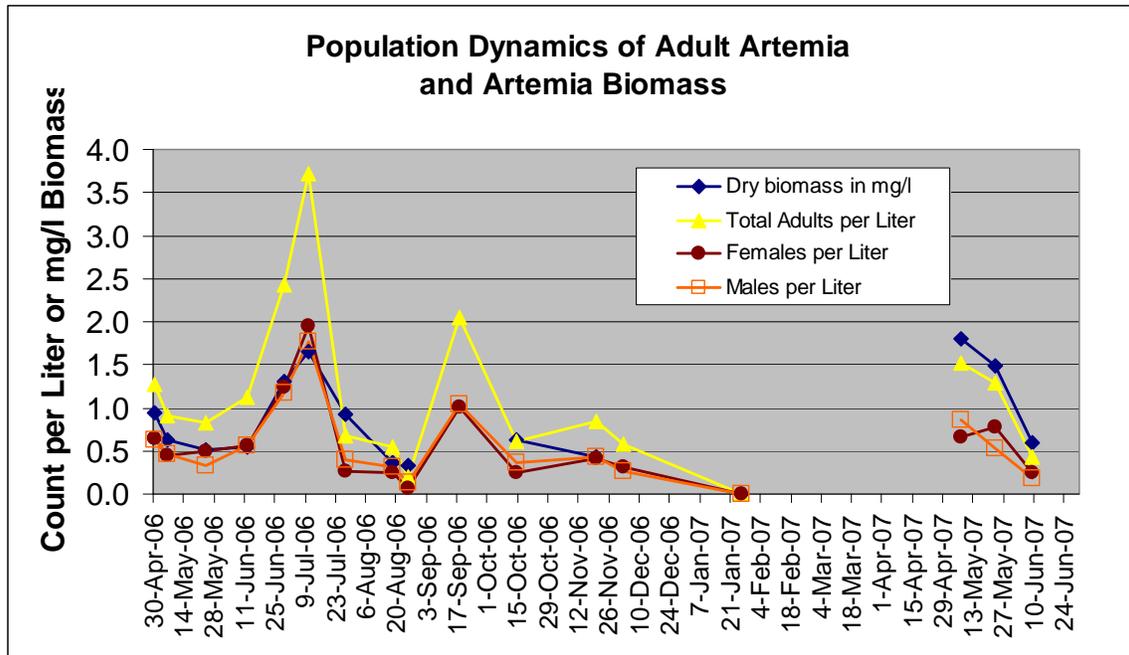


Figure 11. Adult *Artemia* population dynamics for the GSL during 2006 to 2007. Dry biomass expressed as mg/L is also shown and includes all age classes of *Artemia*.

The sex ratio of adult *Artemia franciscana* varies within specific time periods, but over the course of the reproductive season the average remains close to a 1:1 ratio—the ratio of males:females over the course of this study is 1.19:1.00 (Figure 12). Sex ratio is an important consideration for the GSL as there have been some concerns about the introduction of foreign *Artemia* (e.g., parthenogenetic species) into the GSL. A change in the sex ratio could be an important indicator of a shift in the genetic composition of the

GSL *Artemia* population. The results of this study are consistent with a bisexual *Artemia* population.

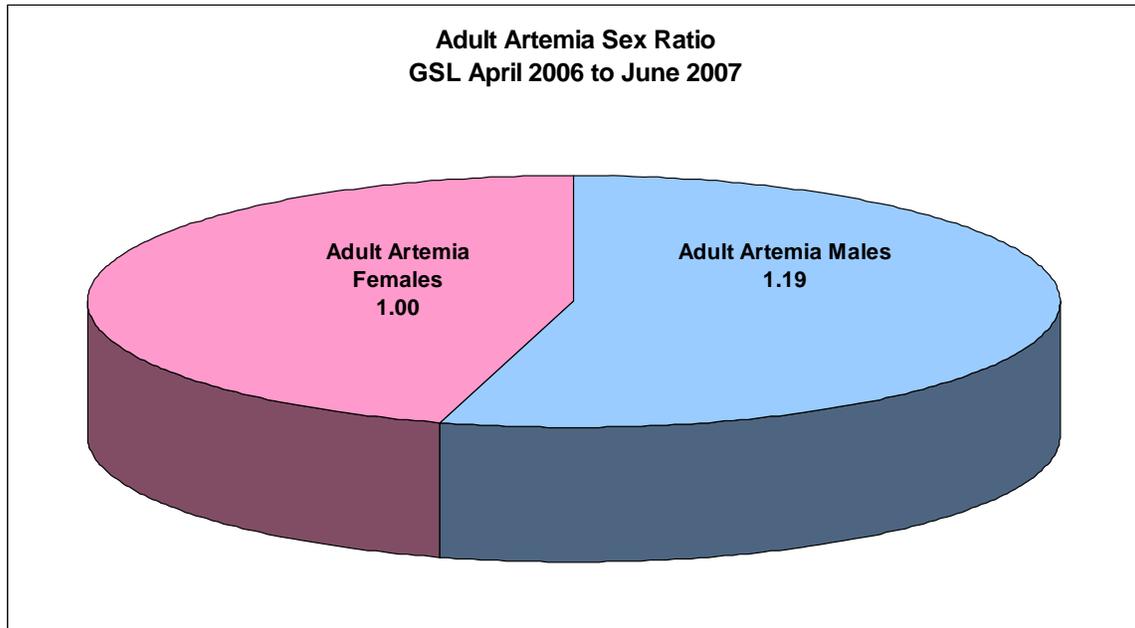


Figure 12. Sex ratio of adult *Artemia* from April 2006 to June 2007. Substantial differences in sex ratios were observed within a particular sampling program, however the average ratio for all sampling programs remained close to 1:1 (male:female).

There are typically between 3 to 5 identifiable generations in the brine shrimp population during the reproductive season, and in our study this pattern was also observed. Peak abundance of combined nauplii (nauplii and meta-nauplii) occurred in April, June, July, and August (Figure 13). There may have been one earlier F1 nauplii abundance spike in April that was not recorded---the onset of our sampling schedule was likely too late to have recorded the initial synchronous hatching of cysts and production of F1 nauplii. The highest count of combined nauplii that we observed occurred on June 29th with a count of 60.1/L. Peak abundance of combined nauplii in May and June corresponds to the

maximal reproductive output of the first generation. There was a slight increase in the number of combined nauplii per liter in November (4.36/L). This is somewhat unusual as the abundance of the younger age classes of *Artemia* generally falls below 1/L in October due to the predominant shift from ovoviviparity to oviparous reproduction and rapidly decreasing water temperature. Juvenile brine shrimp exhibited a similar pattern as the combined nauplii in terms of the cycles of abundance, albeit on a much lower scale, and with an altered temporal component. Peak juvenile abundance was observed during the first two sampling programs (April 30th and May 6th, 2006) then on June 29th, September 18th, and again at the end of November and early December. On December 2, 2006 1.8 juveniles/L were counted. It is quite surprising to document an abundance of >1.0 juvenile/L at this time of year because juvenile brine shrimp are the least tolerant of environmental stressors (Belovsky, 2006). Adults can remain viable on the GSL well into December, and in the current study adult brine shrimp were still present on December 2, 2006. By January 26th no live brine shrimp were observed at any of the sample locations.

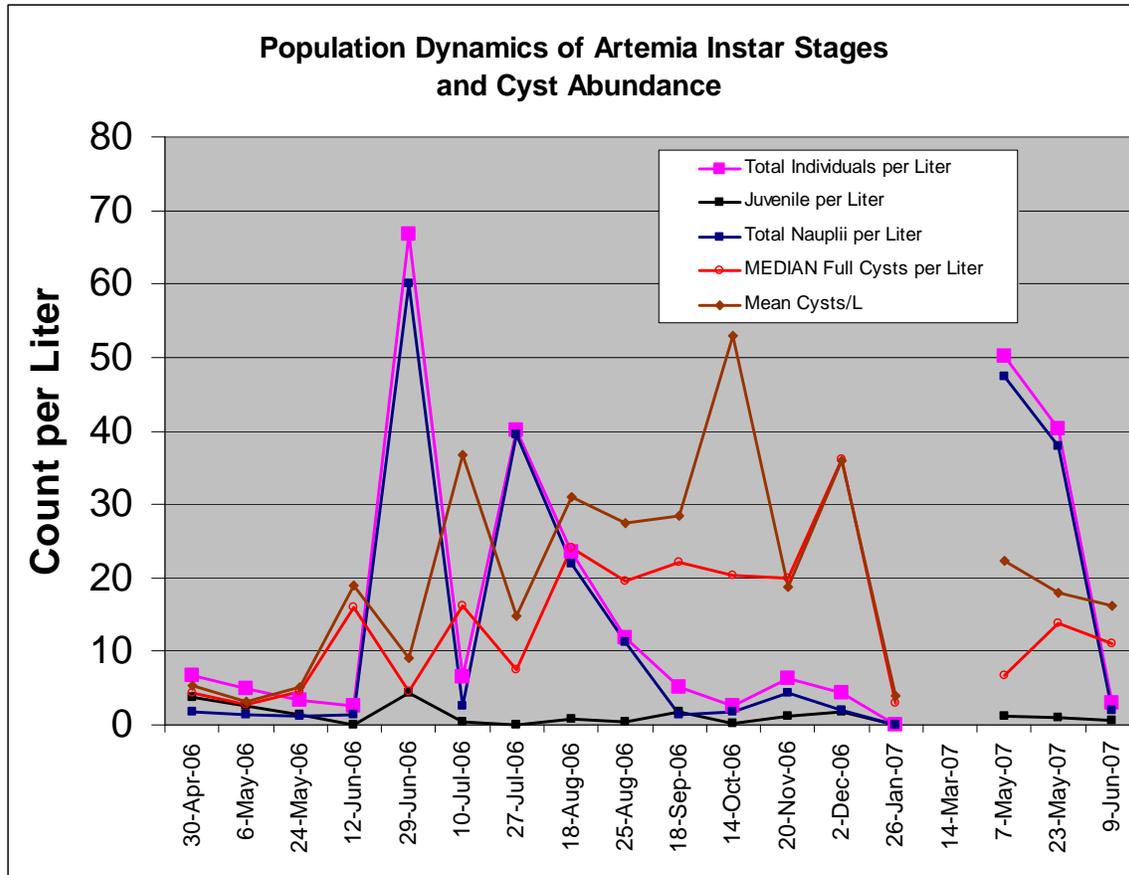


Figure 13. Juvenile, combined nauplii, and cyst abundance for the GSL from 2006 to 2007. Cyclical patterns of production, survival, and collapse are evident. Predominant cyst production is initiated in July and continues into early winter. Cyst depletion from October to January is largely attributable to industry harvesting pressure

Cyst abundance in the GSL during 2006 ranged from a low of 3.3/L on May 6th to a high of 53.0/L on October 14th (Figure 13). The April 30th count was slightly higher (5.3/L) than the May 6th count and this coincides with an increase in the number of nauplii per liter from April 30th to May 6th, suggesting that overwintering cysts were still viable and continued to hatch during early May. Cyst abundance increased sharply in July as the shift from ovoviviparous reproduction to oviparity began. Brood counts were initiated

only after the shift to oviparity was observed. This was done as a means of tracking cyst production from July through the onset of winter.

Brine Shrimp Fecundity and Cyst Production.

Fecundity (e.g., cyst production) during the summer and fall is an important measure of individual fitness—the ability to produce viable offspring and propagate one’s genetic information. It is also one of the dominant factors influencing population dynamics in the subsequent reproductive season. Intact brood contents (Figure 14) were evaluated for brood size and brood characteristics (i.e., embryo, cyst, or nauplii production).

Figure 14. Female *Artemia* with intact broods. Brood contents can be observed under a dissecting microscope. In the image below ovisacs are visible with cysts (brown spheres) and live young (pale-yellow). Individual females are randomly selected, the ovisac is dissected, brood contents are identified and counted. Brood contents are characterized as embryos, cysts, or nauplii. Undifferentiated embryos were also noted and recorded. Any brood abnormalities were documented. Photo is from the DWR website.



Cyst brood sizes in 2006 ranged from 60 (September) to 114 (August) and 112 (November) (Figure 15). Females reproducing ovoviviparously exhibited a range of brood sizes between 109 (June) to 11 (September) cysts per brood. Oviparous reproduction predominated from July until winter, with very low numbers ($<0.01/L$) of ovoviviparous females observed from September through December. Peak brood sizes in 2007 occurred in May, with maximum average size of 121 cysts per ovisac on May 7, 2007. Ovoviviparous reproduction also showed very high per capita reproductive potential on May 7th—the average nauplii brood size was 182 nauplii per ovisac. Brood sizes diminished substantially in June for both ovoviviparous and oviparous females; brood sizes were less than 50 offspring per female. Brood sizes among ovoviviparous females showed a similar pattern as oviparous females, albeit usually smaller average sizes (80%) than cyst broods. There was one exception on May 7th in which nauplii brood sizes were 50% larger than corresponding cyst brood sizes.

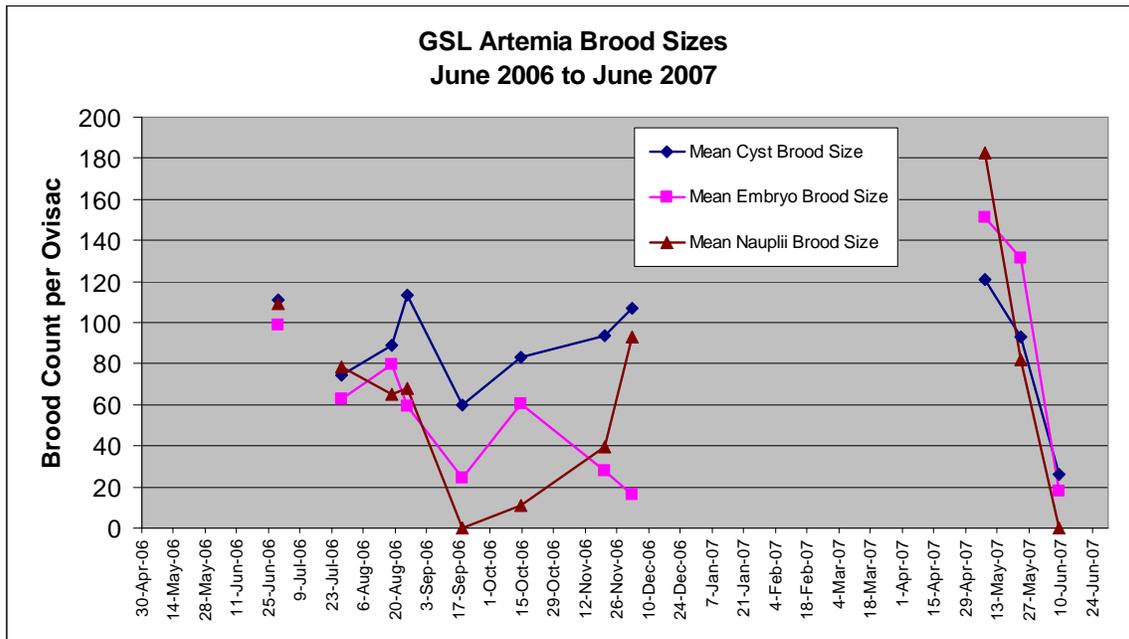


Figure 15. *Artemia* brood sizes from April 2006 to June 2007. Broods were characterized as containing embryos, nauplii, or cysts. Brood contents were counted from a subset of females from each sample location. The sharp decline in brood sizes between late May and June 2007 corresponds to low chlorophyll concentrations in the water column (chlorophyll-a < 2.0 ug/L).

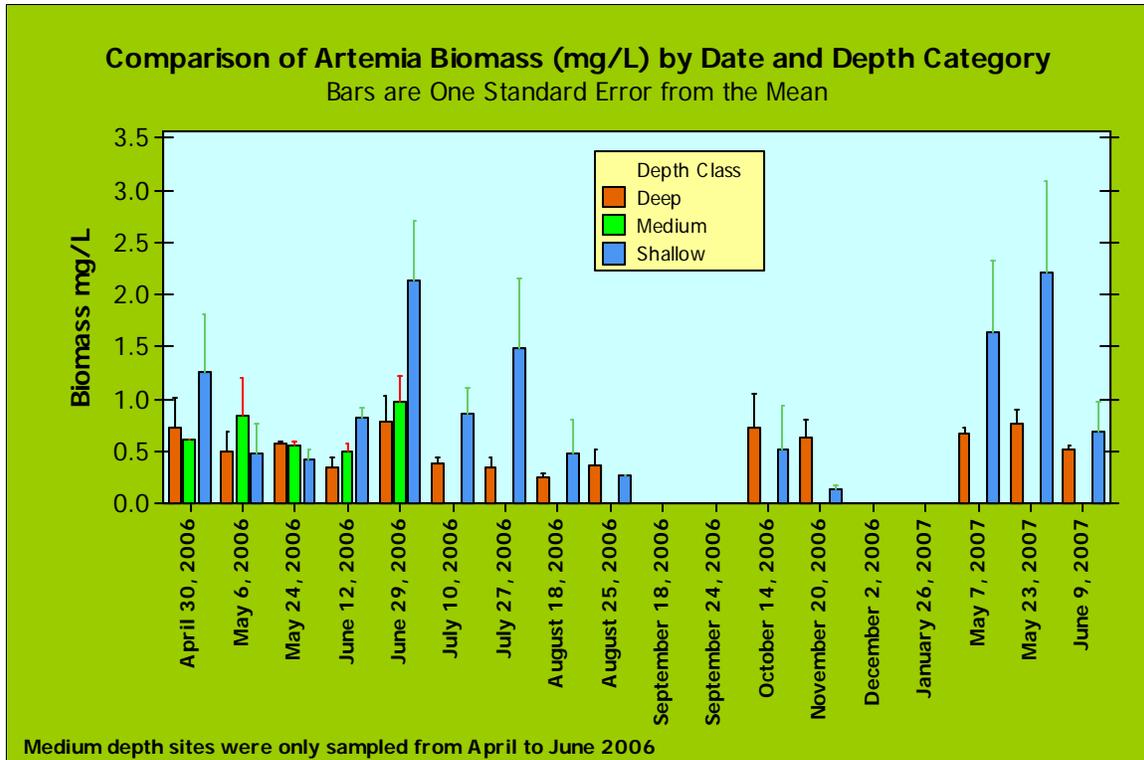
Productivity, defined as cysts per ovisac multiplied by the number of oviparous females per cubic meter, is a useful measure of the reproductive potential of the population at a given time and location on the GSL. Productivity in 2006 peaked on June 29th, July 27th, and then again on October 14th. The maximal productivity measured in this study occurred on July 27th at 14,270 additional cysts per cubic meter. Sustained productivity was observed throughout the late fall and onset of winter. On December 2, 2006 the *Artemia* population still had a productivity count of 3,119 additional cysts per cubic meter. By January the productivity index for the population was zero. During the spring of 2007 both ovoviviparous and oviparous females were present. Productivity on May

23, 2007 was 2,643 additional cysts per cubic meter. No measure of productivity for May 7, 2007 was available, although oviparous females were present and the average cysts brood size was 121 cysts per ovisac.

Brine Shrimp Biomass.

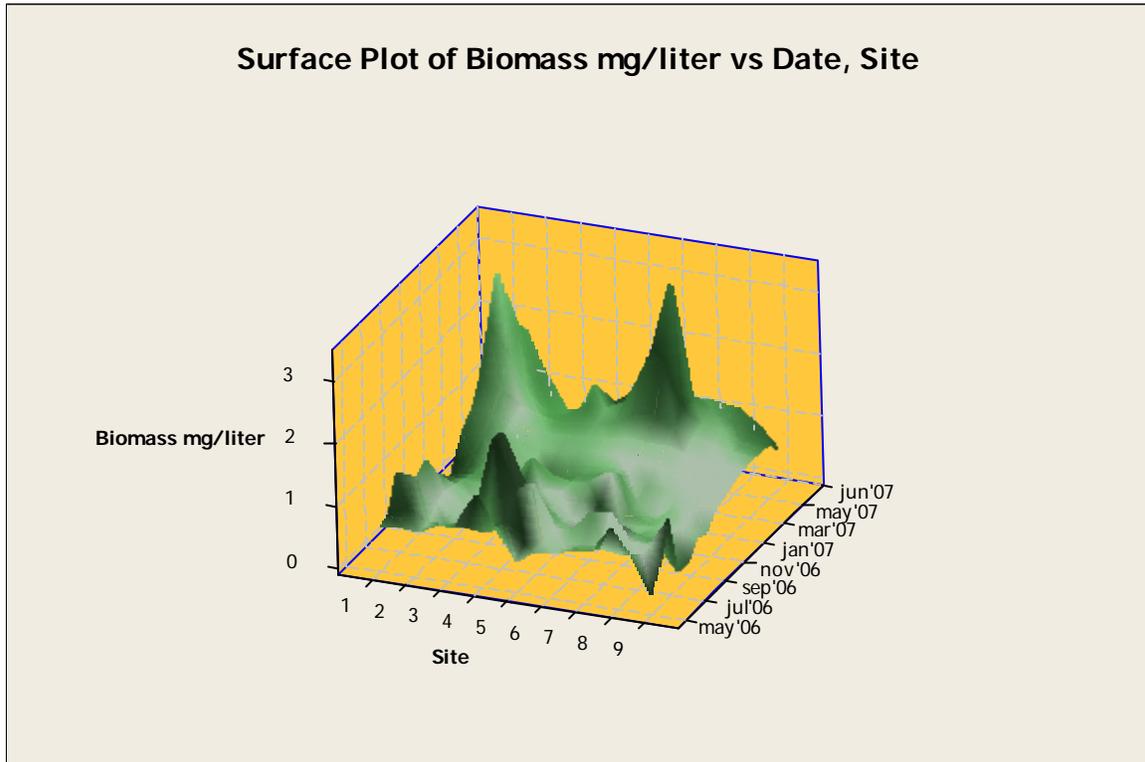
In terms of the application of *Artemia* population statistics to an inquiry of selenium impacts on GSL biota, and the transfer of selenium through the food web, *Artemia* biomass, and its availability to foraging birds, is perhaps the most relevant statistic to consider. *Artemia* biomass in 2006 ranged from a low of 0.33 mg/L on August 25th to a high of 1.65 mg/L on July 10th. During the spring of 2007 a peak of 1.80 mg/L was recorded on May 7th. Biomass decreased to 1.48 mg/L on May 23rd and continued decreasing to 0.60 mg/L by June 9th (Figure 16). This decrease corresponded with increasing water transparency and grazing of phytoplankton. Over this same time period in 2007 chlorophyll decreased from an average of 7.5 ug/L (maximum of 15.0 ug/L) to 1.6 ug/L (maximum of 2.1 ug/L).

Figure 16. The temporal pattern of brine shrimp biomass is shown from April 2006 to June 2007. Biomass was determined empirically by drying and weighing a subsample of *Artemia* biomass from every sample location and sampling program. Biomass was not estimated using literature values of average *Artemia* dry weights and then extrapolating using population statistics. Biomass values represent the average distribution in the water column, but may be well below values found in patchy accumulations of floating biomass or cysts.



A three dimensional plot of biomass by sample site and date is shown in Figure 17. The shallow sites #1 (Fremont Island site) and #4 (Hat Island) were the highest in biomass production per cubic meter of the sites sampled in this study. Dense accumulations of biomass and cysts were observed throughout this study, but were not included in the determination of biomass. All samples for biomass determination were taken from water column samples. Birds were commonly seen foraging on accumulations of biomass or cysts, especially in the area close to Hat Island.

Figure 17. Three-dimensional relationship of *Artemia* biomass, sample site, and date of sampling program. Shallow sites appeared to be more productive than deep or medium depth locations. Site #4 (Hat Island, shallow site) in particular had elevated dissolved oxygen relative to other sites as well as consistently high statistics for *Artemia* population growth and reproductive output.



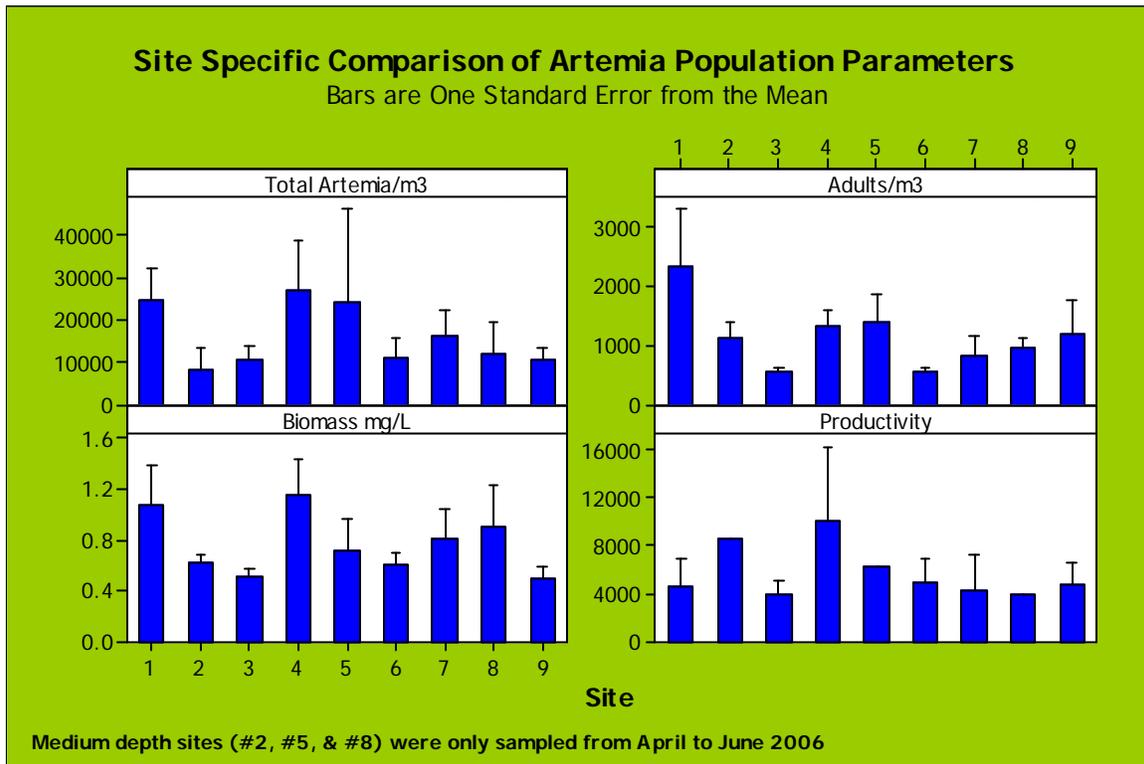
Whereas, it is well documented that there are pronounced temporal changes in zooplankton and phytoplankton abundance on the GSL it is not established whether there is a spatial component influencing population dynamics. From a conceptual standpoint there should be differences spatially—the lake has distinct localized input sources, hydrochemical characteristics, currents, depths, and other physical and chemical features that should exert an influence on phytoplankton and zooplankton growth, survival, and reproduction. However, brine shrimp are mobile organisms and can propel themselves throughout the water column (although they do use their locomotion primarily for

foraging). Brine shrimp are also certainly subjected to the movements of the many pronounced currents, mixing zones, thermal and density cycling events, and wind-related disturbances that are commonplace at the GSL.

The many aspects of movement by the brine shrimp throughout the GSL adds an important element of uncertainty when evaluating population and selenium results within a spatial context—the collection of brine shrimp that may be found in a given location on a particular sampling date may very well be transported to a distant location on subsequent days. The uncertain movement of brine shrimp needs to be considered in terms of the interpretation of spatial results. That being said, there are still important spatial patterns of population growth, abundance, reproductive capacity, and tissue selenium concentration that are relevant to compare and to consider.

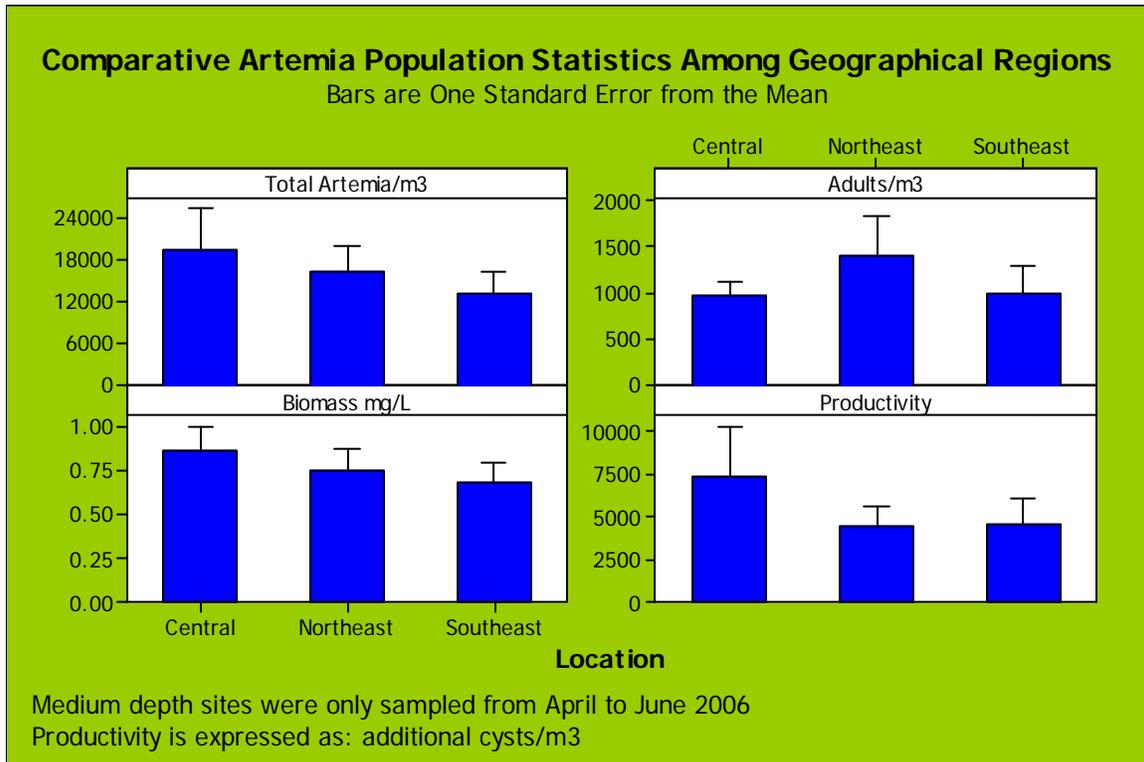
Parameters of *Artemia* population size, composition, and reproductive output were compared on a site-specific basis and across geographic locations. The results are detailed in Appendix 6.1 for each sample site surveyed and are shown in Figure 18.

Figure 18. Site-specific statistics for measures of *Artemia* population structure, biomass, and reproductive output. There are apparent differences among specific sample sites in terms of the brine shrimp population size and productivity.



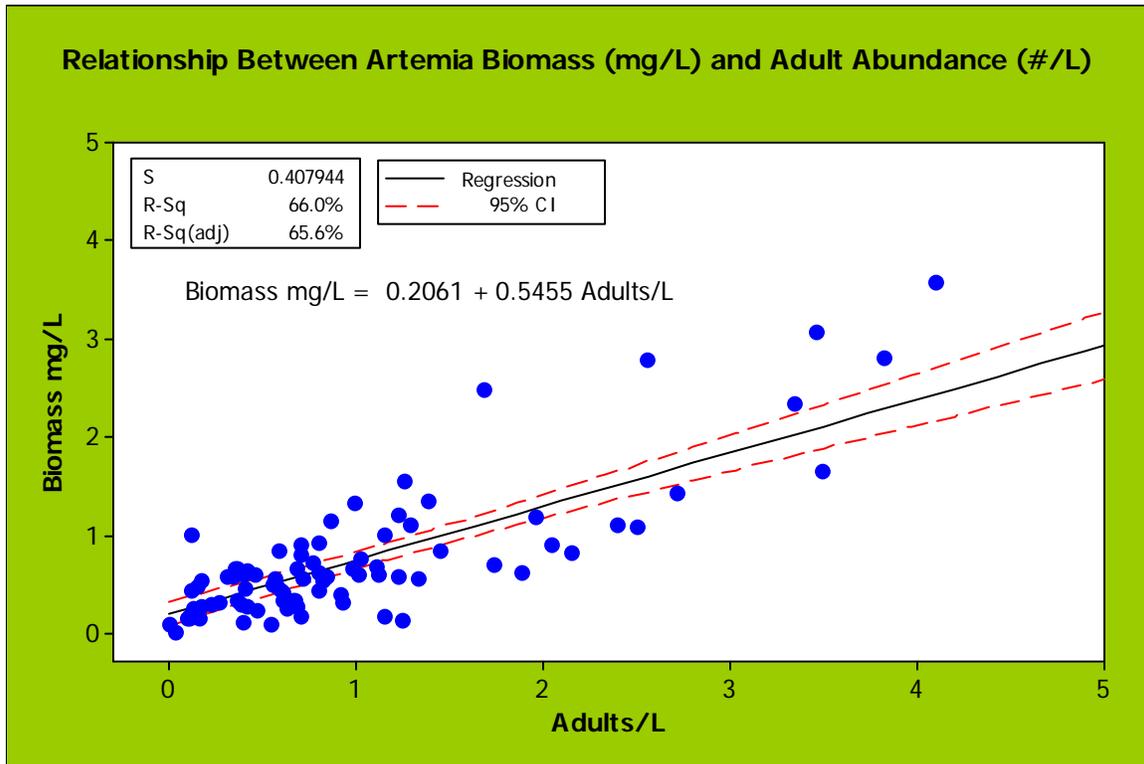
Statistical analyses were calculated across geographic locations. There were no statistically significant differences across these spatial categories (Northeast, Central, Southeast): (Cyst per Brood: $P=0.784$; $df: 2, 65$; Biomass: $P=0.457$; $df: 2, 90$; Productivity: $P=0.624$; $df: 2, 61$; Adults/m³: $P=0.874$; $df: 2, 113$). Descriptive statistics for these regions are shown graphically in Figure 19 below.

Figure 19. *Artemia* population statistics presented in terms of spatially distinct regions of the GSL. Average results for various measures of *Artemia* biology were examined over the summer and fall months of 2006. Population and reproductive data grouped according to these spatial categories were not statistically separable.



Although all age classes were used for the biomass calculation, adult abundance was the best predictor of biomass--there is a positive linear correlation ($R^2 = 0.66$) between adult abundance (adults/m³) and biomass (mg/L) (Figure 20). Individual adult weights were estimated by deducting nauplii and juvenile biomass from total biomass and then calculating the biomass per adult. The results of this estimate showed average adult biomass of 0.864 mg/adult (± 0.636). The average weight of all individuals was 0.138 mg/individual brine shrimp.

Figure 20. Counts of adult brine shrimp per cubic meter allow for predictions of biomass in the GSL. Although the total count of all age classes of brine shrimp is also correlated with biomass weight, the counts for adults provides a more reliable relationship and predictive equation.



Water depth influences nutrient cycling, temperature regulation, light penetration, zooplankton and phytoplankton growth and productivity. Because of this, *Artemia* reproductive and biomass statistics are compared across depth categories (Figure 21). Average values for biomass and productivity suggest that shallow sites are more productive for *Artemia* than deep sites (Tables 5, 6, and 7). However, a T-test comparing means between deep and shallow sites does not show statistically significant differences for cyst brood size ($P = 0.252$, $df: 1, 65$), productivity ($P = 0.674$, $df: 1, 49$), or biomass ($P = 0.394$, $df: 1, 64$). There was, however, a significant difference between deep and

shallow sites in the average number of adults per cubic meter ($P=0.052$; $df: 1, 91$): shallow sites had a greater number of adults/m³. It is possible that stromatolites and their resident population of benthic algae, offer an alternative food supply for *Artemia* during times of over-grazing of the phytoplankton in the upper water column. This would provide an advantage for *Artemia* exploiting shallow sites rather than deep sites.

In comparison to all other sites, sample site #4 (shallow site near Hat Island) was uniquely an area of high phytoplankton and *Artemia* productivity. This site was typically 20% to 50% higher than other sites in measures of reproductive output, population size, and biomass. The Hat Island shallow site had the highest overall productivity per cubic meter (11,205 additional cysts per cubic meter), the highest average number of *Artemia* per cubic meter (27,001 brine shrimp/m³), the most biomass (1.158 mg/L), and consistently had the highest average (113.7%), minimum (55.5%), and maximum (214.0%) dissolved oxygen percentages. This site has been observed in past GSL research projects to be among the most productive of locations surveyed on the GSL. This location is in close proximity to the gull colony on Hat Island and is therefore of interest when considering availability of *Artemia* for the diets of gulls and other avian species utilizing Hat Island.

Figure 21. Cyst brood size, productivity, and biomass results for Great Salt Lake *Artemia* population during May 2006 to June 2007. Statistics are presented in terms of depth category (shallow, medium, deep). Shallow and deep sites were included throughout the study. Medium depth sites were only included from April until June 2006.

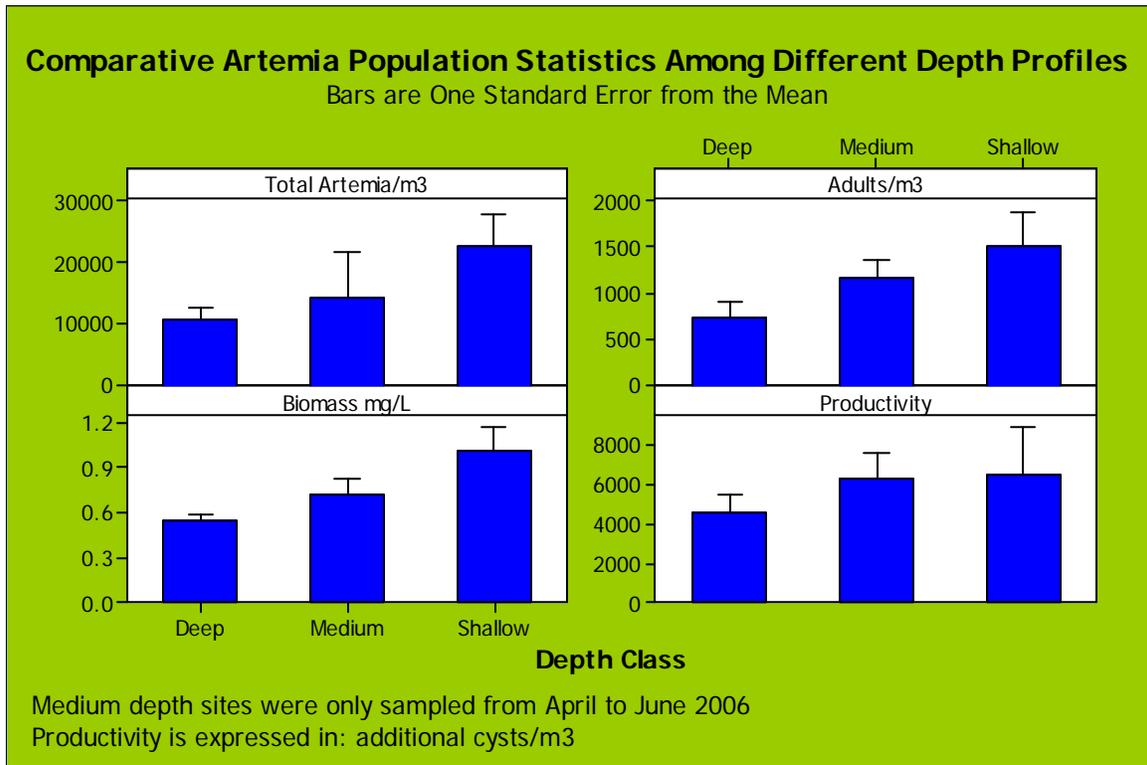


Table 5. Great Salt Lake *Artemia* biomass in mg dry weight per liter.

Artemia Biomass in mg/L by Depth Category						
April 2006 to June 2007						
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	0.642	0.689	107.30	0.17	4.50	52
Medium	0.727	0.380	52.26	0.34	1.56	12
Shallow	1.181	1.355	114.70	0.02	7.03	52

Table 6. Average cyst brood size among oviparous female *Artemia*.

Cyst Brood Size by Depth Category						
April 2006 to June 2007						
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	91	34	38	27	157	35
Medium	104	10	9	93	112	3
Shallow	81	34	42	24	154	30

Table 7. Productivity estimates of *Artemia* reported as cyst brood size x number of females carrying encysted eggs in their ovisac.

Productivity per Cubic Meter (cyst brood size x # females w/cysts) by Depth Category						
April 2006 to June 2007						
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	4,580	5,672	124	27	23,871	35
Medium	6,324	2,371	37	3,950	8,692	3
Shallow	6,562	13,565	207	28	69,450	30

Cyst Abundance, Harvest Yield.

Average cyst abundance on the GSL is the critical parameter used to regulate the brine shrimp industry and to predict the annual harvest yield. It is also the most influential determinant of the amount of floating or shoreline brine shrimp cyst accumulations on the GSL during the winter months. These cyst accumulations are widely exploited as a food source by overwintering species of water birds, gulls, and shorebirds (Figure 22).

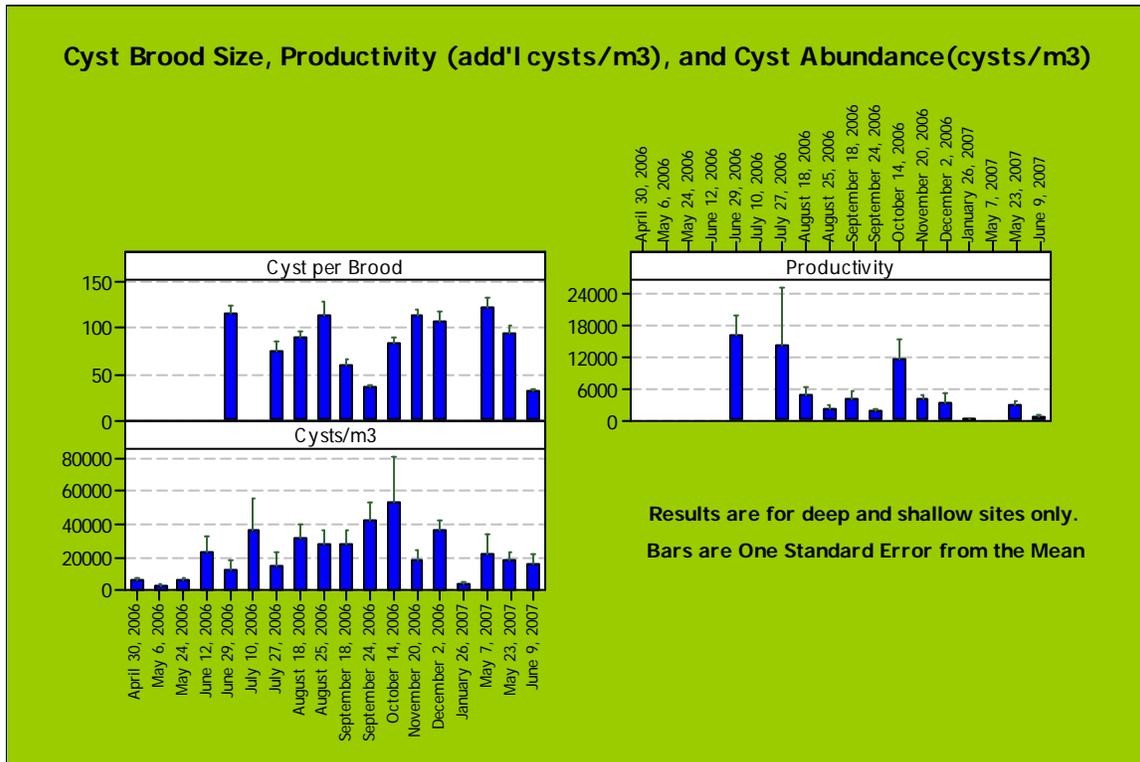
Figure 22. Brine shrimp cyst accumulation on the surface of the GSL. Accumulations can be a diffuse monolayer or can accumulate to a thickness exceeding 3 cm. Floating brine shrimp cyst and biomass accumulations are extensively utilized by foraging birds.



Peak cyst abundance during 2006 was observed on October 14th and showed a density of 52.9 cysts per liter (Figure 23 and Appendix 5.1). The lowest measure of cyst abundance during 2006 was on May 6th when 3.2 cysts/L were counted. The range of cysts per liter

during 2007 was: 4.0 (January 26th) to 22.3 on May 7th. Cyst abundance within the GSL can be patchy in distribution, rendering the arithmetic mean a less accurate measure of central tendency of cyst abundance. Median cyst abundance has been used by previous investigators as the most accurate representation of cyst abundance (Stephens, 1997). Median cyst abundance showed a generally lower value than the mean, especially in terms of peak values; the highest median value was 36.0 cyst/L on December 2, 2006. The highest median measure prior to the harvest season was 24.1 cysts/L in August. In the following sections the arithmetic mean will be considered because it is the statistic used by the State of Utah, Department of Natural Resources, Division of Wildlife Resources (DWR) to regulate the industry---thereby allowing for direct comparisons of the DWR results with our study.

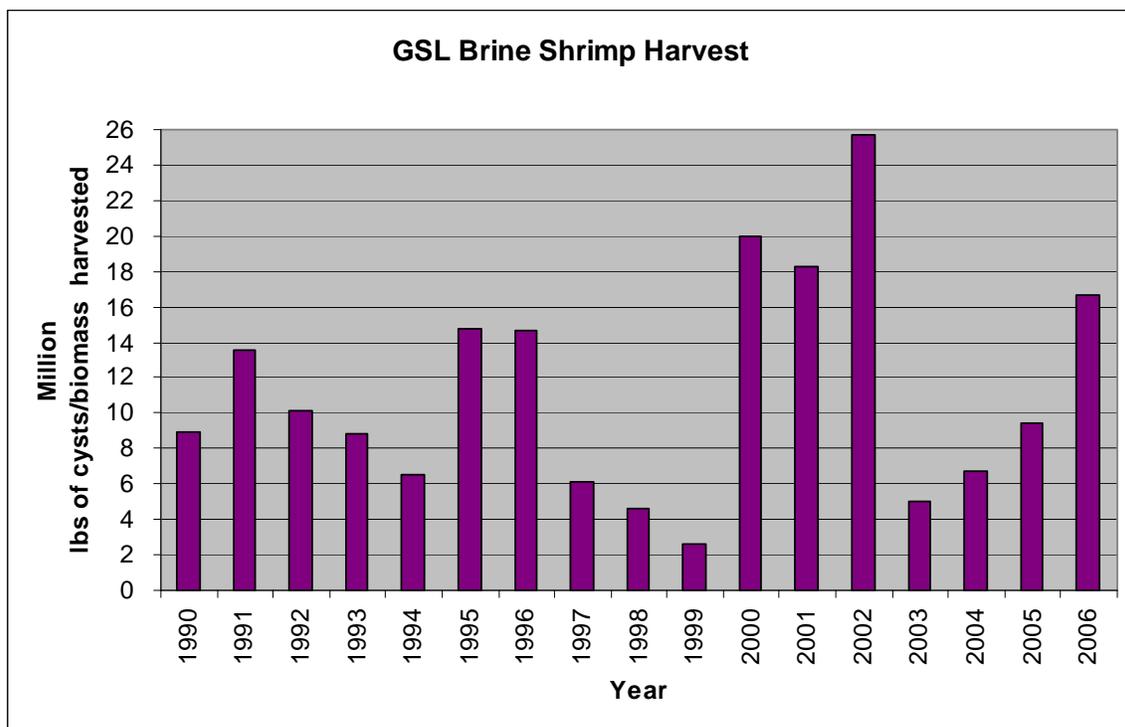
Figure 23. Cyst production by *Artemia* and cyst abundance within the GSL are shown. The dominant shift to oviparity occurred in June and exhibited a triphasic pattern. Cyst production resulted in a steady increase in cyst abundance from June until the onset of commercial harvesting in October 2006.



Because commercial harvesting had already begun on October 1st, the estimate of maximal cyst production on the GSL is artificially low. Although cyst abundance was lower, by approximately three-fold, than some of the previous years on the GSL, the brine shrimp industry harvesting total was relatively high. During 2001 to 2005 peak cyst abundance on the GSL ranged from 87 to 158 cysts per liter just prior to the brine shrimp harvest season, and during that time period the industry harvested 5.0 to 25.7 million pounds per season. This season the brine shrimp industry harvested a total of 16.6 million pounds of raw biomass from the GSL from October 1, 2006 to January 31, 2007 (Figure 24). By comparison, in 2003 the peak preseason average cyst abundance was 86

cysts/L (median = 72 cysts/L), but the industry only harvested 5 million pounds of raw biomass. The harvest yield for this season may be partially attributable to increased effort during the 2006-2007 harvesting season relative to previous years. Based on our measures of population dynamics, per-capita productivity, and harvest yield for the brine shrimp industry there is no indication that the *Artemia* population is substantially threatened by current conditions on the GSL, whether the concern is contaminants (eg., mercury, zinc, copper, selenium, hydrocarbons), food availability, abiotic characteristics, predation, or other influential factors.

Figure 24. Raw *Artemia* biomass harvested from the Great Salt Lake from 1990 to 2006. Values are reported in million pound increments.



Selenium Load in *Artemia* Biomass and Selenium Removal from GSL via Commercial Harvesting of Biomass and Cysts.

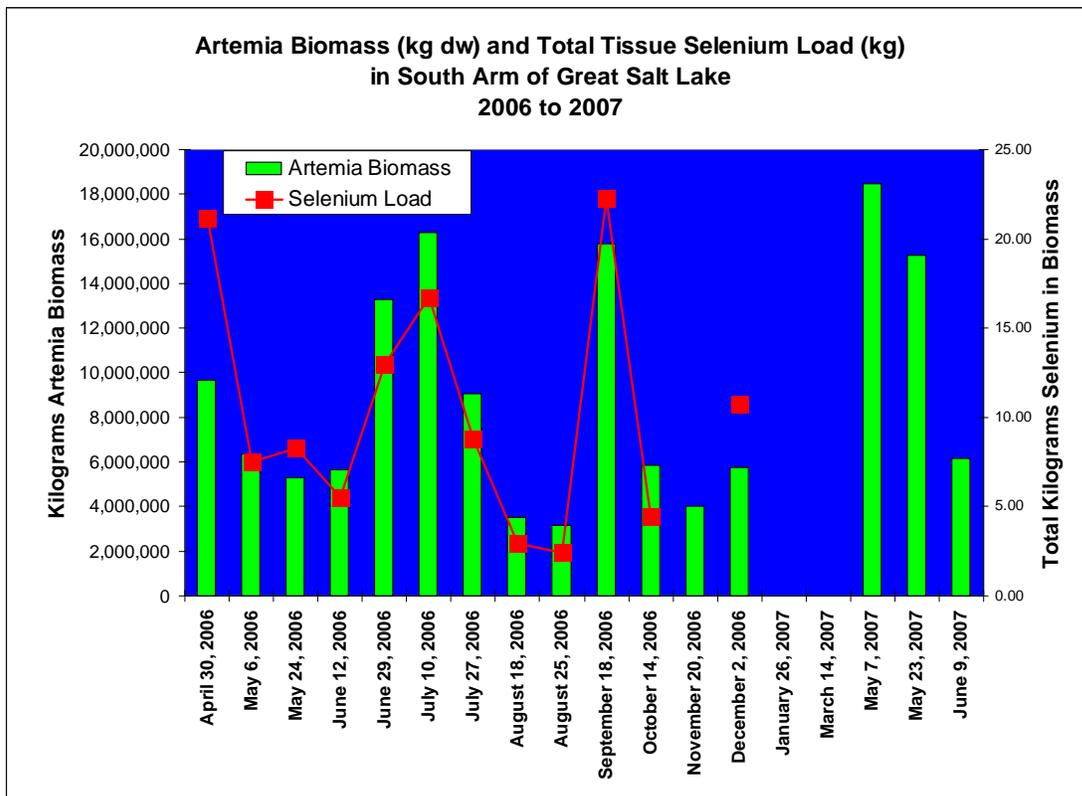
Selenium concentrations in brine shrimp adults, juveniles, and nauplii/cysts were evaluated in this study. However, a limited number of selenium analyses were conducted on juveniles and nauplii/cysts from the 2006 sample season due to budget constraints. All three age classes were collected in larger quantities during the 2007 season and all age classes were submitted for selenium concentration determination for each sampling program. The results of the 2007 selenium analyses are not yet available. Additionally, samples of only cysts (no other *Artemia* biomass present) were collected during January 2007, submitted for selenium analysis, but not yet analyzed.

Because of the limited number of younger age classes analyzed for selenium content, our evaluation of selenium loading in the brine shrimp population will, for the purposes of this preliminary report only, rely solely upon the 2006 adult values. Adults comprise the vast proportion of brine shrimp biomass over the course of the growth season and are therefore a reliable measure of population level selenium load. The selenium load in the adult biomass on any particular sampling date during the 2006 sampling season was between 2.91 kg and 22.2 kg (Figure 25). The average load was a mere 10.3 kg.

These values are based on dry *Artemia* biomass statistics (mg/L), South Arm GSL elevation to volume relationships as determined by Baskin (2005), and adult tissue selenium concentration (ug/g dw). Removal of selenium from the GSL system via commercial harvesting of brine shrimp biomass and cysts can best be estimated from the selenium concentration in cysts and harvest yields. Detailed information on the relative

percentage of *Artemia* biomass removed versus clean cysts is not yet available from the industry. Therefore, calculations have to be derived from estimates of the relative percentage of cysts as compared to brine shrimp tissue in the total biomass removed from the GSL.

Figure 25. Brine shrimp biomass and the calculated selenium tissue load are shown for each sampling program. The total biomass of brine shrimp in the South Arm of the GSL is derived from the population counts and elevation/volume relationships determined by Baskin (2005) in his extensive bathymetric survey of the GSL.



The brine shrimp industry (Figure 26) removed 16.6 million pounds of cysts and *Artemia* biomass over the 2006-2007 season (DWR, 2007). Although we don't have precise figures for industry dry yields, nor the selenium concentration in cysts, it is evident that the removal load via commercial harvesting is likely to be inconsequential with respect to

the overall mass balance of selenium in the GSL. Using a characteristic industry estimate of 23% dry yield for the commercial harvest and a range of average tissue selenium concentrations of 1.18 ug/g (Project 2b data) to 5.7 ug/g dry weight (Project 1b), the annual removal of selenium would be between 2.21 kg to 10.75 kg per year.

Figure 26. Brine shrimp harvesting vessel with consolidated cysts enclosed by floating containment barrier. The estimated haul from this collection of cysts is 12 to 14 tons wet weight.



Phytoplankton, Chlorophyll, and Water Transparency.

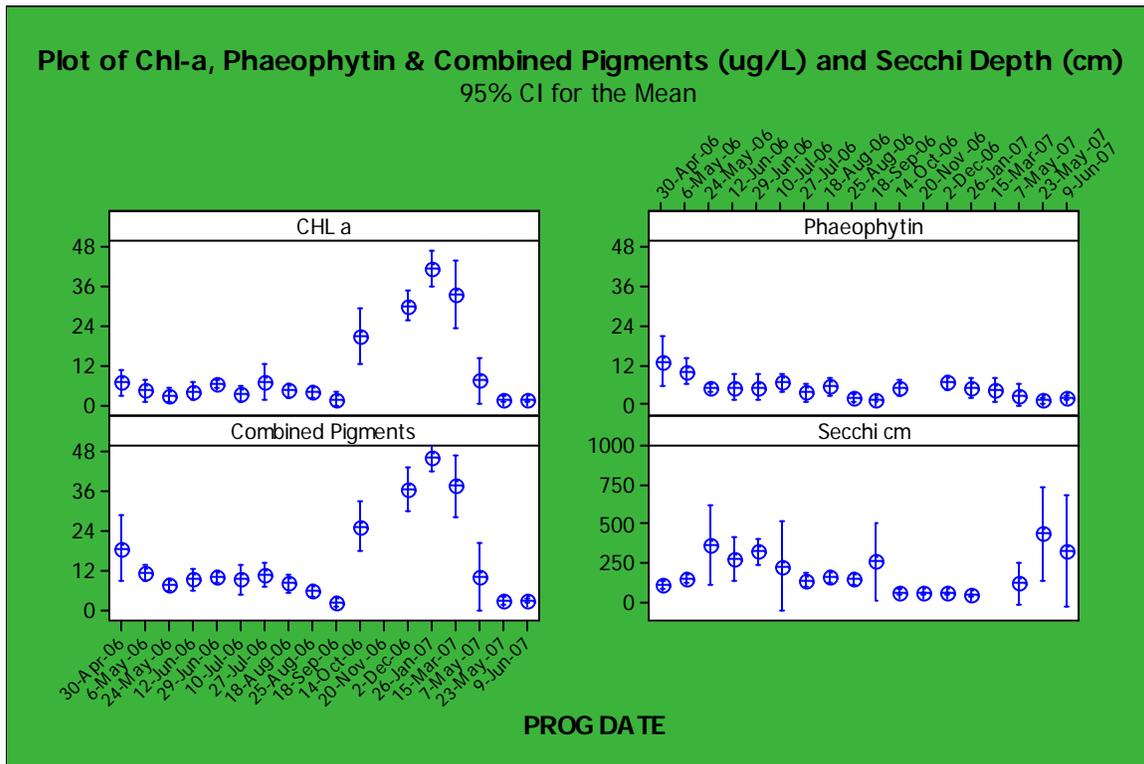
Water samples were collected during each sampling program and were used to assess chlorophyll pigment concentrations as well as for algae identification and enumeration. Water samples were analyzed for chlorophyll-a and phaeophytin pigments. Average chlorophyll-a levels during 2006 were in the range of 1.9 ug/L (September 18th) to 30.3 ug/L (December 2nd) (Appendix 7.1). Chlorophyll-a levels from April 30th to August 25th 2006 did not exceed 7.2 ug/L. However, site-specific levels did show a range of 0.7 ug/L to 16.0 ug/L over this same time period. Throughout the spring and summer the *Artemia* population exerted substantial grazing pressure on the algal food supply and likely kept chlorophyll levels low. Coinciding with decreased grazing pressure in the fall of 2006 (*Artemia* population size reduced to 1.7 individuals/L) the phytoplankton responded with rapid growth and concomitant increases in chlorophyll-a pigments (an average value of 20.8 ug/L and a high of 32.0 ug/L on October 14th) and decreases in transparency—on October 14, 2006 the greatest visible depth was 100 cm and the average was 65.5 cm. This is in contrast to the maximum water transparency in September which was 460 cm, and the average was 260 cm (Figure 8 and Appendix 7.4).

During the winter of 2007, when grazing pressure on the phytoplankton by *Artemia* was reduced to zero, the algal community responded with abundant growth. Mean chlorophyll-a concentration increased to 41.7 ug/L, and a high of 51.0 ug/L, in January. By March 15th the average concentration had decreased to 33.7. Following the onset of hatching and the recolonization of *Artemia* in April, the concentration of chlorophyll-a

had decreased to 7.5 ug/L. Subsequent sampling programs on May 23rd and June 9th showed similar, albeit lower chlorophyll-a levels to those observed during the spring and early summer of 2006. The concentrations were 1.8 and 1.7 ug/L for May 23 and June 9, 2007 respectively.

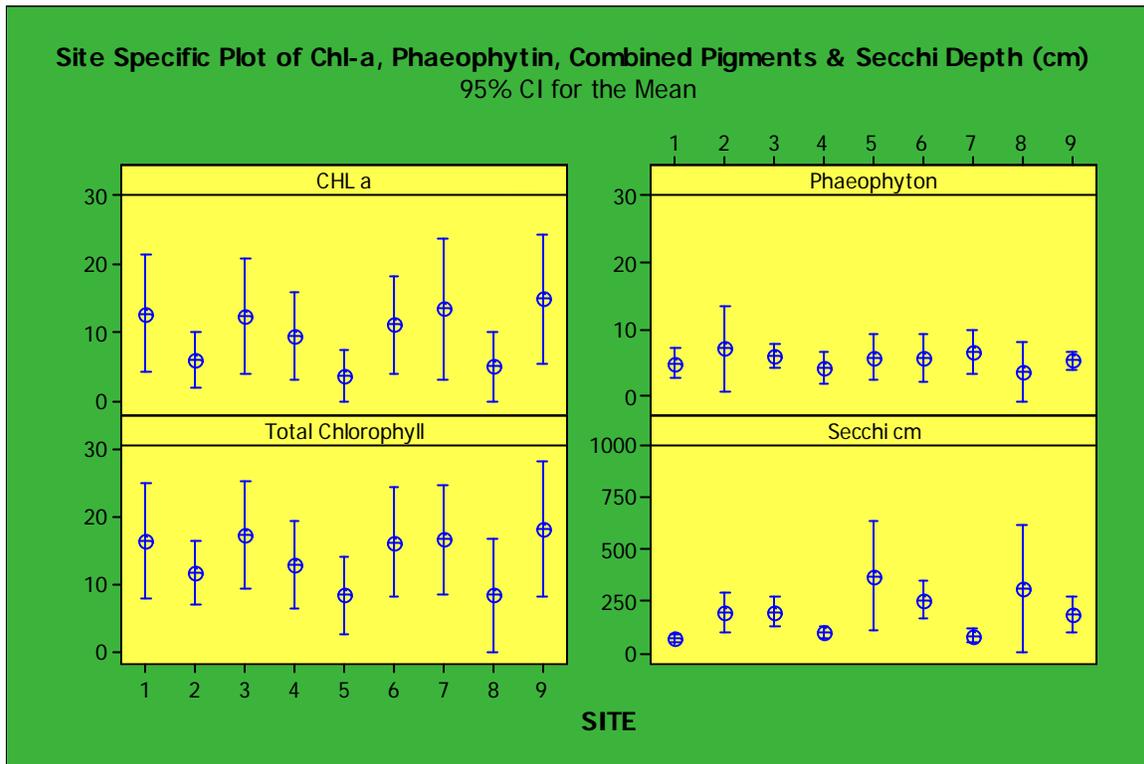
There were substantial differences in phaeophytin concentration between the spring of 2006 and 2007 (Appendix 7.2). In 2006 the phaeophytin concentration was highest on April 30th (13.1 ug/L) (Figure 27). The concentration decreased steadily thereafter and was in the range of 1.2 to 6.5 ug/L for the remainder of 2006. In contrast, phaeophytin levels during 2007 have not exceeded 6.5 ug/L and steadily decreased from this level in December to a low of 1.2 ug/L on May 23rd.

Figure 27. Interval plots in ug/L for chlorophyll-a, phaeophytin, and combined pigments (phaeophytin & chlorophyll-a) and secchi depth (cm) for GSL water samples collected from April 2006 to June 2007.



A comparison of average chlorophyll concentration by site is a useful indirect measure of differences that may exist spatially in algal production. Figure 28 shows mean values and 95% confidence intervals for chlorophyll-a, phaeophytin, combined pigments and Secchi depth by sample location.

Figure 28. Site-specific interval plots in ug/L for chlorophyll-a, phaeophytin, and combined pigments (phaeophytin & chlorophyll-a) and secchi depth (cm) for GSL water samples from April 2006 to June 2007.

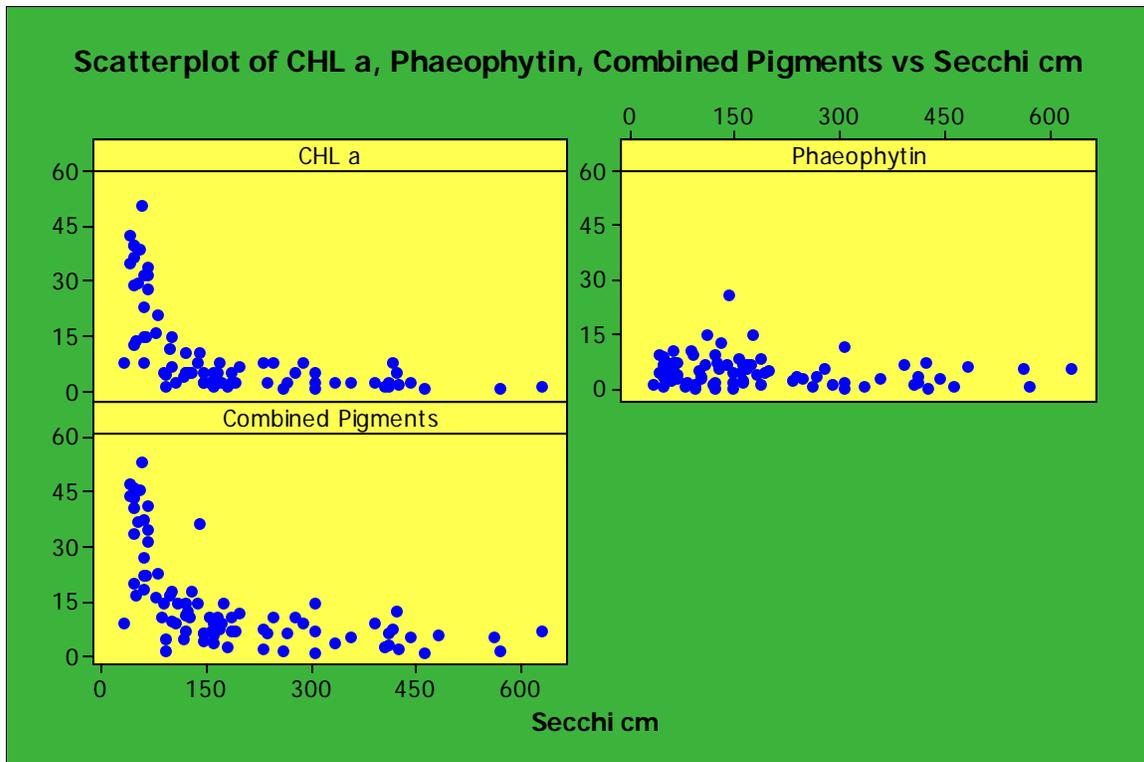


The results for sites 2, 5, and 8 (medium depth) are generally lower than the other sites. This is understandable in the context of the sampling schedule—medium depth sites were only included in the study during the spring and early summer of 2006. During this time period grazing pressure on the algae remained high and did not allow for substantial algal growth. The maximum values of chlorophyll-a for all deep and shallow sites, except site #1 (Fremont Island), were quite similar and ranged from 37 to 43 ug/L. Site #1 did have a higher peak value of 51 ug/L, suggesting that this location may have greater primary

productivity than the other locations. It is noteworthy that this location is near fresh water inputs from the Bear River, Ogden Bay, and Farmington Bay. Medium depth sites had much larger 95% confidence intervals, which may be attributable to the limited number of samples taken from these sites relative to the deep and shallow sites.

Water transparency measurements can be used as an indirect measure of primary productivity in lakes. The relationship between Secchi depths and chlorophyll-a concentrations is presented in Figure 29. We observed a pattern of exponentially increasing chlorophyll-a concentrations as Secchi depth decreases below 1.5 meters. Similar patterns demonstrating an exponential relationship between low Secchi depth and chlorophyll have been documented in other lake studies (Dodds, 2002). At Secchi depths of ≤ 1 meter chlorophyll-a concentrations were generally between 10 to 50 ug/L. Between one meter and three meters transparency the chlorophyll-a values were usually between 3 and 8 ug/L. At high levels of water clarity, at least with respect to the GSL, chlorophyll-a levels were very low, typically falling below 3 ug/L.

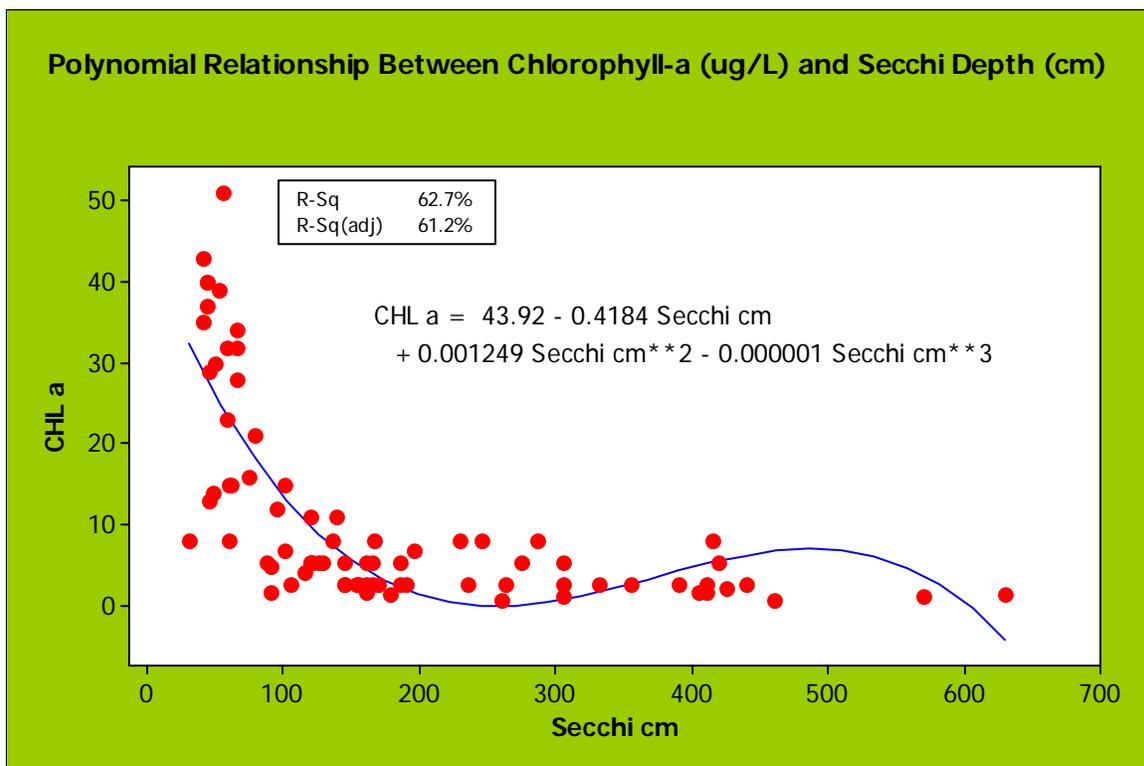
Figure 29. Scatter plot of Secchi depth and algal pigments for the GSL. Samples were collected from April 2006 to June 2007. Results show a characteristic exponential decline in chlorophyll-a as Secchi depth increases. Secchi depths of less than 1.5 meters correspond to levels of chlorophyll-a that are generally associated with robust growth and productivity of *Artemia*.



A best fit line was described for the relationship between chlorophyll-a and secchi depth (Figure 30). A polynomial equation was defined that can be used to estimate chlorophyll-a levels in the GSL when provided with secchi depth measurements. It must be kept in mind that the accuracy of this equation will be influenced by the relative composition of the phytoplankton population due to differences in amounts of chlorophyll-a produced by the many species of algae found within the GSL. Turbidity, decomposing biomass, and

other factors can affect secchi depth measurements. However, in a chlorophyte dominated algal population this equation should be a generally useful predictive tool.

Figure 30. The relationship between Secchi depth and chlorophyll-a for GSL water samples is shown and a best-fit line is provided. A reasonably good fit of a cubic polynomial equation ($R^2 = 0.627$) describes the relationship observed for the GSL during 2006 and 2007. The distribution of chlorophyll measurements may be decidedly different with changes in the relative abundance of phytoplankton taxa.



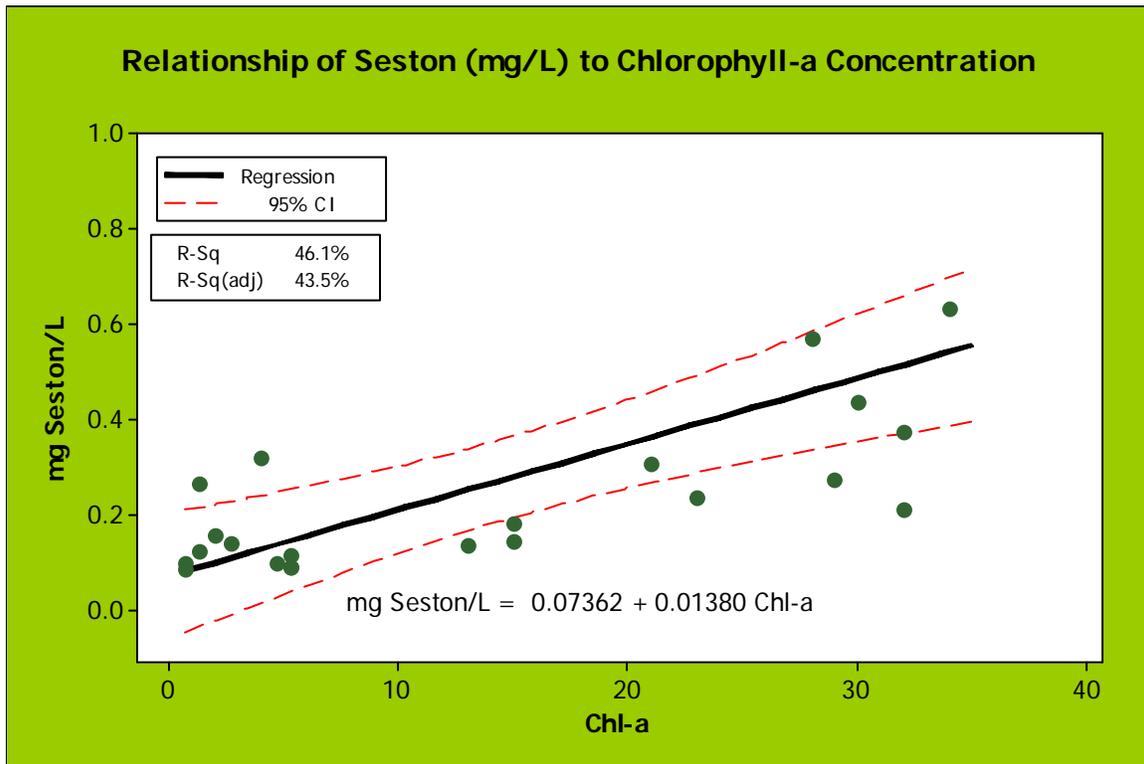
The mean and median chlorophyll-a concentration for all sites and sampling dates were 10.12 and 5.30 ug/L respectively. These statistics, and the maximum range over which chlorophyll-a is observed in the GSL, would characterize the GSL as a mesotrophic lake, fluctuating between robust algal growth and transient depletion of phytoplankton due to

Artemia grazing pressure. As chlorophyll-a levels decline below 5 to 7 ug/L on the GSL food-stress appears to induce a shift to oviparous reproduction. This shift to oviparity occurs at a similar concentration of chlorophyll as indicated in laboratory studies (Gliwicz, et.al., 1995). Other investigators have shown that survival declines dramatically as chlorophyll-a concentrations fall below 5.0 ug/L, and especially below 2.5 ug/L, (Belovsky and Mellison, 1997). In our study there were 7 sample programs in 2006, and 2 programs in 2007, in which the average chlorophyll-a concentration was below 5.0 ug/L. There were three sampling programs in which it was below 2.5 ug/L (Appendix 7.1). Improved accuracy in identifying the critical threshold of chlorophyll that is associated with changes in reproductive modes would require frequent sampling (i.e., weekly) from March to mid-June.

The relationship between chlorophyll concentration and seston yield per liter filtered was examined in the data. This relationship and that of Secchi depth to seston yield have practical applications for this and future studies. It is of value in the design of lake sampling protocols to anticipate seston yield from water filtration. The relationship between an easily measured endpoint (e.g., Secchi depth) or an alternative endpoint (e.g., chlorophyll) and seston yield can assist the investigator in anticipating the volume of filtered water required to provide adequate seston sample size for analytical purposes.

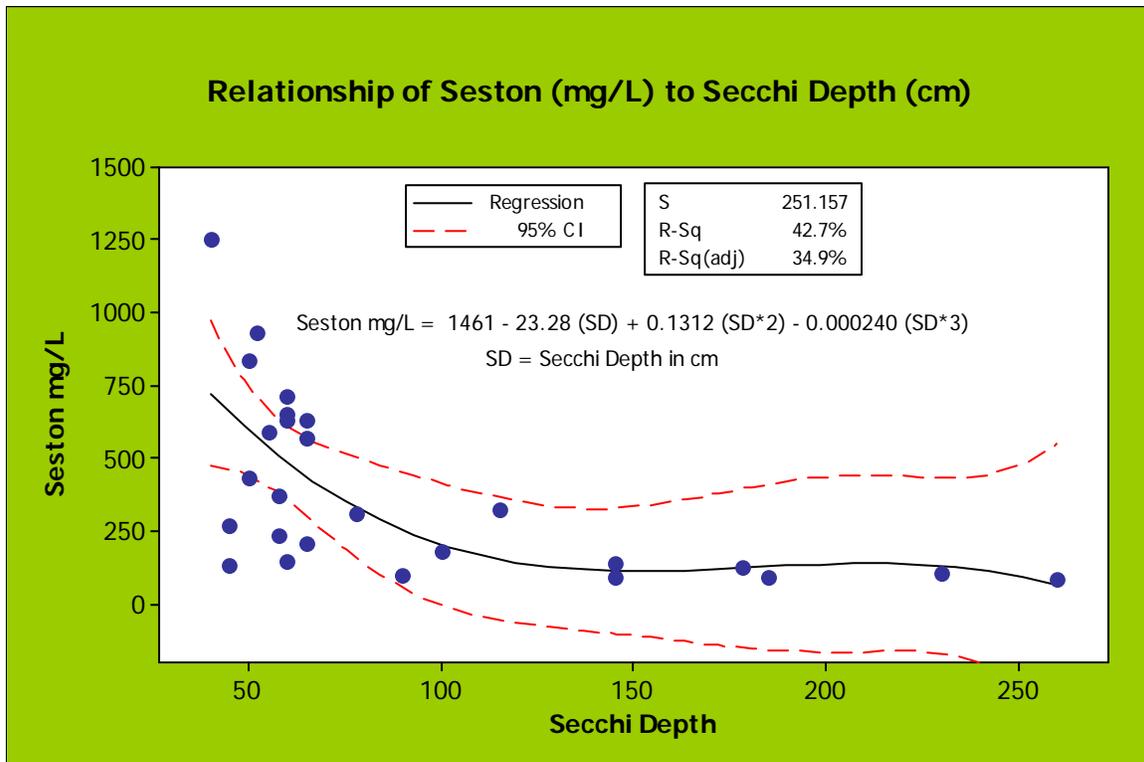
The relationship of chlorophyll and seston yield is shown below in Figure 31. There is a moderate positive relationship ($R^2 = 0.461$) between chlorophyll-a and the yield of seston in mg/L.

Figure 31. Chlorophyll-a concentration in GSL water is examined with respect to seston yields from the same sample location and sampling program. A positive correlation between these two variables was observed.



The correlation between Secchi depth and seston yield was examined in terms of identifying a relatively easy endpoint to measure that can guide seston sampling protocols. There was a negative nonlinear negative relationship between seston yield and Secchi depth. A best-fit line relationship is shown below in Figure 32. Whereas the equation provides a range of expected seston yield values, there are obvious limitations to the use of Secchi depth as a predictor of seston yield, especially at the extremes of Secchi depth.

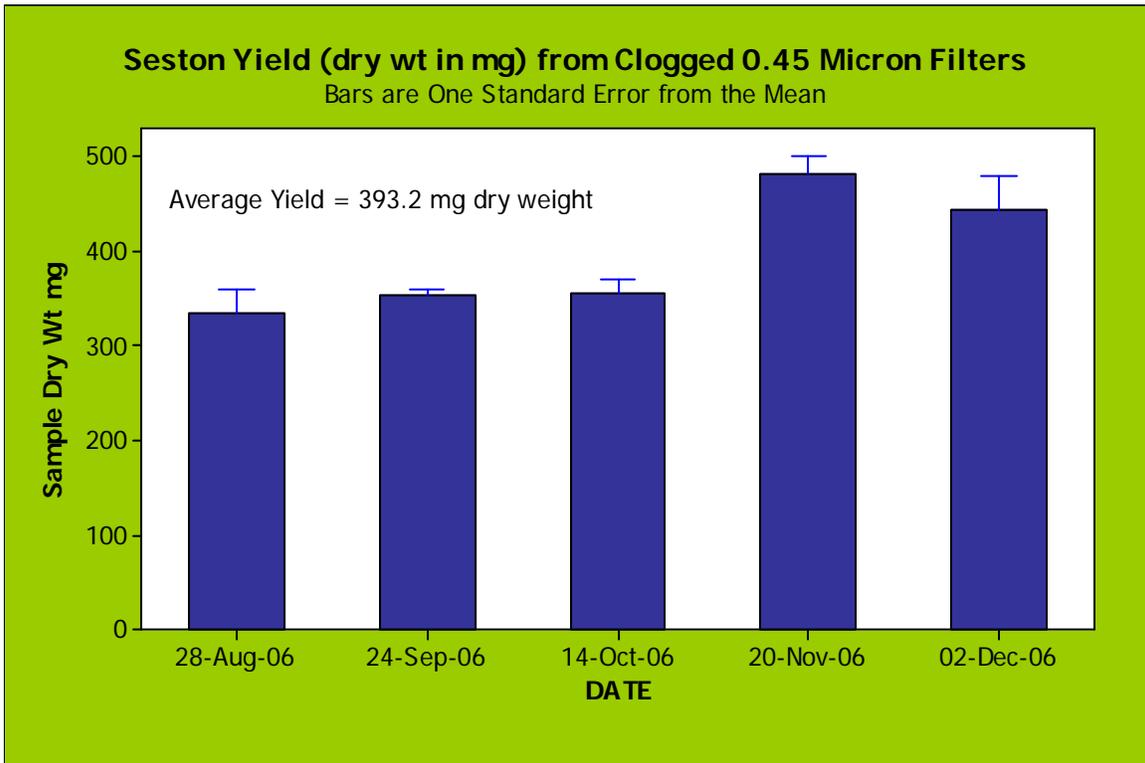
Figure 32. A negative polynomial relationship between seston (mg/L) and Secchi depth can be described for GSL water samples. This relationship has practical applications for estimating the volume of filtered GSL water required for adequate seston sample size. The estimate of volume required can be based on a simple assessment of water transparency.



Seston samples were collected by filtering known volumes of GSL water through 0.45 micron, 142 mm, cellulose acetate filters (flatstock filters). Filtration was initially done (May to July 2006) on equivalent volumes (one liter) of GSL at each sample site. Due to concerns about low yield, and limits of detection on seston samples, the volume filtered was increased—filtration was continued until the filters were clogged with particulate matter. The volume of GSL water filtered was then recorded. The cellulose acetate

filters used in this study exhibited similar capacities at the point of clogging—the average weight of material on the filters was 393 mg of seston (Figure 33).

Figure 33. The maximum yield in seston (mg) collected via filtration using 142 mm, 0.45 micron cellulose acetate filters. Water was filtered until the filters were clogged.



Phytoplankton Composition and Abundance.

Although phytoplankton analysis was not included in the initial project budget, it was deemed important to examine, to the extent possible, the phytoplankton composition over the course of this study. Water samples were pooled according to geographic region (Northeast, Central, Southeast) then preserved in a combination of Lugol's solution

(0.5%) and 1% formaldehyde solution. The samples were used for phytoplankton identification and enumeration. The results from May through August 2006 are shown below in Figures 34 to 39. Results from subsequent sampling programs are awaiting finalization.

Figure 34. Relative abundance of GSL phytoplankton on May 25, 2006.

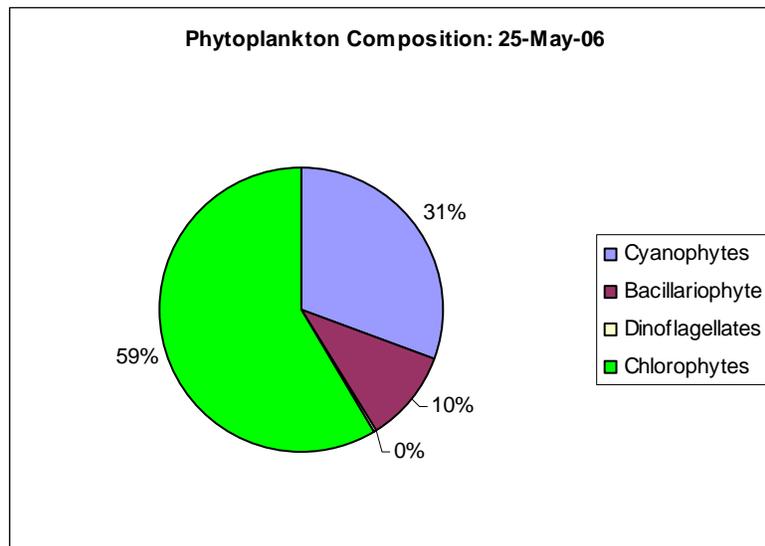


Figure 35. Relative abundance of GSL phytoplankton on June 29, 2006

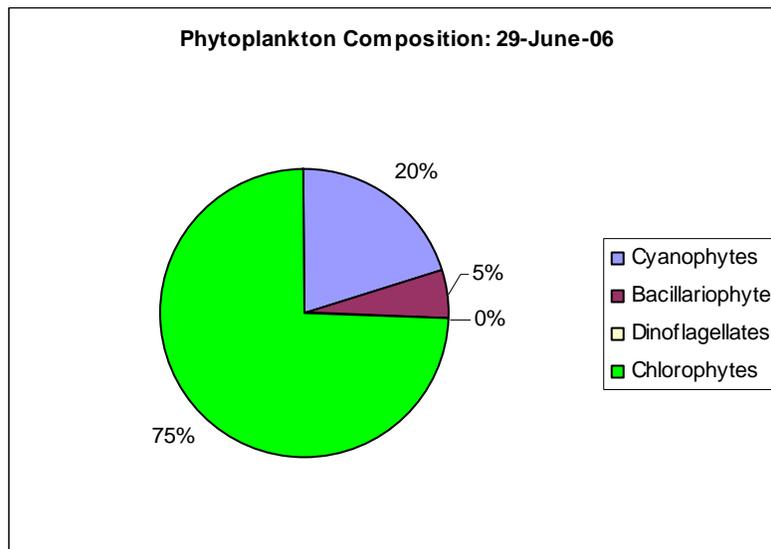


Figure 36. Relative abundance of GSL phytoplankton on July 10, 2006

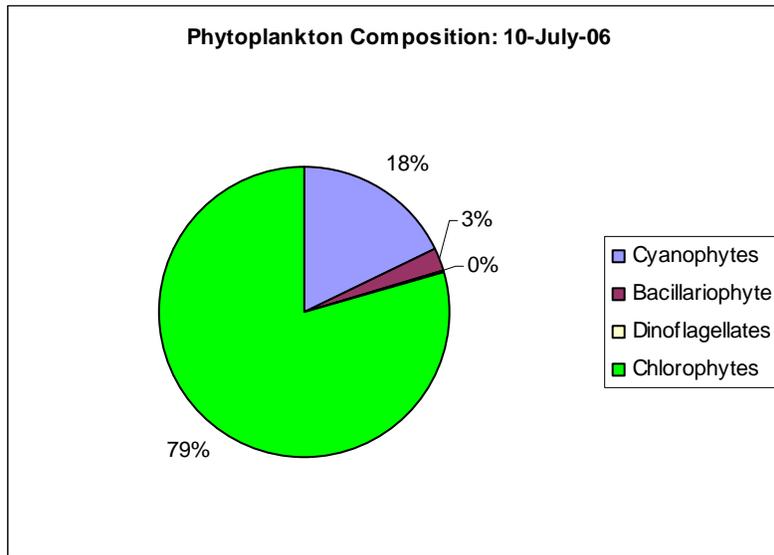


Figure 37. Relative abundance of GSL phytoplankton on July 27, 2006

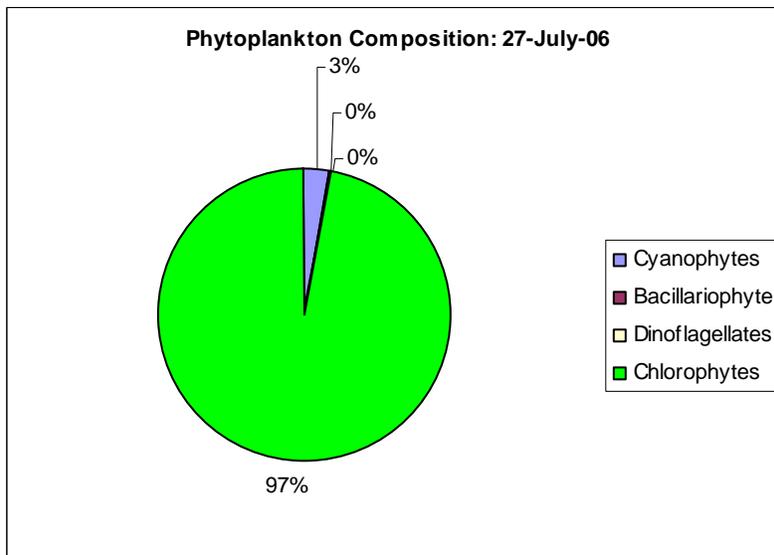


Figure 38. Relative abundance of GSL phytoplankton on August 18, 2006

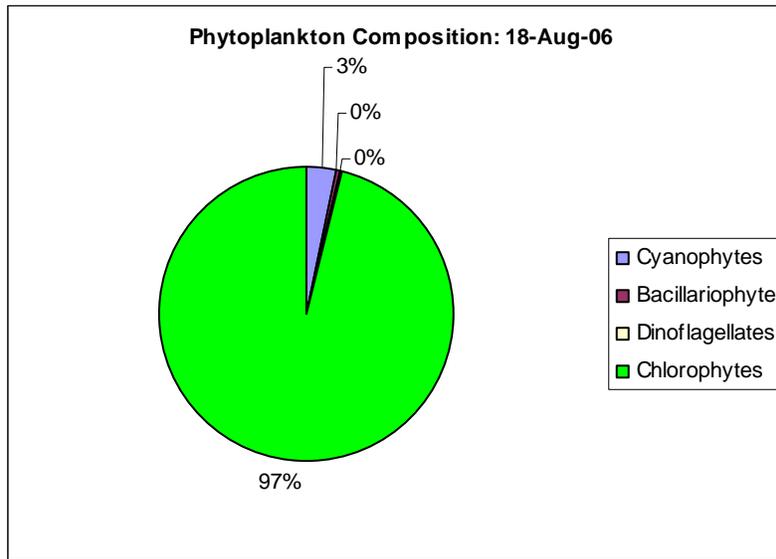
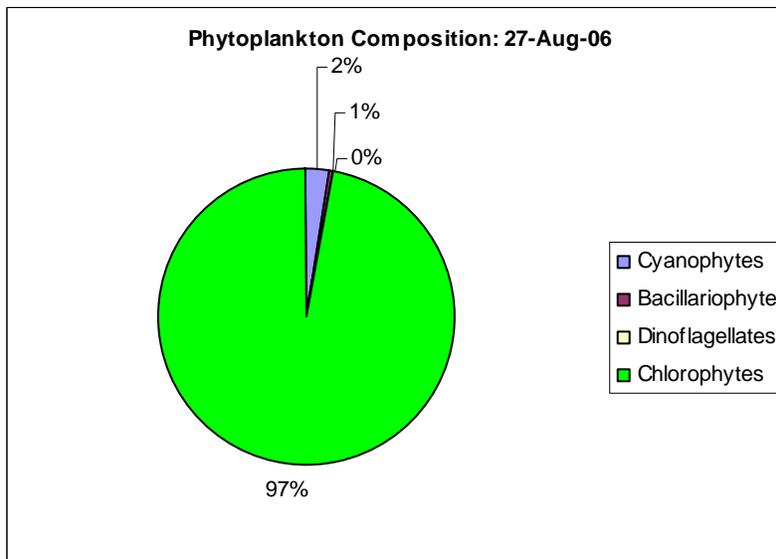


Figure 39. Relative abundance of GSL phytoplankton on August 27, 2006



There was a progressive shift in relative abundance from May to August 2006 in which the relative percentage of chlorophytes increased in dominance reaching a peak relative abundance of 97% in late July and sustaining this level throughout August. The composition of phytoplankton during earlier months exhibited a greater presence of other algae. In May, chlorophytes represented only 59% of the phytoplankton while cyanobacteria (31%) and bacillariophytes (10%) made up the remaining 41%. The combined percentage of cyanobacteria and bacillariophytes decreased to 25% in June and then to 13% in early July. A complete list of confirmed phytoplankton genera, or species, for all sample programs completed will accompany the final report.

Cell counts were determined in the phytoplankton samples and are shown in Table 8. Cell counts were lowest in June (47,672 cells per liter) and were the highest on July 27th (622,350 cells per liter). These results do not correlate well with chlorophyll measurements—a regression analysis of the relationship between algal cell count and chlorophyll results in a weak positive linear relationship (R^2 value = 0.239). Algal cells are quite fragile and can easily be damaged during prolonged storage or transport, especially flagellated cells. Ideally, samples should be analyzed within days of collection (Stephens, 1997). It is possible that storage conditions and transport may have had an adverse impact on the algal cells and may have altered the accuracy of cell counts. Notwithstanding these concerns, our results for algal cell counts are similar in range to previous studies (Stephens 1997, 1998, 1999). It is also noteworthy that in these previous

studies no clear relationship between chlorophyll, brine shrimp population structure, and algal cell counts was reported.

Table 8. Phytoplankton cell counts from GSL water samples taken from May 2006 to August 2006. Counts are expressed in cells per liter.

Date	Cyanophyceae	Bacillariophyceae	Dinophyceae	Chlorophyceae	Total
May 25, 2006	16,157.66	5,531.26	167.60	30,921.79	52,778.31
June 29, 2006	9,683.43	2,467.41	-	35,521.41	47,672.25
July 10, 2006	27,541.90	4,022.34	111.73	123,156.42	154,832.38
July 27, 2006	17,569.83	1,747.37	-	603,032.24	622,349.45
August 18, 2006	12,247.06	999.39	105.53	341,852.90	355,204.87
August 25, 2006	1,725.63	366.23	-	67,554.30	69,646.17

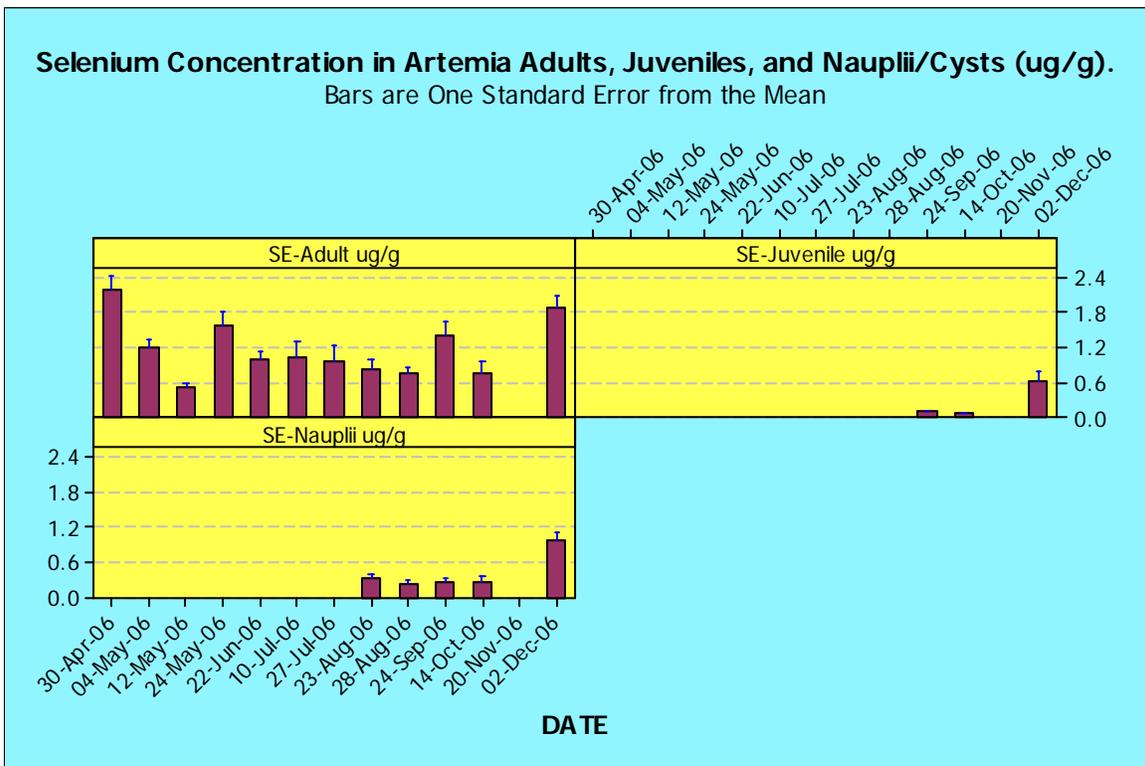
Selenium Concentration in Brine Shrimp, Water, and Seston Samples.

Brine shrimp were successfully collected by multiple plankton net hauls from each site and then selectively filtered according to size distribution (850, 500, and 125 micron). In the laboratory the samples were inspected and further sorted to verify age class designations were correct within each size fraction (adult, juvenile, and nauplii/cyst). The purpose of separating the brine shrimp into age classes for selenium tissue analysis is to determine if there is an age related difference in tissue selenium concentration. Any other zooplankton species, debris, or algal clumps in the brine shrimp biomass were removed in an effort to ensure that values reported reflected brine shrimp biomass and not other incidental material or tissue. Selenium was analyzed for total selenium only--selenium speciation was not included in the analysis for these tissue samples.

The results for each sample date are depicted below in Figure 40 and are provided in greater detail in Appendices 8.1 to 8.5. The arithmetic mean concentration in adult brine shrimp from April 30, 2006 to December 2, 2006 was 1.185 ug/g and the geometric mean was 0.984 ug/g. The highest concentration in the adult tissue samples was 3.30 ug/g. Average concentrations varied across sampling program dates. The highest average concentration of selenium in adult brine shrimp tissue was recorded on April 30, 2006 (2.19 ug/g). The lowest average concentration of 0.50 ug/g was observed on May 12, 2006. Tissue selenium concentration in adult brine shrimp were transformed (Johnson

transformation) and then analyzed by sample date using one-way ANOVA. Selenium concentrations did vary significantly over time ($P < 0.01$, df: 11, 68).

Figure 40. Tissue selenium concentration in brine shrimp adults, juveniles, and nauplii/cysts. Samples were collected for all age classes on each sample date. A limited number of the younger age classes has been analyzed. Selenium concentrations are expressed as arithmetic means for each sample location on a given date.



The adult brine shrimp tissue concentration reported herein (1.18 ± 0.68 ug/g) was generally lower than the few other samples of brine shrimp collected and analyzed by concurrent GSL research teams or in the scientific literature. The average value of selenium in brine shrimp in Conover's database was 4.5 ug/g and of the few samples listed for Cavitt the values were 2.5 to 3.2 ug/g. Our concentration of 1.18 ug/g was also

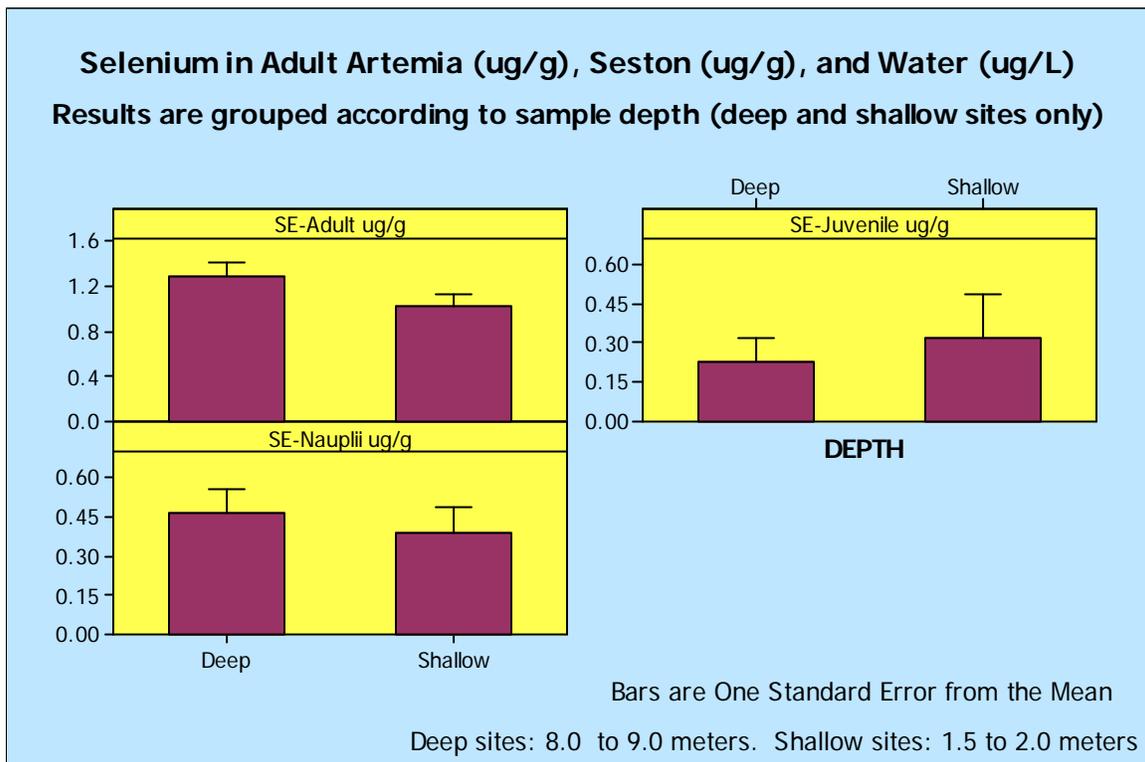
somewhat lower than that reported by Brix et al., (2003)—these authors reported selenium tissue concentrations of 2 to 3 ug/g for samples collected from the open water of the GSL. Our values are closer to those presented by Dr. Marge Brooks in her science panel presentation; she cited studies from 1994 to 2004 that measured 0.3 to 4.5 ug/g selenium in brine shrimp. The range of concentrations observed in brine shrimp tissue (0.10 to 3.30) ug/g in the current study was similar to the range of concentrations reported by Cavitt (2007) for brine fly larvae (0.8 to 3.8 ug/g) and those reported for brine fly larvae (1.3 ug/g) and pupae (1.8 ug/g) by Wurtsbaugh (2007).

One explanation for the lower value for brine shrimp tissue selenium reported in our results as compared to others could be the additional rinsing, cleaning, and sorting steps that were undertaken to separate brine shrimp according to age classes and to remove any incidental debris. Also, with small volume samples, such as the juvenile fraction, there was residual GSL water, or moisture, in the sample that may have lowered the apparent selenium concentration on a dry weight basis. The additional step, implemented for 2007 sample preparation, of using negative pressure filtration to remove residual moisture from brine shrimp tissue samples should alleviate this as a confounding factor in the samples collected during 2007.

Tissue concentrations of selenium were quite similar when grouped by sample site (Figure 41). Statistical analyses for geographic distribution were done according to regional sample locations (Northeast, Central, Southeast), rather than for site-specific results. No significant differences were found in selenium concentrations across sample

locations ($P = 0.759$, $df: 2, 77$). Grouping brine shrimp tissue concentrations according to depth categories was of interest for this study because of the distinct differences in biogeochemical processes that occur among sites with distinctly different maximum depths. Since medium depth sites were not sampled throughout the study period statistical tests by depth included only the shallow and deep sites. Although the average concentration of selenium in brine shrimp tissue collected at deep sites was slightly higher ($+ 0.28 \text{ ug/g}$) than the average for shallow sites, the difference in mean values between these depth categories was not statistically different at the $P \leq 0.05$ level ($P=0.085$, $df: 1, 66$).

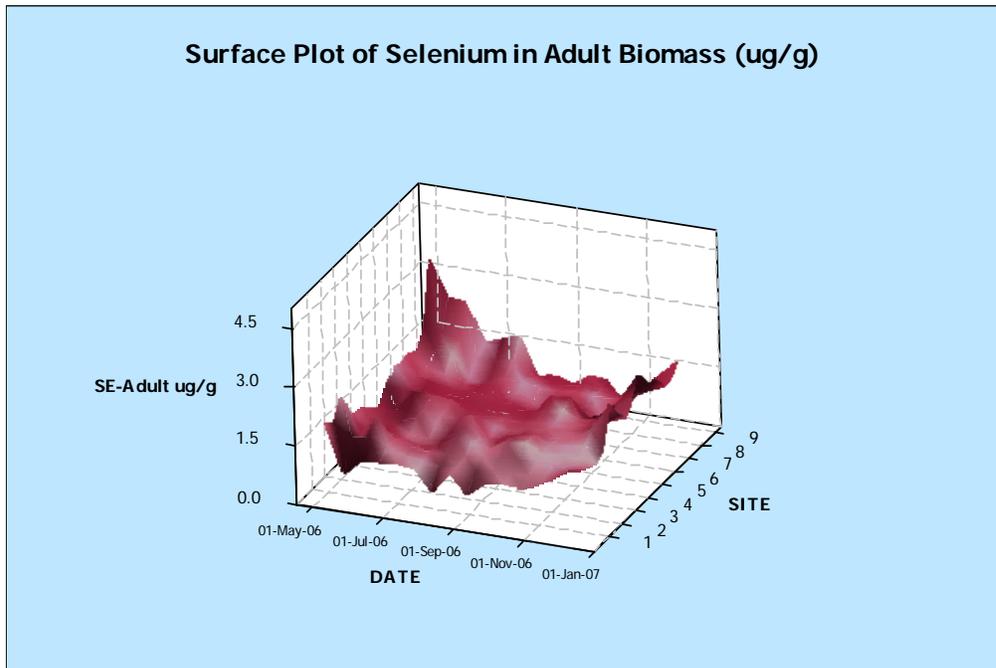
Figure 41. Selenium concentration in brine shrimp tissue (ug/g), seston (ug/g) and water (ug/L) grouped according to sample depth. The average concentration in adult brine shrimp tissue for the deep sites was greater than the selenium tissue concentration for the corresponding shallow site in each region of the GSL.



A plot of selenium in adult brine shrimp tissue depicted spatially and temporally is shown below in Figure 42. This surface plot provides a constructive visual representation of the pattern of selenium in brine shrimp tissue. Site #9 (deep site in Southeastern region of the lake) had the highest value observed (3.300 ug/g) and was ranked second in average selenium concentration (1.487 ug/g). Site #7 (shallow site near the southern end of Antelope Island) had the lowest mean value (0.885 ug/g). Temporally, April (2.115 ug/g) and December (1.804 ug/g) showed the highest mean concentrations of selenium in adult brine shrimp tissue.

As mentioned previously, with regard to evaluating spatial differences in brine shrimp population dynamics and reproductive output, one must always consider that grouping and analyzing results spatially runs the risk of making the incorrect assumption that brine shrimp sampled at given location have been in that particular location sufficiently long to be influenced physiologically or biologically by local biotic and abiotic conditions. We cannot say with certainty that this is the case for the brine shrimp collected in each specific location—we can only examine the results in terms of consistent or meaningful spatial patterns. For the most part, spatial groupings did not show significant differences in tissue or water concentrations of selenium.

Figure 42. Surface plot of selenium concentration in adult brine shrimp tissue from April to December 2006. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed. Although significant differences did exist over time no such differences were found among the geographic locations.



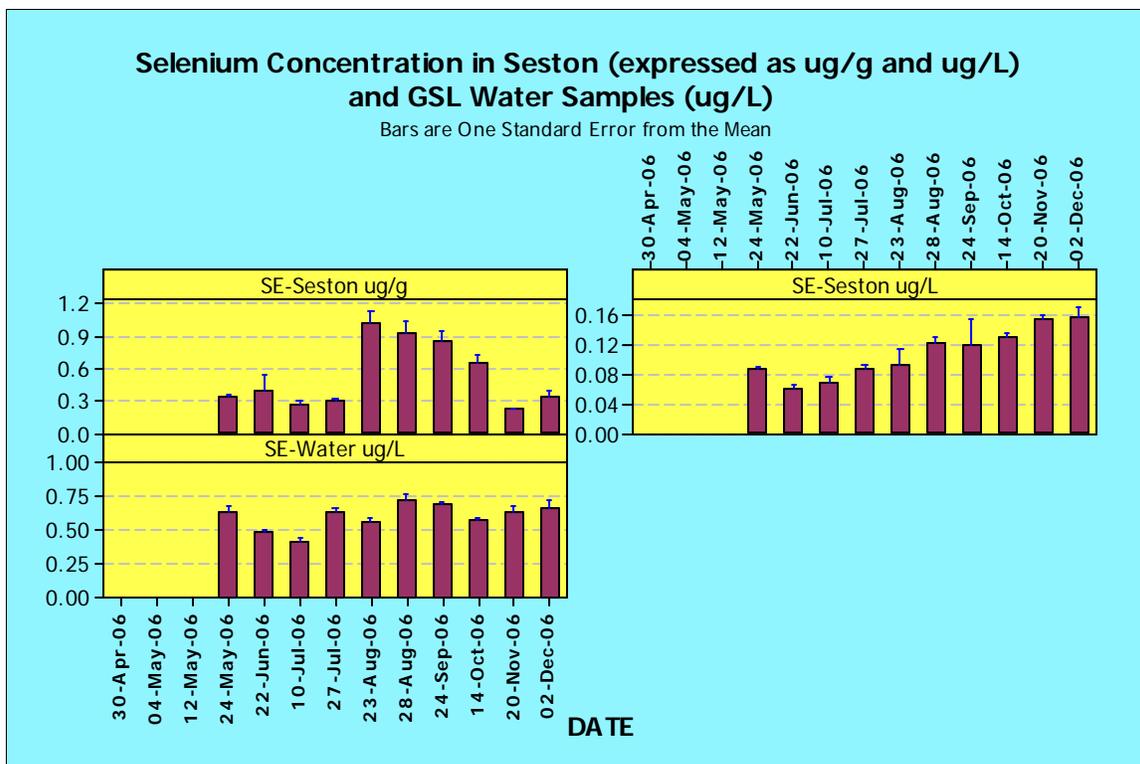
Although juvenile and nauplii/cyst fractions were collected and stored for each sampling program, not all of the samples were analyzed. This was done because the primary focus of this study is in regard to avian dietary exposure to selenium via the food web, and adults comprise the majority of the *Artemia* biomass as well as the diets of birds foraging on brine shrimp. Therefore, it was determined that all adults would be analyzed and that younger age class *Artemia* would be analyzed from a subset of the sampling programs (August 2006 through June 2007).

The results for the younger age classes indicate that there is an age related difference in the tissue concentration of selenium. Juveniles were 6% to 32% and the nauplii/cyst fraction was 18% to 54% of the selenium concentration in adults for the same sample site and date (Figure 40 and Appendices 8.1 & 8.2). Average juvenile tissue selenium levels were quite low with values of 0.06 to 0.61 ug/g tissue dry weight and for the nauplii/cyst fraction the selenium concentration was 0.24 to 1.01 ug/g. The maximum tissue concentration observed for juveniles was 1.40 ug/g (December 2, 2006) and 1.30 ug/g for the nauplii/cyst fraction on the same date. Biomass sample sizes for the smaller age classes were low compared to the adult fraction and this may have had some influence on the selenium concentration determination. Sample sizes for all age classes were increased substantially during the 2007 sampling programs. Samples from January through June 2007 have been sent to LET for analysis, but are awaiting completion.

Seston samples were collected by filtering between 1 and 5 liters of GSL water through a 0.45 micron (pore size), 142 mm, flatstock cellulose acetate filter. Filters and particulates, primarily algal cells, were freeze-dried and weighed. The entire filter and filtrate were then acid-digested and analyzed for selenium concentration. The geometric mean for selenium in all seston samples was 0.415 ug/g and the arithmetic mean was 0.504 ug/g (Appendix 8.3). The highest selenium concentration in seston (1.408 ug/g) was on June 22, 2006 and the lowest concentration occurred in November and December, 2006 (0.166 & 0.167 ug/g) (Figure 43). The selenium concentration in seston on a volumetric basis was also calculated (the volume of GSL water filtered was recorded to the nearest 5 ml for all seston samples). The results show a geometric mean value of

0.097 ug/L and an arithmetic average of 0.105 ug/L. The concentration of selenium in seston on a per volume basis should be similar to the calculated particulate fraction in water samples (total – dissolved = particulate). Our results for selenium in seston (ug/L) are similar to the calculated particulate fraction for GSL water samples (0.14 ug/L) as reported by Johnson et al., (2007), and it also corresponds to our calculated particulate fraction for water (0.088 ug/L).

Figure 43. Selenium concentration in seston samples and water. Seston samples are expressed on a per weight and per volume basis. The concentration of selenium in seston (ug/L) shows a definitive increasing temporal trend. This trend corresponds to an increase in the phytoplankton population. This secondarily coincides with a decrease in grazing pressure following a reduction in the size of the *Artemia* population. The temporal trend, on a dry weight basis, from August to December suggests an inverse relationship between selenium tissue concentration and phytoplankton abundance.



Spatial and temporal differences in seston selenium concentration were evaluated. There were no significant differences in terms of geographic location ($P = 0.614$; $df: 2, 60$) (Figure 44) nor with respect to the depth category of the sample sites ($P = 0.826$; $df: 1, 54$) (Figure 45).

Figure 44. Selenium in seston and water samples according to geographic location. The average concentration of selenium in water or seston from May 2006 to December 2006 did not differ spatially when grouped according to lake regions.

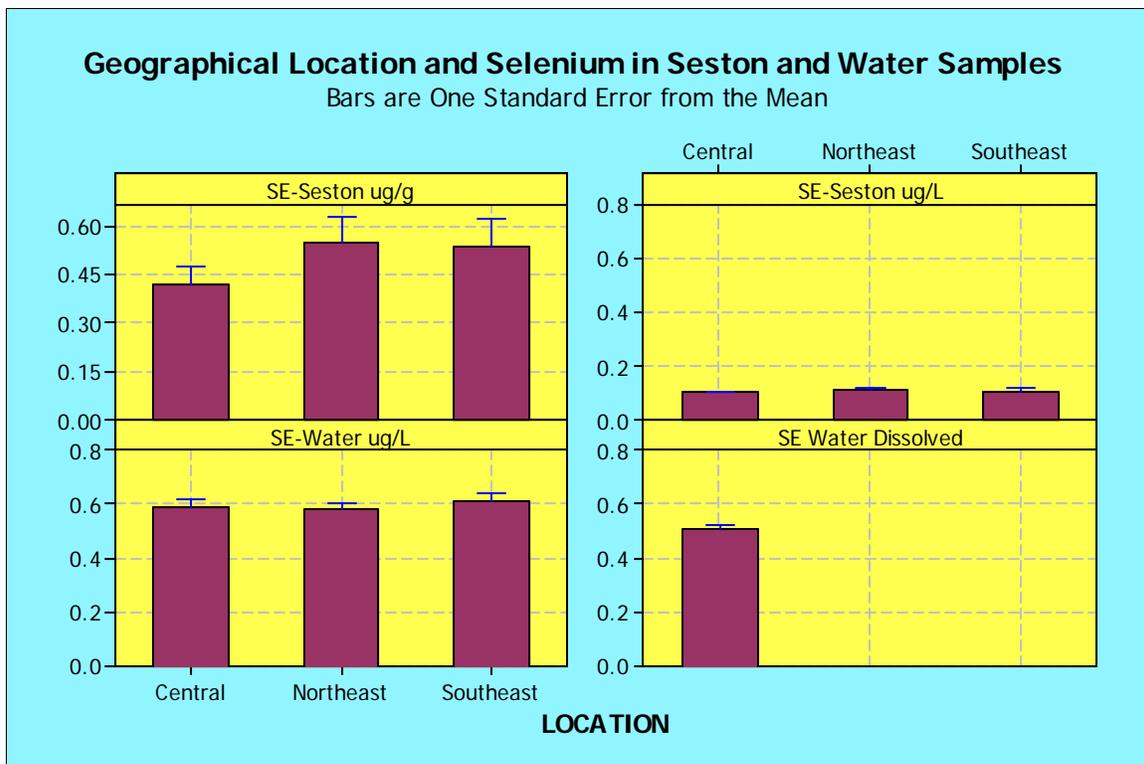
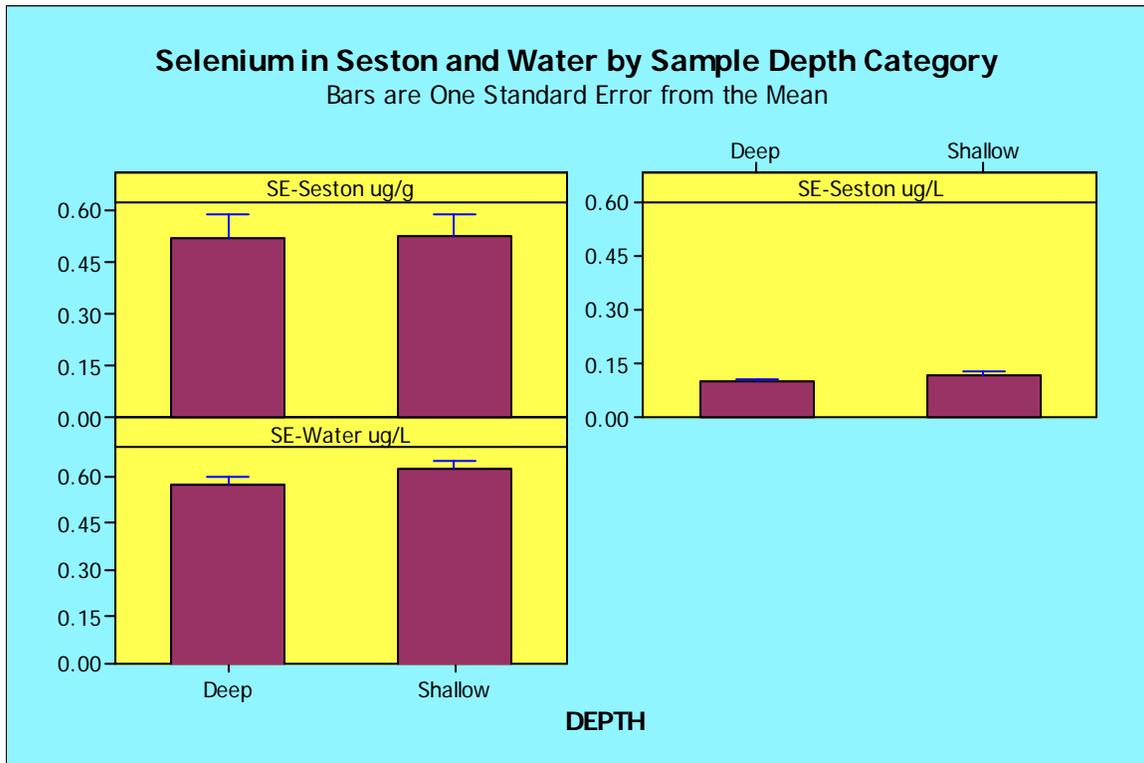
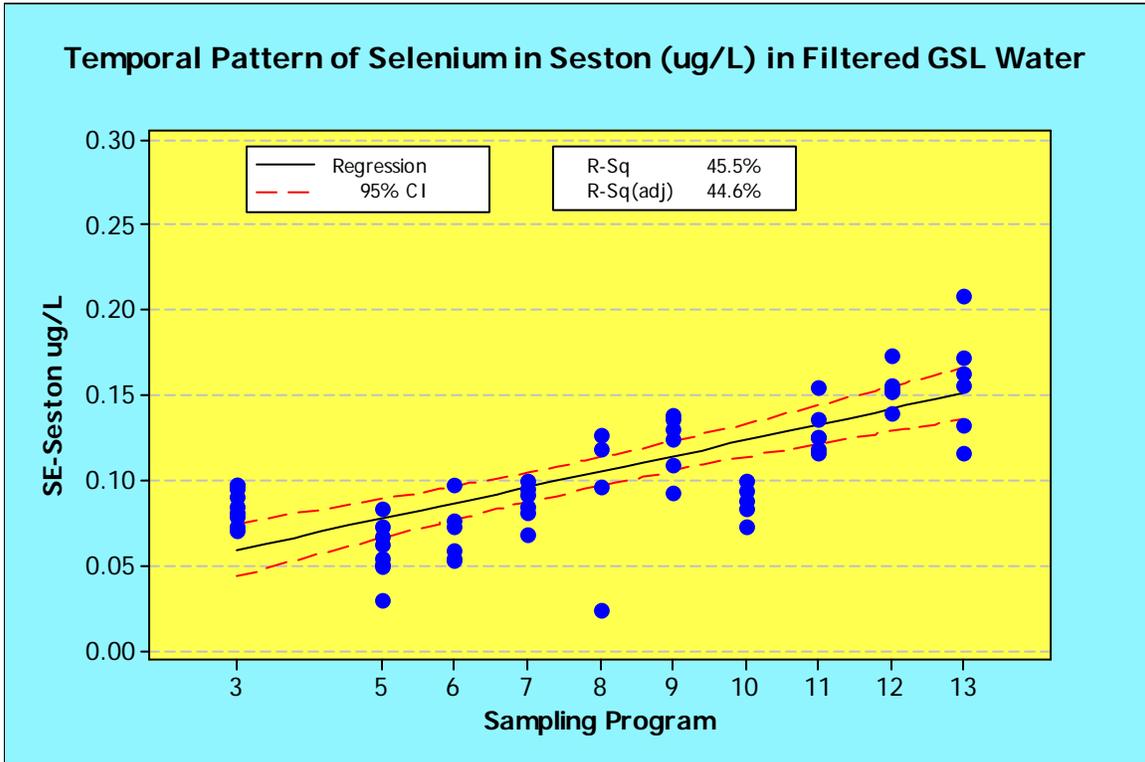


Figure 45. Selenium in seston and water samples according to sample depth category. There were no differences in average selenium concentration in water or seston in terms of the site depth category. Selenium data is from May 2006 to December 2006.



Temporally, the samples did substantially differ--there was a significant difference in the samples among the sampling dates ($P < 0.01$; $df: 9, 53$). Some interesting patterns in the seston data emerged. The concentration of selenium in the seston fraction on a dry weight basis increased sharply in August and then decreased steadily from August to November, 2006. The concentration in November and December was similar to levels observed from May through July. Alternatively, the seston concentration on a per volume basis showed a linear increasing trend over time (Figure 46).

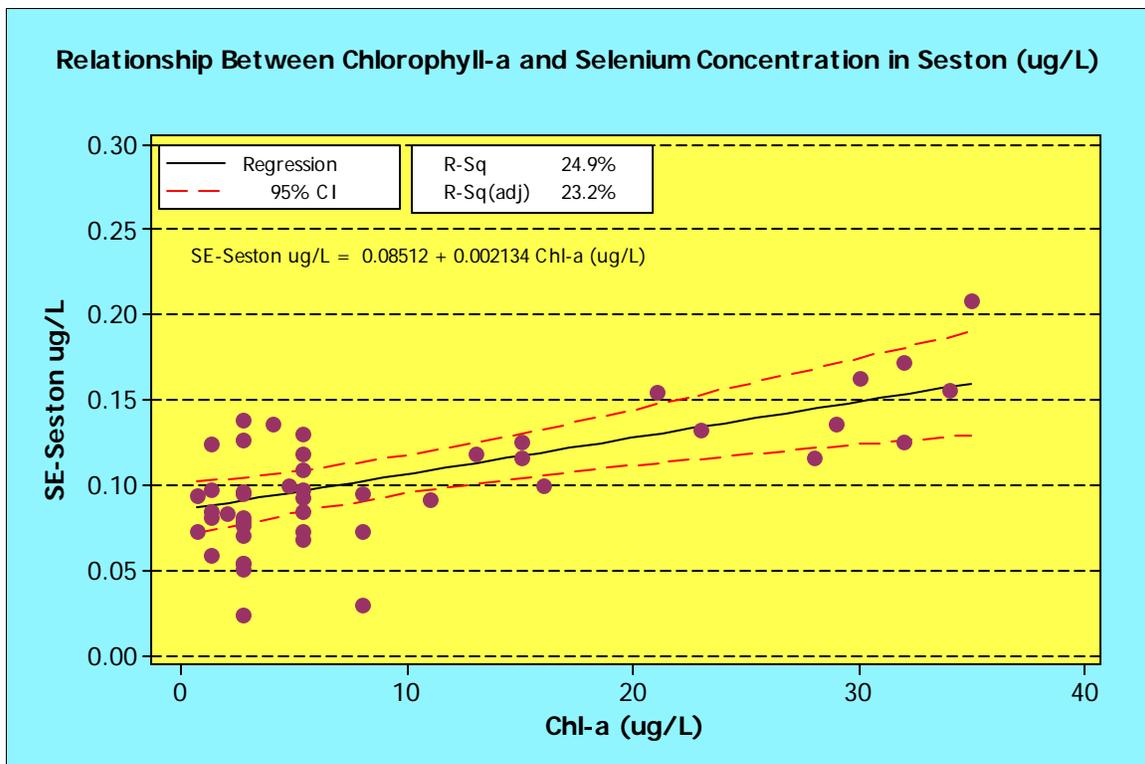
Figure 46. The concentration of selenium in the particulate fraction of GSL water increased steadily from May 2006 to December 2006. The increase appears to be more a function of the algal mass than of increasing selenium per gram of particulate matter.



This trend can likely be explained by the increase in algal growth, and therefore in the mass of algae per liter, attributable to decreased grazing pressure by the brine shrimp. To investigate this interpretation the seston results are plotted in terms of chlorophyll-a (Figure 47). There is a weak positive linear correlation ($R^2 = 0.24$) between increasing chlorophyll-a (i.e., increasing algal production) and the concentration of selenium in the particulate fraction of water. A linear relationship between chlorophyll-a and particulate selenium concentration in GSL water can be expected if chlorophyll-a is an accurate and linear measure of algal cell abundance, selenium uptake and loss in algal cells approaches

equilibrium, and the pool of bioavailable selenium is not depleted by uptake into a rapidly growing algal population.

Figure 47. Relationship between chlorophyll-a concentration in GSL water and the selenium concentration in suspended particulate matter. An increase in particulate selenium (ug/L) is expected to have a linear relationship with algal population growth if there is no depletion in the selenium source and if uptake and loss approach equilibrium. This trend is similar to that observed between the mass of seston per liter and chlorophyll-a concentration (Figure 31).



It will be quite informative to examine the 2007 results in terms of the relationship between selenium in dry weight seston, particulate component of water, and phytoplankton abundance.

Total selenium results for water were consistent spatially (Figure 44) but varied temporally (Figure 43). The geometric mean of selenium in water for all sample dates and locations was 0.584 ug/L and the arithmetic mean was 0.597 ug/L (Appendix 8.5). The lowest and highest concentration of selenium in water was 0.297 and 0.899 ug/L respectively. An average net increase of 0.033 ug/L was calculated for sequential sampling dates across all locations on the GSL (Table 9).

Table 9. Net change in arithmetic mean selenium concentration (ug/L) in GSL water samples. Net change is determined on each subsequent sampling date for all sample locations. The result indicates a net increase of 0.033 ug/L. However, this value falls within one standard deviation of the mean and therefore may be attributable to sampling error rather than being indicative of a distinct increasing trend.

Change in Average Water Selenium Concentration for All Sample Sites by Sampling Date.		
Date	Arithmetic Mean	Net Change From Previous Date (ug/L)
April 30, 2006	ND	ND
May 4, 2006	ND	ND
May 12, 2006	ND	ND
May 24, 2006	0.634	xx
June 22, 2006	0.484	-0.150
July 10, 2006	0.418	-0.066
July 27, 2006	0.639	0.221
August 23, 2006	0.554	-0.085
August 28, 2006	0.718	0.164
September 24, 2006	0.691	-0.027
October 14, 2006	0.572	-0.119
November 20, 2006	0.630	0.058
December 2, 2006	0.668	0.037
Net Change in Se Conc.		0.033
Grand Mean Se in Water (ug/L)	0.597	
Standard Deviation	0.124	

The same calculation on a per site basis gave a cumulative net decrease of -0.272 ug/L selenium in GSL water (Table 10). However, this calculation includes medium depth sites that were not sampled over the entire course of the study. Omitting the medium depth sites and then calculating a cumulative net change in water selenium concentration results in a net increase of 0.098 ug/L. The site-specific net change in selenium concentration among our study sites was inconsistent spatially: half of our sites (including only those that were sampled for the full duration of the study) showed a net decrease in selenium concentration. The remaining sample sites had a net increase in water selenium concentration (Figure 48). The cumulative net change for these six sites is within one standard deviation of the mean selenium concentration in water, and may therefore be simply an indicator of sample variability rather than being indicative of a definitive trend of selenium in water samples.

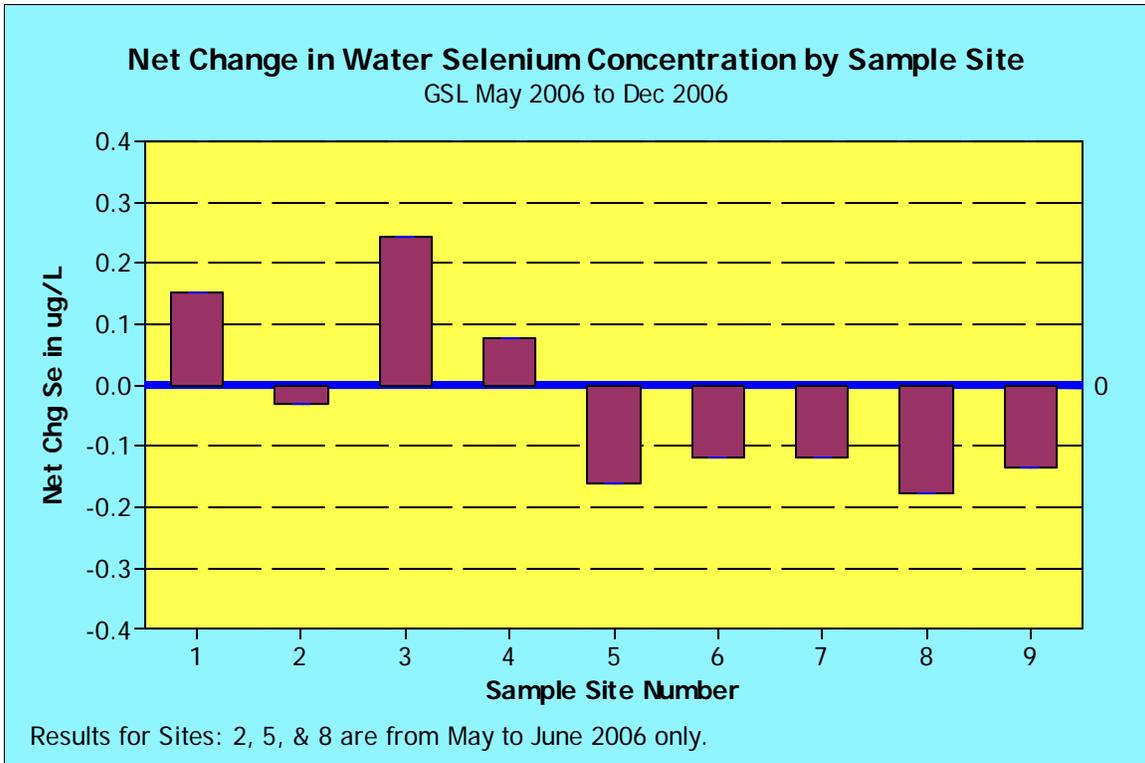
The results are similar to those reported by Naftz et. al., (2007). In their report they document a net increase in water selenium concentration of 0.009 ug/L to 0.226 ug/L. The model developed by this group is based on loading/loss measurements and predicts a net increase of 0.074 ug/L. Both our data and the results by Naftz are close to this value. It is difficult to say whether it is simply coincidental or meaningful, but the mean for the net increase in water concentration at monitored sites in the study by Naftz was +0.096 ug/L, which is indeed very close to the cumulative net change among our six complete sample sites (+0.098 ug/L).

Table 10. Net change in arithmetic mean selenium concentration (ug/L) in GSL water samples calculated on a per site basis. The net change is reported for all sites and then for deep and shallow sites only. Inclusion of the medium depth sites is valid only as a comparison of values from May through June. The net change for deep and shallow sites represents the net change in selenium in water samples from May through December 2006.

Change in Average Water Selenium Concentration By Sample Site				
Sample Site	Net Change Se	Min.	Max	N
1	0.153	-0.24	0.321	9
2	-0.031	-0.031	-0.031	1
3	0.242	-0.203	0.237	9
4	0.077	-0.16	0.205	9
5	-0.161	-0.161	-0.161	1
6	-0.119	-0.295	0.307	9
7	-0.12	-0.285	0.297	9
8	-0.178	-0.178	-0.178	1
9	-0.135	-0.382	0.189	9
Cumulative Change in All Sample Sites		-0.272		
Cumulative Change In Deep/Shallow Sites		0.098		
Note: Medium depth sites (2, 5, & 8) were not sampled for the entire duration of study.				

The results suggest that there was a net increase in selenium in water samples collected in the Northeastern region of the GSL, whereas in the Central and Southeastern regions there was a net decrease. However, statistically there is no difference across geographic locations in average concentration of selenium ($P = 0.736$; $df: 2, 63$).

Figure 48. Net change in arithmetic mean selenium concentration (ug/L) in GSL water samples calculated on a per site basis. The net change is reported for all sites.

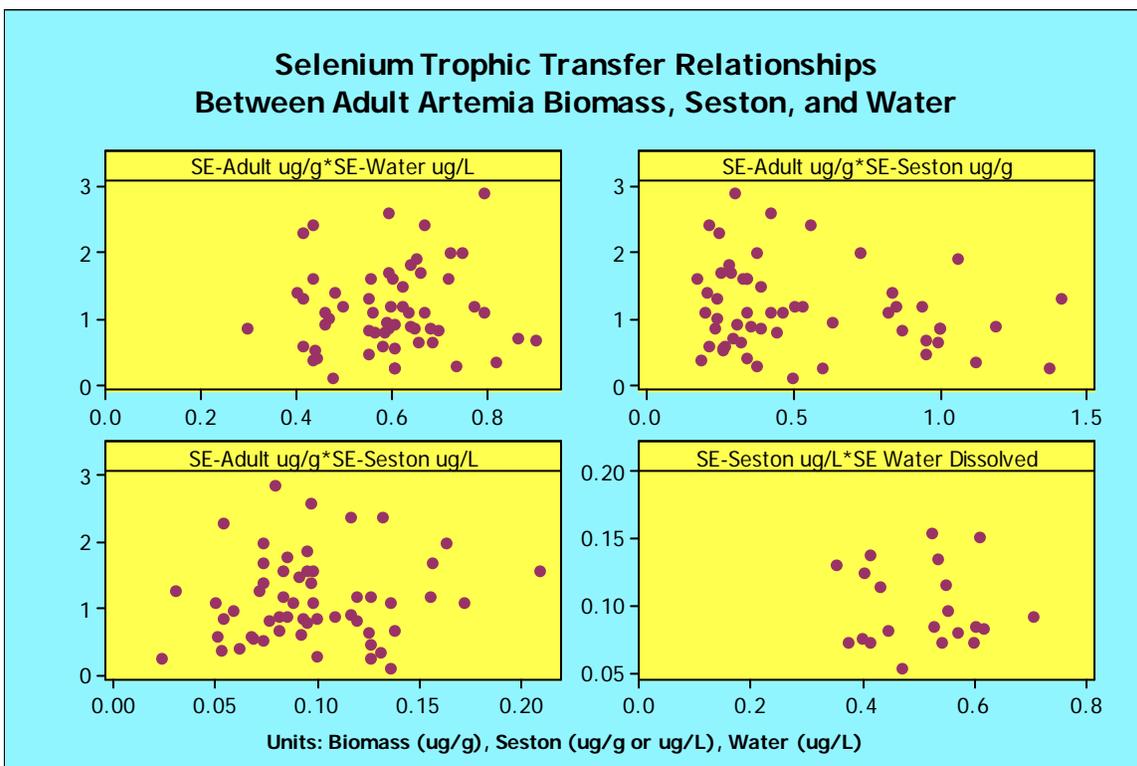


Transformed (Johnson transformation) data were analyzed using one-way ANOVA for comparisons across sample date. A T-test was used to analyze results according to depth categories. No significant differences in average water selenium concentration were found for water depth categories ($P = 0.119$, $df: 1, 57$). Water concentration of selenium did show a significant difference across sample dates ($P < 0.01$, $df: 9, 56$).

The data suggest that there are temporal events that influence selenium loading into specific trophic compartments. The source of these temporal events is not entirely clear, but may be more apparent once the data from all research programs are integrated and interpreted collectively.

The relationship between selenium concentrations and linked trophic components (e.g., water to seston or seston to brine shrimp) was evaluated and plotted. The results of this evaluation indicate that there is no discernible regression relationship between these compartments in the transfer of selenium (Figure 49).

Figure 49. The relationship between trophic compartments and selenium concentration. There is no discernible correlation between the concentration of selenium in water and the tissue concentration in either algae or brine shrimp adults. Similarly, no pattern is identifiable between seston and brine shrimp tissue selenium concentration.



The inability to establish a regression relationship between these trophic compartments is not surprising given the small range of exposure concentrations encountered on the GSL.

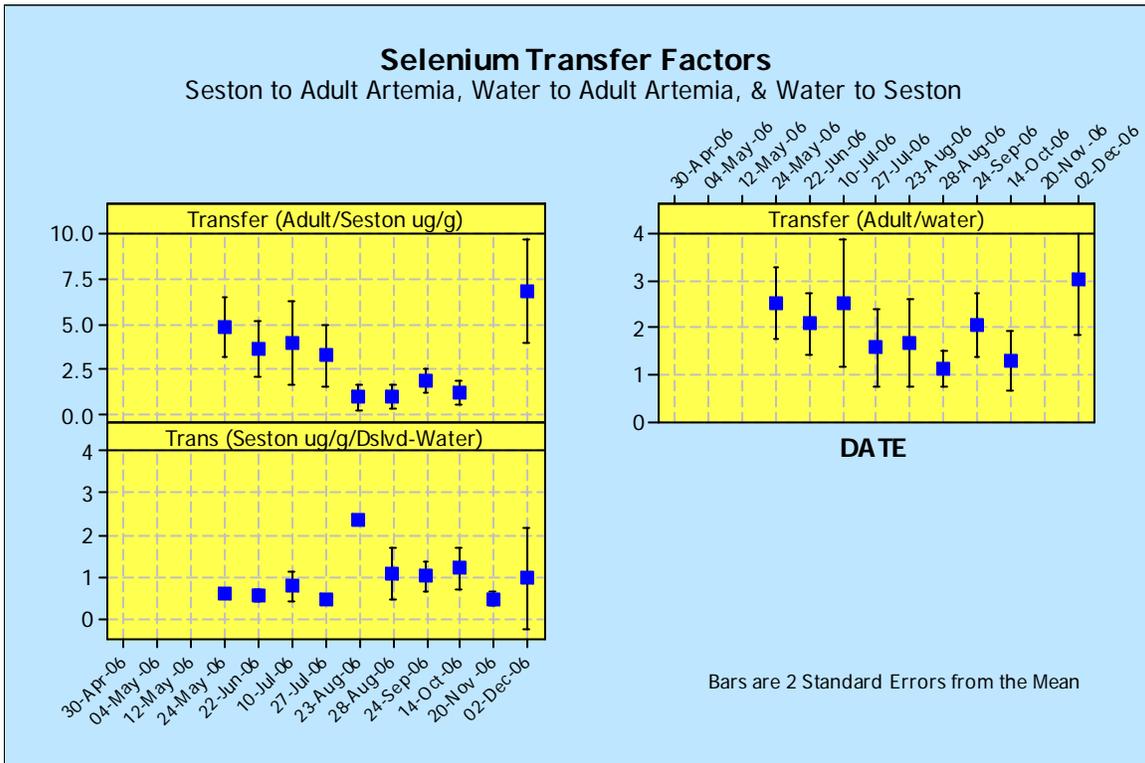
For example, the total range over which *Artemia* are exposed via water is 0.6 ug/L (0.30 to 0.90 ug/L) and the exposure range in the seston is 1.24 ug/g or 0.24 ug/L.

Other investigators have previously reported a weak relationship between low concentrations of selenium in water and algae and brine shrimp tissue. In the presentation given to the science panel (November 2006) Dr. Marge Brooks indicated that in the range of 1 to 11 ug/L selenium in water there is a poorly defined relationship with brine shrimp tissue selenium levels. Brooks further inferred that at these low environmental concentrations the brine shrimp are regulating their selenium levels in a manner largely independent of exposure concentration. The concentration of selenium in water for all sample dates and locations in our study was well below 11 ug/L. We concur with the observation of Brooks that there is a poorly defined relationship between brine shrimp tissue concentrations and exposure to selenium in water or algae at such low concentrations. We cannot make any inferences regarding the ability of brine shrimp to regulate selenium levels at low exposure concentrations. Given the consistently low concentration of selenium in the GSL water it will be very challenging for researchers to define a regression relationship for the trophic transfer of selenium from water or algae (particulate phase of water) to brine shrimp based on GSL field data.

Because of the difficulty in deriving a regression relationship for selenium between trophic levels within the GSL, transfer factors are examined as an alternative means of interpreting the flow of selenium through the GSL food web. Transfer factors have been used by other authors to describe the relationship between selenium in soil and ephemeral

pools (Byron, et. a.l., 2003). Transfer factor relationships for paired samples (by date and location) are shown below in Figure 50.

Figure 50. Trophic transfer factors calculated from pairwise comparisons of selenium concentrations in water, seston, and brine shrimp adults by sample date. Relationships are presented from May 2006 to December 2006. Substantial differences do exist temporally in the transfer factors. Units used for selenium were: adult *Artemia* (ug/g), seston (ug/g), and water (ug/L) (dissolved selenium).



Notwithstanding their simplicity, and limited representation of selenium movement through the GSL food web, transfer factors are useful as a measure of central tendency of selenium in biota given an average concentration of selenium in the water and seston. In this sense, these statistics narrow the scope of uncertainty about the levels of selenium in algae and brine shrimp in the GSL when the water concentration is <1.0 ug/L. A summary table of the transfer factors is shown below (Table 11).

Table 11. Trophic transfer relationships between various compartments of the GSL pelagic zone. Results below do not indicate biomagnification of selenium through the food web. The transfer from water to seston is only considered with respect to dissolved selenium in water to seston in ug/g. Not all dissolved water samples from our study were analyzed for selenium., therefore there are fewer total counts, and perhaps a less robust figure, for this transfer relationship.

Selenium Trophic Transfer Relationship	Mean	Std Dev	CV	N
Seston (ug/g) to Adult <i>Artemia</i> (ug/g)	3.23	2.71	83.92	56
Total Water (ug/L) to Adult <i>Artemia</i> (ug/g)	1.99	1.17	58.74	59
Dissolved Water (ug/L) to Seston (ug/g)	0.86	0.50	57.95	21

The transfer factors presented above imply that there is a simple mathematical relationship between exposure concentrations in water, or phytoplankton, and the tissue concentration in collocated brine shrimp. In reality, such a simple relationship is highly unlikely. Previous investigators, and the current kinetics study being conducted by Dr. Martin Grossell, have demonstrated that there are complex and dynamic physical and physiological factors that ultimately affect uptake and accumulation of selenium in invertebrates. These aspects of the dynamic relationship between brine shrimp and their environment are not captured in transfer factors. The implementation of transfer factors into a predictive model of selenium flow through the GSL ecosystem should therefore be done with adequate caution and restraint.

The results from the kinetics study by Dr. Grosell, when used in conjunction with field generated transfer factors, may provide a more accurate predictive model of potential changes in selenium concentration in brine shrimp tissue in the event that water concentrations of selenium are increased. The use of transfer factors as an independent

means of predicting brine shrimp tissue levels given changes in selenium water or algae concentrations is not recommended.

CONCLUSION

This interim report contains summary findings from a pelagic study of the GSL investigating selenium in water, seston, and brine shrimp conducted from April 2006 to June 2007. In addition to a survey of selenium in water and biota, an extensive effort was made to document the population characteristics of resident brine shrimp and phytoplankton. Some aspects of the research were modified to improve the accuracy of results during the 2007 season. Various components of the study are not yet complete and will be finished over the course of the next few months.

These preliminary results indicate that selenium is found across all sample locations and sample dates in water, seston, and brine shrimp tissue. The mean concentration of selenium in water documented from May 2006 to December 2006 (0.597 ± 0.124 ug/L) corresponds well to the results of other concurrent studies (0.56 ± 0.18 ug/L) (Naftz, et. al., 2007; Johnson, et. al., 2007). The cumulative net change in all sample locations that were surveyed over this same time period was 0.098 ug/L. Naftz et. al., reports a cumulative net selenium increase in water samples of 0.094 ug/L for his monitored locations. Although our reported values, and those of Naftz et. al., do generally agree with the model prediction of an increase in water selenium of 0.074 ug/L, it is also possible that the cumulative net results are simply a function of sample variability.

Seston samples were analyzed and the average dry weight selenium concentration was 0.504 ± 0.336 ug/g. Seston selenium values were alternatively used to determine the particulate fraction of selenium in the water phase. The average seston value per liter of

GSL water filtered was 0.105 ± 0.044 ug/L. This is in agreement with values reported by Johnson (2007) for the particulate fraction of GSL water (0.14 ug/L).

The concentration of selenium in adult brine shrimp tissue (1.18 ug/g) was about 1.4 ug/g below previous studies on the GSL (Brix et.al., 2004; Adams, 2005). Procedurally there were differences in the handling, cleaning, and sorting of brine shrimp in our study relative to others that may have had some affect on the selenium calculations. Younger age classes of brine shrimp were analyzed for tissue selenium, and the results show substantially lower concentrations than those found for adults (6% to 54% of adults). All brine shrimp collected and analyzed were well below the critical 5 mg/kg level for protection of birds. The sample mass of *Artemia* collected was increased substantially in 2007 to alleviate some concerns about the influence of sample size on selenium determination.

The data comparing selenium concentration between brine shrimp tissue, seston, and water were not amenable to regression analysis. As an alternative, transfer factors were defined and presented. Whereas transfer factors are informative and descriptive statistics, the use of transfer factors to predict the relationship between various physical compartments in the GSL ecosystem may misrepresent, and misconstrue, the complex physiological, chemical, and biological interactions that take place between trophic levels. The use of such a rudimentary approach for the interpretation of selenium trophic transfer is an undeniable oversimplification of the GSL food web. Yet, this has become a logical distillation of selenium relationships in the GSL ecosystem. These transfer

factors should be evaluated realistically and, if they are applied to predictive models or used for management decisions, they must be implemented with full recognition of their limited interpretive value.

The results of the brine shrimp population data show population cycles, reproductive output, biomass production, and cyst accumulation in the water column that are indicative of a 'healthy' brine shrimp population. All of the reproductive parameters investigated were within the range of values reported for the GSL over the past decade. There is no indication of any serious adverse impacts on the brine shrimp population during 2006 and the spring of 2007. Brine shrimp biomass was available as a food source throughout the study period for aquatic and semi-aquatic birds.

The phytoplankton population was dominated by algae (e.g., Chlorophyceae) that are generally quite favorable and nutritious as a prey base for brine shrimp. The algal population demonstrated an ability to rapidly respond to release from *Artemia* grazing pressure and to effectively re-colonize the water column following the collapse of the brine shrimp population. Chlorophyll concentrations were lower than some previous years, but the winter concentration (41.7 ug/L) was sufficiently high to indicate an abundant nutritional foundation for the emerging brine shrimp population in the spring of 2007.

More data is forthcoming from 2007. Selenium results will be updated from May to August 2007 and from November 2006. Population results from June through August

2007 will be presented, along with the full complement of supporting experiments.

These additional results will be a useful and informative complement to the 2006 data presented in this report, and should serve to enhance our continuing understanding of the GSL ecosystem.

APPENDIX 1.1: DESCRIPTIVE STATISTICS FOR LIMNOLOGICAL CONDITIONS

Dissolved Oxygen Expressed as Percent Saturation

Dissolved Oxygen (% Saturation) by Sample Depth						
April 2006 to June 2007						
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	90.7	32.1	35.4	27.0	211.0	135
2	99.2	40.7	41.0	42.7	214.0	45
3	77.7	28.4	36.6	12.0	144.9	90
5	66.7	30.2	45.3	0.2	148.4	90
6	61.2	26.3	43.1	0.7	107.3	90
7	1.8	2.2	120.8	0.1	8.9	45
8	0.7	0.2	28.6	0.5	0.9	45

Salinity in gms/L

Salinity by Sample Depth						
April 2006 to June 2007						
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	129.1	10.9	8.5	110.0	147.2	135
2	129.2	8.3	6.4	118.0	144.0	45
3	129.1	9.9	7.7	111.0	146.0	90
5	131.5	9.4	7.1	116.0	150.0	90
6	140.0	9.8	7.0	120.0	165.0	90
7	160.7	25.9	16.1	120.2	225.0	45
8	192.0	22.4	11.6	152.0	233.0	45

APPENDIX 1.2: DESCRIPTIVE STATISTICS FOR LIMNOLOGICAL CONDITIONS

Temperature in Degrees Centigrade

Water Temperature (degrees Centigrade) by Sample Depth						
April 2006 to June 2007						
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	18.7	8.3	44.4	(2.0)	29.5	135
2	17.4	9.7	55.8	(1.9)	28.8	45
3	18.5	8.0	43.2	(2.1)	28.4	90
5	17.8	8.0	45.0	(2.0)	28.2	90
6	17.9	9.1	51.0	(2.0)	28.1	90
7	15.7	5.9	37.4	2.3	25.1	45
8	13.3	4.3	32.4	4.0	19.8	45

APPENDIX 2.1: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Adult *Artemia* Statistics

Artemia Adult (M+F) per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	1266	934	74	676	3341	7
May 6, 2006	913	318	35	411	1253	8
May 24, 2006	828	437	53	335	1879	9
June 12, 2006	1127	671	60	462	2040	6
June 29, 2006	2426	1515	62	921	5829	9
July 10, 2006	3722	7152	192	396	18307	6
July 27, 2006	674	939	139	93	2557	6
August 18, 2006	550	958	174	34	2498	6
August 25, 2006	205	126	61	102	411	6
September 18, 2006	2054	3725	181	185	9626	6
September 24, 2006	710	452	64	362	1468	5
October 14, 2006	619	492	79	0	1383	6
November 20, 2006	844	281	33	540	1222	6
December 2, 2006	582	463	80	159	1485	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	1516	1672	110	115	3819	6
May 23, 2007	1297	1461	113	170	4099	6
June 9, 2007	431	399	93	149	1218	6
Arithmetic Mean	1,127					
Standard Dev.	2,039					
Median	620					

APPENDIX 2.2: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Adult Artemia Statistics

Artemia Adult Male per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	626	619	99	258	2,015	7
May 6, 2006	465	215	46	191	772	8
May 24, 2006	327	242	74	140	958	9
June 12, 2006	563	326	58	213	922	6
June 29, 2006	1,178	812	69	492	3,082	9
July 10, 2006	1,767	3,334	189	189	8,565	6
July 27, 2006	404	534	132	62	1,468	6
August 18, 2006	306	483	158	21	1,283	6
August 25, 2006	131	81	61	67	286	6
September 18, 2006	1,045	1,899	182	132	4,904	6
September 24, 2006	345	173	50	222	645	5
October 14, 2006	363	320	88	0	887	6
November 20, 2006	426	157	37	244	669	6
December 2, 2006	266	233	88	83	726	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	862	936	109	76	2,357	6
May 23, 2007	524	541	103	127	1,553	6
June 9, 2007	190	173	91	79	535	6
Arithmetic Mean	556					
Standard Dev.	988					
Median	284					

APPENDIX 2.3: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Adult Artemia Statistics

Artemia Adult Female per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	640	323	50	348	1,326	7
May 6, 2006	448	142	32	220	642	8
May 24, 2006	501	227	45	195	921	9
June 12, 2006	564	356	63	249	1,133	6
June 29, 2006	1,248	736	59	387	2,747	9
July 10, 2006	1,955	3,818	195	207	9,742	6
July 27, 2006	270	405	150	29	1,089	6
August 18, 2006	244	476	195	13	1,215	6
August 25, 2006	73	57	78	34	165	6
September 18, 2006	1,008	1,827	181	44	4,722	6
September 24, 2006	365	282	77	141	823	5
October 14, 2006	256	176	69	0	496	6
November 20, 2006	418	131	31	295	611	6
December 2, 2006	316	235	74	76	760	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	654	819	125	38	2,122	6
May 23, 2007	773	921	119	42	2,546	6
June 9, 2007	241	228	95	70	683	6
Arithmetic Mean	571					
Standard Dev.	1,064					
Median	331					

APPENDIX 3.1: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Nauplii per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	684	595	87	159	1,697	7
May 6, 2006	935	1,559	167	0	4,444	8
May 24, 2006	341	232	68	0	723	9
June 12, 2006	694	640	92	127	1,697	6
June 29, 2006	21,737	15,521	71	8,381	52,980	9
July 10, 2006	326	558	171	0	1,414	6
July 27, 2006	3,847	3,730	97	931	10,183	6
August 18, 2006	2,890	285	10	2,418	3,235	6
August 25, 2006	1,273	635	50	358	1,949	6
September 18, 2006	251	226	90	1	643	6
September 24, 2006	194	222	115	30	557	5
October 14, 2006	966	1,433	148	0	3,819	6
November 20, 2006	1,584	1,306	82	91	3,501	6
December 2, 2006	1,033	1,599	155	0	4,243	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	36,417	30,339	83	2,864	70,873	6
May 23, 2007	34,948	29,553	85	7,081	73,988	6
June 9, 2007	737	830	113	68	1,856	6
Arithmetic Mean	6,222					
Standard Dev.	15,114					
Median	733					

APPENDIX 3.2: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Meta-Nauplii per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	1112	763	69	424	2387	7
May 6, 2006	443	533	120	0	1697	8
May 24, 2006	751	646	86	106	2015	9
June 12, 2006	657	777	118	71	2130	6
June 29, 2006	38312	43935	115	8465	147707	9
July 10, 2006	2146	1903	89	341	5445	6
July 27, 2006	35563	32367	91	2400	95470	6
August 18, 2006	19133	13423	70	6434	43803	6
August 25, 2006	9948	3173	32	7637	15276	6
September 18, 2006	1125	1034	92	318	3050	6
September 24, 2006	695	682	98	0	1667	5
October 14, 2006	835	513	61	182	1697	6
November 20, 2006	2792	3165	113	364	8910	6
December 2, 2006	1003	808	81	0	2122	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	10973	11650	106	110	33357	6
May 23, 2007	3052	5271	173	0	13366	6
June 9, 2007	1172	1537	131	3	4010	6
Arithmetic Mean	7,731					
Standard Dev.	18,675					
Median	1,040					

APPENDIX 3.3: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Juveniles per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	3,715	4,954	133	759	14,872	7
May 6, 2006	2,647	2,641	100	282	8,537	8
May 24, 2006	1,362	539	40	296	2,089	9
June 12, 2006	1	3	245	-	8	6
June 29, 2006	4,307	2,535	59	1,781	9,848	9
July 10, 2006	417	688	165	13	1,800	6
July 27, 2006	27	42	157	1	110	6
August 18, 2006	855	1,962	229	0	4,857	6
August 25, 2006	433	395	91	-	1,034	6
September 18, 2006	1,739	3,106	179	9	8,013	6
September 24, 2006	111	142	128	6	299	5
October 14, 2006	105	123	117	-	320	6
November 20, 2006	1,132	777	69	524	2,673	6
December 2, 2006	1,799	2,239	124	364	6,269	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	1,243	1,337	108	25	3,556	6
May 23, 2007	929	1,311	141	13	3,479	6
June 9, 2007	587	266	45	185	980	6
Arithmetic Mean	1,331					
Standard Dev.	2,218					
Median	536					

APPENDIX 4.1: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Total *Artemia* Abundance and Biomass

Total *Artemia* Abundance per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	6,778	5,754	85	2,375	19,327	7
May 6, 2006	4,938	3,539	72	931	11,481	8
May 24, 2006	3,282	1,406	43	1,528	6,309	9
June 12, 2006	2,479	1,756	71	887	5,150	6
June 29, 2006	66,781	52,356	78	26,491	193,081	9
July 10, 2006	6,611	9,344	141	1,432	25,553	6
July 27, 2006	40,111	31,956	80	3,740	98,404	6
August 18, 2006	23,428	13,004	56	9,077	47,310	6
August 25, 2006	11,858	3,198	27	8,569	17,098	6
September 18, 2006	5,169	7,255	140	679	19,518	6
September 24, 2006	1,709	1,101	64	520	2,970	5
October 14, 2006	2,525	2,365	94	796	7,220	6
November 20, 2006	6,353	3,781	60	2,492	12,211	6
December 2, 2006	4,416	3,841	87	851	9,778	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	50,149	42,003	84	3,114	109,826	6
May 23, 2007	40,226	34,761	86	8,100	92,509	6
June 9, 2007	2,926	2,329	80	775	6,956	6
Arithmetic Mean	16,410					
Standard Dev.	28,444					
Median	4,381					

APPENDIX 4.2: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Total *Artemia* Abundance and Biomass

Artemia Biomass in mg/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	0.936	0.684	73	0.191	2.342	7
May 6, 2006	0.619	0.472	76	0.143	1.555	8
May 24, 2006	0.516	0.122	24	0.283	0.623	9
June 12, 2006	0.554	0.236	43	0.252	0.922	6
June 29, 2006	1.300	0.852	66	0.331	3.075	9
July 10, 2006	1.649	2.650	161	0.271	7.026	6
July 27, 2006	0.920	0.966	105	0.167	2.800	6
August 18, 2006	0.368	0.377	102	0.018	1.104	6
August 25, 2006	0.333	0.221	66	0.169	0.658	6
September 18, 2006						
September 24, 2006						
October 14, 2006	0.628	0.581	93	0.094	1.357	6
November 20, 2006	0.432	0.335	78	0.108	0.927	6
December 2, 2006						
January 26, 2007						
May 7, 2007	1.795	1.595	89	0.455	4.499	6
May 23, 2007	1.482	1.260	85	0.499	3.574	6
June 9, 2007	0.596	0.343	58	0.165	1.206	6
Arithmetic Mean	0.770					
Standard Dev.	0.695					
Median	0.592					

APPENDIX 5.1: DESCRIPTIVESTATISTICS FOR ARTEMIA POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Cyst Abundance per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	5,343	3,519	66	1,432	9,653	7
May 6, 2006	3,228	1,707	53	926	6,172	8
May 24, 2006	5,088	2,689	53	2,459	10,502	9
June 12, 2006	18,865	17,659	94	1,768	49,644	6
June 29, 2006	9,148	12,007	131	891	39,381	9
July 10, 2006	36,794	45,876	125	11,138	128,988	6
July 27, 2006	14,868	20,678	139	3,000	56,857	6
August 18, 2006	31,015	21,832	70	13,820	72,255	6
August 25, 2006	27,384	21,711	79	10,986	70,187	6
September 18, 2006	28,353	20,225	71	9,229	61,736	6
September 24, 2006	41,742	24,357	58	15,578	81,906	5
October 14, 2006	52,966	68,931	130	5,864	187,118	6
November 20, 2006	18,697	13,708	73	1,955	35,748	6
December 2, 2006	35,990	16,235	45	16,730	52,773	6
January 26, 2007	3,976	3,044	77	1,641	9,759	6
May 7, 2007	22,311	29,013	130	273	62,054	6
May 23, 2007	18,067	13,175	73	7,425	43,643	6
June 9, 2007	16,195	12,654	78	6,205	37,915	6
Arithmetic Mean	20,284					
Standard Dev.	26,188					
Median	10,744					

APPENDIX 5.2: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Cyst Brood Size per Female w/Cysts

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006						
May 6, 2006						
May 24, 2006						
June 12, 2006						
June 29, 2006	111	18	16	93	151	9
July 10, 2006						
July 27, 2006	74	24	32	48	102	6
August 18, 2006	89	14	15	67	103	6
August 25, 2006	114	36	32	69	157	6
September 18, 2006	60	14	24	43	76	6
September 24, 2006	34	7	21	24	44	5
October 14, 2006	83	17	20	64	108	6
November 20, 2006	112	15	13	88	128	6
December 2, 2006	107	26	25	56	128	6
January 26, 2007						6
May 7, 2007	121	22	18	89	136	6
May 23, 2007	93	20	21	67	111	6
June 9, 2007	31	4	12	27	36	6
Arithmetic Mean	87.34					
Standard Dev.	33.90					
Median	92.00					

APPENDIX 5.3: DESCRIPTIVE STATISTICS FOR ARTEMIA POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Productivity (Cyst Brood Size x # Females w/cysts) per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006						
May 6, 2006						
May 24, 2006						
June 12, 2006						
June 29, 2006	12,879	8,963	70	3,950	27,557	9
July 10, 2006						6
July 27, 2006	14,270	27,099	190	978	69,450	6
August 18, 2006	3,765	3,462	92	1,827	9,889	6
August 25, 2006	2,076	1,293	62	233	3,908	6
September 18, 2006	3,178	3,642	115	588	9,508	6
September 24, 2006	1,519	931	61	605	2,921	5
October 14, 2006	11,464	9,100	79	66	23,871	6
November 20, 2006	3,125	2,493	80	116	5,414	6
December 2, 2006	3,119	4,462	143	111	10,880	6
January 26, 2007						
May 7, 2007						
May 23, 2007	2,643	2,112	80	69	4,689	6
June 9, 2007	323	732	227	27	1,816	6
Arithmetic Mean	5,533					
Standard Dev.	9,873					
Median	2,354					

APPENDIX 6.1: COMPARATIVE STATISTICS FOR ARTEMIA POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Artemia Biomass in mg/L by Sample Site						
April 2006 to June 2007						
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	1.082	1.063	98.2	0.117	3.574	18
2	0.625	0.146	23.3	0.428	0.839	5
3	0.510	0.245	48.0	0.186	1.158	18
4	1.158	1.028	88.7	0.165	3.075	18
5	0.723	0.484	67.0	0.339	1.432	4
6	0.616	0.322	52.2	0.244	1.334	18
7	0.817	0.793	97.0	0.018	2.491	16
8	0.903	0.572	63.3	0.491	1.555	3
9	0.503	0.321	63.7	0.167	1.189	16
Arithmetic Mean	0.770					
Standard Dev.	0.695					
Median	0.592					

APPENDIX 6.2: COMPARATIVE STATISTICS FOR ARTEMIA POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Cyst Brood Size by Sample Site						
April 2006 to June 2007						
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	74	34	46	24	136	11
2	107			107	107	1
3	94	36	38	34	151	12
4	85	29	34	33	122	11
5	112			112	112	1
6	87	33	39	27	128	12
7	86	43	50	36	154	8
8	93			93	93	1
9	94	36	39	31	157	11
Arithmetic Mean	87.34					
Standard Dev.	33.90					
Median	92.00					

APPENDIX 6.3: COMPARATIVE STATISTICS FOR ARTEMIA POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Productivity per Cubic Meter (cyst brood size x # females w/cysts) by Sample Site						
April 2006 to June 2007						
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	5,188	7,702	148	28	25,188	10
2	8,692			8,692	8,692	1
3	4,282	4,292	100	34	14,954	11
4	11,205	21,075	188	69	69,450	10
5	6,331			6,331	6,331	1
6	5,459	6,685	122	27	23,871	11
7	4,938	9,291	188	66	27,557	8
8	3,950			3,950	3,950	1
9	5,248	6,463	123	31	20,490	11
Arithmetic Mean		5,533				
Standard Dev.		9,873				
Median		2,354				

APPENDIX 7.1: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Chlorophyll –A in ug/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	7.00	3.14	44.82	2.70	11.00	6
May 6, 2006	4.56	2.59	56.76	2.70	8.00	8
May 24, 2006	3.16	2.36	74.65	1.30	8.00	9
June 12, 2006	4.25	2.44	57.32	2.70	8.00	6
June 29, 2006	6.31	1.40	22.14	5.30	8.00	9
July 10, 2006	3.46	1.77	51.28	1.30	5.30	6
July 27, 2006	7.17	5.28	73.73	2.70	16.00	6
August 18, 2006	4.45	2.16	48.44	2.70	8.00	6
August 25, 2006	3.98	1.68	42.08	1.30	5.30	6
September 18, 2006	1.88	1.66	88.56	0.70	4.70	6
October 14, 2006	20.83	8.01	38.45	13.00	32.00	6
November 20, 2006						
December 2, 2006	30.33	4.41	14.55	23.00	35.00	6
January 26, 2007	41.67	4.97	11.92	37.00	51.00	6
March 15, 2007	33.67	4.16	12.37	29.00	37.00	3
May 7, 2007	7.47	6.86	91.91	1.10	15.00	6
May 23, 2007	1.78	0.89	49.70	0.50	2.70	6
June 9, 2007	1.55	0.34	21.88	1.10	2.10	6
Arithmetic Mean	10.12					
Standard Dev.	12.28					
Median	5.30					

APPENDIX 7.2: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Phaeophytin in ug/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	13.1	7.1	54.4	6.7	26.0	6
May 6, 2006	9.9	4.2	42.4	5.5	16.0	8
May 24, 2006	4.8	1.9	39.0	1.3	7.7	9
June 12, 2006	5.1	3.8	75.5	1.3	12.0	6
June 29, 2006	5.2	4.5	87.4	1.3	15.0	9
July 10, 2006	6.5	2.6	40.2	3.9	9.6	6
July 27, 2006	3.5	2.7	77.3	0.5	6.7	6
August 18, 2006	5.2	2.3	44.2	2.1	8.5	6
August 25, 2006	1.8	1.4	77.2	0.3	4.3	6
September 18, 2006	1.2	0.7	54.8	0.7	2.3	6
October 14, 2006	4.7	2.3	49.6	2.0	7.7	6
November 20, 2006						
December 2, 2006	6.5	2.1	32.9	4.1	9.6	6
January 26, 2007	4.8	3.0	62.7	1.1	9.3	6
March 15, 2007	4.2	1.5	35.1	2.6	5.5	3
May 7, 2007	2.7	3.2	117.2	0.1	7.7	6
May 23, 2007	1.2	0.8	71.4	0.1	2.6	6
June 9, 2007	1.6	0.6	35.1	0.9	2.5	6
Arithmetic Mean	4.92					
Standard Dev.	4.20					
Median	4.30					

APPENDIX 7.3: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Combined Chl-a & Phaeophytin, and Water Transparency by Date

Combined Chl-a and Phaeophytin in ug/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	18.9	9.5	50.1	9.4	37.0	6
May 6, 2006	11.5	2.8	24.2	8.0	16.0	8
May 24, 2006	7.7	2.3	30.7	5.6	13.0	9
June 12, 2006	9.3	3.2	34.3	5.6	14.7	6
June 29, 2006	10.2	2.6	25.7	7.4	15.0	9
July 10, 2006	9.3	4.4	46.6	5.6	14.9	6
July 27, 2006	10.6	3.5	32.8	7.4	16.8	6
August 18, 2006	8.2	2.6	31.3	4.8	11.2	6
August 25, 2006	5.8	1.7	29.9	2.7	7.3	6
September 18, 2006	2.6	1.4	55.6	1.4	5.4	6
October 14, 2006	25.6	7.3	28.6	18.1	35.2	6
November 20, 2006						
December 2, 2006	36.9	6.3	17.1	27.3	44.6	6
January 26, 2007	46.5	4.2	9.0	41.1	53.5	6
March 15, 2007	37.9	3.8	9.9	33.6	40.5	3
May 7, 2007	10.2	9.8	96.3	1.2	22.7	6
May 23, 2007	2.9	1.4	46.6	1.8	5.3	6
June 9, 2007	3.1	0.6	18.9	2.3	4.1	6
Arithmetic Mean	14.07					
Standard Dev.	12.98					
Median	9.30					

APPENDIX 7.4: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Water Transparency (Secchi Disk in cm)

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	112.5	29.4	26.1	60.0	139.0	6
May 6, 2006	156.7	34.3	21.9	85.0	195.0	8
May 24, 2006	365.2	239.9	65.7	30.0	630.0	9
June 12, 2006	282.6	112.9	40.0	100.0	390.0	6
June 29, 2006	324.5	74.7	23.0	245.0	420.0	9
July 10, 2006	230.5	178.0	77.2	87.0	480.0	6
July 27, 2006	140.0	42.5	30.4	75.0	190.0	6
August 18, 2006	166.7	36.7	22.0	125.0	230.0	6
August 25, 2006	153.6	28.4	18.5	115.0	185.0	6
September 18, 2006	260.0	152.5	58.7	90.0	460.0	6
October 14, 2006	65.5	21.1	32.2	45.0	100.0	6
November 20, 2006	56.2	4.5	8.0	50.0	60.0	6
December 2, 2006	56.0	9.6	17.2	40.0	65.0	6
January 26, 2007	46.7	5.9	12.7	40.0	55.0	6
March 15, 2007						
May 7, 2007	119.8	105.4	88.0	48.0	305.0	6
May 23, 2007	442.3	119.9	27.1	332.0	570.0	6
June 9, 2007	325.0	142.9	44.0	160.0	410.0	6
Arithmetic Mean	179.3					
Standard Dev.	142.2					
Median	137.0					

APPENDIX 8.1: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN ARTEMIA BIOMASS, SESTON, AND WATER.

Selenium Concentration in *Artemia* Biomass: Adult *Artemia* (ug/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	2.115	2.186	0.636	29.108	1.600	3.300	7
May 4, 2006	1.100	1.184	0.462	39.040	0.610	1.900	8
May 12, 2006	0.458	0.502	0.205	40.937	0.200	0.720	6
May 24, 2006	1.396	1.556	0.768	49.381	0.700	2.900	9
June 22, 2006	0.895	0.976	0.406	41.619	0.420	1.600	9
July 10, 2006	0.874	1.028	0.680	66.108	0.390	2.300	6
July 27, 2006	0.800	0.965	0.607	62.903	0.280	1.800	6
August 23, 2006	0.724	0.830	0.424	51.082	0.270	1.400	6
August 28, 2006	0.712	0.755	0.256	33.973	0.350	1.100	6
September 24, 2006	1.340	1.412	0.508	35.953	0.860	2.000	5
October 14, 2006	0.556	0.757	0.471	62.312	0.100	1.200	6
November 20, 2006							
December 2, 2006	1.804	1.867	0.505	27.035	1.100	2.400	6
All Samples	0.984	1.185	0.683				

Selenium Concentration in *Artemia* Biomass: Juvenile *Artemia* (ug/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006							
June 22, 2006							
July 10, 2006							
July 27, 2006							
August 23, 2006							
August 28, 2006							
September 24, 2006	0.08	0.09	0.04	47.3	0.03	0.15	6
October 14, 2006	0.05	0.06	0.04	74.0	0.02	0.12	6
November 20, 2006							
December 2, 2006	0.51	0.61	0.42	69.2	0.26	1.40	6
All Samples	0.134	0.275	0.365				

APPENDIX 8.2: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN ARTEMIA BIOMASS, SESTON, AND WATER.

Selenium Concentration in *Artemia* Biomass: Nauplii Biomass (ug/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006							
June 22, 2006							
July 10, 2006							
July 27, 2006							
August 23, 2006	0.34	0.35	0.10	27.2	0.22	0.47	6
August 28, 2006	0.21	0.24	0.16	63.9	0.12	0.54	6
September 24, 2006	0.22	0.26	0.17	67.1	0.13	0.57	6
October 14, 2006	0.23	0.29	0.22	77.2	0.11	0.62	6
November 20, 2006							
December 2, 2006	0.97	1.01	0.25	25.3	0.56	1.30	6
All Samples	0.323	0.432	0.349				

**APPENDIX 8.3: DESCRIPTIVE STATISTICS FOR SELENIUM
CONCENTRATION IN ARTEMIA BIOMASS, SESTON, AND WATER**

Selenium Concentration in Seston in ug/g

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.329	0.335	0.068	20.329	0.234	0.437	9
June 22, 2006	0.303	0.394	0.414	105.029	0.195	1.408	8
July 10, 2006	0.263	0.271	0.073	27.135	0.181	0.383	6
July 27, 2006	0.306	0.308	0.043	13.869	0.252	0.370	6
August 23, 2006	1.002	1.020	0.239	23.405	0.831	1.370	4
August 28, 2006	0.895	0.941	0.271	28.779	0.420	1.184	6
September 24, 2006	0.838	0.864	0.216	24.957	0.525	1.065	6
October 14, 2006	0.638	0.655	0.165	25.145	0.495	0.866	6
November 20, 2006	0.215	0.217	0.028	12.999	0.167	0.242	6
December 2, 2006	0.304	0.333	0.153	45.989	0.166	0.551	6
All Samples	0.415	0.504	0.336				

**APPENDIX 8.4: DESCRIPTIVE STATISTICS FOR SELENIUM
CONCENTRATION IN ARTEMIA BIOMASS, SESTON, AND WATER**

Selenium Concentration in Seston in ug/L

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.085	0.086	0.010	12.0	0.07	0.10	9
June 22, 2006	0.057	0.059	0.016	27.7	0.03	0.08	9
July 10, 2006	0.067	0.069	0.017	25.1	0.05	0.10	6
July 27, 2006	0.086	0.087	0.011	13.2	0.07	0.10	6
August 23, 2006	0.077	0.091	0.047	51.0	0.02	0.13	6
August 28, 2006	0.120	0.122	0.018	14.6	0.09	0.14	6
September 24, 2006	0.106	0.120	0.081	67.2	0.07	0.28	6
October 14, 2006	0.129	0.129	0.014	11.1	0.12	0.16	6
November 20, 2006	0.154	0.155	0.011	7.0	0.14	0.17	6
December 2, 2006	0.155	0.158	0.032	20.3	0.12	0.21	6
All Samples	0.097	0.105	0.044				

APPENDIX 8.5: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN ARTEMIA BIOMASS, SESTON, AND WATER

Selenium Concentration in Unfiltered GSL Water in ug/L

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.626	0.634	0.11	17.9	0.55	0.86	9
June 22, 2006	0.479	0.484	0.07	15.1	0.41	0.59	9
July 10, 2006	0.413	0.418	0.06	14.9	0.30	0.47	6
July 27, 2006	0.637	0.639	0.05	8.1	0.60	0.73	6
August 23, 2006	0.546	0.554	0.10	18.3	0.40	0.70	6
August 28, 2006	0.711	0.718	0.11	15.7	0.63	0.90	6
September 24, 2006	0.689	0.691	0.05	6.6	0.65	0.77	6
October 14, 2006	0.570	0.572	0.05	9.2	0.48	0.62	6
November 20, 2006	0.621	0.630	0.12	19.4	0.47	0.83	6
December 2, 2006	0.656	0.668	0.13	18.7	0.43	0.79	6
All Samples	0.584	0.597	0.124				

Summary Statistics: Selenium in Adult, Juvenile, Nauplii Biomass (ug/g), Seston (ug/g and ug/L), and Unfiltered Water (ug/L).

Variable	Total Count	Mean	StDev	CoefVar	Minimum	Maximum
SE-Adult ug/g	87	1.1854	0.6831	57.63	0.1000	3.3000
SE-Juvenile ug/g	87	0.2746	0.3654	133.06	0.0200	1.4000
SE-Nauplii ug/g	87	0.4324	0.3490	80.72	0.1100	1.3000
SE-Seston ug/g	87	0.5043	0.3361	66.63	0.1658	1.4085
SE-Seston ug/L	87	0.1054	0.0443	42.04	0.0240	0.2845
SE Water Total	87	0.5968	0.1235	20.70	0.2970	0.8990

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GREAT SALT LAKE WATER QUALITY STUDIES
DEVELOPMENT OF A SELENIUM STANDARD FOR THE
OPEN WATERS OF THE GREAT SALT LAKE

PROJECT 2B

SYNOPTIC SURVEY OF THE PELAGIC ZONE:
SELENIUM IN WATER, SESTON, AND ARTEMIA

2007 UPDATE

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1. INTRODUCTION

This document details additional sampling programs that were conducted as an extension of research performed during 2006 for the State of Utah, Department of Environmental Quality, Division of Water Quality, Great Salt Lake Water Quality Study—Selenium Program. Additional sampling programs were undertaken to provide further information on the concentration of selenium in water, seston and brine shrimp. Trophic transfer relationships for selenium in the Great Salt Lake (GSL) food web were of primary interest as well as the concentration of selenium in brine shrimp during the peak reproductive season for resident breeding birds. It was determined by the Science Panel that additional sampling results during another breeding season for brine shrimp and birds would add additional interpretive value to the data that had been previously collected. The additional data would also provide more details that could be incorporated into a predictive model for selenium in the GSL.

2. METHODS

Methods used for sample collection, storage, and analysis adhered to the same methods and procedures as were previously detailed in the 2006 report. One important modification, however, was made in the collection and preparation of brine shrimp samples: an additional filtration step was added to remove residual GSL water from the samples. This procedure was implemented due to concerns about the impact that residual saline water, and therefore salt in the dried sample, had on the apparent concentration of selenium in the brine shrimp tissue. The selenium results from brine shrimp samples collected during 2006 were lower than other reported values. The geometric mean value for adult brine shrimp tissue sampled during 2006 was: 0.984 ug/g dry weight. This is considerably lower than the results indicated by previous research on the GSL as well as being lower than the few samples collected and analyzed for the GSL Selenium Program, Project 1a (2.5 – 3.2 ug/g) (Cavitt, 2007) and Project 1b (3.9 to 4.5 ug/g) (Conover et. al., 2007) . Although no specific laboratory or field collection procedural error was

identified that would reduce the concentration of selenium in the brine shrimp tissue, it was postulated that the apparent lower value was the result of residual salt in the sample. Residual salt would add dry weight to the sample, thereby lowering the apparent concentration of selenium on a tissue dry weight basis.

2.1 Brine Shrimp Collection and Preparation Modifications

Because of the concern mentioned above regarding residual salt, an additional filtering step was introduced for the sample preparation of brine shrimp tissue. This procedure involved vacuum filtering the brine shrimp samples in the laboratory on the same day as sampling and prior to freezing. Because this added procedure represented a deviation from the sample preparation method used in 2006, two additional sampling programs were added to compare results using the two methods. The selenium results for brine shrimp tissue from these two methods were also compared to methods previously employed for the collection and preparation of brine shrimp samples (Brix et. al., 2004; Adams, 2005). In this third method (the Adams method) all age classes are pooled together, brine shrimp are collected from the upper 1-2 meters of the water column by repeated net hauls, sample sizes are larger (10 to 30 grams minimum mass wet weight) than the mass typically obtained for Project 2b 2006 sampling season, and the residual GSL water is passively drained from the sample.

Table 1. Selenium concentration in tissue from brine shrimp adults and nauplii. Results for the three methods of sample collection and preparation are shown. A weighted average result for selenium in the adult and nauplius samples, that were analyzed separately, is also indicated.

Artemia Age Class	Filtered (Yes or No)	Program ID Comparative Study (CS)	Sample Date	Mean Selenium in ug/g	SD	Mean Wet Weight gm	Mean Dry Weight gm	% Moisture Content	Number of Samples
Adult	Yes	CS-1	5/8/07	4.92	0.81	6.12	0.74	88	6
Adult	¹ No	CS-1	5/8/07	1.33	0.25	7.71	0.89	89	5
Nauplius	Yes	CS-1	5/8/07	2.11	0.48	1.12	0.24	80	6
All	² No	CS-1	5/8/07	3.91	0.17	18.43	2.19	88	5
Adult	Yes	CS-2	8/31/07	4.68	0.25	6.51	0.98	85	5
Nauplius	Yes	CS-2	8/31/07	2.30	0.18	1.33	0.40	70	5
All	² No	CS-2	8/31/07	3.96	0.09	8.66	1.21	86	5
Calculated Selenium in Filtered Adult+Naup	Yes	CS-1	5/8/07	4.10					12
Calculated Selenium in Filtered Adult+Naup	Yes	CS-2	8/31/07	4.01					10
	¹ 2006 Method								
	² Adams Method								

2.2 Interpretation of Brine Shrimp Collection and Preparation Modifications

The results from the comparative study indicate that the brine shrimp tissue selenium values from 2006 are indeed artificially low. The results from 2007 for filtered samples are in alignment with other investigators, especially when the weighted averages of adult

and nauplius fractions are combined. The results from the comparative studies in both May and August show an average concentration of 4.10 and 4.01 ug/g dry weight for the combined adult and nauplius fractions. The weighted average concentration is in general agreement with the Adams method, thereby lending credibility to the simplified method that is used by Adams for collecting brine shrimp samples for selenium analysis. The advantage of the Adams method is that it does not involve the multiple steps of separating age classes of brine shrimp and the subsequent filtration step to remove residual salt water. With each laborious step time is involved and there is an added element of variability that is introduced. The disadvantage of the Adams method is that differences between the age classes cannot be discerned. Our results do indicate that the differences between adult and nauplius age classes is substantial, and if comparisons are to be made with laboratory studies of a particular age class, then it is necessary to separate brine shrimp on the basis of developmental stage.

Separately, the adults were nearly twice the concentration that was observed in the nauplii. The larval stages that were grouped in the nauplius age class include some early instar stages in which the nauplius is primarily deriving energy from the metabolism of stored lipids. During older stages the stored lipids become depleted and meta-nauplii begin to actively forage for algae. The concentration of selenium in nauplii is slightly higher than the baseline value for selenium in the brine shrimp cysts (1.77 ug/g) observed during the late winter (March 15, 2007), suggesting uptake of selenium by larval stages.

3. SELENIUM RESULTS

3.1 Selenium in Water

Both filtered and unfiltered water samples were collected at each sample location during the sampling program. Water was filtered through a 0.45 micron capsule filter for the dissolved selenium water samples. All water samples were pre-filtered through a 125 micron filter to remove brine shrimp biomass and other large organic or inorganic debris. The results for both the total selenium (particulate and dissolved) and dissolved selenium in water samples are shown below in Table 2 and Table 3.

Table 2. Particulate and dissolved selenium (total selenium) concentration in water samples collected from May to August 2007.

Sampling Program #	Sample Date	Mean Selenium in ug/L	SD	Number of Samples
16	May 4, 2007	0.59	0.04	6
17	May 23, 2007	0.60	0.02	6
18	June 9, 2007	0.63	0.04	6
19	June 27, 2007	0.68	0.02	6
20	July 27, 2007	0.68	0.02	4
21	August 21, 2007	0.66	0.06	6
Grand Mean		0.64	0.05	34

Figure 1. Particulate and dissolved selenium (total selenium) concentration in water samples collected from May to August 2007. Results are presented for each location that was sampled throughout the project. Sites 2, 5, and 8 were not included because they were only sampled during spring 2006.

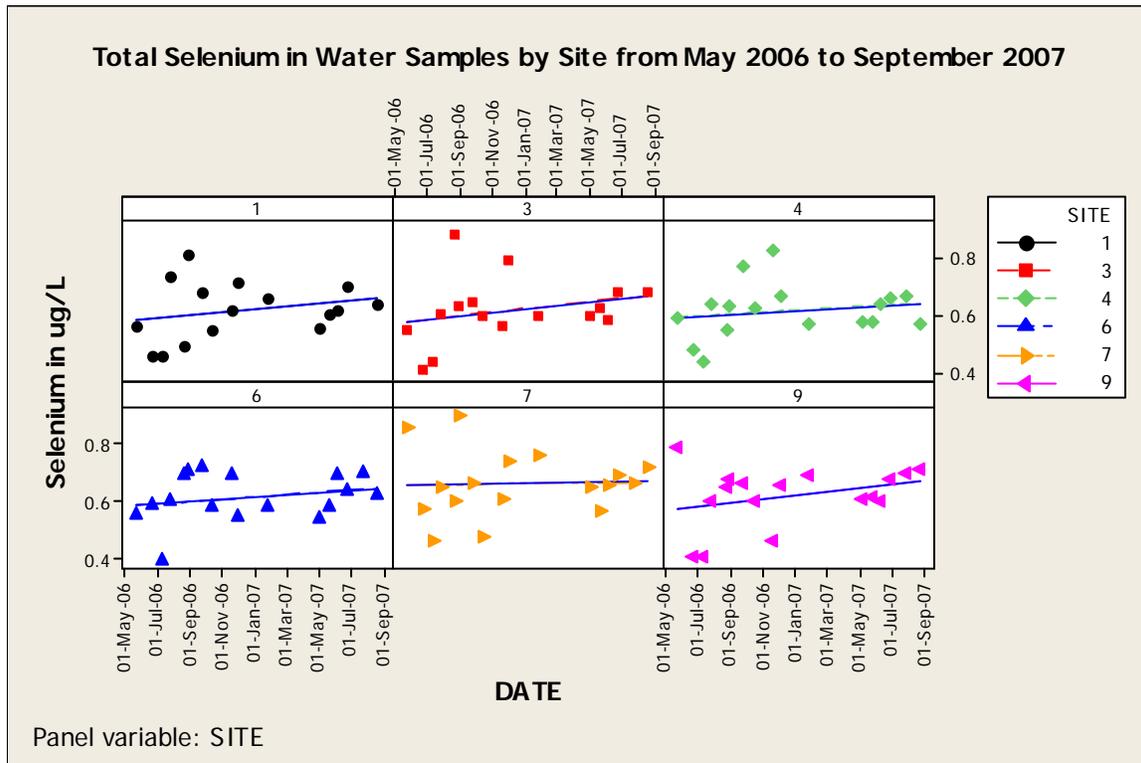
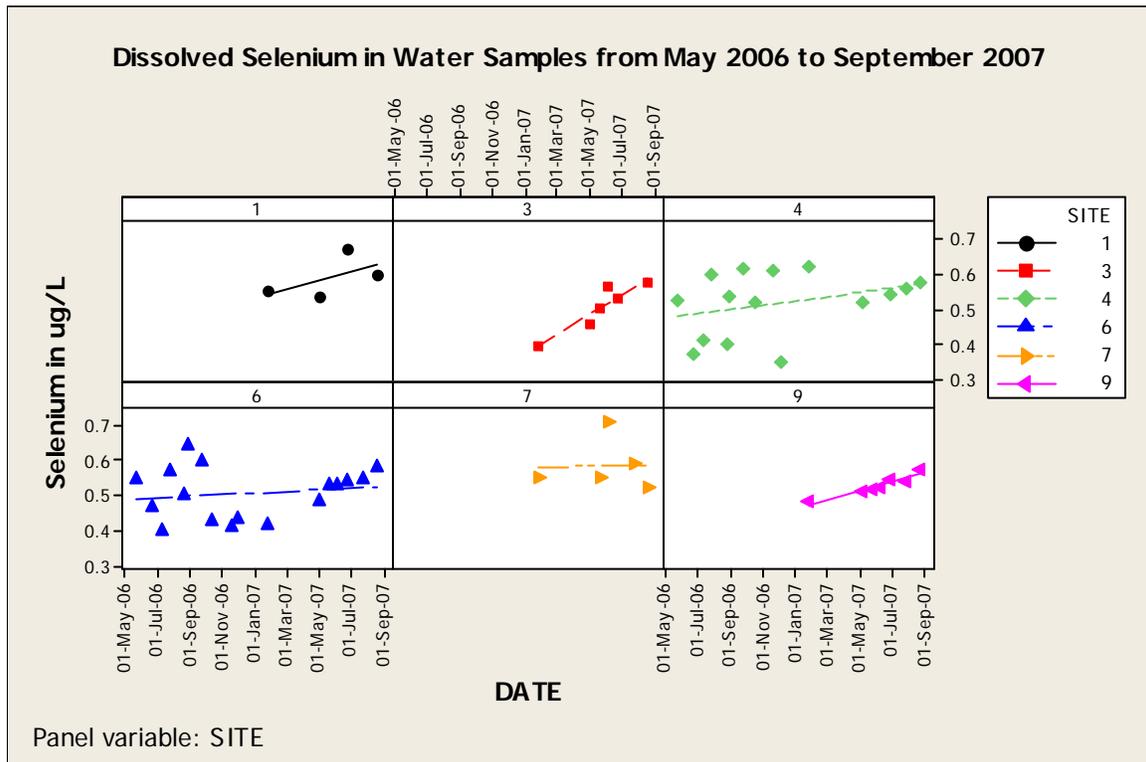


Table 3. Dissolved selenium concentration in water samples collected from May to August 2007.

Sampling Program #	Sample Date	Mean Selenium in ug/L	SD	Number of Samples
16	May 4, 2007	0.50	0.03	5
17	May 23, 2007	0.53	0.02	4
18	June 9, 2007	0.58	0.09	4
19	June 27, 2007	0.56	0.06	5
20	July 27, 2007	0.56	0.02	4
21	August 21, 2007	0.57	0.02	6
Grand Mean		0.54	0.06	28

Figure 2. Dissolved selenium in water samples collected from May to August 2007. Sites 2, 5, and 8 were not included because they were only sampled during spring 2006



3.2 Selenium in Seston

Table 4. Selenium concentration in seston samples collect from May to August 2007. Samples were filtered through 0.45 micron cellulose acetate filters. Values are reported in ug/g dry weight and dry weights are corrected for filter weight and residual salt mass.

Sampling Program #	Sample Date	Mean Selenium in ug/g	SD	Number of Samples
16	May 4, 2007	0.57	0.55	6
17	May 23, 2007	1.64	1.23	6
18	June 9, 2007	0.61	0.23	6
19	June 27, 2007	1.01	0.41	6
20	July 27, 2007	1.39	1.16	3
21	August 21, 2007	1.05	0.46	6
Grand Mean		0.95	0.73	33

Table 5. Selenium concentration in seston samples collect from May to August 2007. Water samples were filtered through 0.45 micron cellulose acetate filters. Values are reported in ug/L. These values reflect the total selenium mass in the filtered samples divided by the volume of GSL water filtered.

Sampling Program #	Sample Date	Mean Selenium in ug/L	SD	Number of Samples
16	May 4, 2007	0.13	0.03	6
17	May 23, 2007	0.08	0.03	6
18	June 9, 2007	0.06	0.01	6
19	June 27, 2007	0.17	0.06	6
20	July 27, 2007	0.11	0.06	4
21	August 21, 2007	0.30	0.07	6
Grand Mean		0.14	0.09	34

3.3 Selenium in Artemia

Table 6. Selenium concentration in brine shrimp adult tissue. All samples listed below were vacuum filtered to remove residual salt water prior to freezing. All values are reported in dry weight.

Sampling Program #	Sample Date	Mean Selenium in ug/g	SD	Number of Samples
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16	May 4, 2007	3.79	0.76	6
17	May 23, 2007	4.16	0.89	6
18	June 9, 2007	5.21	1.13	6
19	June 27, 2007	3.37	0.20	6
20	July 27, 2007	4.90	1.05	4
21	August 21, 2007	3.76	0.59	6
Method Comparison Program #1	May 8, 2007	4.92	0.81	6
Method Comparison Program #2	August 31, 2007	4.68	0.25	5
Grand Mean		3.97	1.25	45

Table 7. Selenium concentration in brine shrimp nauplius and meta-nauplius tissue. All samples listed below were vacuum filtered to remove residual salt water prior to freezing. All values are reported in dry weight.

Sampling Program #	Sample Date	Mean Selenium in ug/g	SD	Number of Samples
15	March 15, 2007	1.76	0.49	3
16	May 4, 2007	3.56	1.57	5
17	May 23, 2007	2.55	0.40	6
18	June 9, 2007	2.10	0.44	6
19	June 27, 2007	2.50	0.52	6
20	July 27, 2007	2.18	0.56	4
21	August 21, 2007	2.65	0.14	6
Method Comparison Program #1	May 8, 2007	2.11	0.48	6
Method Comparison Program #2	August 31, 2007	2.30	0.18	5
Grand Mean		2.44	0.74	47