PROJECT 1A: CONCENTRATION AND EFFECTS OF SELENIUM ON SHOREBIRDS AT GREAT SALT LAKE, UTAH

OCTOBER 1, 200

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INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972 (i.e. the Clean Water Act) mandated that each state identify the beneficial uses of its water bodies and establish water quality standards to protect those uses. The Great Salt Lake (GSL) is well known as one of North America's most important inland shorebird sites. At least 22 species of shorebirds utilize the GSL during migration and another eight species nest in habitats associated with the lake. The breeding populations of American Avocets (*Recurvirostra americana;* AMAV) and Black-necked Stilts (*Himantopus mexicanus*; BNST) are among the highest in North America (Aldrich and Paul 2002). Consequently, the GSL is recognized as a site of hemispheric importance within the Western Hemisphere Shorebird Reserve Network (Andres et al. 2006). Because of the lake's importance to shorebirds, as well as other waterbirds, aquatic wildlife habitat is listed as a beneficial use of the GSL. However, numeric water quality standards do not exist for the GSL.

A recent proposal by the Southwest Jordan Valley Groundwater Project to dispose of reverse osmosis concentrate within the south arm of the GSL has led to public concern over potential selenium contamination. Selenium (Se) is a toxic trace element that may disrupt avian development, and increase mortality (Ohlendorf et al. 1988, 1989). This concern has brought a renewed focus on the need for numeric water quality standards.

The transfer of Se into the GSL food chain occurs at the level of microorganisms and phytoplankton (Johnson et al. 2006). These organisms are consumed by both brine shrimp (*Artemia* spp.) and brine flies (*Ephydra* spp.), which in turn are likely a major component of shorebird diets within the GSL (Cavitt 2006). The development of a water quality standard requires the knowledge of current Se levels found within the water, sediments, macro-invertebrates, and shorebirds. This background information should also be coupled with the biological significance of these existing Se concentrations (e.g. effects on egg hatchability).

I compiled these data for two common shorebird species breeding at GSL, the AMAV and BNST. The objectives of this study included the following:

- Determine the diet of American Avocets and Black-necked Stilts at Great Salt Lake
- Measure the ambient concentration of Se in the water, sediment, and macro-invertebrates consumed by shorebirds
- Measure the concentration of Se within the blood and liver of American Avocets and Black-necked Stilts
- Measure the concentration of Se within the eggs of American Avocets and Black-necked Stilts
- Determine the hatchability, and breeding productivity of American Avocets and Black-necked Stilts

METHODS

Data were collected for this study from late April until August 2006.

Study sites

An aerial survey of the Great Salt Lake was flown on April 23, 2006. A flight pattern was chosen so that the southern shoreline, western shoreline, and eastern shoreline could be surveyed for aggregations of AMAV and BNST. This was followed by ground surveys (walking, ATV) and boat surveys (hovercraft) to refine and pinpoint study site locations (4/24/2006 – 5/12/2006).

As a result of these surveys, the following study areas were identified (Figure 1):

Figure 1. Study sites monitored for this project during the 2006 breeding season.

- *Antelope Island, Bridger Bay* – This study site is located at Bridger Bay adjacent to Antelope Island State Park. AMAV were observed foraging around a submerged roadway in the bay at water depths of approximately 60cm. No freshwater sources are found in the area. The study site is located at 41°02.662' N 112°15.857'W.

- *Ogden Bay* – This study site is located at the Ogden Bay Waterfowl Management Area along the eastern shore of the Great Salt Lake. AMAV and BNST were observed in large numbers during the surveys. Freshwater from the Weber River flows into the bay at this location and attracts large numbers of shorebirds and waterfowl. The study site is located at 41°12.038' N 112°14.597'W.

- *Saltair* – This study site is located along the south shore of the Great Salt Lake. The site receives freshwater inflows from the Kennecott wastewater discharge. Several AMAV pairs and one BNST pair were observed foraging in this location. The study site is located at 40°46.116' N 112°10.466'W.

- *West Carrington* – This area is the western-most study site and is located northwest of Badger Island. AMAV were observed foraging in salt water of ~ 10cm in depth. The coordinates of this study location are 40°56.037' N 112°36.588'W. No freshwater sources were observed in the area.

Adult collections for tissue and dietary analyses

Adult AMAV and BNST were randomly collected by shotgun (USFWS Permit # MB043593-0; UT Division of Wildlife Resources COR# 1COLL7037) at Antelope Island, Ogden Bay, and Saltair after ~ 15min. of active foraging. Following the collection, birds were dissected in the field. The mouth and pharynx were rinsed with 80% ethanol and the wash collected into plastic containers. In addition, the esophagus, proventriculus and ventriculus were each removed and stored in separate containers with 80% ethanol. Blood was collected from a ventricle of the heart using a sterile syringe and then placed within a 1.8-ml Nalgene® cryogenic vial. Each vial was labeled, and placed on ice until returned to the laboratory. A lobe of the liver (~ 5g) was removed, weighed, labeled and placed in a Whirl-pak® bag and stored on ice until returned to the laboratory. All liver and blood samples were frozen upon return to the laboratory and until shipment for analysis of total selenium content. All blood samples were analyzed as whole blood.

Gut contents were removed and food items identified to family and order using Merritt and Cummins (1984) and Voshell (2002). Invertebrates were counted and volumes determined for each taxon by water displacement. Data from samples were summarized as aggregate % volume.

Invertebrate samples

Food-item sampling areas (FISAs) were located from the point birds were first detected foraging, to the point where the adult was collected. Invertebrates within the FISAs were collected using sweep nets (Figure 2), sorted by taxon and life stage (i.e., larvae, pupae and adult), weighed, placed in ® bags and frozen for total selenium analysis. Every attempt was made to collect at three points within each FISA and to collect ~5g per taxon/life stage.

Figure 2. Sweep sampling for invertebrates at Ogden Bay Waterfowl Management Area.

Water and sediment samples

One to five water samples were collected from each FISA. Each water sample was a composite sample with 20% of the sample coming from each of five different sites systematically distributed across the FISA. Water was filtered through a 1-mm mesh to remove large items from the sample and stored at room temperature. After 48 hours, the water was then decanted into a Nalgene® bottle, to separate the water sample from any sediment, and shipped for analysis of total selenium content.

Three sediment samples were collected for each colony with a hand corer (5.08 cm diameter, 10 cm depth). The sediment sample was a composite sample with 20% of the composite sample coming from each of five sediment core samples collected from five sites systematically distributed across each FISA. The sediment sample was stored under refrigeration until shipped for analysis of total Se.

Breeding productivity

Each study site was visited every three to four days from late April until early August to locate and monitor nests. Nests were located by either systematic searches of potential nesting sites or by observing the behavior of adults. We recorded the location of each nest with Magellan Explorist 100 Global Positioning System (GPS) unit. To facilitate relocating nests in dense colonies, each nest was marked with a 10-cm wooden tag, placed in the ground at the edge of the nest so only the top 3-4cm was visible (Figure 3). A unique nest identification number was written on each tag with permanent marker.

Because shorebirds lay only 1 egg/day, the laying date of first eggs (clutch initiation date) was determined by back-dating when nests were found prior to clutch completion. Clutch size was assigned for a nesting attempt only when the same number of eggs was recorded on two consecutive visits and there was evidence that incubation had commenced (i.e., adult behavior and egg temperature). Clutch initiation dates were also estimated for nests located after clutch completion and in which young successfully hatched. The incubation stages of nests found with complete clutches were estimated by egg flotation, which allowed for the prediction of hatching date.

The status of extant nests was determined by visitations every 3-4 days until either eggs hatched or the nest failed. Nests were defined as successful if at least one young hatched and survived to nest-leaving. Nests were presumed successful if eggs disappeared near the expected date of hatching and there was evidence of a successful hatching. This evidence included the presence of young, the presence of eggshell tops and bottoms near the nest, egg shell fragments ~1-5mm in size and detached egg membrane within the nest lining (Mabee 1997, Mabee et al. 2006). A failed nest was classified as depredated if all eggs disappeared prior to the expected date of nest-leaving and there was no basis for weather- or flood-induced mortality. Further evidence of egg depredation included eggshell pieces in the nest (> 5mm in size), and yolk within the nest material.

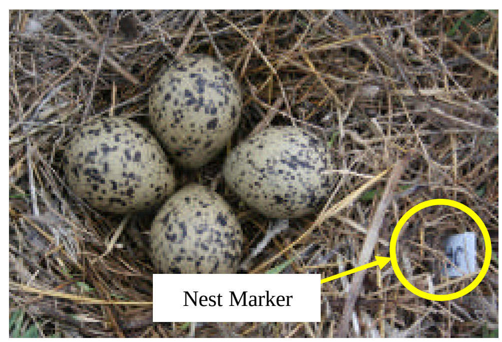

Figure 3. American Avocet nest illustrating nest marker used to uniquely identify nests.

For each nest we recorded the following information: date of clutch initiation, maximum number of eggs, clutch size, date of hatching, number of eggs hatched, number of young produced, and nest fate. From these data I was able to calculate hatchability, daily nest survival rate and nesting success. Hatchability of eggs is defined as the proportion of eggs present at hatching time that produce young (Koenig 1982). Consequently, eggs taken by nest predators or those flooded are not included in the calculation. Hatchability was calculated as # eggs hatched/# full term eggs in the nest. For nests where eggs were removed for Se analysis, the formula was # eggs hatched /(# full term eggs in the nest - # eggs removed).

I examined nesting success by estimating daily survival rates (DSR) and their associated SE according to Mayfield's (1961, 1975) method as modified by Johnson (1979) and Hensler and Nichols (1986). The DSR (s) and the corresponding Mayfield estimator of nesting success (P_2) are calculated as:

$$P_2 = s^h = (1 - \frac{N_u}{E})$$

Where E = the total number of exposure days, N_u = total number of unsuccessful nests, and h = the mean laying period plus incubation period for successful clutches.

Variation in DSR between sites was compared using the program CONTRAST (Sauer and Williams 1989). The program is based on establishing variance-covariance matrices that contrast two or more DSRs and then comparing their differences with a chi-square distribution.

Egg collections/dissections

Eggs were collected to determine the incidence of embryo malpositions and malformations and to determine the concentration of selenium. A single, uncracked egg was randomly collected from a subset of nests early in the incubation period, from a subset of nests late in the incubation period and from dropped eggs found within colonies. Dropped eggs are defined as, "eggs laid on the ground without evidence of scraping" (Robinson et al. 1997). Because nest failure can be quite high at study sites, we collected dropped eggs to ensure there was a sufficient sample for analysis in the event of colony failure. Eggs were marked with a unique identification number, placed in an egg carton and transported to the laboratory. The nest identification number, GPS coordinates of the nest, number of eggs in the nest and estimated incubation stage were also recorded. All eggs were refrigerated upon arrival at the laboratory and dissected within 7 days. Each egg was weighed, and measured (maximal length and breadth) with calipers. A small window was cut at the blunt end of each egg just above the air cell. The stage of development, position of the embryo and condition were noted. Fertility of each egg was determined by the presence of a blastodisc. The normal position of the embryo during the later stages of development is with the head in the blunt end of the egg, with the head under the right wing and with the bill pointed toward the air cell. Malpositions were classified according to Romanoff and Romanoff 1972 as:

I. head between thighs,
II. head in small end of egg,
III. head under left wing,
IV. embryo rotated so that the bill not directed toward air cell,
V. feet over head,
VI. bill over right wing

The condition of the embryo was also noted, including absence of eyes and of limbs or limb buds; presence and number of digits on the feet; evidence of internal hemorrhage, edema, brain swelling, or failure of the body wall to completely close. When embryos were not present, the yolk was examined for the presence of a blastodisc. Egg contents were then placed in Nalgene® containers, labeled and frozen until shipment for analysis of total selenium.

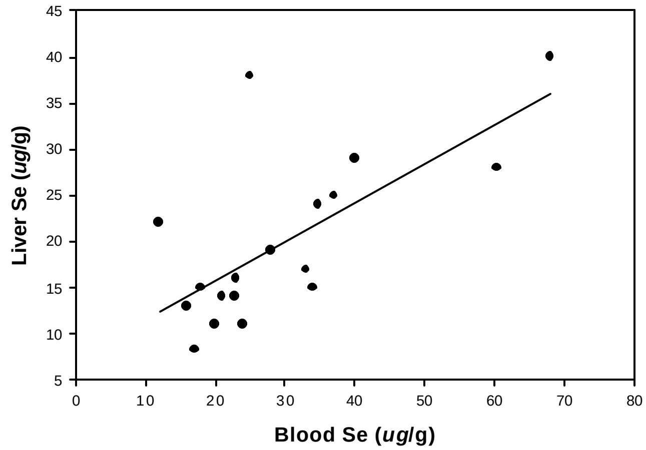

Figure 4. Relationship between blood and liver Se concentrations (µg/g dw) for both AMAV and BNST ($F_{1,18}$= 15.29, r^2 = 0.474, *P* = 0.001; 2 data points occur at the same position, 23 µg/g blood, 16 µg/g liver)

RESULTS

Because free-living birds vary in tissue moisture (e.g. Tieleman and Williams 2002, Tieleman et al. 2003), all tissue results reported below are on a dry-weight basis.

Adult tissue analysis

A total of 15 AMAV (5 each from Antelope Island, Ogden Bay, and Saltair) and 5 BNST (Ogden Bay) were collected for both dietary analysis and to examine total Se concentrations (µg/g dw) in liver and blood tissues (see Appendices 1 and 2 for data sets). I was unable to collect blood from one AMAV (6106-4-AML) taken at Antelope Island; thus, the number of blood samples included in AMAV analyses is only 14.

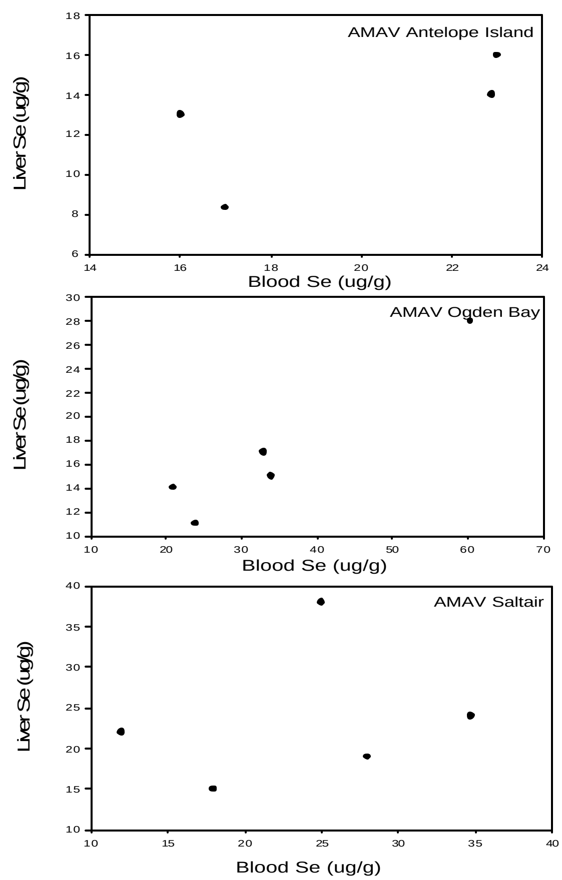

Figure 5. Relationship between blood and liver Se concentrations (µg/g dw) for AMAV by site. See text for statistics.

There was no significant relationship between the log-transformed concentrations of Se in the blood and liver for AMAV ($F_{1,13}$= 2.5, r^2 = 0.172, *P* = 0.140), but there was a significant positive relationship for BNST ($F_{1,4}$= 58.01, r^2 = 0.951, *P* = 0.005) and for both species combined ($F_{1,18}$= 15.29, r^2 = 0.474, *P* = 0.001; Figure 4). This suggests that for BNST both samples are reflective of current body burden and dietary exposure. If the same data are examined on a site by species basis (Figures 5 and 6), there is a significant relationship between the Se concentration in the blood and liver for AMAV and BNST at Ogden Bay (AMAV - $F_{1,4}$= 36.23, r^2 = 0.924, P = 0.009; BNST - $F_{1,4}$= 58.01, r^2 = 0.951, P = 0.005), but not for AMAV at Antelope Island ($F_{1,3}$= 1.95, r^2 = 0.495, P = 0.297) or Saltair ($F_{1,4}$= 0.169, r^2 = 0.053, P = 0.709).

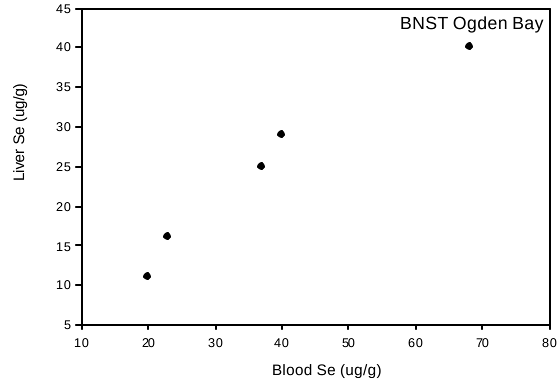

Figure 6. Relationship between blood and liver Se concentrations (µg/g *dw*) for BNST at Ogden Bay ($F_{1,4}$= 58.01, r^2 = 0.951, P = 0.005).

The mean blood and liver Se concentrations did not differ significantly between species (blood t = -1.54, df = 17, P = 0.141; liver t = -1.47, df = 18, P = 0.159; Figure 7). However, I have treated each species separately in the remaining analyses because the number of BNST in the analysis is small and they were restricted to a single site.

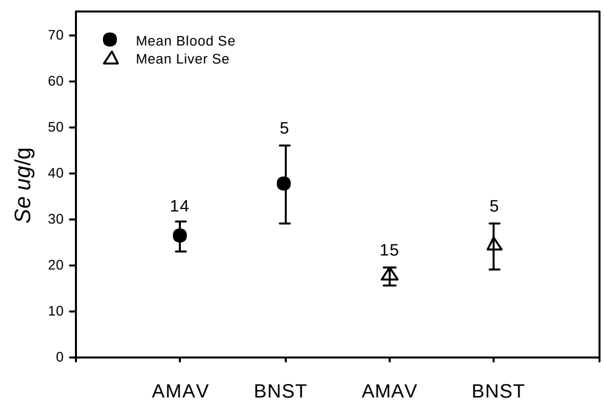

Figure 7. Mean ± std error of tissue Se concentrations (µg/g *dw*; (blood t = -1.54, df = 17, P = 0.141; liver t = -1.47, df = 18, P = 0.159).

AMAV adults had high blood Se concentrations (Figure 8), ranging from 12 - 60 µg/g *dw*. Likewise, liver Se concentrations were also high (Figure 9), ranging from 8.3 - 38 µg/g *dw*. There were no significant differences in blood Se concentration among sites ($F_{2,14}$ = 2.276, P = 0.149; Figure 8); however, adults collected from Ogden Bay tended to have a higher mean concentration relative to the other sites. The concentration of Se in AMAV liver tended to be higher at Saltair relative to either Ogden Bay or Antelope Island, although not significantly at α = 0.05 ($F_{2,14}$ = 3.79, P = 0.053). Males and females did not differ in blood Se concentration (t = -0.592, df = 12, P = 0.565), liver Se concentration (t = -1.733, df = 13, P = 0.107) or body mass (U = 11, df = 14, P = 0.170). There was a significant negative relationship between liver Se concentration and body mass (r = -0.54, P = 0.038; Figure 10A), but

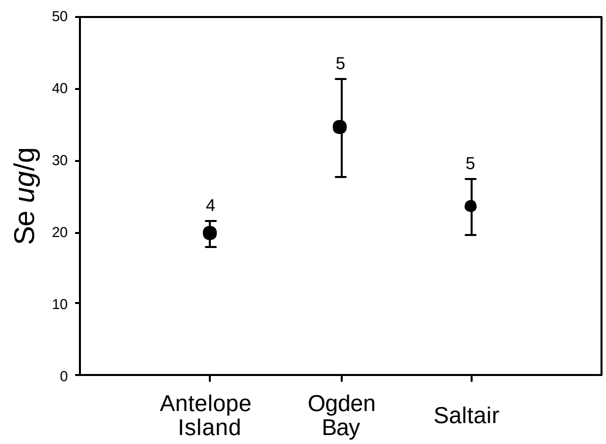

Figure 8. Mean ± std error AMAV blood Se concentration (µg/g *dw*) at each site sampled ($F_{2,14}$ = 2.276, P = 0.149).

no relationship with blood Se concentration (r = -0.04, P = 0.90).

BNST adults had high blood Se concentrations (Figure 6, 7), ranging from 20-68 µg/g *dw*. Liver Se concentrations were also high (Figure 6, 7) ranging from 11 - 40 µg/g *dw*. Since BNST were found nesting only at Ogden Bay, site comparisons could not be made for this species. The body mass of BNST tended to be lower for those birds with higher liver Se concentration (r = -0.826, P = 0.085; Figure 10B), and higher blood Se concentration (r = -0.796, P = 0.11) although not significantly. Since only a single female was collected, differences in Se tissue concentrations between sexes could not be tested.

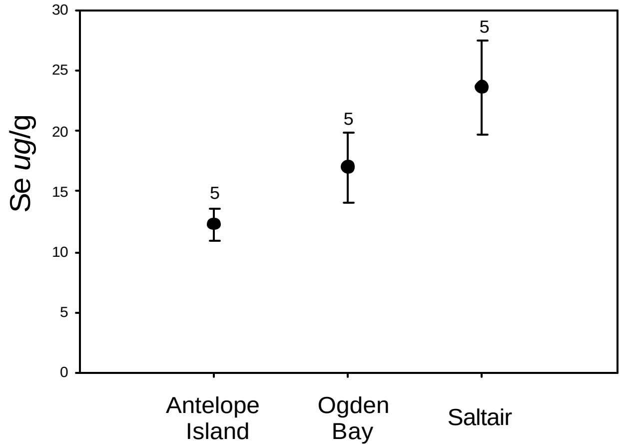

Figure 9. Mean ± std error AMAV liver Se concentration (µg/g *dw*) at each site sampled ($F_{2,14}$ = 3.79, P = 0.053). Data provided in Appendix 1 and 2.

Diet

The diet of AMAV varied among sites. At Antelope Island, 100% of the food items recovered from the digestive tract (mouth, esophagus, proventriculus) were brine flies (Ephydridae; Figure 11). Seeds were recovered from the ventriculus of four individuals (Figure 12). At Ogden Bay, 66% of the aggregate volume of food items recovered were midges (Chironomidae) and 20% brine flies (Figure 11). At Saltair a larger proportion of brine flies (36%) were consumed at Ogden Bay but less than at Antelope Island (Figure 11).

BNST diets at Ogden Bay were somewhat more varied and included water boatmen (Corixidae), brine flies and beetles (Coleoptera; indicated by mandibles, and exoskeletons, Figure 13). The diets of each individual together with the corresponding tissue Se concentrations and body mass are presented in Appendices 1 and 2.

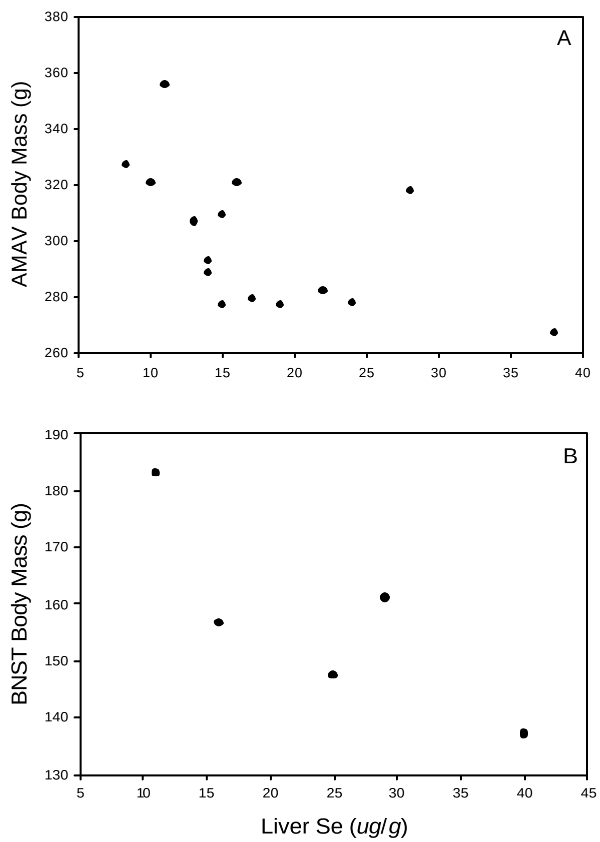

Figure 10. Relationship between AMAV (A- r = -0.54, P = 0.038) and BNST (B - r = -0.826, P = 0.085) body mass (g) and liver Se concentration (µg/g *dw*). Data provided in Appendix 1 and 2.

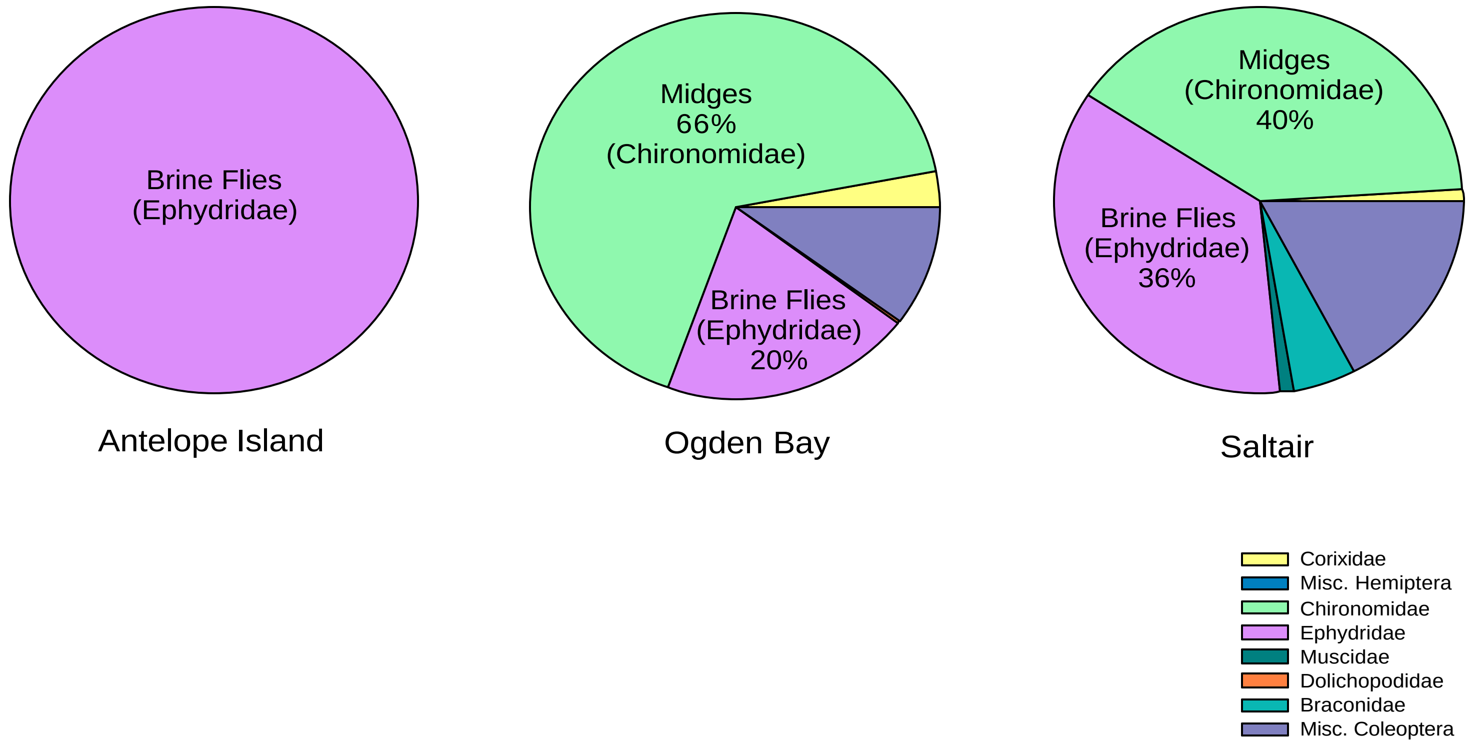

Figure 11. Aggregate % volume of food items recovered from AMAV digestive tracts (mouth, esophagus, and proventriculus) at each site.

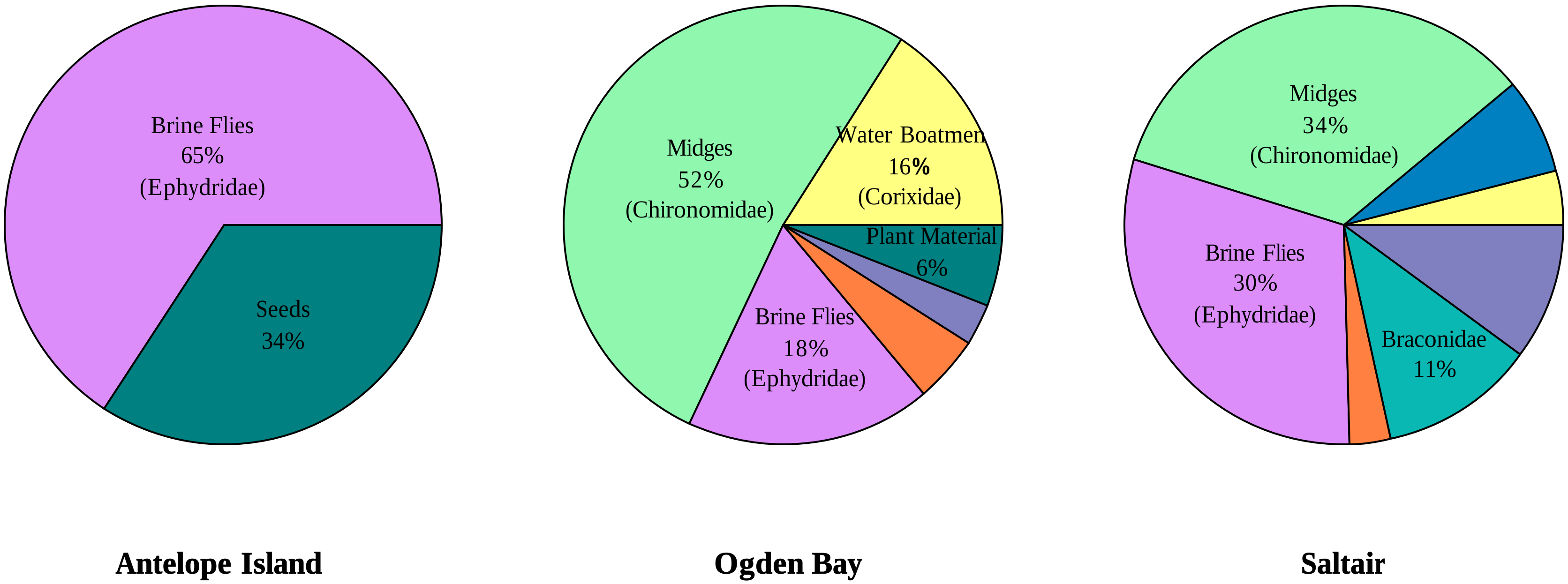

Figure 12. Aggregate % volume of food items recovered from entire AMAV digestive tracts (mouth, esophagus, proventriculus, and ventriculus) at each site.

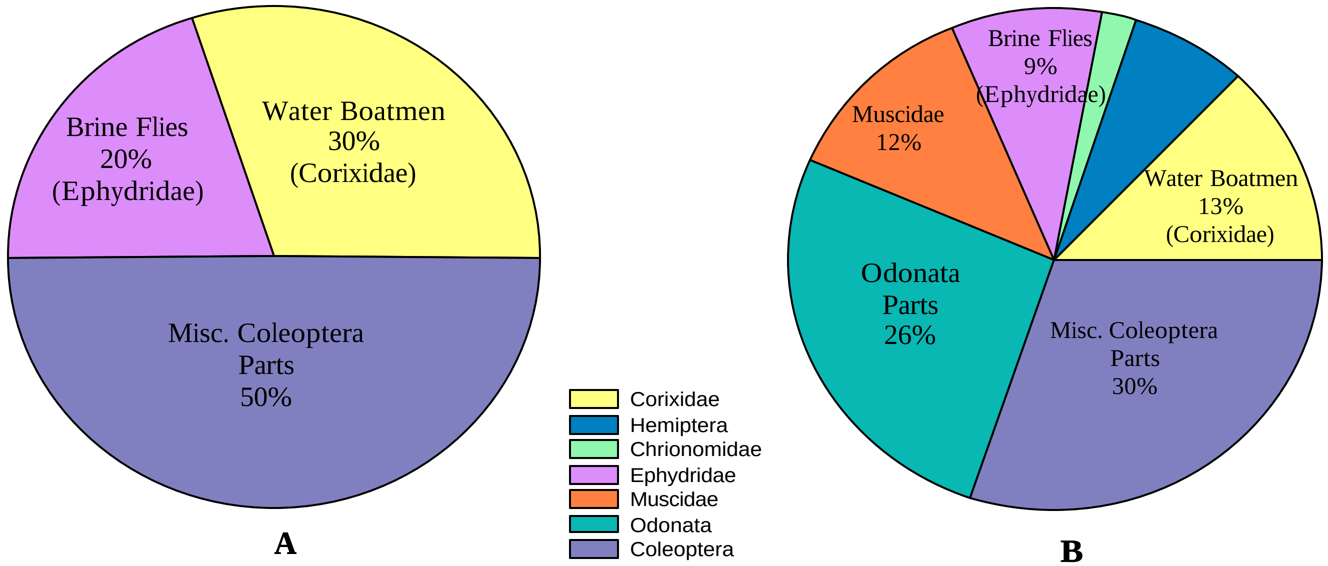

Figure 13. Aggregate % volume of food items recovered from BNST digestive tracts at Ogden Bay
A - mouth, esophagus, and proventriculus
B - mouth, esophagus, proventriculus and ventriculus

Invertebrates

The concentration of Se in invertebrates sampled ranged from 0.3 µg/g *dw* in snails at Ogden Bay to 3.8 µg/g *dw* in brine flies collected at Saltair. There were no significant differences in Se concentrations among stages of the brine fly life cycle (adult, larvae, pupae; $H = 2.61$, $df = 2$, $P = 0.271$). Consequently, all stages are considered together to compare among sites.

Brine fly Se concentration did not differ significantly among sites, yet individuals collected at Saltair tended to have a higher mean concentration relative to either Antelope Island or Ogden Bay ($F_{2,15} = 3.40$, $P = 0.065$). The Se concentrations of all invertebrates collected are reported in Appendix 3.

Water and sediments

The Se content of water samples taken from Saltair were significantly higher than those taken from either Antelope Island or Ogden Bay ($H = 7.2$, $df = 2$, $P = 0.004$; Figure 14). Although sediment samples did not differ significantly, a similar trend existed with Saltair having a greater median Se content relative to either Antelope Island or Ogden Bay ($H = 7.7$, $df = 2$, $P = 0.07$; Figure 15). The data sets for each sample are presented in Appendix 4.

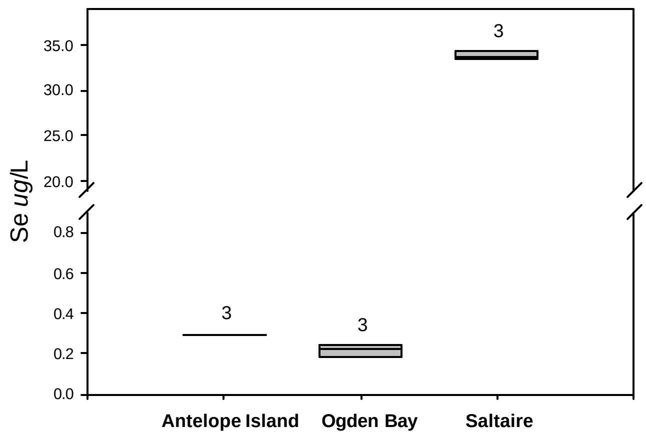

Figure 14. Median Se concentration of water samples collected at each site ($H = 7.2$, $df = 2$, $P = 0.004$).

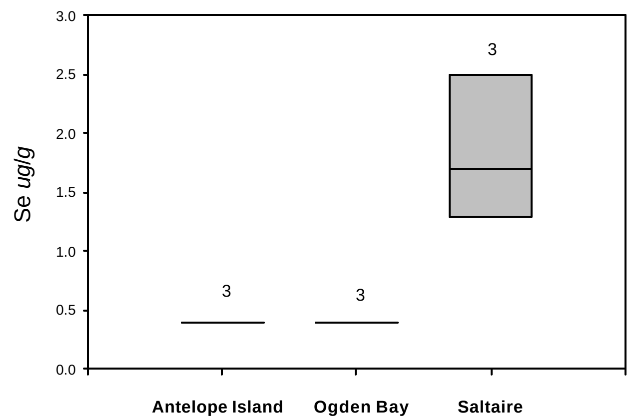

Figure 15. Median Se concentration of sediment samples collected at each site ($H = 7.7$, $df = 2$, $P = 0.07$).

Breeding productivity

Antelope Island, Bridger Bay - A total of 196 AMAV nests were identified and monitored throughout the breeding season at the Antelope Island Bridger Bay site (Figure 1 and 16). Two Snowy Plover (*Charadrius alexandrinus*) were also identified at this site (Figure 16). First eggs were laid at this site on 5/15, and the last young hatched on 7/13. The median date of clutch initiation for this colony was 6/9. A total of 669 eggs were laid with an average clutch size of 3.78 eggs/nest (range 2-5 eggs; modal clutch size= 4; Table 1). The site produced a total of 293 young with an average of 3.42 young produced per successful nest (Table 1). The hatchability of eggs was 0.94.

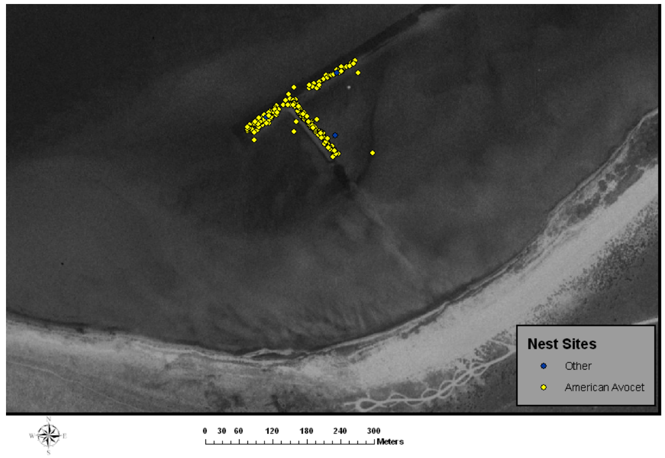

Figure 16. Nest site locations at Antelope Island, Bridger Bay. Nest sites are located along an old road bed.

The most common source of nest failure at this site was attributed to nest predation (50%, Figure 17). These nests were found with large egg shell fragments and occasionally with holes pecked into the side. California Gulls (*Larus californicus*) were consistently observed near the colony and have been seen taking both AMAV eggs and young at other locations (Robinson et al. 1997, Cavitt personal observation). The second most important source of nest failure was due to unknown causes (28%). These nests were also likely nest depredations but insufficient evidence was available to assign a fate to the nest.

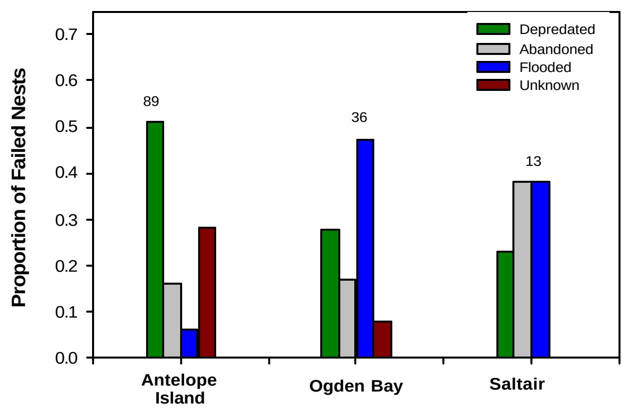

Figure 17. Causes of AMAV nest failure at each site.

The daily survival rate of nests at the Antelope Island site was 0.972 ± 0.003. This corresponds to a Mayfield nesting success estimate of 0.472.

Table 1. Productivity data collected for each study site (mean clutch size, hatchability and average number of young to nest leaving ± standard error).

Site	Species	Total Eggs Laid (total nests)	Clutch Size (n)	Hatchability (#nests/#eggs)	Total Young Produced	Average # Young Leaving/Nest (n)
Antelope Island	AMAV	669 (196)	3.77 ± 0.05 (90)	0.94 ± 0.01 (86/308)	293	3.42 ± 0.08 (86)
Ogden Bay	AMAV	296 (90)	3.77 ± 0.08 (44)	0.97 ± 0.02 (40/138)	137	3.34 ± 0.10 (41)
	BNST	137 (39)	3.84 ± 0.09 (19)	1.0 ± 0 (18/58)	70	3.33 ± 0.10 (21)
Saltair	AMAV	32 (13)	4.0 ± 0 (2)	-	0	-

Ogden Bay - A total of 90 AMAV and 39 BNST nests were identified and monitored throughout the breeding season at the Ogden Bay site (Figure 1 and 18). Nests of other species located at Ogden Bay included, two Mallards (*Anas platyrhynchos*), three Redheads (*Aythya americana*), two Wilson's Phalaropes (*Phalaropus tricolor*) and one Killdeer (*Charadrius vociferus*). First AMAV eggs were laid at this site on 5/10, and the last young hatched on 7/25. BNST initiated nests five days later on 5/15 and the last young hatched on 7/25. The median date of clutch initiation was 6/13 for AMAV and 6/8 for BNST. A total of 296 AMAV eggs were laid with an average clutch size of 3.77 eggs/nest (range 2-5 eggs; modal clutch size= 4; Table 1). BNST laid a total of 137 eggs with an average clutch size of 3.84 eggs/nest (range 2-5 eggs; modal clutch size= 4; Table 1). The site produced a total of 137 AMAV young with an average of 3.34 young produced per successful nest (Table 1) and 70 BNST young with an average of 3.33 young/successful nest. Hatchability data are presented in Table 1.

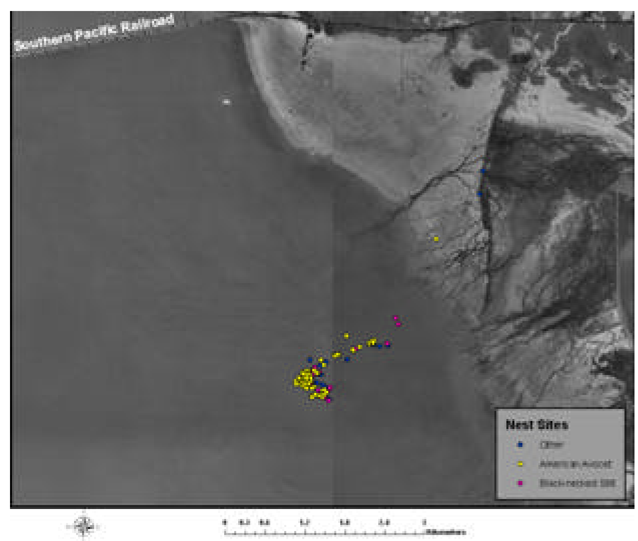

Figure 18. Nest site locations at Ogden Bay.

The most common source of nest failure at this site for both species was flooding, followed by nest predation (Figure 17). Because nests were located at the terminal end of the Weber River and along the shoreline of the Great Salt Lake, they were very susceptible to abrupt changes in water level. The flooding event that was responsible for the flooding nest losses occurred between 6/9 and 6/10 when 2.18 cm of rain fell and flooded 17 AMAV and 6 BNST nests.

The daily survival rate of AMAV nests at the Ogden Bay site was 0.979 ± 0.02. This corresponds to a Mayfield nesting success estimate of 0.56. The daily survival rate of BNST nests was 0.98 ± 0.006 and a Mayfield nesting success estimate of 0.61.

Saltair – A total of 13 AMAV nests were located and monitored at this site (Figure 1 and 19). This site did not produce any successful nests but the last date a nest was observed active at the site was on 6/10. A total of 32 eggs were laid but no young were produced. One of the major sources of nest failure at this site was a flooding event (Figure 17) that occurred between 5/28 and 5/30 which destroyed five nests. A total of 0.9 cm of rain was received at the Salt Lake International Airport on 5/27 and 5/28. Like the nesting aggregations at Ogden Bay, all the AMAV nests were along the shoreline of the Great Salt Lake and within the outflow of the Kennecott wastewater discharge. Consequently they were vulnerable to increased outflows.

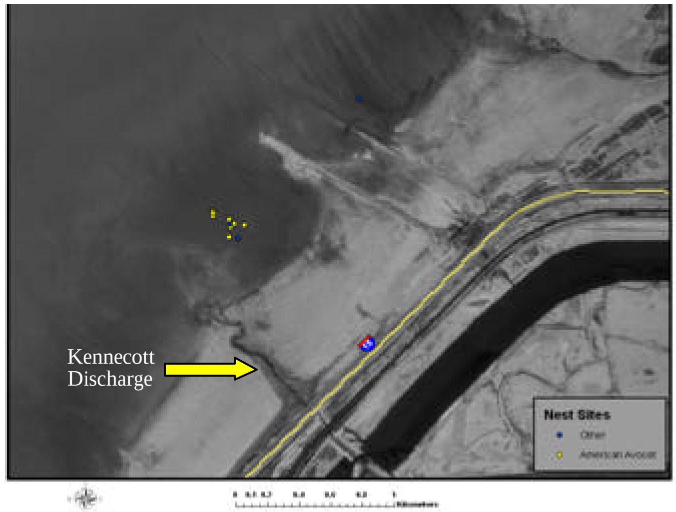

Figure 19. Nest site locations at Saltair.

Because so few birds were nesting at this site and because we were concerned that predation or additional flooding could jeopardize the collection of useable data, we collected a single egg from each of four newly initiated nests. These collections resulted in the abandonment of the nest due to our disturbance.

West Carrington – On 5/24 a few pairs of AMAV were observed on a small island in West Carrington Bay (Figure 1 and 20). A single nest was discovered on the island and an egg was collected. On 5/27 we only monitored the colony from a distance because of an approaching storm. At this visit we noted that an additional four birds were attending nests on the island. Three days latter on 5/30 we reached the island to discover that the entire colony had been abandoned with no signs of eggs or egg fragments. A Common Raven (*Corvus corax*) nest was located within 100m of the colony and may have contributed to the colony's abandonment. This species has been known to take both eggs and adult AMAV (Robinson et al. 1997). The site was revisited on several occasions but renesting never occurred. Two Snowy Plover nests were also located at this site.

Figure 20. Nest site location at West Carrington.

There were no significant differences between Antelope Island and Ogden Bay in AMAV hatchability (U = 1611.5, df = 1, P = 0.352) or DSR (X^2 = 0.048, df = 1, P = 0.83).

Egg collections/dissections

A total of 70 eggs (53 AMAV, 17 BNST) were collected, dissected and analyzed for total Se content (Table 2, Appendix 5). Nest visit data are included for nests in which eggs were collected (see Appendix 6). There were no malformations identified in the dissected embryos. Four eggs were classified as infertile. Two of the four were dropped AMAV eggs (one each from Ogden Bay and Saltair) and the other two infertile eggs were collected from AMAV nests at Ogden Bay where the remainder of the eggs successfully hatched. One AMAV egg collected from Antelope Island (AML-03-06, 17 + days old) had a possible Type I malposition. No other malpositions were observed. The fates of nests from which the eggs were collected are presented in Table 2.

In order to determine if the Se concentrations of eggs affected the fate of nests, comparisons were made within each sampling site. When only a single nest fate was represented within a sample, it was not included in the analysis. The Se concentration of AMAV eggs collected from nests that were ultimately successful at Antelope Island were significantly lower (mean ± se = 2.15 ± 0.08; n = 15) relative to eggs collected from nests that later were depredated (2.85 ± 0.05; n = 2) and those nests which later failed for unknown causes (2.7 ± 0.1; n = 2; $F_{2,18} = 6.670$, $P = 0.008$). Eggs collected from nests ultimately deserted at Saltair had significantly lower Se concentrations (3.78 ± 0.56; n = 4) relative to eggs whose nests later flooded (7.1 ± 1.1; n = 3; $t = -2.87$, $df = 5$, $P = 0.035$). No differences were found with nest fate for either AMAV or BNST at Ogden Bay (AMAV - $t = 0.309$, $df = 18$, $P = 0.761$; BNST - $F_{2,14} = 0.843$, $P = 0.454$).

To examine if AMAV eggs collected from nests with low hatchability had higher Se concentration, nests were classified as either complete (hatchability = 1.0), or low (hatchability < 1.0) and then Se concentrations compared with a t-test. There was no significant effect of Se concentration on the hatchability of AMAV eggs ($t = 0.12$, $df = 25$, $P = 0.905$).

The mass of eggs collected did not differ significantly among sites ($F_{2,48} = 0.251$, $P = 0.779$). However, sites differed significantly in the median Se concentration of eggs ($H = 19.07$, $df = 2$, $P = 0.001$). Eggs collected at Saltair were significantly higher in median Se concentration (5.4 µg/g *dw*) relative to both Antelope Island (2.2 µg/g *dw*) and Ogden Bay (2.0 µg/g *dw*, Figure 21).

Table 2. Ultimate fate of nests from which eggs were collected for Se analysis.

Fate of nest	**Site**				
	Antelope Island	Ogden Bay		Saltair	West Carrington
	AMAV	AMAV	BNST	AMAV	AMAV
Success	15	13	9		
Depredated	2	1	3		1
Flooded	1	1	1	3	
Abandonment	1			4	
Failure unknown	2	1	1		
Dropped eggs (no nest)		7	3	1	
Total	**21**	**23**	**17**	**8**	**1**

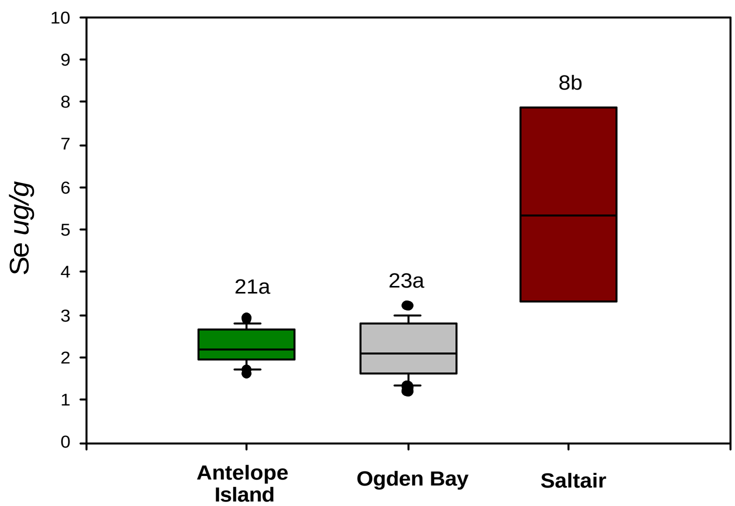

Figure 21. Median concentration of Se (µg / g *dw*, upper and lower quartiles) in eggs collected from each site ($H = 19.07$, $df = 2$, $P = 0.001$). Boxes with the same letter are not significantly different. Dots represent upper and lower extreme values. Sample sizes are located above each box plot.

DISCUSSION

The Se concentrations found within water samples collected at both Antelope Island and Ogden Bay were within reported average background levels (USDI 1998). However, the dissolved Se concentrations within water samples taken at Saltair (median = 33.7 µg/L) were much higher than reported background levels. Saltair water samples were also significantly higher relative to either Ogden Bay (median = 0.22 µg/L) or Antelope Island (median = 0.29 µg/L) samples. The Saltair site receives freshwater inflows from the Kennecott wastewater discharge. This discharge site drains the Kennecott Utah Copper Mine's tailings impoundment and thus high levels of Se entering the GSL at this site are not surprising. The dissolved Se concentrations within water samples at Saltair were high enough to warrant concern. At Kesterson National Wildlife Refuge, where Se toxicity produced high egg mortality and deformities within shorebirds and waterfowl, Se levels ranged from 15 – 350 µg/L (Ohlendorf et al. 1986, Ohlendorf et al. 1988).

The most important food items consumed by AMAV were chironomids (0-66% of total volume) and brine flies (20-100% of total volume). At Antelope Island, AMAV consumed exclusively brine flies but at Ogden Bay, where a significant freshwater inflow from the Weber River exists, AMAV consumed a more diverse diet of chironomids, brine flies, coleopteran larvae, and corixids. These results are consistent with data collected at other wetland sites within the GSL ecosystem (Cavitt 2006).

At Ogden Bay where AMAV and BNST co-occur, differences in diet were evident. BNST consumed more corixids (30% of total volume) and coleopteran larvae (50% of total volume) whereas AMAV diet consisted of a greater proportion of chironomids (66% of total volume). Data from this and other studies at GSL suggest that AMAV select food items in proportion to their availability within foraging sites, whereas BNST are more selective in their diet (Cavitt 2006).

Because of their importance in the diet of AMAV, brine fly larvae may represent a food chain link for the transfer of Se. The concentration of Se within brine fly larvae ranged from 0.8 to 3.8 µg/g *dw*. Brine fly larvae collected at Saltair tended to have a higher concentration of Se relative to the other sites. Unfortunately, only a single sample of chironomid larvae could be collected; the Se concentration of this sample collected at Ogden Bay was 2.0 µg/g *dw*. Maier and Knight (1994) reported a range of ambient selenium concentrations of 0.5 to 2.0 µg/g *dw* in invertebrates. Seven of the 16 brine fly samples were above the Maier and Knight (1994) upper background concentrations. Four of the five Saltair brine fly samples from FISAs were above 2.0 µg/g *dw* and one Saltair FISA sample had the highest Se concentration (3.8 µg/g *dw*) found within all macro-invertebrates collected. Although brine shrimp were not a major food item consumed by either AMAV or BNST collected for this study, their Se concentration were also high (range 2.5 – 3.2 µg/g *dw*). Lemly (1996a, 1996b) reported that Se concentrations in bird diets that are greater than 3 µg/g *dw* are above the toxicity threshold for sensitive species.

The Se concentrations found within the blood and livers of both AMAV (*mean* ± *se* – blood = 26.4 ± 3.2 μg/g *dw*; liver = 17.6 ± 2.0 μg/g *dw*) and BNST (blood = 37.6 ± 8.5 μg/g *dw*; liver = 24.2 ± 5.0 μg/g *dw*) were higher than expected based on concentrations found within invertebrate food sources. Furthermore, these concentrations are much higher than average background levels reported for these tissues (USDI 1998). Selenium concentrations in whole blood above 2 *ppm* are of concern and 5 *ppm* is a suggested threshold of toxicity (USDI 1998, Santolo and Yamamoto 1999). Background Se concentrations in liver tissue has been reported as less than 10 *ppm* (6.0 – 9.9 in recurvirostids; USDI 1998). However in this study AMAV had liver Se concentrations ranging from 8.3 – 38 *ppm* and BNST ranging from 11 – 40 *ppm*. Concentrations of Se in whole blood of predatory birds from a contaminated site in California ranged from 1.5 *ppm* to 38 *ppm*.

One possible explanation for the high Se concentrations found at GSL may be an interaction with elevated mercury (Hg) concentrations (Santolo and Ohlendorf 2006). Both Hg and Se seem to act antagonistically forming a stable complex. This complex may act to increase both the retention and buildup of Hg and Se in tissues. Studies have been initiated to examine this potential relationship.

The significant negative relationship found between AMAV liver Se concentrations and body mass suggest that these elevated levels may affect adult body condition. Previous studies have also reported reduced body mass (e.g., Ohlendorf et al. 1988, Smith et al. 1988, Ohlendorf et al. 1990, Heinz and Fitzgerald 1993) or lean mass (Yamamoto and Santolo 2000) in birds exposed to elevated levels of Se. This relationship may have important survival consequences for migratory shorebirds like the AMAV, as they must obtain sufficient reserves following reproduction to prepare for the prebasic molt and fall migration. However, mass loss is a complex physiological process in birds and has been demonstrated in some species to be adaptive (e.g. Cavitt and Thompson 1997). Consequently more studies are needed to understand the relationship between Se concentration and adult body conditions in shorebirds.

Despite the elevated levels of Se found within adult tissues, egg Se concentrations were relatively low. It is widely accepted that elevated Se levels can reduce the reproductive success of birds (Ohlendorf et al. 1988, 1989, Heinz et al. 1989, Adams et al. 2003); however, the threshold level at which negative effects occur is unclear. The suggested threshold of egg Se concentrations range from 6 μg/g to 16 μg/g (USDI 1998, Fairbrother et al. 1999, 2000, Adams et al. 2003, and Ohlendorf 2003). None of the BNST eggs collected were above 6 μg/g *dw* and 5.5% of AMAV eggs analyzed were above this level (range 1.2 – 9.2 μg/g *dw*). However, all AMAV eggs above this lower threshold were collected at Saltair. Although I did not observe any developmental abnormalities of embryos, the median Se concentrations of eggs (5.4 μg/g *dw*) was significantly higher at Saltair relative to the other sites.

The results of this study also indicate that on a population level, AMAV and BNST productivity at Antelope Island and Ogden Bay are not impacted by existing levels of Se in eggs. Due to nest depredation and flooding events I was unable to determine hatchability data for birds nesting at either Saltair or West Carrington. However, hatchability at Antelope Island and Ogden Bay ranged from 0.94 to 1.0. Hatchability of BNST eggs at Bear River

Migratory Bird Refuge, located in the north arm of the GSL, was found to be 0.95 for 24 nests during the 1980's (Sordahl 1996). In central Oregon, AMAV hatchability was only 0.9 for 59 nests monitored (Gibson 1971). In contrast, Ohlendorf et al. (1989) reported hatchability rates of 0.876 for BNST breeding at Kesterson Reservoir. On average the hatchability for uncontaminated populations of aquatic birds seems to be above ~ 0.91 (Ohlendorf 1989). Recent estimates of hatchability for AMAV and BNST at other sites within the GSL are also consistent with the rates found in this study. For example, at Farmington Bay Waterfowl Management Area, hatchability rates estimated from 2005 and 2006 are as follows: AMAV = 0.93, 0.96; BNST = 0.96, 0.97 (Cavitt 2006). Furthermore, Mayfield estimates of AMAV nesting success at Antelope Island (0.472) and Ogden Bay (0.56) are comparable to recent estimates at other sites within the GSL (Farmington Bay – 0.56; Bear River – 0.45 - 0.56; Cavitt 2006).

A single field season of data may be insufficient to adequately describe background levels of Se within the GSL and its potential impacts on AMAV and BNST. However, the data collected during the 2006 breeding season suggest that the concentration of Se found in water samples, food chain invertebrates and eggs at Antelope Island and Ogden Bay were low and within typical background levels reported elsewhere. Data collected at Saltair however, are elevated relative to the other sites. Since Saltair receives freshwater inflows from the Kennecott wastewater discharge, a shallow emergent wetland attractive to breeding shorebirds has developed.

The concentrations of Se found within adult tissues (blood and liver) were elevated and warrant additional study. Santolo and Ohlendorf (2006) suggest an interaction with Hg as an explanation. Additional studies were initiated during the 2007 breeding season to match Se and Hg concentrations of blood, liver and eggs from female AMAV.

SUMMARY

Selenium concentrations in blood from nesting birds on the Great Salt Lake were higher than expected given the concentrations found in livers, eggs and diets. In selenium feeding studies of mallards (Anas platyrhynchos; Heinz and Fitzgerald 1993) and American kestrels (Falco sparverius; Yamamoto et al. 1998), blood selenium concentrations did not significantly exceed dietary concentrations and were similar to diet concentrations after four to eight weeks. Concentrations of selenium in predatory terrestrial birds (kestrel, red-tailed hawk [Buteo jamaicensis], northern harrier [Circus cyaneus], barn owl [Tyto alba], and loggerhead shrike [Lanius ludovicianus]) from a contaminated grassland in California ranged from 1.5 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g dry weight are considered to exceed normal background, and 5 µg/g dry weight is considered a provisional threshold indicating that further study is warranted (UDSI 1998). However, toxicity studies of marine species were not reviewed for the development of those guidelines, and the ecotoxicology of selenium to marine birds may differ from that for other species. For example, female spectacled eiders (Somateria fischeri) nesting on the Yukon-Kuskokwim Delta, Alaska, in 1996 had mean selenium concentrations in their blood (64 µg/g dry weight; Wilson et al 2004) that were higher than found in birds from the Great Salt Lake, but estimated mean concentration in their eggs (about 3.84 µg Se/g dry weight, converted from wet weight) that was only slightly higher than typical background for freshwater birds, and there was no significant effect of selenium on nest success or egg viability (Grand et al. 2002).

Studies are being conducted to determine the cause of the apparent anomaly in Great Salt Lake birds. Inter-laboratory comparisons are being conducted to validate the laboratory results for selenium, and blood and livers from additional Great Salt Lake birds are being analyzed. The new samples will be analyzed for mercury in addition to selenium, because of possible interactions that might increase bioaccumulation and retention of selenium in blood by the birds. We expect these studies, along with information obtained from the literature, to help us understand the high concentrations of selenium in blood.

ACKNOWLEDGEMENTS

Many thanks to the staff and managers of Antelope Island State Park, Kennecott Utah Copper, Ogden Bay Waterfowl Management Area, and US Magnesium for their support and access to study sites. Harry Ohlendorf and Gary Santolo, CH2M Hill, provided guidance on all aspects of this project and have greatly improved drafts of this manuscript with their comments and suggestions. Thanks also to Theron Miller and Bill Moellmer, Utah Division of Water Quality, for many stimulating conversations and assistance in identifying study sites. A debt of gratitude is owed to the many field assistants who endured the rigors of field research at Great Salt Lake including, Lindsay Anderson, Chris Bryan, Sunee Buck, Jen Cary, Nate Cooney, Jannette Dickinson, Christian Edwards, Kate Ennenga, Matt Fisher, Amber Freeland, Mike Gamble, Karla Krause, Aaron Layton, Andy McFadden, Trina Nixon, Brian Oney, Trey Parker, Shane Pearson, Josh Shepard, Nicole Snow, and Kyle Stone. Special thanks to Jen Cary, Christian Edwards, Kyle Stone, Rich Emerson, and Karla Krause for assistance with data entry and analyses.

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APPENDIX 1. Volume (cm^3) of food items recovered (mouth, esophagus, and proventriculus) and corresponding concentration of Se (µ*g*/*g dw*) of tissues and adult body mass (wet weight) from adults collected at each study site (ANTI – Antelope Island, OGBA – Ogden Bay, SALT – Saltair).

Bird #	Species	Sex	Location	Blood Se	Liver Se	Mass (g)	Corixidae	Carabidae	Coleoptera parts	Chironomidae	Ephydridae	Muscidae	Dolichopodidae	Ceratopogonidae	Braconidae	Plant Material	Other
6106-1-AML	AMAV	F	ANTI	22.9	14	288.5	-	-	-	-	0.01	-	-	-	-	-	-
6106-2-AML	AMAV	M	ANTI	23	16	320.4	-	-	-	-	0.01	-	-	-	-	-	-
6106-3-AML	AMAV	M	ANTI	17	8.3	326.8	-	-	-	-	-	-	-	-	-	-	-
6106-4-AML	AMAV	F	ANTI	-	10	320.8	-	-	-	-	-	-	-	-	-	-	-
6106-5-AML	AMAV	M	ANTI	16	13	306.6	-	-	-	-	-	-	-	-	-	-	-
6606-1-JFC	AMAV	M	OGBA	60.4	28	317.9	-	-	-	0.01	-	-	-	-	-	0.01	-
6606-2-JFC	AMAV	M	OGBA	33	17	279.2	-	-	-	0.01	-	-	-	-	-	-	-
6606-3-JFC	AMAV	M	OGBA	34	15	276.9	0.3	-	-	1.38	0.01	0.03	-	0.01	-	-	-
6606-4-JFC	AMAV	F	OGBA	21	14	292.9	-	-	-	-	0.05	-	-	-	-	-	-
6606-5-JFC	AMAV	F	OGBA	24	11	355.7	-	-	-	0.03	-	-	-	-	-	-	-
61306-1-AML	BNST	M	OGBA	23	16	156.7	-	-	0.02	-	-	-	-	-	-	-	-
61306-2-AML	BNST	F	OGBA	20	11	183.1	-	-	0.02	-	-	-	-	-	-	-	0.01
61306-3-AML	BNST	M	OGBA	40	29	161	-	-	-	-	0.01	-	-	-	-	-	-
6706-1-JFC	BNST	M	OGBA	68	40	137.2	0.01	-	-	-	-	-	-	-	-	-	-
6706-2-JFC	BNST	M	OGBA	37	25	147.5	0.01	-	0.01	-	-	-	-	-	-	-	-
6606-10-AML	AMAV	M	SALT	28	19	277.1	-	-	0.01	-	0.01	-	-	-	-	-	-
6606-6-AML	AMAV	M	SALT	18	15	309.1	-	-	-	1.2	0.22	-	0.06	-	0.26	-	-
6606-7-AML	AMAV	M	SALT	34.7	24	277.7	0.08	-	-	0.98	0.78	-	0.04	-	0.09	-	-
6606-8-AML	AMAV	M	SALT	12	22	281.9	-	-	0.01	0.02	0.02	-	-	-	-	-	-
6606-9-AML	AMAV	M	SALT	25	38	267.3	-	-	-	-	-	-	-	-	-	-	-

APPENDIX 2. Volume (cm^3) of food items recovered from the entire digestive tract (mouth, esophagus, and proventriculus, ventriculus), corresponding concentration of Se ($\mu g / g\ dw$) of tissues, and adult body mass (wet weight) from adults collected at each study site (ANTI – Antelope Island, OGBA – Ogden Bay, SALT – Saltair).

Bird #	Species	Sex	Location	Blood Se	Liver Se	Mass (g)	Cordulegadae	Zygoptera	Macrovelidae	Corixidae	Carabidae	Hydrophilidae	Coleoptera parts	Chironomidae	Ephydridae	Muscidae	Dolichopodidae	Ceratopogonidae	Braconidae	Plant Material	Other
6106-1-AML	AMAV	F	ANTI	22.9	14	288.5	-	-	-	-	-	-	-	-	0.07	-	-	-	-	0.05	-
6106-2-AML	AMAV	M	ANTI	23	16	320.4	-	-	-	-	-	-	-	-	0.22	-	-	-	-	0.02	-
6106-3-AML	AMAV	M	ANTI	17	8.3	326.8	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-
6106-4-AML	AMAV	F	ANTI	-	10	320.8	-	-	-	-	-	-	-	-	0.10	-	-	-	-	0.03	-
6106-5-AML	AMAV	M	ANTI	16	13	306.6	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-
6606-1-JFC	AMAV	M	OGBA	60.4	28	317.9	-	-	-	0.02	0.01	-	-	0.24	-	-	-	0.01	-	0.01	-
6606-2-JFC	AMAV	M	OGBA	33	17	279.2	-	-	-	0.01	0.01	-	-	0.04	0.08	0.02	-	-	-	0.01	-
6606-3-JFC	AMAV	M	OGBA	34	15	276.9	-	-	-	0.6	-	-	-	1.78	0.02	0.05	-	0.01	-	0.03	-
6606-4-JFC	AMAV	F	OGBA	21	14	292.9	-	-	-	0.03	-	-	-	0.14	0.14	0.01	-	-	-	-	-
6606-5-JFC	AMAV	F	OGBA	24	11	355.7	-	-	-	0.08	-	-	-	0.12	-	0.01	-	-	-	0.02	-
61306-1-AML	BNST	M	OGBA	23	16	156.7	-	0.02	-	-	-	-	0.04	-	-	0.01	-	-	-	-	-
61306-2-AML	BNST	F	OGBA	20	11	183.1	-	-	-	0.02	-	-	0.02	-	-	-	-	-	-	-	0.01
61306-3-AML	BNST	M	OGBA	40	29	161	-	-	-	-	-	-	-	-	0.04	0.05	-	-	-	-	-
6706-1-JFC	BNST	M	OGBA	68	40	137.2	0.03	-	-	0.03	-	0.01	0.12	-	0.02	-	-	-	-	-	-
6706-2-JFC	BNST	M	OGBA	37	25	147.5	-	-	0.03	0.04	-	-	0.01	0.01	-	-	-	-	-	-	-
6606-10-AML	AMAV	M	SALT	28	19	277.1	-	-	-	-	-	-	0.04	-	0.05	-	-	-	-	-	0.05[1]
6606-6-AML	AMAV	M	SALT	18	15	309.1	-	-	-	-	-	-	0.01	1.65	0.30	-	0.08	-	0.36	0.01	-
6606-7-AML	AMAV	M	SALT	34.7	24	277.7	-	-	-	0.10	-	-	0.11	3.8	0.97	-	0.07	-	0.09	-	-
6606-8-AML	AMAV	M	SALT	12	22	281.9	-	-	-	0.02	-	-	0.01	0.05	0.11	0.03	-	-	0.04	-	-
6606-9-AML	AMAV	M	SALT	25	38	267.3	-	-	-	0.01	-	-	0.01	0.01	0.03	-	-	-	0.02	-	-

[1] Unidentifiable Hemiptera parts

APPENDIX 3. Se concentration (µ*g*/*g dw*)of invertebrates collected at each site. Means and standard deviations are presented for replicated samples.

Site	Taxa	Life Stage	Se µg/g dw	Date Collected	Mean	Stdev
Antelope Island	Brine Fly	Adult	2.2	16-June-06		
			2.0	16-June-06		
			2.3	16-June-06	2.17	0.15
		Larvae	1.5	16-June-06		
			0.9	16-June-06	1.20	0.42
		Pupae	1.4	16-June-06		
			1.4	16-June-06		
			0.8	16-June-06	1.20	0.35
	Brine Shrimp		3.2	16-June-06		
			2.5	16-June-06		
			3.2	16-June-06	2.97	0.40
	Corixid		2.5	16-June-06		
Ogden Bay	Brine Fly	Adult	0.97	23-June-06		
		Pupae	3	23-June-06		
			1	23-June-06	2.0	1.41
	Carabidae		1	23-June-06		
	Chironomid	Larvae	2	23-June-06		
	Corixid		2	23-June-06		
			3	23-June-06	2.5	0.71
	Muscidae		1	23-June-06		
	Snail		0.3	23-June-06		
Saltair	Brine Fly	Adult	2.2	21-June-06		
			3.8	21-June-06		
			2.1	21-June-06	2.7	0.95
		Larvae	3.4	21-June-06		
		Pupae	1.9	21-June-06		
	Corixid		2.1	21-June-06		

APPENDIX 4. Selenium concentrations from sediment ($\mu g/g\ dw$) and water samples ($\mu g/l$).

Site	Replicate	Number of samples	Sample	Date	Se Content
Antelope Island	1	5	Sediment	16-Jun-06	0.4
Antelope Island	2	5	Sediment	03-Jul-06	0.4
Antelope Island	3	5	Sediment	03-Jul-06	0.4
Ogden Bay	1	5	Sediment	25-Jul-06	0.4
Ogden Bay	2	5	Sediment	25-Jul-06	0.4
Ogden Bay	3	5	Sediment	25-Jul-06	0.4
Saltair	1	5	Sediment	28-Jun-06	1.3
Saltair	2	5	Sediment	28-Jun-06	2.5
Saltair	3	5	Sediment	28-Jun-06	1.3
Antelope Island	1	5	Water	16-Jun-06	0.293
Antelope Island	2	5	Water	16-Jun-06	0.294
Antelope Island	3	1	Water	16-Jun-06	0.297
Ogden Bay	1	5	Water	23-Jun-06	0.22
Ogden Bay	2	5	Water	23-Jun-06	0.246
Ogden Bay	3	5	Water	23-Jun-06	0.179
Saltair	1	5	Water	14-Jun-06	33.4
Saltair	2	5	Water	14-Jun-06	33.7
Saltair	3	5	Water	14-Jun-06	34.4

APPENDIX 5. Se concentration of collected eggs (µ*g*/*g dw*), adjusted hatchability (#young hatched/# eggs incubated - # eggs removed for Se analysis), and ultimate fate of remaining eggs[1]

Site	Egg Identification	Spp.	Se Content µg/g dw	Embryo Age Estimate[2]	Adjusted Hatchability[3]	Fate of remaining eggs in nest
Antelope Island						
	AML-01-06	AMAV	2.4	36	1	SUCCESS
	AML-02-06	AMAV	1.8	30-31	1	SUCCESS
	AML-03-06	AMAV	2.8	39-40		DEPREDATED
	JAC-03-06	AMAV	2.9	14		DEPREDATED
	JAC-04-06	AMAV	2.2	19-23+	1	SUCCESS
	JAC-05-06	AMAV	1.7	13-17	0.67	SUCCESS
	JAC-06-06	AMAV	1.6	33-34	1	SUCCESS
	JAC-07-06	AMAV	2.7	6	0.67	SUCCESS
	JAC-08-06	AMAV	2.4	23- 28	0.67	SUCCESS
	JAC-09-06	AMAV	2.2	3-19	1	SUCCESS
	JAC-20-06	AMAV	1.8	37		FLOODED
	JAC-21-06	AMAV	2	23-28	1	SUCCESS
	JAC-22-06	AMAV	2.7	23-28	1	SUCCESS
	JAC-30-06	AMAV	1.9	29-30	1	SUCCESS
	JAC-31-06	AMAV	2.3	23-28		ABANDON
	JAC-32-06	AMAV	2.1	23+	1	SUCCESS
	JAC-33-06	AMAV	2.2	30	1	SUCCESS
	JAC-34-06	AMAV	2.3	23-28	1	SUCCESS
	JAC-60-06	AMAV	2.8	6-19		FAIL UNKNOWN
	JAC-61-06	AMAV	2.6	19		FAIL UNKNOWN
	JAC-62-06	AMAV	2	23+	1	SUCCESS
Ogden Bay						
	BJO-07-06	AMAV	2.8	Infertile	1	SUCCESS
	BJO-08-06	AMAV	2.6	0-19		FAIL UNKNOWN
	BJO-100-06	AMAV	3.2	3		DROPPED
	BJO-05-06	AMAV	2.1	19	1	SUCCESS
	CNE-502-06	AMAV	2.6	19-23+	1	SUCCESS
	JAC-15-06	AMAV	2	Infertile		SUCCESS
	JAC-50-06	AMAV	1.4	2	1	SUCCESS
	JAC-51-06	AMAV	2.1	No data collected		DROPPED
	JFC-32-06	AMAV	1.4	3-6	1	SUCCESS
	JFC-33-06	AMAV	1.4	3		DROPPED
	JFC-34-06	AMAV	1.6	2		DROPPED

[1] Abandon = nest with eggs left unattended
Depredated = eggs taken by nest predator
Dropped = eggs laid on ground with no nest scrape present
Fail Unknown = insufficient evidence to assign nest fate
Flooded = flooding event destroyed nest
Success = nest with at least 1 egg hatching
[2] Age of embryo estimated from Hamburger and Hamilton 1951.
[3] In the case marked as (?), the hatchability of the nest could not be determined due to uncertainty in original number of eggs incubated.

	JFC-35-06	AMAV	1.3	2	1	SUCCESS
	JFC-36-06	AMAV	1.2	3		DROPPED
	JFC-37-06	AMAV	2.6	3-5		FLOODED
	KT-1-06	AMAV	2.8	Infertile		DROPPED
	LJA-152-06	AMAV	2.5	7-9	1	SUCCESS
	LJA-212-06	AMAV	3	3		DROPPED
	LJA-213-06	AMAV	3	No data collected	1	SUCCESS
	MEF-74-06	AMAV	3	1-6	1	SUCCESS
	NS-08-06	AMAV	2.1	19-23+		DEPREDATED
	SAP-19-06	AMAV	1.6	45+-46	1	SUCCESS
	SAP-22-06	AMAV	1.8	37	0.67	SUCCESS
	SAP-25-06	AMAV	1.6	37	1	SUCCESS
	BJO-67-06	BNST	2.7	1-6	1	SUCCESS
	BJO-68-06	BNST	2.8	25-29	1	SUCCESS
	CNE-500-06	BNST	2.4	3-5		DROPPED
	CNE-501-06	BNST	1.7	No data collected		DEPREDATED
	KEE-02-06	BNST	2.5	9-23+	1	SUCCESS
	KEE-05-06	BNST	2.1	6		FAIL UNKNOWN
	KEE-169-06	BNST	3.4	0		DROPPED
	KEE-171-06	BNST	2.7	30	1	SUCCESS
	KEE-175-06	BNST	2.5	18-38+	1	SUCCESS
	LJA-151-06	BNST	1.3	23-28	1	SUCCESS
	LJA-160-06	BNST	3.6	3		DEPREDATED
	LJA-211-06	BNST	2.8	3-5		DEPREDATED
	NS-06-06	BNST	2.1	3-19	1	SUCCESS
	NS-100-06	BNST	3	7-9		DROPPED
	NS-10-06	BNST	3	43-44	1	SUCCESS
	NS-09-06	BNST	2.3	40-43	?	SUCCESS
	SAP-18-06	BNST	1.3	44+		FLOODED
Saltair						
	AML-131-06	AMAV	3.2	1		ABANDON
	JFC-09-06	AMAV	9.2	3		FLOODED
	JFC-12-06	AMAV	6.8	28		FLOODED
	JFC-6-06	AMAV	5.3	13		FLOODED
	SAP-1-06	AMAV	2.9	2-3		ABANDON
	SAP-2-06	AMAV	8.2	Infertile		DROPPED
	SAP-4-06	AMAV	3.6	1		ABANDON
	SAP-5-06	AMAV	5.4	2		ABANDON
West Carrington						
	JAC-01-06	AMAV	2.5	39		DEPREDATED

APPENDIX 6. Nest visit information for nests of collected eggs. Column definitions are as follows:

Nest ID – Identification code of nest
Egg ID – Identification code of egg analyzed for SE content
Spp Code – Species
Site – Code for each site monitored (ANTI – Antelope Island State Park, OGBA – Ogden Bay Waterfowl Management Area, SALT – Saltair, WCAR – West Carrington Bay).
SE Content – Se content reported for collected egg (µg/g *dw*).
Sample Date – Date (Julian) egg collected
Date 1…10 – Date (Julian) nest visited
Contents 1…10 – Number of eggs (or young = y) recorded on preceding date
H/F – Nest hatch (H) or Failure (F) code
Nest Fate – Fate code for nests

Nest ID	EggID	Spp Code	Site	SE Content	Sample Date	Date 1	Contents 1	Date 2	Contents 2	Date 3	Contents 3	Date 4	Contents 4	Date 5	Contents 5	Date 6	Contents 6	Date 7	Contents 7	Date 8	Contents 8	Date 9	Contents 9	Date 10	Contents 10	H/F	Nest Fate
KK-20-06	AML-03-06	AMAV	ANTI	2.8	163	163	**4**	167	**3**	171	**2**	173														F	DEPREDATED
MEF-30-06	JAC-03-06	AMAV	ANTI	2.9	149	149	**4**	152	**3**	156	**2**	159	**2**	167	**2**	171	**4**	173	**4**	184	**0**					F	DEPREDATED
AML-69-06	JAC-20-06	AMAV	ANTI	1.8	152	152	**4**	156	**3**	159	**3**	163	**0**													F	FLOODED
JAC-130-06	JAC-31-06	AMAV	ANTI	2.3	156	149	**4**	152	**4**	156	**3**	159	**2**	163	**2**	167		171	**2**	173	**3**	184	**3**	187	**0**	F	ABANDON
AML-125-06	JAC-60-06	AMAV	ANTI	2.8	166	163	**2**	166	**4**	167	**3**	171	**3**	173	**3**	180	**0**									F	FAIL UNKNOWN
KK-02-06	JAC-61-06	AMAV	ANTI	2.6	166	163	**4**	166	**4**	167	**3**	171	**3**	173	**3**	180	**0**									F	FAIL UNKNOWN
AML-99-06	AML-01-06	AMAV	ANTI	2.4	159	159	**4**	163	**0**																	H	SUCCESS
MEF-32-06	AML-02-06	AMAV	ANTI	1.8	159	149	**2**	152	**4**	156	**4**	159	**4**	163	**3**	167	**3**	171	**1**	187		191	**0**			H	SUCCESS
MEF-41-06	JAC-04-06	AMAV	ANTI	2.2	149	149	**4**	152	**3**	156	**3**	159	**3**	163	**3**	167		171								H	SUCCESS
JAC-131-06	JAC-05-06	AMAV	ANTI	1.7	149	149	**4**	152	**3**	156	**3**	159	**3**	163	**3**	167	**3**	171	**2**	173	**1**	180	**0**			H	SUCCESS
MEF-42-06	JAC-06-06	AMAV	ANTI	1.6	149	149	**4**	152	**3**	156	**3**	159	**3**	163	**0**											H	SUCCESS
MEF-43-06	JAC-07-06	AMAV	ANTI	2.7	149	149	**4**	152	**3**	156	**3**	159	**3**	163	**3**	167	**3**	171	**1**	173	**1**					H	SUCCESS
MEF-46-06	JAC-09-06	AMAV	ANTI	2.2	149	149	**3**	152	**2**	156	**2**	159	**2**	163	**2**	167	**2**	171	**2**	173	**2**	180	**0**			H	SUCCESS
AML-70-06	JAC-21-06	AMAV	ANTI	2	152	152	**2**	156	**1**	159	**3**	163	**4**	167	**4**	171	**4**	173	**4**	180	**0**					H	SUCCESS

MEF-40-06	JAC-22-06	AMAV	ANTI	2.7	152	149	**2**	152	**4**	156	**3**	159	**3**	163	**3**	167	**3**	171	**3**	172	**3**	180	**0**			H	SUCCESS
AML-73-06	JAC-30-06	AMAV	ANTI	1.9	156	152	**4**	156	**4**		**3**		**3**	167	**3**	171	**1**	173	**0**							H	SUCCESS
MEF-31-06	JAC-32-06	AMAV	ANTI	2.1	156	149	**3**	156	**3**	169	**2**	163	**2**	167	**2**	171	**0**									H	SUCCESS
AML-79-06	JAC-33-06	AMAV	ANTI	2.2	156	152	**4**	156	**4**	159	**3**	163	**3**	167	**3**	171	**3**	173	**0**							H	SUCCESS
JCB-19-06	JAC-34-06	AMAV	ANTI	2.3	156	156	**4**	159	**3**	163	**3**	167	**3**	171	**3**	173	**3**	177	**1**	180	**0**					H	SUCCESS
AML-98-06	JAC-62-06	AMAV	ANTI	2	166	159	**3**	163	**4**	166	**4**	167	**3**	171	**3**	173	**3**	180	**3**	184	**3**	187	**0**			H	SUCCESS
MEF-44-06	JAC-08-06	AMAV	ANTI	2.4	149	149	**4**	152	**3**	156	**3**	169	**3**	163	**3**	167	**2E1Y**	171	**1**							H	SUCCESS
BJO-70-06	BJO-08-06	AMAV	OGBA	2.6	174	174	**4**	178	**3**	182	**3**	188	**0**													F	FAIL UNKNOWN
NS-44-06	NS-08-06	AMAV	OGBA	2.1	174	158	**1**	171	**4**	174	**4**	178	**1**	182	**0**											F	DEPREDATED
JFC-37-06	JFC-37-06	AMAV	OGBA	2.6	165	165	**3**	171	**0**																	F	FLOODED
MEF-79-06	BJO-05-06	AMAV	OGBA	2.1	174	158	**2**	171	**4**	174	**3**	178	**3**	182	**3**	188	**0**									H	SUCCESS
JFC-20-06	JAC-15-06	AMAV	OGBA	2	151	151	**6**	157	**0**																	H	SUCCESS
JAC-250-06	JAC-50-06	AMAV	OGBA	1.4	165	165	**2**	171	**3**	174	**3**	178	**3**	182	**3**	188	**3**	192	**0**							H	SUCCESS
JFC-32-06	JFC-32-06	AMAV	OGBA	1.4	165	165	**2**	171	**3**	174	**3**	178	**3**	182	**3**	188	**3**	192	**0**							H	SUCCESS
JFC-35-06	JFC-35-06	AMAV	OGBA	1.3	165	165	**1**	171	**2**	174	**4**	178	**4**	182	**4**	188	**4**	192	**4**	195	**0**					H	SUCCESS
LJA-152-06	LJA-152-06	AMAV	OGBA	2.5	165	157	**4**	165	**4**	171	**3**	174	**3**	178	**3**	182	**3**	188	**0**							H	SUCCESS
LJA-213-06	LJA-213-06	AMAV	OGBA	3	165	165	**3**	171	**2**	174	**2**	178	**2**	182	**2**	188	**0**									H	SUCCESS
MEF-74-06	MEF-74-06	AMAV	OGBA	3	174	158	**1**	171	**4**	174	**5**	178	**4**	182	**4**	188	**4**	192	**4**	195	**0**					H	SUCCESS
SAP-22-06	SAP-22-06	AMAV	OGBA	1.8	165	151	**2**	157	**4**	165	**4**	171	**3**	174	**3**	178	**1**	182	**1**	188	**0**					H	SUCCESS
SAP-25-06	SAP-25-06	AMAV	OGBA	1.6	165	151	**1**	157	**4**	165	**4**	171	**3**	174	**3**	178	**0**									H	SUCCESS
BJO-69-06	BJO-07-06	AMAV	OGBA	2.8	174	174	**4**	178	**3**	182	**3**	188	**3**	192	**1E1Y**	195	**0**									H	SUCCESS
CNE-502-06	CNE-502-06	AMAV	OGBA	2.6	165	165	**1**	171	**2**	174	**3**	178	**3**	182	**3**	188	**3**	192	**2**	195	**0E1Y**					H	SUCCESS

SAP-19-06	SAP-19-06	AMAV	OGBA	1.6	156	151	**4**	156	**1**																	H	SUCCESS
KEE-172-06	KEE-05-06	BNST	OGBA	2.1	174	171	**4**	174	**4**	178	**3**	182	**4**	188	**4**	192	**1**									F	FAIL UNKNOWN
LJA-160-06	LJA-160-06	BNST	OGBA	3.6	165	157	**3**	165	**1**	171	**1**	174	**0**													F	DEPREDATED
LJA-211-06	LJA-211-06	BNST	OGBA	2.8	165	165	**3**	171	**0**																	F	DEPREDATED
CNE-501-06	CNE-501-06	BNST	OGBA	1.7	165	165	**3**	171	**2**	174	**2**	178	**1**	182	**0**											F	DEPREDATED
SAP-18-06	SAP-18-06	BNST	OGBA	1.3	156	151	**3**	156	**3**	165	**0**															F	FLOODED
BJO-67-06	BJO-67-06	BNST	OGBA	2.7	174	174	**4**	178	**3**	182	**3**	188	**0**													H	SUCCESS
BJO-68-06	BJO-68-06	BNST	OGBA	2.8	174	174	**4**	178	**3**	182	**3**	188	**0**													H	SUCCESS
KEE-171-06	KEE-171-06	BNST	OGBA	2.7	174	171	**4**	174	**4**	178	**3**	182	**3**	188	**3**	192	**0**									H	SUCCESS
LJA-151-06	LJA-151-06	BNST	OGBA	1.3	165	157	**4**	165	**4**	171	**3**	174	**3**	178	**0**											H	SUCCESS
NS-33-06	NS-06-06	BNST	OGBA	2.1	174	158	**4**	171	**4**	174	**3**	178	**3**	182	**3**	188	**0**									H	SUCCESS
NS-112-06	NS-09-06	BNST	OGBA	2.3	174	174	**4**	178	**1**	182	**0**															H	SUCCESS
KEE-164-06	KEE-02-06	BNST	OGBA	2.5	174	171	**4**	174	**4**	178	**3**	182	**3**	188	**3**	192	**3**	195	**3**	199	**2**	202	**2**	206	**1 Y**	H	SUCCESS
KEE-175-06	KEE-175-06	BNST	OGBA	2.5	174	171	**4**	174	**4**	178	**3**	182	**3**	188	**3**	192	**3**	195	**3 Y**							H	SUCCESS
NS-42-06	NS-10-06	BNST	OGBA	3	174	158	**4**	171	**4**	174	**4**	178	**1 Y**													H	SUCCESS
JFC-10-06	JFC-06-06	AMAV	SALT	5.3	146	147	**4**	147	**3**	150	**0**															F	FLOODED
JFC-12-06	JFC-12-06	AMAV	SALT	6.8	146	146	**4**	147	**2**	150	**0**															F	FLOODED
JFC-09-06	JFC-09-06	AMAV	SALT	9.2	146	146	**3**	147	**3**	150	**0**															F	FLOODED
AML-131-06	AML-131-06	AMAV	SALT	3.2	165	165	**1**	172	**0**																	F	ABANDON
AML-130-06	SAP-01-06	AMAV	SALT	2.9	165	165	**1**	172	**0**																	F	ABANDON
AML-132-06	SAP-04-06	AMAV	SALT	3.6	165	165	**1**	172	**0**																	F	ABANDON
AML-133-06	SAP-05-06	AMAV	SALT	5.4	165	165	**1**	172	**0**																	F	ABANDON
JAC-120-06	JAC-01-06	AMAV	WCAR	2.5	144	144	**3**	150	**0**																	F	DEPREDATED

Project 1A: Selenium and Mercury Concentrations in Breeding Female American Avocets at Ogden Bay, Great Salt Lake, Utah, 2007

November 26, 2007

PROJECT 1A: SELENIUM AND MERCURY CONCENTRATIONS IN BREEDING FEMALE AMERICAN AVOCETS AT OGDEN BAY, GREAT SALT LAKE, UTAH, 2007

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INTRODUCTION

The Great Salt Lake (GSL) is well known as one of North America's most important inland shorebird sites. At least 22 species of shorebirds utilize the GSL during migration and another eight species nest in habitats associated with the lake. The breeding populations of American Avocets (*Recurvirostra americana;* AMAV) and Black-necked Stilts (*Himantopus mexicanus*; BNST) are among the highest in North America (Aldrich and Paul 2002). Consequently, the GSL is recognized as a site of hemispheric importance within the Western Hemisphere Shorebird Reserve Network (Andres et al. 2006). Because of the lake's importance to shorebirds, as well as other waterbirds, aquatic wildlife habitat is listed as a beneficial use of the GSL.

A recent proposal by the Southwest Jordan Valley Groundwater Project to dispose of reverse osmosis concentrate within the south arm of the GSL has led to public concern over potential selenium contamination. Selenium (Se) is a toxic trace element that may disrupt avian development, and increase mortality (Ohlendorf et al. 1988, 1989). This concern has brought a renewed focus on the need for numeric water quality standards.

Recent studies designed to examine the current concentration of Se in nesting shorebirds on the GSL (Cavitt 2007) documented higher concentrations within blood than would be expected given the concentrations found in egg and dietary samples. These results prompted the current study, which collected additional samples at GSL, and analyzed them for both total mercury (Hg) and total Se. Hg and Se may act antagonistically forming a stable complex. That may then increase both the retention and bioaccumulation of Se in tissues.

The objectives for this project were to:

- Determine ambient Se concentrations in brine fly larvae.
- Determine Se and Hg concentrations in American Avocet eggs.
- Determine stomach contents of nesting birds.
- Determine Se and Hg concentrations of American Avocet blood and liver.

METHODS

Data were collected for this study from late April until mid-July 2007.

Study Sites

A preliminary study conducted in 2006 found Ogden Bay (OGBA) to have high levels of Se within both blood and liver of AMAV (Cavitt 2007). Consequently, all AMAV collections during the 2007 breeding season occurred at this site. This study site is located at the Ogden Bay Waterfowl Management Area along the eastern shore of the GSL (Figure 1). Freshwater from the Weber River flows into the bay at this location and attracts large numbers of shorebirds and waterfowl. The study site is located at 41°12.038' N 112°14.597'W.

Figure 1. Ogden Bay Waterfowl Management Area.

In addition, invertebrates were sampled from Saltair, which is located along the south shore of the GSL. The site receives freshwater inflows from the Kennecott wastewater discharge. The study site is located at 40°46.116' N 112°10.466'W.

Adult collections for tissue and dietary analyses

Ogden Bay was searched for AMAV nests during late April – June 2007. Nests were marked during laying when 1 – 3 eggs were present. A spring-loaded nest trap was placed on the targeted nests to catch the laying female (Figure 2). Following capture, the female was euthanized by cervical dislocation (USFWS Permit #MB043593-0; UT Division of Wildlife Resources COR# 1COLL7037; WSU ACUC Approval 4/17/07). Any males captured were banded and then released. Collected birds were then dissected in the field.

Figure 2. Spring-loaded trap used to capture adults (photo courtesy of G. Santolo).

Blood was collected from a ventricle of the heart using a sterile syringe and then placed within a 1.8-mL Nalgene® cryogenic vial. A blood sample was also collected from the jugular vein of one individual for comparison to the ventricular blood sample. Each vial was labeled, and placed on ice until returned to the laboratory. The liver was removed, weighed, labeled and placed in a Whirl-pak® bag and stored on ice until returned to the laboratory. The entire oviduct (*infundibulum – junction with cloaca*) was then removed. Any developing, shelled-egg (oviduct eggs) within the oviduct was removed. The oviduct, and oviduct egg were placed in separate Whirl-pak® bags, labeled, and stored on ice until return to the laboratory.

Following collection, esophagus, and proventricular contents were removed, separated, and contents were examined for identification of food items. However, because birds were not collected while foraging, the esophagus and proventriulus were empty in all birds.

All liver and blood samples were frozen upon return to the laboratory and until shipment for analysis of total Se and total Hg. All blood samples were analyzed as whole blood.

Egg collections/dissections

Any eggs present within the nest were collected, prepared for Se and Hg analysis. The nest identification number, GPS coordinates of the nest, number of eggs in the nest and estimated stage of the eggs (determined by egg floatation) were also recorded. All eggs were refrigerated upon arrival at the laboratory. The eggs were then opened within 7 days and contents frozen until shipped for Se and Hg analysis.

Invertebrate samples

Brine fly larvae were collected from AMAV foraging areas at Ogden Bay and Saltair. Brine fly larvae were collected from the mudflat, benthos, and water column. Sufficient biomass for analysis (target 2 grams) was collected using sweep nets (Figure 3). Samples were sorted by taxon and life stage (i.e., larvae, pupae and adult), weighed, placed in Whirl-pak® bags and frozen for Se and Hg analysis.

Figure 3. Collecting brine flies.

RESULTS

The Ogden Bay breeding colony initiated 231 nests throughout the 2007 breeding season. The first nest was initiated on 25 April but median nest initiation was a month later (on 24 May). Of this total, only 19 nests successfully produced young at Ogden Bay. Most nest losses occurred during two flooding events (20 May and then 5 June) and a diversion of water away from the study site (20 June). This diversion resulted in adults abandoning nests and no further renesting attempts were made.

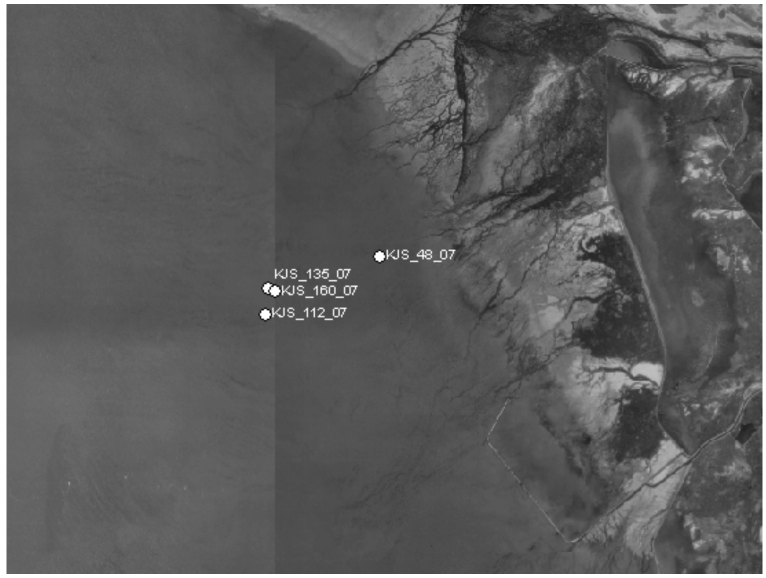

Figure 4. Nest site locations for female AMAV collections.

Because free-living birds vary in tissue moisture (e.g. Tieleman and Williams 2002, Tieleman et al. 2003) and moisture content can vary as a result of sample handing, all tissue results reported below are on a dry-weight basis.

Adult collections for tissue and dietary analyses

The large number of failed nests coupled with infrequent visits of adults to laying nests resulted in only four female AMAV collected (Figure 4, Table 1).

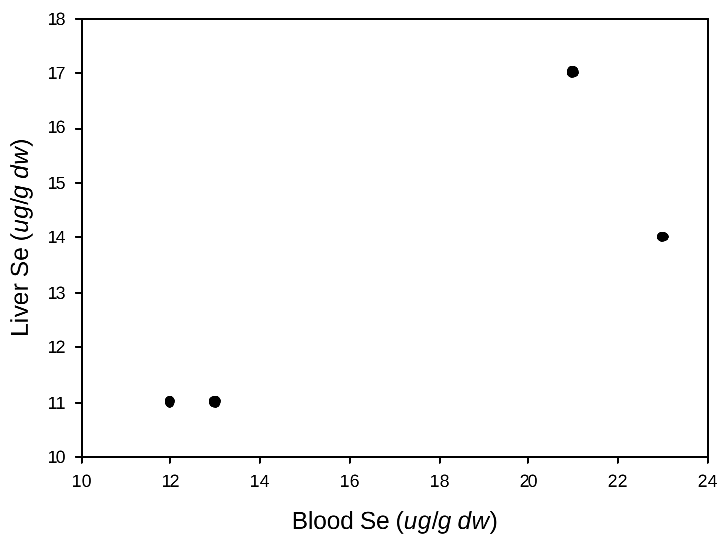

Figure 5. Relationship between blood Se and liver Se (µg/g *dw*).

AMAV females had blood Se concentrations (Figure 5), ranging from 12 - 23 µg/g *dw* and liver Se concentrations (Figure 5), ranging from 11 - 17 µg/g *dw*. There was no significant relationship between the log-transformed concentrations of Se in the blood and liver ($F_{1,3}$= 6.5, r^2 = 0.763, *P* = 0.126; Figure 5).

Blood Se concentrations at Ogden Bay tended to be higher in AMAV during the 2006 breeding season (? = 34.5 µg/g *dw* ± se = 6.95) relative to those captured at the same location in 2007 (? = 17.2 µg/g *dw* ± se = 2.71) although not significantly different (*t* = -2.089, *df* = 7, *P* = 0.075). There also was no significant difference in AMAV liver Se concentration at Ogden Bay between 2006 (? = 17.0 µg/g *dw* ± se = 2.71) and 2007 (? = 13.2 µg/g *dw* ± se = 2.71; *t* = -1.06, *df* = 7, *P* = 0.324).

Hg concentrations in AMAV blood ranged from 0.70 – 1.0 µg/g *dw* and 1.7 – 2.7 µg/g *dw* in the liver. There was no significant relationship between the concentration of Hg in blood and liver ($F_{1,3}$= 0.636, r^2 = 0.49, *P* = 0.51).

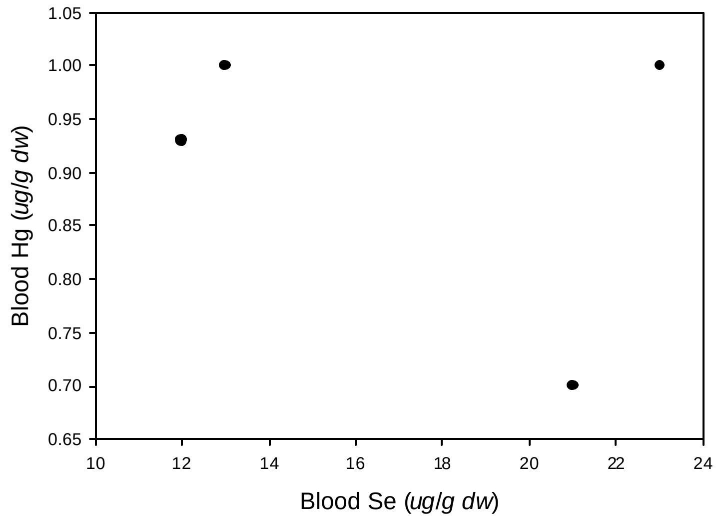

Figure 6. Relationship between blood Se and blood Hg (*µg/g dw*).

There also was no significant relationship between the concentration of Se and Hg in AMAV blood ($F_{1,3}$= 0.227, r^2 = 0.102, *P* = 0.681; Figure 6) or liver ($F_{1,3}$= 0.032, r^2 = 0.016, *P* = 0.875; Figure 7). Nor was there a significant relationship between blood Se concentration relative to the concentration of Hg found within the liver ($F_{1,3}$= 1.52, r^2 = 0.432, *P* = 0.343).

There were no significant relationships between liver Se concentration and body mass ($F_{1,3}$= 0.189, r^2 = 0.86, *P* = 0.71), or between blood Se concentration and body mass ($F_{1,3}$= 0.89, r^2 = 0.307, *P* = 0.446).

Egg collections/dissections

A total of 11 eggs were collected from four nests where females were trapped (Tables 1, 2). Two of the four females collected also had an egg present in their oviduct. These oviduct eggs were also analyzed for Se and Hg content.

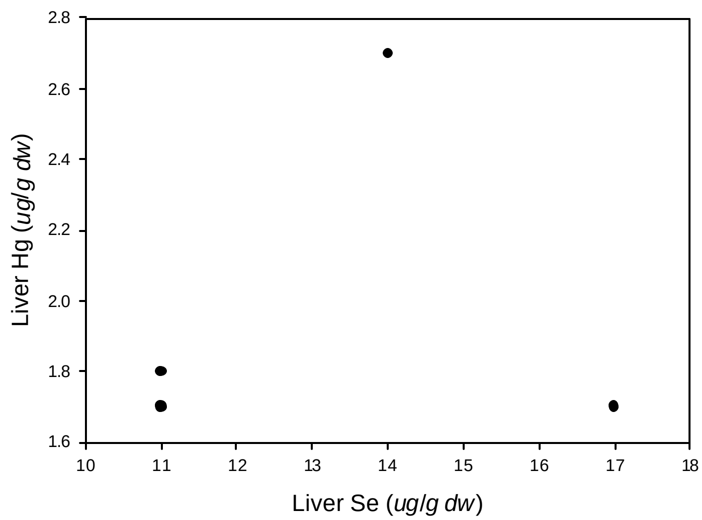

Figure 7. Relationship between liver Se and liver Hg (*µg/g dw*).

To examine if female blood Se concentration was positively associated with the concentration of Se deposited in her eggs, I calculated the mean Se concentration for eggs collected from each nest and regressed this mean on the attending female's blood Se. This resulted in a trend toward a positive relationship ($F_{1,3}$= 12.30, r^2 = 0.86, *P* = 0.073; Figure 8). The mean concentration of Se in eggs was not related to the female's liver Se concentration ($F_{1,3}$= 1.14, r^2 = 0.363, *P* = 0.398). In addition, there was no significant relationship between mean egg Hg and female blood Hg ($F_{1,3}$= 0.27, r^2 = 0.118, *P* = 0.657) or between mean egg Hg and female liver Hg ($F_{1,3}$= 0.34, r^2 = 0.145, *P* = 0.619).

There was no significant relationship between the concentration of Se and Hg within eggs collected ($F_{1,12}$= 2.73, r^2 = 0.2, P = 0.13). The concentration of Se in oviduct eggs was consistent with the concentration found in eggs collected at the nest (Table 2).

Invertebrate samples

Brine fly larvae and adults collected at Ogden Bay had Se concentrations of 1.6 and 1.2 µg/g *dw* respectively. The concentration of Se in brine fly larvae collected at Saltair was 1.4 µg/g *dw*. The concentration of Hg in brine fly adults at Ogden Bay was 0.1 µg/g *dw* and below detectable levels within the larvae samples collected. Hg was not tested for samples collected at Saltair (Table 3).

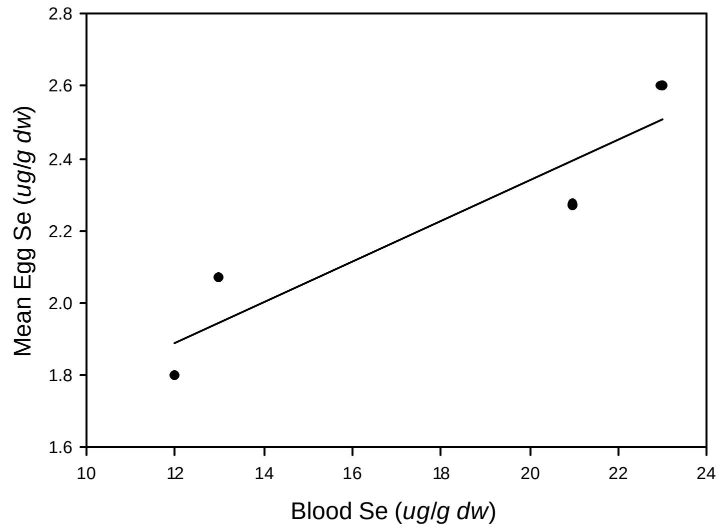

Figure 8. Relationship between blood Se and mean egg Se (*µg/g dw*).

Table 1. Se and Hg (*µg/g dw*) concentrations of females collected at Ogden Bay.

Date	Nest ID / Female ID	Status	Female Mass[1] (g)	Liver Mass (g)	# Eggs collected from Nest	Oviduct Eggs	Blood Se (µg/g dw)	Liver Se (µg/g dw)	Blood Hg (µg/g dw)	Liver Hg (µg/g dw)
5/19/07	KJS-48-07 KJS-1-07	Laying	263.9	8.6	3	1	23	14	1	2.7
6/2/07	KJS-112-07 KJS-2-07	Laying	366.7	7	2[2]	1	12	11	0.93	1.7
6/8/07	KJS-135-07 KJS-3-07	Laying	274.6	7.4	3	-	13	11	1	1.8
6/18/07	KJS-160-07 KJS-4-07	Laying/ Incubation	297.4	8.5	3	-	21	17	0.7	1.7

[1] Female mass determined after the removal of any oviduct eggs
[2] One of three eggs was crushed during trapping, thus only 2 eggs were collected

Table 2. Se and Hg (μg/g dw) concentrations of eggs collected from each nest at Ogden Bay with the corresponding attending female blood and liver Se concentrations.

Date	Nest ID	Egg	Egg Se (μg/g dw)	Egg Hg (μg/g dw)	Egg Mass (g)	Egg Length (mm)	Egg Width (mm)	Stage of development[1]	Female Blood Se (μg/g dw)	Female Liver Se (μg/g dw)
5/19/07	KJS-48-07	a	2.9	0.4	29.80	49.3	35.3	1-2	23	14
		b	2.3	0.42	27.40	46.0	34.5	1-2		
		c	2.8	0.41	28.60	46.8	35.3	3		
		Oviduct	2.4	0.32	8.1	-	-			
6/2/07	KJS-112-07	a	1.8	0.27	24.80	49.5	33.8	1-2	12	11
		b	1.8	0.29	28.10	49.0	33.4	3		
		Oviduct	1.8	0.1	13.4	-	-			
6/8/07	KJS-135-07	a	2.2	0.54	26.8	47.2	33.9	13	13	11
		b	2	0.42	30.7	51.5	34.9	13+		
		c	2	0.37	26.7	48.0	33.4	13		
6/18/07	KJS-160-07	a	2.1	0.32	28.1	49.1	34.3	29+	21	17
		b	2.3	0.39	28.7	50.4	34.3	29+		
		c	2.4	0.27	27.9	49.9	34.4	29+		

[1] Stage of development corresponds to Hamburger and Hamilton 1951. Stage of 1-3 ~ 6-13 hrs after laying; Stage 13 ~ 48-52 hrs after laying; Stage 29+ > 6 days after laying.

Table 3. Se and Hg (μg/g dw) concentrations of invertebrates collected from Ogden Bay and Saltair.

Date	Sample	Site	Se (μg/g dw)	Hg (μg/g dw)
6/22/07	Brine fly adults	Ogden Bay	1.2	0.1
6/22/07	Brine fly larvae	Ogden Bay	1.6	0.05[1]
7/19/07	Brine fly larvae	Saltair	1.4	-

[1] Analyte below detection limit

DISCUSSION

Unfortunately we were only able to capture four females for this project. The difficulty in catching females during the laying stage can be attributed to - 1) nest visitation by both adults during this stage is infrequent (Cavitt personal observation, Gibson 1978); 2) females typically spend less time at the nest than males during the early stages of breeding (Gibson 1978); 3) female home ranges are significantly larger during the laying stage than during either the incubation or brood rearing stages (Demers 2007); and 4) adults during the early stages of nesting are very leery of disturbance near their nests (L. Oring personal communication). This limited sample size reduced the power of statistical tests thus hindering the ability to detect differences.

The results of this study do confirm that the concentration of Se in blood and liver tissue at Ogden Bay are elevated above what is expected based on concentrations found within invertebrate food sources. The levels reported here were not significantly different from those reported for the 2006 breeding season (Cavitt 2007). Furthermore, the concentrations found within AMAV blood (12 – 23 *ppm*) are much higher than average background levels reported for these tissues (USDI 1998). Selenium concentrations in whole blood above 2 *ppm* are of concern and 5 *ppm* is a suggested threshold of toxicity (USDI 1998, Santolo and Yamamoto 1999). Background Se concentrations in liver tissue has been reported as less than 10 *ppm* (6.0 – 9.9 in recurvirostids; USDI 1998). However, in this study AMAV had liver Se concentrations ranging from 11 – 17 *ppm*.

Despite the elevated levels of Se found within AMAV tissues, their corresponding egg Se concentrations were relatively low (1.8 – 2.9 $\mu g/g$ *dw*). It is widely accepted that elevated Se levels can reduce the reproductive success of birds (Ohlendorf et al. 1988, 1989, Heinz et al. 1989, Adams et al. 2003); however, the threshold level at which negative effects occur is unclear. The suggested threshold of egg Se concentrations range from 6 $\mu g/g$ to 16 $\mu g/g$ (USDI 1998, Fairbrother et al. 1999, 2000, Adams et al. 2003, and Ohlendorf 2003). None of the eggs collected at Ogden Bay during the 2007 breeding season were above 6 $\mu g/g$ *dw*. The results also suggest that there may be a positive relationship between female blood Se and the corresponding Se concentrations found within the eggs she lays.

We were unable to find any significant relationship between the tissue concentrations of Se and Hg. In each regression we preformed the power of the test was below the desired power of 0.80. One complication in the results was that the female with the lowest blood Hg levels also had the highest blood Se. If this female (KJS-4-07) is considered an outlier and removed from the analysis, the liver Hg to blood Se regression becomes significant ($F_{1,2} = 13467$, $r^2 = 1.0$, $P = 0.005$) and the liver Hg to liver Se regression approaches significance ($F_{1,2} = 120.3$, $r^2 = 0.99$, $P = 0.06$). This should be interpreted cautiously since the removal of one individual reduces the sample to only three data points and the rationale for removing this female from the analysis is questionable.

ACKNOWLEDGEMENTS

Thanks to Val Bachman, manager of Ogden Bay Waterfowl Management Area for access to the study site and Lew Oring for the use of additional nest traps. Harry Ohlendorf and Gary Santolo, CH2M Hill, provided assistance on many aspects of this project. Many thanks to the numerous field technicians who endured the rigors of field research at GSL including, Jen Cary, Lindsay Cole, Christian Edwards, and Andy McFadden.

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