

Final Report: 2006 and 2007 Data

Concentration and Effects of Selenium in California Gulls Breeding on the Great Salt Lake

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Abstract

*We examined selenium concentrations in California gulls (*Larus californicus*) nesting on the Great Salt Lake, Utah during 2006 and 2007. During 2006, the mean selenium concentration (\pm SE) in adult blood samples was 18.1 ± 1.5 $\mu\text{g/g}$ ($n = 35$) on a dry weight basis, 8.1 ± 0.4 in adult liver samples ($n = 36$), and 3.0 ± 0.10 $\mu\text{g/g}$ in eggs ($n = 35$). During 2007, selenium concentrations were 15.7 ± 1.5 $\mu\text{g/g}$ in blood and 8.3 ± 0.4 $\mu\text{g/g}$ in liver; mercury concentrations were 2.4 ± 0.3 $\mu\text{g/g}$ in blood and 4.1 ± 0.5 in liver. Body mass was not correlated with selenium or mercury concentrations in the blood or liver for either adult males or females. Gulls collected from different Great Salt Lake colonies varied significantly in the concentration of selenium in their blood but not in livers or eggs. Selenium concentrations were higher in blood of gulls collected at the GSLM colony than in gulls collected from the Antelope Island colony or Hat Island colony. Gulls collected from a freshwater colony (Neponsett Reservoir) located in the headwaters of the Bear River had similar levels of selenium in the blood and liver as gulls collected on the Great Salt Lake but lower mercury levels. Of 72 eggs collected at random from Great Salt Lake colonies, only one showed no embryo development, and none of the embryos exhibited signs of malposition or deformities. We examined 100 newly hatched chicks from Great Salt Lake colonies for teratogenesis; all chicks appeared normal. Hence, the high selenium concentrations in blood of adult gulls do not seem to be impairing the gulls' health or reproductive ability.*

Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. High concentrations of selenium have been shown, both in captive and free-ranging birds, to cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al. 1989, Ohlendorf 2003). For example, birds foraging in California's Kesterson Reservoir, which was the disposal site for subsurface agricultural drainage from portions of the western San Joaquin Valley, accumulated high concentrations of selenium in their tissues (Ohlendorf 2002, 2003). Selenium concentrations in eggs of all aquatic birds collected from Kesterson Reservoir were higher than background levels (3 $\mu\text{g/g}$), and eared grebes (*Podiceps nigricollis*) had the highest concentrations, with a mean of 70 $\mu\text{g/g}$ (all weights are reported on a dry-weight basis unless otherwise noted). Elevated concentrations of selenium impaired the reproductive ability of several avian species nesting at Kesterson Reservoir and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

Birds accumulate selenium from their food, and if they consume a diet too rich in selenium during the pre-laying period, they transfer selenium to their eggs, causing harmful effects. In laboratory studies, dietary concentrations of about 4.9 $\mu\text{g Se/g}$ of food reduced the reproductive success of mallards (*Anas platyrhynchos*; Ohlendorf 2003). Mallard ducklings maintained on a diet containing 40 $\mu\text{g/g}$ or greater selenium concentrations exhibited high mortality rates within 6 weeks of starting the diet. At Kesterson Reservoir, where many avian species that exhibited reproductive problems, some aquatic insects had mean selenium concentrations greater than 100 $\mu\text{g/g}$ (Hothem and Ohlendorf 1989, Schuler et al. 1990).

Higher selenium concentrations also can impair the health of adult birds. Mallards maintained on a diet enriched with 20 $\mu\text{g Se/g}$ of food had lesions in their liver and integument. Mallards on a diet of 40 $\mu\text{g/g}$ lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998).

The Great Salt Lake (GSL) in Utah is an important habitat for many avian species. For instance, about half of the world's eared grebes spend the fall there eating brine shrimp and accumulating enough nutrients to fly to their wintering grounds in Mexico and California. During the breeding season, the lake also provides foraging and nesting habitat for California gulls (*Larus californicus*) and shorebirds. Hence, there is a need to ensure that selenium concentrations in the GSL do not reach concentrations that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium concentrations in adult California gulls breeding in three different parts of the GSL and in their eggs. We sampled their food during the pre-laying period and took water and sediment samples in their feeding grounds to assess them for selenium. We also checked California gull eggs for viability and embryos for deformities. This study was designed to answer the following specific questions.

1. What is the diet of California gulls during the egg-laying period?
2. What are the ambient selenium concentrations in the water, sediment, and diet items at the foraging sites of nesting California gulls in the GSL?
3. Are selenium and mercury levels in gulls nesting in the saline environment of the GSL similar to gulls nesting on a freshwater reservoir?
4. What is the relationship between selenium and mercury concentrations in the liver and blood of adult gulls and eggs?
5. What are the associated selenium concentrations in nesting California gulls (blood and liver), a random sample of gull eggs, and gull eggs that failed to hatch?

Methods

Collection of adult gulls. During 2006, we collected gulls from nesting colonies located on the Great Salt Lake at Hat Island, the Great Salt Lake Mineral (GSLM) facility, Egg Island, and White Rock Island. Egg Island and White Rock Island are small rocky islands within a few kilometers of each other. Both are within 1 km of the much larger Antelope Island. The gulls nesting in these 2 colonies use the same foraging areas (Conover, personal observation). Hence, we considered Egg Island and White Rock Island as a single colony and referred to them as the Antelope Island colony (Figure 1). During 2007, we re-sampled gulls from Hat Island and GSLM colonies and also collected California gulls from a Neponsett Reservoir colony, which is located in the headwaters of the Bear River in Rich County, Utah.

During the period when the gulls were laying eggs, we used a shotgun to collect 12 gulls from three GSL colonies (Hat Island, GSLM, and Antelope Island). To do this, we positioned ourselves 0.5-1.0 km from a colony and shot gulls that were flying back to the colony in a straight line. We assumed that these gulls were more likely to have food in their esophagus than gulls leaving the colony or gulls that were flying slowly in a circular pattern and appeared to be searching for food. All gulls from a single colony were shot on the same day. We immediately used a syringe to collect at least 1 ml of blood from the thoracic cavity. The blood was kept in the syringe and frozen. Within 12 hours of when the birds were shot, we collected all food from the bird's esophagus and obtained a liver sample. The liver sample was placed in a Whirl-Pak® bag and frozen. Esophagus samples were weighed (wet weight) and were stored in 95% alcohol. We weighed and measured the birds, determined their age by examining their plumage, and their sex by examining the gonads. Food in the esophagus was weighed and sorted by content or species. We determined the proportion of a food sample that could be attributed to different types of food or species.

Before we started collecting gulls, we observed where the gulls were foraging. We then went to those foraging sites and collected food samples by dragging a 1-m² circular seining net with a 5-mm mesh size behind the boat at a speed that just kept the top of the net at the top of the water. Hence, all food samples were obtained from the upper 1 m of the water column. Five seine samples were collected at each colony. Each of these was placed in a separate Whirl-Pak® bag and frozen.

We also collected 5 water samples from the upper 1 m of the water column and used a core to obtain 5 sediment samples from the top 0.1 m of the bottom sediment. The water and sediment samples were collected at the same places where the food samples were collected. These were placed in polypropylene vials and maintained at room temperature. Equal volumes of water from each of five water samples collected at the foraging grounds near each colony were combined to create a single composite water sample per colony. Likewise, the five sediment samples were combined in equal volume and homogenized to create a composite sediment sample for each colony

Selenium Analysis. Blood and liver samples from 11 or 12 gulls at each colony were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium analysis. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Quality control of selenium analyses was conducted using one or more method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006). The seine nets collected almost pure samples of brine shrimp, and the five brine shrimp samples from each colony were also sent to LET for selenium analysis. The water samples were sent to Frontier Geoscience, Seattle, Washington, and sediment samples were sent to LET for selenium analysis.

Collection of California gull eggs. We collected a single egg from each of 24 nests in each GSL colony (72 eggs total) when approximately 10% of the nests contained a chick or pipped egg. (This assured that the eggs we collected were likely to have late-stage embryos; therefore all [or almost all] eggs contained embryos assessable for developmental abnormalities.) All eggs were collected from three-egg clutches where no eggs had hatched. These nests were selected by placing a conceptual grid over the colony containing a series of numbered points, selecting points from a random numbers tables and sampling the nest located closest to that point that met the criteria. Which of the three eggs in that nest was collected was determined by numbering each egg in the clutch and selecting which number to sample based on a random numbers tables. All eggs were collected during 2006 except for the Neponsett Reservoir colony eggs, which were collected during 2007.

Eggs were stored in a refrigerator, and embryos were examined within four days of collection when samples were being prepared for selenium analysis. Each embryo was checked for stage of

embryonic development (embryo age) by comparing to existing aging criteria and atlases (Hamburger and Hamilton 1951; Hamilton 1952; Pisenti et al. 2001) and developmental abnormalities, including a determination of the embryo's pre-hatch position in the egg (i.e., for malposition) based on Romanoff and Romanoff (1972). An egg was considered viable if it contained a developing late incubation stage embryo. The contents of each egg (including the embryo) were placed in a marked chemically-cleaned container and preserved frozen for later chemical analysis. Eleven or 12 eggs from each colony were analyzed for total selenium by LET, and the others were stored for possible later analysis.

Examination of newly hatched chicks of California gulls and salvaged eggs for deformities.

Immediately after the chicks hatched, we revisited the GSLM, Hat, and Antelope colonies to check 100 chicks that had hatched within the last 12 hours for deformities. Forty-eight salvaged eggs also were collected from the Hat Island and GSLM colonies (24 from each colony). A salvaged egg was defined as an egg remaining in a nest after the other eggs in the nest had hatched and that was no longer being incubated (i.e., egg was at ambient temperature). Salvaged eggs were checked to determine fertility and the presence of dead embryos. All embryos (including all contents of those eggs) were placed in chemically-cleaned containers and preserved frozen for later analysis.

Statistical analyses. Data on selenium concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test. Hence, parametric statistics were used. Correlations were conducted to compare selenium concentration in an individual gull's blood and liver. The same analyses were used to compare these to the gulls' mass and mercury concentrations in their blood and liver. Unpaired Students t -tests or F -tests were used to test for differences in mass and selenium concentrations. F -tests were used to test if selenium concentrations differed among colonies. In all tests, results were considered significant if $P < 0.05$.

Results

Food analyses for adults.—Thirty of the 35 adult gulls collected during 2006 had food in their esophagus (Appendix 1). Only one gull had more than a single kind of food item in its esophagus. That one contained 60% brine shrimp, 35% corixids, and 5% adult midges. For the 29 gulls that contained a single food item, 21 (75%) contained brine shrimp, 2 (7%) corixids, 2 (7%) brine fly larvae, 1 (4%) hot dogs, 1 (4%) earthworms, and 1 (4%) rotten carp (*Cyprinus carpio*) flesh. At all colonies, most gulls contained only brine shrimp. Corixids and midges were detected only at the GSLM colony. The earthworm and carp samples came from Antelope Island colony; hot hogs came from Hat Island colony.

Thirty two of the 36 adult gulls collected during 2007 had food in their esophagus (Appendix 2). Three gulls had more than a single kind of food item in its esophagus and those three had a combination of food from terrestrial sources (i.e., garbage and insects). Six gulls from GLSM colony contained brine shrimp, 4 had midge larvae, and 2 contained garbage. Ten of 12 gulls from Hat Island had eaten brine shrimp exclusively, and the other two contained either garbage or terrestrial insects in their esophagus. The eight gulls from Neponsett Reservoir that had food in their esophagus had fed on garbage and terrestrial insects.

Selenium analyses of adults collected during 2006.—Among individual gulls, selenium concentrations in blood and liver were highly correlated ($r^2 = 0.78$, $F = 117.22$; $d.f. = 1, 32$; $P = 0.0001$ [Figure 2]). There was no significant difference ($t = 1.56$, $d.f. = 27$, $P = 0.13$) between the selenium concentrations (mean \pm SE) in the livers of adult males (7.4 ± 0.5 $\mu\text{g/g}$) and adult females (8.7 ± 0.8 $\mu\text{g/g}$). Likewise, there was no significant difference ($t = 1.75$, $d.f. = 27$, $P = 0.09$) between selenium concentrations (mean \pm SE) in the blood of adult males (15.2 ± 1.6 $\mu\text{g/g}$) and adult females

($20.6 \pm 3.0 \mu\text{g/g}$). Hence, data from the two sexes were combined for further analyses. For all adults combined, selenium concentrations in blood samples were $18.1 \pm 1.5 \mu\text{g/g}$ ($n = 35$); they were 8.1 ± 0.4 in liver samples ($n = 36$; Appendix 2).

There was no significant difference in blood selenium concentrations ($F = 0.34$; $d.f. = 1, 27$; $P = 0.56$) between the 22 gulls that had mainly brine shrimp in their esophagus ($16.9 \pm 1.8 \mu\text{g/g}$) and the 7 gulls that had other types of food in their esophagus ($19.2 \pm 4.0 \mu\text{g/g}$). Likewise there was no significant difference ($F = 0.12$; $d.f. = 1, 27$; $P = 0.73$) between selenium levels in the liver of gulls that fed on brine shrimp ($8.4 \pm 1.1 \mu\text{g/g}$) and those that fed on some other type of food ($8.0 \pm 0.5 \mu\text{g/g}$).

Among gulls collected from different colonies, there was a significant difference in the concentration of selenium in blood ($F = 6.27$; $d.f. = 2, 32$; $P = 0.005$) but not in livers ($F = 1.85$; $d.f. = 2, 32$; $P = 0.17$) (Table 1). Selenium concentrations were highest in blood of gulls collected at the GSLM colony, which is close to where water from the Bear River flows into GSL, and lowest in gulls from Antelope Island colony. Gulls from Hat Island colony had intermediate concentrations of selenium. This pattern of the highest selenium concentrations being recorded at the GSLM colony was true for selenium concentrations in blood, liver, eggs, and sediment although differences among colonies were significant only for blood

Not surprisingly, there was a significant difference ($F = 10.31$; $d.f. = 1, 26$; $P = 0.004$) in the body mass of males ($727 \pm 16.4 \text{ g}$) and females ($628 \pm 23.2 \text{ g}$). Hence, the effects of selenium on body mass were analyzed separately for each sex. For males, body mass was not correlated with selenium concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$) or liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$ [Figure 3]). Likewise for females, body mass was not correlated with selenium concentrations in blood ($r^2 = 0.01$, $F = 0.78$; $d.f. = 1, 9$; $P = 0.40$) or liver ($r^2 = 0.03$, $F = 0.23$; $d.f. = 1, 15$; $P = 0.64$ [Figure 4]).

Selenium and mercury analyses of adults during 2007.— For all adults collected during 2007 ($n = 36$), selenium concentrations were $15.7 \pm 1.5 \mu\text{g/g}$ in blood and 8.3 ± 0.4 in liver (Appendix 2). For these same birds, mercury concentrations were $2.4 \pm 0.3 \mu\text{g/g}$ in blood and 4.1 ± 0.5 in liver.

Among individual gulls, selenium concentrations in blood and liver were highly correlated ($r^2 = 0.70$, $F = 80.79$; $d.f. = 1, 34$; $P = 0.001$) as was mercury concentrations in blood and liver ($r^2 = 0.74$, $F = 95.03$; $d.f. = 1, 34$; $P = 0.001$). Blood selenium concentrations were correlated with mercury levels in blood ($r^2 = 0.14$, $F = 5.75$; $d.f. = 1, 34$; $P = 0.02$) but not mercury levels in liver ($r^2 = 0.05$, $F = 1.85$; $d.f. = 1, 34$; $P = 0.18$). Selenium concentrations in liver were not correlated with either mercury levels in the blood ($r^2 = 0.07$, $F = 2.52$; $d.f. = 1, 34$; $P = 0.12$) or liver ($r^2 = 0.03$, $F = 1.22$; $d.f. = 1, 34$; $P = 0.28$).

Among gulls collected during 2007, the highest selenium concentrations were once again found in adult gulls and eggs collected from GSLM colony (Table 2). In fact, selenium levels in GSLM gulls were significantly higher than those gulls from Hat Island but not from Neponsett gulls, which had intermediate levels of selenium (Table 2). Neponsett gulls had intermediate levels of selenium. When gulls collected at GSLM colony during 2007 were compared to those collected during 2006 (Tables 1 and 2), blood selenium concentrations were similar ($F = 0.78$; $d.f. = 1, 21$; $P = 0.39$) as were liver selenium levels ($F = 0.00$; $d.f. = 1, 21$; $P = 0.95$). For gulls collected at GSLM colony, those collected during 2006 had higher selenium levels in their blood than those collected during 2007 ($F = 4.57$; $d.f. = 1, 22$; $P = 0.04$) but selenium levels in their livers were similar ($F = 0.59$; $d.f. = 1, 22$; $P = 0.59$).

Mercury concentrations in blood and liver were similar in gulls collected from Hat Island and GSLM colonies (Table 2). However gulls from the freshwater colony (Neponsett Reservoir) had significantly lower mercury concentrations in blood and liver than gulls from Hat Island and GLSM colonies (Table 2).

Effects of selenium and mercury on body mass were analyzed separately for each sex. For males, body mass was not correlated with selenium concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$), selenium concentrations in liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$), mercury concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$), or mercury concentrations in liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$). Likewise for females, body mass was not correlated with selenium concentrations in blood ($r^2 = 0.01$, $F = 0.78$; $d.f. = 1, 9$; $P = 0.40$), selenium concentrations in liver ($r^2 = 0.03$, $F = 0.23$; $d.f. = 1, 15$; $P = 0.64$), mercury concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$), or mercury concentrations in liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$).

Selenium and mercury analyses of food.—During 2006, selenium concentrations in water and brine shrimp were highest at the Hat Island colony (Table 1). For the water and sediment samples, only a single sample was analyzed from each colony, and statistics could not be used to test these variables.

During 2007, selenium concentrations in brine shrimp at Hat Island were once again higher than at GSLM colony, but mercury levels were similar (Table 2). Mercury concentrations in brine shrimp from the two colonies were similar. Brine shrimp collected at Hat Island during 2006 contained higher selenium concentrations than samples collected from the same colony during 2007 ($F = 27.09$; $d.f. = 1, 8$; $P = 0.001$). Likewise, brine shrimp collected from GSLM colony during 2006 had higher selenium levels than those collected during 2007 ($F = 13.83$; $d.f. = 1, 8$; $P = 0.006$). Food samples from Neponsett Reservoir colony were not analyzed because most gulls were foraging on bread and garbage and there seemed little need to determine the selenium or mercury concentration of bread.

Selenium and mercury analyses of eggs.—Selenium concentrations in eggs collected randomly during 2006 were 3.0 ± 0.10 $\mu\text{g/g}$ ($n = 35$). Selenium concentrations did not differ ($F = 1.76$; $d.f. = 2, 32$; $P = 0.19$) among eggs collected from the different GSL colonies (Table 1 and Appendix 3).

Eggs collected randomly from Neponsett Reservoir during 2007 had selenium concentrations of 2.8 ± 0.10 $\mu\text{g/g}$ and mercury concentrations of 0.26 ± 0.05 $\mu\text{g/g}$ ($n = 12$). Selenium concentrations for eggs collected at Neponsett Reservoir differed from those collected at the GSLM colony ($F = 8.31$; $d.f. = 1, 21$; $P = 0.009$) but not from eggs collected at Hat Island ($F = 0.03$; $d.f. = 1, 21$; $P = 0.87$) or Antelope Island ($F = 0.01$; $d.f. = 1, 21$; $P = 0.92$). For eggs collected at Neponsett Reservoir, selenium concentrations were not correlated with mercury concentrations ($r^2 = 0.03$; $F = 0.30$; $d.f. = 1, 10$; $P = 0.60$).

Analyses of eggs and chicks for viability and deformities.—Among the sample of 24 eggs randomly sampled from 3-egg clutches during the late incubation period from GSL colonies (72 eggs total), all contained developing late incubation stage embryos except a single egg that came from the GSLM colony (Appendix 3). None of the embryos exhibited signs of malposition or deformities. We examined 100 newly hatched chicks from GSL colonies for teratogenesis; all chicks appeared normal. Out of 48 salvaged eggs from GSL colonies, 38 contained dead embryos; all embryos were normal in appearance and position.

During 2007, 1 of 12 eggs collected at Neponsett Reservoir colony was rotten, and one had no embryo (Appendix 3). Ten eggs contained late incubation stage embryos, and none of the embryos exhibited signs of malposition or deformities.

Discussion

In California gulls, we found that selenium concentrations ranged from 4 to 15 $\mu\text{g/g}$ in livers. Mean background selenium concentrations have been reported to be $<10 \mu\text{g/g}$ in livers (USDI 1998, Ohlendorf 2003). We detected selenium concentrations in California gull eggs ranging from 2.0 to 4.3 $\mu\text{g/g}$ in eggs. Mean background selenium concentrations for individual eggs are considered to be $< 5 \mu\text{g/g}$ (USDI 1998, Ohlendorf 2003) or $< 3 \mu\text{g/g}$ for population means (Skorupa and Ohlendorf 1991). Hence, selenium concentrations in our egg and liver samples were generally consistent with background concentrations.

Surprisingly, selenium concentrations in blood of gulls nesting on GSL ranged from 5 to 46 $\mu\text{g/g}$. These concentrations were higher than we 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. We found that mean selenium concentrations in the blood of gulls from different GSL colonies were 2.4 to 5.5 times higher than selenium concentrations in the brine shrimp upon which they were foraging.

Selenium concentrations in the blood of 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 $\mu\text{g/g}$ dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 $\mu\text{g/g}$ dry weight are considered to exceed normal background, and 5 $\mu\text{g/g}$ dry weight is considered a provisional threshold indicating that further study is warranted (USDI 1998). However, toxicity studies of gulls were not reviewed for the development of those guidelines, and the ecotoxicology of selenium to gulls may differ from that for other species. Interestingly, we found that California gulls collected at a freshwater colony (Neponsett Reservoir) had selenium levels in their blood similar to those of GSL gulls but lower mercury concentrations. These results suggest that high selenium concentrations in blood may be a species trait rather than a characteristic of a saline environment.

Reasons for the anomalously high selenium concentrations in blood, but much lower concentrations in liver and eggs are not known. A possible explanation for the elevated concentrations of selenium in our blood samples may be relatively high mercury concentrations found in the Great Salt Lake ecosystem. Selenium and mercury may interact to form a stable, nontoxic complex so that selenium may provide adult birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from faster selenium elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver or kidney tissues (Goede and Wolterbeek 1994).

Although the few studies of selenium-mercury interaction in birds used various forms of Se and Hg (some not using environmentally relevant forms), they do provide approximations of potential effects. In a study by Heinz and Hoffman (1998) using mercury as methylmercury chloride

and seleno-DL-methionine, captive female mallards fed a diet containing both 10 µg Se/g of feed and 10 µg Hg/g had a selenium concentration in the liver 1.5 times higher than females fed a diet containing just selenium (10 µg Se/g). In the same experiment, male mallards fed the selenium and mercury combination diet had almost 12 times the selenium concentration of male mallards fed the selenium-only diet. Similar results were found with Japanese quail fed diets containing methylmercury and selenite (El-Begearmi et al. 1977, 1982). However, our results suggest that a selenium-mercury interaction may not be responsible for the high selenium levels in California gulls. Among individual gulls, we found a statistically significant but weak correlation ($r^2 = 0.14$) between the concentrations of selenium and mercury in blood but no correlation between selenium levels in blood and mercury levels in liver. Also, gulls from Neponsett Reservoir had similar selenium concentrations in their blood as GSL gulls, but they had much lower mercury concentrations.

Among free-ranging birds, sensitivity to selenium varies among species. In black-necked stilts (*Himantopus mexicanus*), the threshold for teratogenesis (EC_{10}) was 37 µg/g in eggs (Skorupa 1998, Ohlendorf 2003). However, the EC_{10} was 23 µg/g for mallards and 74 µg/g for American avocets (*Recurvirostra americana*). Even lower concentrations of selenium can cause a decrease in egg viability. Selenium concentrations in eggs as low as 6–7 µg/g resulted in reduced viability of eggs in black-necked stilts. Heinz (1996) suggested that 10 µg/g be considered the threshold where selenium concentrations start to have an effect on the hatchability of bird eggs, while Fairbrother et al. (1999) recommended a threshold concentration of 16 µg/g.

We found selenium concentrations in 30 California gull eggs collected from GSL colonies ranged from 2.0 to 4.3 µg/g. These concentrations were similar to California gulls eggs collected from Neponsett Reservoir colony located in the upper watershed of the Bear River and are below the concentrations shown in other avian species to cause teratogenesis or a significant decrease in egg viability. We detected no evidence that these concentrations of selenium were causing an adverse effect on California gulls nesting on GSL.

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Table 1. Selenium concentrations in $\mu\text{g/g}$ dry weight (mean \pm standard error) in adult California gulls, their eggs, food, water, and sediment collected at Antelope Island, Hat Island, and Great Salt Lake Mineral (GSLM) colonies located on the Great Salt Lake, 2006.

	Antelope Island	Hat Island	GSLM colony	<i>d. f.</i>	<i>F</i> -value	<i>P</i>
Male mass ($n = 19$)	728 \pm 21 A	769 \pm 20 A	629 \pm 13 B	2, 16	12.24	0.0006
Female mass ($n = 14$)	640 \pm 32	635 \pm 58	619 \pm 29	2, 11	0.13	0.88
Se in adult liver ($n = 35$)	7.3 \pm 0.7	7.8 \pm 0.6	9.2 \pm 0.9	2, 32	1.85	0.17
Se in adult blood ¹ ($n = 35$)	13.8 \pm 1.8 A	16.0 \pm 2.0 A	25.1 \pm 7.9 B	2, 32	6.27	0.005
Se in eggs ($n = 35$)	2.8 \pm 0.2	3.1 \pm 0.3	3.4 \pm 0.1	2, 32	1.76	0.19
Se in brine shrimp ($n = 15$)	3.4 \pm 0.1 A	5.5 \pm 0.1 B	4.6 \pm 0.1 C	2, 12	181.65	0.0001
Se in water ($n = 3$)	0.5	0.6	0.3	--	--	--
Se in sediment ($n = 3$)	0.4	0.4	0.5	--	--	--

¹ Means in rows not sharing the same uppercase letter are significantly different ($P \leq 0.05$). based on the Duncan's Multiple Range Test.

Table 2. Selenium concentrations in $\mu\text{g/g}$ dry weight (mean \pm standard error) in adult California gulls, their eggs, food, water, and sediment collected at Neponsett Reservoir, Hat Island, and Great Salt Lake Mineral (GSLM) colonies located on the Great Salt Lake, 2007.

	Neponsett Reservoir	Hat Island	GSLM colony	<i>d. f.</i>	<i>F</i> -value	<i>P</i>
Male mass ($n = 20$)	673 \pm 27	760 \pm 15	636 \pm 86	2, 17	1.15	0.34
Female mass ($n = 16$)	555 \pm 12	601 \pm 29	591 \pm 24	2, 13	1.49	0.26
Se in adult blood ($n = 36$)	15.5 \pm 2.3 AB ¹	10.7 \pm 1.4 A	20.9 \pm 3.4 B	2, 30	3.79	0.03
Se in adult liver ($n = 35$)	8.3 \pm 0.7	7.2 \pm 0.4	9.3 \pm 1.0	2, 30	2.20	0.13
Hg in adult blood ($n = 36$)	1.3 \pm 0.3 A	3.0 \pm 0.3 B	3.0 \pm 0.6 B	2, 30	7.38	0.003
Hg in adult liver ($n = 36$)	2.4 \pm 0.6 A	5.6 \pm 0.7 B	4.2 \pm 0.9 AB	2, 30	5.52	0.01
Se in brine shrimp ($n = 10$)	No data	4.5 \pm 0.2 A	3.9 \pm 0.2 B	1, 8	5.47	0.05
Hg in bring shrimp ($n = 10$)	No data	0.6 \pm 0.1	0.4 \pm 0.02	1, 8	2.87	0.13

¹ Means in rows not sharing the same uppercase letter are significantly different ($P \leq 0.05$). based on the Duncan's Multiple Range Test.

Appendix 1. California gulls collected on 5/2/06 at the Great Salt Lake Mineral Colony (F= female, M = male, AL = active layer or female that has a large developing egg inside her, g = grams, mm = millimeters, L = length, H = height, and ww = wet weight, $\mu\text{g/g}$ = micrograms of selenium per gram of tissue).

Sample	Sex	Mass (g)	Wing (mm)	Body (mm)	Head length	Bill L × H	Food in esophagus g (ww) Contents	Se ($\mu\text{g/g}$) dry weight	
								Blood	Liver
Cg-01	F-AL*	666	380	496	100	18×16 4.9	100% brine fly larvae	17	6.7
Cg-02	M	656	397	499	111	22×11 8.9	100% brine fly larvae	28	12
Cg-03	F	544	371	500	99	18×15 0.1	2 cori×ids	32	9.9
Cg-04	F-AL	697	384	490	98	18×15 9.1	100% cori×ids	37	13
Cg-05	M	633	370	450	99	18×14 0.0	--	13	6.1
Cg-06	M	635	395	527	109	21×17 0.0	--	18	7.5
Cg-07	M	644	379	495	111	23×16 5.7	100% brine shrimp	5	3.9
Cg-08	F-AL	579	399	495	99	18×14 5.9	100% brine shrimp	33	11
Cg-09	F-AL	542	385	475	98	17×15 1.0	100% brine shrimp	31	11
Cg-10	F-AL	687	375	495	101	17×16 6.4	(60% brine shrimp, 35% cori×ids, 5% midges)	25	8.6
CG-11	M	579	395	500	107	19×17 0.0	--	37	12

Appendix 1 (continued). California gulls collected on 5/4/06 at the Antelope Island colony (F= female, M = male, AL = active layer or female that has a large developing egg inside her, g = grams, mm = millimeters, L = length, H = height, W = width, ww = wet weight, $\mu\text{g/g}$ = micrograms of selenium per gram of tissue).

Sample	Sex	Mass (g)	Ling (mm)	Body (mm)	Head length	Bill L×H	Food in esophagus		Se ($\mu\text{g/g}$) dry weight	
							g (ww)	Contents	Blood	Liver
A1	M	674	416	674	115	21×18	0.0	--	7.7	5.3
A2	M-subadult	787	380	510	108	20 ×14	0.0	--	20	6.9
A3	M	663	400	520	111	21×16	3.3	100% brine shrimp	19	9.5
A4	F-AL	665	385	490	100	19×14	13.9	100% brine shrimp	22	13
A5	M	731	404	500	107	23×16	157.0	100% carp carcass	14	6.1
A6	M	761	400	518	112	22×17	3.0	100% brine shrimp	25	9.9
A7	F	755	406	505	102	19×15	15.9	100% brine shrimp	13	6.0
A8	F	526	380	478	98	18×15	3.0	100% brine shrimp	13	6.7
A9	F	640	405	498	98	20×16	7.9	100% brine shrimp	7.7	4.0
A10	F-subadult	590	388	483	103	21×15	1.5	100% brine shrimp	8.8	6.5
A11	M	688	395	506	113	23×17	16.3	100% earthworms	10	6.9
A12	F-AL	669	386	490	96	18×10	1.2	100% brine shrimp	6.4	6.8

Appendix 1 (continued.). California gulls collected on 5/9/06 at the Hat Island Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, $\mu\text{g/g}$ = micrograms of selenium per gram of tissue).

Sample	Sex	Mass (g)	Wing (mm)	Body (mm)	Head length	Bill L×H	Food in esophagus		Se ($\mu\text{g/g}$) dry weight	
							g (ww)	contents	Blood	Liver
H1	M	806	395	478	112	22×18	16.1	100% brine shrimp	12	6.3
H2	?	767	395	496	109	22×17	27.1	100% brine shrimp	29	13
H3	F	693	382	480	105	20×15	6.4	100% brine shrimp	8.5	5.9
H4	M	767	400	520	109	20×16	33.7	100% brine shrimp	15	6.8
H5	M	854	394	520	107	21×17	24.3	100% brine shrimp	15	6.1
H6	M	657	410	515	109	20×17	5.3	100% brine shrimp	17	8.4
H7	M	813	395	533	109	21×16	13.5	100% brine shrimp	16	9.3
H8	F	578	360	505	99	18×15	0.3	100% brine fly larva	22	8.6
H9	M	784	402	521	109	21×16	14.2	100% brine shrimp	18	8.6
H10	M	709	377	536	110	20×17	7.1	100% brine shrimp	25	9.3
H11	M	737	397	519	109	20×17	41.4	100% brine shrimp	8.1	5.7
H12	M	794	386	526	115	23×19	30.8	100% hot dogs	6.3	5.6

Appendix 2. California gulls collected on 5/7/07 at the Great Salt Lake Mineral Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, $\mu\text{g/g}$ = micrograms of selenium per gram of tissue).

Sample	Sex	Body Mass		Liver Mass g (ww)	Food in crop		Se ($\mu\text{g/g}$ dry weight)		Hg ($\mu\text{g/g}$ dry weight)	
		g (ww)			Mass	Contents	Blood	Liver	Blood	Liver
GSLM -01	F-AL	662		26	9	100% brine shrimp	9.9	7.3	3.4	6.31
GSLM -02	F	562		14	4	100% brine shrimp	13	6.8	6.02	9.94
GSLM -03	M	746		26	25	100% midge larva	28.3	14	2.3	3.1
GSLM -04	M	761		24	21	garbage (bread)	11	6.2	0.63	0.6
GSLM -05	M	741		20	46	garbage (bread)	21.8	7.4	1.0	1.0
GSLM -06	M	740		24	15	100% midge larva	28.9	9	3.2	5.03
GSLM -07	M	680		17	24	100% midge larva	13	7.2	0.72	0.92
GSLM -08	F	563		19	18	100% midge larva	17	11	1.1	1.3
GSLM -09	F	578		18	0.5	100% brine shrimp	45.7	15	7.61	9.59
GSLM -10	M	736		23	15	100% brine shrimp	38	14	3.7	6.3
GSLM -11	M	745		27	21	100% brine shrimp	8.7	7	3.1	3.6
GSLM -12	M	645		26	14	100% brine shrimp	16	6.5	3.5	3.3

Appendix 2 (continued). California gulls collected on 5/9/07 at the Hat Island Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, $\mu\text{g/g}$ = micrograms of selenium per gram of tissue).

Sample	Sex	Body mass g (ww)	Liver mass g (ww)	Food in crop		Se (ug/g) dry weight)		Hg (ug/g) dw)	
				Mass	Contents	Blood	Liver	Blood	Liver
HAT -01	M	716	27	37	100% brine shrimp	23	9.7	3.4	6.57
HAT -02	M	722	20	28	100% brine shrimp	7.1	7.7	3.3	8.92
HAT -03	M	822	32	28	100% brine shrimp	13	8.8	3.4	4.6
HAT -04	M	789	17	85	garbage (bread)	13	5.9	4.3	5.27
HAT -05	F	635	16	45	100% brine shrimp	12	6.5	3.5	5.95
HAT -06	M	745	16	9	100% brine shrimp	4.8	4.7	0.56	0.77
HAT -07	F	612	20	27	90% garbage, 10% beetles	9	6.1	2.8	5.95
HAT -08	M	738	16	17	100% brine shrimp	7	6.7	2.6	3.8
HAT -09	F	673	16	16	100% brine shrimp	5.3	6.6	2.3	5.26
HAT -10	F	582	18	13	100% brine shrimp	12	8.3	3.5	6.3
HAT -11	M	788	21	57	100% brine shrimp	14	7.4	2.6	3.6
HAT -12	F	501	13	3	100% brine shrimp	8.7	8.3	3.3	9.8

Appendix 2 (continued). California gulls collected on 5/11//0 at the Neponset Reservoir Colony , Rich County, Utah Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, $\mu\text{g/g}$ = micrograms of selenium per gram of tissue).

Sample	Sex	Body mass g (ww)	Liver mass g (ww)	Food in crop		Se (ug/g dry weight)		Hg (ug/g, dw)	
				Mass	Contents	Blood	Liver	Blood	Liver
NET -01	F	556	16	2	100% damsel fly larva	21	9.8	0.2	0.3
NET -02	F	553	18	19	100% garbage (bread)	13	6.1	2.2	3.0
NET -03	F	550	18	27	100% garbage (bread)	10	8.1	0.2	0.36
NET -04	M	650	16	0	nothing	22.3	13	1.5	2.0
NET -05	F	560	16	43	90% caterpillars,10% beetles	10	7.9	1.4	3.6
NET -06	M	612	16	0	nothing	5	5.6	0.75	0.93
NET -07	F	580	22	34	95% caterpillars, 5% beetles	24.8	8.2	1.4	5.93
NET -08	M	637	20	1	??	32.2	12	2.7	4.6
NET -09	F	492	17	0	nothing	8.2	6.8	0.21	0.32
NET -10	F	596	20	8	??	12	7.2	0.35	1.1
NET -11	M	764	17	7	2 bird leg bones	13	5.6	3.2	4.9
NET -12	M	700	17	0	nothing	15	8.7	1.0	2.3

Appendix 3. Selenium concentrations ($\mu\text{g/g}$ dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Great Salt Lake Mineral colony on May 15, 2006.

Sample	Se ($\mu\text{g/g}$)	Mass (g)		Length (mm)	Width (mm)	Volume (ml)	H-H	Viable embryo?	Defects?
		Whole egg	Without shell						
M-1	3.6	69.5	62.9	66.1	46.8	65.0	37	YES	NO
M-2	3.0	70.1	63.9	69.7	45.0	63.9	37	YES	NO
M-3	2.6	59.3	53.9	65.6	44.0	60.0	44	YES	NO
M-4	3.2	70.3	62.8	68.1	48.1	76.5	44+	YES	NO
M-5	4.1	64.0	58.2	64.5	46.4	-	45+	YES	NO
M-6	3.7	69.7	62.9	68.9	43.6	70.8	44+	YES	NO
M-7	2.7	63.6	52.1	67.9	46.0	63.7	42	YES	NO
M-8	3.2	65.8	55.0	63.7	47.6	65.2	40	YES	NO
M-9	-	67.2	61.0	67.2	47.0	68.6	39	YES	NO
M-10	3.5	62.3	53.8	61.7	47.2	59.4	38	YES	NO
M-11	4.3	70.6	64.1	63.5	47.4	66.6	44+	YES	NO
M-12	3.3	62.6	54.3	65.2	47.0	-	45	YES	NO
M-13		60.5	54.0	66.7	45.6	-	45	YES	NO
M-14		65.8	56.5	64.0	46.8	61.4	38	YES	NO
M-15		67.2	60.7	65.3	45.1	58.0	36+	YES	NO
M-16		58.7	53.2	61.6	46.3	-	45	YES	NO
M-17		65.9	57.5	68.7	45.9	56.8	-	NO	?
M-18		66.4	59.8	64.4	46.1	54.8	39	YES	NO
M-19		73.1	66.6	68.1	48.8	71.8	43	YES	NO
M-20		66.3	59.7	64.1	46.9	-	44	YES	NO
M-21		67.4	56.8	63.1	48.4	81.3	45	YES	NO
M-22		68.0	59.9	66.0	46.1	78.0	37	YES	NO
M-23		68.1	61.4	66.2	47.3	61.8	39	YES	NO
M-24		54.8	47.0	58.3	47.7	-	44+	YES	NO

Appendix 3 (continued). Se concentrations ($\mu\text{g/g}$, dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Hat colony on May 25, 2006.

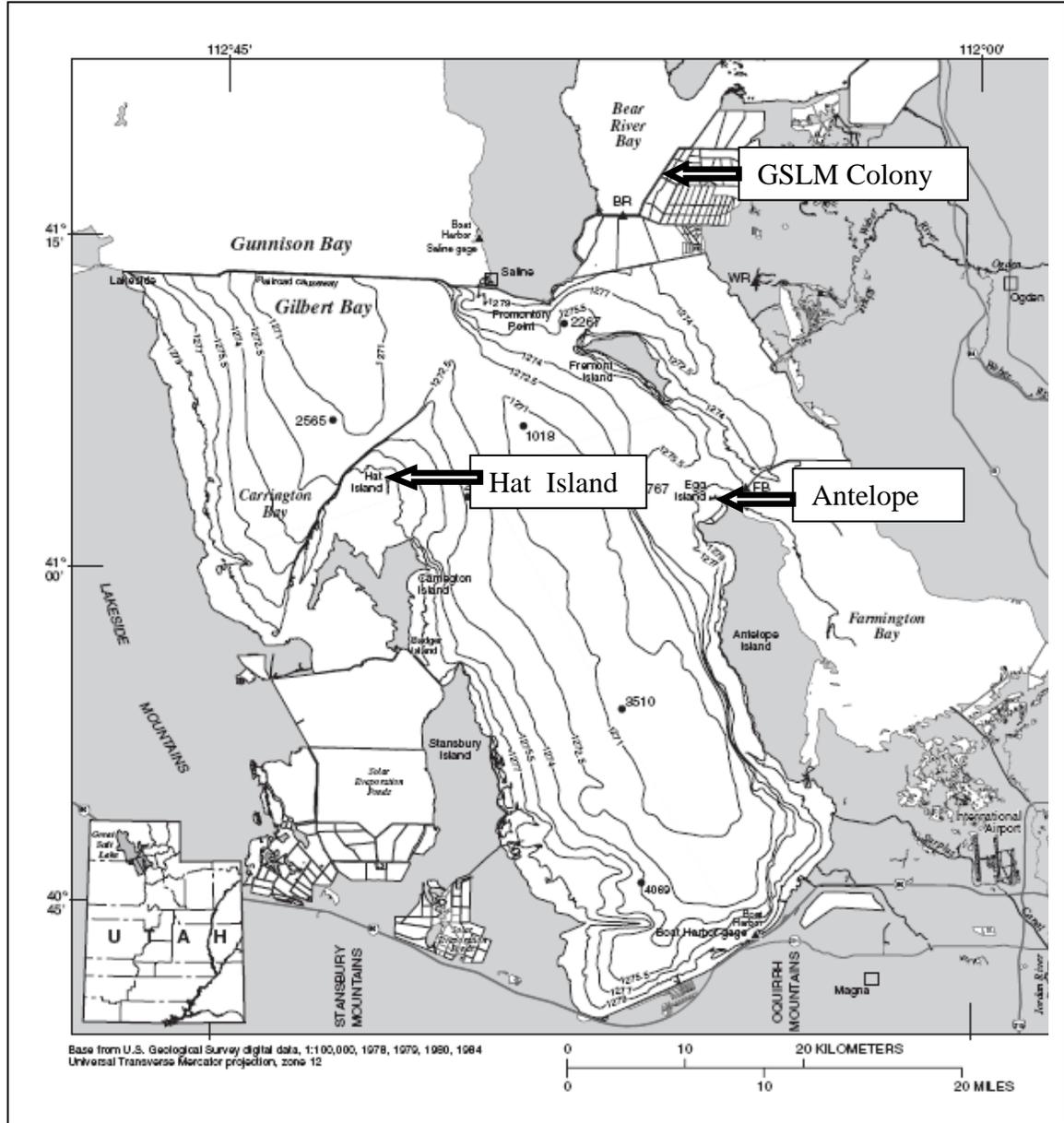
Sample	Se ($\mu\text{g/g}$)	Mass (g)		Length (mm)	Width (mL)	Volume	H-H	Viable embryo?	Defects?
		Whole egg	Without shell (mm)						
H-1	-	68.5	61.6	64.2	45.0	56.4	8	YES	NO
H-2	3.4	65.5	55.4	65.6	45.6	65.5	40	YES	NO
H-3	2.1	66.5	55.0	69.1	46.3	-	45+	YES	NO
H-4	3.4	66.0	57.8	63.5	46.1	64.4	41-42	YES	NO
H-5	3.3	66.5	59.2	67.0	44.7	62.1	37	YES	NO
H-6	2.8	63.6	56.6	63.6	46.2	62.2	43-44	YES	NO
H-7	2.3	63.1	53.2	62.5	46.3	64.0	43-44	YES	NO
H-8	-	75.3	64.3	64.7	48.2	74.5	42-43	YES	NO
H-9	3.1	72.1	65.1	65.3	47.3	71.3	36+	YES	NO
H-10	2.8	64.9	58.2	63.2	46.5	62.9	43-44	YES	NO
H-11	3.2	63.2	56.5	64.3	44.7	63.8	38+	YES	NO
H-12	2.5	57.7	52.3	62.7	44.7	60.2	45	YES	NO
H-13	2.0	67.4	58.1	67.0	45.5	66.0	42-43	YES	NO
H-14		69.5	63.0	67.3	47.1	72.1	44+	YES	NO
H-15		70.1	61.7	64.2	46.2	67.2	33	YES	NO
H-16		60.0	54.7	63.8	45.9	64.0	38+	YES	NO
H-17		67.7	61.0	68.0	44.9	68.6	41-42	YES	NO
H-18		58.4	51.6	64.3	43.4	57.5	43-44	YES	NO
H-19		72.4	63.8	67.8	46.0	71.7	37	YES	NO
H-20		63.9	55.5	66.9	44.5	64.5	42-43	YES	NO
H-21		63.2	53.3	64.4	44.7	62.9	44+	YES	NO
H-22		60.8	51.2	63.2	45.2	59.9	45	YES	NO
H-23		76.6	65.3	69.8	47.9	77.3	45	YES	NO
H-24		66.6	59.1	67.1	44.5	66.7	42-43	YES	NO

Appendix 3 (continued). Se concentrations ($\mu\text{g/g}$, dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Antelope Island colony on May 23, 2006.

Sample	Se ($\mu\text{g/g}$)	Mass (g)		Length (mm)	Width (mL)	Volume	H-H	Viable embryo?	Defects?
		Whole egg	Without shell (mm)						
A-1	3.2	62.6	53.4	64.0	45.4	62.9	42-43	YES	NO
A-2	3.0	63.4	55.0	62.2	46.9	66.0	44+	YES	NO
A-3	2.7	61.0	52.8	65.5	44.0	59.7	44+	YES	NO
A-4	4.1	57.8	52.6	62.4	44.3	-	45+	YES	NO
A-5	2.4	68.6	59.4	67.7	46.4	71.2	44+	YES	NO
A-6	-	61.5	54.2	60.6	47.2	-	45	YES	NO
A-7	2.1	58.1	51.4	62.1	45.4	62.5	38	YES	NO
A-8	2.6	61.3	53.5	66.5	44.6	61.5	41-42	YES	NO
A-9	2.6	78.4	69.5	68.1	47.2	73.2	29	YES	NO
A-10	2.4	82.0	71.8	67.1	48.3	-	23+	YES	NO
A-11	2.4	68.9	62.6	69.2	45.3	65.7	41-42	YES	NO
A-12	2.8	64.7	58.3	65.5	46.6	-	45+	YES	NO
A-13		75.7	67.0	66.6	47.1	70.1	18	YES	NO
A-14		72.1	62.6	64.2	47.2	68.8	39	YES	NO
A-15		63.7	55.2	62.0	45.8	62.6	42-43	YES	NO
A-16		69.4	60.2	64.3	47.3	71.0	42-43	YES	NO
A-17		63.9	54.5	65.6	45.5	-	45+	YES	NO
A-18		69.2	62.6	65.7	46.4	66.9	37	YES	NO
A-19		64.7	55.1	62.2	47.4	65.4	42-43	YES	NO
A-20		67.0	55.4	63.0	47.2	66.8	45	YES	NO
A-21		63.6	53.7	63.6	46.4	65.0	45	YES	NO
A-22		65.8	59.6	66.4	46.5	69.8	44+	YES	NO
A-23		71.6	64.5	66.8	45.6	68.6	35	YES	NO
A-24		66.9	59.7	63.0	47.4	67.5	41-42	YES	NO

Appendix 3 (continued). Se and Hg concentrations ($\mu\text{g/g}$, dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Neponsett Reservoir colony on June 9, 2007.

Sample	Hg ($\mu\text{g/g}$)	Se ($\mu\text{g/g}$)	Mass (g)		Length (mm)	Width (mm)	Volume (mm)	H-H (ml)	Viable	Defects?	
			Whole	Without shell						embryo?	
P-1	0.19	2.5	61.0	56.2	62.3	44.5	51	38	YES	NO	
P-2	0.16	2.5	68.5	63.2	64.3	46.1	61	33	YES	NO	
P-3	0.07	2.2	56.9	52.9	60.6	44.6	51	41-42	YES	NO	
P-4	0.37	2.7	68.4	63.0	62.6	47.1	62	33	YES	NO	
P-5	0.16	2.6	61.1	56.3	62.5	44.4	56	39	YES	NO	
P-6	0.24	2.4	58.5	54.2	66.0	43.1	53	34	YES	NO	
P-7	0.45	3.0	59.1	53.5	63.7	44.2	63	--	NO (rotten)	NO	
P-8	0.39	3.1	65.7	61.2	70.1	44.0	52	44+	YES	NO	
P-9	0.1	3.3	52.2	48.3	59.5	43.2	49	40	YES	NO	
P-10	0.7	3.0	66.5	60.7	65.9	45.2	56	34	YES	NO	
P-11	0.16	2.2	72.4	67.4	65.6	46.5	60	--	NO (infertile)	NO	
P-12	0.1	3.8	54.2	50.7	60.0	41.7	--	--	YES	NO	



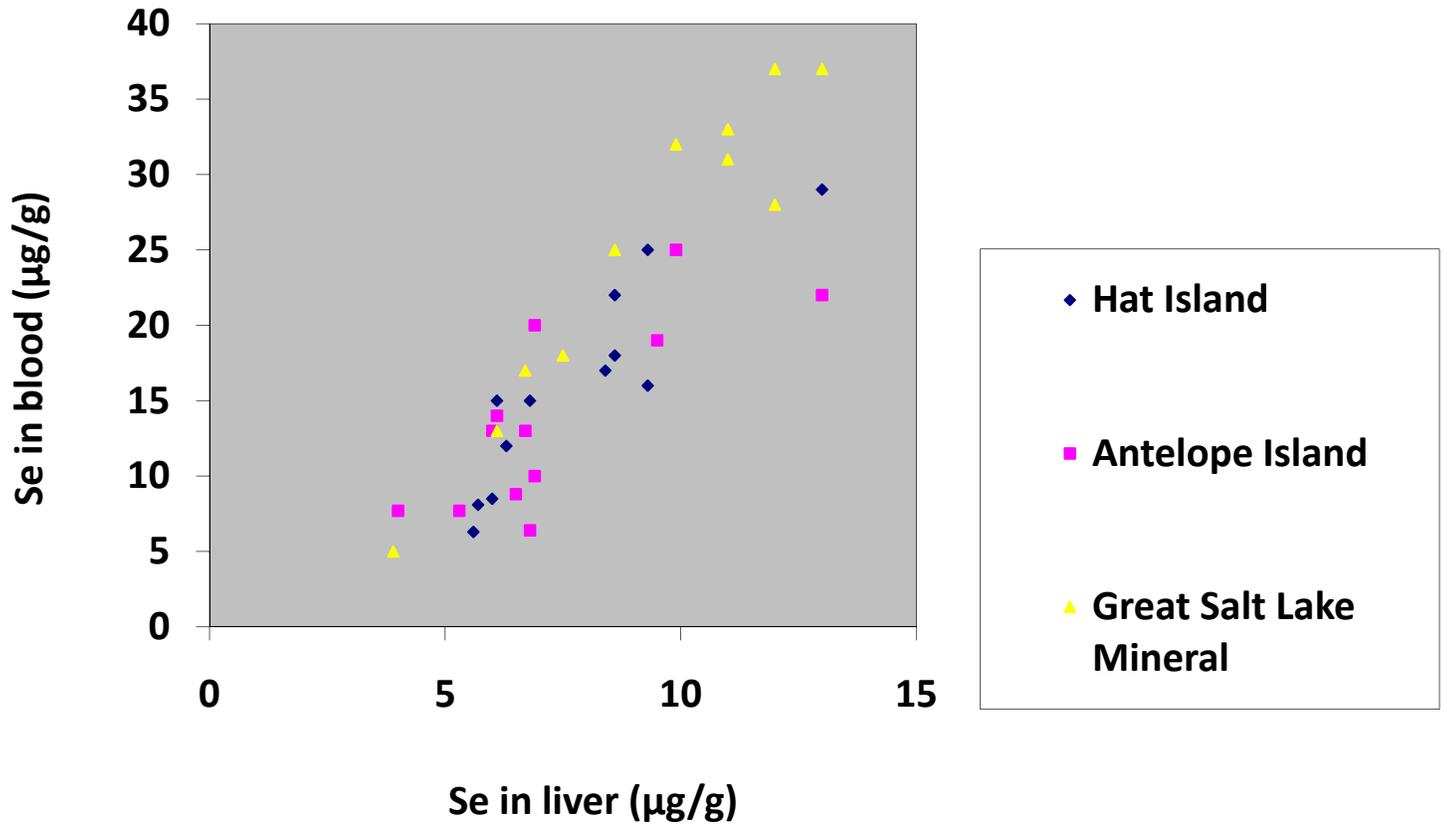


Figure 2. Relationship between a California gull's selenium concentration (µg/g, dry weight basis) in its blood and liver. Gulls collected from the three colonies are plotted separately.

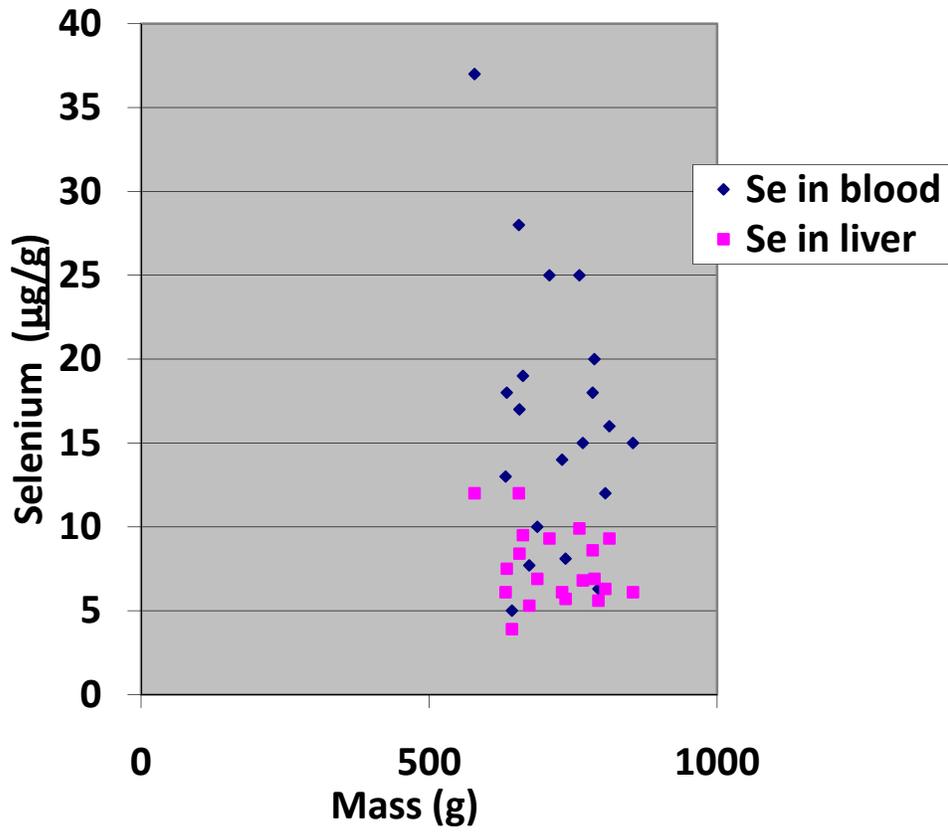


Figure 3. Relationship between the mass of male California gulls and the selenium concentration($\mu\text{g/g}$, dry weight basis) in their blood and liver.

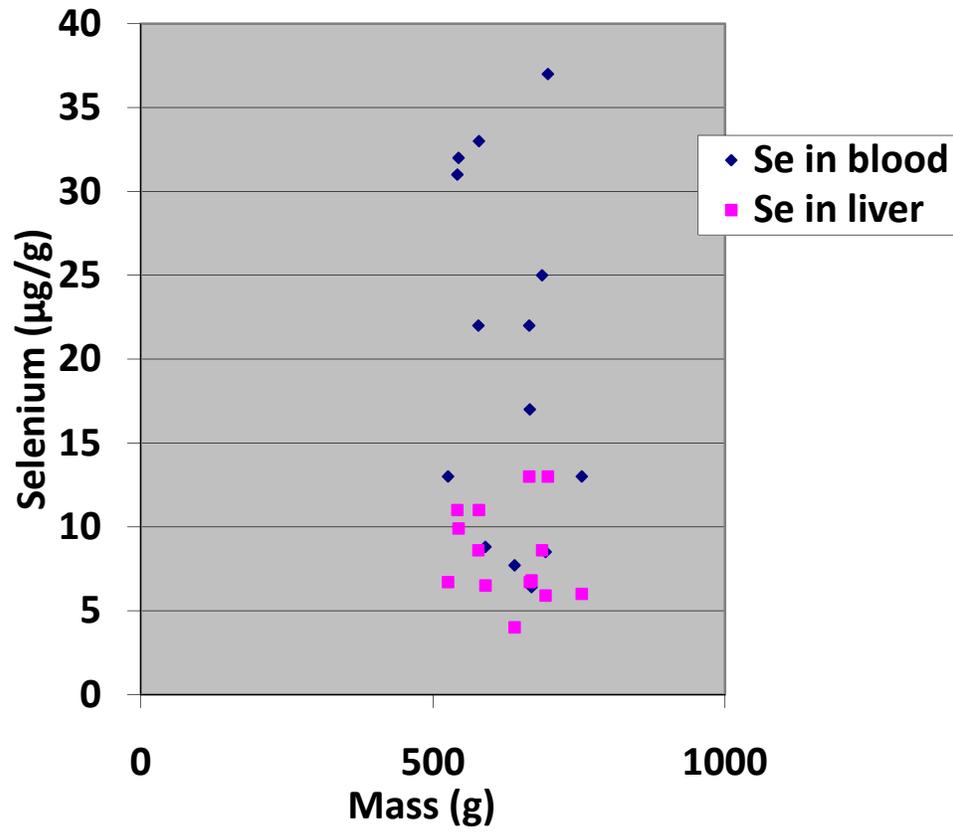


Figure 4. Relationship between mass of female California gulls and the selenium concentration ($\mu\text{g/g}$, dry weight basis) in their blood and liver.

Final Report:

Concentrations of Selenium in Eared Grebes from the Great Salt Lake, Utah

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Abstract

We examined selenium and mercury concentrations in eared grebes (*Podiceps nigricollis*) that spent the fall of 2006 on the Great Salt Lake, Utah. Food items in the birds' esophagus consisted primarily of brine shrimp. Selenium concentrations in livers varied based on when the grebes were collected (lower in September [mean \pm SE = 9.4 ± 0.7 $\mu\text{g/g}$ on a dry weight basis] than November [14.5 ± 1.4 $\mu\text{g/g}$]), where the birds were collected (Antelope Island = 8.6 ± 0.5 $\mu\text{g/g}$ and Stansbury Island = 15.2 ± 1.4 $\mu\text{g/g}$), and the grebe's age (juveniles 8.5 ± 1.5 $\mu\text{g/g}$ and adults = 15.8 ± 1.3 $\mu\text{g/g}$), but not by sex. In contrast, selenium concentrations in blood differed only by collection site (Antelope Island = 16.8 ± 2.3 and Stansbury Island = 25.4 ± 3.0 $\mu\text{g/g}$). Mercury concentration in the blood of grebes varied by when the grebes were collected (September = 5.6 ± 0.5 $\mu\text{g/g}$ and November = 8.4 ± 1.2 $\mu\text{g/g}$), where the birds were collected (Antelope Island = 4.3 ± 0.5 and Stansbury Island = 10.1 ± 2.6 $\mu\text{g/g}$), and the grebe's age (juveniles = 5.5 ± 0.8 and adults 8.4 ± 1.0 $\mu\text{g/g}$), but not by sex. Selenium concentrations in blood were correlated with selenium concentrations in the liver and mercury concentrations in both blood and liver. Mercury levels in blood and liver were also correlated. Liver mass, pancreas mass, and spleen mass were not related to either selenium or mercury concentrations. Body mass of grebes increased dramatically from September (381 ± 14 g) to November (591 ± 11 g). Body mass was either not correlated with selenium or mercury concentrations, or the relationship was positive. These results suggest that high mercury and selenium levels were not preventing grebes for increasing or maintaining mass.

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Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. Elevated concentrations of selenium have been shown, both in captive and free-ranging birds, to cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al. 1989, Ohlendorf 2003). For example, several avian species foraging in California's Kesterson Reservoir accumulated high concentrations of selenium in their tissues that impaired their reproductive ability and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

The Great Salt Lake (GSL) in Utah is an important habitat for many avian species. About half of North America's eared grebes (*Podiceps nigricollis*) spend the fall on the GSL eating brine shrimp and accumulating enough nutrients to fly to their wintering grounds in Mexico and California. Hence, there is a need to ensure that selenium concentrations in the GSL do not reach levels that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium concentrations in eared grebes in September (soon after they arrived on the GSL) and then again in late November before they migrate from the GSL. Because of the possible interactions between selenium and mercury that may affect bioaccumulation and effects, we also measured concentrations of mercury in grebe blood and livers.

This study was designed to answer the following specific questions.

1. What are selenium and mercury concentrations in blood and liver of eared grebes collected on the GSL?
2. Do eared grebes accumulate selenium and mercury while on the GSL?
3. Do selenium and mercury concentrations vary based on where the grebes were collected on the GSL or the age or sex of the birds?
4. Are selenium and mercury concentrations in blood and liver correlated?
5. Do selenium or mercury concentrations affect body condition of eared grebes on the GSL?

Methods

Collection of grebes. During September and November 2006, we collected eared grebes located in the GSL off Antelope Island and Stansbury Island (Figure 1). During these months, the grebes are flightless, and we used a shotgun and steel shot to collect them as they swam on the water surface. We collected 30 grebes during each month with an equal number (15) being collected at each site.

We immediately used a syringe to collect at least 1 mL of blood from the thoracic cavity. The blood was kept in the syringe and frozen. Within 12 hours of when the birds were collected, we collected all food from the bird's esophagus and obtained a liver sample. The liver sample was placed in a Whirl-Pak[®] bag and frozen. Esophagus samples were weighed (wet weight) and were stored in 95% alcohol. We determined the birds' body mass, aged them by eye color (Cullen et al. 1999), and determined their sex by gonadal inspection. We weighed each bird's liver, spleen, and pancreas. Food in the esophagus was sorted by species, and numbers of each species were counted because food items were too small and scarce to accurately weigh.

Selenium and mercury analysis. Blood and liver samples from some grebes were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium and mercury analysis. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry and mercury using cold vapor atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Selenium and mercury concentrations are reported on a dry-weight basis. Quality control of chemical analyses was conducted using one or more method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006).

Statistical analyses. To determine if the data were normally distributed, I examined data on the grebes collected during September separately from the grebes collected during November. For both

datasets, selenium and mercury concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test.

Analyses of Variance (ANOVAs) were used to determine the effect of collection date (September versus November), collection site (Antelope Island versus Stansbury Island), age of bird (juveniles versus adults), and sex on selenium concentrations in blood and liver. We did not determine the mercury concentrations in liver samples from juvenile birds. Because of this, there was an insufficient sample size to conduct an ANOVA on mercury concentrations in livers. We did, however, conduct an ANOVA to examine the effect of collection date, collection site, and sex on mercury concentrations in blood samples.

Regression tests were conducted to compare selenium and mercury concentration in an individual grebe's blood and liver. Selenium and mercury concentrations were also regressed with body mass, liver mass, spleen mass, and pancreas mass. Fat mass was not used because grebes fast before migrating from the GSL; therefore, it is not a reliable predictor of body condition of grebes. Because grebe mass varies by age and sex, we first conducted regression tests on all birds combined, and then separately analyzed juvenile males, adult males, juvenile females and adult females using only those birds collected in November. In all tests, results were considered significant if $P < 0.05$.

Results

Food analyses.—All grebes had a mass of feather fragments and brine shrimp (*Artemia* spp.) cysts in their gizzard; individual food items in the gizzard could not be identified. Hence, food analyses were limited to items in the birds' esophagus. Collected grebes had so few food items in their esophagus that food items were individually counted because weights were meaningless. During September, grebes were feeding primarily on adult brine shrimp and adult brine flies. During November, food items in the grebes contained almost entirely adult brine shrimp (Appendix 1).

Selenium and mercury analyses.—Selenium concentrations in livers varied based on when the grebes were collected (lower in September [mean \pm SE = 9.4 ± 0.7 $\mu\text{g/g}$ on a dry-weight basis] than November [14.5 ± 1.4 $\mu\text{g/g}$]), where the birds were collected (Antelope Island = 8.6 ± 0.5 and Stansbury Island = 15.2 ± 1.4 $\mu\text{g/g}$), and the grebe's age (juveniles = 8.5 ± 1.5 and adults = 15.8 ± 1.3 $\mu\text{g/g}$), but not by sex (Tables 1-3). In contrast, selenium concentrations in blood differed only by collection site (Antelope Island = 16.8 ± 2.3 and Stansbury Island = 25.4 ± 3.0 $\mu\text{g/g}$ dry weight). Mercury concentration in the blood of grebes varied by when the grebes were collected (September = 5.6 ± 0.5 $\mu\text{g/g}$ and November = 8.4 ± 1.2), where the birds were collected (Antelope Island = 4.3 ± 0.5 $\mu\text{g/g}$ and Stansbury Island = 10.1 ± 2.6), and the grebe's age (juveniles = 5.5 ± 0.8 $\mu\text{g/g}$ and adults = 8.4 ± 1.0), but not by sex (Tables 1-3).

When all birds were combined, selenium concentrations in blood and liver and mercury concentrations in blood and liver were all positively correlated with each other (Table 4). When juvenile males, adult males, juvenile females, and adult females collected in November were analyzed separately (Tables 5 and 6), selenium concentrations in blood were correlated with selenium concentrations in liver in all sex-age groups. In males, selenium concentrations in the liver and blood were correlated with mercury levels in blood but not mercury levels in livers (Table 5). In females, selenium concentrations were not correlated with mercury concentrations (Table 6), but sample sizes for females were so small that the probability of a Type II error was high. This was also true for comparisons involving mercury concentrations if the livers of males.

When all grebes were combined, there was a positive correlation between body mass and selenium concentrations in blood and liver and mercury concentrations in liver (Table 4). When only

grebes collected in November were considered and each age-sex group was analyzed separately, body mass was not correlated with selenium or mercury concentrations with two exception — mass of adult males was correlated with selenium concentrations in the liver ($r^2 = 0.36$) and mass of juvenile females was correlated with mercury concentrations in the blood ($r^2 = 1.0$). In both cases, the relationship was positive (Tables 5 and 6). Liver mass, pancreas mass, and spleen mass were not correlated with either selenium or mercury concentrations (Table 4).

Discussion

In eared grebes, we found that selenium concentrations in livers ranged from 5 to 28 $\mu\text{g/g}$. In California gulls (*Larus californicus*) that we collected from the GSL during the spring, selenium concentrations ranged from 4 to 14 $\mu\text{g/g}$ (Conover et al. 2007). In other species, mean background levels of selenium have been reported to be less than 10 $\mu\text{g/g}$ in livers (USDI 1998, Ohlendorf 2003). Our results indicate that selenium concentrations in liver samples were generally consistent with background concentrations for grebes collected in September. For eared grebes captured in November, however, all of those from Stansbury Island (range 17.4 to 28.4 $\mu\text{g/g}$) had selenium concentrations in livers that exceeded the 10 $\mu\text{g/g}$ threshold that is considered to be the background level in liver tissue (Ohlendorf 2003). Grebes captured during November near Antelope Island had selenium concentrations (range 6.7 to 8.7 $\mu\text{g/g}$) consistent with background levels.

Among grebes collected during November, selenium concentrations in blood ranged from 1 to 18 $\mu\text{g/g}$ from birds collected near Antelope Island and 22 to 55 $\mu\text{g/g}$ from birds collected near Stansbury Island. In California gulls that we collected during their breeding season on the GSL, selenium concentrations in blood ranged from 5 to 46 $\mu\text{g/g}$ (Conover et al. 2007). These concentrations were higher than we expected given the concentrations found in livers. Selenium concentrations in the blood of predatory terrestrial birds (kestrel [*Falco sparverius*], 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 to 38 $\mu\text{g/g}$ dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 $\mu\text{g/g}$ dry weight are considered to exceed normal background, and 5 $\mu\text{g/g}$ dry weight is considered a provisional threshold indicating that further study is warranted (USDI 1998).

We do not know why grebes collected around Stansbury Island during November had higher concentrations of selenium than those from around Antelope Island. However, during November, Stansbury Island grebes also had much higher mercury concentrations in their blood (range = 11.5 to 18 $\mu\text{g/g}$) than Antelope Island grebes (range = 2.5 to 4.7 $\mu\text{g/g}$). Selenium and mercury can interact to form a stable complex so that selenium can provide adult birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from faster selenium initial elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver or kidney tissues (Goede and Wolterbeek 1994). When we analyzed juvenile males, adult males, juvenile females, and adult females separately and used only those birds collected in November, selenium concentrations in both blood and liver were correlated with mercury concentrations in blood for males but not females. However, sample sizes were small for females and this increased the likelihood of a Type II error. Still, we discovered among female grebes a positive correlation between selenium concentrations and blood mercury levels.

Although the few studies of selenium-mercury interaction in birds used various forms of selenium and mercury (some not using environmentally relevant forms), they do provide approximations of potential effects. In a study by Heinz and Hoffman (1998) using mercury as methylmercury chloride and seleno-DL-methionine, captive female mallards (*Anas platyrhynchos*) fed a diet containing both 10 µg Se/g of feed and 10 µg Hg/g had a selenium concentration in the liver 1.5 times higher than females fed a diet containing just selenium (10 µg Se/g). In the same experiment, male mallards fed the selenium and mercury combination diet had almost 12 times the selenium concentration of male mallards fed the selenium-only diet. Similar results were found with Japanese quail fed diets containing methylmercury and selenite (El-Begearmi et al. 1977, 1982).

High selenium concentrations can affect the health of mature birds. At Kesterson Reservoir, chronic selenium toxicosis caused American coots (*Fulica americana*) to lose mass and feathers (Ohlendorf et al. 1990). American kestrels (*Falco sparverius*) fed a diet containing 12 µg Se/g of food had a lower ratio of fat and a higher ratio of lean mass to total body mass (Yamamoto and Santolo 2000). Adult mallards maintained on a diet enriched with 20 µg Se/g of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998). We noted none of these abnormalities among the eared grebes we collected from the GSL, and their body mass was usually not related to either selenium or mercury concentrations. Furthermore, when there was a statistically significant correlation between body mass and selenium or mercury concentrations, the relationship was positive. Liver mass, pancreas mass, and spleen mass were not correlated with either mercury or selenium concentrations.

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Table 1. Effect of collection site, collection date, sex of bird, and its age on the mean (\pm SE) concentration of selenium ($\mu\text{g/g}$ dry weight); concentration of mercury ($\mu\text{g/g}$ dry weight); and mass of body, liver, pancreas, and spleen (g wet weight) of eared grebes collected during 2006 on the Great Salt Lake, Utah.

	<u>Collection sites</u>		<u>Collection dates</u>		<u>Sex</u>		<u>Age</u>	
	Antelope	Stansbury	September	November	Male	Female	Juvenile	Adult
Se – blood	16.8 \pm 2.3	25.4 \pm 3.0	18.5 \pm 2.5	23.3 \pm 2.9	21.8 \pm 3.0	19.7 \pm 2.4	16.1 \pm 2.3	25.2 \pm 2.8
Se—liver	8.6 \pm 0.5	15.2 \pm 1.4	9.4 \pm 0.7	14.5 \pm 1.4	12.0 \pm 1.2	11.8 \pm 1.2	8.5 \pm 0.7	15.8 \pm 1.3
Hg—blood	4.3 \pm 0.5	10.1 \pm 1.0	5.6 \pm 0.5	8.4 \pm 1.2	7.1 \pm 1.0	6.8 \pm 0.9	5.5 \pm 0.8	8.4 \pm 1.0
Hg—liver	--	12.9 \pm 1.7	10.1 \pm 2.6	15.6 \pm 1.9	14.1 \pm 2.4	10.6 \pm 1.7	13.1 \pm 3.6	12.7 \pm 1.8
Mass—body	480 \pm 21	491 \pm 25	381 \pm 14	591 \pm 11	521 \pm 23	440 \pm 20	431 \pm 24	549 \pm 16
Mass—liver	17.9 \pm 1.2	17.0 \pm 0.9	14.1 \pm 0.8	20.8 \pm 0.8	18.7 \pm 1.0	15.7 \pm 0.9	15.5 \pm 1.1	19.8 \pm 0.7
Mass—pancreas	0.25 \pm 0.05	0.22 \pm 0.05	0.15 \pm 0.03	0.36 \pm 0.07	0.24 \pm 0.03	0.24 \pm 0.09	0.25 \pm 0.06	0.22 \pm 0.05
Mass—spleen	0.20 \pm 0.02	0.19 \pm 0.01	0.19 \pm 0.01	0.21 \pm 0.02	0.21 \pm 0.02	0.18 \pm 0.01	0.19 \pm 0.02	0.22 \pm 0.02

Table 2. Mean (\pm SE) concentration of selenium (ug/g dry weight), concentration of mercury, (ug/g dry weight), and body mass (g wet weight) of eared grebes collected during November 2006 on the Great Salt Lake, Utah.

	Juveniles		Adults		
	Males	Females	Males	Females	
Se – blood	17.8 \pm 3.5 (<i>n</i> = 5)	14.6 \pm 5.1 (<i>n</i> = 4)	29.2 \pm 6.6 (<i>n</i> = 7)	27.1 \pm 4.7 (<i>n</i> = 5)	
Se—liver	8.4 \pm 1.2 (<i>n</i> = 9)	12.7 \pm 5.8 (<i>n</i> = 3)	17.9 \pm 2.4 (<i>n</i> = 12)	17.6 \pm 2.4 (<i>n</i> = 6)	
Hg—blood	6.2 \pm 2.3 (<i>n</i> = 5)	4.0 \pm 2.0 (<i>n</i> = 4)	10.4 \pm 2.3 (<i>n</i> = 7)	11.6 \pm 1.8 (<i>n</i> = 5)	
Hg—liver	--	--	15.7 \pm 3.1 (<i>n</i> = 6)	14.7 \pm 1.6 (<i>n</i> = 3)	
Mass—body	593 \pm 20	(<i>n</i> = 9)	569 \pm 61 (<i>n</i> = 3)	623 \pm 13 (<i>n</i> = 12)	539 \pm 17 (<i>n</i> = 6)

Table 3. ANOVA tables for the effect of collection site, collection time, sex of bird, and age of bird on selenium and mercury concentrations (number of birds used for a comparison is one more than the two different degrees of freedom).

Term	Selenium (blood)			Selenium (liver)			Mercury (blood)		
	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>
Site	5.91	1,27	0.02	53.65	1,44	0.0001	63.16	1,27	0.0001
Date	1.98	1,27	0.17	23.21	1,44	0.0001	19.93	1,27	0.0001
Site X Date	8.67	1,27	0.007	83.26	1,44	0.0001	34.09	1,27	0.0001
Sex	0.75	1,27	0.39	0.97	1,44	0.33	1.76	1,27	0.20
Site X Sex	0.01	1,27	0.94	2.80	1,44	0.10	1.63	1,27	0.21
Date X Sex	0.35	1,27	0.55	0.09	1,44	0.77	3.50	1,27	0.07
Site X Date X Sex	0.67	1,27	0.42	0.28	1,44	0.60	1.70	1,27	0.20
Age	1.80	1,27	0.19	7.49	1,44	0.009	0.84	1,27	0.36
Site X Age	0.11	1,27	0.73	1.41	1,44	0.24	0.11	1,27	0.73
Date X Age	0.06	1,27	0.81	5.54	1,44	0.02	1.92	1,27	0.17
Site X Date X Age	1.35	1,27	0.26	1.58	1,44	0.22	0.64	1,27	0.42
Sex X Age	2.64	1,27	0.11	0.10	1,44	0.76	5.84	1,27	0.02
Site X Sex X Age	0.05	1,27	0.83	1.15	1,44	0.29	0.05	1,27	0.83
Date X Sex X Age	3.05	1,27	0.09	6.61	1,44	0.01	0.00	1,27	0.94
Site X Date X Sex X Age	0.36	1,27	0.55	15.02	1,44	0.0004	0.72	1,27	0.40

Table 4. Regression analyses among selenium and mercury concentrations in the blood and liver and mass of body, liver, pancreas, and spleen using all eared grebes (males and females, juveniles and adults) collected during 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

Variable 1	Variable 2	r^2	F	df	P	
Se (blood)	Body mass	0.09	4.03	1,40	0.05	
	Liver mass	0.002	0.07	1,40	0.80	
	Pancreas mass		0.003	0.06	1,18	0.82
	Spleen mass	0.06	1.82	1,27	0.19	
	Se (blood)	--	--	--	--	
	Se (liver)	0.49	37.98	1,40	<0.001	
	Hg (blood)	0.49	38.78	1,41	<0.001	
	Hg (liver)	0.47	12.46	1,14	0.003	
Se (liver)	Body mass	0.32	27.72	1,58	<0.001	
	Liver mass	0.06	3.41	1,58	0.07	
	Pancreas mass		0.10	2.63	1,23	0.12
	Spleen mass	0.02	0.75	1,38	0.39	
	Se (blood)	see above				
	Se (liver)	--	--	--	--	
	Hg (blood)	0.54	47.12	1,40	<0.001	
	Hg (liver)	0.22	5.12	1,18	0.04	
Hg (blood)	Body mass	0.20	10.06	1,40	0.003	
	Liver mass	0.04	1.64	1,40	0.21	
	Pancreas mass		0.08	1.49	1,18	0.24
	Spleen mass	0.003	0.08	1,27	0.78	
	Se (blood)	see above				

	Se (liver)	see above			
	Hg (blood)	--	--	--	--
	Hg (liver)	0.59	20.14	1,14	<0.001
Hg (liver)	Body mass	0.08	1.62	1,18	0.22
	Liver mass	0.01	0.18	1,18	0.68
	Pancreas mass		0.99	92.26	1,3 0.07
	Spleen mass	0.23	1.87	1,6	0.22
	Se (blood)	see above			
	Se (liver)	see above			
	Hg (blood)	see above			
	Hg (liver)	—	—	—	—

Table 5. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using male eared grebes collected during November 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

Variable 1	Variable 2	Juvenile males				Adult males			
		r^2	F	df	P	r^2	F	df	P
Se (blood)	Body mass	0.32	1.40	1,3	0.08	0.28	1.92	1,5	0.23
	Se (blood)	--	--	--	--	--	--	--	--
	Se (liver)	0.98	162.72	1,3	0.001	0.92	56.58	1,5	0.001
	Hg (blood)	0.96	78.27	1,3	0.003	0.65	9.58	1,5	0.03
	Hg (liver)	insufficient data				0.48	1.84	1,2	0.31
Se (liver)	Body mass	0.31	3.12	1,7	0.12	0.36	5.74	1,10	0.04
	Se (blood)	see above				see above			
	Se (liver)	--	--	--	--	--	--	--	--
	Hg (blood)	0.98	155.27	1,3	0.001	0.82	24.12	1,5	0.004
	Hg (liver)	insufficient data				0.53	4.55	1,4	0.10
Hg (blood)	Body mass	0.42	2.19	1,3	0.23	0.46	4.27	1,5	0.09
	Se (blood)	see above				see above			
	Se (liver)	see above				see above			
	Hg (blood)	--	--	--	--	--	--	--	--
	Hg (liver)	insufficient data				0.64	3.67	1,2	0.19
Hg (liver)	Body mass	insufficient data				0.36	2.21	1,4	0.21
	Se (blood)	insufficient data				see above			
	Se (liver)	insufficient data				see above			
	Hg (blood)	insufficient data				see above			
	Hg (liver)	--	--	--	--	--	--	--	--

Table 6. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using female eared grebes collected during November 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

Variable 1	Variable 2	Juvenile females				r^2	Adult females			
		r^2	F	df	P		r^2	F	df	P
Se (blood)	Body mass	0.96	25.42	1,1	0.12	0.15	0.54	1,3	0.51	
	Se (blood)	--	--	--	--	--	--	--	--	
	Se (liver)	1.0	7930.0	1,1	0.007	0.68	6.44	1,3	0.09	
	Hg (blood)	0.86	12.72	1,2	0.07	0.41	2.06	1,3	0.25	
	Hg (liver)	insufficient data				0.47	0.90	1,1	0.52	
Se (liver)	Body mass	0.96	22.67	1,1	0.13	0.46	3.45	1,4	0.14	
	Se (blood)	see above				see above				
	Se (liver)	--	--	--	--	--	--	--	--	
	Hg (blood)	0.95	20.1	1,1	0.14	0.80	11.94	1,3	0.04	
	Hg (liver)	insufficient data				0.00	0.00	1,1	0.99	
Hg (blood)	Body mass	1.0	6521.0	1,1	0.008	0.22	0.87	1,3	0.42	
	Se (blood)	see above				see above				
	Se (liver)	see above				see above				
	Hg (blood)	--	--	--	--	--	--	--	--	
	Hg (liver)	insufficient data				0.91	10.7	1,1	0.19	
Hg (liver)	Body mass	insufficient data				0.31	0.45	1,1	0.63	
	Se (blood)	insufficient data				see above				
	Se (liver)	insufficient data				see above				
	Hg (blood)	insufficient data				see above				
	Hg (liver)	--	--	--	--	--	--	--	--	

Appendix 1. Data on individual eared grebes collected during 2006 on the Great Salt Lake including food in their esophagus (bs = adult brine shrimp, bf = adult brine flies, bfl = brine fly larva, c = hundreds of cysts).

Sample	Location date	Sex Age 1= male 2= female 1= juvenile 2 = adult	Mass					Selenium		Mercury		Food
			Body	Liver	Gizzard	Pancreas	Spleen	Blood	Liver	Blood	Liver	
EG-A1	Antelope 9/11/06	1 1	293	4.4	--	--	0.098	7.1	5.9	0.55	-	
EG-A2	Antelope 9/11/06	2 1	342	12.5	--	0.096	0.200	12.8	8.4	6.6	-	
EG-A3	Antelope 9/11/06	2 2	455	18.9	30.5	0.135	--	31.5	11.2	4.8	-	
EG-A4	Antelope 9/11/06	2 2	478	23.0	31.4	--	0.227	20.1	10.7	5.81	-	
EG-A5	Antelope 9/11/06	1 1	357	13.8	24.0	0.116	0.140	16	9.8	4.9	-	12 bs, 11 bf, c
EG-A6	Antelope 9/11/06	2 2	504	18.8	28.3	--	0.187	32.8	16.8	6.35	-	
EG-A7	Antelope 9/11/06	1 2	424	14.1	28.4	0.264	0.307	36.3	15.2	3.7	-	
EG-A8	Antelope 9/11/06	1 1	285	9.5	18.0	--	0.122	45.9	5	8.6	-	
EG-A9	Antelope 9/11/06	1 2	582	18.0	29.1	0.127	0.368	6.8	16	3.2	-	104 bs, 6 bf, c
EG-A10	Antelope 9/11/06	2 2	444	19.1	27.7	0.032	0.183	21.3	11.4	8.19	-	19 bs, 1bf, c
EG-A11	Antelope 9/11/06	1 1	388	17.9	30.8	0.287	0.329	9.7	6.9	7.78	-	15 bs, 8 bf
EG-A12	Antelope 9/11/06	2 1	366	11.5	28.4	0.082	0.187	0.3	11.9	0.09	-	36 bs, 6 bf
EG-A13	Antelope 9/11/06	2 1	394	14.0	30.1	0.081	0.112	-	8.6	-	-	20 bf
EG-A14	Antelope 9/11/06	2 1	245	9.0	13.3	0.025	0.085	-	5.9	-	-	3 bs, 2 bf
EG-A15	Antelope 9/11/06	2 1	318	7.0	24.2	--	--	-	7.2	-	-	
EG-A51	Antelope 11/10/06	1 1	651	21.6	29.3	0.119	0.240	13	7.1	3.8	-	100% bs
EG-A52	Antelope 11/10/06	1 2	633	23.0	33.2	0.369	0.213	17.8	7	4.2	-	100% bs
EG-A53	Antelope 11/10/06	1 2	542	17.7	31.6	0.347	0.191	15.2	7.5	3.2	-	100% bs
EG-A54	Antelope 11/10/06	1 1	604	33.2	34.2	--	0.147	14.2	6.4	4.3		
EG-A55	Antelope 11/10/06	2 1	490	14.0	25.8	0.581	0.139	15.9	7.1	2.6	-	
EG-A56	Antelope 11/10/06	1 1	550	20.7	33.9	0.405	0.247	16.1	7.3	3.3	-	

EG-A57	Antelope 11/10/06	1 1	520	17.3	23.5	--	0.432	-	6.9	-	-	100% bs
EG-A58	Antelope 11/10/06	1 1	580	24.3	30.0	0.397	0.319	-	7.8	-	-	100% bs
EG-A-59	Antelope 11/10/06	1 1	565	27.2	37.6	0.085	0.168	-	7.2	-	-	100% bs
EG-A60	Antelope 11/10/06	1 2	607	26.6	33.7	0.358	0.200	10.3	8.7	4.4	-	
EG-A61	Antelope 11/10/06	2 2	500	18.6	27.6	--	0.189	12.8	7.1	4.7	-	100% bs
EG-A62	Antelope 11/10/06	1 1	673	20.4	31.4	--	--	-	8.2	-	-	
EG-A63	Antelope11/10/06	2 1	529	18.6	29.0	0.902	0.147	15.8	6.7	4	-	100% bs
EG-A64	Antelope 11/10/06	1 1	520	14.3	18.4	0.335	0.200	14.2	6.8	4	-	100% bs
EG-A65	Antelope 11/10/06	1 2	587	28.0	25.8	0.041	0.140	-	7	-	-	100% bs
EG-A66	Antelope 11/10/06	2 1	----	----	----	--	--	1.1	-	0.05	-	
EG-Hat1	Stansbury 9/13/06	2 1	342	13.1	26.5	0.211	0.267	6.8	5.5	7	7.06	65 bs, c
EG-Hat2	Stansbury 9/13/06	2 1	378	16.7	27.6	--	0.214	13.7	7.1	3.5	-	42 bs, c
EG-Hat3	Stansbury 9/1/3/06	1 1	384	15.3	32.7	0.078	0.110	32.7	12.7	8.13	10.2	
EG-Hat4	Stansbury 9/13/06	1 2	403	16.0	30.0	--	0.257	9.1	6.2	4.8	4.6	
EG-Hat5	Stansbury 9/13/06	2 2	397	10.3	18.4	--	--	25.2	9.7	5.83	7.45	1 bs
EG-Hat6	Stansbury 9/13/06	1 2	499	21.7	33.6	0.337	0.160	7.7	5.6	4.9	5	15 bs
EG-Hat7	Stansbury 9/13/06	2 1	401	18.1	34.7	0.235	0.260	10.4	7.2	8.62	-	16 bs, 1 bf
EG-Hat8	Stansbury 9/13/06	1 1	363	17.4	35.6	--	0.188	22.4	10.5	6.42	7.23	
EG-Hat-9	Stansbury 9/13/06	2 1	336	10.6	18.4	--	0.130	-	6	-	4.5	
EG-Hat10	Stansbury 9/13/06	1 1	308	9.8	14.6	--	--	13.5	8	6.35	12.3	
EG-Hat-11	Stansbury 9/13/06	1 1	336	11.1	23.8	--	0.170	-	8.9	-	-	26 bs, 1 bfl, c
EG-Hat-12	Stansbury 9/13/06	2 1	324	15.6	31.4	--	0.212	-	7.9	-	-	1 bfl
EG-Hat13	Stansbury 9/13/06	2 2	469	19.2	28.7	--	0.176	25.6	20.3	6.66	10.5	55 bs, 1 bf
EG-Hat14	Stansbury 9/13/06	2 1	316	8.2	19.5	0.312	0.192	-	6	-	-	6 bs, 1 bf
EG-Hat16	Stansbury 9/13/06	1 1	297	8.5	14.4	--	0.108	-	8.8	-	32.2	5 bs
EG-Hat71	Stansbury 11/22/06	1 2	622	18.6	24.8	--	--	55.3	28.4	14	17	100% bs
EG-Hat72	Stansbury 11/22/06	1 2	717	16.8	25.7	--	--	50	27.4	18	28	
EG-Hat73	Stansbury 11/22/06	1 1	675	21.8	32.6	--	--	31.7	17.8	15.4	17.9	
EG-Hat74	Stansbury 11/22/06	1 2	598	26.0	27.9	--	--	31.7	17.8	14.6	5.87	100% bs

EG-Hat75	Stansbury 11/22/06	2 2	562	20.6	22.8	--	--	26	17.2	11.5	13.1	100% bs
EG-Hat76	Stansbury 11/22/06	2 2	600	23.4	27.3	--	--	37.8	24.2	12.7	13.1	100% bs
EG-Hat77	Stansbury 11/22/06	2 2	559	19.6	21.2	--	--	22.2	20.6	15.5	18	100% bs
EG-Hat78	Stansbury 11/22/06	1 2	660	18.6	30.4	--	--	24	18.1	14.4	11.6	100% bs
EG-Hat79	Stansbury 11/22/06	1 2	655	20.2	30.5	--	--	-	24.9	-	12.7	100% bs
EG-Hat80	Stansbury 11/22/06	1 2	591	22.4	25.6	--	--	-	22.5	-	18.8	100% bs
EG-Hat81	Stansbury 11/22/06	2 2	500	12.4	24.0	--	--	36.9	19.3	13.5	-	100% bs
EG-Hat82	Stansbury 11/22/06	2 2	513	20.2	24.8	--	--	-	17.4	-	-	100% bs
EG-Hat83	Stansbury 11/22/06	1 2	604	21.3	22.7	--	--	-	18.8	-	-	100% bs
EG-Hat84	Stansbury 11/22/06	1 2	660	20.6	26.2	--	--	-	26.3	-	-	100% bs
EG-Hat85	Stansbury 11/22/06	2 1	688	17.4	28.9	--	--	25.7	24.2	9.27	-	100% bs

Final Report:

Concentrations of Selenium and Mercury in Common Goldeneyes from the Great Salt Lake, Utah

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Abstract

We examined selenium and mercury concentrations in male common goldeneyes (*Bucephala clangula*) that spent the winter of 2005–2006 on the Great Salt Lake, Utah. Selenium concentrations in livers were 15.3 ± 1.2 $\mu\text{g/g}$ (mean \pm SE on a dry-weight basis) and 16.7 ± 1.2 $\mu\text{g/g}$ in blood. Mercury concentrations were 38.8 ± 4.5 $\mu\text{g/g}$ in livers and 14.3 ± 1.2 $\mu\text{g/g}$ in blood. Selenium concentrations in liver, selenium concentrations in blood, mercury concentrations in liver, and mercury concentrations in blood were all highly correlated with each other. Body mass and liver mass were not correlated with the concentration of selenium or mercury concentration in either blood or liver. Fat mass was negatively correlated with liver concentrations of selenium and mercury and with blood concentrations of mercury, but not blood concentrations of selenium. Selenium and mercury concentrations increased across time in ducks collected around Fremont Island but not in ducks collected around Stansbury Island.

Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. Elevated concentrations of selenium can cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al. 1989, Ohlendorf 2003). For example, birds foraging in California's Kesterson Reservoir, which was the disposal site for subsurface agricultural drainage from portions of the western San Joaquin Valley, accumulated high concentrations of selenium in their tissues (Ohlendorf 2002, 2003). The high concentrations of selenium impaired the reproductive ability of several avian species nesting at Kesterson Reservoir and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

The Great Salt Lake (GSL) is the fourth-largest terminal lake in the world and is an important region for breeding and migratory waterbirds including common goldeneyes (*Bucephala clangula*) that overwinter on it (Aldrich and Paul 2002). Because GSL is a closed basin, contaminants (e.g., mercury and selenium) may accumulate in the GSL. Thus, GSL ducks are likely exposed to these contaminants, and elevated contaminant concentrations may adversely affect their survival and reproduction (reviewed in Takekawa et al. 2002). Indeed, mercury concentrations identified in a 2005 reconnaissance investigation on the GSL were the highest among published results for common goldeneye (Gerstenberger et al. 2004). Hence, there is a need to ensure that selenium concentrations in the GSL do not reach levels that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium and mercury concentrations in common goldeneyes soon after they arrived on the GSL and then again in February and March before they migrate from the GSL. Although the continental population of common goldeneye is relatively stable compared to other North American sea duck populations (e.g., eiders and scoters), insight into mercury and selenium concentrations in common goldeneye wintering on GSL presents a potentially unique opportunity to understand relationships between selenium and mercury concentrations in ducks and how their concentrations affect the condition of wintering sea ducks.

This study was designed to answer the following specific questions.

1. What are selenium and mercury concentrations in the blood and liver of male common goldeneye that winter on the GSL?
2. Do goldeneyes accumulate selenium and mercury while on the GSL?
3. Do selenium and mercury concentrations vary based on the age of the birds?
4. Are selenium and mercury concentrations in blood and liver correlated?
5. Do selenium or mercury concentrations affect body condition of goldeneyes?

Methods

Collection of goldeneyes. From November 2005 through March 2006, we used a shotgun to collect 40 male goldeneyes located on the GSL (Appendix 1). We collected ducks from two parts of the Great Salt Lake. One part was around Fremont Island in the northeastern section of the Great Salt Lake (Fremont Island and Farmington Bay); these ducks will be referred to as Fremont Island ducks. The other collection area was around Stansbury Island, Gilbert Bay, and the southern side of Carrington Bay; these ducks will be called the Stansbury Island ducks.

We used a syringe to collect at least 1 mL of blood from the thoracic cavity. Liver and blood samples were placed in separate Whirl-Pak[®] bags and frozen. We weighed and measured the birds, and determined their age by plumage. We also removed and weighed abdominal and intestinal fat.

Selenium and mercury analysis. Blood and liver samples from all ducks were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium and mercury analyses. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry and mercury using the cold vapor atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Quality control of chemical analyses was conducted using one or more

method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006).

Statistical analyses. Data on selenium and mercury concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test. Hence, parametric statistics were used. Analyses of Variance (ANOVAs) were used to determine the effect of collection site (Fremont Island versus Stansbury Island), and age of birds (juveniles versus adults) on selenium and mercury concentrations in blood and liver. Correlation analyses were conducted to compare selenium and mercury concentration in an individual duck's blood and liver. Selenium and mercury concentrations also were tested for correlation with body mass, liver mass, and fat mass. In all tests, results were considered significant if $P < 0.05$.

To assess the effect of collection date, we changed all collection dates to an Ordinal day with day 1 being November 29, 2005: the first day that a duck was collected. March 16, 2006, which was the last day a duck was collected, was changed to day 114. We then conducted a regression analysis to compare the different dependent variables to the Ordinal day. Data for collection date and site were confounded because almost all Fremont Island ducks were collected prior to February 1, 2006 and Stansbury Island ducks were collected after that date. Hence, we analyzed Fremont Island and Stansbury Island ducks separately.

Results

Selenium and mercury analyses.— Mean (\pm SE) selenium concentrations in livers were 15.3 ± 1.2 $\mu\text{g/g}$ on a dry-weight basis and 16.7 ± 1.2 $\mu\text{g/g}$ in blood. Mercury concentrations were 38.8 ± 4.5 $\mu\text{g/g}$ in livers and 14.3 ± 1.2 $\mu\text{g/g}$ in blood (Table 1). Selenium and mercury concentrations in both livers and blood did not vary by age but collection site (Fremont Island versus Stansbury Island) (or associated sampling date) affected selenium concentrations in liver and mercury concentrations in both liver and blood (Table 2).

Selenium concentrations in liver, selenium concentrations in blood, mercury concentrations in liver, and mercury concentrations in blood were all highly correlated with each other (Table 3). Body mass and liver mass were not correlated with concentrations of selenium or mercury in either blood or liver (Table 3). Fat mass was negatively correlated with selenium concentrations in liver, mercury concentrations in liver, and mercury concentrations in blood.

Among Fremont Island ducks, selenium and mercury concentrations in both liver and blood samples varied by collection day but this was not true for Stansbury Island ducks (Table 4, Figure 1-4). Body mass, liver mass, and fat mass did not vary by collection day for either Fremont Island or Stansbury Island ducks (Table 4).

Discussion

In male common goldeneyes, we found that selenium concentrations in livers ranged from 4 to 48 $\mu\text{g/g}$. In earlier studies on birds collected from GSL (Conover et al. 2007a, b), we found that selenium concentrations in livers ranged from 5 to 28 $\mu\text{g/g}$ in eared grebes (*Podiceps nigricollis*) and 4 to 14 $\mu\text{g/g}$ in California gulls (*Larus californicus*). Mean selenium concentration in livers was higher in goldeneyes (mean = 15.3 $\mu\text{g/g}$) than in eared grebes (mean = 12.0 $\mu\text{g/g}$) or California gulls (mean = 8.1 $\mu\text{g/g}$). In other avian species collected elsewhere, mean background levels of selenium have been reported to be less than 10 $\mu\text{g/g}$ in livers (USDI 1998, Ohlendorf 2003).

Mean selenium concentration in blood samples from our goldeneyes was 16.7 $\mu\text{g/g}$ (range = 1 to 34). In California gulls that we collected on the GSL, mean selenium concentration in blood was 18.1 $\mu\text{g/g}$ (range = 5 to 46) and in eared grebes 20.9 $\mu\text{g/g}$ (range= 1 to 55; Conover et al. 2007a,b). Selenium concentrations in the blood of American kestrels (*Falco sparverius*), 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 to 38 $\mu\text{g/g}$ dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 $\mu\text{g/g}$ are considered to exceed normal background, and 5 $\mu\text{g/g}$ is considered a provisional threshold indicating that further study is warranted (USDI 1998).

In GSL goldeneyes, we found that selenium levels in liver and blood samples were both highly correlated with mercury concentrations in liver and blood. Among California gulls, selenium concentrations in blood were correlated with mercury concentrations in blood but not in livers (Conover et al. 2007a). Among male eared grebes, selenium concentrations in both blood and liver tissues were correlated with mercury levels in blood but not in livers (Conover et al. 2007b). Among female eared grebes, selenium and mercury concentrations were not related (Conover et al. 2007b). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver tissues (Goede and Wolterbeek 1994). In surf scoters (*Melanitta perspicillata*) collected from San Francisco Bay, California, selenium and mercury concentrations were not correlated (Ohlendorf et al. 1991).

One reason that selenium and mercury concentrations in birds are correlated is because selenium and mercury can interact to form a stable, complex so that selenium may provide birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from initial faster selenium elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001).

In eared grebes and California gulls collected from the GSL, we found that age, collection day, and collection site affected selenium concentrations in their blood and liver. In this study, we found that age did not affect selenium or mercury concentrations in male goldeneyes from the GSL but collection day affected selenium and mercury concentrations for Fremont Island ducks but not Stansbury Island ducks. We are unable to assess the impact of collection site on selenium and mercury concentrations because collection day was confounded by collection site (most Fremont Island ducks were collected prior to February 1 and most Stansbury Island ducks were collected after that date). However, it is likely that collection site did not have a significant effect on selenium concentrations in goldeneyes because these ducks were very mobile while on GSL and foraged over wide areas, including in freshwater marshes (J. Vest, unpublished). In contrast, eared grebes are not very mobile while on the GSL because they cannot fly. Likewise, California gulls on the GSL cannot venture far from the nest to forage during the breeding season.

High selenium concentrations can affect the health of mature birds. At Kesterson Reservoir, chronic selenium toxicosis caused American coots (*Fulica americana*) to lose mass and feathers (Ohlendorf et al. 1990). American kestrels (*Falco sparverius*) fed a diet containing 12 $\mu\text{g Se/g}$ of food had a lower ratio of fat and a higher ratio of lean mass to total body mass (Yamamoto and Santolo 2000). Adult mallards (*Anas platyrhynchos*) maintained on a diet enriched with 20 $\mu\text{g Se/g}$

of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998). We noted no abnormalities among the goldeneyes that we collected from the GSL. In our goldeneyes, body and liver mass were not correlated with either selenium or mercury concentrations. However, fat mass was negatively correlated with liver concentrations of both selenium and mercury and mercury concentrations in blood. These findings raise the possibility that high levels of these contaminants may reduce the ability of male goldeneyes that are overwintering on GSL to accumulate or retain fat.

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Table 1. Effect of collection site, collection date, and duck age on the mean (\pm SE) concentration of selenium (ug/g dry weight), concentration of mercury (ug/g dry weight), and avian mass (g wet weight) of male goldeneyes collected from around Fremont Island and Stansbury Island on the Great Salt Lake, Utah from November 2005 through January 2006 (early season) and from February 2006 through March 2006 (late season).

	All birds	Collection sites		Collection dates		Age	
		Fremont	Stansbury	Early	Late	Juvenile	Adult
<i>N</i> =	40	20	20	21	19	17	23
Se – liver	15.3 \pm 1.2	12.6 \pm 1.5	18.0 \pm 1.7	12.2 \pm 1.4	18.7 \pm 1.7	12.7 \pm 1.6	17.2 \pm 1.6
Se—blood	16.7 \pm 1.2	16.3 \pm 1.9	17.1 \pm 1.7	15.9 \pm 1.8	17.6 \pm 1.7	14.8 \pm 1.5	18.1 \pm 1.8
Hg—liver	38.8 \pm 4.5	23.5 \pm 3.7	54.1 \pm 6.7	22.3 \pm 3.6	56.4 \pm 6.6	31.3 \pm 6.5	44.3 \pm 6.0
Hg—blood	14.3 \pm 1.2	10.5 \pm 1.1	18.1 \pm 1.8	10.4 \pm 1.0	14.1 \pm 2.4	13.4 \pm 1.8	15.0 \pm 1.6
Mass—body	1086 \pm 14	1114 \pm 20	1057 \pm 16	1117 \pm 19	1050 \pm 16	1048 \pm 20	1113 \pm 16
Mass—liver	32.1 \pm 1.0	33.9 \pm 1.6	30.4 \pm 1.3	34 \pm 1.5	30.1 \pm 1.3	33.2 \pm 1.5	31.3 \pm 1.4
Mass—fat	10.5 \pm 1.0	12.5 \pm 1.3	8.6 \pm 1.3	12.8 \pm 1.3	8.0 \pm 1.2	10.7 \pm 1.6	10.4 \pm 1.2

Table 2. Results of ANOVA tests examining the effect of collection site (around Fremont Island versus Stansbury Island) and age of bird (juveniles versus adults) on concentrations of selenium and mercury in male goldeneyes collected on the Great Salt Lake during the winter of 2005–2006 (d.f. = 1,32 for all tests).

Term	Selenium (liver)		Selenium (blood)		Mercury (liver)		Mercury (blood)	
	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Site	5.25	0.03	0.04	0.84	14.39	0.001	13.10	0.001
Age	1.61	0.21	1.38	0.25	0.37	0.55	0.06	0.81
Site X Age	2.67	0.11	1.16	0.29	0.94	0.34	1.09	0.30

Table 3. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using all male goldeneyes (juveniles and adults) collected from November 2005 through March 2006 on the Great Salt Lake, Utah (*d.f.* = 1,38 for all tests).

Variable 1	Variable 2	<i>r</i> ²	<i>F</i>	<i>P</i>
Se (liver)	Body mass	0.01	0.27	0.61
	Liver mass	0.09	3.79	0.06
	Fat mass	0.12	5.23	0.03
	Se (liver)	--	--	-
	Se (blood)	0.57	51.04	<0.001
	Hg (liver)	0.81	162.43	<0.001
	Hg (blood)	0.59	55.48	<0.001
Se (blood)	Body mass	0.01	0.25	0.62
	Liver mass	0.01	0.35	0.56
	Fat mass	0.01	0.22	0.64
	Se (liver)	see above		
	Se (blood)	--	--	--
	Hg (liver)	0.28	15.08	<0.001
	Hg (blood)	0.33	19.15	<0.001
Hg (liver)	Body mass	0.04	1.67	0.20
	Liver mass	0.09	3.73	0.06
	Fat mass	0.15	6.85	0.01
	Se (liver)	see above		
	Se (blood)	see above		
	Hg (liver)	--	--	--

	Hg (blood)	0.74	108.74	<0.001
Hg (blood)	Body mass	0.04	1.68	0.20
	Liver mass	0.01	0.07	0.80
	Fat mass	0.17	7.59	0.01
	Se (liver)	see above		
	Se (blood)	see above		
	Hg (liver)	see above		
	Hg (blood)	—	—	—

Table 4. Regression analyses between collection date (converted to an **Ordinal** day) and selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using male goldeneyes collected around Fremont Island from December 7, 2005 through January 17, 2006 and around Stansbury Island from December 7, 2005 through March 22, 2006 on the Great Salt Lake, Utah (*d.f.* = 1,18 for all tests).

Location	Dependent variable	r^2	F	P
Fremont Island				
	Body mass	0.00	0.00	0.95
	Liver mass	0.04	0.74	0.40
	Fat mass	0.05	1.00	0.33
	Se (liver)	0.53	20.58	<0.001
	Se (blood)	0.34	9.26	0.007
	Hg (liver)	0.65	33.58	<0.001
	Hg (blood)	0.66	34.34	<0.001
Stansbury Island				
	Body mass	0.06	1.27	0.28
	Liver mass	0.09	1.73	0.20
	Fat mass	0.12	2.49	0.13
	Se (liver)	0.09	1.81	0.20
	Se (blood)	0.01	0.11	0.75
	Hg (liver)	0.13	2.70	0.12
	Hg (blood)	0.08	1.49	0.23

Figure 1. Effect of collection date (**Ordinal** day 1 is November 29, 2005 while day 50 is January 17, 2006) on selenium concentrations (ug/g dry weight) in livers of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

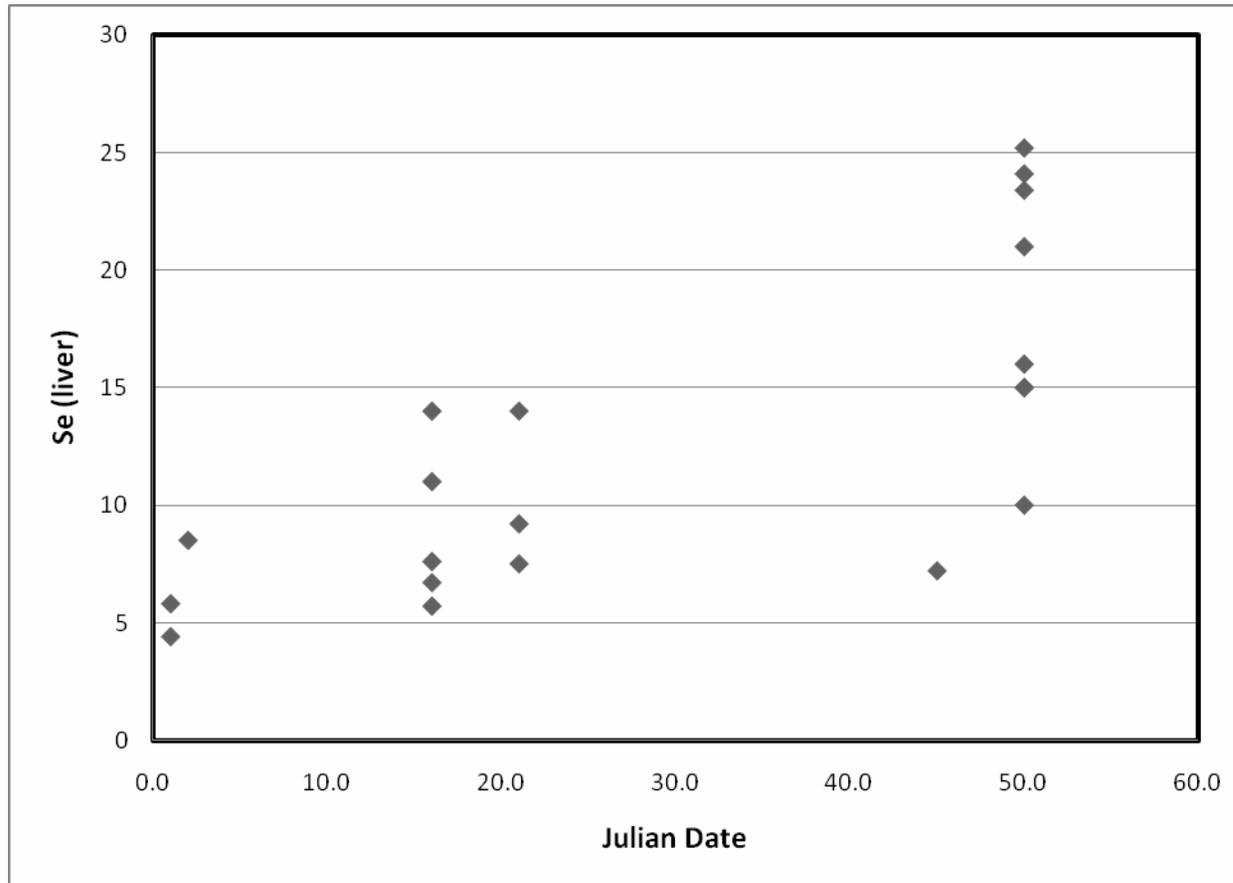


Figure 2. Effect of collection date (**Ordinal** day 1 is November 29, 2005 while day 50 is January 17, 2006) on selenium concentrations (ug/g dry weight) in blood of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

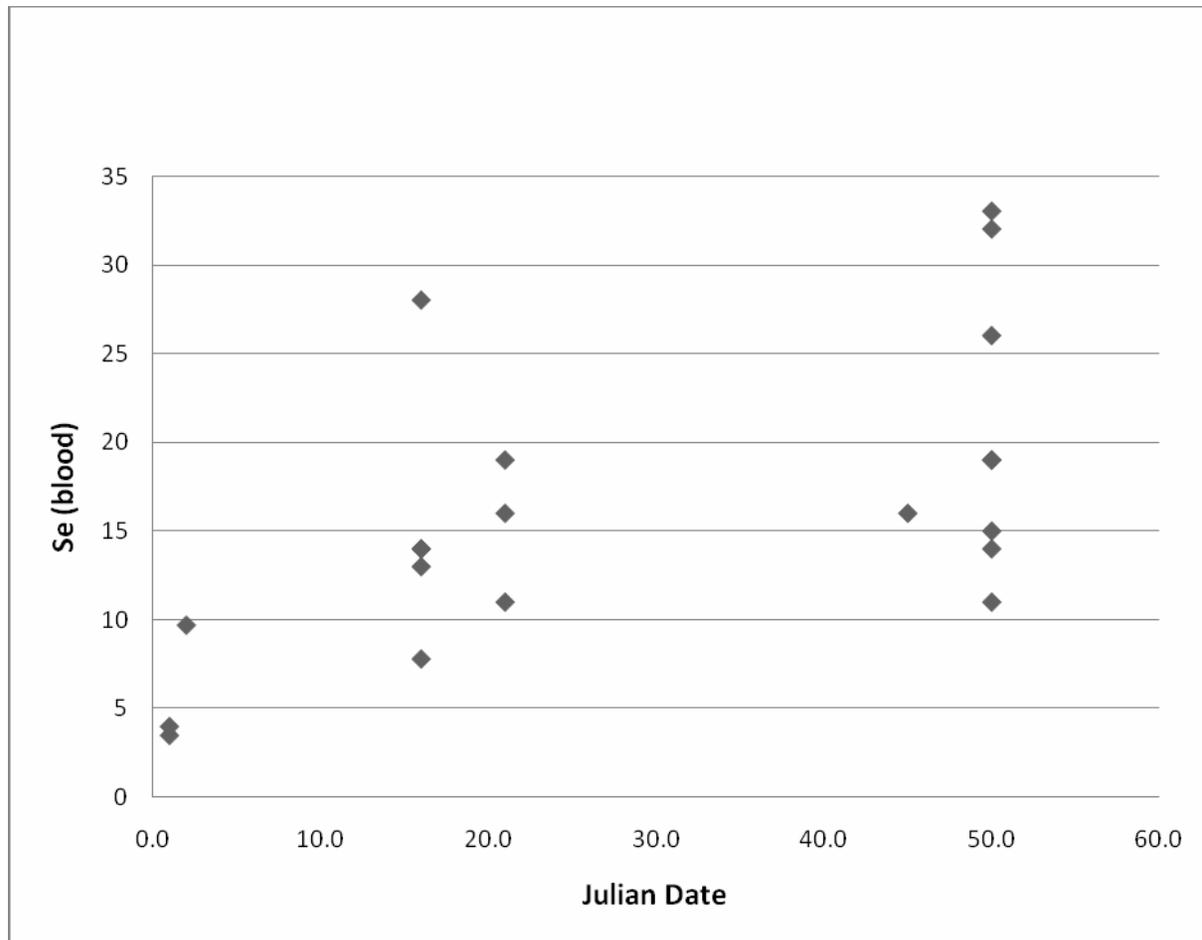


Figure 3. Effect of collection day (**Ordinal** day 1 is November 29, 2005 while day 50 is January 17, 2006) on mercury concentrations (ug/g dry weight) in livers of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

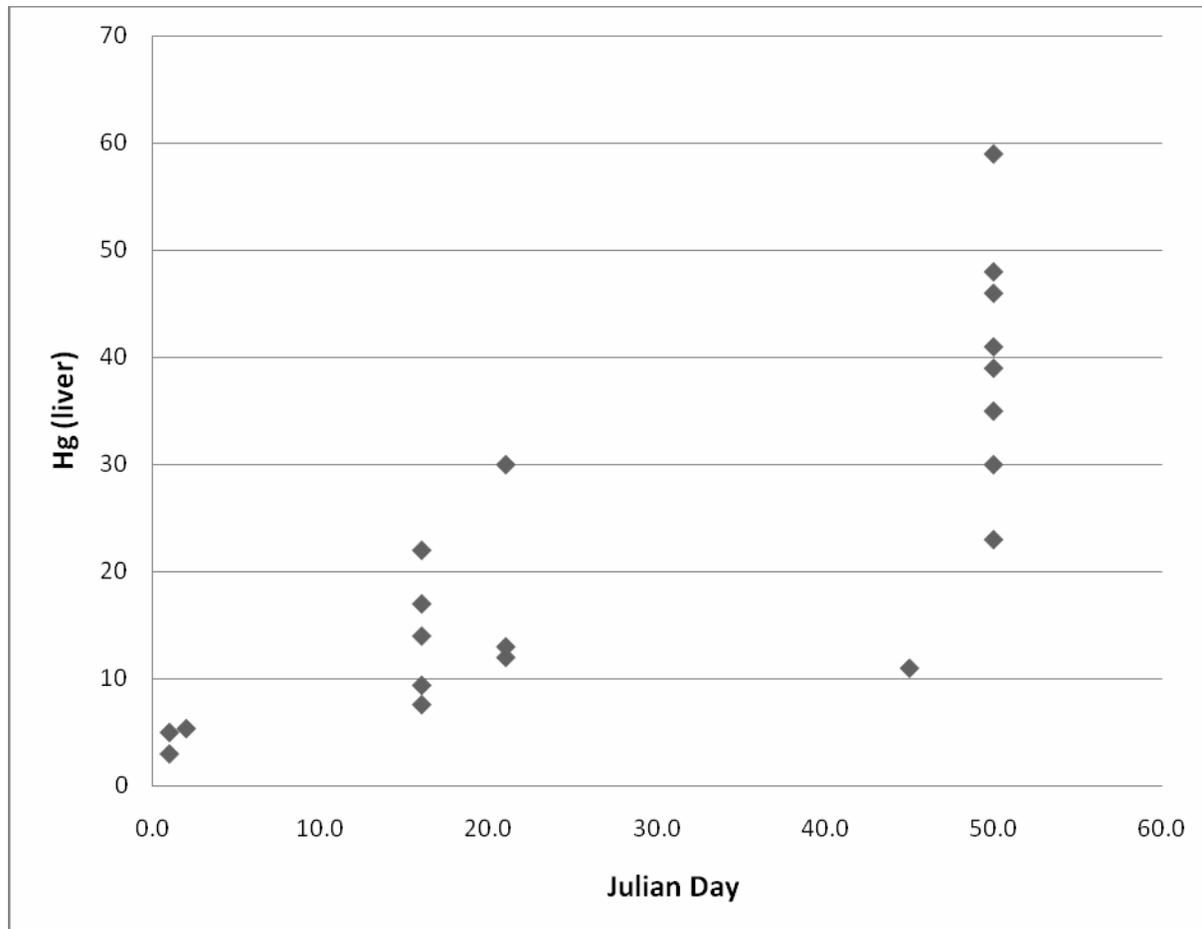
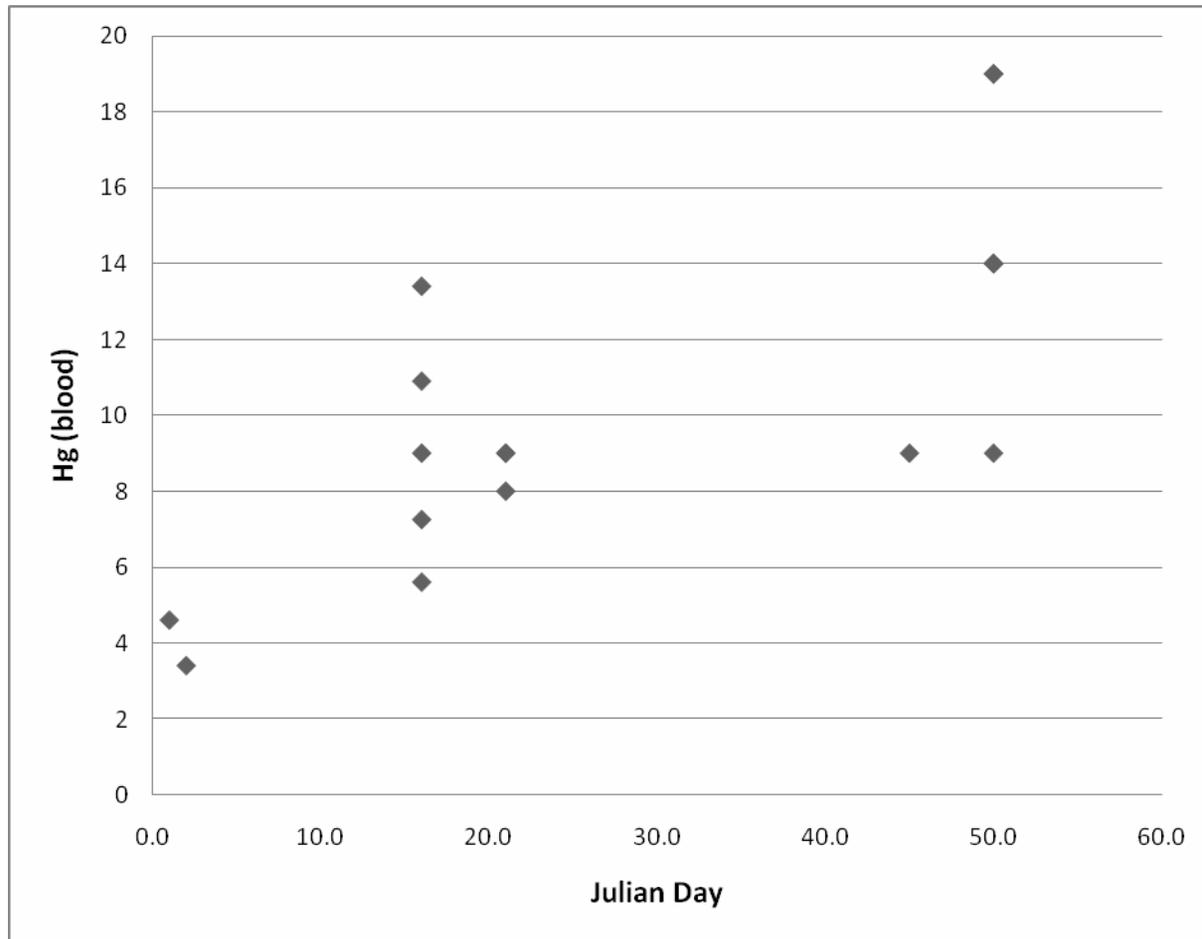


Figure 4. Effect of collection day (**Ordinal** day 1 is November 29, 2005 while day 50 is January 17, 2006) on mercury concentrations (ug/g dry weight) in the blood of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.



Appendix 1. Mass (wet weight) and concentrations of selenium and mercury (dry weight basis) of common goldeneyes collected during the winter of 2005-2006 on the Great Salt Lake, Utah.

ID No.	Age	Location	Date	Mass (g)			Se ($\mu\text{g/g}$)		Hg ($\mu\text{g/g}$)	
				Body	Liver	Fat	Liver	Blood	Liver	Blood
CG432	Adult	SW Gilbert Bay	3/6/2006	995	27	4.4	25	32	88.5	27.2
CG433	Adult	SW Gilbert Bay	3/6/2006	1074	23	21.1	3.6	1.1	1.6	0.57
CG437	Adult	SW Gilbert Bay	3/22/2006	1023	37	5.1	5.2	4	6.09	3.4
CG438	Adult	SW Gilbert Bay	3/22/2006	1045	36	11.3	25	25	80.7	23
CG439	Adult	SW Gilbert Bay	3/22/2006	1145	28	14.6	34	26	114	29
CG440	Adult	SW Gilbert Bay	3/22/2006	1155	35	5.6	18	12	62.7	27.1
CG445	Adult	SW Gilbert Bay	3/16/2006	1049	28	4.9	23	18	75.4	18.4
CG446	Adult	SW Gilbert Bay	3/16/2006	1122	33	3.8	17	13	50	14
CG450	Juv	SW Gilbert Bay	3/22/2006	992	37	3.7	27	16	94.2	25
CG456	Juv	Gilbert Bay	3/2/2006	921	34	4.0	18	17	57	30
CG469	Adult	SW Gilbert Bay	3/22/2006	1015	43	7.1	10	16	31	16
CG493	Juv	Fremont Island	12/14/2005	1203	32	28.4	6.7	14	9.39	7.25
CG494	Juv	Fremont Island	12/14/2005	1068	26	13.9	14	28	7.6	5.6

CG495	Juv	Fremont Island	12/14/2005	1194	48	16.7	7.6	14	17	13.4
CG497	Juv	Farmington Bay	11/30/2005	1008	39	7.3	8.5	9.7	5.36	3.4
CG513	Juv	Fremont Island	12/14/2005	1018	36	10.1	5.7	7.8	14	10.9
CG514	Juv	Fremont Island	12/14/2005	962	28	5.4	11	13	22	8.95
CG515	Adult	Fremont Island	12/19/2005	1246	39	10.7	7.5	11	11.9	8.14
CG516	Adult	Fremont Island	12/19/2005	1221	37	24.8	9.2	19	12.7	9.24
CG517	Adult	Fremont Island	12/19/2005	1164	32	10.4	14	16	30	9.31
CG523	Juv	Farmington Bay	1/12/2006	1050	34	14.8	7.2	16	10.8	8.98
CG545	Adult	Gilbert Bay	2/16/2006	1017	32	5.8	11	17	23	15
CG555	Adult	Fremont Island	1/17/2006	1238	47	11.5	21	32.2	30	19
CG565	Adult	Fremont Island	1/17/2006	1082	27	6.1	23.4	19	41	9.1
CG566	Adult	Fremont Island	1/17/2006	1038	33	6.1	16	15	48	14
CG587	Juv	Fremont Island	1/17/2006	1050	30	9.8	10	11	23	14
CG594	Juv	Gilbert Bay	12/7/2005	1191	36	19.0	5.5	7.8	11.6	8.5
CG596	Adult	Carrington Bay	2/9/2006	1089	24	9.1	18	22.9	51.4	16
CG600	Adult	Carrington Bay	2/9/2006	1130	22	9.6	17	13	44	13.2
CG601	Adult	Carrington Bay	2/9/2006	1058	26	5.3	20	19	52.1	22.8
CG606	Juv	Fremont Island	11/29/2005	1094	42	9.5	4.4	3.5	5.07	4.6
CG616	Juv	Carrington Bay	2/9/2006	960	28	4.9	20	23	63.9	23.2

CG617	Adult	Carrington Bay	2/9/2006	1159	22	20.7	21.8	22	65	16
CG621	Juv	Carrington Bay	2/9/2006	954	29	5.1	22.1	24	39	15
CG622	Juv	Carrington Bay	2/9/2006	1052	27	6.2	19	14	71.2	19
CG626	Adult	Fremont Island	1/17/2006	1254	36	14.5	24.1	33	39	19
CG627	Adult	Fremont Island	1/17/2006	1142	26	10.3	25.2	26	59.1	14
CG642	Juv	Fremont Island	1/17/2006	1056	36	11.9	15	19	35	15
CG644	Juv	Fremont Island	1/17/2006	1043	23	10.5	15	14	46	15
CG665	Adult	Fremont Island	11/29/2005	1150	27	17.0	5.8	4.3	2.8	2.2
