Sea Duck Joint Venture
Annual Project Summary for Endorsed Projects
FY 2007–(October 1, 2006 to Sept 30, 2007)

Project Title: No. 94: Inorganic Contaminant Concentrations and Body Condition of Common Goldeneye Wintering on the Great Salt Lake, Utah

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Partners: Utah Division of Wildlife Resources Great Salt Lake Ecosystem Project, Utah Division of Water Quality, Utah Veterinary Diagnostic Laboratory, Utah State University

Project Description: The Great Salt Lake (GSL) is the fourth largest terminal lake in the world and is an important region for breeding and migratory waterbirds and wintering common goldeneye (Aldrich and Paul 2002, J. Vest unpublished data). Because the GSL is a closed basin, contaminants (e.g., mercury, selenium, cadmium, and others) associated with industrial and urban development in the Salt Lake Valley or from non-local sources (e.g., atmospheric deposition) may accumulate in the GSL system (Waddell 1998, Brix et al. 2004, Naftz et al. 2005). Recently, water and sediment samples from the GSL revealed high concentrations of mercury and selenium and methylmercury concentrations in GSL water samples were among the highest ever recorded in surface water by the USGS Mercury Laboratory (Waddell 1998, Naftz et al. 2005). Thus, GSL waterfowl are likely exposed to these contaminants and elevated contaminant concentrations may adversely affect survival and reproduction in waterfowl (reviewed in Takekawa et al. 2002). Indeed, mercury concentrations identified in a 2005 reconnaissance investigation were the highest among published results for common goldeneye (Gerstenberger et al. 2004, Vest et al. 2006). Although the continental population of common goldeneye are relatively stable compared to other North American sea duck populations (e.g., eider and scoter spp.), insight into relationships between trace elements and goldeneye body condition will be useful in understanding potential impacts of trace elements and contaminants for other sea duck populations. Determining trace element concentrations in common goldeneye wintering on GSL presents a potentially unique opportunity to understand physiological relationships with high contaminant concentrations (e.g., mercury) in a population of wild migratory sea ducks.

Objectives: 1) Document hepatic inorganic trace element concentrations including arsenic, boron, cadmium, copper, lead, mercury, selenium, and zinc in common goldeneye wintering on GSL; 2) Evaluate temporal variation in hepatic trace element concentrations in common goldeneye wintering on GSL; 3) Evaluate relationships between hepatic trace element concentrations and measure of physiological condition (e.g., lipid, protein, and mineral reserves; body, spleen, pancreas masses) of common goldeneye with respect to temporal variation, sex, and age class.

Preliminary Results:

Trace Element Concentrations and Temporal Variation

We submitted 240 common goldeneye liver samples collected from GSL during winters 2004–05 and 2005-06 to Utah Veterinary Diagnostic Laboratory and obtained 30 trace element values per sample. We conducted sex specific analyses to evaluate variation in trace element concentrations with respect to age (hatch year or after hatch year) and temporal variation (year, winter period). We used multivariate analysis of variance (MANOVA) to evaluate if 28 trace element concentrations differed in relation to age, year, collection period (early, mid, and late winter), and all interactions. We did not include silver (Ag) or beryllium (Be) in the MANOVA due to low detection rates (≥ 60% nondetection rates for all [Be] or most temporal categories [Ag]; Table 1,2). We detected a significant year*period interaction for male (Wilks' λ=0.288, $P < 0.001$) and female (Wilks' λ=0.295, $P < 0.001$) goldeneye and a year*age interaction for male goldeneye (Wilks' λ=0.623, $P = 0.018$). Subsequent ANOVAs of male goldeneye trace elements detected year*age interactions for Ca, Ni, and Sr ($P < 0.05$) only. Main effects of year, period, and age were significant for both male and female goldeneye (Wilks' λ=0.097–0.393, $P < 0.001$). We present year and period specific trace element concentrations for male and female goldeneye to simplify presentation of summary statistics and to identify which elements may be of biological concern (Table 1,2). Future analyses will evaluate age specific variation of trace elements in male and female goldeneye.

Inspection of trace element concentrations indicated that most elements were within normal ranges. However, Hg and Se concentrations were elevated (Hg: 1.0 ppm, Se: 3.0 ppm) or at potentially harmful levels (Hg: 30 ppm, Se: 10 ppm) for many year and period categories in both sexes (Table 1,2; Heinz 1996, Thompson 1996). Therefore, we further evaluated temporal trends in Hg and Se concentrations. Subsequent ANOVAs indicated only a period effect in Hg and Se concentrations in both sexes ($P < 0.001$). Thus, we pooled data across years to assess linear trends in temporal variation of Hg and Se concentrations for each sex. Female Hg concentrations exhibited a curvilinear relationship to collection day, thus a quadratic term was included in the model (Figure 1). Male Hg and Se concentrations of both sexes exhibited positive relationships with collection day (Figure 1).

Trace Element Concentrations and Physiological Condition

We obtained estimates of total body lipid, protein, and mineral content for each goldeneye reported above by standardized methods from Bird Studies Canada's Avian Energetics Lab (http://www.avianenergeticslab.com). We also obtained external morphometrics and internal organ masses during necropsy procedures at USU. We conducted separate ANCOVAs for lipid, protein, mineral, spleen, and pancreas masses for each sex to evaluate effects of log transformed Hg, Se, and Cd on each measure of body condition while controlling for body size, liver mass, and collection day and designating year as a random term (PROC MIXED, SAS 2002). Although Cd concentrations were generally within normal ranges for most of our samples, we included this element into our models because Cd has been related to body condition of other sea duck species (Fisk et al. 2005). We included a Se*Hg interaction and a quadratic term for selenium (non-log transformed) in our initial models. We used backward elimination procedures ($\alpha = 0.05$) to select final models (Zar 1999). For each significant trace element effect of interest we plotted and calculated the type III partial relationship and r^2, respectively, as described in Anteau et al. (2007). We observed a weak positive relationship between total body lipid content and Se concentrations in both male ($r^2 = 0.13$, $P < 0.001$) and female ($r^2 = 0.04$, $P = 0.023$) goldeneye (Figure 2). However, we did not detect any significant relationship between trace elements concentration and protein and mineral reserves. We found significant but weak negative relationships between female spleen mass and Hg concentrations ($r^2 = 0.08$, $P = 0.002$) as well as between male pancreas mass and Hg ($r^2 = 0.06$, $P = 0.010$) and Cd ($r^2 = 0.07$, $P = 0.004$) concentrations (Figure 3).

Briefly, Hg concentrations in our samples are much higher than those reported in the literature for common goldeneye and among the highest values reported for many other waterfowl species. Se concentrations were elevated in a large proportion of our samples. Similar to our findings, a positive correlation between lipid levels and Se concentrations has been reported for wintering and migratory lesser scaup (Anteau et al. 2007). Hg and Se concentrations were highly correlated for both female ($r = 0.52$, $P < 0.001$) and male $r = 0.75$, $P < 0.001$) goldeneye. Some aquatic vertebrates may detoxify either Hg or Se by forming biologically inert compounds such as mercuric selenide (HgSe) (Ohlendorf

2002, Ikemoto et al. 2004) and may partially explain the relatively weak or lack of correlations observed in our preliminary analyses.

Project Status: Trace element concentrations have been obtained for all goldeneye liver samples submitted to Utah Veterinary Diagnostic Lab. Future analyses will evaluate inclusion of other trace element known to interact with and influence Se and Hg concentrations (e.g., As*Se, B*Se). We anticipate completion of analytical procedures and submission of final report to SDJV December 2007.

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Table 1. Geometric mean concentrations (µg/g wet weight [ppm]), 95% CI, and ranges of trace elements in liver tissues of female common goldeneye collected from Great Salt Lake, Utah during winters 2004-2005 and 2005-2006. Values were combined across age classes within year and collection periods.

		2004-2005			2005-2006		
Element	Detection Limit	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 17)	Mar–Apr (*n* = 23)	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 20)	Mar–Apr (*n* = 20)
Ag	0.001	0.022	ND[a]	0.024	0.008	ND	0.016
		(0.012–0.040)		(0.012–0.048)	(0.005–0.014)		(0.010–0.025)
		(0.001–0.161)	(9nd[b]–0.007	(3nd–0.593)	(1nd–0.054)	(15nd–0.038)	(1nd–0.129)
Al	0.001	0.08	0.21	0.13	0.23	0.15	0.24
		(0.05–0.13)	(0.17–0.27)	(0.08–0.20)	(0.19–0.27)	(0.11–0.19)	(0.18–0.34)
		(1nd–0.37	(0.09–0.78)	(6nd–0.53)	(0.13–0.60)	(0.06–0.97)	(0.08–1.50)
As	0.001	0.32	0.34	0.33	0.45	0.45	0.45
		(0.26–0.39)	(0.28–0.42)	(0.29–0.39)	(0.37–0.55)	(0.37–0.55)	(0.39–0.52)
		(0.10–0.68)	(0.21–1.0)	(0.12–0.55)	(0.22–1.34)	(0.10–0.78)	(0.27–0.89)
B	0.001	1.08	1.18	0.82	1.41	1.21	1.13
		(0.84–1.37)	(0.94–1.47)	(0.66–1.01)	(1.19–1.68)	(0.93–1.59)	(1.00–1.35)
		(0.34–2.21)	(0.45–2.54)	(0.29–2.61)	(0.46–2.11	(0.37–2.37)	(0.46–2.25)
Ba	0.001	0.05	0.08	0.10	0.05	0.10	0.08
		(0.03–0.07)	(0.04–0.16)	(0.06–0.15)	(0.04–0.08)	(0.06–0.15)	(0.05–0.12)
		(0.01–0.47)	(0.02–0.96)	(0.03–1.66)	(0.02–0.23)	(0.03–0.93)	(0.02–0.71)
Ca	0.01	108	151	140	138	161	97.9
		(90–129)	(115–198)	(117–167)	(110–176)	(127–204	(81.1–118)
		(51–272)	(63–455)	(71–316)	(51–366)	(80–529)	(48.7–243)
Cd	0.001	0.26	0.20	0.38	0.16	0.19	0.32
		(0.16–0.41)	(0.15–0.27)	(0.29–0.50)	(0.10–0.25)	(0.12–0.28)	(0.25–0.42)
		(0.05–1.01)	(0.08–0.50)	(0.11–1.32)	(0.03–1.12)	(0.05–0.95)	(0.10–0.91)
Co	0.001	0.043	0.042	0.052	0.039	0.042	0.050
		(0.038–0.048)	(0.038–0.046)	(0.045–0.059)	(0.034–0.043)	(0.035–0.050)	(0.045–0.056)
		(0.022–0.060)	(0.025–0.056)	(0.023–0.095)	(0.021–0.054)	(0.021–0.077)	(0.030–0.076)
Cr	0.001	0.23	0.22	0.24	0.19	0.22	0.20
		(0.20–0.26)	(0.21–0.23)	(0.23–0.25)	(0.18–0.20)	(0.21–0.24)	(0.19–0.21)
		(0.17–0.61)	(0.19–0.26)	(0.21–0.29)	(0.17–0.22)	(0.17–0.27)	(0.17–0.23
Cu	0.001	14.6	10.4	14.2	12.4	12.4	13.7
		(12.6–17.0)	(9.1–11.9)	(11.8–17.2)	(10.4–17.7)	(10.9–14.1)	(11.5–16.4)
		(9.1–25.6)	(7.0–16.6)	(6.4–33.0)	(7.0–21.1)	(8.4–19.7)	(7.8–42.7)
Fe	0.001	698	492	888	694	720	632
		(569–857)	(405–598)	(714–1104)	(557–863)	(604–860)	(506–790)
		(200–1467)	(132–840)	(351–1808)	(211–1224)	(344–1283)	(265–1724)
Hg	0.0001	3.18	16.30	6.38	3.00	12.16	12.14
		(2.19–4.62)	(10.61–25.06)	(3.60–11.30)	(2.09–4.32)	(7.30–20.27)	(7.63–19.30)
		(0.87–10.08)	(3.14–38.35)	(1.00–31.01)	(0.96–13.76)	(0.432–32.41)	(1.892–46.06)
K	0.01	3080	2812	2979	3100	3080	3035
		(2982–3181)	(2699–2929)	(2887–3074)	(3008–3195)	(2991–3172)	(2956–3116)
		(2615–3408)	(2394–3232)	(2400–3288)	(2652–3394)	(2753–3503)	(2812–3487)
Li	0.001	0.12	0.22	0.08	0.19	0.18	0.16
		(0.08–0.19)	(0.19–0.26)	(0.06–0.12)	(0.15–0.22)	(0.16–0.21)	(0.12–0.20)
		(.02–0.51)	(0.12–0.33)	(0.02–0.29)	(0.10–0.47)	(0.10–0.34)	(0.03–0.40)

Table 1. continued

		2004-2005			2005-2006		
Element	Detection Limit	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 17)	Mar–Apr (*n* = 23)	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 20)	Mar–Apr (*n* = 20)
Mg	0.01	311	302	311	296	301	285
		(266–365)	(260–350)	(270–359)	(252–348)	(262–344)	(256–317)
		(209–629)	(217–594)	(217–658)	(210–660)	(227–782)	(220–648)
Mn	0.001	4.94	5.45	5.26	5.11	5.42	5.37
		(4.24–5.75)	(4.93–6.01)	(4.69–5.90)	(4.63–5.63)	(4.86–6.05)	(4.92–5.86)
		(2.59–9.53)	(4.07–7.80)	(2.55–7.61)	(3.47–7.64)	(3.11–8.26)	(3.37–7.37)
Mo	0.001	1.05	0.85	0.97	1.00	0.97	0.97
		(0.97–1.14)	(0.79–0.91)	(0.88–1.07)	(0.92–1.09)	(0.90–1.05)	(0.85–1.11)
		(0.82–1.39)	(0.62–1.09)	(0.67–1.60)	(0.72–1.30)	(0.69–1.35)	(0.70–2.71)
Na	0.01	979	1084	992	936	945	924
		(904–1060)	(1036–1135)	(941–1047)	(877–999)	(876–1020)	(865–986)
		(787–1656)	(891–1241)	(842–1465)	(627–1143)	(682–1337)	(733–1256)
Ni	0.001	0.012	0.018	0.014	0.011	0.018	0.013
		(0.009–0.015)	(0.016–0.019)	(0.013–0.016)	(0.010–0.013)	(0.016–0.020)	(0.012–0.014)
		(0.006–0.041)	(0.012–0.029)	(0.007–0.024)	(0.006–0.022)	(0.011–0.025)	(0.010–0.021)
P	0.001	4426	4413	4812	4906	4381	4583
		(4279–4578)	(4293–4536)	(4541–5099)	(4758–5058)	(4219–4549)	(4416–4756)
		(3756–5005)	(3856–4698)	(4056–6475)	(4324–5354)	(3637–4983	(3894–5094)
Pb	0.001	0.14	0.34	0.29	0.19	0.40	0.37
		(0.10–0.21)	(0.28–0.42)	(0.23–0.37)	(0.14–0.26)	(0.27–0.61)	(0.28–0.50)
		(0.03–0.41)	(0.16–0.67)	(0.06–1.02)	(0.06–0.48)	(0.02–1.26)	(0.09–1.01)
Sb	0.001	0.005	0.011	0.005	0.005	0.015	0.005
		(0.003–0.008)	(0.007–0.017)	(0.004–0.007)	(0.003–0.008)	(0.010–0.022)	(0.004–0.008)
		(1nd–0.025)	(0.004–0.048)	(0.002–0.017)	0.001–0.040)	(0.003–0.077)	(0.001–0.019)
Se	0.001	2.58	5.38	6.91	2.82	5.41	5.26
		(2.12–3.12)	(4.40–6.58)	(5.56–8.58)	(2.40–3.32)	(4.63–6.33)	(4.06–6.81)
		(1.09–6.60)	(2.26–10.85)	(1.88–15.44)	(1.63–5.73)	(2.74–11.06)	(1.44–12.33)
Si	0.001	25.5	27.5	25.0	25.6	27.2	20.9
		(23.1–28.1)	26.9–28.2)	(23.4–26.6)	(24.1–27.1)	(26.0–28.5)	(19.4–22.6)
		(19.2–36.1)	(25.8–30.0)	(20.3–34.0)	(19.6–30.6)	(22.7–35.5)	(17.1–34.4)
Sn	0.001	0.003	0.005	0.002	0.002	0.003	0.002
		(0.002–0.004)	(0.003–0.007)	(0.001–0.003)	(0.001–0.003)	(0.002–0.006)	(0.001–0.003)
		(0.001–0.029)	(0.001–0.013)	(0.001–0.011)	(0.001–0.033)	(3nd–0.011)	(1nd–0.016)
Sr	0.001	0.38	0.27	0.47	0.32	0.31	0.28
		(0.28–0.51)	(0.16–0.45)	(0.33–0.66)	(0.22–0.48)	(0.18–0.55)	(0.19–0.42)
		(0.13–1.76)	(0.06–2.27)	(0.17–2.27)	(0.09–1.35)	(0.06–4.94)	(0.07–1.47)
Tl	0.001	0.001	0.001	0.002	0.001	0.001	0.002
		(0.001–0.002)	(0.001–0.002)	(0.001–0.002)	(0.001–0.002)	(0.001–0.002)	(0.002–0.002)
		(0.001–0.003)	(6nd–0.003)	(1nd–0.008)	(0.001–0.004)	(4nd–0.003)	(0.002–0.003)
V	0.001	0.033	0.031	0.040	0.021	0.034	0.024
		(0.027–0.041)	(0.027–0.035)	(0.032–0.050)	(0.018–0.024)	(0.030–0.038)	(0.021–0.027)
		(0.020–0.136)	(0.020–0.054)	(0.018–0.155)	(0.014–0.038)	(0.020–0.057)	(0.015–0.059)
Zn	0.001	41.0	39.2	40.6	39.4	40.3	39.4
		(38.4–43.9)	(36.4–42.3)	(37.7–43.7)	(36.7–42.2)	(36.5–44.5)	(36.9–42.2)
		(31.2–53.7)	(27.7–49.9)	(26.3–56.1)	(29.8–55.5)	(22.6–64.9)	(30.2–50.6)

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[a] 60% of samples below detection limit

[b] ≥ Number of samples below detection limit

Table 2. Geometric mean concentrations (µg/g wet weight [ppm]), 95% CI, and ranges of trace elements in liver tissues of male common goldeneye collected from Great Salt Lake, Utah during winters 2004-2005 and 2005-2006. Values were combined across age classes within year and collection periods.

		2004-2005			2005-2006		
Element	Detection Limit	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 17)	Mar–Apr (*n* = 23)	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 20)	Mar–Apr (*n* = 20)
Ag	0.001	0.012	ND[b]	0.026	ND	ND	ND
		(0.007–0.019)		(0.014–0.047)			
		(1nd[a]–0.080)	(15nd–0.010)	(3nd–0.329)	(12nd–0.009)	(16nd–0.011)	(18nd–0.003)
Al	0.001	0.21	0.19	0.28	0.28	0.27	0.27
		(0.15–0.30)	(0.14–0.27)	(0.22–0.36)	(0.23–0.35)	(0.23–0.31)	(0.21–0.35)
		(0.06–1.59)	(0.08–0.89)	(0.15–2.35)	(0.13–0.77)	(0.17–0.57)	(0.11–0.82)
As	0.001	0.37	0.43	0.37	0.38	0.37	0.46
		(0.28–0.49)	(0.34–0.54)	(0.31–0.44)	(0.30–0.47)	(0.27–0.49)	(0.36–0.58)
		(0.09–0.75)	(0.19–0.89)	(0.13–0.61)	(0.09–0.68)	(0.09–0.97)	(0.20–1.27)
B	0.001	1.16	1.31	1.13	1.10	0.94	1.10
		(0.85–1.59)	(1.05–1.62)	(0.91–1.41)	(0.83–1.46)	(0.69–1.29)	(0.92–1.33)
		(0.25–2.98)	(0.43–2.54)	(0.40–2.72)	(0.12–2.34)	(0.19–1.89)	(0.37–2.04)
Ba	0.001	0.09	0.09	0.07	0.08	0.10	0.09
		(0.05–0.16)	(0.06–0.15)	(0.05–0.11)	(0.05–0.12)	(0.06–0.16)	(0.05–0.15)
		(0.02–1.24)	(0.02–0.58)	(0.02–0.87)	(0.03–0.48)	(0.02–1.27)	(0.01–0.46)
Ca	0.01	152	155	124	144	120	142
		(106–217)	(119–201)	(92–168)	(124–166)	(100–145)	(113–179)
		(71-1451)	(87–514)	(70–2405)	(87–345)	(65–325)	(79–401)
Cd	0.001	0.31	0.32	0.43	0.22	0.33	0.31
		(0.18–0.53)	(0.19–0.52)	(0.33–0.57)	(0.13–0.37)	(0.20–0.52)	(0.20–0.50)
		(0.04–1.32)	(0.07–1.35)	(0.13–1.37)	(0.05–2.04)	(0.08–2.04)	(0.04–1.86)
Co	0.001	0.044	0.054	0.049	0.044	0.045	0.050
		(0.040–0.049)	(0.042–0.071)	(0.045–0.054)	(0.038–0.050)	(0.036–0.055)	(0.043–0.058)
		(0.029–0.078)	(0.033–0.350)	(0.029–0.066)	(0.025–0.074)	(0.018–0.090)	(0.018–0.073)
Cr	0.001	0.21	0.21	0.26	0.23	0.26	0.27
		(0.21–0.22)	(0.19–0.22)	(0.23–0.29)	(0.21–0.25)	(0.23–0.28)	(0.25–0.28)
		(0.18–0.26)	(0.16–0.25)	(0.15–0.45)	(0.17–0.30)	(0.19–0.43)	(0.22–0.36)
Cu	0.001	12.3	11.2	10.6	15.4	13.3	11.9
		(10.2–14.7)	(7.9–15.7)	(8.9–12.8)	(13.6–17.5)	(12.0–14.6)	(9.9–14.3)
		(7.0–36.9)	(6.5–117)	(5.8–25.0)	(9.7–27.6)	(8.1–18.1)	(5.5–37.0)
Fe	0.001	960	595	1044	920	874	766
		(808–1142)	(436–813)	(854–1276)	(786–1075)	(718–1064)	(600–979)
		(601–2292)	(143–1310)	(550–2900)	(569–2088)	(354–1897)	(303–2082)
Hg	0.0001	4.87	15.1	11.8	3.97	14.05	15.7
		(3.02–7.85)	(11.1–22.6)	(6.27–22.4)	(2.83–5.57)	(10.5–18.8)	(8.92–27.6)
		(1.02–33.7)	(1.41–31.9)	(0.27–71.5)	(0.85–24.0)	(3.84–29.0)	(0.65–48.8)
K	0.01	3138	2930	2989	3075	3082	3083
		(2991–3293)	(2812–3053)	(2874–3109)	(3007–3144)	(2982–3185)	(2983–3186)
		(2651–3634)	(2575–3522)	(2594–3559)	(2830–3376)	(2739–3551)	(2577–3417)
Li	0.001	0.16	0.24	0.16	0.20	0.18	0.17
		(0.13–0.20)	(0.20–0.28)	(0.10–0.24)	(0.16–0.25)	(0.13–0.25)	(0.12–0.23)
		(0.05–0.34)	(0.15–0.38)	(0.04–1.94)	(0.06–0.70)	(0.02–0.52)	(0.02–0.43)

Table 2. continued.

		2004-2005			2005-2006		
Element	Detection Limit	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 17)	Mar–Apr (*n* = 23)	Nov–Dec (*n* = 20)	Jan–Feb (*n* = 20)	Mar–Apr (*n* = 20)
Mg	0.01	352	348	251	292	295	274
		(270–458)	(277–439)	(227–278)	(263–325)	(253–343)	(234–320)
		(228–1492)	(221–946)	(192–459)	(242–628)	(207–693)	(193–705)
Mn	0.001	6.87	6.51	5.09	6.77	6.14	5.26
		(5.48–8.62)	(5.57–7.60)	(4.54–5.71)	(5.97–7.68)	(5.45–6.91)	(4.96–5.58)
		(4.26-25.6)	(4.35–13.9)	(3.45–9.22)	(4.97–14.6)	(4.49–13.3)	(3.67–6.30)
Mo	0.001	1.12	0.95	1.08	1.06	1.12	1.06
		(0.99–1.27)	(0.84–1.07)	(0.99–1.17)	(0.95–1.20)	(1.01–1.25)	(0.85–1.32)
		(0.78–2.40)	(0.70–1.85)	(0.78–1.81)	(0.79–2.34)	(0.72–1.98)	(0.63–5.83)
Na	0.01	962	1079	1135	1100	1033	1089
		(913–1013)	(996–1167)	(1036–1244)	(1012–1195)	(954–1119)	(1018–1166)
		(779–1130)	(777–1338)	(757–2140)	(843–1844)	(682–1298)	(865–1422)
Ni	0.001	0.016	0.021	0.018	0.016	0.018	0.018
		(0.013–0.020)	(0.017–0.027)	(0.016–0.020)	(0.013–0.020)	(0.016–0.019)	(0.016–0.020)
		(0.009–0.060)	(0.014–0.105)	(0.012–0.045)	(2nd–0.027)	(0.012–0.031)	(0.013–0.032)
P	0.001	4751	4533	5408	4656	4501	4631
		(4548–4962)	(4370–4701)	(5051–5790)	(4444–4878)	(4339–4669)	(4430–4841)
		(4034–5772)	(3980–5348)	(4093–6875)	(3736–5396)	(3866–5343)	(3967–5487)
Pb	0.001	0.17	0.35	0.35	0.21	0.42	0.32
		(0.12–0.22)	(0.28–0.46)	(0.27–0.46)	(0.14–0.32)	(0.37–0.48)	(0.23–0.46)
		(0.04–0.46)	(0.18–1.01)	(0.06–1.00)	(0.04–1.42)	(0.26–0.89)	(0.07–1.06)
Sb	0.001	0.006	0.021	0.009	0.022	0.021	0.019
		(0.004–0.008)	(0.012–0.035)	(0.006–0.014)	(0.014–0.031)	(0.015–0.029)	(0.014–0.026)
		(1nd–0.021)	(0.006–0.130)	(0.004–0.277)	(0.007–0.108)	(0.007–0.089)	(0.007–0.065)
Se	0.001	2.36	5.89	6.62	3.20	5.64	6.97
		(2.09–2.67)	(4.96–6.98)	(5.28–8.31)	(2.62–3.91)	(4.72–6.75)	(5.27–9.24)
		(1.73–4.39)	(2.75–10.5)	(1.26–16.0)	(1.49–9.35)	(2.51–8.65)	(1.30–13.6)
Si	0.001	30.4	29.8	33.6	34.6	28.1	31.6
		(27.4–33.8)	(28.5–31.0)	(31.2–36.1)	(32.2–37.1)	(27.2–29.0)	(30.3–33.0)
		(16.1–48.0)	(24.0–33.1)	(22.5–47.0)	(30.1–50.9)	(25.2–32.6)	(28.1–37.5)
Sn	0.001	0.003	0.003	0.003	0.003	0.003	0.009
		(0.002–0.004)	(0.002–0.006)	(0.002–0.004)	(0.002–0.006)	(0.002–0.005)	(0.005–0.015)
		(2nd–0.084)	(0.001–0.051)	(0.001–0.028)	(1nd–0.293)	(0.001–0.047)	(0.002–0.090)
Sr	0.001	0.55	0.39	0.34	0.35	0.27	0.30
		(0.30–1.02)	(0.22–0.69)	(0.21–0.55)	(0.24–0.51)	(0.18–0.40)	(0.18–0.48)
		(0.08–15.5)	(0.07–4.50)	(0.15–28.4)	(0.10–2.51)	(0.08–1.82)	(0.10–3.78)
Tl	0.001	0.002	0.002	0.001	0.002	0.002	0.001
		(0.001–0.002)	(0.001–0.004)	(0.001–0.002)	(0.001–0.002)	(0.001–0.002)	(0.001–0.002)
		(0.001–0.011)	(4nd–0.040)	(0.001–0.007)	(3nd–0.005)	(3nd–0.007)	(1nd–0.003)
V	0.001	0.031	0.027	0.036	0.041	0.035	0.029
		(0.027–0.035)	(0.022–0.033)	(0.030–0.043)	(0.037–0.046)	(0.031–0.040)	(0.026–0.033)
		(0.022–0.055)	(0.012–0.052)	(0.022–0.094)	(0.022–0.062)	(0.024–0.062)	(0.021–0.047)
Zn	0.001	46.5	42.1	42.0	51.0	47.4	44.1
		(42.5–51.0)	(39.5–44.9)	(39.4–44.8)	(48.3–53.9)	(44.5–50.5)	(40.4–48.3)
		(35.7–71.8)	(32.7–54.3)	(33.4–54.9)	(36.9–58.7	(36.4–57.8)	(26.2–59.7)

[a] Number of samples below detection limit

[b] ≥ 60% of samples below detection limit

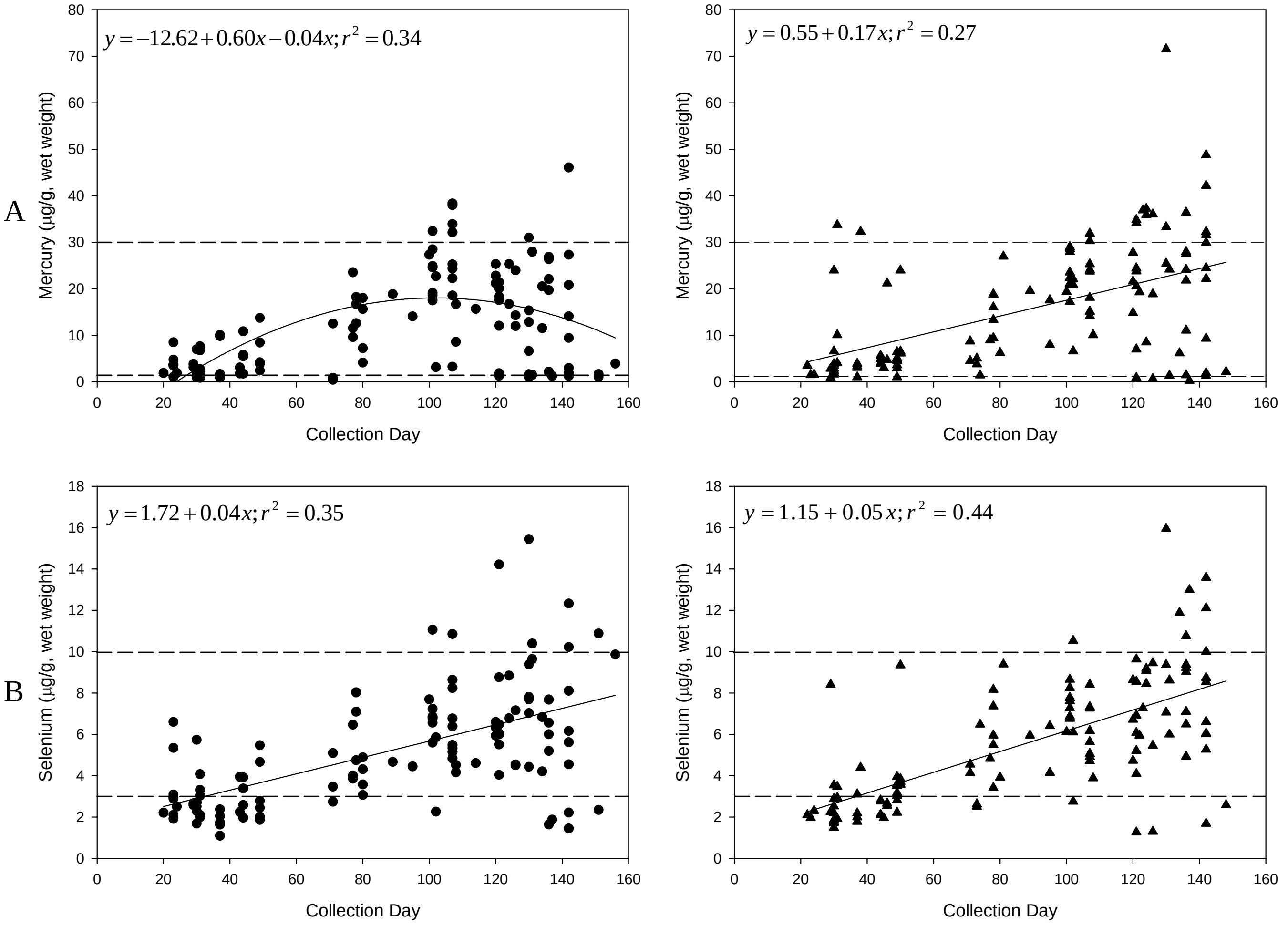

Figure 1. Temporal dynamics of Hg (A) and Se (B) concentrations (µg/g, wet weight [ppm]) in liver tissues of female (circles) and male (triangles) common goldeneye collected from Great Salt Lake, Utah winters 2004–05 and 2005–06. The horizontal dashed lines in A at 1.0 ppm and 30 ppm represent the thresholds above which concentrations may be considered elevated and potentially harmful, respectively, for other waterbirds. The horizontal dashed lines in B at 3.0 and 10 ppm represents the thresholds above which mallards may experience reproductive impairment and health-related problems, respectively. Day 0 on X axis represents November 1.

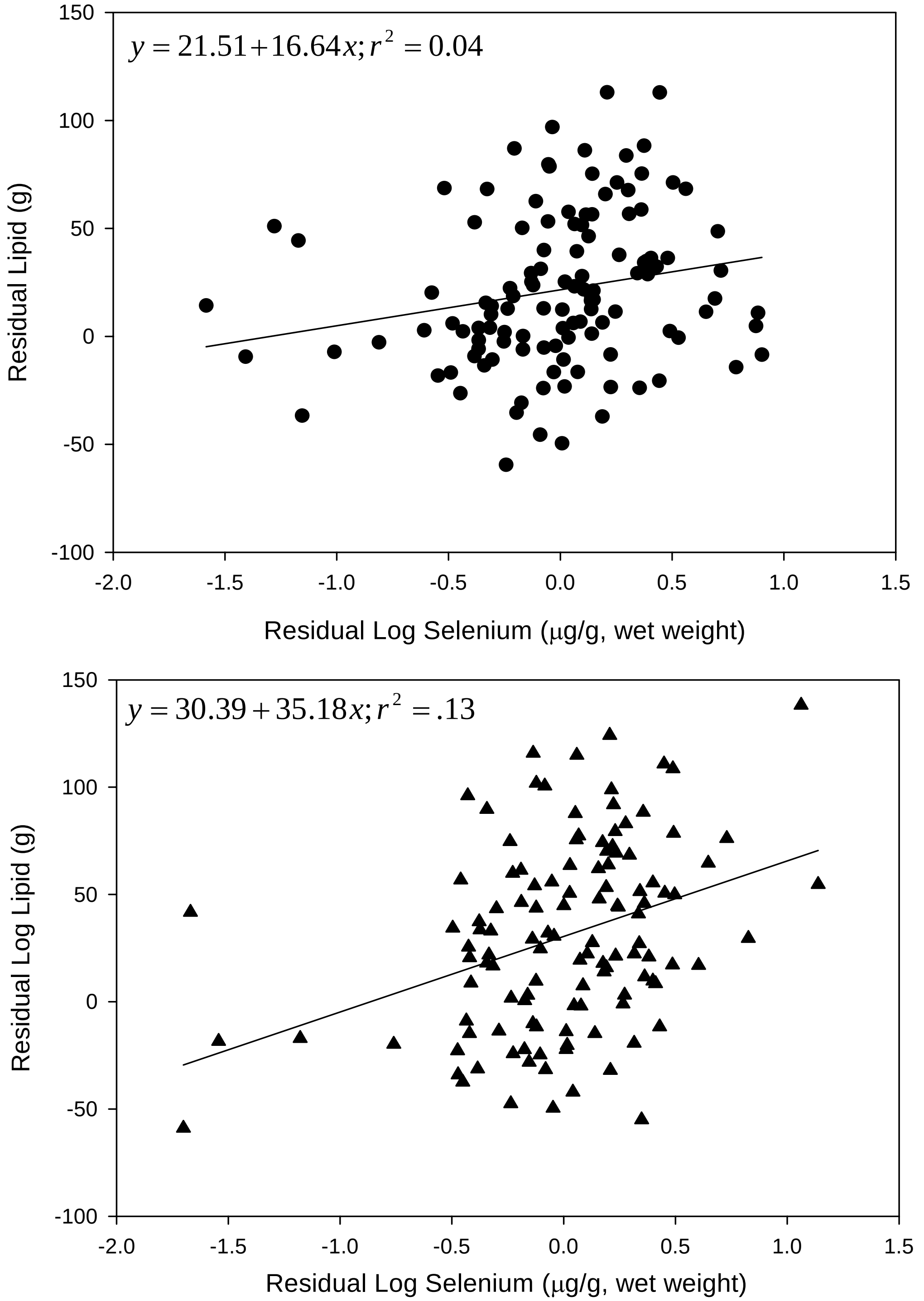

Figure 2. Type III partial relationships between lipid reserve residuals and log hepatic selenium concentration residuals for female (circles) and male (triangles) common goldeneye collected from the Great Salt Lake, Utah winters 2004–05 and 2005–06.

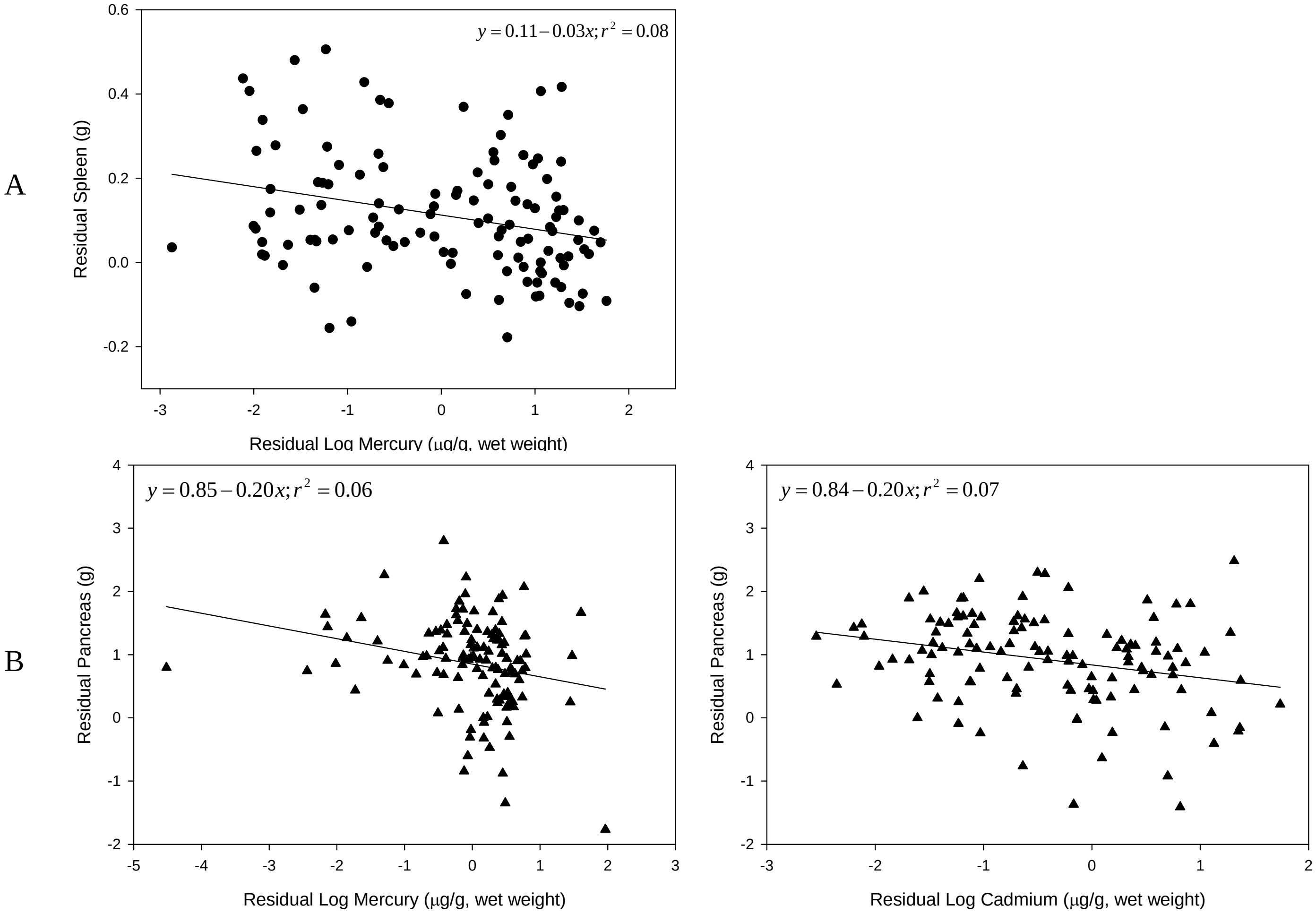

Figure 3. Type III partial relationship between female spleen mass residuals and log hepatic Hg concentration residuals (A) and male pancreas mass residuals and log hepatic Hg and Cd concentration residuals (B) for common goldeneye collected from the Great Salt Lake, Utah during winters 2004–05 and 2005-06.