Arch Environ Contam Toxicol
DOI 10.1007/s00244-010-9625-z

Selenium Concentrations in Greater Scaup and Dreissenid Mussels During Winter on Western Lake Ontario

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Received: 2 July 2010 / Accepted: 12 November 2010

Abstract One hypothesis for the decline of the North American greater (*Aythya marila*) and lesser (*A. affinis*) scaup population is that contaminant burdens acquired on wintering or staging areas impair reproduction or cause lethal or sublethal health effects. Recent studies have found increased selenium (Se) concentrations in scaup but have focused on the fall and spring staging periods. From January to March 2006 and December to March 2006 and 2007, we analyzed liver tissues collected from greater scaup wintering in western Lake Ontario for 16 trace elements. We also measured Se concentrations in greater scaup blood and Dreissenid mussel tissue. Se was the only trace element that occurred at increased concentrations (>10 μg/g liver dry weight) in a substantial proportion (99%) of greater scaup livers. We also found that hepatic Se concentrations increased throughout winter and were increased in nearly all birds from January to March, suggesting that accumulation of this trace element occurred soon after their arrival in fall. Se concentrations were similar in male and female birds, but juvenile birds had higher concentrations than did adults. Blood Se concentrations were correlated to liver Se concentrations in 2006 only, suggesting that blood Se concentration is an unreliable predictor of liver concentration. Se in Dreissenid mussels generally decreased with mussel size and did not change throughout winter. Overall, our results suggest that greater scaup wintering on western Lake Ontario acquire sufficiently high Se concentrations to potentially impact their health. Thus, several indicators of health and survival should be examined in relation to Se concentrations in wintering scaup.

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Acquisition of environmental contaminants and trace elements can decrease reproduction, health, and survival in several bird species (Heinz et al. 1989; Pain 1996; Yamamoto and Santolo 2000) and in some cases can cause population declines (Blus 1996; Hoffman et al. 1996). Similar effects may be involved in the long-term population decline of North American greater scaup (*Aythya marila*) and lesser scaup (*A. affinis*) because large concentrations of these birds often stage or winter in areas where contaminants occur at significant concentrations (Austin et al. 2000; Custer and Custer 2000; Petrie et al. 2007). The lower Great Lakes region (LGL) has become a focus for studies investigating this "contaminants hypothesis" due to its history of aquatic contamination and its increased importance for staging and wintering scaup (Wormington and Leach 1992; Petrie and Knapton 1999).

Scaup wintering and/or staging on the LGL have been analyzed for several potentially significant contaminants, including chlorinated pesticides, polychlorinated biphenyls, and several metals and trace elements (Custer and Custer 2000; Petrie et al. 2007). Selenium (Se), a semimetallic trace element that can cause reproductive and chronic health problems in birds, was elevated (>10 ppm) in a large portion of staging lesser and greater scaup collected on the LGL (Custer and Custer 2000; Petrie et al. 2007). Increased Se concentrations were detected in 95%

Published online: 01 December 2010

of lesser scaup from urban areas of the LGL (Custer and Custer 2000). Increased Se concentrations were also found in 75% of spring-collected lesser scaup and 93% of greater scaup from rural areas of the LGL (Petrie et al. 2007). Large numbers of greater scaup overwinter on the LGL, whereas lesser scaup primarily use the lakes as a fall and spring staging area. Therefore, greater scaup may be at increased risk to effects of Se because of prolonged exposure due to their lengthier time spent on the LGL. Previous contaminant studies of scaup on the LGL have not collected data from important greater scaup wintering areas and have also failed to examine contaminant burdens and dynamics of Se accumulation throughout the winter.

High concentrations of Se in scaup from the LGL often have been attributed to the invasion of zebra (*Dreissena polymorpha*) and quagga (*D. bugensis*) mussels. Since their introduction during the mid-1980s and early 1990s (Hebert et al. 1990; May and Marsden 1992), Dreissenid mussels have been a reliable and abundant food source and likely a contributing factor in the past increase in numbers of scaup staging and wintering on the LGL (Wormington and Leach 1992; Petrie and Knapton 1999; Badzinski and Petrie 2006). Unlike traditional scaup food items, such as gastropods and amphipods (Ross et al. 2005), Dreissenid mussels filter large amounts of water, zooplankton, and phytoplankton and are thus capable of accumulating water- and pelagic-based contaminants into their tissues (deKock and Bowmer 1993; Fisher et al. 1993). Dreissenid mussels from some areas of the LGL have high concentrations of Se (Mills et al. 1993), but few studies have examined how Se concentrations vary throughout the wintering period in various size classes of mussels.

In this study, we examined Se and other potential contaminant concentrations in greater scaup and Dreissenid mussels during winter at Hamilton Harbour in western Lake Ontario. Our primary objectives were to (1) quantify hepatic trace element concentrations in greater scaup and identify which, if any, exceed background levels and are potentially harmful; (2) identify important sources of variation, including capture date, capture year, sex, and age, in hepatic Se concentrations of greater scaup; (3) determine if blood Se concentrations were reliable predictors of hepatic Se concentrations in greater scaup; and (4) examine if concentrations of Se in Dreissenid mussels differ among size classes and change throughout winter.

Methods

Greater Scaup Collection and Dissection

Greater scaup ($n = 73$) were collected at Hamilton Harbour in western Lake Ontario from January to March 2006 and December to March 2006 to 2007. Birds were collected under the authority of the Canadian Wildlife Service (permit no. CA 0171) using protocols that were approved by the Ontario Ministry of Natural Resources Animal Care and Use Committee (protocol no. 06-106). Greater scaup ($n = 18$) were trapped from January 6, 2006, to February 17, 2006, using a floating mist net (Kaiser et al. 1995). Because the catch-per-unit effort was low using floating mist nets, we caught scaup ($n = 46$) from February 18, 2006, to March 9, 2006, and from December 30, 2006, to January 31, 2007, by lifting up a submerged mist net from underneath swimming birds. We also captured greater scaup using a funnel trap baited with corn from March 1 to 30, 2007 ($n = 9$). All March trapping was conducted with caution and was ceased when evidence of the arrival of spring migrant scaup was observed. However, it is possible that birds captured in late March included early spring migrants.

Immediately after capture, we collected $\leq$10 mL blood from the brachial artery or tarsus vein. Blood was emptied into labeled serum tubes, stored in an ice-filled cooler, and frozen as soon as possible. Birds were then killed by cervical dislocation, double-bagged in labeled plastic bags, placed in an ice-filled cooler, and frozen as soon as possible. We transported all collected scaup to the Avian Energetics Lab (AEL) in Port Rowan, Ontario.

At the AEL, specimens were aged and sexed by external (plumage condition and coloration) and internal (bursa) characteristics. All birds were partially thawed at room temperature and plucked. Dissections were performed after carcasses thawed, at which time the pancreas, kidneys, spleen, liver, and heart were excised and weighed to 0.01 g for a separate study of health effects associated with Se exposure. We removed the liver, rinsed it with deionized water to remove bile, and blotted it with article towel. Right and left liver lobes were separated and frozen separately. We sent the right lobe of each liver and all blood samples to the Central Analytic Facility in the Department of Chemistry and Biochemistry at Laurentian University for metal and trace element analysis.

Dreissenid Mussels

Zebra and quagga mussels were collected from three main scaup feeding areas in Hamilton Harbour. Two collection areas were within 40 m of LaSalle Park Marina in Burlington along a manmade rock point. The third collection area was along the eastern shore of the point of Bayfront Park in Hamilton. Mussels were sampled weekly from January 10 to March 25, 2006, and monthly from October 26, 2006, to March 20, 2007; ice cover prevented sampling during December 2006. Three to five large rocks were collected by hand and/or a metal rake from 1 to 2 m–deep water. We removed mussels from each rock using a metal

paint scraper, double-bagged them in one-gallon plastic freezer bags, placed them in a cooler, and then froze them as soon as possible. At the AEL, thawed mussels from each sampling period were sorted by species, and their lengths (size) were measured at the longest axis using digital calipers (± 0.01 mm). Afterward, mussels from each sampling period were sorted into five size classes: class 1 (6.00–11.99 mm), class 2 (12.00–17.99 mm), class 3 (18.00–23.99 mm), class 4 (24.00–29.99 mm), and class 5 (30.00–35.99). Mussels of a particular species and size class were then placed into a subsampler pan to obtain a pooled tissue sample. We randomly selected individual mussels from the pan with the aid of a random number generator and removed the flesh from their shell, which we then added to the pooled sample for that species, size class, and sampling period. We added mussel tissue to the pooled sample until it weighed 1 g. Each pooled sample was bagged, labeled, frozen, and sent to the Central Analytic Facility for Se analysis.

Metal and Trace Element Analyses

Scaup liver, blood, and mussel tissue samples were freeze-dried at –15°C and ground using a mortar and pestle. A subsample of 0.2 g of each sample was transferred to a sterilized Teflon vial. Then 2.0 mL 30% (w/w) analytic reagent–grade H_2O_2 and 8.0 mL concentrated (15 M) analytic reagent–grade HNO_3 were added to each vial and mixed. Each prepared sample was digested in a microwave oven in five stages for a total of 55 minutes, at which time subsample reached a maximum temperature of 220°C.

Potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), and zinc (Zn) were measured in liver samples by flame atomic absorption spectrometry using a Perkin Elmer 5000 spectrometer. Cadmium (Cd), chromium (Cr), nickel (Ni), manganese (Mn), arsenic (As), aluminum (Al), and lead (Pb) were measured in liver samples by graphite furnace atomic absorption spectrometry. Total mercury (Hg) in liver was measured by cold-vapor atomic fluorescence spectrometry using a Tekran Series 2600 mercury analyzer. Total Se in liver, blood, and mussel tissue samples was measured by hydride generation atomic fluorescence spectrometry using a PSA 10.055 Millennium Excalibur; this unit was equipped with a continuous-flow hydride generation system and a boosted discharge hollow cathode Se lamp as the radiation source for the atomic fluorescence detector. Trace element concentrations were reported as μg/g dry weight.

Quality Control

Reference materials and blank reagents were analyzed once every eight samples to assess data quality. DOLT-3 (dogfish liver certified reference material) was used as a standard reference material for all liver and blood sample analyses. Recovery from reference material for liver samples averaged 88% (range 78–101%). For blood samples, reference material recovery averaged 94% (range 86–108%). DORM-2 (dogfish muscle certified reference material) was used for Dreissenid mussel analyses. Recovery from reference material for Dreissenid mussels averaged 100% (range 84–121%).

Statistical Analyses

We used multivariate analysis of variance (MANOVA) to evaluate whether trace element concentrations differed by age, year, and sex in greater scaup. By using MANOVA, we were able to identify important sources of variation and covariation for each trace element. Only elements with detection rates ≥80% were included in analyses. When nondetection (ND) values were present within this data set, we replaced ND with half the value of the element's detection limit.

We converted collection dates each year into an ordinal date (hereafter "date") by treating the first day of mass arrival of greater scaup on our study site as day 1. During fall 2005 and 2006, daily observations showed that November 10 was the average mass arrival date of scaup to Hamilton Harbour. We used a general linear model (GLM) primarily to determine if Se concentrations changed throughout winter (i.e., by date). The model included date, age, and age-by-date interaction.

To assess whether blood Se concentration was a reliable predictor of liver Se concentrations in wintering greater scaup, we used a GLM to model liver Se concentrations as a function of blood Se concentration and year; we also included the interaction of blood Se by year to evaluate if the relation between Se concentrations in the liver and blood differed between study years.

We used a GLM to examine sources of variation in Dreissenid mussel Se concentrations. The initial model included year, species, size class, and date, as well as all two-way interactions between these predictors.

Assumptions (normal distribution of residuals, homoscedasticity) for GLMs and MANOVAs were tested using Levene's test and visual examination of error distributions. All contaminant data were log-transformed ($\log_{10}$) to satisfy model assumptions. All initial GLMs were decreased in a backwards stepwise manner until we obtained a final model (all effects $p \leq 0.10$). We used Wilks' lambda and F-tests (type III sum of squares) to evaluate statistical significance of effects within multivariate (MANOVA) and univariate analyses, respectively. Log-transformed trace element concentrations were backtransformed when reported in results. All post hoc comparisons of means of the reduced models were made using Scheffe's adjustment

for multiple comparisons (Zar 1999). We used SYSTAT (Systat Software, Inc., Chicago, IL) and SAS (SAS Institute, Inc., Cary, NC) software to analyze data. Because of unplanned comparisons and small sample sizes, all tests were considered significant at $p \leq 0.10$.

Results

Sources of Variation in Hepatic Se and Other Trace Element Concentrations

As was detected in only 16% of greater scaup livers, and all detected concentrations were < 2.00 μg/g, so As was not included in further analyses. Ni and Pb were detected in 86% and 97% of GRSC livers, respectively, and were thus included in further analyses. The remaining trace elements were detected in all liver samples.

Contaminant concentrations in greater scaup differed by age (MANOVA: Wilks' $\lambda = 0.51$, $p < 0.01$) and year (Wilks' $\lambda = 0.13$, $p < 0.01$) but not sex (Wilks' $\lambda = 0.73$, $p = 0.20$). Al was higher in adult greater scaup (mean = 4.66, 95% confidence interval [CI] = 3.92 to 5.55, range (R) = 1.57 to 19.7 μg/g) than in juvenile scaup ($\bar{x} = 2.54$, CI = 2.00 to 3.22, $R = 0.90$ to 5.69 μg/g) ($p < 0.01$, Scheffe's). Cd was higher in adult birds $\bar{x} = 3.38$, CI = 2.73 to 4.18, $R = 0.37$ to 9.80 μg/g) than in juvenile scaup ($\bar{x} = 1.25$, CI = 1.07 to 1.68, $R = 0.60$ to 4.62 μg/g) ($p < 0.01$). Se concentrations in juvenile greater scaup ($\bar{x} = 25.8$, CI = 22.30 to 29.80, $R = 12.70$ to 47.23 μg/g) were higher than in adult scaup ($\bar{x} = 20.18$, CI = 18.143 to 22.45, $R = 9.64$ to 35.47 μg/g) ($p < 0.01$).

Concentrations were higher in 2006 for Cr, K, Na, and Pb and higher in 2007 for Al, Cu, Hg, Mg, Mn, and Zn (Table 1). No explained variation was detected in the concentrations of Ca ($\bar{x} = 216$, CI = 204 to 229, $R = 133$ to 1180 μg/g), Fe ($\bar{x} = 1460$, CI = 1320 to 1590, $R = 520$ to 2931 μg/g), and Ni ($\bar{x} = 9.73$, CI = 9.62 to 9.84, R = ND to 2.39 μg/g).

Temporal Variation in Hepatic Se Concentrations

We used a GLM to identify whether there were any annual or temporal patterns in hepatic Se concentrations in greater scaup wintering at Hamilton Harbour. The age-by-date interaction was removed from the initial model ($p > 0.10$). The final model ($R^2 = 0.16$, $F_{2,70} = 6.48$, $p < 0.01$) indicated that juvenile scaup had higher Se concentrations (23.86, CI = 20.54 to 27.71, $R = 12.70$ to 47.23 μg/g) than did adult scaup (20.15, CI = 18.46 to 21.99, $R = 9.64$ to 35.47 μg/g) ($p = 0.07$, Scheffe's). In addition, there was a positive correlation between Se concentration and date ($b = 0.002$, SE = ± 0.001, $F_{1,70} = 3.63$, $p = 0.06$).

Blood Se Concentrations

Hepatic Se concentrations in greater scaup were correlated with blood Se concentrations (model: $R^2 = 0.38$, $F_{3,56} = 9.10$, $p < 0.01$; blood: $F_{1,56} = 14.57$, $p < 0.01$). There was a significant interaction of blood Se by year ($F_{1,56} = 18.03$, $p < 0.01$). Separate GLMs comparing liver and blood Se concentrations were conducted for each year. A positive relation between liver Se and blood Se concentrations was detected for greater scaup sampled in 2006 ($R^2 = 0.48$, $b = 0.65 \pm 0.106$, $F_{1,40} = 37.19$, $p < 0.01$) (Fig. 1). However, there was no relation between liver and blood Se concentrations in 2007 ($R^2 = 0.004$, $b = -0.03 \pm 0.128$, $F_{1,16} = 0.07$, $p = 0.79$).

Table 1 Geometric mean concentrations (μg/g dry weight), 95% CIs, and ranges of trace elements that varied annually in greater scaup wintering in Hamilton Harbour, Lake Ontario, during 2006 and 2007

Element	2006			2007			p[a]
	Mean	95% CI	Range	Mean	95% CI	Range	
Al	2.94	2.50–3.46	1.39–19.5	4.02	3.18–5.08	0.90–19.73	0.03
Cr	1.12	0.95–1.30	0.47–3.67	0.57	0.45–0.71	0.48–0.85	<0.01
Cu	39.8	36.2–43.8	21.8–86.3	49.7	43.4–57.1	25.2–97.0	<0.01
Hg	0.23	0.19–0.27	0.02–0.88	0.78	0.60–1.00	0.41–2.10	<0.01
K	8600	8240–8980	5930–10800	7070	6620–7390	5680–7940	<0.01
Mg	485	468–503	368–621	632	600–666	440–721	<0.01
Mn	14.8	13.5–15.6	9.48–23.8	17.5	15.3–20.0	8.80–75.9	0.04
Na	3340	3140–3610	2420–5110	2650	2420–3560	1940–8080	<0.01
Pb	0.56	0.40–0.79	0.26–26.6	0.23	0.14–0.38	ND–1.83	<0.01
Zn	65.5	61.6–69.7	46.7–88.9	105	96.2–115	61.2–158	<0.01

[a] Scheffe's post hoc test

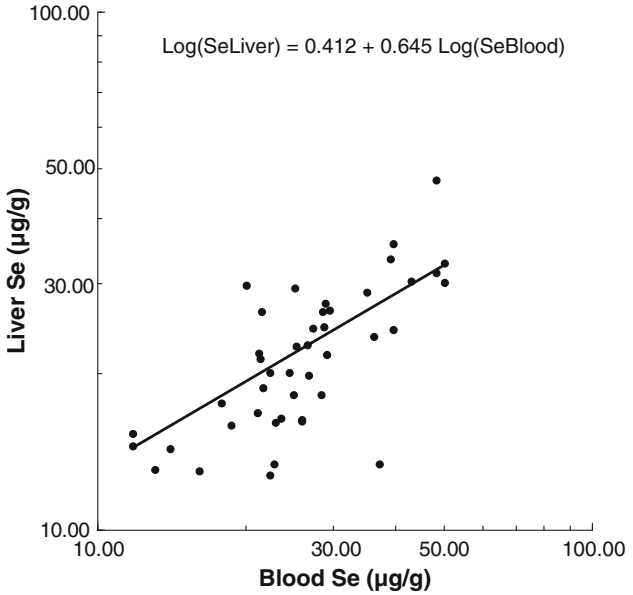

Fig. 1 Relation between Se concentrations in the blood and liver of greater scaup wintering on Hamilton Harbour, Lake Ontario, in 2006 ($R^2 = 0.48$, $p < 0.01$)

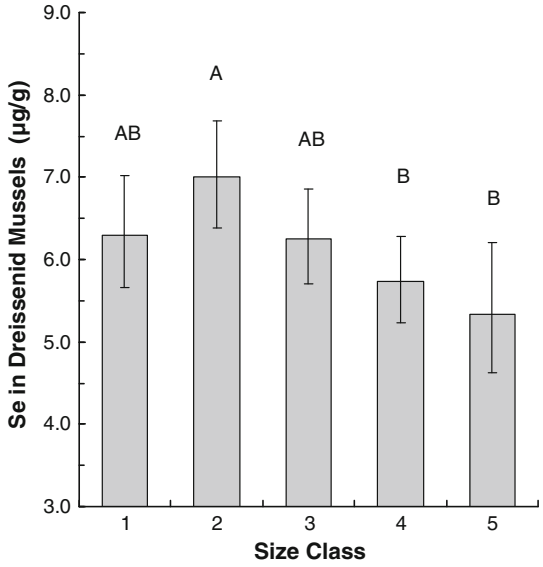

Fig. 2 Differences in mean Se concentrations between size classes of Dreissenid mussels collected from Hamilton Harbour, Lake Ontario, during winters of 2006 and 2007. The letters above the bars represent size classes that are similar ($p < 0.10$) in Se concentration

Se Concentrations in Dreissenid Mussels

Se in mussels varied only by size class ($R^2 = 0.15$, $F_{4, 80} = 3.44$, $p = 0.01$); species, year, date, and all two-way interactions were not included in the final model (all $p > 0.10$). Class 2 (12.00–17.99 mm) mussels had higher Se concentrations than did those in class 4 (24.00 to 29.99 mm) and class 5 (30.00 to 35.99 mm) Dreissenid mussels (Fig. 2). There were no other differences between size classes ($p > 0.10$ for all pairwise comparisons).

Discussion

Trace Element Concentrations

Concentrations of most contaminants (Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn) were low and not considered toxicologically significant compared with background levels established in other studies (Gasaway and Buss 1972; Fimreite 1974; Furness 1996; Custer and Custer 2000). Cd, which is often bioavailable to birds and can become problematic to molluscivorous birds at high concentrations (Scheuhammer 1987), was higher than background levels (<3 µg/g; Scheuhammer 1987) in 47% of greater scaup. However, concentrations were <10 µg/g in all birds, which is well below the 133 µg/g threshold for Cd poisoning in birds (Furness 1996). Another consideration in examining contaminant concentrations in birds is the possibility of interactions between elements. When present in similar concentrations, Hg and Se have been known to counteract each other's toxicity (Heinz and Hoffman 1998). In this study, Hg concentrations were low and considerably lower than Se concentrations, implying little possibility of inhibitory interactions between Hg and Se.

Se Concentrations

Consistent with previous studies of contaminants in scaup from the LGL (Custer and Custer 2000; Petrie et al. 2007), Se was the only trace element present in high enough concentrations to be of concern for greater scaup wintering at Hamilton Harbour, Lake Ontario. Se was increased (>10 µg/g) (Heinz 1996) in 99% (72 of 73) of greater scaup. Se concentrations were higher in juvenile than in adult birds, but birds in both age classes had increased Se concentrations, and the means of the two groups were within 6 µg/g of each other. Therefore, whereas the difference in Se concentrations between juvenile and adult scaup is noteworthy, it is unlikely to have a large biologic role in the effects of Se on greater scaup.

Greater scaup Se concentrations increased throughout winter and reached peak concentrations in late winter. Although Se increased during winter, concentrations were generally high throughout the entire sampling period in nearly all of the greater scaup we collected. For example, 99% (72 of 73) of scaup had Se concentrations >10 µg/g, and all individuals had concentrations >9 µg/g. Because greater scaup generally breed in remote areas where high

levels of Se from industrial sources do not occur (Bellrose et al. 1976; Badzinski et al. 2009), liver Se is likely near background concentrations (< 10 ppm) when scaup arrive at western Lake Ontario in autumn. This was apparent in a previous study where greater scaup collected in fall (October) had substantially lower hepatic Se concentrations than did those collected during spring on the LGL (Petrie et al. 2007). Because Se concentrations in this study were consistently high and its acquisition rate in winter relatively moderate, the most rapid period for Se uptake in greater scaup likely occurred before we initiated sampling in late December and early January. Therefore, the rate of Se acquisition for greater scaup in Hamilton Harbour was likely underestimated in this study. However, because Se appears to have reached increased concentrations in these birds in a relatively short period of time, our results are consistent with other evidence that Se can accumulate quickly in waterfowl liver tissue (Heinz et al. 1990).

One notable result of this study was that nearly all (99%) greater scaup that we collected during winter (December to March) contained hepatic concentrations of Se that are considered elevated for some waterfowl. Petrie et al. (2007) reported that 46% of fall-collected (October to December) and 93% of spring-collected (March to May) greater scaup had increased concentration of Se in liver tissues. In the same study, 14% of fall-collected and 75% of spring-collected lesser scaup had increased Se concentrations (Petrie et al. 2007). The greater scaup that we collected during winter had virtually identical mean Se concentrations to greater scaup that Petrie et al. (2007) collected during spring migration (22.6 and 22.3 ppm, respectively), whereas concentrations of Se in spring-collected lesser scaup were substantially lower (15.6 ppm) (Petrie et al. 2007). The differences in the proportion of greater scaup with increased Se between this study and that of Petrie et al. (2007) may have resulted from us sampling individuals that had likely spent the entire winter on Lake Ontario. The sample collected by Petrie et al. (2007) likely included birds obtained during spring that did not overwinter on the LGL and thus were likely eating foods with relatively lower Se contents. The presence of coal-burning steel mills and the limited exchange of water between the harbour and Lake Ontario might also partly explain why a higher proportion of scaup from Hamilton Harbour had increased Se concentrations than reported in other studies. Concentrations of Se in water are two times higher in Hamilton Harbour than other parts of western Lake Ontario (L. Ware and S. Petrie [unpublished data]), and satellite telemetry data has confirmed that greater scaup in Hamilton Harbour rarely move to other parts of Lake Ontario or other bodies of water during winter (S. Petrie and S. Badzinski, unpublished data). Thus, the high percentage of greater scaup with increased Se concentrations are likely attributed to spending large amounts of time feeding in an Se-enriched area.

Blood Se Concentrations

Our results suggest that blood Se is not a good overall predictor of liver Se burdens for greater scaup wintering at Hamilton Harbour. Previous studies of other waterfowl also report relatively weak positive correlations between blood and liver Se concentrations (Wayland et al. 2001). Wayland et al. (2001) suggested that blood mostly reflects relatively recent and short-term exposure, whereas liver tissues likely reflect longer-term exposure to Se. This might explain why blood Se is a poor predictor of liver Se. The ability to estimate liver Se concentrations from blood concentrations may be possible with in-depth laboratory-based studies of liver and blood Se concentrations, but obtaining accurate and reliable predictions outside of a laboratory setting would be unlikely due to the unpredictable, annual variations that occur in the field.

Se in Dreissenid Mussels

Se concentration generally decreased with increasing size of Dreissenid mussels. This suggests that Dreissenid mussels do not continue to bioaccumulate Se as they age and likely have a depuration mechanism that regulates Se accumulation. However, we did not detect any change in Dreissenid mussel Se concentrations during winter, which suggests that depuration mechanisms are not operating during that time. Alternatively, the decreased Se concentrations may be a growth dilution effect, in which case the lack of change in Se concentrations during winter may be due to a lack of substantial growth during winter.

The average Se concentrations across all Dreissenid mussel size classes were well above the recommended 3 μg/g threshold for Se concentrations for food items eaten by fish and wildlife (Heinz 1996). These increased concentrations support the well-accepted indication that high Se burdens in scaup are due to the consumption of Dreissenid mussels (Custer and Custer 2000; Petrie et al. 2007). However, despite high Se burdens in Dreissenid mussels, Se concentrations in water from Hamilton Harbour and Lake Ontario are relatively low and average 0.67 ± 0.06 μg/L (L. Ware and S. Petrie [unpublished data]). Concentrations of Se in water that range from 106 to 451 μg/L are considered to be harmful for freshwater organisms (United States Environmental Protection Agency 1976). Our data provide more evidence supporting the high filtering- and contaminant-accumulating capabilities of Dreissenid mussels (deKock and Bowmer 1993; Fisher et al. 1993), plus they suggest that high Se concentrations likely would not have been available to

scaup before the arrival of Dreissenid mussels in the LGL.

Conclusion

Nearly all greater scaup that winter in Hamilton Harbour had increased concentrations of Se, whereas concentrations of all other trace elements were lower than levels of concern. In some species of aquatic birds, continuous Se exposure can cause chronic health effects, such as weakness, lethargy, anorexia, spleen atrophy, enlarged liver, pancreas, and kidneys, sloughed or broken claws, skin abnormalities, feather loss, histologic lesions, oxidative stress, and mortality (Ohlendorf et al. 1988; Albers et al. 1996; Green and Albers 1997). Because greater scaup remain on the LGL for approximately 6 months and have increased Se for much of this period, there is potential for health problems due to long-term Se exposure.

Recent studies have suggested that Se is likely not a major contributing factor to the continental decline of greater and lesser scaup (Devink et al. 2008a, b), despite the fact that Se has repeatedly been one of the most common contaminants found in high concentrations in these birds. In addition, research associated with this study suggests that greater scaup wintering on Hamilton Harbour are not experiencing increased oxidative stress, decreased body condition, or impaired tissue health from increased Se exposure (Ware 2008). It has been suggested that the lack of chronic health effects associated with high Se concentrations found in greater scaup may be due to a high tolerance of Se toxicity because greater scaup have traditionally used naturally Se-rich marine environments during winter (Devink et al. 2008a). However, further studies should be conducted to evaluate additional measures of health to fully assess whether greater scaup in this important wintering area are potentially being impacted by increased Se concentrations. We advocate conducting captive studies that would allow researchers to monitor measures of health that are difficult to assess in the field, such as survival, stress response, immune function, and reproductive behavior.

Acknowledgments Funding for this project was provided by Long Point Waterfowl, the Bluff's Hunt Club, the Delta Waterfowl Foundation, the Metals in the Human Environment Strategic Network, Ducks Unlimited Canada, the Waterfowl Research Foundation, and the Ontario Federation of Anglers and Hunters. We thank Bird Studies Canada and the Canada Centre for Inland Waters for logistical support, and E. Apse, T. Barney, D. Casady, M. Casady, J. Cook, D. Gertig, L. Kennedy, B. Naumann, and R. Wood for field and laboratory assistance. We also thank N. Belzile and Y. Chen for conducting and providing assistance with trace elements analyses. R. Garrett and two anonymous reviewers provided helpful comments on this manuscript.

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