LEAD POISONING OF TRUMPETER SWANS IN THE PACIFIC NORTHWEST: CAN RECOVERED SHOT PELLETS HELP TO ELUCIDATE THE SOURCE?

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EXTENDED ABSTRACT.—At least 2,577 Trumpeter (*Cygnus buccinator*) and Tundra Swans (*Cygnus columbianus*) have died in northwestern Washington and southwestern British Columbia over the past nine winters (1999–2008). An average of 283 swan carcasses were recovered annually, with annual variation ranging from 108 to 401 individuals. Most of the fatalities were attributed to ingestion of lead shot (80%; 1,376 of the 1,727 intact remains suitable for toxicological testing from 1999 to 2006). Degernes et al. (2006) previously reported on the approximate 400 swan fatalities that occurred in Washington during the winters of 2000–02. Lead related swan fatalities have been documented in Washington State in the past (Kendall and Driver 1982, Blus et al. 1989, Lagerquist et al. 1994), however, the only other large-scale mortality event occurred in 1992, involving approximately 100 swans (Wilson et al. 1998).

Swan lead fatalities from ingestion of spent lead shot have been occurring since at least 1925 (Munro 1925). Swans may intentionally ingest spent shot, mistaking it as grit or seeds or may inadvertently pick it up while foraging on associated vegetation (Blus 1994, Mateo and Guitart 2000). Once ingested, the shot is retained in the gizzard where the grinding action and acidic environment exacerbates the absorption of lead which is ultimately distributed to soft tissues and bones (Clemens et al. 1975). Ingestion of only two to three pellets may cause mortality in approximately three weeks (USGS-NWHC, pers. comm.).

The use of lead shot for waterfowl hunting was banned in Whatcom County, Washington in 1989 and Sumas Prairie, British Columbia in 1992. Lead shot continues to be permitted for upland hunting and target shooting and for the Migratory Bird Convention Act species including doves, Band-tailed Pigeons (*Columba fasciata*), and American Woodcock (*Scolopax minor*).

A working group comprised of Environment Canada, Washington Department of Fish and Wildlife, US Fish and Wildlife Service, Trumpeter Swan Society, University of Washington (Washington Cooperative Fish and Wildlife Research Unit), and other organizations made efforts to locate the source(s) of lead shot since 2001. To identity the sources of lead shot

causing swan deaths, biologists have conducted a multi-faceted investigation (see Smith et al. 2009, this volume, for details). This extended abstract focuses on information obtained from the shot recovered from lead-poisoned swan gizzards and sediment/soil from suspected source areas (roost sites/forage fields). We attempt to identify specific roosts and forage fields responsible for swan poisonings by comparing the type and size of shot as well as the lead isotope ratios of shot collected from suspected source areas with shot recovered from the gizzards of lead-poisoned swans.

The results presented here are preliminary, as this investigation is ongoing. We plan to examine shot collected from more recently identified suspected source areas, determine the type and size of shot from a greater number of lead poisoned swans, and measure lead isotope ratios in lead poisoned and non-lead poisoned swans. Over the past two winters, an adaptive management action of hazing or preventing swans from using a major roost site (Judson Lake) was conducted to ascertain the role of the lake in the lead-related swan fatalities. The number of documented lead poisoned swans in these years declined by approximately 50% compared to the average of previous years. We still want to compare the type, size and lead isotope ratio of shot recovered from swan gizzards during these two discrete time periods.

Shot were recovered while conducting lead shot density assessment of suspected source areas (14 agricultural fields in Canada, eight permanent water-bodies (four in Canada, four in the USA), and six temporarily flooded agricultural fields (sheet-water) in the USA. Agricultural fields were sampled by collecting core samples in a spray pattern from hunting blinds (biased sampling design). Conversely, the entire permanent water-bodies and sheet-water areas were sampled in a grid pattern (non-biased sampling design). Cores were 6-inches in diameter with a depth of 6–12 inches. Shot, grit and vegetation were separated from individual cores through repeated washing using a series of different sized sieves. Shot was recovered from 1,727 dead swans collected either from major roosts or in response to calls from the public from 1999 to 2006. Individual swan carcasses were examined by a veterinarian to determine probable cause of death, and tissues were collected for additional testing. Shot, grit and vegetation were separated from individual gizzards though repeated washing, using a series of different sized sieves. Environment Canada Wildlife Enforcement Officers identified the size and type of shot through visual examination and testing with a magnet. To date, preliminary results on the size and type of shot recovered from the sediment/soil and swan gizzards includes only a portion of the total shot collected (6,052 shot from 108 lead poisoned swans were also analyzed for lead isotope ratios). Finally, lead isotope ratios were analyzed from shot collected in sediment/soil samples from suspected source areas (n=319), livers from 108 lead-poisoned swans (n=1 swan from a Canadian forage field and n=107 swans from permanent water-bodies), and a portion of the shot from the gizzards of the same 108 swans (n=1,078 shot; 10 shot from a Canadian field, 1,068 shot from permanent water-bodies). Lead isotope ratios were determined as described in Scheuhammer et al. (2003).

The location where a swan carcass is recovered does not necessarily reflect the location where shot were ingested. Swans which ingest lead shot may remain ill for a considerable time before dying. During this time it is probable that these individuals would seek shelter on a water-body which provides some protection from predators. Therefore, it was not surprising that, in our investigation, the majority of sick and dead swans were recovered from water-bodies (85%, 1,796/2,123) and the rest were collected from forage fields or along roadways.

Of the 1,270 gizzards examined from 1999 to 2006, an average of 22 lead and nine non-toxic shot were recovered per gizzard (total 38,695 shot). The majority of swans (72%) had <25 lead shot per gizzard, but 9% of swans had >50 lead shot per gizzard. The trend of swans ingesting more lead shot compared to non-toxic shot differs from the results of Anderson et al. (2000) which demonstrated that ducks ingested mostly non-toxic shot.

The specific size of lead and non-toxic shot from 108 swan gizzards (n=6,052 pellets) and from sediment/soil sampled at roosts/forage fields of suspected source areas (n=375 pellets) ranged from sizes typical of waterfowl hunting, to smaller sizes

typical of upland game bird hunting and target shooting. The sediment/soil samples contained predominately lead shot sizes typically used for waterfowl hunting (#2–6) and a mix of non-toxic shot sizes typically used for waterfowl (#2–3) and upland game bird hunting (#4–6). Swan gizzards had a mix of lead shot sizes typically used for upland game bird hunting (#6) and target shooting (#7.5–8) and predominately non-toxic shot sizes typically used for upland game bird hunting (#4–6).

At least seven non-toxic shot alternatives are currently commercially available in Canada (steel, bismuth, tungsten iron, tungsten matrix, tungsten polymer, tin, and tungsten hevi, Forsyth 2005). Steel is the least expensive and most readily available non-toxic shot. Of the 197 shot recovered from sediment/soil which have been examined, 85% (n=168 pellets) was lead with comparatively fewer non-toxic shot. The majority of non-toxic shot was steel (79%, n=23 pellets), with only three tungsten-matrix and three bismuth pellets identified. The relative presence of shot types in the environment does not reflect current surveys on shot type used by hunters (Stevenson et al. 2005). Possible explanations for these differences could be continued presence of 'old' spent lead shot, continued use of lead shot for waterfowl hunting by non-compliant hunters, or continued use of lead shot for upland game bird hunting and backyard target shooting.

Lead isotope ratios can be used to help differentiate among sources of environmental lead. There are four stable isotopes of lead, three of which are products of radioactive decay (^{206}Pb, ^{207}Pb, ^{208}Pb; but not ^{204}Pb). The lead isotope ratios vary in different ores depending on the relative amount of radiogenic lead. Any combination of ratios can help identify geological origin of lead samples but ^{206}Pb:^{207}Pb is most commonly used. The ^{206}Pb:^{207}Pb ratio reflects the time at which uranium mixed into the ore. Ratios of 0.93–1.08 are associated with Canadian Precambrian Shield lead ores; ratios of 1.15–1.22 are associated with most non-Precambrian lead ores in North America; ratios of 1.27–1.37 are associated with Mississippi Valley lead ores (Scheuhammer and Templeton 1998). The ^{206}Pb:^{207}Pb ratio also can reflect differences in sources of atmospheric lead. Ratios of 1.13–1.16 are associated with leaded gasoline use in Canada (Sturges and Barrie 1987); ratios of 1.18–1.20 are associated with leaded gasoline used in the US (Flegal et al. 1989). The ^{206}Pb:^{207}Pb ratios measured in lead shot pellets from various manufacturers range widely (mean 1.18 ± 0.05) but generally do not overlap with Precambrian lead isotope ratios, thus reflecting predominant use of USA, and Central and South American lead sources in their manufacture (Scheuhammer and Templeton 1998).

Patterns of ^{206}Pb:^{207}Pb ratios in shot from suspected source areas, in shot from gizzards of lead-poisoned swans, and in liver of lead poisoned swans were compared. Only 56% of the ^{206}Pb:^{207}Pb ratios measured in the shot collected from sediment/soil fell within the range found for shot collected from the swan gizzards. Therefore, it appears that swans are not consuming the whole range of shot sizes recovered from agricultural fields and water-bodies. The reason for this phenomenon is currently unclear; however the distribution of shot sizes from the gizzards was also different from that found in sediments/soils.

To summarize, preliminary results do not indicate a specific identifiable source of lead shot responsible for the swan fatalities. There is no clear explanation for some preliminary results, but additional analyses are planned which may provide further insight and understanding. Should the preliminary results suggesting higher prevalence of shot from upland game bird hunting in gizzards of lead-poisoned swans continue to hold true, then this lead-poisoning investigation of the fatality of more than 2,500 swans over the past nine years may implicate lead shot for trap or skeet practice in areas frequented by waterfowl. *Received 30 May 2008, accepted 24 July 2008.*

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