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NONTOXIC AND LEAD SHOT LITERATURE REVIEW

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The following is: 1) a list of manuscripts relating to lead and nontoxic shot, lead toxicity, lead accumulation in soils and animal tissues, and the impacts of lead shot on wildlife, humans, and the environment, and 2) summaries of selected manuscripts. This literature review was originally compiled with the help of student interns and appeared as an appendix in the *Nontoxic Shot Advisory Committee Report* compiled by the Section of Wildlife, Minnesota Department of Natural Resources, December 12, 2006 (Nontoxic Shot Advisory Committee 2006). Many of the summaries were written for this report by Roxanne Franke and later appended by Dan Smedberg, student interns from Minnesota State University-Mankato.

NONTOXIC/LEAD SHOT-RELATED MANUSCRIPTS:

- Adler, F.E.W. 1944. Chemical analyses of organs from lead-poisoned Canada geese. *Journal of Wildlife Management* 8(1):83-85.
- African-Eurasian Water Bird Agreement (AEMA). 2002. Special Edition: Lead poisoning in waterbirds through the ingestion of spent lead shot. *AEMA Newsletter, Special Issue #1*. 28 pp.
- Akoshegyi, I. 1997. Lead poisoning of pheasants caused by lead shots. *Magyar Allatorvasok Lapja* 119(6):328-336.
- Ancora, S., N. Bianchi, C. Leonzio, and A. Renzoni. 2008. Heavy metals in flamingos (*Phoenicopterus ruber*) from Italian wetlands: The problem of ingestion of lead shot. *Environmental Research*. In press.
- Anderson, W.L. 1975. Lead poisoning in waterfowl at Rice Lake, Illinois. *Journal of Wildlife Mangement* 39:264-270.
- Anderson, W.L., and S. P. Havera. 1985. Blood lead, protoporphyrin, and ingested shot for detecting lead poisoning in waterfowl. *Wildlife Society Bulletin* 13(1):26- 31. (Summary)
- Anderson, W.L. and S.P. Havera. 1989. Lead poisoning in Illinois waterfowl (1977-1988) and implementation of nontoxic shot regulations. *Illinois Natural History Survey Biological Notes* 133.
- Anderson, W.L., S.P. Havera, and B. W. Zercher. 2000. Ingestion of lead and nontoxic shotgun pellets by ducks in the Mississippi flyway. *Journal of Wildlife Mangement* 64:848-857.
- Ankney, C.D. 1975. Incidence and size of lead shot in lesser snow geese. *Wildlife Society Bulletin* 3(1):25-26.
- Ankney, D. 1989. The great lead shot boondoggle. *Angler and Hunter*, May. 3 pp.
- ANZECC (Australian and New Zealand Environment and Conservation Council). 1994. Report to the Australian and New Zealand Environment and Conservation Council on alternative shot to lead in hunting. Prepared by NSW National Parks and Wildlife Service, April. 32 pp.

- Artmann, J.W. and E.M. Martin. 1975. Incidence of ingested lead shot in sora rails. *Journal of Wildlife Mangement* 39(3):514-519.
- Averbeck, C. 1990. X-ray investigations of lead shot pellets in the tissues of various species of birds found dead in Northern Germany. *Zeitschrift fuer Jagdwissenschaft (Germany, F.R.)*30-42.
- Bagley, G.E. and L.N. Locke. 1967. The occurrence of lead in tissues of wild birds. *Bulletin of Environmental Contamination and Toxicology* 2:297-305.
- Bagley, G.E., L.N. Locke, and G.T. Nightingale. 1967. Lead poisoning in Canada geese in Delaware. *Avian Diseases* 11:601-608.
- Baker, J.L. and R.L. Thompson. 1979. Shot ingestion by waterfowl on National Wildlife Refuges in Florida. *Proceedings of the Annual Conference of the Southeastern Association Fish and Wildlife Agencies* 32:256-262.
- Barrett, M.W., and L.H. Karstad. 1971. A fluorescent erythrocyte test for lead poisoning in waterfowl. *Journal of Wildlife Management* 35:109-119.
- Bates, F.Y., D.M. Barnes, and J.M. Higbee. 1968. Lead toxicosis in mallard ducks. *Bulletin of the Wildlife Disease Association* 4:116-125.
- Battaglia, A., S. Ghidini, G. Campanini, and R. Spaggiari. 2005. Heavy metal contamination in little owl (*Athene noctua*) and common buzzard (*Buteo buteo*) from northern Italy. *Ecotoxicology and Environmental Safety* 60(1):61-66.
- Baxter, G.S., C. Melzer, D. Byrne, D. Fielder, and R. Loutit. 1998. The prevalence of spent lead shot in wetland sediments and ingested by wild ducks in coastal Queensland. *The Sunbird* 28(2):21-25.
- Beck, N. 1997. Lead shot ingestion by the common snipe (*Gallinago gallinago*) and the jacksnipe (*Lymnocyptes minimus*) in northwestern France. *Gibier Faune Sauvage (France)*65-70.
- Baintema, N. (compiler). 2001. Lead poisoning in waterbirds. International Update Report 2000. African- Eurasian Waterbird Agreement, Technical series No. 3. Accessed Feb. 8, 2007. Available online: http://www.unep-aewa.org/surveys/hunting_and_trade/wi_lead_poison_wbirds_en_2000.pdf **(Summary)**
- Baintema, N. (compiler). 2004. Non-toxic shot: A path towards sustainable use of the waterbird resource. African- Eurasian Waterbird Agreement, Technical series No. 3. Accessed Feb. 8, 2007. Available online: http://www.unep-aewa.org/publications/technical_series/ts3_non-toxic_shot_english.pdf **(Summary)**
- Bellrose, F.C. 1959. Lead poisoning as a mortality factor in waterfowl populations. *Illinois Natural History Survey Bulletin* 27(1):235-288. **(Summary)**
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- Best, T.L., T.E. Garrison, and C.G. Schmidt. 1992a. Availability and ingestion of lead shot by mourning doves (*Zenaidura macroura*) in southern New Mexico. *Southwest Naturalist* 37(3):287-292.
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- Beyer, W.N., J.W. Spann, L. Sileo, and J.C. Franson. 1988. Lead poisoning in six captive avian species. *Archives of Environmental Contamination and Toxicology* 17:121-130.
- Birkhead, M., and C. Perrins. 1985. The breeding biology of mute swan (*Cygnus olor*) on the River Thames with special reference to lead poisoning. *Biological Conservation* 23:1-11.

- Bjerregaard, P., P. Johansen, G. Mulvad, H.S. Pedersen, and J.C. Hansen. 2004. Lead sources in human diet in Greenland. *Environmental Health Perspectives* 112(15):1496-1498. **(Summary)**
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- Blus, L.J. 1994. A review of lead poisoning in swans. *Comparative Biochemistry and Physiology, Part C* 108(3):259-267.
- Blus, L.J., C.J. Henry, D.J. Hoffman, and R. A. Grove. 1991. Lead toxicosis in tundra swans near a mining and smelting complex in northern Idaho. *Archives of Environmental Contamination and Toxicology* 21:549-555.
- Bowen, J.E. and S.A. Petrie. 2007. Incidence of artifact ingestion in Mute Swans and Tundra Swans on the lower Great Lakes, Canada. *Ardea* 95(1):135-142.
- Bowles, J.H. 1908. Lead poisoning in ducks. *Auk* 25(3):312-313.
- Brand, C.J. 1986. Lead poisoning monitoring program: 1983-84 and 1984-85. Unpublished report. (Research Information Bulletin), National Wildlife Health Laboratory, USFWS, Madison, WI.
- Breurec, J.Y., A. Baert, J.P. Anger, and J.P. Curtes. 1998. Unusual diagnosis: non occupational adult lead poisoning. *Toxicology Letters* 95(1):76. **(Summary)**
- Brinzal. 1996. SOS venenos: bu'ho chico. *Quercus* 124:45.
- Brister, B. 1992. Steel shot: ballistics and gunbarrel effects. Pages 26-28 in D. J. Pain (ed), *Lead poisoning in waterfowl*. IWRB Special Publication No. 16, Slimbridge, U.K.
- Brown, C.S., J.Luebbert, D. Mulcahy, J. Schamber, and D.H. Rosenberg. 2006. Blood lead levels of wild Steller's eiders (*Polysticta stelleri*) and black scoters (*Melanitta nigra*) in Alaska using a portable blood lead analyzer. *Journal of Zoo and Wildlife Medicine* 37(3):361-365.
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- Buerger, T., R.E. Mirarchi, and M.E. Lisano. 1986. Effects of lead shot ingestion on captive mourning dove survivability and reproduction. *Journal of Wildlife Management* 50(1):1-8. **(Summary)**
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SUMMARIES OF SELECTED MANUSCRIPTS:

Anderson, W. L., and S. P. Havera. 1985. Blood lead, protoporphyrin, and ingested shot for detecting lead poisoning in waterfowl. *Wildlife Society Bulletin* 13(1):26- 31.

- Gizzards were collected from 3,389 mallards at 26 locations in Illinois during the 1979 hunting season and inspected for lead.
- Blood also taken from 2,265 waterfowl at 7 locations and analyzed for concentrations of lead (Pb) and PP (a blood pigment precursor to hemoglobin that increases as a response to lead poisoning).
- The percentage of 3,389 mallards with ingested shotgun pellets was 6.3% (determined by manual examination of grit), 7.9% (X-rayed), and 8.2% (found via fluoroscopy). Differences between the techniques were significant ($P < 0.05$).
- Radiology, as opposed to manual examination, is preferred for detecting shot-gun pellets in gizzards, but is only a conservative estimate for the severity of Pb poisoning.
- Blood lead levels were found to be the most sensitive indicators of lead poisoning.
- Blood samples from mallards from 4 areas indicated that an average of 8.1% of the mallards had concentrations of lead that equaled or exceeded the threshold of lead poisoning (0.5 ppm) and average of 3.9% had concentrations of PP that equaled or exceeded the threshold (40 ug/dl).

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- Reviews the international environmental problem of lead shot ingestion by waterbirds.
- Provides an analysis of a questionnaire of 75 countries (governments and NGOs) and 9 international organizations world-wide
- Addresses the current state of lead shot legislation, levels of lead shot awareness, coordination, research and development.
- Provides counter-arguments for not using non-toxic shot, and discusses differences between the shot types.
- Reviews relevant developments since 1995.
- Makes lead shot recommendations to governments, non-governmental organizations, hunters' associations and ammunition manufacturers

Beintema, N. (compiler). 2004. Non-toxic shot: A path towards sustainable use of the waterbird resource. African- Eurasian Waterbird Agreement, Technical series No. 3. Accessed Feb. 8, 2007.

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- Review of world-wide status of Pb shot use for waterbirds, and various conventions and agreements pertaining to the use of Pb shot.

- Emphasizes that invisible losses of small, continuous numbers of birds are probably much greater than conspicuous, large scale die offs.
- Argues that a switch to non-toxic shot is necessary to “preserve waterbirds and their habitats for the future.”
- Reports an average of 15% of hunted waterfowl exhibit lead levels that are higher than the generally accepted health standard of half a milligram of Pb / Kilogram of meat. (No citation)
- Argues that crippling rates will not necessarily increase by switching to steel shot.

Bellrose, F.C. 1959. Lead poisoning as a mortality factor in waterfowl populations. Illinois Natural History Survey Bulletin 27(1):235-288.

- Reviewed some history of lead poisoning in waterfowl citing literature from the 1930's - 1950's.
- Joint research project between Illinois Natural History Survey and Western Cartridge Co. (now Winchester) with objectives: 1) evaluating waterfowl losses due to lead, 2) look at alternatives to lead shot, 3) determine physiological effects of lead poisoning on waterfowl. (Only the first objective reported in this paper)
- Early waterfowl die offs were recorded as early as 1874 - (an 1894 article) reporting waterfowl die offs near Galveston, TX, assumed from lead
- Hundreds of ducks died from lead poisoning in Indiana in 1922
- Feb. 1930 - coastal Louisiana die-off from lead poisoning. In a 200 acre rice field they found 199 dead ducks, mostly pintails and mallards
- 'Recent' die offs (1930's-1950's) reported in a table listing location, time of occurrence, species, bird numbers, and reference. Number of birds in die-offs is as high as 16,000 in 2 cases (Missouri 1945-1957; Arkansas 1953-1954)
- Outbreaks dependent on size of late fall/early winter population in an area, species of ducks with similar feeding habits, type and amount of food available, amount of lead shot present, bottom conditions, water level, and ice cover
- Die-offs are seasonal. Most die-offs during late fall and early winter - **after** high hunting pressure. Hunting activity keeps ducks from feeding in hunting areas reducing die-offs during hunting season. Spring die-offs rare in ducks, more common in swans and geese.
- “From a compassionate as well as management viewpoint, lead poisoning is a problem that should concern every sportsman.”
- Review of some of the Illinois research

Bjerregaard, P., P. Johansen, G. Mulvad, H.S. Pedersen, and J.C. Hansen. 2004. Lead sources in human diet in Greenland. Environmental Health Perspectives 112(15):1496-1498.

- A sample of the Greenland population was surveyed, and blood lead adjusted for age and sex was found to be associated with the reported consumption of sea birds.
- Participants reporting eating less than weekly intake of sea birds had blood lead levels of ~75 µg /L, while those reporting eating several birds a week had concentrations of ~110 µg /L.
- Source of lead was believed to be lead shot used in harvesting birds.

Breurec, J.Y., A. Baert, J.P. Anger, and J.P. Curtes. 1998. Unusual diagnosis: non-occupational adult lead poisoning. Toxicology Letters 95(1):76.

- Reports two cases of non occupational adult lead poisoning by ingestion. The symptoms are easy fatigue, abdominal pain, and constipation.
- One patient had frequently eaten game birds containing small shots, and her blood lead levels were 600 µg per L blood.

Buerger, T. T., R. E. Mirarchi, and M. E. Lisano. 1986. Effects of Lead Shot Ingestion on Captive Mourning Dove Survivability and Reproduction. *Journal of Wildlife Management* 50:1-8.

- Treatments involved force feeding mourning doves 0, 1, 2, or 4 No. 8 Pb shot.
- The mortality rates of the mourning doves receiving 1, 2, or 4 No. 8 Pb shots was 24, 60, and 52%, respectively. Birds not dosed with lead shot had 0% mortality.
- Mourning doves that did not survive typically died within 11 days of the dosing treatments.
- The Pb concentrations in the kidneys and livers of doves that survived, whether dosed or not, were noticeably lower (but not significantly) than doves that did not survive.
- Ingestion of No. 8 shot by female mourning doves caused a reduction in the hatchability of their eggs, but did not have an effect on productivity or fertility.
- The reduction in hatchability was due to high early embryonic mortality, possibly from transfer of Pb from adult to embryo.

Burger, J., R.A. Kennamer, I.L. Brisbin, and M. Gochfeld. 1998. A risk assessment for consumers of mourning doves. *Risk Analysis* 18(5):563-573.

- Tested dove meat from a managed dove field and a non-hunted, but potentially polluted area.
- Currently no set Reference Doses (Rfd) for Pb. Centers for Disease control level of concern for Pb is 10 µg/dL.
- Found that Pb levels were highest in meat from the hunted area, posing a slightly increased risk for Pb consumption in children eating dove meat regularly.
- Data suggests that hunting on public lands that have received high Pb shot volume in the past poses the greatest health risk to consumers of dove meat.
- Recommend closing dove fields containing high levels of Pb shot to hunting as one method to reduce the risk of Pb exposure, if concern warrants.
- Banning lead shot for hunting doves is desirable.

Butler, D. A., R. B. Sage, R. A. H. Draycott, J. P. Carroll, and D. Pottis. 2005. Lead exposure in ring-necked pheasants on shooting estates in Great Britain. *Wildlife Society Bulletin* 33(2):583-589.

- Authors noted this is the first pheasant study looking a prevalence of shot ingestion.
- Wing-bone lead concentrations for 98 hen pheasants collected in 1997.
- Gizzards from 32 shooting estates during 2 springs and 2 hunting seasons.
- 3% of pheasants had ingested lead, no difference between years.
- No decline in body condition relative with amount of lead in wing bones.
- Found that ingestion of shot occurs in pheasants.
- Authors suggest "measures to reduce this problem".

Cade, T.J. 2007. Exposure of California condors to lead from spent ammunition. *Journal of Wildlife Management* 71(1):2125-2133.

- Summarizes current scientific data supporting exposure of California condors to lead poisoning.
- 18 clinical necropsies revealed high levels of lead in body tissues and/or presence of lead shotgun pellets and bullet fragments.
- Condors showed crop paralysis and starvation with toxic levels of lead in blood.
- Lead exposure among free flying condors, many with clinically exposed or acute levels, is widespread.
- Temporal and spatial correlations exist between big game hunting seasons and elevated lead levels in condors.
- Lead isotope ratios from exposed condors show close similarity to isotope ratios of ammunition lead.

- Concluded that current levels of lead exposure are too high to allow reintroduced condors to develop self-sustaining pops in AZ and CA.

Campbell, H. 1950. Quail picking up lead shot. *Journal of Wildlife Management* 14:243-244.

- Dead quail was discovered and autopsied for cause of death.
- Gizzard contained 13 lead shot ranging in size from No. 4 to No. 8.
- No other cause of death was found, so it was suggested as a possibility, but not proven, that the quail died from lead poisoning.

Cao, X., L.Q. Ma, M. Chen, D.W. Hardison, Jr., and W.G. Harris. 2003. Weathering of lead bullets and their environmental effects at outdoor shooting ranges. *Journal of Environmental Quality* 32:526-534.

- Examined weathering of Pb munitions and environmental effects in four shooting ranges.
- Found significant elevation of Pb concentration in soil, water, and vegetation. Pb levels in most sampled soils exceeded EPA's critical level.
- Recommended precautionary measures be taken while mowing grass on shooting ranges to minimize worker exposure to airborne lead.
- These increased levels in aboveground biomass increases wildlife exposure.
- Weathering of bullets is dependent on soil pH and amount of organic matter present.

Case, D.J. and Associates. 2006. Non-toxic shot regulation inventory of the United States and Canada. D.J. Case and Associate, Mishawaka, IN. 29 pp.

- Survey regarding nontoxic shot regulations and discussion for regulations; data for regulations for various species by state or province.
- 45% (26) states and provinces have nontoxic shot regulations beyond the federal waterfowl regulations.
- Nine states/provinces that have nontoxic shot regulations are discussing additional regulations; 17 with nontoxic regulations are not discussing additional regulations.
- Regulations exist for species other than waterfowl, for example 15 states/provinces have regulations for dove, 22 for snipe, 13 for grouse, 12 for quail, and 12 for pheasants.

Castrale, J.S. 1989. Availability of spent lead shot in fields managed for mourning dove hunting. *Wildlife Society Bulletin* 17:184-189.

- Studied abundance and accumulation of Pb shot in fields managed for dove hunting.
- Found Pb shot can accumulate rapidly on soil surface over 1 hunting season, and it remains available to doves until plowed under.
- Recommends tilling fields immediately after hunting season or planting thick vegetation undesirable to foraging doves.

Cheatum, E. L., and D. Benson. 1945. Effects of lead poisoning on reproduction of mallard drakes. *Journal of Wildlife Management* 9(1):26-29.

- Mated mallard drakes that had recovered from severe lead poisoning with normal females.
- Three or four #4 shot ingested at intervals over a period of two months caused mortality by lead poisoning at approximately 20%.
- Hatchability of mallard eggs in the test group and control group was similar, with percentages of 58.5 and 58.3, respectively.
- Survival of the mallard ducklings was 66.7% in the test group and 69.6% in the control group.
- Fertility not reduced, however authors suggest vitality of males may impact reproduction in the wild.

Clark, A. J., and A. M. Scheuhammer. 2003. Lead poisoning in upland foraging birds of prey in Canada. *Ecotoxicology* 12:23–30.

- Examined lead exposure in 184 dead raptors found across Canada (16 species).
- 3–4% of total mortality in the 3 most commonly encountered species (RTHA, GHOW, GOEA) was attributed to lead poisoning.
- Conclude that upland-foraging birds of prey and scavengers, that typically include game birds and mammals in their diets, are at risk for lead poisoning from the ingestion of lead projectiles from ammunition used in upland hunting.
- The use of non-lead ammunition for hunting upland game would effectively remove the only serious source of high lead exposure and lead poisoning for upland-foraging raptors.

Cohen, S. Z. 2004. The Science Underlying Best Management Practice for Shooting Ranges: A Focus on Lead and Arsenic. Page 193-203 in *World Symposium on Lead Ammunition*, Scheinost, A. (ed.), Published by the World Forum on the Future of Sport Shooting Activities.

- Best Management Practices(BMP's) are management plans used to minimize offsite pollution of lead, arsenic, and other toxic materials.
- Shooting ranges can be managed in an environmentally responsible manner if BMP's are used.
- BMP's vary according to each individual shooting range.
- Erosion is an important factor in controlling heavy metal mobility, particularly lead.
- Vegetation management is important because it provides plant uptake of nutrients and limits erosion of sediment that contains lead.
- Shooting ranges located in fertilized areas and near water resources typically have a negative impact on attempts to control mobility of heavy metals such as lead and arsenic.

Cook, R. S., and D. O. Trainer. 1966. Experimental lead poisoning of Canada geese. *Journal of Wildlife Management* 30:1-8.

- Wild caught Canada geese were penned and exposed to lead shot and showed first signs of lead poisoning 5-7 days after ingestion.
- Amount of lead ingested directly correlated with time until death, as 25 or more lead pellets caused death within 10 days, while 10 or fewer lead pellets allowed survival for up to 72 days.
- Lead in blood levels of poisoned Canada geese were found to range from 0.320-1.680 mg/100 g, while normal lead levels in blood of Canada geese were found to be 0.018-0.037 mg/100 g.
- High levels of lead in blood and liver tissue, typical signs, and pathological lesions were Required in order to diagnose lead poisoning in Canada geese.
- Direct mortality from Pb poisoning may not be the greatest effect, but rather the effects on survival and reproduction in chronically poisoned birds may be more important.

Craighead, D. and B. Bedrosian. 2008. Blood lead levels of Common ravens with access to big-game offal. *Journal of Wildlife Management* 72(1):240-245.

- Examined blood samples from ravens feeding on hunter-killed gutpiles.
- 47% of ravens sampled during hunting season had elevated blood levels, only 2% had elevated levels during nonhunting season.

Cummings School of Veterinary Medicine at Tufts University. Lead Poisoning. Department of Environmental and Population Health. Cummings School of Veterinary Medicine, North Grafton, Massachusetts. Accessed 2/4/08. Available online: <http://www.tufts.edu/vet/lead/index.html>

- The website is "intended to address the prevalence of lead poisoning and the interconnection of this issue between species and taxonomic groups."

- Provides a summary and selected literature for lead issues such as: mechanisms of poisoning, aquatic birds, predatory birds, humans, environment, lead alternatives, etc.

Dewailly, E., P. Ayotte, S. Bruneau, G. Lebel, P. Levallois, and J.P. Weber. 2001. Exposure of the Inuit population of Nunavik (Arctic Quebec) to lead and mercury. *Archives of Environmental Health* 56(4):350-7.

- Evaluated 492 blood levels of lead and mercury in Inuit adults of Nunavik (Arctic Quebec, Canada).
- ANOVA revealed that smoking, age, and consumption of waterfowl were associated with lead concentrations ($r^2 = .30$, $p < .001$).
- A significant proportion of reproductive-age women had lead and mercury concentrations that exceeded those that have been reportedly associated with subtle neurodevelopmental deficits in other populations.

Dieter, M. P. and M. T. Finley. 1978. Erythrocyte delta-aminolevulinic acid dehydratase activity in mallard ducks: duration of inhibition after lead dosage. *Journal of Wildlife Management* 42(3):621-624.

- 30 mallard males and 30 females were fed one No. 4 lead shot, and 8 mallard males and 8 males were not dosed and considered control birds.
- 2 of the birds expelled their shot, and were excluded from the study.
- After 3 weeks, only 5.5% of dosed ducks retained shot in the gizzards, suggesting a rapid and complete erosion of shot.
- Blood samples were taken from each bird and delta-aminolevulinic acid dehydratase (ALAD) enzyme levels were analyzed.
- Inhibition of ALAD has been proven to indicate the incidence and degree of lead contamination in waterfowl.
- Authors believe that waterfowl possessing more than 50 percent ALAD enzyme inhibition have been exposed to acutely high lead levels, which are caused by the ingestion and erosion of lead shot pellets present in the environment.

Edwards, D.H. 2002. Lead distribution at a public shooting range. Master's thesis. Virginia Tech, Blacksburg, VA. 41 pp.

- Part of a larger study that examines the amount and nature of lead munitions on selected shooting ranges, the rates of corrosion, and the degree to which Pb is solubilized.
- Lead expended in munitions constitutes the largest influx into the American environment today (2002), approximately 55,000 metric tons / year.
- In 1985 USFWS estimated that hunters averaged 8.6 shots / waterfowl bird bagged, with each shot expending 29-44 grams of Pb.
- Progressive sampling revealed most of the Pb shot dispersed in the surrounding forest, in this study. Shot was found embedded in trees >100 m from shooting box.
- Fine particles of Pb were found near the shooting box. These smaller particles have greater surface area, and therefore potential to leach Pb into the environment.

Elder, W. H. 1954. The Effect of Lead Poisoning on the Fertility and Fecundity of Domestic Mallard Ducks. *Journal of Wildlife Management* 18:315-323.

- Domestic Mallard ducks were obtained and fed and raised in the same manner to maintain accuracy.
- No. 6 Pb shot pellets were placed in a small gelatin capsule and used on the ducks in four different breeding groups: both sexes poisoned, only females poisoned, only males poisoned, and neither sex poisoned.

- In the second year, ducks that received 18 No. 6 Pb shot pellets suffered from severe toxemia, when combined with an all grain diet.
- Throughout the duration of the experiment, hens that were dosed with lead displayed lower fecundity (fewer eggs laid) than did non dosed hens.

Erickson, D. W. and J. S. Lindzey. 1983. Lead and Cadmium in Muskrat and Cattail Tissues. *Journal of Wildlife Management* 47: 550-555.

- Lead and cadmium levels in cattails and liver and kidney tissues of muskrats were analyzed to determine the correlation of heavy metal between an animal and its environment.
- Elevated levels of lead in cattails and muskrats from the same site indicated that there is an obvious relationship between the levels of lead in the environment, and that assimilated into cattails and subsequently into muskrat tissues.

Estabrooks, S.R. 1987. Ingested lead shot in Northern red-billed whistling ducks (*Dendrocygna autumnalis*) and northern pintails (*Anas acuta*) in Sinaloa, Mexico. *Journal of Wildlife Diseases* 23(1):169.

- Reports occurrence of ingested Pb shot (no apparent poisoning) in northern Red-billed whistling ducks and Northern Pintails in Mexico.

Finley, M. T., and M. P. Dieter. 1978. Toxicity of experimental lead-iron shot versus commercial lead shot in mallards. *Journal of Wildlife Management* 42(1):32-39.

- Lab experiment with mallards, comparing lead-iron shot (38.1 % lead) or commercial lead shot.
- Mortality was higher in groups given with commercial lead shot than in groups given lead-iron shot.
- After 14 weeks, one #8 shot caused 35% mortality with higher amounts of lead causing 80-100% mortality. 5% mortality was caused by ingestion of two #4 lead-iron shot.

Fisher, I.J., D.J. Pain, and V.G. Thomas. 2006. A review of lead poisoning from ammunition sources in terrestrial birds. *Biological Conservation* 131(3):421-432.

- Review collates the current knowledge of lead poisoning from ammunition in non-waterbirds.
- 59 terrestrial bird species have been documented (as of Oct. 2005) to have ingested lead or suffered lead poisoning from ammunition sources. 9 of these species were Globally Threatened or Near Threatened.
- Terrestrial birds are exposed to Pb mainly through ingestion. Secondary poisoning of raptors also occurs.
- Retention time of Pb, frequency, past history to exposure, environmental stress, and nutritional factors all can impact the level of Pb poisoning birds experience.
- In Canada, upland game birds and raptors are now more likely to contain lead shot than waterfowl.

Harradine, J. 2004. Spent Lead Shot and Wildlife Exposure and Risks. Page 119-130 in *World Symposium on Lead Ammunition*. Scheinosst, A. (ed.), Published by the World Forum on the Future of Sport Shooting Activities.

- Cursory review of lead shot and wildlife, from the UK.
- P 119 – “Lead is a toxic material, and unlike many other essential metals, has no known biological function. Its ingestion or absorption by people, animals and plants carries risks of harm.”

- Lead poisoning of wildlife occurs by direct ingestion of shot, ingestion of shot by predatory or scavenging animals or birds eating prey containing lead shot, and ingestion of lead from within the bodies of prey animals or plants.
- P 127 – “The issue of lead poisoning in wildlife as a consequence of shooting activities has long been debated as to its occurrence, its impact and how it should be managed. On the basis of evidence to date, and in general terms, waterfowl, some non-waterfowl species, and birds of prey are the groups of wildlife most at risk of poisoning by virtue of being most exposed to spent lead shot and vulnerable to its effects.”
- P127 – “Ingestion of lead by other types of wildlife (other than waterfowl and birds of prey), from the relatively few studies to date, appears to be extensive in terms of species in which ingestion has been recorded, but in many cases these amount only to infrequent or even rare occurrence. Some species, such as mourning dove and pheasant, however, which are subject to substantial hunting and which feed in those hunted areas, are exposed to relatively high levels of ingestion and its predictable consequences.”

Hui, C.A. 2002. Lead distribution throughout soil, flora, and an invertebrate at a wetland skeet range. *Journal of Toxicology and Environmental Health, part A*, 65(15):1093-1107.

- Lead pellets from skeet range in Southern California impart Pb into the local soil, plants, and animals.
- Pb concentrations in soil are significantly correlated to shot pellet densities.
- Horn snails had mean Pb concentration 100 x greater than the leaves of plant species at the same site.
- “Avian predators of gastropods may receive minimum exposure to Pb due to calcium in shells, but incidental ingestion of soil and direct ingestion of pellets may provide significant exposure to birds.”

Hunt, W. G., W. Burnham, C. N. Parish, K. K. Burnham, B. Mutch, and J. L. Oaks. 2006. Bullet fragments in deer remains: implications for lead exposure in avian scavengers. *Wildlife Society Bulletin* 34(1):167-170.

- Conducted examinations on whole or partial remains of 38 deer killed with standard center-fire, breach-loading rifles.
- All whole or eviscerated deer killed with lead-based bullets contained bullet fragments.
- The proportion (90%) of offal piles containing fragments is not surprising, given that gut piles contain the thoracic organs normally targeted by hunters.
- Copper bullets do not have a high level of fragmentation in comparison to lead bullets.
- The high incidence of Pb fragments and their distribution and density suggest a high potential for exposure of avian scavengers to lead.

Johansen, P., G. Asmund, and F. Riget. 2001. Lead contamination of seabirds harvested with lead shot — implications to human diet in Greenland. *Environmental Pollution* 112(3):501-504.

- Lead contamination of thick-billed murre hunted using lead shot was studied.
- Carcass was cleaned, cooked, and visible pellets removed.
- Breast meat lead values in birds killed with lead shot were 10 times higher than birds not killed with lead shot (mean 0.22µg/g wet weight).
- Lead in the meat exists as small fragments, left during the passage of pellets through the breast.
- “Birds killed with lead shot are a significant source of lead, probably the most important single source, of the diet of many people in Greenland.”
- US Center for Disease Control has defined a blood lead level of 100 µg/L as a level of medium concern, but there may not be a ‘safe’ lower limit.

Kendall, R. J., T. E. Lacher, Jr., C. Bunck, B. Daniel, C. Driver, C. E. Grue, F. Leighton, W. Stansley, P. G. Watanabe, and M. Whitworth. 1996. An Ecological Risk Assessment of Lead Shot Exposure in Non-Waterfowl Avian Species: Upland Game Birds and Raptors. *Environmental Toxicology and Chemistry* 15(1):4-20.

- Exposure to spent lead shot by upland birds and ingestion of spent lead shot by raptors consuming wounded game can cause mortality and other harmful effects.
- "Ingestion of spent lead shot is the most common means of exposure to lead in upland game birds, particularly mourning doves."
- Mourning doves tested had evidence of ingested spent lead shot. Substantial risks of mortality in mourning doves is highest in habitats located in shooting or hunting areas.
- In contrast to game fields, data on shot densities in other habitats is extremely limited.
- The deposition of spent Pb shot in upland hunting is almost 5 times greater than that associated with waterfowl hunting.
- Studies of waterfowl in the US suggest that Pb poisoned birds are more susceptible to being shot.
- Effects of Pb poisoning are exacerbated by exposure to cold temperatures and poor diets.

Knopper, L.D., P. Mineau, A.M. Scheuhammer, D.E. Bond, and D.T. McKinnon. 2006. Carcasses of shot Richardson's ground squirrels may pose lead hazards to scavenging hawks. *Journal of Wildlife Management* 70(1):295-299.

- Shooting with lead bullets and poisoning with bait are management practices for controlling Richardson's ground squirrels (RGS).
- Determined that 1 in 5 RGS carcass had lead levels that were lethal in bald eagles.
- RGS carcasses appear to be a source of lead that could be fatal in scavenging (Ferruginous and Swainson's) hawks.
- Estimate that 6.5 RGS carcasses eaten over 23 days would contain a lethal dose of lead for scavenging raptors.
- Hazard could be avoided with the collection of carcasses and use of nontoxic-shot.

Kreager, N., B.C. Wainman, R.K. Jayasinghe, and L.J.S. Tsuji. 2007. Lead pellet ingestion and liver-lead concentrations in upland game birds from southern Ontario, Canada. *Archives of Environmental Contamination and Toxicology* (published online, ahead of print).

- 123 gizzards from upland game birds harvested by hunters in southern Ontario were examined for lead pellet ingestion.
- 5% of gizzard content samples for common pheasants had >10 pellets, suggesting acute lead poisoning.
- Lead pellets were ingested by chukars (8%) and the common pheasant (34%).
- 13% of bird livers analyzed had elevated lead concentrations (chuckars, pheasants, wild turkey, Hungarian partridge).
- Liver-lead concentrations above Health Canada's guidelines for human consumption of fish protein were found in 40% of livers analyzed.

LaBare, M.P., M.A. Butkus, D. Riegner, N. Schommer, and J. Atkinson. 2004. Evaluation of lead movement from the abiotic to biotic at a small-arms firing range. *Environmental Geology* 46(6-7):750-754.

- Lead concentrations were examined in sediment, soil, water, plants, fish, and invertebrates at a small-arms firing and skeet range in New York.
- There was an elevated concentration of lead in soil, sediment, and evidence of bioconcentration of lead by the surrounding biota.

- Earthworms had 90% and tadpoles 20% higher concentrations of lead at the firing and skeet range than at controls.
- Lead uptake by indigenous plants varied, and total leachable Pb was highest in animals versus plants.

Larsen, R.T. 2006. Ecological investigations of chuckars (*Alectoris chukar*) in western Utah. Master's thesis. Brigham Young University, Provo, UT

- Found lead shot in 1.9% of the gizzards and 10.7% of the crops checked
- Mentioned lead shot ingestion could be related to rocky nature of chuckar habitat. Shot is available longer in this habitat because it is untilled.
- All the major shot sizes used for hunting in the study area correlate strongly with the diameter size of grit picked up by chuckars.

Lance, V.A., T.R. Horn, R.M. Elsey and A. de Peyster. 2006. Chronic incidental lead ingestion in a group of captive-reared alligators (*Alligator mississippiensis*): possible contribution to reproductive failure. *Toxicology and Pharmacology* 142:30–35.

- An American alligator (*Alligator mississippiensis*) breeding facility was established, and eggs produced showed a lower hatching rate than those collected from the wild.
- Tissues were collected at necropsy from 44 the captive and 15 wild animals and assayed for metals. Results showed that captive alligators had significantly higher tissue levels of Pb than wild alligators.
- High yolk Pb was suggested as a probable cause for early embryonic death in alligator eggs.
- The high tissue lead levels in captive alligators was attributed to long-term consumption of nutria (*Myocastor coypus*) meat contaminated with lead shot.

Lévesque, B., J.F. Duchesne, c. Gariépy, M. Rhainds, P. Dumas, A.M. Scheuhammer, J.F. Proulx, S. Déry, G. Muckle, F. Dallaire, and É. Dewailly. 2003. Monitoring of umbilical cord blood lead levels and sources of assessment among the Inuit. *Occupational and Environmental Medicine* 60:693-695.

- Analysis of 475 umbilical cords showed 7% of Inuit newborns had Pb blood concentration levels equal to or greater than the intervention level adopted by many government agencies.
- Lead shots used for game hunting were an important source of lead exposure in the Inuit population. "Lead shots may be a major source of lead exposure to humans that consume hunted game animals."
- Cohort study shows significant decrease in cord blood Pb concentrations after a public health intervention to reduce the use of lead shot.
- Recommends banning the use of lead ammunition for all hunting using shotguns, and recommends actively promoting the use of non-toxic shot.

Lewis, L.A., R.J. Poppenga, W.R. Davidson, J.R. Fischer, and K.A. Morgan. 2001. Lead toxicosis and trace element levels in wild birds and mammals at a firearms training facility. *Archives of Environmental Contamination and Toxicology* 41(2):208-214.

- Lead poisoning was diagnosed in a yellow-rumped warbler and gray squirrel. 7 yellow-rumped warblers and one solitary vireo were found dead due to lead poisoning.
- 72 wild animals (22 different species) were collected surrounding an outdoor firearms shooting range and tested for lead exposure.
- 24 (33.3%) animals (11 species) had lead levels >1.00 ppm, and 12 of these had levels >2.00 ppm.
- Findings indicate significant lead exposure of local wild bird and mammal communities via bullets and fragments in and on the soil surface of the four outdoor ranges.

Locke, L. N., S. M. Kerr, and D. Zoromski. 1982. Lead poisoning in common loons (*Gavia immer*). *Avian Diseases* 26(2):392-396.

- Common loons were necropsied, and 3 loons were found to be lead poisoned.
- Lead fragments of fishing tackle were found in 2 loons with high lead liver levels.
- 13 other loons that died of other causes had low Pb liver levels.

Ma, L. W., X. Cao, D. W. Hardison Jr., M. Chen, and W. Harris. 2004. Chemical and Physical Weathering of Pb Bullets in Soils of Florida Shooting Ranges. Page 165-171 in *World Symposium on Lead Ammunition*. Published by the World Forum on the Future of Sport Shooting Activities.

- Weathering of metallic Pb bullets is a major source of Pb contamination in shooting range soil.
- Chemical and physical weathering experiments were performed on Pb bullets.
- Weathering of metallic Pb bullets in soil can be decreased by reducing soil moisture level, by removing soil organic matter, and increasing soil pH.
- Abraded Pb from Pb bullets passing through soil has a large contribution to Pb contamination in soils.
- Abrasions from the Pb bullet allowed fragments and particles to disperse, exposing more surface area for possible corrosion.
- Metallic Pb corrosion in the absence of soil was extremely slow, regardless of the level of moisture.

Martin, P.A., D. Campbell, K. Hughes, and T. McDaniel. 2008. Lead in the tissues of terrestrial raptors in southern Ontario, Canada, 1995-2001. *Science of The Total Environment* 391(1):96-103.

- Lead exposure in 225 birds of 19 species of terrestrial raptors was examined through analysis of bone, liver, and kidney tissues.
- Turkey vultures had the highest mean concentrations of lead compared to other raptors.
- Lead levels exceeded threshold concentrations associated with subclinical or acute toxicity in ~2% of raptors assessed.
- "...The continued use of lead shot for upland hunting in Ontario likely remains as one of the primary sources of lead and a continued risk to these birds of prey."
- Elevated lead in bone represent long-term lead exposure.

Mateo, R., M. Taggart, and A.A. Meharg. 2003. Lead and arsenic in bones of birds of prey in Spain. *Environmental Pollution* 126(1):107-114.

- Bones of 229 birds of prey from 11 species were analyzed for Pb and As to evaluate their exposure to lead shot.
- Pb poisoning has been diagnosed in 8 upland raptor species (Eurasian eagle-owl, Red kite, Eurasian griffon, etc.).
- Raptors feeding on species targeted by hunters in upland habitats suffer from lead poisoning.

McCracken, K. G., A. D. Afton, and M. Peters. 2000. Condition bias of hunter-shot ring-necked duck exposed to lead. *Journal of Wildlife Management* 64:585-590.

- Tested the null hypothesis that ducks shot by hunters do not differ physiologically from those collected randomly.
- Random collection of ducks was defined as shot at night with the aid of lights, and ducks shot by hunters were done so over decoys.
- Ring-necked ducks shot over decoys were in poorer physical condition than those collected randomly.
- Ingesta-free body mass, lipid, and protein were all negatively related to Pd concentration in the adjusted model.

- “Lead exposure is likely to have far-reaching effects on overwinter survival (including hunting mortality), not to mention subsequent abilities to migrate and reproduce successfully.”
- “In conducting studies, researchers need to recognize and account for lead as a possible source of condition bias.”

Michigan Department of Natural Resources. 2002. Michigan Wildlife Diseases Manual. Michigan Department of Natural Resources, Wildlife Disease Laboratory, Lansing, MI 48910-8106. Accessed Feb. 22, 2008. Available online: http://www.michigan.gov/dnr/0,1607,7-153-10370_12150_12220---,00.html

- Suggests that mortality directly due to Pb poisoning may be secondary to the indirect, non-lethal effects such as reproductive problems, greater susceptibility to disease, infection, and predation.
- Plowing under areas shot over may be a technique to make Pb shot unavailable to upland birds.

Migliorini, M., G. Pigino, N. Bianchi, F. Bernini, and C. Leonzio. 2004. The effects of heavy metal contamination on the soil arthropod community of a shooting range. *Environmental Pollution* 129(2):331-40.

- Soils at 7 clay pigeon shooting ranges were examined for heavy metals and their effects on the arthropod community.
- Significant amount of Pb from spent shot is “bioavailable in the soil and can be bioaccumulated by edaphic organisms, entering the soil trophic network, but without biomagnification.”

Minnesota Department of Natural Resources. 2007. Trumpeter swan die-off at Grass Lake, Wright County. DNR Fact Sheet. February 28, 2007. Division of Ecological Services, St. Paul, MN.

- At least 20 trumpeter swans died at the inlet of Grass lake in Wright Co., MN from January to February, 2007.
- The Swans typically wintered on the Mississippi River, but a mild winter created favorable conditions at Grass lake.
- Grass lake was an area of heavy duck hunting where lead shot was used extensively.
- 1 found to have ingested lead pellets – note below
- Follow-up letter indicated that 3 carcasses were obtained, and all three had lead shot.

Osmer, T. L. G. 1940. Lead shot: its danger to water-fowl. *The Scientific Monthly* 50(5):455-459.

- During waterfowl hunting season the chances of lead poisoning increase.
- Lead shot remains available to waterfowl after the hunting season.
- Osmer stated “It has been experimentally determined that the ingestion of 6 No. 5 shot by a duck is fatal. Even 2 or 3 shot are often fatal.” (Osmer did not provide a citation or evidence for the statement.)
- Many lakes across the nation were hunted heavily before becoming refuges which left these sites with accumulated old lead shot and a continuing potential for lead poisoning.
- Grit is essential for a ducks digestive system and apparently they cannot differentiate between lead shot, granite, or quartz of the same size.
- To determine the availability of lead shot to gravel sampling was done with a Peterson dredge in the areas where waterfowl feed.

Platt, J.B. 1976. Bald eagles wintering in the Utah desert. *American Birds* 30:783-788.

- Found that bald eagles feeding on jackrabbits shot with lead were ingesting shot, with 71% regurgitated pellets having shot in them.

Sanborn, W. n.d. Lead Poisoning of North American Wildlife from lead shot and lead fishing tackle. Draft. HawkWatch International, 1800 South West Temple, Suite 226, Salt Lake City, UT 84115. 31 pp.

- Summary of lead literature, contains 125 references through 2002.
- Table 1 lists pellet deposition in hunting areas. Note the final lines of Table 1 with hundreds of thousands of lead pellets/acre at Washington pheasant release sites.
- Table 2 (waterfowl), Table 3 (upland game birds) and Table 5 (raptors) lists evidence of lead exposure and poisoning for more than a 19 species. Not a complete list by any means. Our literature review (which has additional literature and has been updated since is appeared in the Minnesota advisory group report) has more information on some species. (Let me know if anyone would like a copy of the January 15, 2008 version - we are updating it on a daily basis.)
- Table 6 - Birds poisoned by lead fishing tackle.
- Table 7 - Wildlife lead exposure at shooting ranges.
- Table 10 - Available nontoxic ammunition.
- Table 11 - Price comparison between lead and non-toxic pheasant loads.

Scheuhammer, A. M., D.E. Bond, N.M. Burgess, and J. Rodrigue. 2003. Lead and stable lead isotope ratios in soil, earthworms, and bones of American woodcock (*Scolopax minor*) from Eastern Canada. *Environmental Toxicology and Chemistry* 22:2585-2591.

- Wing bones collected from young of the year woodcock along with soil and earthworm samples at several sites in Canada were tested for total Pb and stable Pb isotopes.
- Woodcock with high bone-Pb accumulation had ratios substantially different from worms and soils sampled from same areas.
- Although woodcock feed extensively on soil invertebrates, ratios were consistent with ingestion of spent Pb shotgun pellets.

Scheuhammer, A.M., and S.L. Norris. 1995. A review of the environmental impacts of lead shotshell ammunition and lead fishing weights in Canada. Occasional Paper Number 88, Canadian Wildlife Service. National Wildlife Research Centre, Hull, Quebec. 56 pages.

- Manuscript covers a variety of topics for Canada for lead shot and sinkers.
- Topics include production/use of lead shot and sinkers, environmental chemistry and toxicity of lead, alternatives.
- For hunting waterfowl, other birds, and small mammals, they estimate more than 1800 tons of lead is annually deposited into the environment (Table 2) in Canada.
- For trap and skeet, they estimate that between 128-260 tons of lead is deposited annually into the environment.
- "Ultimately all of the.." lead from shot and sinkers is transformed in the environment into particulate and molecular lead and dispersed through the environment to some degree. This can result in very high concentrations of lead in local environments.
- Tens to hundreds of years required for total breakdown of lead shot pellets depending on chemistry of water or soils. Aerobic, acidic conditions increase the rate of break-down.
- Lead concentrations near clay target shooting ranges are very high and create significant risk of shot ingestion and poisoning to waterfowl.
- Lead from spent shot enters the food chain.
- Reviews lead toxicity in waterfowl and non-waterfowl species.
- Predators (eagles) experience lead poisoning mortality from eating prey animals with lead shot in their tissues or gizzards.
- Millions of migrating ducks and geese, alive and healthy, carry lead in their tissues; exceeds 20% of the population of these species. Hunted upland game birds also carry shot in their tissues.

- Silage with lead can poison cattle. When Pb pellets were removed in one study, there was still enough Pb present in silage to be toxic.
- Loon mortality from lead sinkers of jigs.
- Three options to reduce lead are: habitat manipulation (lower water levels to get waterfowl to leave the area), coated shot (but ingestion of coated shot occurs), and alternative shot materials (steel, bismuth/tin, and zinc).

Scheuhammer, A. M., J. A. Perrault, E. Routhier, B. M. Braune, and G. D. Campbell. 1998. Elevated lead concentrations in edible portions of game birds harvested with lead shot. *Environmental Pollution* 102:251-257.

- Conducted field experiment in Canada, evaluating lead concentrations in pectoral muscles of hunter shot game birds.
- Of 827 right pectoral muscles pools, 92 had lead concentrations $> 0.5 \mu\text{g/g}$ wet weight.
- Although all visible pellets were removed, radiographs showed embedded fragments of lead.
- Embedded fragments of lead from shot are a potential source of dietary lead exposure for predators, and human consumers of wild game.
- Also notes that ~20% of free-living waterfowl carry lead shot in tissues from non-lethal or crippling shots.
- Recommend the use of non-toxic shot for hunting.

Scheuhammer, A. M., C. A. Rogers, and D. Bond. 1999. Elevated lead exposure in American woodcock (*Scolopax minor*) in eastern Canada. *Archives of Environmental Contamination and Toxicology* 36:334-340.

- Wing bones collected from 1,588 woodcock in Canada.
- A high proportion of birds had elevated Pb concentrations, compared to other wild bird species.
- 52% adults and 29% young of yr. had concentrations $>20.7\text{g/g}$.
- American woodcock feeding habits are consistent with the occasional ingestion of Pb shot, and ingestion of contaminated soil may be an important source of Pb exposure.
- Concentrations of lead varied significantly by gender, age, and geographic region.

Schultz, J.H., P.I. Padding, and J.J. Millspaugh. 2006. Will mourning dove crippling rates increase with nontoxic-shot regulations? *Wildlife Society Bulletin* 34(3):861-865.

- Evaluated crippling rates in waterfowl prior to, during, and after implementation of nontoxic-shot regulations in the U.S.
- Prenontoxic-shot period crippling rates for ducks were lower than the 5 yr phase in period rates, but higher than non-toxic shot crippling rates.
- In geese, prenontoxic-shot period crippling rates and 5 yr phase in period rates were both greater than nontoxic-shot crippling rates, but did not differ significantly.
- Decline in crippling rate that followed full implementation of the nontoxic-shot regulation is of ultimate importance when considering the impacts of lead shot restrictions for mourning doves.
- Long-term mourning dove crippling rates might not increase as evidenced from historical waterfowl data.

Sileo, L., R. N. Jones, and R. C. Hatch. 1973. The effect of ingested lead shot on the electrocardiogram of Canada geese. *Avian Diseases* 17(2):308-313.

- Lab experiment: 5 geese dosed with 15 No. 6 lead shot, also fed corn along with commercial food (to enhance toxicity of the lead).

- Electrocardiograms and body weights were recorded daily until poisoned geese died, then necropsies were done.
- All dosed geese lost 25 to 45% of their initial body weight and died 11-45 days after ingesting lead.

Spahn, S.A. and T.W. Sherry. 1999. Cadmium and Lead Exposure Associated with Reduced Growth Rates, Poorer Fledging Success of Little Blue Heron Chicks (*Egretta caerulea*) in South Louisiana Wetlands. *Archives of Environmental Contamination and Toxicology* 37(3):377-384.

- Cadmium and lead were detected in food samples, guano, and feathers of little blue heron chicks in contaminated wetlands.
- Exposure to lead was correlated with increased nestling mortality.

Stendell, R. C., R. I. Smith, K. P. Burnham, and R. E. Christensen. 1979. Exposure of waterfowl to lead: a nationwide survey of residues in wing bones of seven species, 1972-73. US Government Printing Office 1802-M/7.

- Wing bones were collected from seven species of waterfowl from 3 flyways and analyzed for lead.
- 4,190 duck wing bones were collected in 1972, 1973 reflecting lead residues ranging from trace amounts (<0.5 ppm) to 361 ppm.
- Species of redheads, black ducks, mallards, canvasbacks, and pintails all had intermediate levels of lead. Wing bones of mottled ducks contained the highest levels and lesser scaup had the lowest level of lead.
- Compared geographic patterns of lead exposure in the species along flyways. For example immature mallard lead levels were higher from the Atlantic flyway than the Pacific and Mississippi flyway.

Stevenson, A.L., A.M. Scheuhammer, and H.M. Chan. 2005. *Archives of Environmental Contamination and Toxicology* 48(3):405-413.

- Found significant decrease in mallard and Am. black duck bone-Pb concentrations when comparing before and after the national ban on lead shot for waterfowl hunting.
- Declines were consistent with waterfowl hunter survey, which showed a high level of compliance to nontoxic shot regulation.
- American woodcock showed no decrease in mean bone-Pb concentration. 70% of waterfowl hunters surveyed who also hunt upland game birds continued to use Pb shot.

Strom, S.M., K.A. Patnode, J.A. Langenberg, B.L. Bodenstein, and A.M. Scheuhammer. 2005. Lead contamination in American Woodcock (*Scolopax minor*) from Wisconsin. *Archives of Environmental Contamination and Toxicology* 49(3):396-402.

- Wing bones from hunter donated woodcock showed young of yr were accumulating high Pb levels.
- 43.4% young of year woodcock and 70% chicks had bone-Pb levels in elevated range.
- Elevated lead exposure in WI woodcock is common and begins shortly after hatch.
- Source of lead was not determined.

Tavecchia, G., R. Pradel, J. Lebreton, A.R. Johnson, and J. Mondain-Monval. 2001. The effect of lead exposure on survival of adult mallards in the Camargue, southern France. *Journal of Applied Ecology* 38(6):1197-1207.

- Captured 2710 adult mallards from a wintering area for several species of water birds.
- Investigated influence of lead pellet exposure (presence of ingested pellets and the presence of pellets in the muscles) on survival.

- Maximum count of pellets in the gizzard was 50, estimated proportion of gizzard-contaminated birds was 11%.
- Distribution in 4 groups: 68% no exposure to, 8% gizzard-contaminated only, 20% muscle-contaminated only, and 3.4% both gizzard and muscle contaminated.
- Survival of lead-affected mallards was 19% lower than unaffected birds for both types of lead exposure. The two sources of mortality were additive.

Thomas, V.G. 1997. The environmental and ethical implications of lead shot contamination of rural lands in North America. *Journal of Agricultural and Environmental Ethics* 10(1):41-54.

- Lead shot deposited in fields and woodlands near shooting ranges and intense, upland, hunting adds an enormous tonnage of lead to environments, worldwide.
- Many nations are slow to require use of nontoxic-shot, despite the marked awareness of the problems of lead shot contamination and toxicosis.
- "This is due to hunters and international sport shooting organizations opposing the use of non-toxic substitutes and overt emphasis by government agencies on the burden of scientific proof for every situation, rather than taking preventative action according to the Precautionary Principle."
- The ethical approach of Denmark and The Netherlands, which banned all uses of lead shot, is advocated as a precedent for other nations to adopt.

Thomas, V. G., and Owen, M. 1996. Preventing lead toxicosis of European waterfowl by regulatory and non-regulatory means. *Environmental Conservation* 23(4):358-364.

- Proposals to eliminate the use of lead shot in wetlands has been made under Bonn and Bern Conventions.
- Proposal was also made by European Union –USA to reduce the use of different categories of lead under an Organization of Economic Cooperation and Development Council Act, but did not include lead shot.
- The passing of European Council regulation has seen the most effective remediate for the trans-boundary toxic problem.
- Responsibility to enact and enforce a European Council regulation is the prerogative of each member state, a single regulation would promote consistency of action amongst all states.

Thomas, V. G., and M. P. Twiss. 1995. Preventing lead contamination of lakes through international trade regulations. *Lake and Reservoir Management* 11(2):196.

- Lead contamination in Canada's lakes has been a potential problem for toxicosis in waterfowl and fish-eating birds.
- Under the Canadian Environmental Protection Act, Canada has the potential to regulate production and commerce in lead shot and sinkers.
- The North American Free Trade Agreement and its environmental adjunct, The North American Agreement, on Environmental Cooperation could regulate trade in lead substitutes among parties.
- Actions taken by Canada, the USA, and Mexico would promote the security of water-birds habitats on a continental scale.

Trainer, D. O., and R. A. Hunt. 1965. Lead poisoning of whistling swans in Wisconsin. *Avian Diseases* 9(2):252-264.

- Mortality of swans due to lead poisoning has been recognized in Wisconsin since 1944.
- Wild Swans were collected for necropsy and analysis for lead.
- During 1964, more than 200 swans died in Wisconsin. Results (45 birds) established lead poisoning was responsible for the majority of the mortalities.

- Number of pellets recovered from the effected birds ranged from 0 to 201 and averaged 50 pellets per bird.

Tsuji, L.J.S., E. Nieboer, J.D. Karagatzides, R.M. Hanning, B. Katapatuk. 1999. Lead Shot Contamination in Edible Portions of Game Birds and Its Dietary Implications *Ecosystem Health* 5 (3):183–192.

- Study conducted in the Mushkegowuk region (western James Bay area of northern Ontario, Canada).
- Livers of 2% (5/233) of game birds collected showed lead concentrations $>0.5 \mu\text{g/g ww}$, and 9% (33/371) of the gizzard (striated muscle) tissue samples obtained through harvesting of waterbirds and upland game birds employing lead shot, showed lead levels greater than the Health Canada guideline for fish.
- “People who consume *any* game species harvested with lead shot risk exposure to this metal by way of ingestion of tissue-embedded lead pellets and fragments.”
- A ban on the use of lead shot for *all* game hunting should be considered because of potential human health concerns.

Vyas, N.B., J.W. Spann, G.H. Heinz, W.N. Beyer, J.A. Jaquette, and J.M. Mengelkoch. 2000. Lead poisoning of passerines at a trap and skeet range. *Environmental Pollution* 107 (1):159-166.

- Tested blood and tissue Pb levels in ground foraging passerines on woodlands surrounding a trap and skeet range.
- Sparrows and juncos sampled at the range had significantly higher Pb exposure than those at an uncontaminated site.
- Most of the Pb shot at the range was found in the top 3 cm of soil, where it is available to wildlife.
- Pb measurements in earthworms were between 660-840 ppm.

Vyas, N.B., J.W. Spann, and G.H. Heinz. 2001. Lead shot toxicity to passerines. *Environmental Pollution* 111 (1):135-138.

- Evaluated toxicity of a single 7.5 lead shot to passerines.
- On a commercial diet no mortalities, but on natural diet, 3 of 10 cowbirds died within 1 day.
- All but 1 surviving bird excreted the shot within 1 day, but birds which retained their shot died.
- “Despite short amount of time shot was retained, shongbirds may absorb sufficient Pb to compromise their survival.”

Wilson, I. D. 1937. An early report of lead poisoning in waterfowl. *Science, New Series* 86(2236):423.

- Lead poisoning in ducks, geese and swans discovered in Back Bay, Virginia, and Currituck Sound, North Carolina.
- Analyzed gizzards, contained over 100 full sized No. 4 lead shot and partly ground remains.