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A review of the environmental impacts of lead shotshell ammunition and lead fishing weights in Canada

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Cover photos (left to right): Common Loon (David Pond), Mallard (G.W. Beyersbergen), and Bald Eagle (Richard Fyfe)

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Abstract

This report reviews the available information, from Canada and elsewhere, on the use, environmental fate, and toxicity of spent lead shot and lost lead fishing weights and discusses options for managing the negative impacts of these products.

Lead shot ammunition and fishing sinkers worth an estimated $25–$35 million are purchased annually in Canada. For lead shot, more product is imported (primarily from the United States) than is manufactured in Canada; for lead sinkers, more product is produced domestically than is imported. A major proportion of Canadian lead sinker production is probably attributable to individuals and very small local companies. Between 1988 and 1993, the total deposition of lead shot and sinkers into the Canadian environment by hunters, clay target shooters, and sport anglers averaged about 2400–2700 t/yr. About 70–80% of the total deposition was lead shot from hunters. Most of the deposition of shot and sinkers occurs in Ontario and Quebec, but some deposition occurs in all provinces and territories. Local deposition rates vary from almost nil to very high in some locations (certain rivers, lakes, marshes, target shooting clubs) where shooting or angling pressure has traditionally been high. Where they have been measured, shot pellet densities at waterfowl hunting sites in Canada are comparable to those measured in the United States and elsewhere.

Metallic lead pellets deposited onto soils and aquatic sediments are not chemically or environmentally inert, although tens or hundreds of years may be required for total breakdown and dissolution of pellets. The rates of erosion, oxidation, and dissolution of metallic lead pellets in the environment depend on various physical and chemical factors. Aerobic, acidic conditions enhance the rate of pellet breakdown, whereas anaerobic, alkaline conditions decrease it. Physical factors such as high water flow rates, soils or sediments dominated by the presence of coarse sand or gravel, and frequent disturbance of contaminated soils all serve to enhance the rate of lead pellet breakdown. Lead concentrations in soils and sediments of shotfall zones of clay target shooting ranges can exceed the Canadian Environmental Quality (Remediation) Criteria for lead in soils. This may also be true for sites experiencing heavy hunting pressure, but data from such sites are generally lacking. The leachable lead concentrations in soils or sediments associated with clay target shooting ranges are often sufficiently high as to exceed lead criteria for hazardous waste. Molecular lead from the breakdown of spent shot can be transferred to biota, especially soil and sediment invertebrates and terrestrial and aquatic plants, and thence to higher trophic levels.

Lead shot ingestion is probably the primary source of elevated lead exposure and poisoning in Canadian waterfowl and most other bird species. For some species (e.g., Common Loons), lead sinker ingestion is a more frequent cause of lead poisoning. Based on gizzard and wing bone surveys of the species of ducks most commonly hunted and extrapolation from U.S. estimates, up to 6 million of the approximately 50–60 million game ducks migrating from Canada every fall may ingest one or more spent lead shotgun pellets while in Canada. These individuals suffer either mortality (~200 000–360 000) or sublethal lead poisoning (several million). Because the United States has banned the use of lead shot for waterfowl hunting nationwide since 1991, Canada is now responsible for an increasingly large proportion of the lead poisoning problem in North America and may be the major continental source of migrating waterfowl that carry embedded lead shot. Lead shot ingestion also occurs in a wide variety of non-waterfowl species, including upland game birds, shorebirds, raptors, and scavengers. Where it has been explicitly studied in Canada and the United States, lead poisoning mortality of Bald and Golden eagles from eating prey animals with lead shot embedded in their tissues or the gizzards of birds with ingested lead shot accounts for an estimated 10–15% of the recorded post-fledging mortality in these raptorial species. Several studies have demonstrated that the incidence of embedded shot in apparently healthy, free-flying waterfowl frequently exceeds 20%, indicating that millions of migrating ducks and geese carry embedded shot. A significant proportion of heavily hunted upland species and small game mammals, and even some nonhunted species, also carry embedded shot.

Clay target shooting ranges, especially those in which the shotfall zones include ponds, marshes, lakes, rivers, beaches, or other aquatic-type environments, create

a significant risk of shot ingestion and poisoning for waterfowl.

In North American freshwater environments where sport angling activity and loon populations co-occur, lead poisoning from ingestion of small (<50 g) lead sinkers or jigs can account for 10–50% of recorded adult loon mortality, depending on the location studied.

Good-quality, nontoxic alternatives to lead shot and sinkers are currently being produced, and additional such products are being developed. Nontoxic alternatives now available are more expensive than lead shot or sinkers but would increase the average hunter's total yearly expenses by only about 1–2% (based on the use of steel shot) and those of the average angler by <1–2%. There will probably be a marginal market for and incomplete availability of nontoxic shot and sinkers until lead shot and sinkers are made unavailable.

Modern steel and bismuth/tin shotshell ammunition are both effective for bagging waterfowl and other game animals over accepted shotgun shooting ranges (up to about 45 m for waterfowl). Crippling of game animals is much more a function of the skill of the shooter than of the type of ammunition (lead, steel, bismuth/tin) used. For hunting with nontoxic shot, the single major undesirable consequence is wastage due to crippling loss. The undesirable aspects of hunting with lead shot, however, include crippling losses, losses from lethal and sublethal lead poisoning of waterfowl and other wild birds through "primary" poisoning, losses from lethal and sublethal poisoning of raptors and scavengers ("secondary" poisoning), the risk of lead exposure of some livestock species (e.g., domestic fowl, cattle), unnecessary lead exposure of humans consuming game bagged with lead shot, and the eventual breakdown of metallic lead pellets in the environment and subsequent transfer of particulate and molecular lead to plants and animals.

Neither the federal government nor the provincial/territorial governments have the resources to comprehensively assess all areas for which nontoxic shot zoning or use of nontoxic sinkers may be appropriate, nor do they have the capability to effectively enforce bans on the use of lead shot or sinkers in numerous local "hot spot" areas. From the point of view of hunter and angler compliance, effective enforcement, efficient and predictable retail availability of nontoxic products, and the protection of wildlife and ecosystem health, partial bans on lead shot or small lead sinkers/jigs are less than ideal solutions to the lead poisoning problem and cause their own additional problems. Other countries have successfully banned the use of small lead sinkers and of lead shot for waterfowl and other hunting and are in the process of banning the use of lead shot for clay target shooting, using a phasing-out process that gives manufacturers, sellers, and users adequate time to adjust to the regulations.

In Canada, several provinces and territories are committed to phasing out the use of lead shot for waterfowl hunting throughout their jurisdictions, and there will be a national ban on the use of lead shot for all migratory game bird hunting beginning in 1997. Sport anglers have been increasingly encouraged by federal and provincial/territorial environment departments and by several nongovernmental environmental organizations to voluntarily use nontoxic fishing sinkers. The present report can serve as the basis for further government actions to manage the negative impacts of lead shot and fishing sinkers in Canada.

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Introduction

Lead (Pb) is a soft, bluish, metallic element found naturally at trace concentrations in all environmental media. It has been mined and used in society for many hundreds of years. Lead's low melting point, malleability, ease of processing, and low cost have resulted in its use in a wide range of applications, including lead shotshell and other ammunition and lead fishing weights (sinkers and jigs). However, owing to lead's relatively high intrinsic toxicity and the continual refinement of the science of lead toxicology, which has resulted in the recognition of adverse effects of lead at lower and lower levels of exposure, many of the traditional uses of lead have been phased out in recent decades. Its uses in solder, plumbing pipes, paints, pottery glazes, crystal ware, and gasoline have been banned or severely reduced.

The problem, potential or actual, of waterfowl poisoning associated with the use of lead shotshell ammunition for wetland hunting has been recognized since the turn of the century (Grinell 1894). In the Canadian Wildlife Service (CWS), significant concern over lead poisoning of waterfowl from lead shot ingestion surfaced in the late 1960s and early 1970s. At that time CWS, in collaboration with the National Research Council of Canada, conducted research to develop ballistically acceptable nontoxic alternatives to lead shot. Concerted research and monitoring efforts to study the nature and extent of lead shot poisoning nationally were initiated in Canada in the late 1980s when the United States announced its intent to completely ban the use of lead shot for waterfowl hunting by 1991. Prior to that time, only a very few local or regional studies of the incidence of lead shot ingestion by waterfowl had been undertaken in Canada. In 1990 and 1991, once substantial additional research had been completed (collated in Kennedy and Nadeau 1993), CWS, using its regulatory authority under the Migratory Birds Convention Act, and with provincial agreement, established the first Canadian nontoxic shot zones in British Columbia, Manitoba, and Ontario. At that time, CWS judged that there was insufficient evidence to justify a national ban on the use of lead shot for waterfowl hunting, and it developed a set of criteria for assessing whether local lead exposure in waterfowl was sufficiently severe as to require nontoxic shot regulations. This framework (CWS 1990; Wendt and Kennedy 1992) and its subsequent modifications are typically referred to as the "hot spot" approach to regulating the use of lead shot. The CWS criteria were accepted in 1990 by federal and provincial/territorial wildlife ministers as an interim policy for managing the problems associated with the use of lead shot for waterfowl hunting. Since that time, much additional research has been undertaken by CWS and others on several fronts, including a closer examination of the secondary poisoning of eagles and other raptors by lead shot, the international dimensions of the lead poisoning problem, and the development of new alternatives to lead shot. These developments, along with changing public opinion, required that the CWS zoning policy be reassessed by Environment Canada.

Problems relating to the use of lead fishing sinkers and jigs have only more recently come to light in Canada. No federal or provincial/territorial regulations against the use of lead fishing sinkers (or jigs) have yet been established, nor have Canadian scientific research papers on this topic been published. However, data from Canada, the United States, Great Britain, and elsewhere indicate that lead intoxication of loons, swans, and other water birds from the ingestion of fishing sinkers is a phenomenon that requires the attention of the appropriate regulatory agencies. In Great Britain, the sale of lead fishing sinkers weighing less than 28.35 g (1oz.) has been banned since 1987 (Government of Great Britain 1986) because of widespread mortality of swans in that country and the incomplete success of voluntary efforts to phase out the use of such sinkers. In the United States, the use of lead sinkers in Yellowstone National Park and Red Rock Lakes National Wildlife Refuge has been banned, and the U.S. Environmental Protection Agency (USEPA) has proposed to prohibit nationwide the manufacture, processing, and commercial sale of lead sinkers of a size range most likely to be ingested by water birds, based on the documented mortality of loons and other water birds. Public consultations of the USEPA proposal are still ongoing.

This report reviews the import, manufacture, and use patterns of lead shot and sinkers in Canada (Chapter 1), the environmental chemistry and fate of metallic lead pellets in the environment (Chapter 2), and toxicity from ingestion of metallic lead from shot and sinkers (Chapter 3). It then discusses the approaches taken by different nations to deal with the problems caused by lead shot and sinker use and identifies strategies for managing the negative impacts of these products in Canada (Chapter 4).

Chapter 1
Production, import, and use of lead shot and fishing sinkers in Canada

1.1 General

In 1994, world production of lead ores/concentrates and refined metal was about 2.8 and 5.4 million tonnes, respectively (ILZSG 1994). Canadian production accounted for about 6.6% and 4.1%, respectively, of the world totals. Approximately 69% of Canadian lead production is primary production; the rest is secondary production from recycled lead wastes and scrap metal, some of which is imported. In 1992, for example, Canada imported, almost exclusively from the United States, 50 538 t of lead waste and scrap (Keating and Wright 1994). Most lead produced (primary and secondary production) in Canada is exported, mainly to Europe, Japan, and the United States. The amount of lead exported from Canada is about three times that used domestically. In 1992 and 1993, Canadian industries consumed about 79 700 and 91 700 t of lead, respectively (Keating and Wright 1994).

The principal current uses of lead are given in Table 1. Battery and pigment manufacturing together account for about 76% of the world production of lead. The manufacture of lead shot and sinkers represents a relatively minor use of lead. For countries within the Organization for Economic Co-operation and Development (OECD), the quantity of lead used in manufacturing shot and other ammunition ranged from 60 000 to 80 000 t annually between 1970 and 1990 (OECD 1993). This represents <1% of world lead production.

Table 1
Principal global uses of lead

Lead Use	% of world total
Batteries	63.0
Pigments	12.8
Rolled metal	7.7
Cable sheathing	4.5
Gas additives	2.2
Other uses	9.9

Source: ILZSG (1992).

1.2 Lead shot

Lead shot is used in two distinct types of sporting activity: 1) hunting and 2) clay target (skeet/trap/sporting clay) shooting.

1.2.1 Hunting

Waterfowl (ducks, geese) and other migratory birds (woodcock, snipe, coot, cranes, doves, pigeons), upland birds (grouse, pheasants, partridge, quail, ptarmigan), and some small mammals (rabbit, hare, squirrel) are the game species hunted primarily with lead shot ammunition. In 1991, an estimated 1.5 million Canadians participated in some form of hunting activity; 394 000 (26% of hunters) hunted waterfowl, and 723 000 (48% of hunters) hunted other game birds (Filion et al. 1993).

The expenditures associated with shotgun hunting activities in Canada are presented in Table 2. Individually, game bird and small mammal hunters spend an average of about \$230–\$450 per year on their sport, of which ammunition is a relatively small component. About 80% of total expenditures go towards equipment (guns, clothing, camping gear, etc.), transportation, food, and accommodations (Filion et al. 1993). In Canada, the average waterfowl hunter bags about 8–10 birds per year (Legris and Lévesque 1991). Using the U.S. Fish and Wildlife Service (USFWS) estimate of six shots fired per duck bagged (USFWS 1986), we estimate that the average Canadian waterfowl hunter discharges about 54 rounds per year. At current prices, this means that the average Canadian waterfowler spends about \$27 per year on lead shotgun shells, or about 6% of his total annual waterfowl hunting budget.

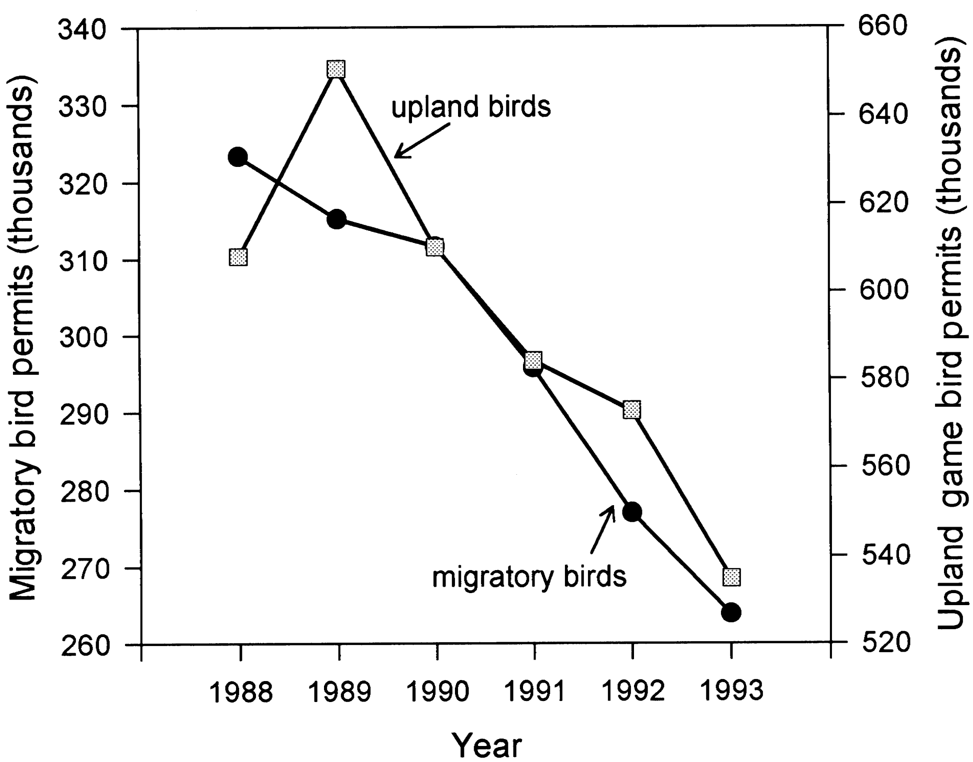
We attempted to determine whether there were recent trends in the popularity of shotgun hunting sports. We obtained CWS records of migratory game bird permits sold annually between 1988 and 1993 and similar data from provincial natural resources departments for upland game bird permit sales. Unambiguous declining trends were observed for each of these hunting activities. Based on permit sales, the hunting of migratory birds and upland birds declined by approximately 19% and 12%, respectively, between 1988 and 1993 (Fig. 1). For waterfowl, there was also a decline in harvest of approximately 20% over the same period. For migratory

Table 2
Shotgun hunting and clay target shooting by Canadians

	Estimated no. of participants	Annual expenditure ($) Total	Per person	Approximate lead discharged (t/yr)[b]
Hunters[a]				
Waterfowl	394 000	177 million	450	777
Other birds	723 000	224 million	310	706
Small mammals	612 000	141 million	229	406[c]
Clay target shooters	3 000	?	?	®260

[a] Estimates of number of participants and annual expenditures are from Filion et al. (1993).
[b] Includes estimates for aboriginal harvest.
[c] We have no estimate of total harvest of small mammals, and probably not all small mammal hunting is done with shotguns. Assuming that about one-half of the small mammal harvest is taken with lead shot and that tonnes of lead discharged per hunter is similar to that for game birds (0.0013), then about 406 t of lead shot are discharged per year for small mammal hunting.

Figure 1
Trends in the purchase of migratory and upland bird hunting permits in Canada between 1988 and 1993.[a]



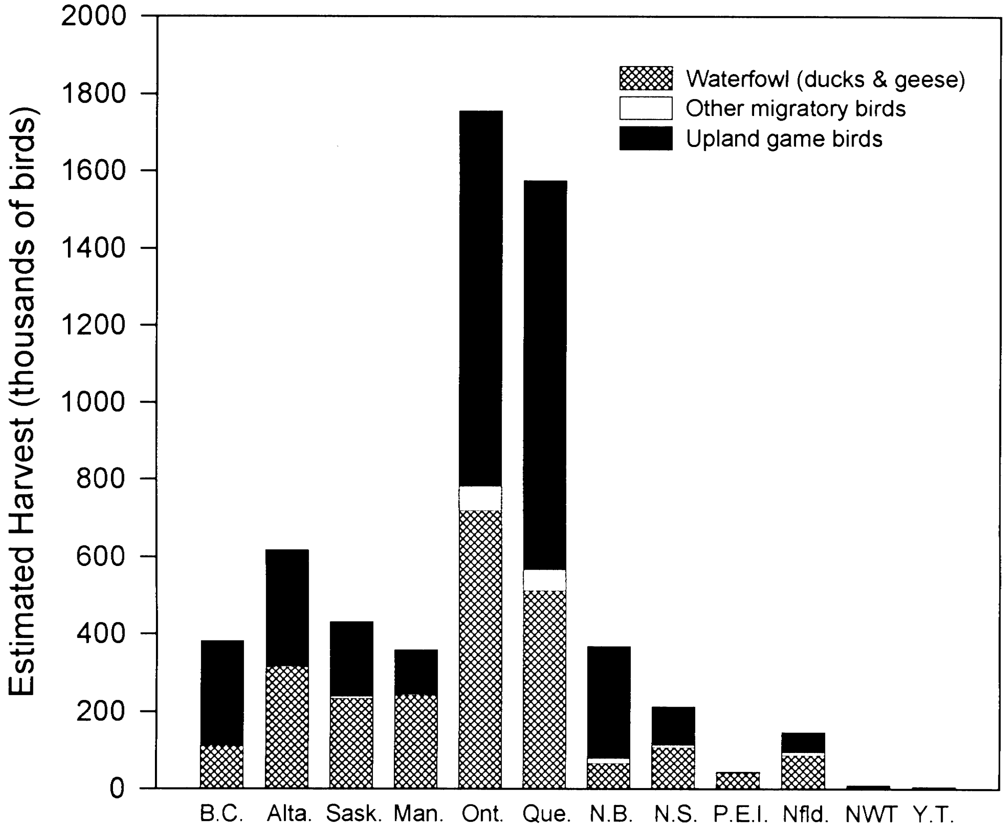
[a] Migratory game bird permit numbers are from CWS annual records. For upland bird permits, numbers calculated and provided by the provinces (British Columbia, Manitoba, Newfoundland) were used or numbers were estimated by subtracting migratory bird licences from the total number of small game or game bird licences sold per province. Our estimates of upland permits are thus conservative because they do not include migratory bird hunters who also hunt upland birds.

bird hunting, a decline has been under way since 1978, when almost 525 000 permits were sold (Legris and Lévesque 1991). In comparison, 263 878 permits were sold nationally in 1993 (CWS, unpubl. data). This declining trend is seen in all provinces and territories.

For the early 1980s, Jaques (1985) estimated the deposition rate of spent lead shot into the Canadian environment at about 1500 t/yr. In order to arrive at a more recent estimate, we used two different approaches: 1) a calculation based on game bird harvest data and 2) a calculation based on shot import and production data.

For the estimate based on harvest data, we obtained records of game bird harvest from CWS and the appropriate provincial/territorial departments. Most of the game birds harvested by hunters in Canada are shot in Ontario and Quebec, which together represent about 60% of the national harvest (Fig. 2). In total, approximately 5.5 million game birds are shot annually in Canada. For waterfowl, the USFWS (1986) has estimated that an average of about six shots is fired for each duck bagged. We do not know if this estimate is similar for upland game birds, and, to our knowledge, no number has been calculated for upland birds. Using the USFWS estimate

Figure 2
Estimated average yearly harvest of game birds by licensed hunters in Canada.[a]



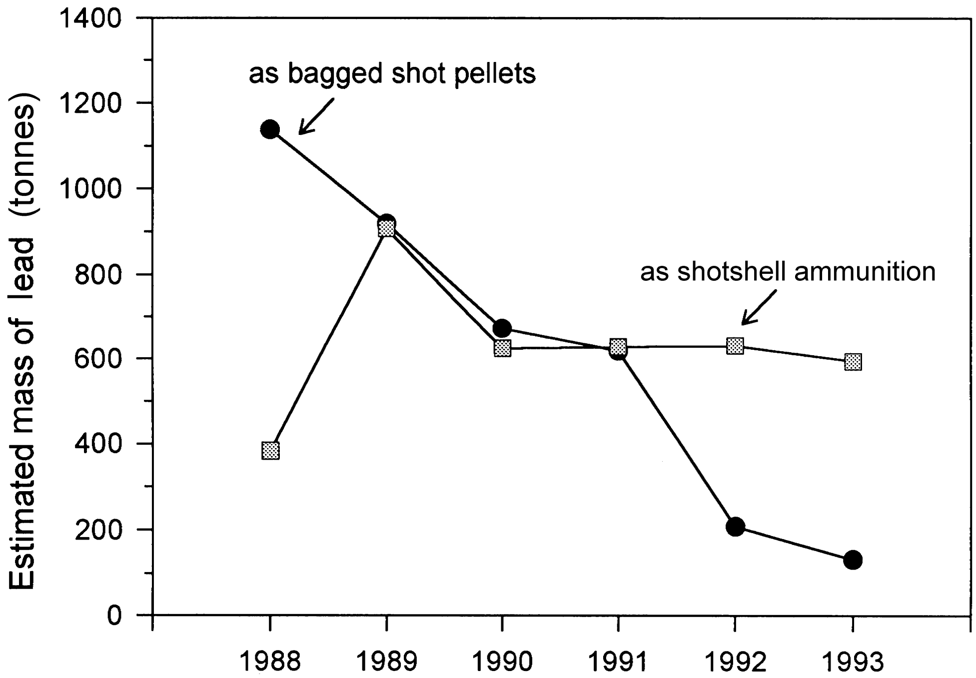
[a] For waterfowl and other migratory birds, estimates are mean harvest over the period 1988–1993 from the CWS Harvest Survey. For upland birds, data over a similar period, if available, as provided by the appropriate provincial/territorial departments were used. For Ontario, data are from the 1983 *Small Game Hunter Report* (OMNR 1983). Data for upland bird harvest were not supplied for Manitoba, Quebec, Newfoundland, or the Yukon. For Quebec and Manitoba, harvest was estimated by multiplying the number of permits sold by the known harvest per permit for Ontario (3.6). Harvest was similarly estimated for Newfoundland, using the known harvest per permit for Nova Scotia (3.66). For the Yukon, the harvest for the Northwest Territories (3549 birds) was used.

for ducks and applying it to all game birds, we calculate that about 33 million rounds of shotshell ammunition are discharged annually in Canada by licensed game bird hunters. Of this, about 15 million rounds are discharged by waterfowlers. The average weight of lead contained in a single waterfowl hunting load shotshell is about $1\frac{1}{4}$ oz., or about 35 g, and that in an upland hunting load is about 28 g. Thus, we can estimate that between 1988 and 1993 approximately 1029 t of lead per year were discharged into the Canadian environment by licensed game bird hunters. Harvest by native hunters is in addition to that by licensed hunters. The magnitude of the native harvest is not recorded formally, but CWS has been recently attempting to estimate the annual kill of waterfowl from this source. Preliminary estimates indicate that about 730 000 ducks and 470 000 geese are killed annually by aboriginal hunters in Canada (CWS, unpubl. data). If we assume that a roughly comparable number of upland birds is also taken (as is the case for licensed hunters; Fig. 2), then we can conclude that about 2.4 million game birds are shot per year in Canada by aboriginal hunters. This corresponds to about 454 t of lead. Small mammal hunting probably adds significantly to the total, whereas illegal hunting and casual target shooting, the magnitude of which cannot be estimated from harvest data, probably account for a proportionally small additional amount of lead. The estimate of 1500 t/yr made by Jaques (1985) is thus a reasonable, albeit conservative, estimate for the average annual amount of lead shot discharged in Canada. By our estimate, the average annual discharge is about 2000 t. A separate estimate for the discharge of lead by clay target shooters is presented below (Section 1.2.2). Table 2 summarizes the estimated annual amounts of lead shot discharged into the environment by hunters and clay target shooters.

Having estimated the amount of lead released into the Canadian environment using available statistics on game bird hunting and harvest, we next estimated the amount of lead shot imported into Canada plus that manufactured domestically. It was of interest to compare these two estimates.

Canada imports shot in two forms: shotshell ammunition and bagged shot pellets. We obtained data on the annual wholesale import value in Canadian dollars (1988–1993) of both these forms of shot from the International Trade Division of Statistics Canada and converted the data to quantity of lead in tonnes. Conversion from dollars to tonnes was based on estimates of wholesale value per kilogram that we obtained by surveying the appropriate suppliers and retailers. For

Figure 3
Recent trends in the importation of lead as shotshell ammunition and bagged shot pellets into Canada



Source: Adapted from data provided by the International Trade Division, Statistics Canada

bagged shot, we estimated an average wholesale value of approximately $1.40/kg; for shotshell ammunition, we estimated an average wholesale value of approximately $0.42/shell (32 g of lead), or $13.13/kg.

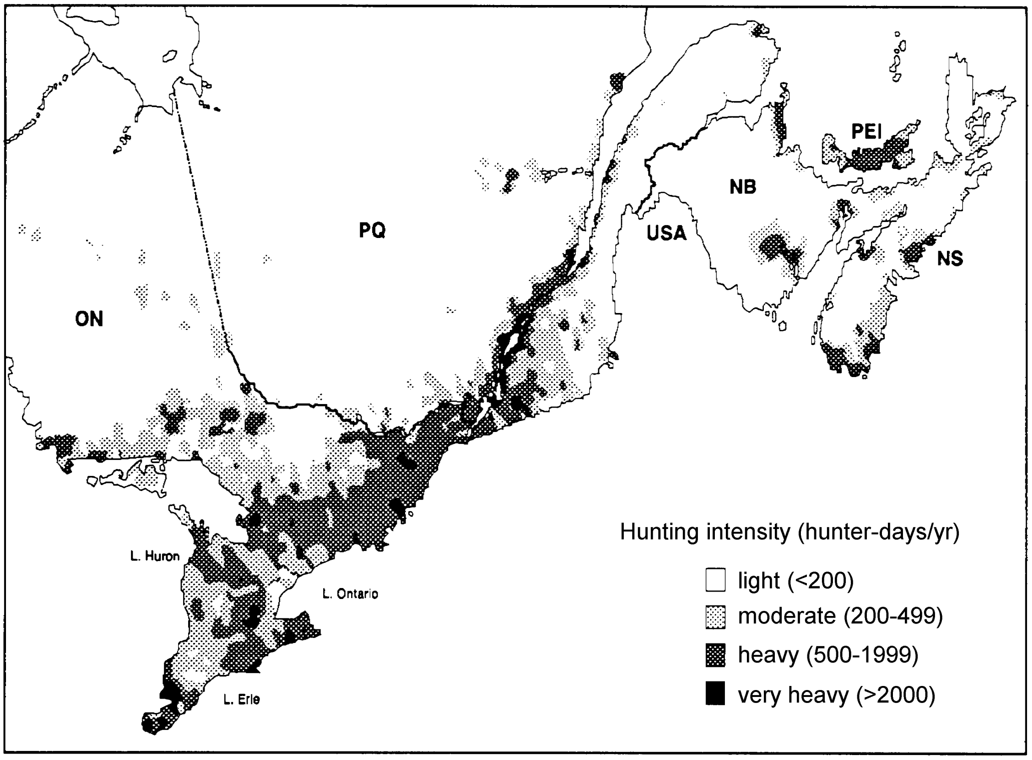
Most (~80%) of the shot imported into Canada originates from the three main U.S. shotshell manufacturers (Winchester, Federal, Remington). Minor amounts come from other countries, such as Italy, Hungary, and the former Yugoslavia and Czechoslovakia. Not surprisingly, most (~80%) of the shot imported goes to Ontario and Quebec, where the majority of hunters reside. Figure 3 shows the national trends in shot imports from 1988 to 1993. Total lead shot imports fell from ~1800 t in 1989 to ~700 t in 1993. The declining trend is seen primarily for bagged shot and reflects similar trends already described for the purchase of game bird hunting permits (Fig. 1). The average amount of lead as shot (shotshell ammunition and bagged shot) that was imported annually between 1988 and 1993 is estimated to be about 1240 t.

In addition to that imported, bagged lead shot is produced in Canada. Most of this shot is sold to shotshell manufacturers (the largest such company is Challenger Ammunition, Quebec) or to smaller shotshell loading/reloading companies and to individual reloaders. A partial list of loading/reloading companies is provided in Appendix 1. There is almost no Canadian export of lead shot or shotshell ammunition. The largest manufacturers of lead shot pellets in Canada are Hummason Manufacturing Ltd., Ancaster, Ontario, and Canadian Superior Munitions, Edmonton, Alberta. In early October 1994 we wrote to these and other potential Canadian manufacturers of lead shot and requested that they provide us with estimates of the yearly amounts of lead used, the amounts of shot produced, and the ratio of hunting loads (BB-6) to target loads (7-9) produced. We received a written response only from Rona-B Lead Shot Industries, Calgary, Alberta, which informed us that the company has been out of business for four years. It is thus difficult for us to estimate accurately the amount of lead shot produced in this country.

Nevertheless, based on limited information that we have been able to obtain (number of companies producing shot, approximate value of sales, and the number of persons employed), we estimate that probably a few hundred tonnes of lead shot are produced annually in Canada. An average lead shot import of roughly 1200–1300 t per year plus an estimated several hundred tonnes produced by Canadian companies corresponds well with the estimated total discharge of lead shot by hunters and target shooters. Section 15 of the Canadian Environmental Protection Act could be used, if necessary, to obtain more accurate production information from Canadian manufacturers of shot and shotshell products.

The pattern of environmental lead shot deposition is very heterogeneous. Some fields and wetlands are heavily hunted, whereas others are virtually free of hunting pressure. Figure 4 illustrates the heterogeneous nature of waterfowl hunting in eastern Canada. In general, deposition is greatest where the combined abundance of hunters and game animals is greatest. In the Judson Lake and Pitt Lake areas of British Columbia, sediments contained 37 000 – 177 000 pellets per hectare (Wilson et al. 1995). In the Prairies, pellet densities in hunted marsh sediments ranged from zero from five study sites in Alberta to over two million pellets per hectare at some sites around Chatique Lake, Manitoba (Hochbaum 1993). The shot densities for Chatique Lake are among the

Figure 4
The pattern of duck hunting intensity by licensed hunters in eastern Canada[a]



[a] Data plotted are mean yearly hunter-days per 10-minute block for the period 1972–1988. “Hunter-days per 10-minute block” is the total number of days spent hunting ducks for all permit holders who hunted within any 10-minute block (10 minutes longitude x 10 minutes latitude).

Source: Scheuhammer and Dickson (1995)

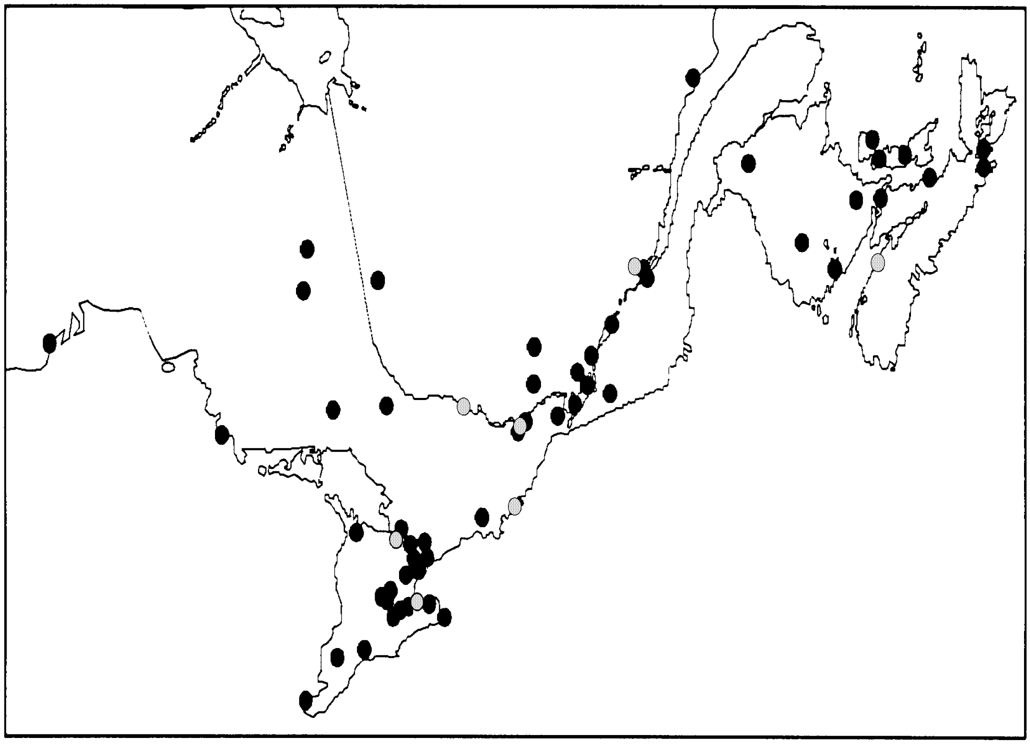
highest recorded for any marsh anywhere in the world. This lake is now within a nontoxic shot zone. In Atlantic Canada, pellet densities in 14 heavily hunted marshes ranged from 35 000 to 57 000 per hectare in New Brunswick, 9000 to 86 000 per hectare in Nova Scotia, and 48 000 to 91 000 per hectare in Prince Edward Island (Kennedy and Nadeau 1993). Pellet densities in hunted marshes in Canada are comparable to those in the United States (USFWS 1986) and other countries.

1.2.2 Clay target (trap/skeet) shooting

The Shooting Federation of Canada is the national governing body for Olympic and recreational trap and skeet shooting in this country. From the federation, we obtained a listing of all their affiliated provincial and territorial associations (Appendix 2); these were contacted by letter and requested to provide us with the names and locations of the clay target shooting ranges in their respective jurisdictions, the approximate number of individuals participating in clay target shooting sports, and the approximate number of shells used annually per average shooter. We received responses from associations in British Columbia, Manitoba, Ontario, Prince Edward Island, and the Northwest Territories. Based on the information provided by these sources, we conclude that 1) most (~90%) of the shotshell ammunition used in clay target shooting is from reloaders, rather than from factory production and retail sale, as is the case for hunters (certain companies, such as Canadian Superior Munitions, have informed us that most of the lead shot they produce is for target shooting); 2) there is a maximum of about 3000 registered trap/skeet shooters in Canada; and 3) each shooter discharges an average of about 1500 shells per year.

Clay target loads contain ⅞–1⅛ oz. of lead, or an average of about 1 oz. (~28.4 g). From this information, we calculate that registered clay target shooters deposit about 128 tonnes of lead into the environment annually (compared with an estimated ~2000 t deposited by hunters). This estimate is probably a conservative one because we have taken into account only registered shooters. In Atlantic Canada, it is common for local fish and game clubs to have a nonregistered clay target range that is used on weekends in the summer and fall (N. Burgess, pers. commun.). In Ontario, about 23 trapshooting clubs have affiliated with the Ontario Trapshooting Association; however, we have determined that there are at least 14 additional, presumably unaffiliated and smaller, clubs in the province. If this is a general condition occurring in other provinces, the lead deposition by clay target shooters may be considerably greater than our estimate of 128 t/yr. However, even if our estimate is low by 100%, it is unlikely that more than about 260 t of lead are discharged annually into the Canadian environment by trap and skeet shooters. In Canada, considerably less lead shot is discharged through clay target shooting than through hunting. (Table 2).

Figure 5
Location of clay target ranges that were operational as of fall 1994 in eastern Canada.[a] Black circles are privately owned properties; grey circles are Department of National Defence-owned properties.



[a] There are probably numerous additional small ranges of which we are not aware.

As is the case for hunting, the discharge of lead shot into the environment through clay target shooting is heavily concentrated in certain local sites. Maps indicating the locations of clay target ranges in Canada are provided in Figures 5 and 6. A few of these ranges are Department of National Defence (DND)-owned target ranges on which public shooting is allowed; the remainder are privately owned facilities, some of which have been in operation for 50 years or more. Although at some trap/skeet ranges shot are, or were, discharged into wetlands or other aquatic habitats (e.g., Cole Harbour, N.S.; Moncton, N.B.; Harrison Hot Springs, B.C.), the majority of ranges are located over dry land. The Manitoba Trapshooting Association has informed us that all shooting in that province is over dry land. For this review, we have not had sufficient time or resources to characterize the type of terrain associated with each of the approximately 120 clay target ranges in Canada. Such an inventory should be produced.

We have no data on possible trends in the popularity of clay target sports, so we cannot estimate whether the deposition of lead from these activities is stable, increasing, or declining.

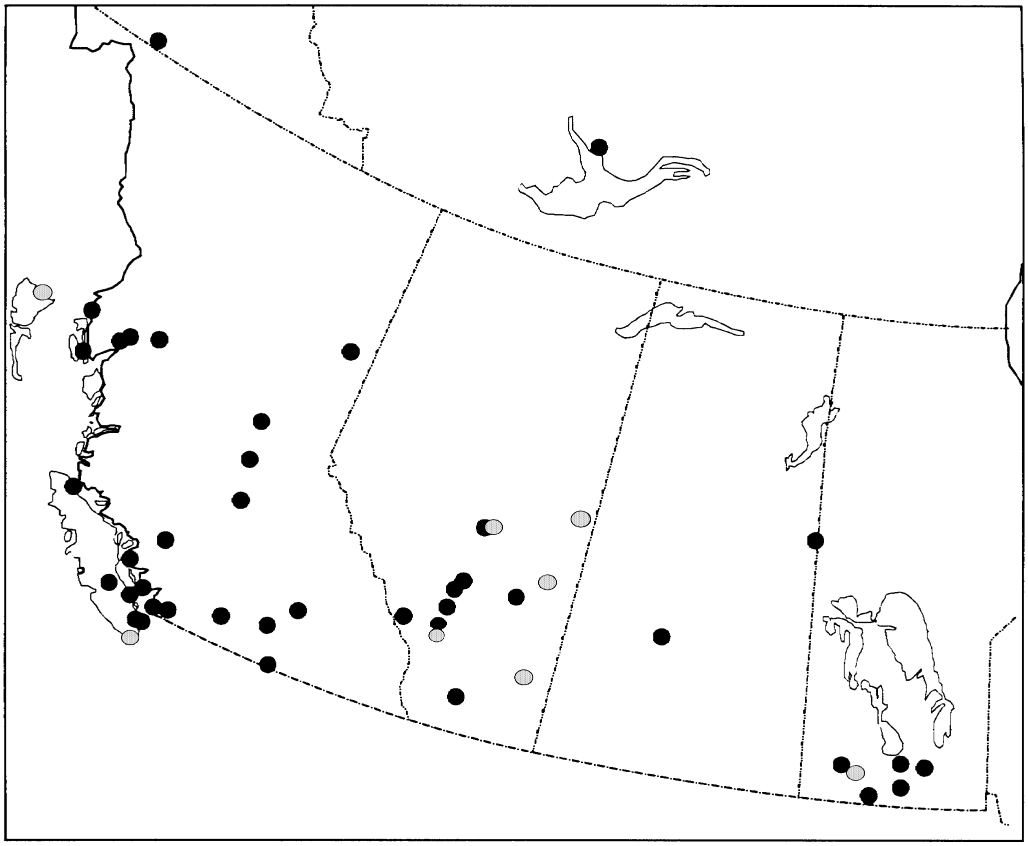
1.3 Fishing sinkers and jigs

Fishing sinkers and jigs of a size range of concern for this review are used exclusively by a single group of sportsmen: sport anglers. Other sinkers and lead weights, exceeding about 2 oz. (57 g), are not ingested by water birds and will not be discussed in any detail in the present review.

Sinkers used in freshwater sport fishing range in weight from about 0.3 to 230 g and in length or diameter from about 2 mm to 8 cm. Although sinkers vary considerably in size and shape, there are a few common types used in freshwater angling: split shot, worm weights, egg sinkers, bass casting sinkers, and pyramid sinkers (USEPA 1994a). Split shot sinkers are estimated to account for almost half of total U.S. sinker production; and the majority of lead sinkers of all types are less than 2 cm in any direction (USEPA 1994a). Jigs are weighted hooks, often brightly painted and otherwise decorated, used as lures in sport angling. Like sinkers, they are made in a variety of shapes and sizes.

On the basis of the average number of yearly sport angling permits sold provincially, we estimate that there are currently about 3.8 million resident adult licensed anglers in Canada. This is a conservative estimate of the total number of anglers, because many people who fish do not purchase or are not required to purchase permits (e.g., residents under 18 years of age), nor does our estimate include nonresident anglers. Filion et al. (1993) reported that in 1991, an estimated 5.5 million Canadians over 15 years of age took part in recreational fishing, the average participant fished on 14 days during the year, and Canadian anglers spent about $2.8 billion (or an average of about $509 each) on their sport. Of the total expenditure, 98.7% was spent within Canada. Between 60% and 65% of all anglers reside in Ontario and Quebec. Figure 7 illustrates that, like game bird hunting permits (Fig. 1), the sale of angling permits in Canada has been declining in recent years.

Figure 6
Location of clay target ranges that were operational as of fall 1994 in western Canada.[a] Black circles are privately owned properties; grey circles are Department of National Defence-owned properties.



[a] There are probably numerous additional small ranges of which we are not aware.

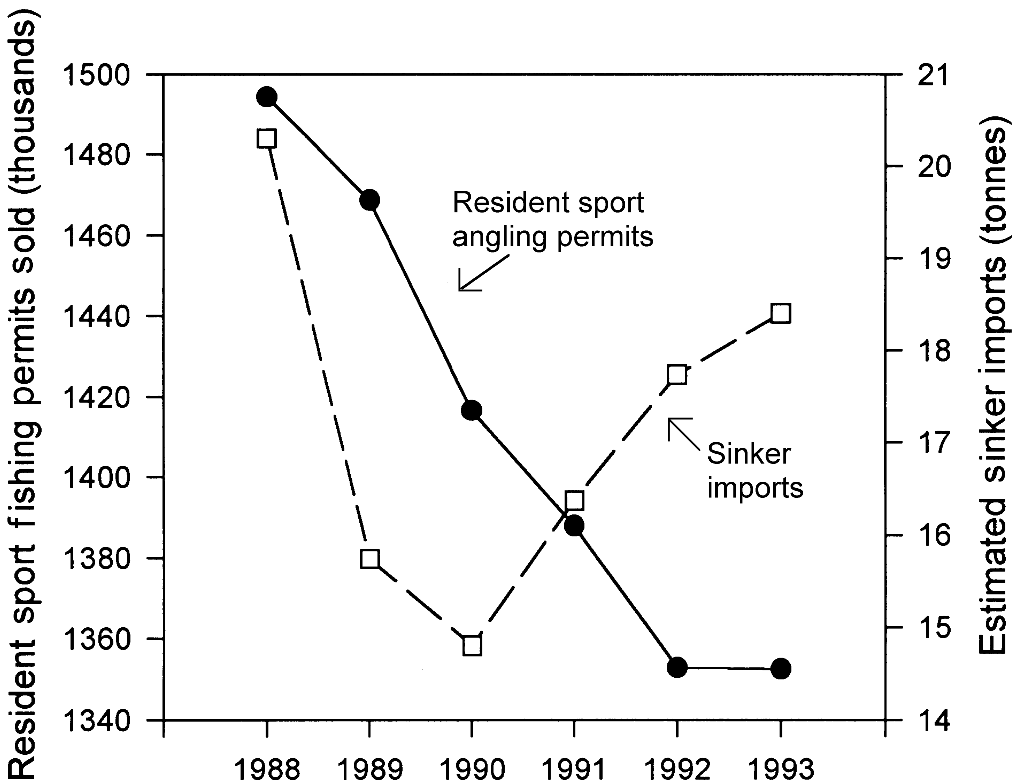
Of the approximately $500 per angler per year spent on fishing in Canada, the proportion spent on sinkers is minuscule. The USEPA (1994a) estimated that anglers spend about $1.50–$3.50 U.S./yr on sinkers. Using the estimated number of anglers in Canada (3.8–5.5 million) and the average estimate of expenditure/angler on sinkers (~$3.25 Can./yr), we calculate that Canadian anglers spend a total of $12.4–$17.9 million per year on fishing sinkers. We surveyed local retail outlets to determine the price range for fishing sinkers, have weighed numerous types and sizes of lead sinker, and conclude that the average retail cost for sinkers is about $0.032/g of lead. From these figures, we estimate that the mass of lead sold as fishing sinkers annually in Canada is in the range of 388–559 t. An undetermined additional amount of lead is sold in the form of jigs. Virtually all of this lead is destined to be deposited into the environment.

In order to estimate the annual importation and domestic production of lead sinkers and jigs, we consulted the International Trade Division of Statistics Canada and also contacted Canadian companies that were in the business of manufacturing fishing tackle supplies. The yearly import value of sinkers used in sport fishing is tracked by Statistics Canada, but imports of jigs are not. It is thus impossible to estimate the average total annual amount of lead as sinkers and jigs imported into Canada.

Canada imports sinkers primarily from the United States and Taiwan, which together represent about 80% of total sinker imports. Relatively minor imports originate from Korea and the United Kingdom. From 1988 to 1993, the average yearly value of sinkers imported into Canada was about $465 000. Based on an estimated wholesale sinker value of about $0.027/g of lead, this translates to approximately 17.2 t of lead sinkers imported annually (compared with at least 388 t purchased by anglers). Figure 7 illustrates changes in sinker imports over the period 1988–1993. Declining sinker imports are not mirrored by declining sport angling permit sales, probably because imports account for only a small proportion of the total Canadian commerce in sinkers.

Fishing tackle supplies, including lead sinkers and jigs, are also manufactured by Canadian-based companies. We contacted 15 Canadian fishing tackle companies, either by letter or by phone, to determine 1) if they manufactured sinkers or jigs, 2) the approximate amounts of lead used to manufacture these products, and 3) the approximate proportion of the companies' total sales that could be attributed to sinkers/jigs. A list of companies that are confirmed to manufacture sinkers and/or jigs in Canada is presented in Appendix 3. Very few companies agreed to disclose the amounts of lead that they use or the annual value of their sinker/jig sales. Few, if any, of these companies make only sinkers or jigs. Sinkers accounted for <5–20% of total annual sales, depending on the company. From the information that we have been able to obtain, we estimate that a maximum of about 40 t of lead sinkers is produced annually by fishing tackle companies in Canada. We were not able to estimate the amount of

Figure 7
Recent trends in the import of lead fishing sinkers and sales of resident sport angling permits in Canada[a]



[a] Import statistics are adapted from data provided by the International Trade Division, Statistics Canada. Permit sales are from information provided by the provinces of Alberta, Saskatchewan, Manitoba, Quebec, Newfoundland, and Prince Edward Island — those province that provided year-by-year data.

lead used in manufacturing jigs, but it is probably substantial. For example, one company informed us that its jig production consumes two to three times the lead used in its sinker production. However, this is not the case for all companies. As for Canadian shot manufacturers, Section 15 of the Canadian Environmental Protection Act could be used, if necessary, to obtain accurate and complete information regarding production of lead sinkers and jigs by Canadian companies.

In the United States, an estimated 0.8–1.6 million individuals participate in the home manufacture of lead sinkers, which are then sold to individual anglers, sinker distributors, and tackle retailers (USEPA 1994a). This “cottage industry” contributes substantially (30–35%) to the total production of lead sinkers in the United States, which is estimated to use about 2700 U.S. tons of lead annually (Nussman 1994). Although we have no direct information regarding the magnitude of a similar cottage industry in Canada, we judge that there must be such an industry, given that the estimated annual purchase of sinkers by Canadian anglers (at least 388 t of lead) is very much higher than the estimated import and production by major Canadian tackle companies (<60 t of lead). One tackle manufacturing representative and one sporting goods wholesaler have indicated to us that sinker production by small tackle companies and cottage industries does indeed account for the majority (~95%) of sinkers made and sold in Canada.

1.4 Summary and conclusions

- ❖ Lead shot ammunition and fishing sinkers worth an estimated \$25–\$35 million are purchased annually in Canada.
- ❖ Between 1988 and 1993, the total deposition of lead shot and sinkers into the Canadian environment by hunters, clay target shooters, and sport anglers averaged about 2400–2700 t/yr.
- ❖ About 70–80% of the total deposition is lead shot from hunters.
- ❖ Most of the deposition of shot and sinkers occurs in Ontario and Quebec, but some deposition occurs in all provinces and territories.
- ❖ Local deposition rates vary from almost nil to very high in some locations (certain rivers, lakes, marshes, target shooting clubs) where shooting or angling pressure has been traditionally high. Pellet densities at waterfowl hunting sites in Canada are comparable to those measured in the United States and elsewhere.

- ❖ For lead shot, more product is imported (primarily from the United States) than is manufactured in Canada; for lead sinkers, more product is produced domestically than is imported. A major proportion of Canadian lead sinker production is probably attributable to individuals and very small local companies.

Chapter 2
Environmental chemistry and fate of metallic lead from shot and fishing sinkers

2.1 Background levels and environmental quality criteria for lead in soils and water

Lead is found in nature as a component of various minerals (McCulley et al. 1991). Some, such as galena (PbS), cerussite ($PbCO_3$), and anglesite ($PbSO_4$), are economically important sources of lead. In Canada and elsewhere, the average concentrations of lead in the earth's crust is approximately 15 µg/g (Heinrichs et al. 1980). Nriagu (1978) reported that most noncontaminated soils contain lead concentrations of about 10–40 µg/g. In Canada, soil lead levels ranged from 15 µg/g in the interior plains to 25 µg/g in the St. Lawrence lowlands (McKeague and Wolynetz 1980). For agricultural soils in Ontario, lead levels in a majority of sites sampled ranged from 1 to 50 µg/g, with a mean of 14.1 µg/g (Frank et al. 1976). For urban and rural parklands in Ontario, 98% of soil samples had lead concentrations of ≤98 µg/g and ≤45 µg/g, respectively (OMEE 1993). Lead levels in most urban industrial soils should lie between 100 and 1000 µg/g (OMEE 1993).

Background concentrations of total lead in surface waters and groundwaters in Ontario were reported to range from nondetectable to 10 µg/L (Fleming 1994). A survey of 76 Ontario municipal water systems undertaken from 1981 to 1987 reported an average lead concentration of 30 µg/L in drinking water (Fleming 1994). Another study examined drinking water samples from five Canadian cities and reported lead concentrations ranging from 0.25 to 71.2 µg/L, averaging 8.8 µg lead/L (Dabeka et al. 1987).

To promote consistency in the implementation of the National Contaminated Sites Remediation Program, the Canadian Council of Ministers of the Environment (CCME) has established national assessment and remediation criteria for lead and other contaminants in soils and water (CCME 1991). Remediation criteria are meant to be used as benchmarks to evaluate the need for further investigation or remediation with respect to a specified land use and to provide the common basis for the establishment of site-specific remediation objectives. The environmental quality criteria for lead are considered to be conservative values for the protection of human and environmental health for specified uses of soil and water and may be applied at the site-specific level as objectives with few or no modifications, especially at sites not having naturally high background concentrations of lead (CCME 1991). Interim remediation criteria are as follows: 375 µg/g for agricultural soils, 500 µg/g for residential/parkland soils, 1000 µg/g for commercial/industrial soils, 1–7 µg/L in water for protection of aquatic life, 200 µg/L in irrigation water, 100 µg/L for water consumed by livestock, and 10 µg/L in drinking water (CCME 1991). Site-specific objectives may be equal to, or more or less stringent than, the Canadian criteria, depending on individual site circumstances. When remediation criteria adopted or adapted for site-specific use are exceeded, the need for remedial action is indicated (CCME 1991).

2.2 Chemical transformation of metallic lead from spent shot

It has often been assumed that lead from spent shot and lost fishing sinkers is environmentally stable or inert and thus not worthy of consideration as a source of environmental lead contamination and transfer, except as relates to the direct ingestion of shot or sinkers by animals. However, there is now sufficient evidence to conclude that ultimately all of the metallic lead in shot and sinkers will be transformed into particulate and molecular lead species and will be dispersed through the environment to some degree. This process can result in local lead concentrations in soils and water far in excess of normal concentrations. Various physical and chemical conditions influence the rate of metallic lead decomposition and transformation, and these are discussed below.

2.2.1 Terrestrial environments

When metallic lead in the form of spent shot or sinkers is exposed to air or water, lead oxides, carbonates, and other compounds are produced by weathering of the pellets (Sever 1993). Analyses of spent shot pellets collected from target shooting ranges in Canada and Denmark have shown pellets to be visibly corroded and covered with a crust of white, grey, or brown material (Jorgensen and Willems 1987; Emerson 1994). These crusts are composed of various lead compounds, predominantly cerussite, hydrocerussite ($Pb(CO_3)_2(OH)_2$), and small amounts of anglesite. Pellets from all soil samples over a wide range of pH (3.5–8.1) contained crust material; however, older pellets (Emerson 1994) and pellets from acidic soils (pH <6.0) had larger quantities of material, reflecting a more advanced state of shot breakdown. Jorgensen and Willems (1987) reported that in soils with a high pH and high organic content, lead transformation products are only slightly soluble and may adhere to pellet surfaces or remain bound in the upper soil layers.

For an uncultivated grassland with a soil pH of about 5.5, Jorgensen and Willems (1987) calculated that half of a lead pellet's metallic lead content would be transformed into lead compounds within 54–63 years and that total pellet transformation would occur in 100–300 years. Under circumstances of intensive mechanical treatment, such as cultivation of the soils, these time periods may be shortened to 15–20 and 30–90 years respectively. Similar breakdown of lead shot pellets has also been reported in Finland (Nummi 1990; Tanskanen et al. 1991). Fisher et al. (1986) also reported significant breakdown of buried lead shot. Shot pellets buried for about 20 years at the Anahuac National Wildlife Refuge on the Gulf coast of Texas displayed highly eroded surfaces and were much smaller than expected, given the typical size of pellets used for waterfowl hunting.

2.2.2 Wetland/aquatic environments

Lead shot erosion leading to elevated lead levels in water was reported by Stansley et al. (1992) in an investigation of eight target shooting ranges in the United States that had surface waters (ponds, marshes, etc.) in their shotfall zones. The authors of this study suggested that the suspension of pellet crust compounds containing lead, as described by Jorgensen and Willems (1987), might explain the high concentrations of waterborne lead observed at the ranges (41.9–838 µg/L, vs. 7.4 µg/L at control sites).

John Peterson, Project Manager of Firing Range Remediation, Marco Environmental, has investigated numerous shooting range sites in the United States and has acquired extensive data on lead pellet degradation in various environments. Peterson (pers. commun.) has documented lead oxide crust formation on spent lead pellets deposited in stream bottoms, corroborating observations of similar transformation products by Jorgensen and Willems (1987) and Emerson (1994) in soils. Under neutral or basic pH stream water conditions (pH >7.0), lead oxidation products are relatively insoluble; however, if sand is present in the stream sediment, erosion of the crust material occurs, removing it from the pellet and releasing particles of lead compounds into the water flow. More acidic pH conditions favour the dissolution and increased mobility of these lead compounds.

Erosion/oxidation of lead fishing sinkers producing lead transformation compounds has not been explicitly investigated; however, lost sinkers exposed to water and air weathering processes similar to those shown to affect spent lead shot would, presumably, break down in the same time periods as have been estimated for lead shot.

2.3 Factors affecting the environmental mobility of lead compounds

The behaviour of lead in soils and water has been extensively reviewed (Jaworski 1978; Swaine 1986; Dames and Moore Canada 1993). For the purposes of this report, highlights of these reviews, as well as discussion of other studies, will be presented as they relate to metallic lead shot and fishing sinkers.

There are several potential pathways through which mobilized lead particles or compounds resulting from the physical/chemical decomposition of shot deposited during hunting and clay target shooting activities may be distributed through the environment (Sever 1993), including 1) airborne dust particles; 2) waterborne particles in storm or river runoff; 3) dissolved lead in storm runoff or other surface water movement; and 4) dissolved lead in ground water.

Wind generally does not move heavy lead particles very far, and therefore deposition of airborne lead dust occurs mainly in close proximity to shooting activity.

Particulate metallic lead, lead oxides and carbonates, or other compounds produced by shot pellet weathering may be transported by water, either as storm runoff or in groundwater. Factors such as rainfall intensity, pH, topographic slope, soil type, and extent of vegetative cover influence lead mobility.

Table 3 summarizes various factors that may influence the transport of particulate or dissolved lead compounds arising from shot decomposition. Conditions causing increased risk of lead mobility include low soil or surface water pH, high amounts of annual precipitation, and the absence of organic compounds in the soil. High annual precipitation increases the time during which lead is in contact with water, resulting in an increased risk of lead transport in storm runoff. Vegetative cover slows surface runoff, and high organic content of soils adsorbs lead, reducing its mobility. Similarly, a high clay content in soils reduces groundwater flow and adsorbs lead, reducing its concentration in groundwater. Conversely, if the soil is mainly silica sand, gravel, or fractured granite, soluble lead in groundwater may be transported over long distances (Sever 1993).

Soil pH is one of the most important factors affecting the mobility and bioavailability of lead (Swaine 1986). Increased risk of lead mobility occurs in environments with acidic soils, rocks, or surface waters. As pH decreases, the amount of Pb^{2+} in solution increases by about two orders of magnitude with each unit of pH. On the other hand, rocks containing calcium, magnesium, iron, or other minerals may raise the pH of the water passing over them, precipitating lead out of solution. Very little detectable lead remains in solution at pH >8.0.

2.4 Lead concentrations in soils and sediments due to lead shot deposition

Almost all studies that have investigated the concentrations of lead in soils, sediments, water, or biota in areas of high lead shot deposition have taken place on or around clay target shooting sites. It would be instructive to have similar data from heavily hunted marshes and dryland fields, but we have been unable to find such data. The data from shot-over wetland and

Table 3
Factors affecting the transport of lead in surface runoff and groundwater

Risk factor	Safe	Moderate risk	High risk
Annual precipitation (cm)	<51	80–115	150+
Topographic slope (m/100 m)	Flat	10	20
Soil type	Coarse sand or gravel for particulate lead in suspension Clay for dissolved lead in groundwater or surface runoff	Fractured rock and fine sand, silt	Clay and silt for particulate lead in suspension Coarse sand and gravel for dissolved lead in groundwater or surface runoff
Soil chemistry	Basic rock (dolomite)	Neutral soil, calcareous sand	Acidic soil and rock (granite)
Acidity of surface water or groundwater (pH)	≥8.0	6.5–7.5	<6.0
Lead pellet contact time with water	No contact	Short duration of contact	Continuous contact (shot deposited directly into water)
Soil cover	Organic peat	Grass	No soil cover
Vegetative cover/barriers	Dams or dikes that stop water flow	Grass or forested area	No vegetative cover
Depth to groundwater (m)	61+	9–15+	<3
Distance to surface stream (km)	1.5+	0.4–0.8	Shot deposited directly into water

Source: Adapted from Sever (1993).

terrestrial target shooting ranges, therefore, must suffice for the present assessment.

In a Finnish study, lead from shot pellets at a shooting range was found to be mobilized by acidic rain water (pH 4.4–4.7) into the humus soil layer (Manninen and Tanskanen 1993). Acidic rain water contributed to soil acidity, one of the main factors facilitating lead dissolution, and caused extremely high concentrations of lead in range soils, compared with reference soil samples from areas located outside the range property. Most of the soil lead was found to be in an EDTA (ethylene-diaminetetraacetic acid) -extractable form, which is bioavailable to plants and may exert toxic effects on growth. Total lead concentrations (pellets excluded) in the humus layer of range soils ranged between 4700 and 54 000 µg/g (Manninen and Tanskanen 1993), far exceeding soil concentrations that are believed to be toxic to plants (100–500 µg/g).

Soil samples were taken at various depths from several sites adjacent to a target shooting range located at St. Thomas, Ontario. Soils were dried, sieved (0.355-mm mesh) to remove pellets, and analyzed for lead concentration (Emerson 1994). In surface soil samples (0–5 cm depth) from the two most contaminated sites (sites having the highest pellet densities), lead concentrations ranged from 6600 to 17 000 µg/g. Even at depths up to 10 cm, soil lead concentrations sometimes exceeded 1000 µg/g. The site with the highest lead concentrations also had the most acidic soil (pH 5.3–7.1) (Emerson 1994). Lead concentrations in neutral (pH 7.2–7.5) soils obtained from a Scarborough, Ontario, skeet and trap shooting range (41–325 µg/g dry weight (dw)) were elevated over lead levels in control site soils (10–23 µg/g dw) (Bisessar 1994) but did not contain lead concentrations as high as those observed at some other shooting ranges.

The Lincoln Park Gun Club operated on the shore of Lake Michigan in Illinois between 1918 and 1991 and was estimated to have deposited about 3 tons of lead shot per month into the lake (Yurdin 1993). Sieved sediments (all pellets removed) from the gun club's shotfall areas contained concentrations of lead significantly above background, and concentrations varied directly with the quantity of shot recovered from the sample. Leaching tests demonstrated dissociation of lead from the sediment and/or solubilization directly to the water column, and one sediment sample surpassed the hazardous waste criterion (5.0 mg/L) for leachable lead (Yurdin 1993). This study again establishes that lead shot pellets deposited into soils or sediments are not inert and that, ultimately, all of the metallic lead will be transformed and distributed as particulate and molecular lead into the soils, sediments, and water.

An investigation of sediment quality with respect to heavy metals was conducted by the Canadian Parks Service and the Inland Waters Directorate of Environment Canada in Point Pelee Marsh (McCrea and Schito 1992). Lead concentrations from 19 sediment samples ranged from 12.6 to 64.6 µg/g. Lead levels in the sediments were consistent with 1987 records (39–63 µg/g). Eighty-four percent of the sediment samples exceeded the provincial sediment quality guidelines' lowest-effect level for lead, indicating that the sediments were marginally polluted with lead and that benthic species may be adversely affected. Sediment lead concentrations at former hunting sites averaged 45.1 µg/g and were generally higher than at nonhunting sites. In addition to lead shot, automotive exhaust may have been a source of lead in the park.

2.5 Lead concentrations in water due to lead shot deposition

Long-term exposure of freshwater invertebrates indicates that negative impacts begin to occur at lead concentrations >10 μg/L in the water (Wren and Stephenson 1991). Anemia and reduced blood ALAD (aminolevulinate dehydratase) enzyme activity (a sensitive biomarker of elevated lead exposure) was noted in rainbow trout *Salmo gairdneri* exposed to 14 μg Pb^{2+}/L for 14 days (USEPA 1985). Maximum acceptable toxicant concentrations (MATC) for pre- and post-hatch fry were found to be 4–7.6 μg/L (Demayo et al. 1982). Bluegill *Lepomis macrochirus* and channel catfish *Ictalurus punctatus* lifetime MATCs range from 70 to 120 μg/L (water hardness 36–41 mg $CaCO_3$/L) (USEPA 1980). Increasing waterborne concentrations of lead over 10 μg/L are expected to provide increasingly severe long-term effects on fish (Demayo et al. 1982).

Close proximity to either surface water or groundwater sources is considered a high risk factor for increasing the chances of lead mobility and transport from sites contaminated by lead shot. For example, at a trap and skeet range located in Westchester County, New York, surface water lead concentrations ranged from 60 to 2900 μg/L (USEPA 1994b). Elevated levels of lead were also found in soils and sediments on the range and in the water of a stream that flowed in close proximity to the shotfall zone. Lead from range runoff, as well as the direct deposition of lead shot into the water course, was judged to pose a risk for off-site lead contamination.

Stansley et al. (1992) investigated eight target shooting ranges in the United States in which lakes, ponds, or marshes were present in the shotfall zone and found generally low total lead concentrations (<1.0–14.6 μg/L) in alkaline surface waters (pH 7.0–8.4). In a slightly acidic marsh shotfall zone (pH 6.3), however, a significantly higher lead concentration (1270 μg/L) was observed. Stansley et al. (1992) suggested that there is little off-site transport of lead via surface water at neutral to alkaline pH; however, lead could be mobilized at lower pH.

DND has conducted environmental assessments of six of its small arms shooting ranges, where contamination is from lead shot and bullets (Dames and Moore Canada 1993). Investigations focused on impacts on soils, sediments, groundwater, and surface water. The investigations determined that lead, although often present at very high concentrations in gun butt soils (5000–30 000 μg/g), was not contaminating off-site soils or groundwater. However, surface water at four of the six sites was observed to exceed CCME criteria for protection of freshwater life (1–7 μg/L), and surface waters at two of the sites were discharged into larger water bodies, leading to the possibility of off-site transport of lead. At the Connaught Range, Canadian Forces Base Ottawa, surface water lead concentrations in a beaver pond and farther downstream in a wetland area were elevated and in exceedance of CCME freshwater life criteria; and water samples taken from Shirleys Bay had a lead concentration of 1 μg/L, which represents the lower limit of the freshwater life criteria. Excavation and disposal of contaminated range soils were judged to be impractical, because leachable lead from these soils exceeds hazardous waste criteria, necessitating expensive transport and disposal at a hazardous waste landfill site (Dames and Moore Canada 1993). Similarly, leachable lead concentrations from surface soils at a privately owned St. Thomas, Ontario, gun club ranged from 3.3 to 820 mg/L, in most cases above Ontario lead criteria for hazardous waste (5 mg/L) (Emerson 1994). DND has recommended cleaning of soils and recovery of lead metal fragments for recycling (Dames and Moore Canada 1993).

2.6 Lead concentrations in biota near lead shot deposition sites

Elevated lead levels in soils, sediments, surface water, and groundwater may result in uptake of lead by both terrestrial and aquatic plants and animals. Lead shot deposition at clay target ranges has resulted in elevated lead concentrations in soils (Jorgensen and Willems 1987, Dames and Moore Canada 1993; Bisessar 1994; Emerson 1994), sediments (Peterson et al. 1993), aquatic and terrestrial plants (Manninen and Tanskanen 1993; Peterson et al. 1993), and small mammals, including voles, mice, and shrews (Ma 1989). Lead shot deposited in wetland areas, including mudflats, lakes, and rivers, has resulted in elevated lead concentrations in surface waters, sediments, aquatic plants, and aquatic invertebrates (Stansley et al. 1992; Peterson et al. 1993; Yurdin 1993; L. Rutherford, pers. commun.).

To our knowledge, the effects of lead fishing sinker deposition on concentrations of lead in soil, sediment, water, and biota have not been investigated. The dissolution of lead from sinkers and the subsequent transfer of lead to surrounding substrate and biota would be influenced by the same factors as those established for spent lead shot and bullets (i.e., soil/water pH, organic content, water flow rates, etc.). We judge that the numbers of lead sinkers on stream, river, and lake bottoms in Canada would virtually never reach the magnitude of spent shot on clay target ranges or on heavily hunted marshes; however, data on this question are lacking.

2.6.1 Terrestrial plants

Plants accumulate lead in relation to the lead content of the soil (Kovalevskii 1979; Bisessar and McIlveen 1991a, 1991b). However, fixation of soluble lead by organic matter often occurs in the humus soil layer, reducing the amount of soluble lead available for uptake by the plants. Plant lead concentrations can be considerably lower than soil lead concentrations. Lead concentrations in lettuce, beets, cabbage, and carrots were found to be only 1–8% of the concentration of lead in soil (Bisessar and McIlveen 1991a, 1991b). Lead is absorbed mainly by root hairs and is stored in the cell walls, and evidence indicates that translocation of lead to aboveground tissues does not readily occur (Fleming 1994). Soil pH and redox potential are the most important variables determining plant uptake of lead (Swaine 1986). Raising pH (liming) and the addition of organic matter to soils reduce the uptake of lead in plants (Kabata-Pendias and Pendias 1992); however, the eventual decomposition of the organic complex may again release lead into the soil solution.

Very few studies have examined the concentrations of lead in plants in relation to sites that have experienced high deposition of lead shot. For plants on shooting ranges, the highest concentrations of lead were found in the roots, with decreasing concentrations in the leaves and fruit (Manninen and Tanskanen 1993). Foliage from three plant species contained quantities of lead that were elevated over levels in control area plants. Lingonberries (*Sorbus aucuparia* and *Vaccinium vitis-idaea*) collected at the clay target shooting range contained lead concentrations up to 0.3 mg/kg wet weight (ww), which exceeded Finland's Food Safety Guidelines. Mushrooms (*Russula* spp.) exhibited lead concentrations of 4 mg/kg ww, 10-fold higher than the average for *Russula* spp.

2.6.2 Terrestrial animals

We are aware of only a single study in which the effects of environmental lead shot deposition on lead accumulation in terrestrial animals have been examined. In an investigation 20 years after the abandonment of a clay target shooting range in the Netherlands, lead pellets were found to be present predominantly above a depth of 5 cm. The site was characterized by sandy acidic (pH 3.9±0.4) soils, with total lead concentrations of the upper soil layer (pellets included) of 360–70 000 µg/g dw (Ma 1989). Average tissue lead concentrations were higher in small mammals obtained from within the shooting range than from adjacent control areas (Ma 1989). Shrews *Sorex araneus* had the highest kidney, liver, and femur lead levels. Concentrations were intermediate in bank voles *Clethrionomys galreolus* and lowest in wood mice *Apondemus sylvaticus* (based on geometric means). Kidney lead concentrations ranged from a geometric mean of 5.9 µg/g dw in wood mice to 269 µg/g dw in shrews, whereas liver and femur lead concentrations were 2.7–15.9 and 13.5–550 µg/g dw, respectively. The highest individual lead concentrations were found in shrews (1267 µg/g dw in renal tissue and 1469 µg/g dw in the femur). Lead concentrations in kidney tissue of all shrews from the shooting range exceeded the level generally considered to be diagnostic of lead poisoning in mammals (10 µg/g ww; Osweiler et al. 1978). Mice, voles, and shrews sampled from outside the range exhibited lead levels in kidney, liver, and femur tissues of 0.8–18.2, 0.5–2.2, and 2.0–53.7 µg/g dw, respectively. Although histopathological analyses of tissues were not performed in the Ma (1989) study, a significant reduction in body weight and a lower average femur weight were noted in the wood mice from the range property, and lead-exposed shrews and bank voles exhibited significantly increased kidney-to-body-weight ratios. The much greater accumulation of lead in shrews than in bank voles and wood mice was believed to be related to diet. Whereas mice and voles are herbivores, shrews daily ingest three-quarters to one-and-a-half times their own weight of wet food of beetles and earthworms (Southern 1964). Earthworms can have lead concentrations that are comparable to, or exceed, the lead concentrations of the surrounding soil (Fleming 1994). Earthworms are reported to have a high potential to accumulate lead (and other metals) from contaminated soils (Beyer et al. 1982; Ma 1982; Ma et al. 1983), which may in turn result in elevated body burdens in earthworm predators such as shrews, robins, and others.

Investigations of the uptake of lead compounds by earthworms or other terrestrial invertebrates subsequent to sinker or shot deposition have not been conducted; however, it is anticipated that the highly elevated lead levels known to occur in soils from shooting ranges would cause elevated lead concentrations in earthworms and other soil invertebrates, as has been shown to occur in soils contaminated with lead from other sources.

2.6.3 Aquatic plants

Dose-related increases in lead concentrations of submerged and floating plants have been observed upon their exposure to dissolved lead, with accumulation greatest in the roots, followed by stems and leaves (Fleming 1994). Plants may also accumulate lead from sediments through the roots, and dissolved lead may become adsorbed on leaves and stems. Aquatic macrophytes have been reported to accumulate lead from contaminated sediments. Lead concentrations of 443 µg/g in sediment led to 47.6 µg/g dw in *Elodea* (Demayo et al. 1982).

Uptake of lead from shot-contaminated sediments has been observed in aquatic plants. In an investigation of a skeet target shooting range located on the shores of Lake Merced, California, sediments contained lead levels up to 1200 µg/g in the shotfall zone, and tule seedheads and coontails growing within these sediments exhibited lead concentrations averaging 10.3 and 69.2 µg/g dw, respectively, compared with concentrations of 2.3 and 11.9 µg/g dw, respectively, at control sites (Peterson et al. 1993).

2.6.4 Aquatic invertebrates and fish

Lead is most soluble and bioavailable under conditions of low pH, low organic content, low concentrations of suspended sediments, and low concentrations of the salts of calcium, iron, manganese, zinc, and cadmium (Eisler 1988). Aquatic invertebrates, including snails, amphipods, and insects, may accumulate significant amounts of lead, approximating 1000–9000 times the lead concentration in the surrounding water column (Spehar et al. 1978).

Enhanced uptake of lead from the water column by pumpkinseed sunfish *Lepomis gibbosus* and largemouth bass *Micropterus salmoides* was not found by Stansley et al. (1992) in their investigation of target shooting ranges; however, the authors acknowledged the limitations of their statistical comparisons based on a small sample size (n=3).

Elevated lead concentrations were found in the interstitial water of shot-contaminated sediments but not in the overlying water column at a target shooting range located on Long Island Sound at the mouth of the Housatonic River, Connecticut (SAAMI 1993). Ribbed mussels *Modiolus demissus* collected in the estuary contaminated with lead shot from this target range had elevated lead concentrations.

Bloodworms (*Chironomus* spp.), clams, and snails collected from sediments contaminated with lead shot at

Lake Merced, California, had significantly elevated lead concentrations (9.8, 15.6, and 25.1 µg/g dw, respectively) compared with control individuals (3.4, 7.6, and 5.9 µg/g dw, respectively) (Peterson et al. 1993).

Lead uptake from contaminated sediments was also found in Canadian investigations of two Nova Scotia skeet and trap shooting ranges, the shotfall zones of which are saltwater mudflats (L. Rutherford, pers. commun.). Clams (*Mya arenaria* and *Anodonta implicata*) were found to have lead concentrations ranging from 2.25 to 8.33 µg/g dw up to 200 m from the firing line. These concentrations were elevated compared with control samples (1.7–2.04 µg/g dw).

2.7 Summary and conclusions

- Metallic lead pellets deposited onto soils and aquatic sediments are not chemically or environmentally inert, although tens or hundreds of years may be required for total breakdown and dissolution of pellets.

- The rates of erosion, oxidation, and dissolution of metallic lead pellets in the environment depend on various physical and chemical factors. Aerobic, acidic conditions enhance the rate of pellet breakdown, whereas anaerobic, alkaline conditions decrease it. Physical factors such as high water flow rates, soils or sediments dominated by the presence of coarse sand or gravel, and frequent disturbance of contaminated soils all serve to enhance the rate of lead pellet breakdown.

- Lead concentrations in soils and sediments of shotfall zones of clay target shooting ranges can exceed the Canadian Environmental Quality (Remediation) Criteria for lead in soils. This may also be true for sites experiencing heavy hunting pressure, but data from such sites are generally lacking.

- The leachable lead concentrations in soils or sediments associated with clay target shooting ranges are often sufficiently high as to exceed lead criteria for hazardous waste.

- Lead from spent shot can be transferred to biota, especially soil and sediment invertebrates and terrestrial and aquatic plants, and thence to higher trophic levels.

Chapter 3
Toxicity of lead shot and sinkers

3.1 General

The nutritionally nonessential nature and the relatively high toxic potential of lead have been well established for many years. Numerous general reviews of the sources of exposure and toxic effects of lead in humans, livestock, and wild animals have been written (e.g., WHO 1977, 1989; Jaworski 1978; Demayo et al. 1982; Scheuhammer 1987; Eisler 1988; OECD 1993).

The ingestion of lead shot by waterfowl and other avian species and the toxic effects of this ingestion have also been extensively studied and reviewed (e.g., Mudge 1983; Sanderson and Bellrose 1986; USFWS 1986; Pain 1992). We judge it unnecessary, therefore, to present a detailed review of the avian toxicology of lead in general, or of lead shot ingestion specifically, in this report. We will briefly review the major toxic effects of lead from shot or sinker ingestion, but the majority of this chapter will be devoted to documenting the extent of the problems and risks relating to the use of lead shot and sinkers, especially in Canada. The chapter will include discussion of the following topics: results of waterfowl surveys and other research indicating the extent of the problem of lead shot (and sinker) ingestion in Canada; the ingestion of lead shot and sinkers by non-waterfowl species; secondary poisoning of eagles and other raptors, and scavengers, from ingestion of embedded shot in game animals; human exposure to lead from consumption of game animals killed with lead shot; environmental concerns caused by lead at shooting ranges; and transboundary issues relating to lead shot and sinker use. Assessment of possible lead toxicity to fish, invertebrates, or plants from the release of lead from shot and sinkers is not discussed.

It has been known since the late 1800s (Grinell 1894) that waterfowl ingest spent lead shotgun pellets that have been deposited on the bottoms of lakes and marshes, mistaking these pellets for food items or grit. The ingestion of lead shot by a variety of non-waterfowl bird species has also been documented (see Section 3.3). Similarly, Common Loons *Gavia immer*, swans, and other water birds are known to ingest lead fishing sinkers (Birkhead 1982; Ensor et al. 1992; Pokras et al. 1992; USEPA 1994a). Once ingested, the lead pellets often become lodged in the gizzard, where ionic lead is released as a result of the grinding action of the gizzard combined with the acidic environment of the digestive tract. If there has been ingestion of a large number (≥10) of shot, *acute lead poisoning* rapidly ensues, and birds usually die within a few days. Because sinkers are generally much larger than shot pellets, a single lead sinker may induce acute poisoning. Victims of acute poisoning can appear to be in good condition, without pronounced weight loss. More commonly, birds die of *chronic lead poisoning* following ingestion of a smaller number of shot pellets. In these instances, signs of lead poisoning (distension of the proventriculus, green, watery feces, drooping wings, anemia, weight loss) appear more gradually, and affected birds die approximately two to three weeks after ingesting the shot, often in a very emaciated condition. In addition, many sublethally exposed birds probably die, even though mortality cannot be attributed directly to lead poisoning. Lead exerts sublethal toxic effects on many tissues, primarily the central and peripheral nervous systems, the kidneys, and the circulatory/hematopoietic systems. The lesions caused in these tissues by lead exposure result in biochemical, physiological, and behavioural impairments. These impairments contribute to an increased risk of starvation, predation, and disease in affected birds. Sublethal exposure to lead results in an impaired ability to cope with other potential sources of mortality.

3.2 Lead shot ingestion and poisoning in waterfowl

Lead shot ingestion and poisoning of waterfowl has now been documented in many countries, including Canada (Kennedy and Nadeau 1993), Australia (Kingsford et al. 1989), Great Britain (Mudge 1983), France (Pain 1990), the Netherlands (Lumeij and Scholten 1989), Japan (Honda et al. 1990; Ochiai et al. 1993), and the United States (Sanderson and Bellrose 1986; USFWS 1986).

Bellrose (1959) originally estimated the yearly loss of North American waterfowl from lead poisoning from shot ingestion at 2–3% of the continental “population,” or about 1.5–4.0 million individuals. More recent mortality estimates (Clemens et al. 1975; Feierabend 1983) have tended to corroborate Bellrose’s (1959) figures, although there is not complete agreement that these estimates are valid. Although Bellrose (1959) recognized that waterfowl that have ingested lead shot are more prone to be shot by hunters than those that have not ingested shot, and included a correction factor when calculating his estimates, others believe that Bellrose's correction factor may be too conservative (e.g., Heitmeyer et al. 1993). Nevertheless, the study upon which Bellrose's conclusions are based has never been superseded by a more definitive study, and we accept that the estimate of 2–3% mortality from lead shot ingestion is a reasonable order-of-magnitude estimate.

Because lead poisoning is related to the availability of shot pellets, which in turn is related in large part to hunting pressure, the Canadian contribution to the overall North American mortality can be roughly estimated by knowing the proportion of the total North American harvest that occurs in Canada. In 1991, waterfowl hunting in Canada accounted for about 20% (exclusive of native harvest) of the total North American harvest (USFWS 1992; Lévesque et al. 1993). Using Bellrose's (1959) and Sanderson and Bellrose's (1986) estimates of ingestion and mortality rates, and an estimated average fall flight of waterfowl of about 60 million birds, we calculate that on average about 240 000–360 000 individual waterfowl die of lead poisoning in Canada annually from lead shot ingestion, assuming no prohibitions against the use of lead shot. Because the United States has banned the use of lead shot for waterfowl hunting nationwide since 1991, Canada is now undoubtedly responsible for an increasingly large proportion of the current North American waterfowl mortality from shot ingestion.

Mortality of waterfowl from lead shot ingestion becomes manifest either as large-scale die-offs or as less conspicuous, day-to-day mortality. Many instances of die-offs have been recorded in the United States (USFWS 1986). In Canada, conspicuous lead poisoning die-offs of waterfowl have also been reported. In 1974–75, after previously dry land was flooded, hundreds of ducks and geese died from lead shot ingestion at the Aylmer Wildlife Management Area in Ontario. Investigations showed that during World War II, when the property was functioning as an RCAF training centre, the affected areas had been used as an officer trap and skeet range (OMNR 1975; Kennedy and Nadeau 1993). Several thousands of dollars were required to clean up the contaminated area. Lead-poisoned birds have also been found in the fallout area of a clay target range near Montreal, Quebec (Wendt and Kennedy 1992). Several hundred Mallard *Anas platyrhynchos* and American Black Ducks *Anas rubripes*, as well as Canada Geese *Branta canadensis* and Tundra Swans *Cygnus columbianus*, were killed in the early 1970s, and again in the late 1980s, in the vicinity of Lake St. Clair, Ontario (Kennedy and Nadeau 1993).

Lead poisoning from lead shot ingestion has put the success of a Trumpeter Swan *Cygnus buccinator* reintroduction program in Ontario in jeopardy (Langelier 1994; Wye Marsh Wildlife Centre, pers. commun.). At least one-half of the swans released at Wye Marsh have become lead poisoned. Lead poisoning from ingestion of lead shot has been a relatively common occurrence among Trumpeter Swans wintering in southwestern British Columbia. Die-offs have been recorded since 1925 (Munro 1925). In 1992, 29 lead-poisoned Trumpeter Swans were collected from Judson Lake near Abbotsford, B.C. (Wilson et al. 1995). In Washington, lead poisoning has been identified as the primary cause of death in wild Trumpeter and Tundra swans, accounting for 29% of the observed mortality (Lagerquist et al. 1994). In his review, Blus (1994) stated that at least 10 000 swans of six species from 14 countries have been reported to have died of lead poisoning, most from ingestion of lead shot or fishing weights. Blus (1994) considered this to be a gross underestimate of actual mortality because, in many areas, no research or monitoring activity relevant to this issue has taken place.

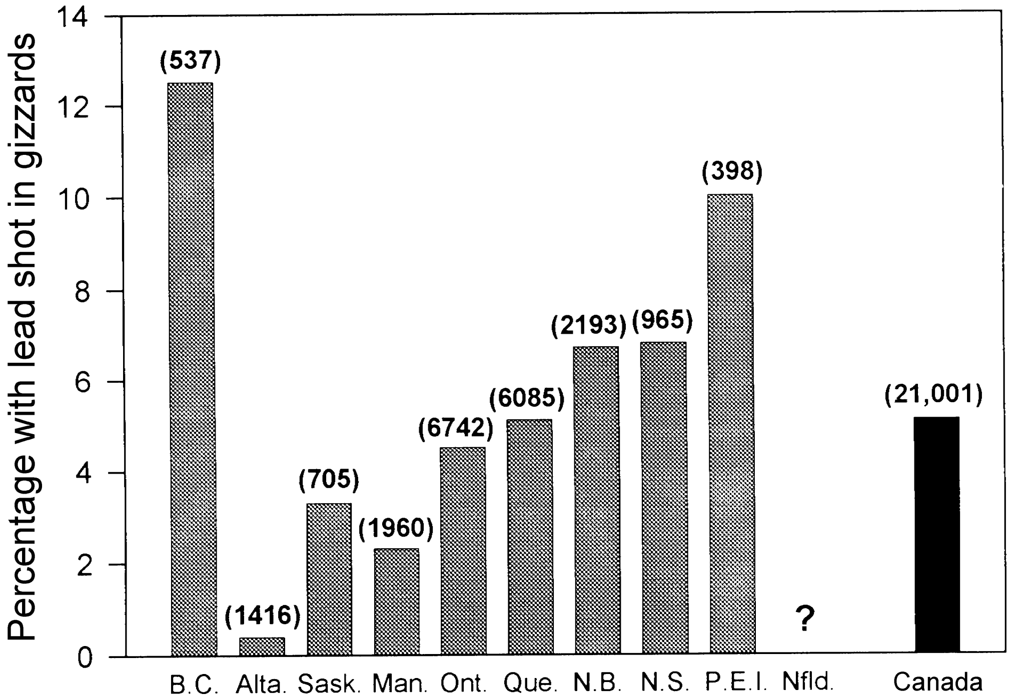
Although spectacular outbreaks of mortality have drawn public attention to the issue of lead poisoning, these episodes are probably less important than the largely invisible losses of small numbers of birds on a daily basis. Sick and dying birds generally become increasingly reclusive. After death, carcasses are not likely to be seen, even by trained observers (Stutzenbaker et al. 1986). Carcasses are not often noticed unless the mortality rate surpasses the ability of predators and scavengers to efficiently remove them. Because of the difficulties inherent in directly measuring the day-to-day mortality of waterfowl from lead poisoning, various indicators of lead exposure have been developed and used as indirect measures of the relative magnitude of lead shot exposure and poisoning in different species, at different geographical locations, or at different times of the year. In Canada, as elsewhere, the most widely used method has been the gizzard survey, which estimates the incidence of shot ingestion at local sites at the time of sampling. On a national scale, Canada has also conducted an extensive bone lead survey in which bone lead concentrations in almost 9000 young-of-the-year birds were determined. This survey was valuable for estimating the incidence of elevated lead exposure over a wider geographical scale than that covered by gizzard surveys. The results of Canadian studies using these two methods are briefly summarized below.

3.2.1 Gizzard surveys

Gizzard surveys have been conducted in all provinces except Newfoundland; they have not been conducted in the Yukon or Northwest Territories. Surveys were generally carried out in marshes or other sites known to experience relatively high hunting pressure. In the late 1980s, CWS began to develop criteria based, in part, on the incidence of lead shot in gizzards to determine if a local area should be zoned for nontoxic shot use (Wendt and Kennedy 1992). It was decided that if 5% or more of all ducks contain shot in their gizzards, the area should be considered for nontoxic shot zoning, based on further assessment to identify the predominant species present, the intensity of hunting, the waterfowl diet composition, and the availability of shot (nature of the substrate). If the ingestion rate is 10% or greater in dabbling ducks, a serious problem is likely, and the area should be zoned for nontoxic shot. These criteria were later expanded to include indicators other than gizzard counts and species other than waterfowl.

The overall results of Canadian gizzard surveys performed to date are presented in Figure 8. Dabbling ducks in British Columbia, Prince Edward Island, New Brunswick, Nova Scotia, and Quebec all have provincial ingestion rates of 5% or more, with Ontario close to 5% (4.5%). The highest rates (≥10%) were observed in British Columbia and Prince Edward Island. Except for the

Figure 8
Summary of results of gizzard surveys undertaken in Canada. Numbers in parentheses designate sample size on which the percentage is based. Species represented are dabbling ducks, primarily Mallards and American Black Ducks.



British Columbia results, a definite east-to-west trend is evident, with Alberta having the lowest shot ingestion rates (<1%) in the nation.

The mean national ingestion rate for dabblers was 5.1% (Fig. 8). It should be noted that the incidence of shot ingestion, based on gizzard surveys, is valid only for a period of about 20 days prior to sampling, because shot are either completely eroded or have passed through the digestive tract within that time (Dieter and Finley 1978). With every additional 20 day period, there would be another (approximately) 5.1% chance of ingestion. The annual ingestion rate for the Canadian dabbling duck "population" thus depends on the total duration of time that birds are resident in Canada. Arriving in the spring, adult waterfowl spend about 6–8 months in Canada, and their offspring 4–6 months, before migrating out of the country. Ignoring the sometimes considerable shot ingestion that may occur during the spring and summer (Hochbaum 1993), and assuming a fall flight lasting about 60 days for Canada (three 20-day periods) (M. Wayland, pers. commun.) during which time waterfowl may frequent habitats where waterfowl hunting occurs and lead shot is available for ingestion, a total of about 15% of all dabbling ducks in Canada could be ingesting at least one shot pellet every year. Similar considerations caused Sanderson and Bellrose (1986) to estimate that as much as 40% of North American waterfowl ingest shot during a single season of exposure. These are rough estimates of average ingestion incidence, and could vary considerably among different geographical locations, and among different species.

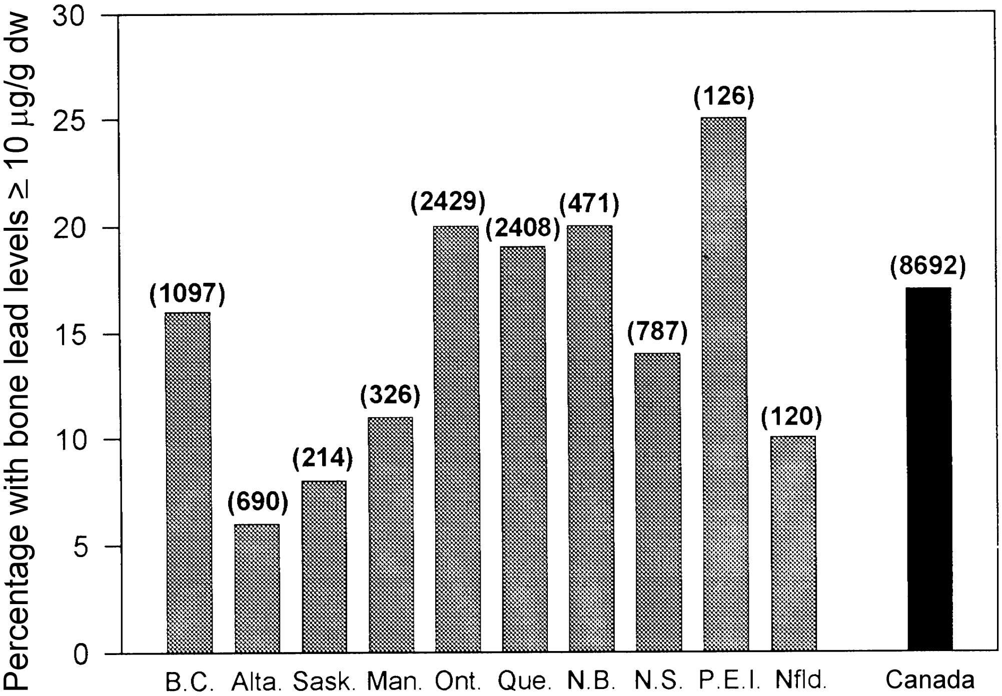
3.2.2 Wing bone lead surveys

Bone lead concentration is a good indicator of the relative degree of lifetime lead exposure because lead has a high affinity for mineralized tissue and readily accumulates in bone. Once deposited there, lead has an extremely long biological half-life. A duck that has ingested one or more lead shot should, assuming it survives, exhibit an elevated bone lead level for the rest of its life. Juvenile birds, unlike adult birds, should have uniformly low bone lead concentrations (<2 µg/g) unless they have recently ingested lead shot or experienced another form of high lead exposure. In the United States, the median bone lead concentrations for immature wild Lesser Scaup *Aythya affinis*, Northern Pintail *Anas acuta*, Canvasbacks *Aythya valisineria*, and Mallards were <2 µg/g in the early 1970s (Stendell et al. 1979).

The main purpose of the CWS wing bone lead study (Dickson and Scheuhammer 1993; Scheuhammer and Dickson 1995) was to estimate the overall pattern of elevated lead exposure for juvenile ducks in Canada and to determine if areas of high lead exposure were correlated with activities known to cause environmental pollution with lead, especially waterfowl hunting. For the purposes of the study, lead exposure in an area was designated as "high" if ≥20% of juvenile dabbling ducks exhibited bone lead levels ≥10 µg/g dw (Scheuhammer and Dickson 1995).

The results of the survey, on a province-by-province basis, are presented in Figure 9. Provinces having high overall lead exposure in juvenile dabblers were Prince Edward Island, New Brunswick, and Ontario. Quebec closely approached a high incidence level, with a provincial average of 19% elevated bone lead. Prince Edward Island had the highest incidence (25%) of

Figure 9
Summary of results of the CWS wing bone lead survey. Numbers in parentheses designate sample size on which the percentage is based. Species represented are juvenile dabbling ducks (Mallards and American Black Ducks).



elevated lead exposure, and Alberta the lowest (6%). The national incidence of elevated bone lead was about 17%. Recent lead isotope ratio studies indicate that elevated bone lead in juvenile ducks in Canada is consistent with exposure to lead shot and not consistent with elevated exposure to environmental molecular lead from past gasoline combustion (Scheuhammer, unpubl. data).

The incidence of elevated lead exposure as measured by wing bone lead concentrations was invariably higher than that based on shot ingestion rates. This is because bone lead concentrations are a cumulative measure of lifelong lead exposure, whereas gizzard surveys measure exposure to lead shot over the previous three weeks only. The cumulative national ingestion incidence of 15.3%, as calculated for dabbling ducks based on approximately three 20-day periods of exposure, compares well with the measured incidence of elevated lead exposure (17%) obtained from the wing bone lead survey. Also, the provincial pattern of elevated lead exposure is similar whether ingestion data or wing bone lead data are used (Fig. 8 vs. Fig. 9). Consistency is also observed between different waterfowl species. For example, Ring-necked Ducks *Aythya collaris*, a species of diving duck, exhibited much higher frequencies of shot ingestion than dabbling ducks (10.9% and 5.1%, respectively) and also had a much higher frequency of elevated bone lead concentrations than did dabblers (48% and 17%, respectively).

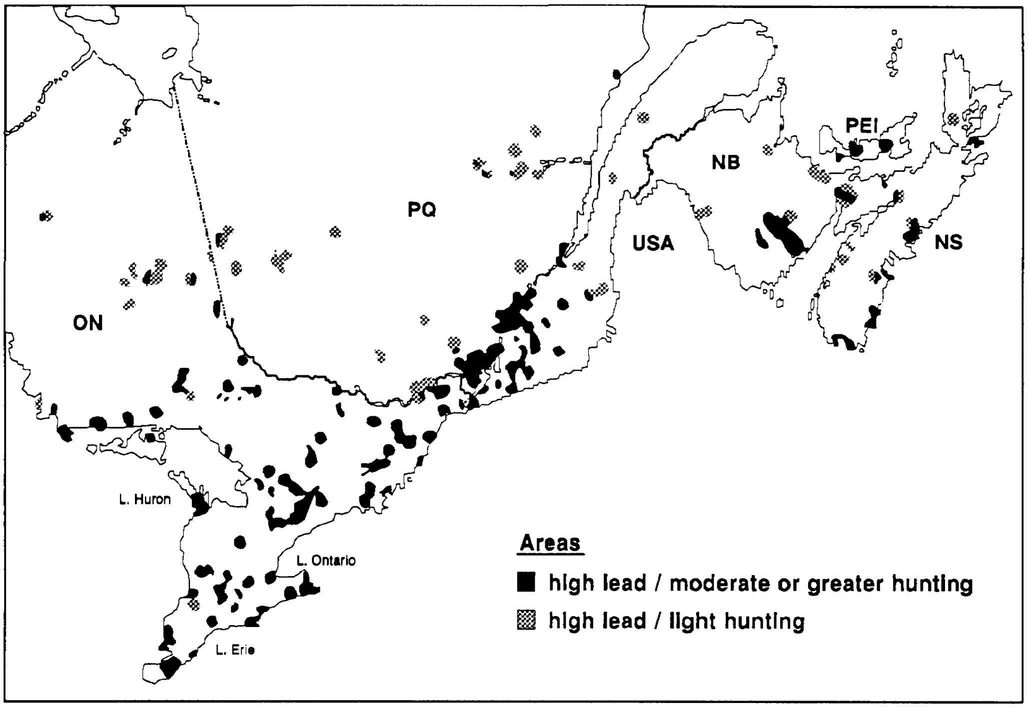
The results of the wing bone survey demonstrated that as hunting intensity at a location increased, the probability for that location to show a high incidence of elevated lead exposure also increased (Scheuhammer and Dickson 1995). In eastern Canada, only about one-quarter of the areas characterized as having “high lead exposure” were associated with light hunting intensity (Fig. 10). These “high lead/light hunting” locales were generally associated with nonferrous mining activity in northern Ontario and Quebec (Scheuhammer and Dickson 1995). The results of the CWS wing bone survey are consistent with the hypothesis that lead shot ingestion is the primary source of elevated lead exposure in Canadian waterfowl. Rather than depicting a few small, well-defined local areas of high lead exposure, the CWS wing bone survey demonstrated a rather widespread pattern of elevated lead exposure in waterfowl across southern and central eastern Canada (Scheuhammer and Dickson 1995).

3.2.3 Estimating lead shot ingestion and mortality in Canadian waterfowl

How many of the approximately 60 million waterfowl migrating out of Canada every autumn ingest lead shot, and how many consequently die of lead poisoning? A rough estimate of Canadian waterfowl mortality, based on an extrapolation from U.S. estimates and a knowledge of relative hunting pressure in Canada versus the United States, was presented at the beginning of Section 3.2. Here we present another calculation of overall ingestion and mortality numbers.

Although the Prairie Provinces (Manitoba, Saskatchewan, Alberta) account for about 80% of waterfowl production in Canada, shot ingestion rates are relatively low in those provinces, averaging from about 2% (based on gizzard surveys) to about 8% (based on the incidence of elevated lead levels in wingbones) in the most common dabbling duck species. Other species, such as Ring-necked Ducks and Redheads, have higher rates of exposure, while species such as Wood Ducks have lower

Figure 10
Map of elevated bone lead concentration in dabbling ducks in Eastern Canada. The map depicts areas in which a high incidence of elevated bone lead coincides with moderate or greater (≥200 hunter-days/year/ 10-minute block) hunting intensity and light (<200 hunter-days/year/10-minute block) hunting intensity.



Source: Scheuhammer and Dickson (1995)

rates. Using the ingestion rates for dabblers, we estimate that shot ingestion occurs in 1–4 million waterfowl on the prairies. For the rest of Canada, ingestion rates averaged from 8% (based on gizzard surveys) to 20% (based on wingbone surveys) in dabblers, which represents an additional 1–2 million birds. Thus we estimate that nationally roughly 2–6 million waterfowl ingest shot every year. When we include a correction factor based on the observation that ducks that have ingested shot are more likely to be killed by hunters and thus be included in gizzard and wingbone surveys than birds that have not ingested shot (Bellrose 1959), these estimates decline to about 1.2–3.6 million birds. On the other hand, our estimate does not include shot ingestion that undoubtedly occurs at some rate in adult ducks returning to Canada in the spring, nor does it account for individuals that have died of lead poisoning and not been bagged by hunters. In addition, gizzard examination routinely underestimates the extent of lead shot ingestion in waterfowl by 20–30% (Anderson and Havera 1985). We therefore consider the estimate of 2–6 million waterfowl ingesting shot each year to be reasonable.

Numerous studies demonstrate that, of the waterfowl ingesting shot, most—on average, 80%—have only one or two pellets in their gizzards (Sanderson and Bellrose 1986). These birds more often live than die, so we estimate a mortality rate of about 20% for waterfowl that have ingested shot. If 2–6 million waterfowl ingest shot every fall in Canada, then an estimated 0.4–1.2 million individuals are likely to die of lead poisoning, and the remainder to suffer sublethal lead toxicity. If the more conservative ingestion estimate of 1.2–3.6 million is used, then 240 000–720 000 individuals are estimated to die annually from lead shot poisoning. These mortality estimates are, on the whole, greater than the estimate of Canadian mortality based on extrapolation from U.S. calculations (240 000–360 000). On balance, we conclude that, conservatively, 250 000 waterfowl probably die every year in Canada from lead shot poisoning, assuming no restriction on the use of lead shot for waterfowl hunting.

3.3 Lead shot ingestion and poisoning in non-waterfowl species

Although research and monitoring studies directed at elucidating the problems and issues associated with the use of lead shot for hunting have focused primarily on waterfowl and their (wetland) habitats, there is a substantial body of evidence indicating that the environmental deposition of lead shot does not create problems exclusively for waterfowl. Non-waterfowl species are also exposed to and ingest lead shot pellets. Ingestion and poisoning occur in one of two general ways: 1) some species, like waterfowl, mistake shot for food or grit and ingest it from wetland or terrestrial environments (= *primary* poisoning); and 2) some species, especially eagles and other raptorial birds, and scavengers, ingest pellets when they consume prey that have been shot with shotshell ammunition and consequently are carrying shot pellets embedded in their tissues (= *secondary* poisoning).

3.3.1 Primary poisoning

In general, primary ingestion is a risk for a wide variety of avian species where shot density in the environment is high and environmental conditions are such that shot are available to the birds. Areas of intensive upland shooting, such as for doves in the United States, can result in shot ingestion and poisoning in these species. Shot ingestion or high tissue lead concentrations in Mourning Doves *Zenaida macroura* have ranged from 1.0% to 6.5% of birds sampled in Tennessee, Maryland, and New Mexico (Locke and Bagley 1967; Lewis and Legler 1968; Best et al. 1992). Other examples of primary ingestion and/or lead poisoning in non-waterfowl species, summarized in USFWS (1986) and in Locke and Friend (1992), include Ring-necked Pheasants *Phasianus colchicus*; Northern Bobwhite *Colinus virginianus*, Scaled Quail *Callipepla squamata*, Gray Partridge *Perdix perdix*, coots (*Fulica* spp.), Sora *Porzana carolina*, King Rail *Rallus elegans*, and Clapper Rail *Rallus longirostris*, Sandhill Cranes *Grus canadensis*, and a number of shorebird species. Hall and Fisher (1985) observed that Texas marsh birds, which typically probe sediments for food and grit, were at particularly high risk for shot ingestion: 19% of a combined sample of Black-necked Stilt *Himantopus mexicanus*, White-faced Ibis *Plegadis chihi*, and Long-billed Dowitcher *Limnodromus scolopaceus* gizzards contained lead shot, whereas no sandpipers, terns, or herons had evidence of ingested shot. In Canada, Kaiser et al. (1980) reported that 9% of 54 Dunlin *Caladris alpina* collected after they had collided with electric power wires contained one to five ingested lead shot each. As reported by Hunter and Haigh (1978), domestic fowl have also died of lead poisoning from lead shot ingestion. Locke and Friend (1992) concluded that “lead poisoning has been documented in a sufficiently wide variety of birds to consider all birds as being susceptible to intoxication after ingesting and retaining lead shot.”

3.3.2 Secondary poisoning

Secondary lead shot poisoning can occur when a predator or scavenger consumes the flesh of animals that have been shot with lead shotshell ammunition and consequently carry lead shot pellets embedded in their bodies, or consumes the gizzard of a bird that has ingested lead shot. It was previously thought that this form of lead poisoning was a rare occurrence and probably did not constitute a significant wildlife management problem. However, research done in various countries, including Canada, over the past 5–10 years has demonstrated that secondary poisoning, particularly of raptors such as Bald Eagles *Haliaeetus leucocephalus*, is a significant source of mortality in many places. Secondary lead shot poisoning has now been documented in many locations in Europe and North America in various raptorial species, including Bald Eagles, Golden Eagles *Aquila chrysaetos*, Northern Goshawks *Accipiter g. gentilis*, European Sparrowhawks *Accipiter nisus*, Marsh Harriers *Circus aeruginosus*, Red-tailed Hawks *Buteo jamaicensis*, and Rough-legged Hawks *Buteo lagopus* (USFWS 1986; Pain and Amiard-Triquet 1993; Pain et al. 1993, 1994). A case of lead poisoning in a wild Peregrine Falcon *Falco peregrinus* has also been reported (Pain et al. 1994), and captive falcons have died following the ingestion of lead shot pellets present in the tissues of hunter-killed game presented to the birds as food (MacDonald et al. 1983). Many free-living raptorial species for which secondary poisoning has not yet been documented nevertheless risk this type of poisoning as a direct consequence of their preferred feeding habits.

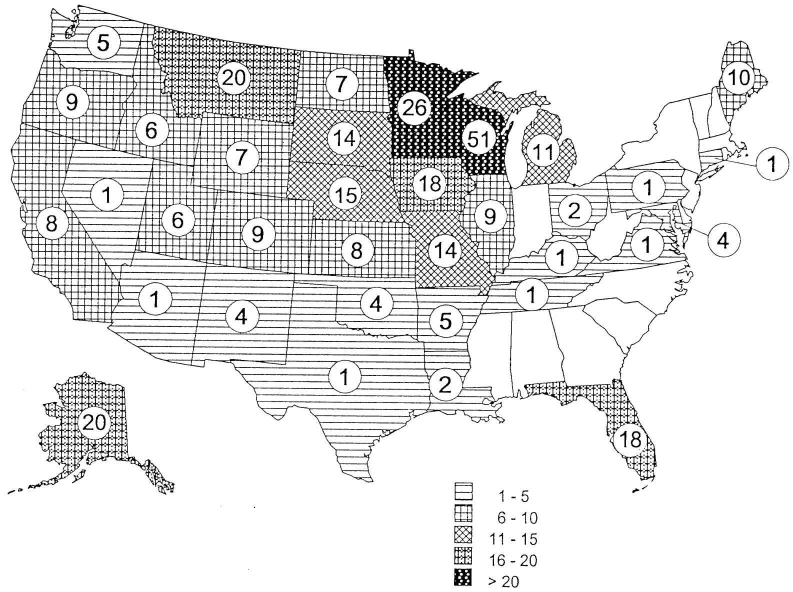
In the United States, 320 Bald Eagles found dead were confirmed to have died of lead poisoning, out of about 3000 carcasses necropsied. Lead poisoning thus accounts directly for about 10% of the recorded post-fledging Bald Eagle mortality in the United States. Figure 11 depicts the geographical distribution of lead-poisoned eagles in the United States. Almost 50% of all eagle deaths occurred in states bordering Canada. An especially high number of deaths have been recorded in Minnesota, Wisconsin, and Montana. Significant losses of Golden Eagles to lead poisoning in the United States have also been documented (USFWS 1986).

After secondary lead shot ingestion, many more eagles experience sublethal lead shot exposure than die directly of lead poisoning. Depending on the location, about 10–70% of regurgitated eagle castings in U.S. studies contained shot pellets (Dunstan 1974; Platt 1976; Griffin et al. 1980; Pattee and Hennes 1983). Sublethal lead exposure undoubtedly contributes to mortality from other causes, because lead-exposed birds may be physiologically compromised. For example, lead shot exposure in eagles can cause severe visual impairments (Pattee et al. 1981), myocardial damage (Langelier et al. 1991), or weakness, anemia, and depression (Redig 1985).

Lead poisoning of Bald and Golden eagles has been documented in Canada. Cases are summarized in Table 4. In British Columbia, lead poisoning of Bald Eagles was first reported by Langelier et al. (1991). A subsequent collaborative study between Langelier and CWS determined that 14% (9/65) of Bald Eagles found dead were lead poisoned and that an additional 23% had experienced subclinical lead exposure (Elliott et al. 1992). Additional birds have since been examined. Of the total number of Bald Eagles so far diagnosed as having died from lead poisoning in British Columbia (29), 17% had lead shot present in the digestive tract, whereas one bird had a bullet, and one had a fishing sinker (K. Langelier, pers. commun.). These findings are consistent with those in the United States (USFWS 1986) and point to lead shot ingestion as the major source of lead poisoning in Bald Eagles.

Recent CWS research has documented lead poisoning of Bald and Golden eagles in Alberta, Saskatchewan, and Manitoba (CWS, unpubl. data). Tissue lead analyses of 65 eagles found dead on the Prairies indicate that 15–17% had been lead poisoned. Ongoing CWS research thus indicates that, as has been extensively documented in the United States, secondary lead shot poisoning of eagles in Canada can be a relatively frequent phenomenon. The lack of reports of secondary poisoning from other regions of Canada where eagles and hunters coexist may well be due to a lack of concerted research and monitoring rather than absence of a problem. Other species in Canada that have experienced secondary poisoning include Great Horned Owls *Bubo virginianus* (Faculté de médecine vétérinaire, Université de Montréal,

Figure 11
Map summarizing cases of lead poisoning of Bald Eagles in the United States as documented by the USFWS, up to September 1994. The total number of lead-poisoned eagles is 320.



Source: Data from USFWS, National Wildlife Health Center, Madison, Wisconsin.

pers. commun.) and Common Ravens *Corvus corax* (Avian Care and Research Foundation, pers. commun.).

As mentioned, a major source of lead shot in cases of secondary poisoning is probably embedded shot carried by waterfowl and other game animals. For waterfowl, numerous studies have been undertaken to estimate the frequency of embedded shot. Table 5 summarizes the results of these studies. For many species of waterfowl, sampled in many different locations, it is common for 20–30% of apparently healthy individuals to be carrying one or more shot pellets. Even a portion (15%) of a completely protected population of Trumpeter Swans has been reported to carry embedded shot (Banko 1960). These findings indicate that literally millions of free-flying waterfowl, in addition to the millions killed or crippled with lead shot, carry embedded shot and are a potential source of lead poisoning in raptorial predators and scavengers. Although few studies have examined the frequency of embedded shot in non-waterfowl species, the frequency is probably high in some other species of heavily hunted game animals. Elder (1955) reported an embedded shot incidence of 27% in male Ring-necked Pheasants. Given that upland game bird hunting in Canada is at least as intense as waterfowl hunting (Fig. 2), it is likely that the most avidly hunted species of upland birds also experience a substantial incidence of embedded lead shot. In the New England states, about 30% of Common Loon carcasses examined to date carried embedded lead shot, although gunshot was responsible for <10% of deaths (M. Pokras, pers. commun.). Nor is the phenomenon of embedded shot restricted to birds. Although most evidence indicates that waterfowl are the most likely source of lead shot ingestion in Bald Eagles, Platt (1976) reported that a population of eagles wintering in a Utah desert ingested lead shot and bullet fragments by feeding heavily on hunter-killed jackrabbits *Lepus californicus*. Hunter-killed jackrabbits may be a major source of lead for Bald Eagles in the U.S. Great Plains, Black Hills, and High Plains of Texas (USFWS 1986). Embedded shot in small game mammals is thus an additional source of lead poisoning in raptors and scavengers. In Canada, small mammal hunting accounts for an estimated ~20% of the total amount of lead shot discharged by hunters (Table 2).

3.4 Lead poisoning at clay target shooting ranges

Significant quantities of lead shot are deposited at clay target shooting ranges. Estimated annual loading rates of lead from these activities are 200–300 t in Canada (Section 1.2.2). Loadings at large individual ranges can be 10–30 t/yr. Shotfall areas of shooting ranges may include dryland fields, ravines, creeks, rivers, mudflats, marshes, ponds, and lakes. Spent shot generally remain within the upper 10 cm of soils and are therefore available to waterfowl and other birds at these sites. As described in Section 2.2, breakdown of lead pellets and transfer of lead to plants and other biota can occur at target shooting ranges. In addition, surface soils from shooting ranges often exceed soil and solid waste guidelines for lead, although impacts on soils beyond shooting range properties and on groundwater are usually not found or are minor.

For wildlife, the greatest immediate concern from target shooting ranges is the potential for lead shot ingestion. Ranges located over or near wetland environments pose a considerable risk to waterfowl. Clay target shooting under such environmental circumstances results in a very high local rate of pellet deposition. Lead shot deposition and risks of ingestion and poisoning are similar to those caused by wetland hunting.

Roscoe et al. (1989) reported lead poisoning of Northern Pintails that ingested lead shot from a tidal meadow within the shotfall zone of a trap and skeet club, now defunct, in New Jersey. The top 7.5 cm of affected sediments contained over 215 million pellets per hectare,

Table 4
Lead toxicosis in eagles in Canada

Species	Location	Total number examined	Number examined for lead	Comments	Source of information
Bald Eagle	B.C.	519	156	29 diagnosed lead poisoned; 6 confirmed shot ingestion; ≥27 additional birds subclinically exposed	IVC
Golden Eagle	B.C.	7	1	1 diagnosed lead poisoned, source not determined	IVC
Golden Eagle	Alta., Sask., Man.	14	14	2 lead poisoned, source not determined; 5 additional birds subclinically exposed	CWS-PNR
Bald Eagle	Alta., Sask., Man.	51	51	9 diagnosed lead poisoned; 1 confirmed shot ingestion; ≥7 additional birds subclinically exposed	CWS-PNR
Bald Eagle	Ont.	15	7	4 diagnosed lead poisoned; one with confirmed ingestion of lead air gun pellet	ACRF GVC
Bald Eagle	N.S., N.B., P.E.I.	14	14	2 diagnosed lead poisoned	AVC

ACRF = K. Chubb, Avian Care and Research Foundation, Verona, Ont.
AVC = Dr. P.-Y. Daoust, Atlantic Veterinary College, Charlottetown, P.E.I.
CWS-PNR = M. Wayland, Canadian Wildlife Service – Prairie and Northern Region.
GVC = Dr. D. Campbell, Guelph Veterinary College, Canadian Cooperative Wildlife Health Centre, Guelph, Ont.
IVC = Dr. K. Langelier, Island Veterinary Clinic, Nanaimo, B.C.

Table 5
Frequency of embedded shot in free-living waterfowl

Country	Species	Frequency (%)	Reference
Canada (Maritimes)	American Black Duck	12–18	CWS, unpubl. data
	Canada Goose	32	
	Common Eider	20–35	
Canada	Small Canada Goose	≥25	MacInnes et al. 1974
Canada	Lesser Snow Goose	28	Ankney 1975
Canada	Mallard	28	Elder 1950
United States	Canada Goose	42	Funk 1951
	Mallard	13	
	Northern Pintail	13	
United States	Redhead	15	Perry and Geissler 1980
	Lesser Scaup	10	
	Ring-necked Duck	21	
	Canvasback	29	
United States	Atlantic Brant	20	Kirby et al. 1983
United States	Mallard	27	Murdy 1952
Netherlands	Mallard	22–68	Lumeij and Scholten 1989

which was over 4000 times the shot density recorded near hunting blinds in the same area.

The Lordship Gun Club (owned by the Remington Arms Co.), a 30-acre site in Stratford, Connecticut, located on Long Island Sound, operated as one of the premier trap and skeet shooting venues on the east coast of the United States between the mid-1920s and 1987 (Ordija 1993). In the 1980s, concerns were expressed over the gun club's deposition of lead shot into the waters and along the shoreline of Long Island Sound and over the close proximity of a wildlife refuge directly across the river. Studies revealed that the gun club had deposited a total of about 1500 tons of lead shot into the environment since it began operations and was causing lead poisoning of waterfowl in the area. On the basis of documented lead contamination of sediments and associated aquatic life and potential impacts on waterfowl, the State of Connecticut ordered the club to cease the discharge of lead shot and to perform remediation, including dredging and cleanup of affected sediments (Ordija 1993). The club closed at the end of 1986.

In Canada, several examples of waterfowl mortality from lead shot ingestion associated with clay target shooting are available. We have already made mention of the waterfowl die-offs that occurred at shooting ranges near the Aylmer Wildlife Management Area, Ontario, and Montreal, Quebec (Section 3.2). Records from the Ontario Veterinary College, University of Guelph, indicate that in

October 1989, 11 or 12 Canada Goose carcasses were found near a clay target range in Brampton, Ontario. Three were examined and found to have approximately 50 skeet-size shot in their gizzards, with liver lead concentrations of 90–200 μg/g dw, indicative of lead poisoning. Another Canada Goose, one of a group of six birds found dead near Brantford, Ontario, in September 1994, had ingested a large number of small-sized lead shot, consistent with trap or skeet shooting, and had a kidney lead concentration of 128 μg/g dw.

Several Canada Geese were found dead near the site of a former gun club in Northbrook, Illinois (USFWS, unpubl. data). Three of these birds were examined by pathologists, and from 16–163 lead shot pellets were found in their gizzards; liver lead concentrations were 98, 48, and 109 μg/g dw.

For geese — birds that feed both on fields and in wetlands — both wetland and dryland clay target ranges and hunting sites may pose a risk for lead poisoning. Large-scale mortality of Canada Geese was observed in corn and winter wheat fields in Colorado (Szymczak and Adrian 1978). In a British study, shot ingestion rates in Pink-footed Geese and Greylag Geese in farmland areas were as high as or higher than those in wetlands (Mudge 1983). Oak Hammock, Manitoba, is a managed hunting area where the marshlands are closed to all shooting and hunting effort is concentrated on adjacent fields. Canada Geese readily ingested lead shot from these fields while feeding, leading to high ingestion rates and die-offs in this area (Hochbaum 1993). Oak Hammock was designated as a nontoxic shot zone by CWS in 1991. Should such a poisoning problem be identified on a target range, the mandate for action by CWS, and the possible repercussions for the gun club, are unclear.

3.5 Effects of lead shot ingestion in cattle

Lead poisoning from ingestion of lead shot is largely an avian phenomenon, in large part because of the peculiarities of the avian gizzard, an anatomical structure not shared with mammals. However, lead poisoning from shot ingestion has been reported in ungulate mammals — in particular, cattle. It was once believed that ingestion of metallic lead pellets did not pose a significant risk to domestic cattle, based on the failure of Allcroft (1951) to observe evidence of lead poisoning in calves fed metallic lead. Also, Bjorn et al. (1982) noted no elevation in blood lead concentrations of heifers grazing in pastures where upland bird hunting was common, and Clausen et al. (1981) reported that cattle retaining up to 100 lead pellets in the reticulum nevertheless had normal lead concentrations in liver and kidney tissue. Other studies, however, indicate that dairy cattle fed grass or corn silage contaminated by lead shot can suffer from lead poisoning (Howard and Braum 1980; Frape and Pringle 1984; Rice et al. 1987). Rice et al. (1987) reported that in 14 steers fed chopped silage prepared from a field that had been used for clay target shooting, one animal died, a second demonstrated clinical signs of lead poisoning, and all animals had substantially inhibited ALAD enzyme activity. It was further noted that even when lead pellets were removed, samples of silage still contained an average of 0.23% lead, which would have resulted in the ingestion of about 18 g of lead per steer per day, based on the consumption of about 8 kg of silage per animal. Rice et al. (1987) suggested that this concentration of lead would have been sufficient to cause toxicity, independent of ingestion of any lead shot pellets. The mechanical/chemical processes of producing silage from material containing lead pellets and/or uptake of lead by plants growing in soils contaminated with metallic lead may be more important risk factors than ingestion of lead shot pellets per se.

To date, Agriculture and Agri-Food Canada has not developed a policy on the use of lead shot (Agriculture and Agri-Food Canada, pers. commun.).

3.6 Hunting with lead shot — human health concerns

There are three potential sources of lead exposure for humans from consumption of wild game killed with lead shot: 1) ingestion of tissues from lead-exposed or lead-poisoned animals that have biologically accumulated higher than normal concentrations of lead; 2) ingestion of tissues containing minute flakes or fragments of metallic lead from the passage of lead shot through the tissues; and 3) ingestion of lead shot pellets themselves. Because consumers of waterfowl and other game animals bagged with lead shot eat almost exclusively the muscle tissue from these animals, the following discussion will focus on lead in muscle tissue.

A Provisional Tolerable Weekly Intake (PTWI) for lead of 50 μg/kg body weight (bw) per week (or about 3000–3500 μg/adult per week) (WHO 1977) was recently revised to 25 μg/kg bw per week for both adults and children (Health Canada, pers. commun.). The PTWI represents the average weekly consumption of lead that is considered to be safe over a lifetime of exposure and has been accepted by Health Canada. For Canadian adults, Dabeka and McKenzie (1992) estimated weekly lead exposure to be about 255 μg. Based on U.S. data, Elias (1985) estimated the average total lead consumption in food, water, and beverages for persons 14–65 years of age to be about 210–350 μg/week and total baseline lead exposure to be about 280–420 μg/week. The average adult baseline North American exposure to lead is thus roughly one-fifth of the maximum weekly exposure considered to be safe over a lifetime.

Although no tissue residue guidelines for lead in poultry (or other avian species) have been established, a lead limit of 0.5 mg/kg ww in fish protein has been set. Lead concentrations in breast muscle of waterfowl and other wild animals are generally low (<0.5 mg/kg ww). In experimentally poisoned Mallards, muscle lead levels averaged 1.4 mg/kg (Longcore et al. 1974), which exceeds the residue guideline for fish protein of 0.5 mg/kg. However, the consumption of muscle tissue from nonpoisoned game animals should not be of concern to human consumers with respect to *biologically incorporated* lead. On the other hand, in the course of analyzing 227 pooled breast muscle samples from waterfowl killed with lead shot, CWS scientists observed that 34 (15%) of these pools contained lead at concentrations >0.5 mg/kg (CWS, unpubl. data). Lead concentrations in these muscle samples ranged as high as 759 mg/kg. Many of the concentrations are far too high to be the result of biologically incorporated lead and have been attributed to small fragments of lead shot. Similarly, Frank (1986) observed high (>100 mg/kg) lead concentrations in tissues of waterfowl killed by shotgun and confirmed the presence of lead fragments by X-ray. Particles of lead ranged from irregular fragments 1–2 mm in length to very fine dust and were judged to be the result of the disruption of lead shot pellets upon collision with bone (Frank 1986). The flesh of any species of game animal killed with lead shot can become contaminated with high concentrations of lead through this mechanism. The CWS data documenting high lead in some waterfowl muscle samples have been reviewed by the Health Protection Branch of Health Canada, which has responded by stating that "efforts should be directed toward discontinuing the use of lead shot for harvesting" wild game.

Health effects in humans following ingestion of whole lead shot pellets have been reported. Of particular interest are reports of increased lead exposure and intoxication in humans from retention of lead shot pellets, most often in the appendix. A Danish study reported that "radiology of the lower abdomen frequently discloses retained lead shot in the appendix. Most commonly, only a few shot are disclosed, but up to 35 lead shot in a single appendix have been seen in our department" (Madsen et al. 1988). Blood lead concentrations were significantly higher in a group of subjects that had a few (1 or 2) lead shot in their appendices compared with a control group without shot retention (11.4 and 6.0 µg/dL, respectively) (Madsen et al. 1988). In some cases, clinical lead intoxication has resulted from this source of exposure (Hillman 1967; Greensher et al. 1974; Durlach et al. 1986). Hillman (1967) discussed a woman who exhibited signs of serious lead intoxication, including paralysis of the hands, anemia, wasting of the upper chest muscles, weakness in all four limbs, and neurological signs, prior to the discovery of at least a dozen lead shot pellets in her appendix, which was subsequently removed. After the appendectomy, the patient gradually recovered over the course of a year, ultimately returning to work. In Canada, Reddy (1985) reported that 62 patients seen in a Newfoundland hospital had from 1 to over 200 retained lead shot in their appendices.

3.7 Lead sinker ingestion and toxicity to water birds

The ingestion and toxicity of lead sinkers in swans in Great Britain and in Common Loons and other water birds in the United States have been extensively documented and reviewed (Nature Conservancy Council 1981; Birkhead 1982; O'Halloran et al. 1988; Pokras and Chafel 1992; USEPA 1994a). These findings have resulted in the banning of lead sinkers in Great Britain, the banning of lead sinkers in some national parks in the United States, a proposal by the USEPA to prohibit nationwide the manufacture, processing, and commercial distribution of lead sinkers of a size range known to be ingested by water birds, and a proposal by the USFWS to ban the use of lead sinkers and jigs on 40 units of the U.S. National Wildlife Refuge system. In Great Britain, the Mute Swan *Cygnus olor* population had declined since the 1960s, a trend that has dramatically reversed since 1986–87, when the sale of small lead fishing weights was banned (Kirby et al. 1994). Other countries have not, to our knowledge, proposed restrictions on the sale or use of lead sinkers.

Unpublished research results from Canada have also documented significant mortality of Common Loons and other birds from sinker ingestion. We have been able to find data from Ontario, Quebec, and the Maritimes that demonstrate that lead sinker or jig ingestion accounts for roughly 30% (38 of 127 birds examined) of adult loons found dead in locations where loon habitat and sport angling overlap. These data are consistent with U.S. research. A large, ongoing study has demonstrated that over 50% of recorded adult Common Loon mortality in the New England states during the breeding season is attributable to lead sinker or jig ingestion and that this source of mortality is of greater importance than any other single mortality factor, including tumours, trauma, fractures, gunshot wounds, and infections (Pokras et al. 1992). The importance of sinker ingestion as a mortality factor is less important, but still significant, in some other locations in the United States — for example, 17% of the recorded mortality in Minnesota (Ensor et al. 1992).

Analyses at CWS's National Wildlife Research Centre have confirmed a direct link between sinker ingestion and loon mortality from lead poisoning. Of 28 individual Common Loons for which we have completed lead analysis, only those loons with confirmed evidence of lead sinker or jig ingestion (6) have elevated tissue lead concentrations (e.g., 17–95 µg/g dw in liver) (Scheuhammer, unpubl. data). Evidence gathered to date indicates that sinker/jig ingestion is the only significant source of elevated lead exposure and of lead toxicity for Common Loons. In Ontario, about four-fifths of the lead poisoning deaths in loons are from ingestion of lead sinkers, and one-fifth is from ingestion of lead-headed jigs.

Lead poisoning from sinker ingestion has also been documented in numerous other species of water bird in the United States, including Trumpeter, Tundra, and Mute swans, various duck species, and Sandhill Cranes (USEPA 1994a). In principle, any species of bird that has feeding habits similar to those of loons or of other species confirmed to have ingested sinkers or jigs are also at risk for lead poisoning from this source.

Table 6 summarizes the data that we have been able to bring together regarding mortality in water birds from lead sinker ingestion in Canada.

3.8 Summary and conclusions

❖ Lead shot ingestion is probably the primary source of elevated lead exposure and poisoning in Canadian waterfowl and most other bird species. For some species such as Common Loons, lead sinker ingestion is a more frequent cause of lead poisoning.

❖ Based on gizzard and wing bone surveys of the species of ducks most commonly hunted and extrapolation from U.S. estimates, up to 6 million of the approximately 50–60 million game ducks

Table 6
Confirmed and suspected cases of avian mortality from ingestion of fishing sinkers in Canada

Species	Number diagnosed as lead poisoned	Number with sinker/jig	Province	Source of information
Bald Eagle	29	1	B.C.	IVC
Common Loon	31	30	Ont.	ACRF; GVC; UG
	3	3	Que.	SCP; VWN
	4	4	N.B., N.S., P.E.I.	AVC; CWS-AR
Common Merganser	?	1	Ont.	GVC
Canada Goose	?	2	Ont.	ABRC
		1	N.B.	Langelier 1994
Trumpeter Swan	?	1	B.C.	Langelier 1994
Mallard	?	1	Ont.	ABRC
Greater Scaup	?	1	Ont.	ABRC
White-winged Scoter	?	1	Ont.	ABRC

ABRC = H. Pittel, Avicare Bird Rehabilitation Centre, Bowmanville, Ont.
ACRF = K. Chubb, Avian Care and Research Foundation, Verona, Ont.
AVC = Dr. P.-Y. Daoust, Atlantic Veterinary College, Charlottetown, P.E.I.
CWS-AR = N. Burgess, Canadian Wildlife Service–Atlantic Region.
GVC = Dr. D. Campbell, Guelph Veterinary College, Canadian Cooperative Wildlife Health Centre, Guelph, Ont.
IVC = Dr. K. Langelier, Island Veterinary Clinic, Nanaimo, B.C.
SCP = Service canadien des parcs, Hull, Que.
UG = Dr. V. Thomas, Department of Zoology, University of Guelph, Guelph, Ont.
VWN = Volunteer Wildlife Network, Ottawa, Ont.
? = not determined

migrating from Canada every fall may ingest one or more spent lead shotgun pellets while in Canada. These individuals suffer either mortality (~200 000–360 000) or sublethal lead poisoning (several million).

❖ Because the United States has banned the use of lead shot for waterfowl hunting nationwide since 1991, Canada is now responsible for an increasingly large proportion of the lead poisoning problem in North America and may be the major continental source of migrating waterfowl that carry embedded lead shot.

❖ Lead shot ingestion also occurs in a wide variety of non-waterfowl species, including upland game birds, shorebirds, raptors, and scavengers.

❖ Where it has been explicitly studied in Canada and the United States, lead poisoning mortality of Bald and Golden eagles from eating prey animals with lead shot embedded in their tissues or the gizzards of birds with ingested lead shot accounts for an estimated 10–15% of the recorded post-fledging mortality in these raptorial species.

❖ Several studies have demonstrated that the incidence of embedded shot in apparently healthy, free-flying waterfowl frequently exceeds 20%, indicating that millions of migrating ducks and geese carry embedded shot. A significant proportion of heavily hunted upland species and small game mammals, and even some nonhunted species, also carry embedded shot.

❖ Clay target shooting ranges, especially those in which the shotfall zones include ponds, marshes, lakes, rivers, beaches, or other aquatic-type environments, create a significant risk of shot ingestion and poisoning for waterfowl.

❖ Ingestion of silage prepared from plants contaminated with lead shot has caused lead poisoning in cattle.

❖ Increased blood lead concentrations and sometimes clinical lead intoxication have been documented in humans with retained lead shot pellets in their appendices.

❖ In North American freshwater environments where sport angling activity and loon populations co-occur, lead poisoning from ingestion of small sinkers or jigs can account for 10–50% of recorded adult loon mortality, depending on the location studied.

Chapter 4
Managing the negative impacts of lead shot and lead sinkers

4.1 General options for managing the lead shot problem

Three general options have been considered as potential solutions to the problem of lead shot poisoning of waterfowl and their raptorial predators (Sanderson and Bellrose 1986; Mudge 1992): 1) manipulation of the habitat to reduce the availability and/or toxicity of spent shot; 2) coating, plating, or otherwise altering lead shot pellets to reduce toxicity; and 3) regulations prohibiting the use of lead shot, combined with the use of alternative, nontoxic shot.

Manipulation of waterfowl habitat to reduce the availability of the spent shot includes lowering water levels in feeding grounds after the hunting season so that waterfowl will leave the area or raising the water level so that spent shot pellets will be out of reach of the waterfowl; ploughing of dry areas to cover up lead shot; the growth of submergent leafy aquatic plants as a food source to reduce the toxicity of ingested shot; and the provision of high-calcium grit sources to reduce the accumulation and toxic effects of lead after shot ingestion. These actions are expensive, labour-intensive, of questionable effectiveness, and inappropriate as general solutions to the lead shot problem. If lead shot ingestion were an isolated event, site-specific techniques could perhaps be developed to deter waterfowl from feeding in affected areas or to provide alternative, high-calcium grit sources (Sanderson and Bellrose 1986). However, lead shot ingestion and poisoning in waterfowl have been extensively documented over wide geographical areas. Habitat manipulation is thus not a preferred control option in general or for Canada specifically.

In an attempt to retain the ballistic qualities of lead but to reduce its toxicity to waterfowl, lead shot was coated with other metals or nonmetallic materials such as plastic (USFWS 1986). Ingestion of shot coated with tin, nickel, or plastic resulted in similar toxicity to that observed with pure lead shot, as these coatings were removed by the grinding action and acidity of waterfowl gizzards. Other attempts were made to reduce the toxicity of lead shot by combining it with a biochemical chelating agent (EDTA) or a water-soluble binder (phosphate) to reduce the uptake of lead following ingestion. However, mortality after ingestion of these modified shot types was equal to or greater than that obtained with pure lead shot. Clearly, none of these techniques represent a general, effective solution to the problems associated with the use of lead shot.

The lack of success in reducing the toxicity of lead shot through various physical alterations led to the search for affordable, nontoxic, ballistically acceptable alternatives to lead. Substitute metals initially tested for ductility, density, and toxicity in the United States included copper, zinc, tin, nickel, iron, and depleted uranium. Steel (or soft iron) was found to be the preferred alternative to lead, considering its lack of toxicity, ready availability, and relatively low cost. Steel shot exhibited somewhat inferior ballistic properties compared with lead; however, it could be used effectively within normal hunting ranges. In addition, sintered shot (50–58% lead and the remainder iron, tin, and zinc) was developed by CWS and the National Research Council of Canada in the 1970s. This shot was initially proposed as a possible alternative to lead, as it was judged to have lower toxic potential than 100% lead and acceptable ballistic qualities (Wendt and Kennedy 1992). Interest in the commercial production of this type of shot, however, was lacking.

Development of newer nontoxic alternative shot products continues in the United States, Canada, and other countries. Regulations prohibiting the use of lead shot, combined with the use of functional, affordable, nontoxic alternatives, have been the preferred options for solving the problems associated with lead shot in those countries where restrictions have been imposed.

4.2 Alternatives to lead shot

Hunting and target shooting are largely recreational activities in which the use of lead shot is not essential. There are high-quality, nontoxic alternatives to lead shot, and acceptance of these alternatives among hunters has been increasing over the past several years. In general, lead shotshells are the least expensive, because of lead's ready availability, low cost, and ease of manufacturing. All alternative products will be more expensive, at least initially, but are not prohibitively costly. A list of maufacturers of currently produced alternative shot products is presented in Appendix 4.

Worldwide, three major nonlead shotshell products are commercially available: steel (Fe), bismuth/tin (Bi/Sn), and zinc (Zn). At least three additional

Table 7
Comparison of lead and alternative shot types

Material	Density of shot (g/ml)	Relative toxicity to waterfowl	Cost per shell (Can. $)	North American availability
Lead	11.3	High	0.50–0.60	Excellent
Steel	7.86	Low	0.52–0.88	Good
Bismuth/tin	9.7	Low	1.50–1.95[a]	Moderate
Tungsten/bismuth/tin	11.3	Low	2.00 (?)	NA
Zinc	7.14	Low–moderate	0.75–0.85	NA
Molybdenum/polymer	10.3[b]	Moderate (?)[c]	0.89[d]	NA
Tungsten/polymer	19.4[b]	Low (?)[c]	0.89[d]	NA

[a] In Great Britain, bismuth shot is much cheaper than in Canada, selling at the equivalent of about $0.56 Can. per shell.
[b] Specific density of the pure metal is given. When it is added as a powder to the lighter plastic polymer, the resulting shot will have a lower density than is listed. For tungsten/polymer, density of actual shot is 11.3.
[c] Probable toxicity of molybdenum and tungsten polymers is indicated as moderate or low, based on the known toxicology of these metals.
[d] Price estimates based on British prices of approximately £0.40 per shell.

NA = not available; shot type is either still under development or not commercially available in North America.

alternatives — molybdenum(Mo)/polymer, tungsten(W)/polymer, and tungsten/bismuth/tin alloy — are at various stages of development and testing. Table 7 compares lead and the alternatives with respect to shot density, relative toxicity, cost, and availability. Appendix 5 assesses the potential cost impact on waterfowl hunters and upland game bird hunters should lead shot become unavailable and steel or bismuth/tin shot be used in its place.

4.2.1 Steel shot

Steel shot, currrently the major alternative to lead, is required for waterfowl hunting in the United States and is approved for use in nontoxic shot zones in Canada and other countries. The North American market for steel shot has been filled primarily by the three largest traditional shotshell manufacturers: Federal, Remington, and Winchester. These companies have successfully converted a significant portion of their manufacture from lead to steel.

High-performance lead cartridges are approximately the same price as some steel loads; in general, however, steel shot is slightly more expensive than lead. Steel shotshells in waterfowl loads are currently available in Canada from large retail chain stores (e.g., Canadian Tire, Home Hardware) and from smaller retailers, although availability outside of nontoxic shot zones is frequently limited. Even though Canada has established several nontoxic shot zones in six provinces, steel shot represents only about 5% of current shotshell sales (Canadian Tire Corporation, pers. commun.). The market for steel and other nonlead shot will probably continue to be marginal as long as the sale and use of lead shot are legal.

One of the most contentious aspects surrounding the phaseout of lead shot for hunting has been the concern that, should steel shot be the only or the major replacement for lead shot, the proportion of game birds injured but not killed by hunters (the crippling rate) would undergo a dramatic increase. The ultimate effect might be that increased losses of birds through crippling would surpass the number of birds saved by the elimination of lead poisoning. There is now sufficient evidence to conclude that this is probably not the case.

There is no doubt that the ballistic properties of lead and steel shot differ. Steel shot pellets are about 30% lighter than lead pellets of the same diameter and are significantly harder than lead pellets. These basic physical differences result in less pellet deformation, denser patterning, shorter shot strings, and a lower retained velocity/energy at long ranges for steel shot compared with lead shot. However, the development of modern steel shotshell ammunition has evolved to the point where the perceived deficiencies of steel have been largely overcome (Brister 1992; Coburn 1992). Increasing the size of steel pellets compensates for steel's inherently lower density. (Hunters switching to steel should use shot at least two sizes larger than the lead loads that they are used to.) Steel shot cartridges are loaded with a greater volume of shot to ensure an effective number of pellets per cartridge. A rigid, plastic wad prevents the harder steel pellets from contacting and possibly scoring the gun barrel upon discharge. Increasing the propellant charge and using a magnum primer ensure that retained velocity of steel shot is comparable to that of a lead load two sizes smaller. To counteract the increased chamber pressures that result from using a greater amount of powder, slower-burning propellants are used in steel shot cartridges. The tighter patterns of steel loads generally require the use of more open chokes.

Between 1950 and 1984, 16 published shooting tests comparing the effectiveness of lead and steel shot were conducted in the United States. The results of these tests are equivocal: three of the tests favoured lead, two favoured steel, two reported mixed results, and eight showed no statistically significant differences in crippling between the two shot types (Morehouse 1992a). Of these tests, the Lacassine, Louisiana, study (Herbert et al. 1984) is most often cited by opponents of steel shot as the definitive and most scientific test conducted (e.g., Ankney 1989). In the Lacassine study, hunters did not know whether they were shooting lead or steel, and trained observers were used to collect the data. Over the two-year course of the study, roughly comparable numbers of lead and steel cartridges were fired (8023 #6 lead, 8615 #4 steel). In total, 337 birds were crippled using lead shot, and 414 using steel shot. There were thus 77 additional birds crippled with steel — an increase of about 23% over lead. It is not surprising to us, given the admitted ballistic differences between lead and steel shot, that hunters who were not trained in shooting steel and who were not informed as to whether they were shooting lead or steel crippled more birds with steel than with lead. What this study showed is not that steel was ineffective in bagging waterfowl (clearly it was effective — 964 birds were bagged using steel), but that hunters who switch to steel cannot expect to perform at their best without training or practice. We are aware of no evidence to suggest that hunters who have been shown how to modify their shooting techniques when using steel and who shoot within the effective range of their guns wound more birds than they would using lead.

In the United States, a nationwide ban on the use of lead shot for waterfowl hunting has been in effect since

1991. The dramatic increase in crippling predicted by many opponents of steel shot has not, however, come to pass. Although an initial expected increase in crippling was seen as hunters switched and adapted to the unfamiliar steel shot, crippling rates have remained within the normal historical range characteristic of lead shot usage, causing the USFWS to conclude that "the slightly higher crippling rate that has been experienced during steel shot implementation cannot nearly approach the combined numbers of waterfowl that were formerly lost each year in the United States through lead poisoning and those that were crippled with lead shot" (Morehouse 1992a). Furthermore, in none of the several lawsuits challenging state or federal nontoxic shot regulations in the United States have the courts accepted arguments that steel shot is ballistically inferior to lead shot, cripples excessively, or damages firearms (Feierabend 1985).

In 1991, the International Waterfowl and Wetlands Research Bureau (IWRB) convened a workshop on lead poisoning in waterfowl. The workshop was attended by representatives from numerous countries, including CWS for Canada. Among the conclusions of the workshop was the recognition that "steel shot loads can be used as effectively as lead for waterfowl hunting, if adjustments are made by hunters to allow for the differences in these two types of ammunition" (IWRB 1992). Similarly, the International Association of Fish and Wildlife Agencies, of which CWS is an active member, has concluded that "currently available steel shotshell ammunition is an effective alternative to that containing lead shot, and the large scale use of steel shot will not result in inordinate crippling losses of waterfowl" (USFWS 1986). In September 1994, Canada hosted an OECD Workshop on Lead Products. One of the workshop sessions examined issues related to the use of lead shot and sinkers. Among the conclusions of the lead shot and sinkers session was that steel shot, as a substitute for lead, had "inferior ballistic qualities, but [is] effective within accepted shotgun range." Probably the single most effective step that the average waterfowl hunter can take to reduce crippling losses is to refrain from shooting at birds beyond about 45 m, regardless of the type of shot used. The use of a trained dog for retrieving downed birds is also recommended.

In the debate over steel versus lead shot, the impression has sometimes been left, intentionally or otherwise, that crippling rates with lead shot are rather low and/or acceptable and that, with a switch to steel, crippling rates will soar. However, crippling is an inevitable consequence of hunting, regardless of the type of shot used, and crippling with lead shot has been responsible for the annual wastage of millions of waterfowl and other game birds for many years. In the United States, the number of waterfowl reported crippled and not retrieved by hunters averaged almost three million birds annually, or about 18% of the number bagged, between 1972 and 1984 (USFWS 1986). Almost no steel shot was in use during this period. This may be an underestimate of crippling losses. In Canada, Nieman et al. (1987) reported that Prairie waterfowl hunters grossly underestimated, or were reluctant to report, their actual crippling losses. Losses recorded by Nieman et al. (1987) were usually 20–45%, although hunters reported losses of only 6–18%. It is the hunter's responsibility to learn how to shoot as efficiently as possible, whether with lead or with an alternative shot type. By the same token, it is the responsibility of government wildlife agencies to provide hunters with ready access to information and training so that shooting efficiency can be improved and crippling of game animals reduced. If hunters and wildlife managers are prepared to take seriously their respective responsibilities regarding this issue, excessive crippling may be controlled, regardless of the type of shot hunters use.

The undesirable effects of hunting with steel shot are restricted to crippling losses. Detrimental effects of lead shot usage include crippling losses, losses from lethal and sublethal lead poisoning of waterfowl and other wild birds through primary poisoning, losses from lethal and sublethal poisoning of raptors and scavengers (secondary poisoning), the risk of lead exposure for some livestock species (domestic fowl, cattle), unnecessary lead exposure for humans consuming game bagged with lead shot, and the eventual breakdown of metallic lead pellets in the environment and subsequent transfer of particulate and molecular lead to plants and animals.

All modern steel shot cartridges enclose the shot in a hard plastic cup, preventing the shot from coming in contact with gun barrels. Major arms and ammunition manufacturers have indicated that currently available steel shot loads cause no significant reduction in the life of most U.S. full-choke shotguns (USFWS 1986). Very light field guns, older guns made with soft thin-walled barrels, Brownings of early serial number, and shotguns with sharp-angled or swedged full chokes may experience some barrel damage if heavy lead and/or steel loads are used (Roster 1978).

4.2.2 Bismuth/tin shot

Bismuth/tin shot is about 86% the density of lead (compared with only about 70% for steel) and thus exhibits shot patterns and downrange velocities and retained energy similar to those of lead (Lowry 1993). Pure bismuth, used in the original bismuth cartridges, is brittle, causing pellets to break in the gun barrel, leading to poor patterning, and causing pellets to shatter on impact. However, the addition of approximately 3% tin and modifications in the production process have reduced shot brittleness, resulting in improved performance. Because bismuth/tin and lead have similar densities and softness, shotshell gauges, chamber sizes, and barrel designs suitable for lead may be used without modification with bismuth/tin cartridges.

Based on oral dosing studies showing bismuth shot to be nontoxic when ingested by waterfowl (Sanderson et al. 1992), bismuth/tin shot was approved on an interim basis for use in Canadian nontoxic shot zones beginning in 1993. Similarly, conditional approval of bismuth/tin for use as a nontoxic shot was granted in the United States for the latter part of the 1994–95 waterfowl hunting season (USFWS 1995) and for Australia's Northern Territory beginning in the 1993 season (King 1993).

Bismuth/tin shotshell ammunition is marketed in Europe by Eley Hawk, Birmingham, England, and in North America by the Bismuth Cartridge Co., Dallas, Texas. Bismuth shot is the most expensive shot product currently available in Canada, in part because of the relatively high cost of the raw material (on average, approximately $10.72 U.S./kg during the late 1980s and early 1990s; Goodwin 1991) compared with that of lead (approximately $0.40–$0.80 U.S./kg; Keating and Wright 1994). World supplies of bismuth are limited, and although the current annual supply of ~3000 tons worldwide (Goodwin 1991) can probably be increased to meet an increased demand, there is no compelling reason to believe that the price of bismuth metal (or of bismuth shotshell ammunition) will decrease much under such conditions. Indeed, prices may increase as less economical sources of the metal are exploited.

Bismuth shot in North America is considerably more costly than the same shot as sold in Britain (about $1.70/shell vs. $0.56/shell, respectively, expressed in Canadian dollars). There thus appears to be some room for future reductions in the price of bismuth/tin shot in Canada and the United States.

Current bismuth/tin shotshell production capacity for North America could supply the Canadian waterfowl hunting demand (~10–20 million shells/yr) should lead be phased out over the next few years (Bismuth Cartridge Co., pers. commun.). However, the three major distributors of bismuth/tin shotshells in Canada purchased only about 40 000 shells for the 1994 hunting season, for sale through independent hunting supply stores. Bismuth/tin shot is not yet readily available through larger retail outlets. As is the case for steel shot, there will probably continue to be a marginal market for bismuth/tin shot in Canada until a plan has been developed, announced, and set in motion for the regulatory phaseout of lead shot.

4.2.3 Zinc shot

The advantages of zinc as a metal for shot manufacture are that it is plentiful and has satisfactory ductility and hardness. However, it is relatively expensive, compared with either steel or lead, and it has relatively poor ballistic qualities because of its low density (less than steel). Nevertheless, zinc shot is apparently effective for hunting over short shooting distances. Unfortunately, zinc shot (and other forms of zinc metal) can be toxic to birds when ingested, although its toxicity is lower than that of lead (Grandy et al. 1968; Reece et al. 1986; Droual et al. 1991; Zdziarski et al. 1994). Zinc shot is produced in Germany by Grillo-Werke AG and is currently being used in several European countries as an alternative to lead shot. It is currently unavailable in North America and, to our knowledge, has not undergone any of the specific toxicity testing protocols required by CWS (1993) and USFWS (1988).

4.2.4 Tungsten/bismuth/tin (TBT) shot

TBT shot is currently in the research and development stage. It is produced by mechanically suspending finely powdered tungsten (39%) in a combination of molten tin (16.5%) and bismuth (44.5%). The resulting shot pellets have a density and hardness virtually identical to that of lead (Ringelman et al. 1993). Initial toxicity tests on Mallards dosed with up to 17 pellets indicate little or no tissue uptake of the constituent metals and no toxic effects (Ringelman et al. 1993). Should this sort of shot become commercially available, it would probably be priced somewhat higher than bismuth/tin shot owing to a more complex production process.

4.2.5 Molybdenum/polymer and tungsten/polymer

A blend of biodegradable polymers and powdered molybdenum results in a shot (Molyshot) that closely resembles lead in its physical and ballistic properties (Jackson 1994). This type of shot has been developed by the Kent Cartridge Co. in Britain and was available for purchase in Europe towards the end of 1994. Molyshot is manufactured by drawing an extrudable plastic mass of the blended material at high temperature into a wire and moulding it between rollers to produce rounded shot of chosen sizes, the densities and hardness of which are very close to those of lead and bismuth/tin. Initial ballistics tests of Molyshot have been encouraging. We are unaware of any toxicity testing of this shot type. However, chronic oral ingestion of molecular molybdenum can be toxic. Adverse effects include growth retardation, anemia, bone deformities, and interference with copper metabolism (Friberg and Lener 1986).

The first attempts at producing and marketing a tungsten/polymer shot were carried out by Eley Hawk in England. Their product (Eley Black Feather cartridges), launched in 1990, caused considerable initial interest. However, problems, including pellets breaking up or coalescing, poor patterning, and very high cost, ultimately resulted in the product being withdrawn from the market. More recently, Elastomer Engineering of Cheshire, England, claims to have overcome the original difficulties. The new tungsten/polymer shot is made using powdered tungsten in a thermo-plastic polymer (made from food-grade raw materials) and can be produced to have a density equal to that of lead (Marchington 1994). The resulting pellets are hard to the touch, yet soft enough to be crushed between the teeth like lead. Once deformed, the pellets retain their new shapes. Tungsten/polymer is also being used to produce bullets for use in indoor ranges to overcome health concerns relating to the use of lead ammunition. The new tungsten/polymer shot is not yet being marketed, to our knowledge, but we expect that the price in North America would be higher than that of steel or bismuth/tin shot. We expect that this form of shot would be nontoxic to birds, based on the known toxicology of tungsten (Kazantzis 1986).

4.3 Options for restricting the use of lead shot

Prior to the 1980s, lead shot had a long tradition of unrestricted use in North America. From performance and cost perspectives, lead shot is well liked by hunters and target shooters. However, given the extent of the negative impacts of environmental lead shot deposition, some restriction on the use of lead shot is appropriate. Options for restricting the use of lead shot range from encouraging a voluntary switch from lead to nontoxic alternatives on the part of manufacturers, retailers, and/or consumers through to regulatory actions restricting the manufacture, sale, and/or use of lead shot either regionally or nationally.

4.3.1 Voluntary switch to nontoxic shot

Attempts to solve the problems of lead shot use by advocating a voluntary switch to nontoxic alternatives have, in general, been ineffective. Any significant level of voluntary conversion to nontoxic shot requires a substantive education and public relations effort. Steel shot has been available for about 20 years in Australia, and more recently bismuth/tin shot has become available; however, only 5% of the shells used in that country are nonlead (ANZECC 1994). Similarly, although high-quality nontoxic shotshells are produced in large numbers in the United States — the major supplier of shotshell ammunition to Canada — nontoxic shot availability and use outside of current nontoxic shot zones in Canada are poor.

The reasons that a general, truly effective voluntary switch to nontoxic alternatives should not be expected are that lead shot is well liked by hunters, has been used for many years, is ballistically as good as or better than the alternatives, is cheaper than the alternatives, and has a well-established distribution and sales network. Given these facts, it is likely that a market for lead shot will continue to exist as long as lead shot is available for sale.

Encouraging a voluntary switch to nontoxic shot may, however, be useful as part of a wider plan for phasing out the use of lead shot. For example, in Great Britain, anyone shooting over wetland habitats is to voluntarily use nontoxic shot beginning September 1995 (Jackson 1994). If it is seen that voluntary replacement is not succeeding over a two-year trial period, official regulations will be established. This scheme had previously been employed to phase out small lead sinkers in Great Britain. A voluntary phase was followed in 1987 by a regulatory ban on the sale of these items when it became clear that voluntary action alone was insufficient (Government of Great Britain 1986). Both Norway and Sweden have banned the use of lead shot for waterfowl or wetland hunting and, in addition, have secured agreements with their respective hunting and target shooting associations for a voluntary phaseout of the uses of lead shot for all other hunting and target shooting activities (Nordic Council of Ministers 1994). It remains to be seen how effective the voluntary phase of this plan will be. In North America, high-quality nontoxic shotshell ammunition has been available for several years, and a nationwide ban on the use of lead shot for waterfowl hunting has been in effect in the United States since 1991; yet in Canada, the use of nontoxic shot is still trivial compared with that of lead for both hunting and target shooting. A policy of voluntary replacement of lead shot would, by itself, probably be ineffective in Canada.

4.3.2 Regulatory restriction of the use of lead shot

Regulatory actions to control the release of various forms of lead into the environment have been taken by many nations. In Canada, lead is on Schedule 1, List of Toxic Substances, of the Canadian Environmental Protection Act. Federal regulations prohibit the use of organolead compounds as antiknock agents in gasoline in Canada and set limits for lead emissions from secondary lead smelters. Both federal and provincial/territorial governments have regulated lead in a variety of media, including ambient air, food, drinking water, soils, sludges, sediments, and consumer products.

The regulatory restriction of lead shot and its replacement with nontoxic alternatives have been the options chosen by most nations that have recognized the risks to wildlife health from the use of lead shot. There are significant variations, however, in the kinds of regulatory actions taken by different nations. Regulations cover a range of possible options, from restricting the use of lead shot for waterfowl hunting in certain small local zones to a ban on lead shot for all hunting and target shooting. In this section, we briefly discuss the major regulatory options, from the least restrictive to the most restrictive. Table 8 summarizes the policies of several of the OECD nations regarding the use of lead shot.

When lead shot ingestion and poisoning of waterfowl are first recognized and documented, it is usual for wildlife managers to assume or to hope that the issue is a relatively minor one and is geographically local in extent (local "hotspots" of high ingestion and poisoning). It is usually judged that the least restrictive sort of regulation will be adequate to manage the problem. Criteria, inevitably somewhat arbitrary in nature, are established to assess where the problem is unacceptably severe. Criteria may be based on the local incidence of poisoning and/or shot ingestion as measured by gizzard surveys or other indicators of ingestion rate and may also include considerations of hunting pressure, density and availability of shot pellets in sediments, and other local conditions. The result, in several countries, has been the establishment of a few small zones wherein the use of lead shot for waterfowl hunting is prohibited. This occurred in the United States in the late 1970s and in Canada in 1991. However, further research and monitoring may identify additional sites of concern and may uncover problems not originally predicted, such as the secondary poisoning of raptors and the transboundary export/import of lead poisoning through embedded and ingested shot. Furthermore, the assessment of an increasing number of potential sites of concern can overwhelm available scientific personnel. Also, the enforcement of small, local lead shot bans is problematic if lead shot is still widely available and legal for use in the majority of hunting situations. As a result of these considerations, a gradual evolution towards larger zones can occur, combined with a greater acceptance of alternative shot types, which in turn can lead to province/territory- or state-wide bans on lead for waterfowl hunting. This is currently occurring in Canada, Australia, and Sweden. Ultimately, a national ban on lead shot for waterfowl hunting (as in the United States and Norway, and in Canada beginning in 1997), for all wetland hunting/shooting (as in Finland), or for all hunting (as in Denmark and the Netherlands) may be established.

Although a national ban on the use of lead shot for waterfowl hunting in Canada will undoubtedly lead to a substantial reduction in lead poisoning of waterfowl and their predators, environmental lead shot deposition would nevertheless continue at a rate equal to about 66% of the present rate, owing to the continued use of lead shot for upland game bird and small mammal hunting and clay target shooting. Some of the continuing deposition of lead shot from these activities would occur in wetlands. This consideration has led some nations (e.g., Finland, Sweden)

Table 8
Actions of various OECD countries for controlling the use of lead shot

Country	Current lead shot policy/actions taken
Australia	Established nontoxic shot zones for waterfowl hunting; state-wide ban on lead for waterfowl in effect in South Australia; considering national ban
Canada[a]	Established nontoxic shot zones for waterfowl hunting; national ban for all migratory game bird hunting starting 1997
Denmark	Total ban on the use of lead shot for all hunting; ban on lead shot for target shooting over water and on agricultural lands
Finland	Total ban on the use of lead shot in wetlands, beginning 1996
Mexico	Established nontoxic shot zone for waterfowl hunting in State of Yucatan to protect flamingos
Netherlands	Total ban on the use of lead shot for all hunting; proposing phaseout of lead for clay target shooting
Norway	Total ban on the use of lead shot for waterfowl hunting; Norwegian Association of Hunters has agreed to a stepwise reduction in the use of lead shot for all other hunting
Sweden	Established nontoxic shot zones for wetland hunting; ban on use of lead shot in all Ramsar sites; agreement with Swedish Sport Shooting Association to phase out lead shot for all sport shooting, excluding Olympic events, by 2000
Switzerland	Established one nontoxic shot zone at Lake Constance; federal government has recommended that only nontoxic shot be used for waterfowl hunting
United Kingdom	Established policy for voluntary switch to nontoxic shot for all wetland hunting/shooting over two years, starting 1995; regulatory action may follow
United States	Total ban on the use of lead shot for waterfowl hunting; phasing in further bans on use of lead shot for squirrel, pheasants, etc. in wetlands of national wildlife refuges

[a] More detailed information on the current nontoxic shot zones in Canada is presented in Appendix 6.

Source: Information for Table 8 is from Clausen 1992; OECD 1993; ANZECC 1994; Dorgelo 1994; Jackson 1994; Nordic Council of Ministers 1994; Swiss Department of the Interior, pers. commun.; USFWS, pers. commun.

to adopt a ban on the use of lead shot in wetlands, rather than a ban on lead only for waterfowl hunting. The United States has also recognized the need for a more generalized ban to adequately protect waterfowl and is phasing in nontoxic shot regulations for hunting upland birds and small mammals on national wildlife refuges where these activities occur on or near wetland habitats. This habitat-based approach is more rational than a species-based approach. At the OECD Lead Risk Reduction Workshop held in Toronto, 12–15 September 1994, the OECD Working Group on the Development of a Lead Council Act agreed that the use of lead shot in wetlands should be reduced with a view to the phaseout of such uses. A wetland-based policy is also consistent with the aims of the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention), to which Canada is a signatory nation, and for which CWS is Canada’s management authority. Canada has designated over 13 million hectares at 32 Ramsar sites.

By 1986, Denmark had banned the use of lead shot for target shooting over shallow water, agricultural lands, and lakes used by breeding waterfowl and was intending to ban lead shot for all hunting (Clausen 1992). Opposition by hunters resulted in a compromise in which lead shot was banned for hunting in Ramsar sites. However, this regulation was impossible to enforce, and the number of nontoxic shotshells purchased by hunters was far below the number fired at the 27 Ramsar areas. Noncompliance and enforcement difficulties resulted in a complete ban on the use of lead shot for all hunting in Denmark in 1993 (Clausen 1992). A wetland-based regulation prohibiting the use of lead shot would probably be even more difficult to enforce effectively in Canada than in Denmark, considering the vast geographical area to be monitored.

We are aware of only two countries (Denmark and the Netherlands) that have banned lead shot for all types of hunting. A few additional countries (Sweden, Norway, United States) have established a complete ban on lead shot for waterfowl or wetland hunting and have taken some additional steps to broaden the restriction to partially include other types of hunting or clay target shooting. Some other countries, including Canada, have established partial bans on the use of lead shot for waterfowl hunting in some areas and are moving to broader bans. Partial bans are probably the most difficult to enforce effectively and the most likely to engender compliance problems, because the availability of lead shot for sale remains good and the sale, possession, and use of lead shot are not, in general, unlawful. Noncompliance with nontoxic shot zoning regulations in the United States and Canada has been estimated to range from about 10% to over 30%, depending on the location (Simpson 1989; DeStefano et al. 1991; Langelier 1994). An additional problem related to enforcement is the fact that, unlike steel shot, which is magnetic, newer types of nontoxic shot such as bismuth/tin and tungsten/polymer cannot be readily differentiated from lead without breaking open the shotshell. From an enforcement perspective, any sort of partial ban on the use of lead shot for hunting is undesirable.

It is more effective to limit the sale of an undesirable product than to attempt to regulate one or a few of its uses, especially if the product is widely available for sale. At the federal level, under the Migratory Birds Convention Act, CWS is authorized to regulate the manner in which the hunting of migratory birds is done (i.e., the *use* of lead shot for this purpose can be regulated), but controls on other uses such as upland bird hunting or clay target shooting even in wetlands, or on the production, import, and/or sale of lead shot, are beyond the regulatory authority of CWS under this act. The development of other strategies, including the use of provincial/territorial regulatory mechanisms, should be explored. Alternatively, the use of the Canadian Environmental Protection Act may be required for the effective management of this issue on a national level.

4.3.3 Transboundary considerations

By definition, migratory birds do not respect provincial/territorial or national boundaries. Losses of migratory birds to lead poisoning and the movement of lead across provincial/territorial, state, or national boundaries as embedded lead shot pellets in waterfowl and other migratory birds are issues of inter-provincial/territorial and international concern. It is logical to assume that birds that carry ingested or em- bedded shot and migrate out of the area where exposure occurred pose a threat to predators and scavengers in other provinces/territories/states or countries anywhere along their migratory routes. Since the United States banned lead shot for all waterfowl hunting in 1991, 79 eagles have been found dead of lead poisoning in the United States (USFWS, pers. commun.). Many (46) of these birds were from states bordering Canada, such as Minnesota, Wisconsin, and Montana. It is feasible that, since 1991, a source of lead shot ingestion in U.S. eagles has been embedded lead from waterfowl shot on the Canadian Prairies. Similarly, Langelier (1994) pointed out that ducks of numerous species arrive in British Columbia from the Yukon, Northwest Territories, and Alberta. Because British Columbia will be establishing a province-wide nontoxic shot zone in 1995 and relatively little licensed hunting is done in the Yukon and Northwest Territories, waterfowl hunting in Alberta may soon be a relatively major source of embedded lead shot exposure for Bald Eagles in British Columbia.

Management options to consider include:

1) use of the Migratory Birds Convention Act to establish, in consultation with the provinces/territories and other stakeholders, a national ban on the use of lead shot for waterfowl or migratory game bird hunting;

2) use of provincial/territorial legislation to ban the use of lead shot for all hunting and clay target shooting that occurs on or near wetlands, lakes, rivers, floodplains, beaches, or other similar environments where waterfowl and other water birds are at risk from lead shot ingestion;

3) use of provincial/territorial regulation, or the Canadian Environmental Protection Act, to phase out lead shot for all hunting; and

4) development of national hunter education programs to include up-to-date information on various nontoxic shot products, information to help hunters improve shooting skills, and clinics for “hands-on” training. Public relations, training, and education are essential aspects of the phaseout of lead shot and the phasein of nontoxic alternatives.

4.3.4 Options for managing the use of lead shot in clay target sports

The issue of establishing environmental guidelines and regulations governing the use of lead shot at gun clubs is in its infancy. Outside Canada, investigations of lead shot use in clay target shooting and the potential for environmental impacts have been conducted in the United States (SAAMI 1993), Denmark (Bjorn et al. 1982), Ireland (Rice et al. 1987), Finland (Manninen and Tanskanen 1993), and the Netherlands (Ma 1989). Denmark banned target shooting over shallow water in 1981, and several trap ranges were closed as a consequence (Clausen 1992). The Netherlands, Sweden, and Norway are currently working with their respective sport shooting associations to phase out the use of lead shot for target shooting. The OECD Working Group on Lead Risk Reduction has agreed that the use of lead shot should be phased out in wetland areas, and we suggest that such uses should include clay target shooting as well as hunting.

In the United States, approximately 12 clay target shooting ranges, at least six of which were located in wetland areas, have been either closed indefinitely or required to use nontoxic shot products by local or state governments (Morehouse 1992b; Ordija 1993; SAAMI 1993; Yurdin 1993). At least 10 other ranges are currently under investigation. Initial investigations of these ranges were prompted by community concern for lead contamination of soils, deposition of lead shot into waters or wetlands, and ingestion of spent shot by waterfowl.

A major impediment to a simple switch to nontoxic shot in clay target shooting is that international rules and regulations governing Olympic and other competitive trap shooting currently are such that the use of lead shot is required, and agencies such as the International Shooting Union and the International Olympic Committee have taken the position that target shooting does not contribute to a significant environmental lead shot problem (Thomas 1994). Most shooting ranges are geared towards traditional trap and skeet shooting, and even the new, rapidly growing sporting clay ranges have not yet embraced the use of steel shot (Sparrowe 1992).

The United States Sporting Arms and Ammunition Manufacturing Institute (SAAMI) believes that solutions to problems from the deposition of lead shot on outdoor shooting ranges should include more vigilant maintenance of ranges, soil and water management, and periodic lead recovery (SAAMI 1993). In the United States, about 15 companies have equipment for recovering lead shot from soil, but this equipment is designed for operation on relatively flat, dry surfaces, and there is no known practical method for recovering lead shot from forested, hilly, or marshy areas. Although reclamation of spent lead has been successfully accomplished on some target ranges in both the United States and Canada, no regulations at either the provincial/territorial or national levels in Canada require environmental monitoring or regular reclamation as part of range maintenance procedures. Recovery and recycling of lead from target shooting ranges are encouraged by the USEPA and the National Rifle Association (Sever 1993) and can actually be a source of profit for the range.

Gun clubs that do not shoot over or near water or wetlands and have an active program to recover lead are least likely to be at risk for environmental impacts and regulatory action. U.S. gun clubs that have shotfall zones for which lead shot recovery is not a practical option (i.e., water bodies or wetlands) have been advised to voluntarily require the use of steel or other alternative nontoxic shot (Ordija 1993). National or provincial/territorial site-specific environmental criteria for lead in range soils and surface waters and regulations requiring ranges to monitor and properly maintain their shooting areas are needed for Canada. Such steps would ensure that lead shot deposition was isolated, that deposition was not resulting in off-site lead contamination or shot ingestion by waterfowl, that lead was periodically recovered, and that ranges were established only on sites where deposited lead shot was capable of recovery.

In Canada, DND-owned small arms ranges where recreational trap and skeet shooting occurs are currently under review by that department. It may be recommended to bases with these ranges to prohibit the use of lead shot, based on the rationale that environmentally safer alternatives to lead are available and that shooting activities frequently take place near water or marshland, posing a risk to water birds (DND, pers. commun.).

Management options to consider include:

1) establishing, in consultation with the provinces/territories and other stakeholders and consistent with the Canadian Environmental Quality Criteria for Contaminated Sites, site-specific soil and water criteria for lead at outdoor target ranges;

2) establishing, in consultation with the provinces/territories, national target shooting organizations, and other stakeholders, minimum national standards for environmental management of outdoor target ranges, including identification of the acceptable terrain characteristics for establishing such ranges and schedules for reclamation of lead shot; and

3) preventing the deposition of lead shot from clay target shooting into wetlands and other aquatic environments.

4.4 Options for managing the lead sinker problem

Coating and/or painting lead fishing sinkers will not likely reduce the risk of lead toxicity in water birds, for the same reasons as those previously outlined for lead shot (Section 4.1).

The USEPA concluded that a labelling provision to identify lead sinkers and jigs as toxic to water birds would not, by itself, adequately reduce the risk to water birds, stating that fishing sinkers typically become deposited in the environment accidentally and labelling would have little effect on their accidental loss (USEPA 1994a). Similar suggestions have been made by a fishing sinker manufacturer in the United States, quoting a survey conducted in Great Britain in 1986, which determined that for every split shot sinker used, up to six might be spilled and lost (Lichvar 1994).

Lead sinkers and jigs will probably dominate the market as long as they are legal because they work well and are cheaper, and therefore are easier to sell, than the alternatives. Despite the production of nontoxic alternatives by several Canadian and U.S. companies (Appendix 7), most retail stores are not stocking these products or carry only a very limited selection. A plan to voluntarily replace lead fishing weights with nontoxic products in Great Britain was not completely successful, necessitating a regulatory ban on the sale of lead sinkers (Government of Great Britain 1986). Producers of nontoxic sinkers in Canada fear that a similar failure of voluntary efforts to phase out lead sinkers would occur in this country. “As long as lead sinkers and jigs are legal, they will dominate the sinker and jig market because they are the cheapest and therefore the easiest to sell. In most cases, the fisherman won’t even get the opportunity to buy a non-toxic alternative. Salesmen, at both the wholesale and retail level, don’t want to be bothered trying to promote environmentally friendly [products] instead of lead. They want to make a quick sale on these `small ticket’ items and move on to sell something else” (BiLogic Tackle, pers. commun.).

Probably the most effective way to reduce lead poisoning of loons and other water birds is to phase out the sale and/or use of lead fishing sinkers through government regulation, which would also stimulate the availability, sale, and use of nontoxic alternatives. Manufacturers of lead sinkers and jigs would require time to modify their production processes. Any phaseout of lead sinkers and jigs must take into account the concerns of these manufacturers. For other producers, however, a move towards nontoxic sinker products may be seen as an opportunity rather than a burden. In addition, regulatory encouragement of new technologies might discourage home production of sinkers, thereby serving to increase the market available to manufacturers. In any case, an adequate time should be allowed for manufacturers, retailers, and users to adapt to the changes resulting from any new regulations that may come into effect regarding these products.

4.4.1 Alternative fishing sinker products

Numerous viable alternative materials exist for use as fishing sinkers and jigs, including tin, bismuth, antimony, steel, brass, tungsten, terpene resin putty, and polypropylene. All of the alternative products are more expensive than lead, and each differs slightly with respect to the types of uses for which it is appropriate. Fishing sinkers are diverse in shape and weight, reflecting the different fishing methods for which they are used. The alternative products, either alone or in combination, appear to have effectively provided substitutes for all of the current lead sinkers and jigs on the market. The majority of nontoxic sinker manufacturers are located in the United States; however, bismuth sinkers and jigs are manufactured in Canada.

Tin sinkers are perhaps the most common and popular alternatives to lead and are available in most styles and sizes. Owing to its brittleness, bismuth cannot be crimped and therefore is not available as split shot, but it may be purchased in other forms (egg, worm, swivels, bullet slips, jig heads, etc.). Low melting point metals, including bismuth and tin, may be poured into the same or similar moulds currently used to manufacture lead sinkers; however, bismuth expands as it cools, in contrast to lead, and therefore must be poured only into high-quality milled moulds (BiLogic Tackle, pers. commun.).

Steel, zinc, and brass sinkers are currently available in various forms and sizes; however, metallic zinc is known to be toxic to waterfowl and other birds, although it is less toxic than lead (Grandy et al. 1968; Zdziarski et al. 1994).

Tungsten/polymer putty compounds are relatively expensive and are not now widely available in North America.

A limited selection of nontoxic alternatives to lead fishing sinkers, including steel, bismuth, and tin, is currently available from large retail chain stores and from tackle and sporting goods stores in Canada. Bismuth sinkers and jigs are also available directly from the manufacturer in Canada. Most large companies that provide alternative sinker products in the United States and Great Britain already have distributors in Canada.

The USEPA (1994a) has estimated that the average U.S. sport angler would incur an additional expense of about $4.00 or less per year on nontoxic sinkers, should lead sinkers be banned. Appendix 8 estimates the costs Canadian anglers would face if lead sinkers were to become unavailable and nontoxic alternatives were substituted.

4.4.2 Options for restricting lead sinkers and jigs

There are a number of options for managing the problems created by lead sinker and jig use. The major options include:

1) a limited ban on the use of lead sinkers and jigs of a specified size range known to be ingested by water birds in certain geographical areas where a poisoning problem has been identified (i.e., a zoning approach);

2) a comprehensive ban on the manufacture, sale, and/or use of certain types of lead sinkers (e.g., split shot);

3) a comprehensive ban on the manufacture, sale, and/or use of all lead sinkers and jigs of a specified size range (e.g., <2 cm in all dimensions) known to be ingested by water birds;

4) a regulation restricting the lead content of sinkers and jigs of a size range known to be ingested by water birds; and

5) a comprehensive ban on the manufacture, sale, and/or use of all sinkers and jigs containing a significant (e.g., >0.1%) lead content.

Zoning approaches would probably suffer from compliance problems and would be difficult to enforce effectively, for reasons similar to those given in Section 4.3.2 for lead shotshell ammunition. Lead fishing sinkers and jigs have a long history of traditional use, they perform as well as or better than the alternatives, they are widely available in a wide variety of types and sizes, and they are cheaper than alternative nontoxic products. The USEPA (1994a) has rejected a geographic zoning approach for regulating lead sinkers because at-risk habitats, in which water birds live and in which anglers fish, essentially include the entire United States. The costs associated with an extensive research and monitoring program to identify all local areas of concern based on documented mortality of water birds from sinker or jig ingestion, the cost of subsequent enforcement, and the likelihood of compliance problems make this option unattractive. A zoning approach may be useful, however, as part of a more comprehensive phaseout plan. For example, preceding the USEPA (1994a) proposal to ban the manufacture, processing, and sale of small lead sinkers, Yellowstone National Park banned the use of lead-headed jigs in 1992 and lead weights in 1994. The United States also banned the use of all lead sinkers in the Red Rock Lakes National Wildlife Refuge, Montana. The USFWS has also identified 40 units of the National Wildlife Refuge system where the use of lead and zinc sinkers and jigs may be banned. This issue is currently undergoing public consultation (K. Morehouse, pers. commun.). Similar actions in Canada might serve as the initial steps in a more comprehensive plan to phase out lead sinkers and jigs.

A ban on only certain types of sinkers and jigs is unjustified, because many different types of these products have been found to be ingested by water birds. For example, loons do not ingest only split shot; worm weights, egg sinkers, bass casting sinkers, and small lead jigs have also been found in Common Loons.

Restricting the lead content of sinkers has been examined and rejected by the USEPA (1994a) on the basis that it may be difficult to accurately measure the lead content of sinkers, making compliance by industry burdensome and enforcement difficult.

Countries that have taken, or are taking, regulatory action to restrict lead sinkers (Great Britain and the United States) have focused on small sinkers known to be ingested by water birds. We judge that banning the sale and use of lead sinkers and jigs under 2 cm in all directions and under 50 g in mass would virtually eliminate the risk of lead poisoning in Common Loons and other fish-eating birds. Such a ban, along with a concurrent ban on lead shotshell ammunition, would with time virtually eliminate the risk of lead poisoning for swans, other waterfowl, and, indeed, all wild bird species.

A comprehensive ban on all manner of lead fishing weights is probably unwarranted if protection of water birds is the only goal. Lead weights bigger than about 2 cm in any dimension, or heavier than about 40–50 g, are not typically ingested by water birds. However, in order to reduce the general contamination of the environment by metallic lead that will ultimately undergo decomposition into various molecular lead species and be distributed through the physical environment and through the food chain, it may be prudent for Canada to consider restrictions on lead sinkers or jigs of any size used in freshwater sport angling.

Management options to consider include:

1) use of provincial/territorial legislation or federal legislation (e.g., Canadian Environmental Protection Act) for the regulatory phaseout of small (<50 g) lead sinkers and lead-headed jigs for sport angling; and

2) establishing public education programs explaining the risks to water birds from lead sinkers and jigs and the nature of alternative nontoxic products; and discussion of options for the collection and disposal/recycling of lead sinker products.

4.5 Summary and conclusions

- ❖ Neither CWS nor the provinces/territories have the resources to effectively assess all areas for which nontoxic shot zoning or use of nontoxic sinkers may be appropriate, nor do they have the capability to effectively enforce bans on the use of lead shot or sinkers in numerous local “hot spot” areas.

- ❖ Currently available nontoxic alternatives are more expensive than lead shot or sinkers but would increase the average hunter’s total yearly expenses by only about 1–2% (steel) and those of the average angler by <1–2%.

- ❖ Good-quality, nontoxic alternatives to lead shot and sinkers are currently being produced, and additional such products are being developed.

- ❖ There will probably be a marginal market for and incomplete availability of nontoxic shot and sinkers until lead shot and sinkers are made unavailable.
- ❖ Modern steel and bismuth/tin shotshell ammunition are both effective for bagging waterfowl (and other game animals) over accepted shotgun shooting ranges (up to about 45 m for waterfowl). Crippling of game animals is much more a function of the skill of the shooter than of the type of ammunition (lead, steel, bismuth/tin) used.
- ❖ For hunting with nontoxic shot, the single major undesirable consequence is wastage due to crippling loss. The undesirable aspects of hunting with lead shot, however, include crippling losses, losses from lethal and sublethal lead poisoning of waterfowl and other wild birds through primary poisoning, losses from lethal and sublethal poisoning of raptors and scavengers (secondary poisoning), the risk of lead exposure of some livestock species (e.g., domestic fowl, cattle), plus unnecessary lead exposure of humans consuming game bagged with lead shot, and the eventual breakdown of metallic lead pellets in the environment and subsequent transfer of particulate and molecular lead to plants and animals.
- ❖ Clay target shooting over wetlands or other aquatic environments poses a risk for lead shot ingestion and poisoning in waterfowl similar to that from waterfowl hunting. In the United States and elsewhere, several such target ranges have been closed indefinitely.
- ❖ Reclamation and recycling of lead shot from target ranges are encouraged by the USEPA, as well as by the National Rifle Association.
- ❖ From the point of view of hunter and angler compliance, effective enforcement, wholesale and retail distribution and sale, and wildlife and ecosystem health, any sort of partial ban on lead shot or small lead sinkers/jigs is a less than ideal solution to the lead poisoning problem and causes its own additional problems.
- ❖ Several countries have successfully banned the use of small lead sinkers and of lead shot for waterfowl and other hunting and are in the process of banning the use of lead shot for clay target shooting, using a phasing-out process that gives manufacturers, sellers, and users adequate time to adjust to the regulations.

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Appendices

Appendix 1
Suppliers of Reloaded Shotshell Ammunition

Bolt Action Reloaders, Kamloops, British Columbia
OMA Products Ltd., Burnaby, British Columbia
Shillito, William A., Campbell River, British Columbia
Sweet Creek Custom Ammunition, Terrace, British Columbia
Valley Cartridge Company, Duncan, British Columbia

A & E Enterprises, Lethbridge, Alberta
Canadian Professional Munitions, Raymond, Alberta
Canadian Superior Munitions Ltd., Edmonton, Alberta
C.B. Ammunition Manufacturer, Sherwood Park, Alberta
The Firing Line Ltd., Calgary, Alberta

Independent Ammunition Manufacturing Company Inc., Saskatchewan
Wilderness Sports Supply, Longham, Saskatchewan

Banner Speciality Ltd., Winnipeg, Manitoba
Excel Ventures Inc., Dugald, Manitoba

A.B.C. Sporting Goods, Wingham, Ontario
Beckett Colonial Industries, London, Ontario
Centre Gunshop, Niagara Falls, Ontario
Circle T. Reloads, Bramalea, Ontario
Ellwood Epps (Orillia) Ltd, Orillia, Ontario
Maranda Inc., Mississauga, Ontario
Northern Arms and Munitions, Sudbury, Ontario
P.R. Sales, Mississauga, Ontario
"Pull!" Reloading Supplies, Alliston, Ontario
R & B Custom Reloading, Chatsworth, Ontario
Shells Galore, Petrolia, Ontario
Soley Sporting Supplies Inc., Ancaster, Ontario
T.R.J. Reloading, Oxford Mills, Ontario

Les Industries Centaur Limitée, Laval, Québec
Munitions M.J.P. Enrg., L'Acadie, Québec
Pistone, Rosario, Montréal, Québec
Rechargement de la Capital Enrg., Ancienne-Lorette, Québec
Rechargement Québec Enrg., Beauport, Québec
Société d'expansion commerciale Libec Inc. (Challenger Ammunition) Montréal, Québec
Tony Sports Enrg., Montréal, Québec

Centre Target, Florenceville, New Brunswick
Precision Reloading, Shediac, New Brunswick

Appendix 2
Provincial and territorial clay target shooting associations

British Columbia Trapshooting Association, Victoria, British Columbia
Alberta Federation of Shooting Sport, Edmonton, Alberta
Manitoba Trapshooting Association Inc., Brandon, Manitoba
Manitoba Skeet Shooting Association, Winnipeg, Manitoba
Ontario Provincial Trap Shooting Association, Milton, Ontario
Ontario Olympic Trapshooting, Collingwood, Ontario
Ontario Skeet Shooting Association, Hampton, Ontario
Fédération Québécoise de Tir, Montréal, Québec
Shooting Federation of Nova Scotia, Halifax, N.S.
Shooting Federation of Prince Edward Island, Charlottetown, P.E.I.
Northwest Territories Federation of Shooting Sports, Yellowknife, N.W.T.
Yellowknife Shooting Club, Yellowknife, N.W.T.
Yukon Shooting Federation, Whitehorse, Yukon

Appendix 3
Lead fishing sinker and/or jig manufacturers in Canada

Caribou Lures, Dorval, Quebec
D & D Lures, Windsor, Ontario
Gibbs/Nortac, Burnaby, British Columbia
Peetz Mfg. Co., Victoria, British Columbia
Radiant Lures, Victoria, British Columbia

Appendix 4
Manufacturers/suppliers of alternative shot/shotshell products

Bismuth Cartridge Co., Dallas, Texas: Bismuth shot and shotshells
Eley Hawk Ltd., Birmingham, England: Bismuth shot and shotshells
Federal Cartridge Corp., Minneapolis, Minnesota: Steel shotshells
Gillo-Werke Aktiengesellschaft, Duisburg, Germany: Zinc shotshells
Kent Cartridge Co., Tonbridge, England: Molybdenum shot
Olin Australia, Geelong, Australia: Bismuth shotsheels
Remington Arms Co. Inc., Bridgeport, Connecticut: Steel shotshells
Winchester Division of Olin Corp., East Alton, Illinois: Steel shotshells

Appendix 5
Consumer costs associated with the use of non-toxic shot for hunting in Canada.

Annual reports of migratory game bird harvests and number of migratory bird permits sold indicate that from 1988 to 1993, an average of nine birds was bagged per waterfowl hunter (Lévesque et al. 1993). Each upland game bird hunter bagged an average of three to four birds per year for those same years. It was estimated that for each bagged duck, a hunter fires approximately six shots (USFWS 1986). We are not aware of similar estimates for number of shots fired per bagged upland bird but have assumed a similar number to those obtained in waterfowl hunting for the purposes of estimating ammunition cost. Waterfowlers and upland game bird hunters would therefore use, on average, about 54 and 21 shells per hunting season, respectively.

Suggested retail prices for lead and alternative shot products were obtained from leading manufacturers and retailers of ammunition. Lead shotshell ammunition represents a small proportion of the total game bird hunting budgets, averaging 6% for waterfowl hunters and 4% for the upland game bird hunters.

The following tables outline average waterfowl and upland game bird budgets per hunting season and the comparative costs associated with using nontoxic shot products currently available in Canada.

Waterfowl hunter: Total budget = $450 per hunting season

Shot	Cost per shell[a] ($)	Range in ammunition expenses/yr[b] ($)	Average ammunition expense/yr ($)	Average price increase/ hunter/yr ($)	Increase in budget (%)[c]
Lead	0.50–0.60	27.00–32.40	29.70	0	0
Steel	0.52–0.88	28.08–47.52	37.80	**8.10**	2
Bismuth/tin	1.50–1.95	81.00–105.30	93.15	**63.45**	14

[a] Price in Canadian dollars.
[b] Based on the estimate of 54 shotshells purchased per year.
[c] Percent increase in total hunting budget of $450.

Upland game hunter: total budget = $310 per hunting season

Shot	Cost per shell[a] ($)	Range in ammunition expenses/yr[b] ($)	Average ammunition expense/yr ($)	Average price increase/ hunter/yr ($)	Increase in budget (%)[c]
Lead	0.50–0.60	10.50–12.60	11.55	0	0
Steel	0.52–0.88	10.92–18.48	14.70	**3.15**	1
Bismuth/tin	1.50–1.95	31.50–40.95	36.23	**24.68**	8

[a] Price in Canadian dollars.
[b] Based on the estimate of 21 shotshells purchased per year.
[c] Percent increase in total hunting budget of $310.

Waterfowl hunters would spend on average $8.00 more for steel shotshells per season than for lead shells and up to $64.00 more for bismuth/tin at current prices. Upland game bird hunters would spend an average of $3.00 more for steel shotshell than for lead ammunition per hunting season and up to $25.00 more for bismuth/tin shells.

It should be noted that in Great Britain, steel and bismuth/tin shotshells are readily available and are sold at prices comparable to those for Canadian lead shotshell ammunition (the equivalent of $0.35 and $0.56 Can. per shell). Current prices of nontoxic ammunition in Canada may drop as production and availability increase.

Zinc, molybdenum/polymer, and tungsten/polymer shotshells range in price from $0.75 to $0.89 (Can.) in Great Britain, which approximates the Canadian cost of steel shells; however, a wide availability of these products in North America is not anticipated in the near future.

Appendix 6
Current nontoxic shot zones in Canada[a]

Province	No. of nontoxic shot zones	Future plans
British Columbia	2	Province-wide nontoxic shot for waterfowl hunting beginning in 1995
Alberta	0	No plans for nontoxic shot zones
Saskatchewan	0	No plans for nontoxic shot zones
Manitoba	1	May expand the current zone
Ontario	2	Will expand 1 current zone (Wye Marsh) and add 1 additional nontoxic zone (Presqu’ile) in 1995; will add a number of new zones in 1996
Quebec	0	Nontoxic shot to be used in all wildlife management areas beginning in 1996; province-wide nontoxic shot use for waterfowl hunting beginning in 1997
Newfoundland	0	No plans for nontoxic shot zones
New Brunswick	2	Province-wide nontoxic shot for waterfowl beginning in 1997
Nova Scotia	2	Province-wide nontoxic shot for waterfowl beginning in 1997
Prince Edward Island	2	Prefers to phase out lead shot as part of a national, rather than sectoral ban
Northwest Territories	0	No plans for nontoxic shot zones
Yukon	0	Considering territory-wide nontoxic shot for waterfowl hunting

[a] Nontoxic shot zones as of 1994–95 hunting season; a national ban on the use of lead shot for hunting migratory game birds will come into effect in 1997.

Appendix 7
Manufacturers of alternative fishing sinker products

Canadian companies
Bilogic Tackle, Thessalon, Ontario: Bismuth sinkers and jigs
Vektor International, Dundas, Ontario (Canadian distributor for Dinsmores): Tin sinkers

British companies
Dinsmores Ltd., W. Mids., United Kingdom: Variety of tin sinkers

U.S. companies
A Better Angle, Jenner, California: Soft carbon steel slip sinkers
American Sports International, Columbia, Alabama: Bismuth egg sinkers and worm weights
Belvoirdale, Wyncote, Pennsylvania (U.S. distributor for Dinsmores): Tin sinkers
Berkley, Outdoor Technologies Group, Spirit Lake, Iowa: Bismuth jigs
Bullet Weights, Alda, Nebraska: Tin and steel weights of various shapes
Custom Bass U.S.A., Bridgeport, Connecticut: Tin buzzbaits, jigs, and spinner bait
Eco-Sync Glass Fishing Sinkers, Aptos, California: Sinkers made from recycled glass
Hildebrandt Corp., Logansport, Indiana: Tin spinnerbait, jig and offset spinners
J & J Tackle, Blemar, New Jersey: Tin jigs
Jadico Inc., Camberton, Missouri: Bismuth jig heads
Loon Tackle, Boise, Idaho: Putty weights
Luhr-Jensen & Sons, Inc., Hood River, Oregon: Rubber drift sinkers
RJC Outdoors, Clifton, New Jersey: Tin jigs
Water Gremlin, White Bear Lake, Minnesota: Tin split shot and bullet, barrel and egg sinkers made of plastic composite resin with iron and tungsten

Appendix 8
Consumer costs associated with the use of alternative sinker products for sport fishing in Canada

In 1991, 5.5 million Canadians 15 years of age and older (26.4% of the total Canadian population) took part in recreational fishing (Filion et al. 1993), an average of 14 days per participant. The average cost per angler was estimated to be $502.00 per season (approx. $35.00 per day), although provincial variation was observed (Filion et al. 1993). Fishing equipment, including boats, motors, fishing rods, and reels, accounted for approximately 45% of the total angling budget, or $224.00 per year. The other major constituent of the angler budget was transportation, which accounted for an estimated $112.00 per year.

The USEPA (1994a) estimated that the average angler purchased $1.50–$3.50 (U.S.) worth of lead fishing sinkers per year. The average price per sinker was estimated to be $0.14 from a survey of retail stores. Therefore, in the United States the average angler may purchase 8–20 sinkers per year, approximating one sinker per angling day. Based on the similarity of participation in the United States and Canada (i.e., an average of 14 days), it is assumed that Canadian use of sinkers would also be similar to that in the United States.

The following table outlines the average annual angling budget and cost associated with the use of lead and alternative fishing sinker products.

Canadian anglers: total annual budget = $502.00

Material	Price range/ sinker[a] ($)	Mid-range price/sinker ($)	Average expenditure/yr[b] ($)	Average increase/ angler/yr ($)	Increase in budget (%)[c]
Lead	0.03–0.25	0.14	1.96	0	0
Tin	0.04–0.33	0.18	2.52	**0.56**	0.1
Bismuth	0.14–1.59	0.86	12.04	**10.08**	2.0

[a] Price in Canadian dollars.
[b] Based on the estimate of 14 sinkers purchased per year.
[c] Percent increase in total angling budget of $502.00 per year.

Lead fishing sinkers account for less than 1% of the total angling budget. The average angler may spend up to an additional $10.00 for the use of alternative sinker products. Prices for other alternative sinker products made from steel, glass, or plastic are not available; however, they are believed to fall within this range.

Grahame Maisey, President of Belvoirdale (U.S. distributor for Dinsmores tin sinkers), and the USEPA (1994a) have stated that deposition of lead sinkers into the environment is often accidental through spillage. A survey conducted in 1986 in the United States estimated that for every one split shot sinker used, four to six sinkers were spilled and lost (Lichvar 1994). Split shot sinkers are estimated to account for almost half of the total lead sinker market in terms of the number of sinkers sold (USEPA 1994a). When the additional costs associated with spill loss and lack of reuse are added to the price of lead sinkers, the price difference associated with the use of reusable, nontoxic sinkers diminishes (G. Maisey, pers. commun.).

Increased consumer cost of up to $10.00 per angler per year may occur with the use of some alternative sinker products in Canada but will not represent a significant or prohibitive increase in the cost of recreational angling activities.

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