LEAD POISONING IN WHITE-TAILED SEA EAGLES: CAUSES AND APPROACHES TO SOLUTIONS IN GERMANY

OLIVER KRONE[1], NORBERT KENNTNER[1], ANNA TRINOGGA[1], MIRJAM NADJAFZADEH[1], FRIEDERIKE SCHOLZ[1], JUSTINE SULAWA[1], KATRIN TOTSCHEK[1], PETRA SCHUCK-WERSIG[2], AND ROLAND ZIESCHANK[2]

[1]*Leibniz Institute for Zoo and Wildlife Research, P.O. Box 601103, D-10252 Berlin, Germany.* E-mail: krone@izw-berlin.de

[2]*Environmental Policy Research Centre, Free University Berlin, Ihnestrasse 22, D-14195 Berlin, Germany.*

ABSTRACT.—Our project aims to identify the causes and consequences of oral lead intoxications of the White-tailed Sea Eagle (*Haliaeetus albicilla*) as an umbrella species for other scavenging birds. A dialogue-oriented and communicative part of the project encourages involved stakeholders like hunting organizations, foresters, the ammunition industry, ammunition dealers and nature conservationists to develop potential solutions for eliminating lead risks for scavenging birds. Veterinarians, biologists, and social scientists work together to elucidate key issues of the biology of White-tailed Sea Eagle (WTSE), analyse information use and attitudes of hunters as well as conflicts between social actors, transfer knowledge quickly to stakeholders, and mediate between the different parties.

Previously, post mortem examinations of more than 390 WTSEs from Germany performed at the Leibniz Institute for Zoo and Wildlife Research, Berlin revealed that lead intoxications are the most important cause of death (23% of mortality). In this study we identified the potential sources of lead intoxications for WTSEs, being waterfowl such as geese and carcasses of game animals or their remains (gut piles) shot with lead-containing bullets. Three species of geese (n = 154) captured and x-rayed carried embedded shot pellets in 21.4% of all cases. Digital radiographs of game animals (n = 315) shot with semi-jacketed bullets revealed a large number of metallic particles. Isolated lead fragments ranged from less than 1 mm to 10 mm. Gut piles (n = 14) of animals shot with conventional bullets contained metallic particles in 100%. Preliminary results of our feeding experiments suggested that WTSE avoided large (>7.7 mm) but not small particles (<4.4 mm) which may have implications for the further design of lead-free rifle bullets.

Our data on the home-range size of WTSEs support attempts to allocate the source of lead-poisoning to the local areas frequented by eagle pairs. An adult female WTSE used an area of 8.2 km^2 (95% Minimum Convex Polygon) and 4.5 km^2 respectively (95% Fixed Kernel).

To test the toxicity of bullet metals (Pb, Zn, Cu), we conducted feeding experiments on Pekin Ducks. Highest bioavailability and organ accumulation of lead was found in liver, kidney, and brain tissue. We compared the performance of lead-free bullets and lead-containing bullets with respect to hunting/killing efficiency. Expanding bullets made of copper or its alloys offer the possibility of harvesting game that is not contaminated with bullet remains and therefore pose no risk of intoxication to humans and wildlife. Our results, together with the field tests performed by hunters using lead-free ammunition, show that the use of lead-free ammunition is possible in hunting practice. The process of reducing lead intoxications in wildlife by changing to lead-free ammunition among hunters greatly depends on the involvement of all relevant stakeholders and a broad information campaign which we tried to realize by producing a leaflet, an internet page (www.seeadlerforschung.de), and organizing several workshops. Thus far, lead-free bullets are used for hunting by two large associations, eight forestry districts in four federal states, and in one National Park in Germany. We believe our interdisciplinary approach and the early involvement of stakeholders are the keys to the success of this project and a model for problem solving in the field of biodiversity conflicts. *Received 17 June 2008, accepted 8 September 2008.*

KRONE, O., N. KENNTNER, A. TRINOGGA, M. NADJAFZADEH, F. SCHOLZ, J. SULAWA, K. TOTSCHEK, P. SCHUCK-WERSIG, AND R. ZIESCHANK. 2009. Lead poisoning in White-tailed Sea Eagles: Causes and approaches to solutions in Germany. *In* R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt (Eds.). Ingestion of Lead from Spent Ammunition: Implications for Wildlife and Humans. The Peregrine Fund, Boise, Idaho, USA. DOI 10.4080/ilsa.2009.0207

Key words: Birds of prey, conservation, game animals, heavy metal, stakeholders.

THE WHITE-TAILED SEA EAGLE (*Haliaeetus albicilla*) is the largest European eagle; females have a wingspan up to 2.60 m and a weight of more than seven kg. The population in Germany is increasing, with ~575 breeding pairs in 2007. However, Germany holds a special responsibility for the resettlement of continental Western Europe, because the western distribution ends in northeastern Germany. A slow but steady expansion of the sea eagle´s range in northern, western, and southern directions can be recognized in the last 20 years (Hauff 1998). The long-lived White-tailed Sea Eagle (WTSE) suits superbly as a bioindicator of the accumulation of environmental pollutants in fresh-water and terrestrial ecosystems which may accumulate within the food chain of this top predator. Its habitat is characterised by fresh-water lakes, large rivers, and shore lines where it uses undisturbed nesting places and trees for perching in search of prey. Susceptibility to disturbance is a result of decades of persecution by man before the species became fully protected in the 1930s; the eagle still reacts very sensitively to new or unknown disturbances, especially during nest construction and breeding. Intensive protection measures and the ban of persistent pesticides (e.g., DDT) resulted in a population increase in Germany since the 1980s. Diet depends on the availability of prey in specific habitats and varies strongly during the seasons. Fish comprise the majority of prey during spring and summer, followed by waterfowl in fall and winter, then mammals, often acquired as carcasses or gut piles, in winter (Oehme 1975, Struwe-Juhl 1998).

Studying the health status, including diseases, accumulation of pollutants, and causes of death of top predators such as the WTSE is valuable to gain information on the environmental health. The WTSE as a bioindicator is more sensitive and responds earlier to changes in ecosystem health than humans do. As a scavenger the WTSE is especially susceptible to poisoning.

Since 1996 WTSEs were routinely examined for their diseases and causes of death at the Leibniz Institute for Zoo and Wildlife Research, Berlin (IZW). At the International White-tailed Sea Eagle Conference in Björko, Sweden in 2000 the relevance of lead poisoning as an important mortality factor for WTSEs in Germany was demonstrated for the first time to an international audience of experts (Krone et al. 2003). Organ samples of eagles examined at the IZW were analysed toxicologically at the Research Institute of Wildlife Ecology in Vienna and revealed lethal concentrations of lead in liver and kidneys (Kenntner et al. 2001). The sources of lead intoxications were fragments of rifle bullets and, more rarely, lead shot ingested together with food, e.g. carcasses of game animals, gut piles, and shot waterfowl.

The results were presented at the first national workshop "Lead containing hunting bullets: Cause of death in White-tailed Sea Eagles?" in April 2005 to all relevant stakeholders such as representatives of hunting organizations, ammunition industry, ammunition suppliers, foresters, and nature conservationists in Berlin (Krone and Hofer 2005). Stakeholders at the workshop could hardly believe the results, and so all participants developed a full catalogue of open questions to be answered in a large scale investigation on the causes and potential solutions of lead poisoning in White-tailed Sea Eagles in Germany. The questions included the following:

1. What are the sources of lead intoxications in the WTSE?
2. Is there any explanation why only small bullet fragments were found in the gizzards of the WTSEs? Do the eagles avoid the ingestion of large metallic particles?
3. Do the sources of lead intoxication to adult, territorial eagles occur within specific areas?
4. Are there any options to reduce the risk of lead exposure?
5. Do lead-free bullets perform as efficiently as lead-containing bullets? How toxic are the alternative metals?

A new project containing social and natural science elements was created to answer these questions, and funded by the Federal Ministry of Education and Research. The natural science part of the project mainly covered the questions mentioned above, whereas the social component was concerned with analysing the knowledge of hunters regarding the lead problem, performing a discourse and conflict analysis, and acting as mediator in the stakeholder discussions. Natural science is important to the description and analysis of the problem of lead poisoning in birds of prey and for the evaluation of lead-free ammunition. Social science targets communication of scientific results as fundamental to societal opinion-making. Our work is focused on different groups of stakeholders, especially hunters, by analysing how they deal with the problem, which kinds of barriers and channels exist, and when changes in behavior are suggested. Our approach in social science therefore encompasses both analytical and dialogue-oriented aspects. Together with results from the ongoing research in the involved disciplines of natural sciences, the joint project is engaged in informing and communicating with stakeholders and with the public.

METHODS

Sources of Lead Intoxication.—To investigate the sources of lead intoxications in the WTSE we examined game animals including geese and game ungulates. Arctic geese such as White-fronted Geese (*Anser albifrons*) and Bean Geese (*Anser fabalis*) were caught in northern Germany during the fall migration with cannon nets or by traditional methods from the Netherlands, as well as flightless Greylag Geese (*Anser anser*) of the German population during their moult in June. Each goose was weighed, ringed, marked with collars and finally x-rayed before release back to the wild.

Game ungulates such as Roe Deer (*Capreolus capreolus*), Wild Boar (*Sus scrofa*), Fallow Deer (*Cervus dama*), Red Deer (*Cervus elaphus*), and Chamois (*Rupicapra rupicapra*) were x-rayed within 90 minutes after they were shot. The game animals were hunted in Bavaria, Berlin, Brandenburg, Mecklenburg-Western Pomerania, and Schleswig-Holstein.

We used two mobile x-ray units (Vet Ray Gamma 2000, Acona and Gamma Titan, Poscom) and imaging plates for computed radiography (Fuji CR ST-VI). The plates were scanned with a VetRay® CR35V scanner (VetRay GmbH) and subsequently processed using a laptop and the software VetRay® Vision 4.4 (VetRay GmbH). Radiographs were taken in laterolateral and ventrodorsal directions. In the game ungulates, entrance and exit wounds were marked with the help of standard medical cannulae. Hunters filled in a standardized shooting report for each animal. All radiographs were examined for wounding patterns and for the number, size, and distribution of metallic particles.

Feeding Behavior.—To understand why only small fragments were found in the gizzards of dissected WTSEs, we conducted feeding experiments on free-ranging sea eagles in Mecklenburg-Western Pomerania. Carcasses of game animals or gut piles were prepared with chamfered metallic nuts of different sizes and offered as food. The nuts were of iron (Fe), constituting no toxicological exposure for the eagles when given in controlled dosage (Fiedler and Rösler 1993, Kelly et al. 1998, Mitchell et al. 2001, Brewer et al. 2003). The feeding behavior of the experimental animals was observed by video surveillance (Scheibe et al. 2008). Baits were x-rayed after sea eagles fed on them, and we recorded the number of nuts ingested. We further examined the experimental site with a metal detector to locate remaining nuts.

Territoriality of White-tailed Sea Eagles.—To answer the question if it is possible to attribute lead intoxication in adult, territorial eagles to a specific area, we equipped adult WTSEs with satellite-reporting transmitters. Our main study area lay in northern Germany within the Lake District of the federal state of Mecklenburg-Western Pomerania. We trapped adult sea eagles with bow nets and fitted them with backpack GPS/VHF transmitters (Vectronic Aerospace, Berlin). All transmitters were programmed to receive one GPS location per day in a chronologically circulating schedule with a delay of one hour per day to insure independence of data. Data from eight tagged animals were available (five females, three males). All GPS locations were imported into a Geographical Information System (GIS, ArcView 3.3 and ArcGIS 9) using vegetation maps and high resolution digital orthophotos as base layers for habitat analysis. Resource selection patterns were analysed using methods such as the Euclidean distance approach (Conner and Plowman 2001), selection indices (Manly et al. 2002), and compositional analysis (Aebischer et al. 1993).

Reducing the Risk of Lead Exposure.—Possibilities of reducing the risk of lead exposure caused by hunting ammunition were discussed at three expert talks/workshops with the involved stakeholders. Representatives from hunting organizations, ammunition industry, ammunition suppliers, foresters, and nature conservationists participated in our workshops.

Lead-free Hunting Ammunition.—To examine if lead-free bullets performed as well as lead-containing bullets with respect to hunting/killing efficiency, x-ray images of hunted game ungulates (see above) were analysed for differences. The absorption rate of lead and metals alternatively used in lead-free bullets was tested in an avian model. We purchased zinc shot (Jagd- und Sportmunitions GmbH/Germany) and lead shot (Rottweil Tiger/Germany) in the sizes which were the recommended size to test non-toxic shot by Environment Canada (1993), similar to the US #4 shot size (~3.3 mm). Spherical copper and brass according to the U.S #4 shot size were obtained from German companies. Details of the shot sizes and weights are given in Table 1.

Six groups consisted of 40 domestic Pekin Ducks (*Anas platyrhynchos*), each held in mesh cages with ground litter, with four ducks within each cage. Six shotgun pellets were placed in the gizzard of each duck of the experimental groups by oral intubation. Application success and retention of pellets were controlled by x-raying each bird on the day after intubation, after the first week, and one day before slaughtering. During routine necropsy, the body condition and sex of each duck were also determined. Organ samples for histopathological examinations were immediately fixed in buffered formalin, whereas those for toxicological analysis were kept at -20°C prior to microwave-assisted acid digestion. We utilized graphite furnace Atomic Absorption Spectroscopy (AAS) methods for lead measurements, and flame AAS methods for analysis of copper and zinc (Analytik Jena ZEEnit 700). Gizzards and intestines of all birds were washed and sieved to screen for retained shot pellets. Retained pellets were measured and weighed.

Table 1. Sizes and weights of each test shotgun pellet (n=20 per shot) used for avian toxicity test.

Group	**1**	**2**	**3**	**4**	**5**
Metal	Control	Copper	Brass	Zinc	Lead
No. pellets	0	6	6	6	6
Size±SD [mm]	-	3.15±0.05	3.0±0.00	3.05±0.14	3.2±0.05
Weight±SD [mg]	-	148±0.33	120±3.2	105±12.3	191±7.1

Social Science Component.—We distinguished between two operating levels and participated accordingly in two different kinds of data collections. Levels included a macroscopic level and a microscopic level. With the former, i.e. political institutions, structures, and policy-making organizations, we implemented methods based on secondary and historical data. On the microscopic level, i.e. interactions and beliefs of individuals, we applied methods based on primary and situation-dependent data. Applied methods were conflict analysis (macroscopic level) and discourse analysis (microscopic level) and referred to all of the stakeholders involved, including hunting organizations, the ammunition industry, ammunition suppliers, forest owners, and nature conservationists, in addition to considering the affected federal agencies in Germany. Our analysis of level of information, problem acceptance, and handling of information pertained to hunters. This analysis mainly derived from a survey on knowledge of lead intoxication in raptors and acceptance of lead-free ammunition. However, we also investigated how average hunters get their information, e.g., from field experience, the internet, or other sources. We distributed the questionnaire by direct mail, by inserts in hunter's magazines, and through hand-outs. To date, more than 70,000 copies have been distributed.

RESULTS

Sources of Lead Intoxication.—Thus far, 154 geese, including 84 White-fronted Geese, 53 Bean Geese, and 17 Greylag Geese have been tested in Germany. Among the total, 21.4% had embedded shot, varying from one to seven shotgun pellets in their body tissue (Table 2). We could not differentiate between lead shot and non-lead shot in the radiographs.

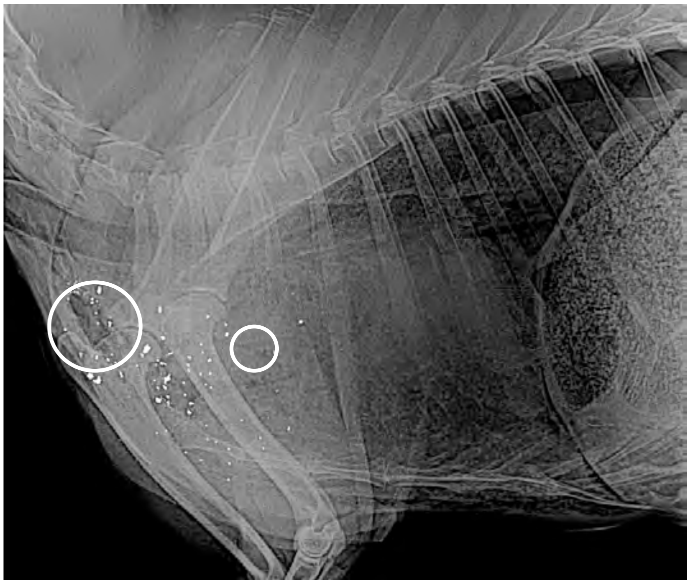
Table 2. Frequency of geese with embedded shot pellets in Germany.

Species	n	shot [n]	shot [%]
Greylag Goose	17	2	12
White-fronted Goose	84	15	18
Bean Goose	53	16	30

Furthermore, we analysed radiographs of 315 game animals (110 Roe Deer, 97 Wild Boars, 103 Fallow Deer, three Red Deer, and two Chamois) shot with lead-containing bullets. Radiographs of animals shot with these semi-jacketed bullets typically revealed a large number of metallic particles located throughout the entire wound channel and its surroundings (Figure 1 and 2). Fragment size ranged from less than 1 mm to almost 10 mm, with many particles being very small. Hits of large bones were not required for the fragmentation. Table 3 gives the mean, minimum, and maximum number of fragments for some common lead-core rifle bullets.

Table 3. Number of metallic particles counted in radiographs of animals shot with lead-core bullets.

Bullet	n	Mean	Median	SD	Minimum	Maximum
Semi-jacketed	26	89	70	58	30	250
Semi-jacketed round nose	15	120	100	83	45	300
Brenneke TUG	6	230	200	157	50	480
Norma Vulkan	13	120	100	45	75	210
RWS Kegelspitz	8	104	100	55	25	200
RWS Evolution	9	279	250	130	120	500



Figures 1 and 2. Ventrodorsal and laterolateral radiographs of a Roe Deer shot with a semi-jacketed bullet. Arrows in Figure 1 mark entrance and exit sites, small circle in Figure 2 indicates the entrance wound, and the larger circle indicates the exit wound.

Gut piles of animals shot with conventional bullets were interspersed with metallic particles in 100% of the cases examined (n=14). The number of fragments varied from two to 600 depending on where the animal had been hit.

None of our findings indicate a lower effectiveness of lead-free bullets. We found no difference between the frequency of retained bullets of lead-free and conventional bullets (Fisher's Exact Test, df=1, $P_{two\ sided}$=1,000, $P_{one\ sided}$=0.456).

Feeding Behavior.—Our preliminary results show that most iron nuts we inserted in carcasses or gut piles were avoided by sea eagles during feeding. In the following we present the frequency of nut avoidance during feeding by one territorial sea eagle pair as well as by roaming juveniles. In the course of three feeding experiments, the sea eagles avoided 71% of the inserted nuts (n = 28 inserted nuts). The proportions of avoided nuts of different diameters by the sea eagles varied distinctively (Figure 3). Nuts with diameters of 8.8 and 7.7 mm were completely avoided. The avoidance of smaller nuts decreased with nut size.

Territoriality of White-tailed Sea Eagles.—Here we present the data of only one adult female WTSE. The female "472" used an area of 8.2 km^2 with respect to the 95% Minimum Convex Polygon, and one of 4.5 km^2, as measured by 95% Fixed Kernel. Her activities were concentrated within a core area of 0.5 km^2 (Figure 4). Mean distances of all GPS locations (n = 476) to the habitat types "lake" and "riparian vegetation" were 416 and 359 m, compared to expected distances of 1644 and 1303 m calculated from a random point data set (Figure 5). This eagle died in January 2004 due to lead intoxication (Krone et al. 2009).

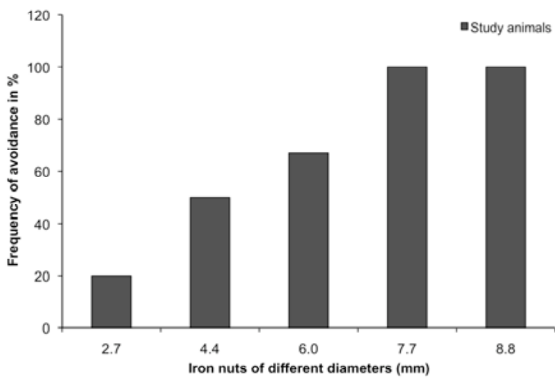


Figure 3. Proportions of avoided steel nuts of different diameters.

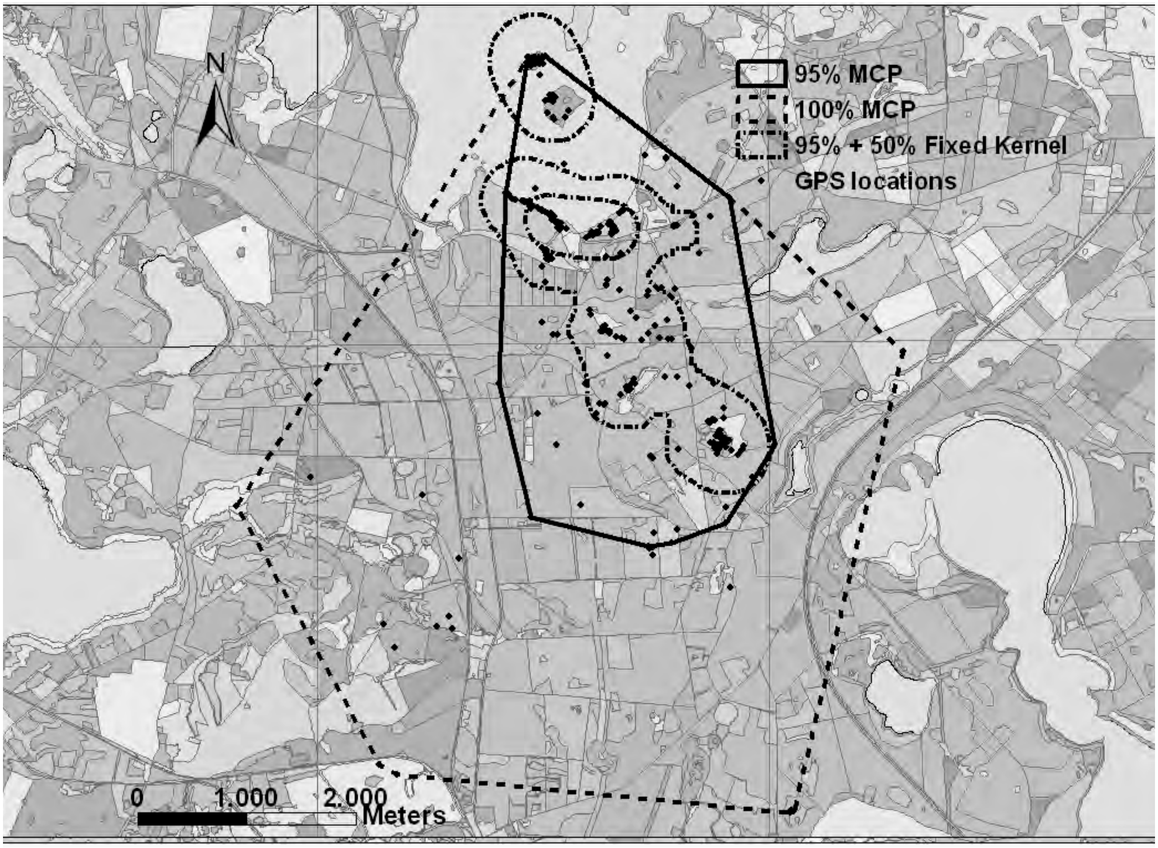


Figure 4. Home range of sea eagle “472”, MCP = Minimum Convex Polygon.

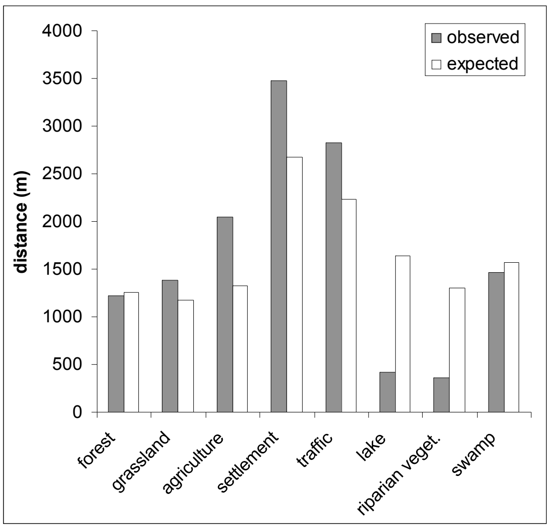
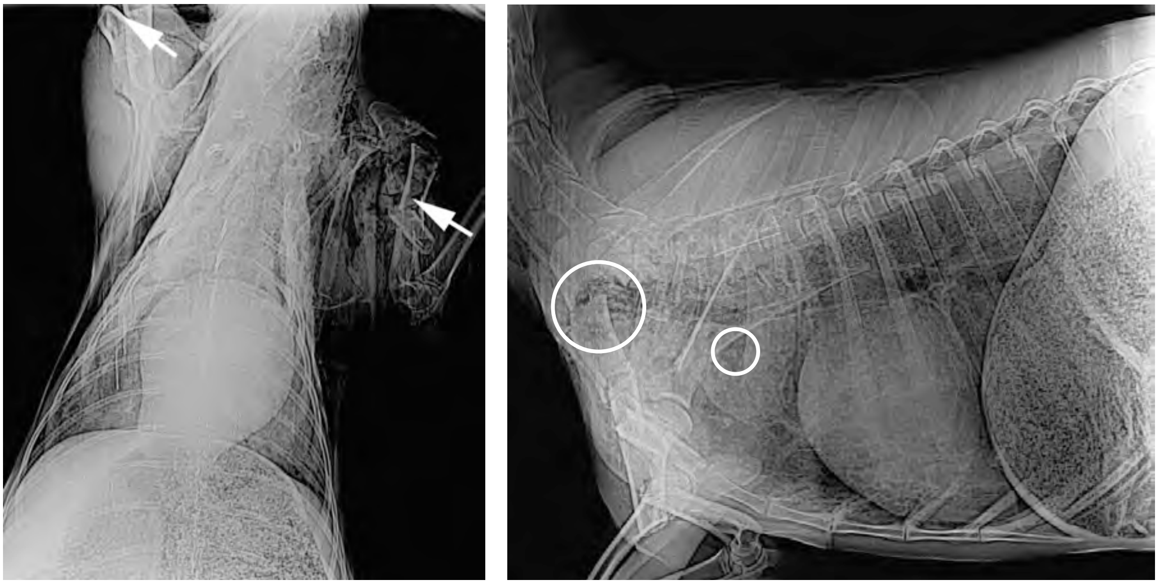


Figure 5. Mean distances to habitat types of sea eagle “472.”

Reducing the Risk of Lead Exposure.—At the first workshop in April 2005, findings on the causes of mortality of WTSEs were presented and the importance of lead intoxication caused by remains of hunting ammunition was emphasized. The sources were described as bullet remains in carcasses of game animals or gut piles, and for lead shotgun pellets as embedded in small game animals such as waterfowl. Our results stimulated a heavy discussion among the stakeholders. Possibilities of reducing the risk of lead exposure caused by hunting ammunition were discussed with all involved stakeholders. Burying gut piles was advanced as a potential intermediate solution to the problem, but switching to lead-free ammunition was considered as a solution only if killing efficiency and low toxicological risk of alternative ammunition could be demonstrated.



Figures 6 and 7. Ventrodorsal and laterolateral radiographs of a Roe Deer shot with an expanding copper bullet (markings as in Figures 1 and 2).

Table 4. Number of metallic particles counted in radiographs of game animals shot with lead-free bullets.

Bullet	n	Mean	Median	SD	Minimum	Maximum
Lapua Naturalis	85	0	0	0	0	0
Barnes XLC	40	0	0	0	0	0
RWS Bionic Yellow	6	23	23	12	8	40
Reichenberg HDBoH	21	6	1	22	0	100
Möller KJG	10	12	10	7	0	25

At the second workshop in March 2007, we presented a leaflet and the project homepage as information material to the stakeholders. In addition, we argued against the potential solution of burying gut piles on the basis that this method can not be realized in frozen ground in winter, the main hunting time, and because of its general impracticality. In several cases, when gut piles were buried, Wild Boar detected and unearthed them, with the result that they were again available to eagles. A major step forward was achieved during the discussion with all involved stakeholders, resulting in two milestones: first the general agreement that lead intoxication in WTSEs was caused by the ingestion of lead-containing bullet fragments, and second that action was necessary to reduce lead poisoning in WTSEs. Results of the third workshop in May 2008 are not available yet; however, the overall idea was a phase-out of lead-containing ammunition as soon as comparable lead-free ammunition became available.

Lead-free Hunting Ammunition.—Expanding copper bullets that are meant to enlarge their cross-sectional area without losing mass did not leave fragments in the wound channel even if major bones were hit (Figure 6 and 7). Other unleaded bullets which are constructed for partial fragmentation left behind some relatively large particles; the numbers we observed in our tests are given in Table 4. In three of 311 (0.97%) cases, lead-free bullets were retained in the animal, whereas one of 123 (0.81%) lead-core bullets did not produce an exit wound.

Toxicity of Alternative Lead-free Ammunition.— The preliminary results represented here show the toxicological findings of 10 ducks of each group for the element levels of lead, copper, and zinc in liver, kidney, and brain tissue. All levels of elements are given in µg/g on a wet weight (ww) basis. None of the birds died during the experimental period, and no consistent or group-specific organ alterations were detected. Weight losses were highest in the zinc and lead shot groups, whereas copper and brass did not show relevant losses after four weeks of retention in duck gizzards (Figure 8). All lead levels in organs (liver, kidney, brain) of the lead group differed significantly from the lead levels of all the other groups, but there were no such differences between the elements copper and zinc and the other groups (Figure 9-11).

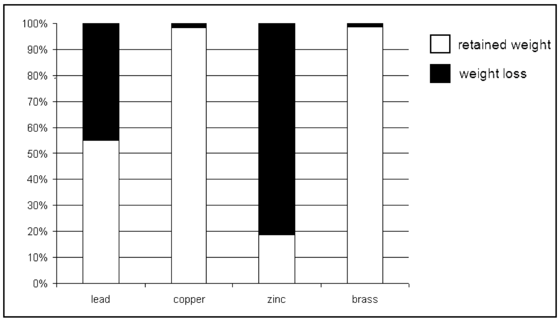


Figure 8. Percentage of weight losses of shot (lead, copper, zinc, brass) during a four-week retention period in the gizzards of Pekin Ducks.

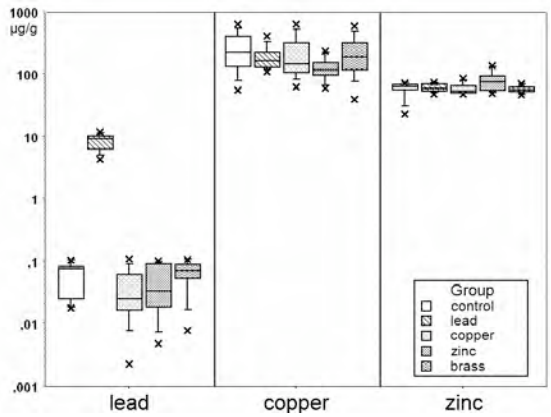


Figure 9. Levels of lead, copper and zinc in liver of Pekin Ducks fed with six shotgun pellets of either lead, copper, zinc or brass and the control group. Each group consists of 10 ducks.

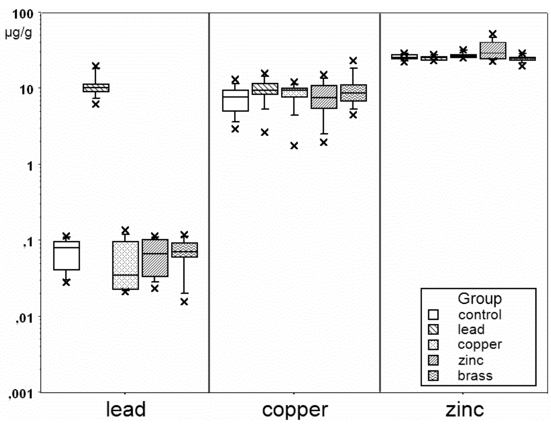


Figure 10. Levels of lead, copper and zinc in kidneys of Pekin Ducks fed with six shotgun pellets either of lead, copper, zinc or brass and the control group. Each group consists of 10 ducks.

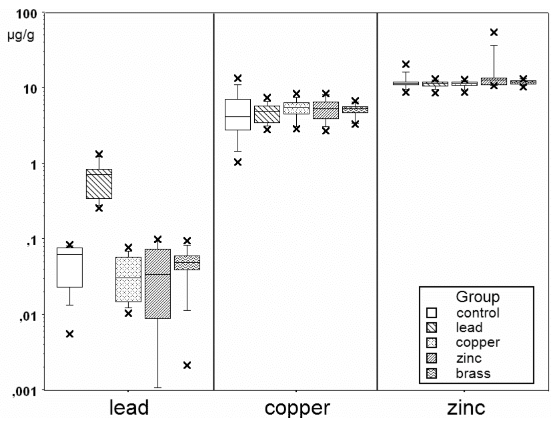


Figure 11. Levels of lead, copper and zinc in brain tissue of Pekin Ducks fed with six shotgun pellets either of lead, copper, zinc or brass and the control group. Each group consists of 10 ducks.

Social Science Component.—We have had three expert talks/workshops (see above) so far. At the first of these, the stakeholders were informed about the problem of lead intoxication in birds of prey. The discourse analysis of the second expert talk showed an agreement among all about the causes of lead intoxication of raptors and about need for action. None of the stakeholders expressed doubt about the lethal effect on sea eagles of feeding on shot game or gut piles containing particles of lead ammunition. Hunting organizations and ammunition industry/suppliers have clearly moved from their former positions.

The discourse analysis of the third expert talk is still ongoing. However, we can now state that the second part of the dialogue reconfirmed the agreement concerning need for action, although all participants do not share the same expectations about when actions can be taken. The questionnaire survey in different parts of Germany is expected to be completed in July 2008; first results will be available in October 2008 or soon thereafter.

DISCUSSION

Sources of Lead Intoxication.—In comparison with the high incidence of 30% and 18% of shot Bean Geese and White-fronted Geese, respectively, we found only 12% among Greylag Geese. However, the sample size of Greylag Geese is still small, but should soon be increased. Averbeck et al. (1990) radiographed 467 birds of 51 species found dead or moribund in northern Germany between 1985 and 1988. In total 15.8% of all birds had been shot, of which 80% had lead shot in their body tissue, and 11 birds were shot with air guns. Out of 355 Pink-footed Geese x-rayed from 1990 to 1992, one quarter (25%) of the first-year ducks and 36% of the adult ducks had embedded shot pellets (Noer and Madsen 1996). Both studies showed similar incidences of birds with embedded shot as our preliminary results.

Particle clouds, also called "lead snowstorms," a common term in forensic literature (Messmer 1998), are caused by semi-jacketed bullets (Hunt et al. 2006). Game animals harvested with conventional lead-core bullets obviously are widely contaminated with bullet material even if the bullet does not hit any bones. The fragments are found in all organs. The small fragment size and the wide area contaminated with particles make it impossible to remove all fragments by cutting off obviously crushed tissues. Complete game animal carcasses as well as gut piles containing lead fragments of semi-jacketed bullets pose a severe threat to scavenging animals and humans consuming game meat.

Feeding Behavior.—Our preliminary results suggest that sea eagles are able to feed selectively and may avoid the ingestion of large metal particles but not small ones. These findings suggest that the use of lead-free rifle bullets that deform or fragment in large pieces may present low risk for metal ingestion by sea eagles (see below). Detailed results and analyses of the selective feeding behavior by sea eagles, including data involving more experimental animals will be published soon.

Territoriality of White-tailed Sea Eagles.—The home range of sea eagle "472" was rather small, and the animal did not undertake excursions regularly (Figure 1). This first adult white-tailed sea eagle equipped with a GPS-datalogger died after 173 days due to an oral lead intoxication caused by the ingestion of fragments of a rifle bullet (Krone et al. 2009).

Lead-free Hunting Ammunition.—Expanding bullets made of copper or its alloys present a possibility of harvesting game that is not contaminated with bullet remains. In case of nose-fragmenting copper or brass bullets, the sizes of remaining fragments are larger than those of conventional bullets, so less metal surface is available for resorption by avian scavengers, and due to the larger size those particles may be avoided during ingestion.

Toxicity of Alternative Lead-free Ammunition.—Our preliminary results indicate highest bioavailability and significant organ accumulation for lead in liver, kidney, and brain tissue of ducks. Highest solubility in duck gizzards was measured for zinc, but organ levels of ducks from the zinc group were comparable with all other groups and within the physiological range of <100 µg/g in liver as summarized by Eisler (1988), and below the toxic levels of about 400 µg/g, 300 µg/g, and 2000 µg/g for liver, kidney, and pancreas, respectively, as reported by Levengood et al. (1999). Copper and brass as metals for lead-free bullets are recommended, because of their very low solubility in duck gizzards, and their non-significant accumulation effects in the investigated organs. There was no significant dissolution or organ accumulation of zinc from brass. However, considering different digestion physiology and the relatively low pH values in gizzards of raptors (Duke et al. 1975), experimental studies on the toxicity of copper and brass in raptors should certify our preliminary results.

Reducing the Risk of Lead Exposure.—Two main possibilities were discussed and tested in the field to reduce the risk of lead intoxication in WTSEs: burying gut piles and switching to lead-free ammunition. Burying gut piles was identified as being an impractical method, whereas the large scale use of lead-free ammunition has the potential to eliminate the lead in the prey and carrion that WTSE and other raptors are feeding on.

At the beginning of our project, several open questions regarding the pathways and consequences of lead poisoning in WTSEs were addressed. We also tested the wound ballistics of lead-free ammunition in game animals. Our preliminary results demonstrated the potential sources of lead as shotgun pellets in geese and lead particle clouds in gut piles and game animals shot with lead-containing bullets. Territorial WTSEs very likely acquire lethal lead concentrations when feeding on carrion or gut piles, or preying on shot waterfowl with embedded lead shot pellets, within their year-round home range. The experiments performed on WTSEs revealed a selective feeding behavior of avoiding large metallic fragments during ingestion of meat, which may be of relevance for future bullet design. Feeding experiments on ducks testing for the bioavailability of alternative metals for lead-free bullets showed that copper and brass were suitable materials for bullets because of their low toxicity in birds.

Our results, together with the field tests performed by hunters using lead-free ammunition, show that the use of lead-free ammunition is acceptable in hunting practice. When using nose-deforming lead-free bullets for hunting, no bullet fragments were found in x-rayed game animals, resulting in uncontaminated food for humans and wildlife.

So far, lead-free bullets are used for hunting in the Nature and Biodiversity Conservation Union (NABU), the Ecological Hunting Association, and eight forestry districts in four federal states and in the Mueritz National Park in Germany. In addition, hunting with lead-containing rifle bullets is forbidden in all state forest districts in the Federal country of Brandenburg by ministry decree.

The process of reducing lead intoxications in wildlife by changing to lead-free ammunition among hunters greatly depends on the involvement of all relevant stakeholders and a broad information campaign which we initiated by producing a leaflet, an internet page (www.seeadlerforschung.de), and several workshops.

Social Science Component.—The realization and documentation of the dialogues between the stakeholders played an important role within the social science part of the project. The dialogues are supposed to intensify the exchange of opinions among different protagonists concerning risks of lead ammunition and to identify options for behavioral change. Scientific results are to be communicated and interfaced with the knowledge and experience of relevant social and economic groups and responsible governmental participants in order to recognize problems and their solutions.

We were unable, in the second expert talk, to remove two conflicts. The first pertains to the demands and standards of alternative ammunition; hunters find them much too expensive in comparison with conventional lead-ammunition. Second, there is the conflict of legal regulation. Does a ban on lead ammunition make sense? Is it the best way for implementation and acceptance in the hunting community? Three alternative actions, each involving uncertainty, became evident during the course of the second expert talk: (1) voluntary application of lead-free ammunition with the option of reversal, (2) legal regulation on the basis of present scientific information, and (3) waiting for definitive results from ongoing monitoring processes.

To summarize, the joint research and communication project is characterised by four central issues:

1. Science as an actor: Research remains not in the background, looking for 'objective' results from the policy field. On the contrary, the members of the project are doing 'action research' and in this understanding they are agents of knowledge transfer.
2. This includes the exchange of information among hunters and other stakeholders about trends in ammunition development, information from state organizations about consumer risks of contaminated game, and dissemination of trends about governance in other countries.
3. Through dialogue-oriented research, the results of the questionnaire will be published in hunter magazines and publications of pressure groups.
4. Stakeholder-dialogues are proven instruments of transdisciplinary discussion of knowledge from natural sciences, social sciences, and know-how of different stakeholder communities.

The next steps of the research programme will deal with in-depth interviews of central stakeholders on topics like basic conflict attitudes or opinions, and possibilities for a self-reinforcing agreement between different organizations. One example could be the creation of a future market for lead-free ammunition together by producers and users of alternative ammunition.

ACKNOWLEDGMENTS

We are grateful to the Federal Ministry of Education and Research (BMBF) for funding and to the Project Management Juelich (PTJ) for administration of this project. We would like to thank T. Scherer, M. Duhr and A. Schulze, all staff members and former staff members of the Ministry of Rural Development, Environment and Consumer Protection of the Federal State of Brandenburg, Forest management and company head-office, who organized the monitoring of lead-free ammunition in hunting practice in the federal state of Brandenburg. We are much obliged to the staff and administration of the nature park "Nossentiner/ Schwinzer Heide" in Mecklenburg-Western Pomerania for their help conducting all the field work on White-tailed Sea Eagles, to the Ministry of Agriculture, Environment and Consumer Protection, and to the State Authority for Environment, Nature Conservation, and Geology, both in Mecklenburg-Western Pomerania, for their support and the permissions necessary for the project. Additionally we would like to thank the Reepsholt Foundation for general support and P. Hauff, Dr. W. Mewes, Dr. W. Neubauer, and C. Scharnweber for sharing their knowledge on White-tailed Sea Eagles.

LITERATURE CITED

AEBISCHER, N. J., P. A. ROBERTSON, AND R. E. KENWARD. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313-1325.

AVERBECK, C., E. KEMPKEN, S. PETERMANN, J. PRÜTER, G. VAUK, AND C. VISSE. 1990. Röntgenuntersuchungen zur Bleischrotbelastung tot aufgefundener Vögel in Norddeutschland. Zeitschrift für Jagdwissenschaften 36:30-42.

BREWER, L., A. FAIRBROTHER, J. CLARK, AND D. AMICK. 2003. Acute toxicity of lead, steel, and an iron-tungsten-nickel shot to Mallard Ducks (*Anas platyrhynchos*). Journal of Wildlife Diseases 39:638-648.

CONNER, L. M., AND B. W. PLOWMAN. 2001. Using Euclidean distances to assess nonrandom habitat use. Pages 275-290 *in* J. J. Millspaugh, and J. M. Marzluff (Eds.). Radio Tracking and Animal Populations. Academic Press, San Diego, California, USA.

DUKE, G. E., A. A. JEGERS, G. LOFF, AND O. A. EVANSON. 1975. Gastric digestion in some raptors. Comparative Biochemistry and Physiology 50A:649 -656.

ENVIRONMENT CANADA. 1993. Toxicity test guidelines for non-toxic shot for hunting migratory birds. Ottawa, Ontario, Canada.

EISLER, R. 1988. Copper hazards to fish, wildlife, and invertebrates: a synoptic review. US Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-1997-0002, Contaminant Hazard Reviews Report 26, Laurel, Maryland, USA.

FIEDLER, H. J., AND H. J. RÖSLER. 1993. Spurenelemente in der Umwelt. Gustav Fischer Verlag, Jena, Germany.

GANUSEVICH, S. 1996. The White-tailed Sea Eagle *Haliaeetus albicilla* in Kola Peninsula. Populationsökologie Greifvogel und Eulenarten 4:101-110.

HAUFF, P. 1998. Bestandentwicklung des Seeadlers *Haliaeetus albicilla* seit 1980 mit einem Rückblick auf die vergangenen 100 Jahre. Vogelwelt 119: 47-63.

HUNT, W. G., W. BURNHAM, C. N. PARISH, K. BURNHAM, B. MUTCH, AND J. L OAKS. 2006. Bullet fragments in deer remains: implications for lead exposure in scavengers. Wildlife Society Bulletin 34:168-171.

KELLY, M. E., S. D. FITZGERALD, R. J. AULERICH, R. J. BALANDER, D. C. POWELL, R. L. TICKLE, W. STEVENS, C. CRAY, R. J. TEMPELMAN, AND S. J. BURSIAN. 1998. Acute effects of lead, steel, tungsten-iron, and tungsten polymer shot administered to game-farm Mallards. Journal of Wildlife Diseases 34:673-687.

KENNTNER, N., F. TATARUCH, AND O. KRONE. 2001. Heavy metals in soft tissue of White-tailed Eagles found dead or moribund in Germany and Austria from 1993 to 2000. Environmental Toxicology and Chemistry 20:1831-1837.

KRONE, O., T. LANGGEMACH, P. SÖMMER, AND N. KENNTNER. 2003. Causes of mortality in White-tailed Sea Eagles from Germany. Pages 211-218 *in* B. Helander, M. Marquiss, W. Bowerman (Eds.). Sea Eagle 2000. Proceedings of the Swedish Society for Nature Conservation/SNF, Stockholm, Sweden.

KRONE, O., F. WILLE, N. KENNTNER, D. BOERTMANN, AND F. TATARUCH. 2004. Mortality factors, environmental contaminants, and parasites of White-tailed Sea Eagles from Greenland. Avian Diseases 48:417-424.

KRONE, O., AND H. HOFER (EDS.). 2005. Bleihaltige Geschosse in der Jagd – Todesursache von Seeadlern? Leibniz Institute for Zoo and Wildlife Research, Berlin, Germany.

KRONE, O., T. STJERNBERG, N. KENNTNER, F. TATARUCH, J. KOIVUSAARI, AND I. NUUJA. 2006.Mortality factors, helminth burden, and contaminant residues in White-tailed Sea Eagles (*Haliaeetus albicilla*) from Finland. Ambio 35:98-104.

KRONE, O., A. BERGER, AND R. SCHULTE. 2009. Recording movement and activity pattern of a White-tailed Sea Eagle (*Haliaeetus albicilla*) by a GPS datalogger. Journal of Ornithology 150:273-280, DOI 10.1007/s10336-008-0347-1

MANLY, B. F. J., L. MCDONALD, D. L. THOMAS, T. MCDONALD, AND W. P. ERICKSON. 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies, 2nd ed. Kluwer Academic Publishers, Dordrecht, Germany.

MESSMER, J. M. 1998. Radiology of gunshot wounds. Pages 209-248 *in* B.G. Brogdon, (Ed.). Forensic Radiology. CRC Press, Boca Raton, Florida, USA.

MITCHELL, R. R., S. D. FITZGERALD, R. J. AULERICH, R. J. BALANDER, D. C. POWELL, R. J. TEMPELMAN, R. L. STICKLE, W. STEVENS, AND S. J. BURSIAN. 2001. Health effects following chronic dosing with tungsten-iron and tungsten-polymer shot in adult game-farm Mallards. Journal of Wildlife Diseases 37:451-458.

NOER, H., AND J. MADSEN, J. 1996. Shotgun pellet loads and infliction rates in Pink-footed Geese *Anser brachyrhynchus*. Wildlife Biology 2:65-73.

OEHME, G. 1975. Zur Ernährungsbiologie des Seeadlers (*Haliaeetus albicilla*), unter besonderer Berücksichtigung der Populationen in den drei Nordbezirken der Deutschen Demokratischen Republik. Universität Greifswald.

SCHEIBE, K. M., K. EICHHORN, M. WIESMAYR, B. SCHONERT, AND O. KRONE. 2008. Long-term automatic video recording as a tool for analysing the time patterns of utilisation of predefined locations by wild animals. European Journal of Wildlife Research 54:53–59.

STRUWE-JUHL, B. 1998. Zur Nahrungsökologie des Seeadlers in Schleswig-Hostein. Pages 51-60 *in* Projektgruppe Seeadlerschutz Dreißig Jahre Seeadlerschutz Schleswig-Holstein e.V. (Hrsg.). Ministerium für Umwelt, Natur und Forsten des Landes Schleswig-Holstein, WWF-Deutschland.

STRUWE-JUHL, B. 2000. Funkgestützte Synchronbeobachtung – eine geeignete Methode zur Bestimmung der Aktionsräume von Großvogelarten (Ciconiidae, *Haliaeetus*) in der Brutzeit. Populationsökologie Greifvogel- und Eulenarten 4:101-110.