LEAD POISONING IN WILD BIRDS IN EUROPE AND THE REGULATIONS ADOPTED BY DIFFERENT COUNTRIES

RAFAEL MATEO

Instituto de Investigación en Recursos Cinegéticos IREC (CSIC, UCLM, JCCM), Ronda de Toledo, s/n, E-13071 Ciudad Real, Spain. E-mail: rafael.mateo@uclm.es

ABSTRACT.—Lead poisoning in birds was described in Europe at the end of the 19th century, but the first epidemiological studies were not done until the second half of the 20th century. So far, most work has focused on waterfowl and birds of prey, with very few reports evaluating the impact on upland game birds.

The density of lead shot in sediments of wetlands has been studied in several countries, with maximal densities observed in southern Europe where up to 399 shot/m^2 in the upper 30 cm of sediment has been reported. Similarly, the highest prevalence of lead shot ingestion has been found in waterfowl wintering in the dry Mediterranean region, where birds concentrate in a limited number of wetlands which have also been intensively hunted for decades. If we consider the Mallard (*Anas platyrhynchos*) as a bioindicator species, the prevalence of lead shot ingestion varies from 2-10% in the wetlands of northern Europe, up to 25-45% in the Mediterranean deltas in southern Europe. The species with the highest prevalence of lead shot ingestion are the Northern Pintail (*Anas acuta*) and the Common Pochard (*Aythya ferina*) with values around 60-70%. Lead poisoning has been identified as an important cause of death for the endangered White-headed Duck (*Oxyura leucocephala*) and for swans (*Cygnus sp*.).

The accumulation of lead shot in upland ecosystems was recently studied in intensively hunted areas and estates used for driven shooting of Red-legged Partridge (*Alectoris rufa*) where densities of 7.4 shot/m^2 in soil prevailed. Prevalence of lead shot ingestion in Red-legged Partridge varies between 1.4% in Britain and 3.9% in Spain. Cases of lead poisoning have also been described in Grey Partridge (*Perdix perdix,* 1.4% of birds found dead), Common Pheasant (*Phasianus colchicus*), and Wood Pigeon (*Columba palumbus*).

Lead poisoning has been described in 17 species of birds of prey in Europe, some of which have been near-threatened (NT) such as the White-tailed Eagle (*Haliaeetus albicilla*), or endangered (EN), specifically, the Spanish Imperial Eagle (*Aquila adalberti*). Some studies have been conducted to evaluate the exposure in populations of raptors based on tissue analysis or the presence of lead shot in regurgitated pellets. Significant rates of lead shot ingestion have been observed in the Spanish Imperial Eagle (11% of pellets with lead shot). Further, 26-40% of Marsh Harriers (*Circus aeruginosus*) had blood lead >30 µg/dL, 91% of Griffon Vultures (*Gyps fulvus*) had blood lead >20 µg/dL, and 28% of White-tailed Eagles found dead or moribund had liver lead >5 µg/g (wet weight).

The ban on lead shot for hunting in wetlands, and/or for the hunting of waterbirds, was adopted by Denmark in 1985, and some years later by Norway, the Netherlands, Finland and Sweden. Other European countries agreed to implement bans on the use of lead for shooting over wetlands by the year 2000 following the African Eurasian Migratory Waterbird Agreement (AEWA). However, only Denmark, Norway, and the Netherlands have extended the ban to all hunted species. *Received 22 May 2008, accepted 6 September 2008.*

MATEO, R. 2009. Lead poisoning in wild birds in Europe and the regulations adopted by different countries. *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.2009.0107

Key words: Conservation, game, heavy metal, lead, raptor, partridge, waterfowl.

BIRDS CAN BE LETHALLY EXPOSED to different sources of lead, such as contaminated sediments from mining and smelting activities (Beyer et al. 2000), leaded paint (Sileo and Fefer 1987) or lead fishing weights (Birkhead 1983), but the most common source associated with clinical lead poisoning is by far the ingestion of lead ammunition, mainly shot pellets, used for hunting as reviewed by several authors (Thomas 1982, Sanderson and Bellrose 1986, Locke and Friend 1992, Pain 1992, Sanderson 1992, Guitart et al. 1999, Fisher et al. 2006). There are two causes of ingestion of lead shot pellets in birds. The species with a more developed muscular stomach (gizzard) like waterfowl or upland game birds (pheasants, partridges or pigeons) usually feed on plant matter or animals with hard shells that make necessary the regular ingestion of sand or gravel (gastroliths or grit) to break and grind the food (Gionfrido and Best 1999). Lead shot pellets accumulated in hunted environments are ingested by these species, confused as grit or possibly, as seeds (Trost 1981, Pain 1990, Moore et al. 1998, Mateo and Guitart 2000). The second cause of lead shot ingestion is found in birds of prey, especially obligatory and occasional scavengers that feed on carcasses with embedded lead ammunition in their flesh (Kenntner et al. 2001, Fisher et al. 2006). Although in many cases, the lead shot or bullet fragments are regurgitated with undigested material such as hair and feathers in the form of pellets, the absorption of lead during food digestion can be enough to kill the raptors.

Lead poisoning in birds by the ingestion of lead ammunition was described in Europe at the end of the 19th century in Common Pheasants (*Phasianus colchicus*) in the UK (Calvert 1876). The first reports of lead poisoning in European waterfowl were from the 1960-70s in France (Hoffmann 1960, Hovette 1971, 1972), the UK (Olney 1960, Beer and Stanley 1965), Italy (del Bono 1970) and the Scandinavian countries (Erne and Borg 1969, Danell and Anderson 1975, Holt et al. 1978). The first cases in birds of prey were reported in the 1980s in falconry and wild birds (MacDonald et al. 1983, Lumeij et al. 1985).

The present review compiles the available data about lead poisoning in Europe due to the ingestion of lead ammunition and the regulatory actions adopted by the different countries to reduce its incidence.

LEAD SHOT INGESTION IN WATERBIRDS

Types of Hunting Activities and Lead Shot Densities in Wetlands.—Waterfowl hunting is done in Europe by several techniques, depending on the species and the wetland. Eurasian Coots (*Fulica atra*) are hunted by pushing them with boats to force birds to fly over the circle of hunters located in boats or on the shore of a lagoon. Ducks are mainly hunted from blinds located on the border of lagoons, marshes, or in rice fields. Hunting is generally restricted to daylight in lagoons, but in some places, like the Ebro Delta (Spain), hunting in rice fields is allowed during several nights around the full moon. Hunters usually bait with grain around their blinds in rice fields to attract birds several days before hunting. Similarly, wildfowling in the UK is done on flight ponds to which waterfowl return for food at dawn and dusk from their daytime resting places on estuaries or large water bodies. These flight ponds are repeatedly baited to attract birds and therefore accumulate high lead shot concentrations (Thomas 1982). In the past, in areas like the Cerro de los Ánsares dune in Doñana (Spain), Greylag Geese (*Anser anser*) were shot when they concentrated there to ingest coarse sand as grit for the gizzard (Mateo et al. 2000a). Also in Doñana, one of the largest wetlands in Europe, flocks of ducks were followed through marshlands on horseback and hunted with guns capable of shooting heavy loads of pellets. The horse ("cabresto") served both as a hide and a support for

the gun (Chapman and Buck 1893). This type of hunting produced a more diffuse contamination of lead shot in the marshes than the techniques based on fixed blinds.

The density of lead shot in wetland sediments has been studied in several countries, with maximal densities observed in southern Europe where up to 399 shot/m^2 in the upper 30 cm of sediment has been reported in the Medina Lagoon in southern Spain (Mateo et al. 2007a). The lead shot densities in Europe have been >100 shot/m^2 in the upper 20 cm of wetland sediments from Denmark, France and Spain, and between 10 and 50 shot/m^2 in most of the wetlands from the UK (Table 1). The highest lead shot densities have been found around shooting ranges located in wetlands. Petersen and Meltofte (1979) found lead shot densities ranging from 44 to 2,045 shot/m^2 at four Danish shallow water localities with shooting ranges. Smit et al. (1988a) found 400 and 2,195 shot/m^2 at two clay pigeon grounds in the Netherlands. At Lough Neagh, Co. Antrim, in Ireland, 2,400 spent gunshot/m^2 in the upper 5 cm were found along 100 m of shore in front of a clay pigeon shooting site and on the lake bed up to 60 m from the shore (O'Halloran et al. 1988b). A similar scenario was found in the El Hondo Natural Park in Spain, where a shooting range was located in a temporary marshland, yielding a density of 1,432 gunshot/m^2 (Bonet et al. 2004). Although no data about lead shot densities exist for many European countries, the highest densities are clearly in the Mediterranean wetlands (Figure 1).

Table 1. Lead shot densities in European wetlands with waterfowl hunting.

Country	Area	Site	Depth (cm)	Year	shot/m^2
Ireland	Cork	Kilcolman W. R.	-	1985-86[a]	7
United Kingdom	Moray/Beauly F.	Longman Bay	15	1981-82[b]	nd
		Lentral Point			2.57
		Easter Lovat			nd
	Loch of Strathbeg	Starnakeppie			2.04
		Back Bar			10.29
		Savoch Burn mouth			7.18
		Savoch Farm			2.04
		Starnafin			3.11
	Caelaverock	The Merse			3.95
	Gayton Sands	Marsh End			nd
		Railing Flash			9.77
	Llyn Ystumllyn	The marsh			3.04
	Gloucestershire	Flight pond			30.00
		Saul Warth			5.45
		The Pill meadow			9.44
		The Pill mud			3.04
	Elmley	Shellfleet Creek			7.44
		Shellfleet Creek			4.88
		Brick fields			13.08
	Norfolk	Flight pond 1			26.80
		Flight pond 2			8.22
	Ouse Washes	The washes			16.00
Denmark	Western Jutland	Agger Fjord	20	1978[c]	14.10
		Thyborøn Fjord			0
		Harboøre Fjord			25.90
		Ringkøbing Fjord			35.70
		Ho Bugt			0
	Ringkøbing Fjord	Klægbanken			53.30
		Haurvig Grund			12.20
		Skjern Åś munding			65.80
		Tipperne øst			88.30

Country	Area	Site	Depth (cm)	Year	shot/m^2
		Tippersande			166.80
		Tipperne vest			183.70
		Nymindestrømmen			145.90
	Sjælland, Køge	Ølsemagle Revle			70.00
The Netherlands	Overissjel	Ketelmeer	7	1979-84[d]	20.20
	Zuid-Holland	Beninger Slikken			18.60
					14.00
	Zuid-Holland	Dordtsche Biesboch			23.10
					43.50
Hungary	Six areas	Ce.	-	-[e]	0.60
		So.			10.41
		Cs.			5.71
		Ur.			0.07
		Vá.			2.58
		Al.			1.82
France	Camargue	Mejanes 1	15-20	1987[f]	6.40
		Mejanes 2			41.90
		North Vaccares 1			6.40
		North Vaccares 2			nd
		North Vaccares 3			25.00
		Fangouse 1			6.40
		Fangouse 2			26.40
		Cameroun			6.40
		Pebre			170.30
		Beluge			12.70
		Tortue			nd
		Paty			199.50
		Consecan 1			nd
		Consecan 2			nd
		La Saline			83.90
	L. de Grand Lieu	La Morne	5	1988[g]	80.00
		La Ségnaigerie 1			46.00
		La Ségnaigerie 1		1989	50.00
Spain	Ebro delta	Buda Island 1	20	1991[h]	28.20
		Buda Island 2		1992	54.50
		Canal Vell rice			6.00
		Buda Island 3		1993[i]	97.10
		Encanyissada			266.10
		Punta de la Banya			nd
		La Llanada			48.50
		L'Aufacada		1996[j]	82.70
		Migjorn			13.90
		Dapsa			66.50
	Tablas de Daimiel	Puesto del Rey		1993[k]	99.40
	Alb. de València	Sueca			287.50
	El Hondo	Embalse de Levante		1993[k,l]	163.00
		Charca Sur			123.60
	Cádiz-Sevilla	Medina 1	10	2002[m]	148.30
		Medina 2	30		398.90
		Salada del Puerto	10		58.90
		Chica del Puerto			12.10
		Jeli de Chiclana			21.60
		Zorrilla de Espera		2001	26.70
		Taraje de Sevilla		2002	8.50
	Guadalquivir M.	Salinas de Sanlúcar		2002	18.30

Country	Area	Site	Depth (cm)	Year	shot/m²
		Santa Olalla		2001	11.80
		Lucio de Marilópez		2002	nd
		Veta la Palma		2002	nd
		Brazo del Este		2001	24.60
		L. Caraviruelas	15	1993[k]	14.40
		Hato Blanco		1997	nd
		C. de los Ánsares	20	1997[n]	16.20
		L. Caballero	15	1997[o]	7.20

[a]O'Halloran et al. 1988b; [b]Mudge 1984; [c]Peterson and Meltofte 1979; [d]Smit et al. 1988a; [e]Imre 1994; [f]Pain 1991a; [g]Mauvais and Pinault 1993; [h]Guitart et al. 1994a; [i]Mateo et al. 1997b; [j]Mateo 1998; [k]Mateo et al. 1998; [l]Bonet et al. 1995; [m]Mateo et al. 2007[a]; [n]2000a; [o]Mateo and Taggart 2007.

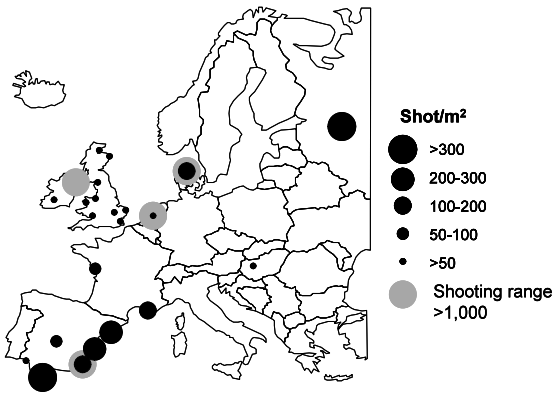

Figure 1. Densities of lead shot in wetlands due to waterfowl hunting and sport shooting.

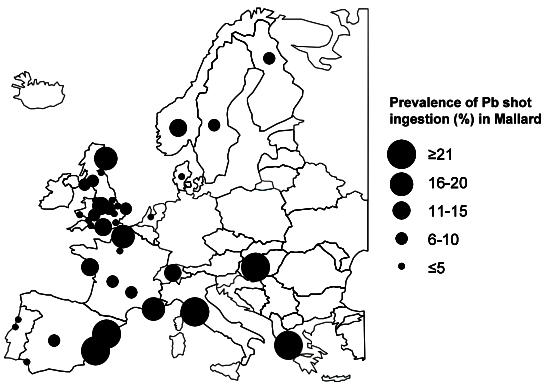

Figure 2. Prevalence of lead shot ingestion in Mallard (*Anas platyrhynchos*) in different European wetlands.

Prevalence of Lead Shot Ingestion and Mortality.— The prevalence of lead shot ingestion in waterfowl has been studied in different countries since 1957 (Tables 2a, 2b). Like lead shot densities in sediments, the highest levels have been found in the waterfowl wintering areas in the dry Mediterranean region, where birds concentrate in a limited number of wetlands intensively hunted for decades (Figure 2). A similar latitudinal trend may be observed in North America (Sanderson and Bellrose 1986).

The Mallard (*Anas platyrhynchos*) can be a good bioindicator species for lead poisoning because it is widely distributed in the world and its prevalence of lead shot ingestion is moderate to high among waterfowl species (Figure 2). The mean prevalence of lead shot ingestion in Mallards from northern Europe varies from 2.2% in Holland to 10.9% in Norway, with an overall value of 3.6% for a sample size of 8,683 shot or trapped individuals (Table 2a, Figure 2). In central and southern Europe, the prevalence of lead shot ingestion in Mallards ranges from 3.2% in Portugal to 36.4% in Greece, with an overall value for 11,239 individuals sampled of 17.3% (Table 2b; Figure 2).

In northern Europe the highest prevalence was observed in Common Goldeneyes (*Bucephala clangula*) with 13.8% of 152 sampled birds, followed by Tufted Ducks (*Aythya fuligula*) with 11.7% of 290 birds (Table 2a). The highest prevalence in these two species was found in Finland, with 32.1% for Common Goldeneye and 58.3% in Tufted Duck (reviewed in Pain 1990b). The species with the highest prevalence of lead shot ingestion in southern-central Europe are the Northern Pintail (*Anas acuta*) with 45% of 598 birds, followed by the Common Pochard (*Aythya ferina*) with 24% of 507 birds (Table 2b). In the case of Mediterranean wetlands like the deltas of rivers Ebro, Rhône and Evros, the prevalence in the Northern Pintail and the Common Pochard ranges from 50 to 70% (Pain 1990a; Pain and Handrinos 1990; Mateo et al.

Table 2a. Prevalence of lead shot ingestion in waterfowl from northern Europe.

Species	United Kingdom 1957-81[a]			Holland 1977-87[b]			Denmark 1974-77[c]			Norway 1978-87[d]			Sweden 1972-94[e]			Finland 1973-1975[f]			Northern Europe		
	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%
Tundra Swan *Cygnus columbianus*	516	1	0.2	-	-														516	1	0.2
Pink-footed Goose *Anser brachyrhynchus*	73	2	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73	2	2.7
G. White-fronted Goose *Anser albifrons*	30	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	0	0.0
Greylag Goose *Anser anser*	42	3	7.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42	3	7.1
Barnacle Goose *Branta leucopsis*	61	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	61	0	0.0
Eurasian Wigeon *Anas penelope*	574	0	0.0	-	-	-	251	4	1.6				142	4	2.8	15	0	0.0	982	8	0.8
Gadwall *Anas strepera*	61	2	3.3	5	1	20.0	-	-	-	-	-	-	-	-	-	-	-	-	66	3	4.5
Common Teal *Anas crecca*	1,188	12	1.0	-	-	-	167	0	0.0				180	0	0.0	88	0	0.0	1,623	12	0.7
Mallard *Anas platyrhynchos*	1,495	86	5.8	3,260	72	2.2	3,251	94	2.9	128	14	10,9	464	40	8.6	85	5	6.0	8,683	311	3.6
Northern Pintail *Anas acuta*	265	11	4.2	-	-	-	44	2	4.5	-	-	-	40	4	10.0	5	2	40.0	354	19	5.4
Northern Shoveler *Anas clypeata*	161	3	1.9	-	-	-	9	0	0.0	-	-	-	15	0	0.0	1	0	0.0	186	3	1.6
Common Pochard *Aythya ferina*	246	15	6.1	-	-	-	1	0	0.0	-	-	-	16	7	43.5	6	3	50.0	269	25	9.3
Tufted Duck *Aythya fuligula*	210	9	4.3	-	-	-	28	1	3.6	-	-	-	28	10	35.7	24	14	58.3	290	34	11.7
Greater Scaup *Aythya marila*	11	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	0	0.0
Common Goldeneye *Bucephala clangula*	15	1	6.7	20	1	5.0	-	-	-	-	-	-	89	10	11.2	28	9	32.1	152	21	13.8

[a]Olney 1960, 1968; Thomas 1975; Mudge 1983; Street 1983; [b]Smit et al. 1988b; Lumeij et al. 1989; Lumeij and Scholten 1989; [c]Wium-Andersen and Fransmann 1974; Petersen and Meltofte 1979; Clausen and Wolstrup 1979; [d]Pain 1990b; [e]Danell and Anderson 1975; Danell et al. 1977; Jågas 1996; [f]Danell 1980. Some of these data reviewed before in Pain 1990b.

Table 2b. Prevalence of lead shot ingestion in waterfowl from southern and central Europe.

Species	Portugal 1993-99[a]			Spain 1977-2004[b]			France 1960-2001[c]			Italy 1990[d]			Switzerland[e] 1979-81			Hungary[f]			Greece[g] 1989-90			Southern-Central Europe		
	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%	n	+	%
Greylag Goose *Anser anser*	-	-	-	161	6	3.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	161	6	3.7
Eurasian Wigeon *Anas penelope*	-	-	-	28	1	3.6	472	20	4.2	13	1	7.7	-	-	-	-	-	-	7	0	0.0	520	22	3.7
Gadwall *Anas strepera*	-	-	-	31	3	9.7	653	25	3.8	-	-	-	11	0	0.0	-	-	-	15	0	0.0	710	28	3.2
Common Teal *Anas crecca*	-	-	-	59	10	16.9	41,131	1,958	4.8	-	-	-	52	3	5.8	-	-	-	34	5	14.7	41,276	1,976	4.8
Mallard *Anas platyrhynchos*	186	6	3.2	245	50	20.4	10,738	1,874	17.5	-	-	-	59	8	13.6	625	186	29.8	11	4	36.4	11,864	2,128	17.9
Northern Pintail *Anas acuta*	-	-	-	108	73	67.6	469	190	40.5	-	-	-	13	3	23.1	-	-	-	8	4	50.0	598	270	54.5
Northern Shoveler *Anas clypeata*	-	-	-	103	29	28.2	1,113	117	10.5	-	-	-	2	0	0.0	-	-	-	9	0	0.0	1,227	146	13.4
Garganey *Anas querquedula*	-	-	-	2	0	0.0	2,001	199	9.9	-	-	-	-	-	-	-	-	-	-	-	-	2,003	199	9.9
Red-crested Pochard *Netta rufina*	-	-	-	78	10	12.8	2	0	0.0	-	-	-	-	-	-	-	-	-	1	0	0.0	81	10	12.3
Common Pochard *Aythya ferina*	-	-	-	44	32	72.7	1,917	456	23.8	4	3	75.0	65	9	13.9	-	-	-	14	7	50.0	2,044	507	25.6
Tufted Duck *Aythya fuligula*	-	-	-	5	4	80.0	3,867	396	10.2	-	-	-	40	4	10.0	-	-	-	1	1	100	3,913	405	10.4
Common Goldeneye *Bucephala clangula*	-	-	-	-	-	-	2	2	100	-	-	-	-	-	-	-	-	-	-	-	-	4	4	100
White-headed Duck *Oxyura leucocephala*				25	8	32.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	8	32.0

[a]Rodrigues et al. 2001; [b]Llorente 1984; Guitart et al. 1994a; Mateo et al. 1997b, 1998, 2000b, 2006, 2007a; Martínez-Haro et al. 2005; [c]Hoffman 1960; Tamisier 1971; Hovette 1974; Pirot 1978; Alouche 1983; Cordel-Boudard 1983; Campredon 1984; Pirot and Taris 1987; Pain 1990a, 1991b; Mauvais and Pinault 1993; Lefranc 1993; Schricke and Lefranc 1994; Lamberet 1995; Pinault 1996; Mondain-Monval et al. 2002; [d]Tirelli et al. 1996; [e]Zuur 1982; [f]Imre 1994; [g]Pain and Handrinos 1990. Some of these data reviewed before in Pain 1990b, Duranel 1999 and Mezieres 1999.

1997b, 2000b). In a recent study, Figuerola et al. (2005) found with a meta-analysis of lead shot ingestion in 51 locations and 27 waterfowl species from North America and Europe that the prevalence in a given species was highly variable between localities, and was not consistently different between dabbling, grazing, and diving species.

Some estimations of mortality by lead poisoning in waterfowl have been done in Europe from the number of ingested shot, as described by Bellrose (1959). Mudge (1983) estimated that about 2.3% of the British population of wild Mallards might die each winter as a direct result of lead pellet ingestion, which represented at a conservative estimate about 8,000 birds. At a more local scale, Thomas (1975) estimated mortality rates in different species from the Ouse Washes (UK) ranging from 1-2.8% in Northern Shovelers (*Anas clypeta*) to 5.1-8.3% in Northern Pintails. In the Ebro Delta (Spain), mortality from lead poisoning within a mainly sedentary population of Mallards would be about 37% (9,600 birds) during the wintering season (Mateo et al. 1997b). From the data compiled in the present review (Tables 2a, 2b) and following the same calculations as the cited studies, about 975,115 waterfowl might die by lead poisoning in Europe during the wintering season from November to February from a total population of 11,228,700 of 17 species (Table 3). This percentage of waterfowl mortality by lead poisoning in Europe of 8.7% is higher than the value estimated in the USA of 2-3% (Bellrose 1959). In fact, several waterfowl species have a higher prevalence of lead shot ingestion in Europe (Table 3) than in North America (Sanderson and Bellrose 1986; Figure 3). Based on recaptures of banded ducks, Tavechia et al. (2001) found that relative monthly survival of lead-affected Mallards (with >1 ingested lead shot in the gizzard) was 19% lower than in unaffected birds over the period 1960–71 in Camargue (France). In a similar study, Guillemain et al. (2007) observed a lower survival in Common Teals (*Anas crecca*) carrying at least one lead shot in the gizzard than in Common Teals with no lead. Tavecchia et al. (2001) did not observe a negative effect on survival in Mallards with only one ingested shot, suggesting that Common Teal were more sensitive to lead poisoning.

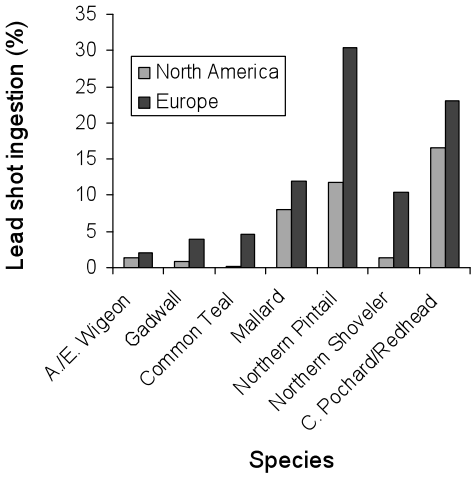

Figure 3. Comparison of the prevalence of lead shot ingestion in waterfowl species from North America (n = 171,697) and Europe (n = 75,761).

Lead poisoning in Mute Swans (*Cygnus olor*) has been observed in the UK (Simpson et al. 1979; Birkhead 1982, 1983; Poole 1986; Sears 1988; Pennycott 1998; Perrins et al. 2003; Kelly and Kelly 2004). These studies reported fatalities due to the ingestion of lead fishing weights, although shotgun pellets have been frequently found in Mute Swans (21.9%, n = 32), Bewick's Swans (*Cygnus columbianus*) (10%, n=20) and Whooper Swans (*Cygnus cygnus*) (40%, n =5) found dead in the UK by Mudge (1983). In Ireland, O'Halloran et al. (1988a, 1988b) studied 101 dead or moribund Mute Swans and found ingested lead fishing weights in 10 birds and shotgun pellets in 49 birds, in all cases with elevated lead levels in tissues; one Whooper Swan also died by lead shot ingestion. Lead poisoning by shotgun pellet ingestion was recorded in two Mute Swans from Marano Lagoon (Perco et al. 1983) and in other Italian wetlands (Di Modugno et al. 1994). Lead poisoning in Mute Swans has been detected in Sweden (7-17% of examined birds; Frank and Borg 1979, Mathiasson 1986). After the ban on the use of lead angling weights in England and Wales in 1987, the incidence of lead poisoning cases in Mute Swans started to fall and the population started to increase, although the problem was not eradicated (Sears and Hunt 1991, Perrins et al. 2003).

Lead shot ingestion has been studied in *Rallidae* species. The prevalence in Eurasian Coot has been

Table 3. Prevalence of lead shot ingestion and estimation of mortality in waterfowl wintering in Europe.

Species	Wintering Population (n)	Trend[a]	Prevalence 1957-2004		Estimated mortality[b]	
			n	(%)	n	%
Tundra Swan *Cygnus columbianus*	23,000	-3	516	0.2	45	0.2
Pink-footed Goose *Anser brachyrhynchus*	290,000	3	73	2.7	8,049	2.8
G. White-fronted Goose *Anser albifrons*	1,100,000	0	30	0.0	0	0.0
Greylag Goose *Anser anser*	390,000	3	203	4.4	17,517	4.5
Barnacle Goose *Branta leucopsis*	370,000	3	61	0.0	0	0.0
Eurasian Wigeon *Anas penelope*	1,700,000	0	1,502	2.0	34,398	2.0
Gadwall *Anas strepera*	96,000	3	776	4.0	3,885	4.0
Common Teal *Anas crecca*	730,000	-1	42,899	4.6	34,271	4.7
Mallard *Anas platyrhynchos*	3,700,000	-1	20,547	11.9	444,942	12.0
Northern Pintail *Anas acuta*	120,000	-2	952	30.4	36,905	30.8
Northern Shoveler *Anas clypeata*	200,000	-2	1,413	10.5	21,365	10.7
Red-crested Pochard *Netta rufina*	84,000	3	81	12.3	10,506	12.5
Common Pochard *Aythya ferina*	790,000	-2	2,313	23.0	184,078	23.3
Tufted Duck *Aythya fuligula*	1,200,000	-2	4,203	10.4	126,977	10.6
Greater Scaup *Aythya marila*	120,000	-3	11	0.0	0	0.0
Common Goldeneye *Bucephala clangula*	310,000	1	156	16.0	50,329	16.2
White-headed Duck *Oxyura leucocephala*	5,700	(-3)[c]	25	32.0	1,848	32.4
All species	11,228,700		75,761	-	975,115	8.7

[a] The trend value was scored from BirdLife International (2004) by considering large increase=3, moderate increase=2, slight increase=1, stable=0, slight decline=-1, moderate decline=-1, large decline=-3. [b] The estimation of mortality has been done following the method described by Bellrose (1959). The calculations were done with the mean distribution of the number of ingested pellets found in European waterfowl (Mudge 1983, Pain 1990a, Mateo et al., 1997b). The distribution was 1 shot: 47.1%, 2: 15.7%, 3: 5.4%, 4: 6.3%, 5: 3.5%, 6: 2%, >6: 19.9%. Birds with these numbers of ingested shot were assumed to have rates of mortality of 9, 23, 30, 36, 43, 50 and 75, respectively. Previously, the prevalences were corrected for the hunting bias (1.5, 1.9, 2.0, 2.1, 2.2, 2.3 and 2.4, respectively). A turn-over factor of 6 was considered. [c]White-headed Duck population fluctuates, but it is “Endangered” and the lowest value of trend has been assigned.

highly variable, with values of 0% in the Ouse Washes (UK) (Thomas 1975, Mudge, 1983), 3.6% in the Ebro Delta (Spain) (Mateo et al. 2000b), 5.1% in Switzerland (reviewed in Thomas 1982) and 14-19% in Camargue (France) (Pain 1990a, Mondain-Monval et al. 2002). The prevalence in the Moorhen (*Gallinula chloropus*) was 0-6.3% in the Ouse Washes (UK) (Thomas 1975, Mudge 1983) and in one of six from Camargue (France) (Pain 1990a). In Camargue, one of four Water Rail (*Rallus aquaticus*) had ingested lead shot (Pain 1990a). The Purple Gallinule (*Porphyrio porphyrio*) in Doñana had a rate of ingestion of 7.4% (Rodríguez and Hiraldo 1975), although a more recent study found no ingested shot in this species (Mateo et al. 2007a). In the shorebirds of the families *Scolopacidae* and *Charadridae*, lead shot ingestion has been observed in 18% of Black-tailed Godwits (*Limosa limosa*), 11% of Ruffs (*Philomachus pugnax*), 8% of Common Snipes (*Gallinago gallinago*) and 0% of Wood Sandpipers (*Tringa glareola*) from Camargue (France) (Pain 1990a, Pain et al. 1992). In the north-west of France the prevalence of lead shot ingestion in the Common Snipe was 1.8-15.6%, and in the Jack Snipe (*Lymnocryptes minimus*) it was 8.5% (Beck and Granval 1997). The Jack Snipe in Gironde (France) had a rate of shot ingestion of 21.6% (Veiga 1985). In the Ouse Washes (UK), 1.5% of Common Snipes had ingested lead shot in the gizzard (Thomas 1975). In the Albufera de València (Spain), lead shot ingestion was not detected in a sample of 30 Common Snipes (Mateo et al. 1998). Lead poisoning has been diagnosed in Black-tailed Godwits in Italy (Galasso 1976) and Spain (Mateo 1998), and Lapwings (*Vanellus vanellus*), and Avocets (*Recurvirostra avosetta*) in Spain (Guitart et al. 1994a, b).

Several fatalities by lead poisoning of Greater Flamingos (*Phoenicopterus ruber*) have been detected in southern Europe. In Spain, 22 Greater Flamingos were found dead in 1991 in Doñana (Ramos et al. 1992), 106 Greater Flamingos died between 1992 and 1994 in El Hondo and Salinas de Santa Pola (Mateo et al. 1997a), and 24% (n=41) of illegally shot Greater Flamingos from the Ebro Delta contained ingested lead shot in the gizzard (Mateo 1998). In France, lead poisoning was observed in three Greater Flamingos from the region of Marseille (Bayle et al. 1986), but low blood lead levels were found in nestlings from Camargue (Amiard-Triquet et al. 1991). More recently, lead poisoning has been diagnosed in 16 Greater Flamingos in the Po Delta (Arcangeli et al. 2007) and two Greater Flamingos from Tuscany (Ancora et al. 2008).

In some species or in some countries there is no data about lead shot ingestion, but there are studies on the accumulation of lead in waterbird livers. From these studies one can expect low exposures in Mallards and Eurasian Coots from the Gösku Delta in Turkey (Ayas and Kolankaya 1996), and a low exposure in Common Eiders (*Somateria mollissima*) in the Netherlands (Hontelez et al. 1992) because all the studied birds had <5 µg/g of lead in dry weight of liver. On the other hand, 14% of Common Eiders trapped in Finland had ≥0.2 µg/g of lead in wet weight of blood, the threshold level of subclinical poisoning in waterfowl (Franson et al. 2000), and four adult birds found dead had a combination of lesions (acid-fast intranuclear inclusion bodies in renal epithelial cells) and tissue lead residues (47.9-81.7 µg/g of lead in dry weight of liver) characteristic of lead poisoning (Hollmén et al. 1998). Similarly, lead shot ingestion may occur in the Greater Scaup (*Aythya marila*) and Common Pochard from the Szczecin Lagoon in Poland because 25% and 46%, respectively, had >10 µg/g of lead in bones (Kalisińska et al. 2007). Lead shot ingestion may also occur in Mallards from Szczecin Lagoon and Słońsk Reserve because 5.7% and 13.5% of shot birds, respectively, had >1.5 µg/g of lead in wet weight of liver (Kalisińska et al. 2004). In Italy, Tirelli et al. (1996) found >40 µg/dL of lead in blood of 54.8% of Mallards from Orbetello lagoon. Rodrigues et al. (2005) found >20 µg/dL of blood lead in 38.6% of 427 Mallards and 20.2% of 92 Common Teals from Vouga Lowlands (N Portugal) and 38.1% of 21 Mallards from Lagoa dos Patos (S Portugal).

Impact on Threatened Species and Population Trends.—Lead poisoning has been identified as an important cause of death for the White-headed Duck (*Oxyura leucocephala*), a globally endangered (EN) species according to IUCN. This species has a global population of 5,700 individuals and 75-94% of them are in Europe. The prevalence of lead shot ingestion is difficult to determine because it is not a hunted species, but the Spanish

program to eradicate the Ruddy Duck (*Oxyura jamaicensis*) and their hybrids with the White-headed Ducks led to the observation of a 32% of prevalence of lead shot ingestion in the *Oxyura* genus. In addition, 73.3% of the *Oxyura* found dead in the Spanish wetlands contained lead shot in the gizzard, and 80% had >20 µg/g dry weight of lead in the liver (Mateo et al. 2001b). The continued monitoring of the White-headed Ducks accompanied by the analysis of lead isotopes confirms the importance of lead poisoning by shot ingestion as a cause of mortality (Svanberg et al. 2006).

The Marbled Teal (*Marmaronetta angustirostris*), a waterfowl species under the Global IUCN category of vulnerable (VU), is also affected by lead poisoning. As with the White-headed Duck, this is not a game species, but some birds found dead due to different causes in southern Spain between 1996 and 2001 have provided data on lead shot exposure in this species. The rate of lead shot ingestion in these fatalities was 32.9%, and 20% had >20 µg/g dry weight of lead in liver (Mateo et al. 2001b, Svanberg et al. 2006).

The Ferruginous Duck (*Aythya nyroca*) is considered near-threatened (NT) and should be monitored for the effect of lead poisoning because other species of the genus *Aythya*, like the Common Pochard and the Tufted Duck, show high prevalence in some European wetlands (Tables 2a, 2b). No information exists about lead poisoning in the Red-breasted Goose (*Branta ruficollis*) (EN) and the Lesser White-fronted Goose (*Anser erythropus*) (VU). However, cases of lead poisoning have been described in other goose species like the Greater White-fronted Goose (*Anser albifrons*), which is closely related to the Lesser White-fronted Goose (Mudge 1983, Ochiai et al. 1993).

The trends of the populations of waterfowl wintering in Europe are of marked decline for Northern Pintail and Common Pochard (BirdLife 2004, Table 3), both with the highest prevalence of lead shot ingestion in southern Europe in the 1990s (Mateo et al. 1997b). Wintering Common Pochard in northwest Europe and west Mediterranean had declined 30% and 70% during the previous two decades. In 1993, the Northern Pintail had the lowest population index in the west Mediterranean since 1969,

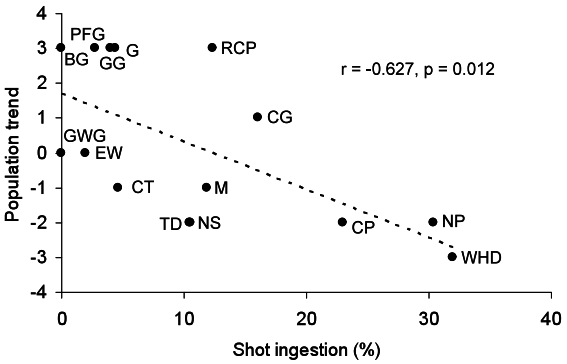

Figure 4. Correlation between the prevalence of lead shot ingestion and the trend of the wintering population in Europe of 15 species of waterfowl. Pink-footed Goose: PFG, Greater White-fronted Goose: GWG, Greylag Goose: GG, Barnacle Goose: BG, Eurasian Wigeon: EW, Gadwall: G, Common Teal: CT, Mallard: M, Northern Pintail: NP, Northern Shoveler: NS, Red-crested Pochard: RCP, Common Pochard: CP, Tufted Duck: TD, Common Goldeneye: CG, White-headed Duck: WHD.

and the east Mediterranean/Black Sea population decreased between 1967 and 1993 at a rate of -6.37% per year (Rose 1995). If we consider all the commonly hunted duck species from Europe we can observe a significant relationship between their wintering population trend and the prevalence of lead shot ingestion in them (Figure 4). Owen (1996) considers lead poisoning as a cause of the decline of the Common Pochard because females winter predominantly in far southern Europe with higher hunting pressure and lead poisoning prevalence; female survival there is only 67% of that of males.

LEAD SHOT INGESTION IN UPLAND GAMEBIRDS AND OTHERS SPECIES

Lead Shot Densities in Hunting Estates.—Lead shot densities in upland habitats has been scarcely studied. Imre (1997) found 0-1.09 shot/m^2 in four Common Pheasant hunting estates in Hungary (mean 0.46 shot/m^2). Ferrandis et al. (2008) studied shot densities on a driven shooting estate in Central Spain used for hunting of Red-legged Partridge (*Alectoris rufa*). The reported density was 7.4 shot/m^2 in 1 cm of soil depth and this is possibly low compared with other estates because the frequency of driven shootings per season in the study

area only ranged from zero to two and the number of hunters spaced around 40 m apart was from six to 16 per shooting line. The densities might be higher in other more intensively driven shooting estates, where farm-reared partridges are released in large numbers just before the hunting day and driven shootings are conducted during all of the hunting season. More information is needed about lead shot densities in upland habitats in Europe, especially in intensive hunting areas.

Prevalence of Lead Shot Ingestion and Mortality.—Cases of lead poisoning in upland species have been described in Common Pheasants from the UK (Calvert 1876, Holland 1882), Denmark (Clausen and Wolstrup 1979) and Hungary (Imre 1997), Grey Partridge (*Perdix perdix*) from the UK (Keymer 1958, Anger 1971, Keymer and Stebbings 1987) and Denmark (Clausen and Wolstrup 1979), and Wood Pigeons (*Columba palumbus*) from Denmark (Clausen and Wolstrup 1979). The Game Conservancy Trust (Potts 2005) studied 1,318 Grey Partridges from 1947 to 1992 in the UK and 1.4% of birds found dead had ingested lead shot in the gizzard, with an increase in the incidence of lead poisoning from 1947-58 to 1963-92. During the second period the incidence was 4.5% in adults and 6.9% in chicks; 16 (76%) of the 21 birds that contained ingested lead shot had died as a result of lead poisoning. Clausen and Wolstrup (1979) found ingested lead shot in 1.6% of Grey Partridges from Denmark between 1971 and 1977. In the Red-legged Partridge from the UK, Butler (2005) found lead shot in the gizzard of one bird (0.16%) among 637 collected between 1955 and 1992, and in two birds (1.4%) of 144 shot in the 2001/02 season. Another study of lead shot ingestion in 437 Common Pheasants shot in 32 estates in the UK from 1996 to 2002 found an overall prevalence of 3%; the number of ingested shot were 1 (77%), 2 (15%), or 3 (8%) (Butler et al. 2005). The prevalence of lead shot ingestion in Common Pheasants (n=947) from 14 hunting estates in Hungary ranged from 0 to 23.1% (all areas=4.75%), and the number of ingested shot ranged from one to eight (Imre 1997). In Spain, Soler-Rodríguez et al. (2004) examined seven shot Red-legged Partridges and found one bird with 14 ingested lead shotgun pellets in the gizzard and 35.6 µg/g of lead in wet weight of liver. Despite the high level detected, no signs of lead poisoning were observed in this Red-legged Partridge. More recently, Ferrandis et al. (2008) examined 76 Red-legged Partridges shot in the same estate where lead shot density was studied (7.4 shot/m^2), and the prevalence of lead shot ingestion was 3.9%, with important variations between years (20% in 2004, 1.5% in 2006), with corresponding lead values in liver and bone tissues. This difference may be explained by variations in diet and grit selection between years.

A particular case of lead poisoning in two Grey-headed Woodpeckers (*Picus canus*) and one White-backed Woodpecker (*Dendrocopos leucotos*) from Sweden was reported by Mörner and Petersson (1999). The source of lead was thought to be lead pellets shot into trees and picked out by the woodpeckers during food search because holes made by shot resemble holes made by insects.

LEAD SHOT INGESTION IN BIRDS OF PREY

Cases of lead poisoning by shot or bullet ingestion have been described in 14 species of diurnal birds of prey and three species of nocturnal raptors in Europe, some of which have been near-threatened such as the White-tailed Eagle (*Haliaeetus albicilla*), or endangered, i.e., the Spanish Imperial Eagle (*Aquila adalberti*) (Figure 5). In several of these cases, lead shot ingestion can be associated with the elevated presence of embedded lead shot in the flesh of prey subjected to intensive hunting, like waterfowl (Mateo et al. 1999, 2001a) or deer (Krone et al. 2009).

Presence of Embedded Lead Shot in Prey.—The presence of embedded shot in the potential prey of raptorial birds has been mainly studied in waterfowl species for the purpose of measuring hunting pressure on a certain species and to estimate the effect on survival of embedded shot in the body. The percentage of waterfowl with embedded shot differs between species, areas with different hunting pressures, and the age of birds. These values in Europe ranged in goose species between 9.2 and 65.3%, in freshwater ducks up to 68%, and in sea ducks between 11.3% and 29.0% (Table 4). In several of these studies, waterfowl were trapped, shot with different ammunition than normally used in the area (bullets or steel), or they died by causes other than shot trauma; thus the values may represent the

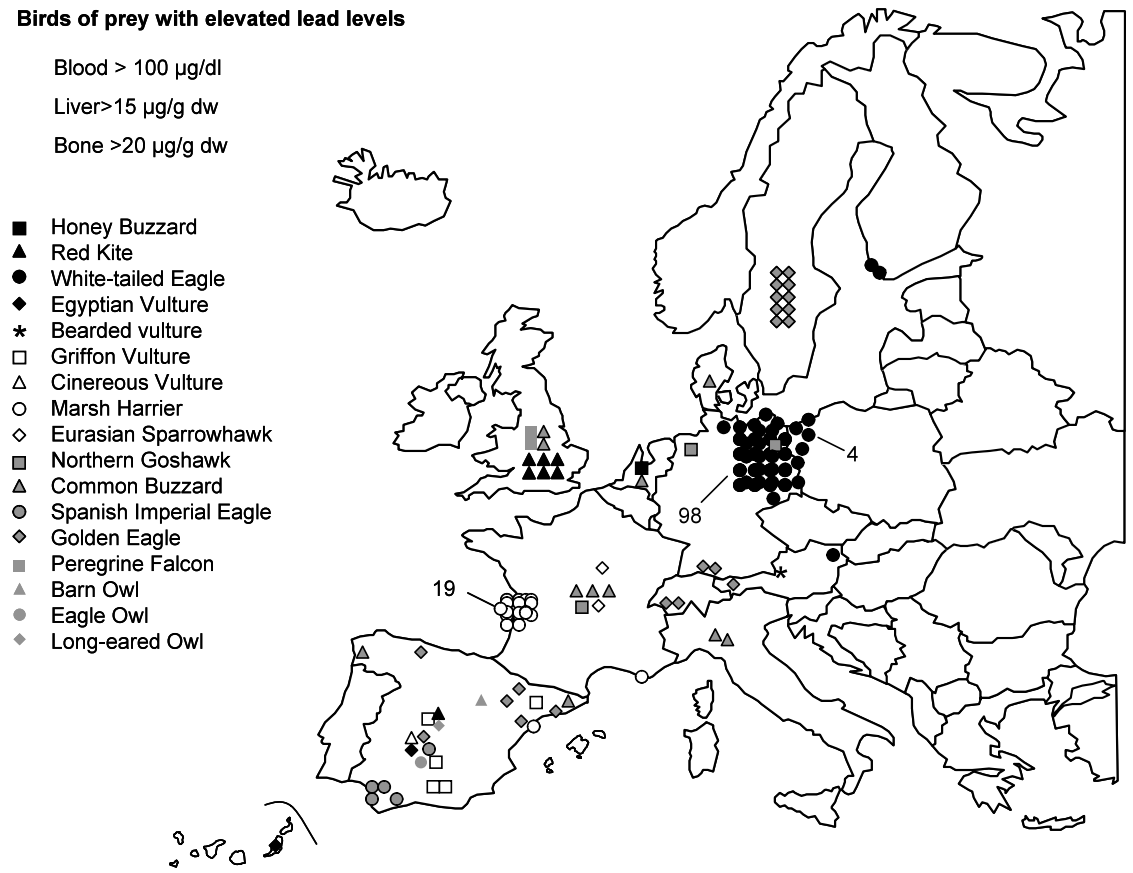

Figure 5. Birds of prey from Europe with elevated lead levels in blood, liver or bone (see references in the text). The map shows the distribution of reports by countries, and in some cases the approximate location.

Table 4. Occurrence of embedded lead shot in potential prey for European raptors.

Species	Zone/Country	M[a]	n	% with embedded shot
Pink-footed Goose	Denmark 1990-92[b]	T	413	24.6-36.0
	Denmark 1998-05[b]	T	1,904	9.2-22.2
Greylag Goose	Doñana, Spain[c]	FD	49	65.3
		T	45	44.4
Common Teal	Camargue, France[d]	T	38,909	4.4-9.6
Mallard	Camargue, France[e]	T	2740	23.4
	The Netherlands[f]	T	865	1.4-3.4 in gizzard wall (22-68 in whole body)
		S	2,859	4.9-6.4 in gizzard wall
	Doñana, Spain[c]	FD	35	14.2
Northern Shoveler	Doñana, Spain[c]	FD	17	0
Common Eider	SW Greenland[g]	FD/T	729	15.1-29.0
King Eider	SW Greenland[h]	FD	114	11.3-20.0
Eurasian Coot	Doñana, Spain[c]	FD	20	5.0
Red-legged Partridge	C Spain[i]	S	64	87.5

[a] T = trapped, FD = found dead, S = shot.
[b]Noer et al. 2007, [c]Mateo et al. 2007a, [d]Guillemain et al. 2007, [e]Tavecchia et al. 2001, [f]Lumeij and Scholten 1989, [g]Merkel et al. 2006, [h]Falk et al. 2006, [i]R. Mateo unpubl. data.

frequency of potential exposure to lead shot in birds of prey by the consumption of birds captured alive. In addition, opportunistic birds of prey would also be exposed to prey shot by hunters, dead or crippled, and not harvested by them. About 15% of geese and 19% of ducks killed by hunters are not retrieved and therefore can be consumed by scavengers with the consequent risk of lead shot ingestion (USFWS 1975). An early description of the opportunistic behaviour of birds of prey was done by Chapman and Buck (1893), when Marsh Harriers (*Circus aeruginosus*) in Doñana (Guadalquivir Marshes, Spain) were faster than were these British naturalists to recover ducks they shot.

Upland gamebirds are intensively hunted in some estates by means of driven shooting techniques, especially in places where farm-reared partridges and pheasants are released in large numbers. An undetermined number of birds, depending on the habitat, may be unretrieved by hunters, as occurs in waterfowl. The presence of lead shot embedded in the bodies of shot Red-legged Partridges in a driven shooting estate in Spain was 87.5%, with the number of embedded shot ranging from one to 22 and a mean ± SD of 4.19 ± 3.48 shot/partridge (R. Mateo unpubl. data).

Exposure to Lead and Cases of Lead Poisoning in Birds of Prey.—Probably the species most affected by lead poisoning in Eurasia has been the White-tailed Eagle, as occurred in North America with the Bald Eagle (*Haliaeetus leucocephalus*) (Pattee and Hennes 1983) or in Asia with the Steller's Sea Eagle (*Haliaeetus pelagicus*) (Kim et al. 1999). The White-tailed Eagle has been considered until recently as near-threatened (NT) in Europe, but its population has increased substantially between 1970-2000. Kenntner et al. (2001) studied 66 White-tailed Eagles found dead, sick or injured between 1993 and 2000 in Germany and Austria; 16 birds (28%) had liver lead values in the range from 5 to 62 µg/g in wet weight of tissue. In a retrospective study, Kenntner et al. (2004) diagnosed nine White-tailed Eagles as lead poisoned from 46 birds found dead in Eastern Germany from 1978 to 1998. In a more extensive compilation of cases, Kenntner et al. (2005) investigated liver and kidney tissues of 277 immature and adult White-tailed Eagles found dead or moribund in Germany between 1979 and 2005 and found levels of lead indicating lead poisoning (>5 µg/g in wet weight) in 66 (24%) of the cases originated by the ingestion of lead shot and bullet fragments. The last update for this species in Germany reports a mortality by lead poisoning of 25% (n=391) (Krone et al. 2009). Muller et al. (2001) describes two clinical cases of lead poisoning in two White-tailed Eagles from Germany. Lead poisoning has also been detected in four White-tailed Eagles from northwestern Poland (n=

Table 5. Occurrence of lead shot in pellets of raptors and carrion eaters from Europe.

Species	Zone/Country	n	%
Red Kite *Milvus milvus*	England, UK[a]	264	1.5-2.3
	Central Spain[b]	1,233	1.05
	Doñana, Spain[c,d]	962	2.2
Egyptian Vulture *Neophron percnopterus*	Ebro V., Spain[e]	327	0.0
	Canary I., Spain[f]	424	3.1
Marsh Harrier *Circus aeruginosus*	Charente-M., France[g]	459	14.8
	Ebro D., Spain[h]	521	10.7
	Doñana, Spain[i]	513	2.1
Spanish Imperial Eagle *Aquila adalberti*	Spain[j]	2,400	0.54
	Doñana, Spain[c,d]	615	4.2
Golden Eagle *Aquila chrysaetos*	Norway[k]	-	70.00
Booted Eagle *Hieraetus pennatus*	Doñana, Spain[d]	76	0.0
Peregrine Falcon *Falco peregrinus*	Doñana, Spain[d]	117	0.9
Barn Owl *Tyto alba*	Doñana, Spain[d]	50	0.0
Raven *Corvus corax*	Doñana, Spain[d]	321	0.0

[a]Pain et al. 2007; [b]García and Viñuela 1999; [c]Mateo et al. 2001a, [d]2007a; [e]Gangoso et al. 2008; [f]Donázar et al. 2002; [g]Pain et al. 1993, 1997; [h]Mateo et al. 1999; [i]González 1991; [j]González and Hiraldo 1988; [k]Pain and Amiard-Triquet 1993.

25, 16%; Falandysz et al. 1988, 2001, Kalisińska et al. 2006), two from Greenland (n=12, 16.7%; Krone et al. 2004) and two from Finland (n=11, 18.2%; Krone et al. 2006).

The second affected species, in number of cases, is the Golden Eagle (*Aquila chrysaetos*). These cases have been widely distributed across Europe, with 10 cases in Sweden (Borg 1975), six in Spain (Cerradelo et al. 1992; R. Mateo unpubl. data), two in Switzerland (Kenntner et al. 2007), two in Germany (Bezzel and Fünfstück 1995) and one in Austria (Zechner et al. 2005). The rate of lead shot ingestion was extremely high in Norway, where 70% of the regurgitated pellets contained lead shot (Table 5).

The Spanish Imperial Eagle is now a vulnerable (VU) species with a global population of 175-180 breeding pairs, and it was considered until recently as endangered (EN) (BirdLife 2004). A significant component of the population breeds in Doñana, where they feed on crippled waterfowl, resulting in the presence of lead shot in 14.7% of the regurgitated pellets in the fall-winter seasons between 1991-96 (Mateo et al. 2001a). A lower occurrence (2.8%) was observed in pellets collected in all years during 1997-2002 (Mateo et al. 2007a). Although a lower rate of lead shot ingestion may be present in upland areas (Table 5), one case of lead poisoning has been described in central Spain (Hernández 1995). Four birds, two of them from Doñana, had bone lead levels >50 µg/g of dry weight (Pain et al. 2005). The ingestion of lead shot in the Spanish Imperial Eagle in Doñana may vary among years depending on the hunting pressure on Greylag Geese that varies according to the water level in the protected areas (Mateo et al. 2007a).

Marsh Harriers in the Mediterranean wetlands frequently ingest lead shot, being opportunistic species often seen in the search of crippled waterfowl at the end of shooting days. In Charente-Maritime (France), Pain et al. (1993, 1997) found lead shot in 11.5-25% of regurgitated pellets in winter, but only in 1.4% of pellets during May and June. In Spain, the occurrence of lead shot in pellets was 10.7% (Mateo et al. 1999) in the Ebro Delta and 1.8-4.3% in Doñana (González 1991, Mateo et al. 2007a). These rates of shot ingestion were reflected in high blood lead levels (>30 µg/dL) in Charente-Maritime (33%; Pain et al. 1993, 1997), in Camargue (26%; Pain et al. 1993) and the Ebro Delta (40%; Mateo et al. 1999). One bird from Charente-Maritime was found dead with 54.9 µg/g of lead in dry weight of liver (Pain et al. 1993).

The Red Kite (*Milvus milvus*) has suffered an important decline in Europe (NT), especially due to the use of poison to kill predators; lead poisoning has also been considered as a significant cause of death in some areas. Pain et al. (2007) studied Red Kites found dead or moribund in England during the reintroduction program initiated in 1989; six of 44 birds had >15 µg/g of lead in dry weight of liver, and four of these (9%) probably died by lead poisoning. The rate of lead shot ingestion in the reintroduced Red Kites was reflected by the presence of lead shot in 1.5-2.3% of the regurgitated pellets. The presence of lead shot has been detected in 5.5% of the regurgitated pellets in Doñana at the end of the hunting season (Mateo et al. 2001a). A lower percentage was observed in pellets collected during the whole year (1.8%; Mateo et al. 2007a) in these marshes and also in other upland areas in Spain (1.05%; García and Viñuela, 1999). One Red Kite found dead in Central Spain had >20 µg/g of lead in dry weight of bone, and another three had values between 10 and 20 µg/g dry weight (Mateo et al. 2003).

Lead poisoning has been described in the four species of vultures living in Europe: Griffon Vulture (*Gyps fulvus*) (Mateo et al. 1997c), Cinereous Vulture (*Aegypius monachus*) (Hernández and Margalida 2008), Bearded Vulture (*Gypaetus barbatus*) (Hans Frey, Richard Faust Bearded Vulture Breeding Centre, Austria, pers. comm.), and Egyptian Vulture (*Neophron percnopterus*) (Rodríguez-Ramos et al. 2009). In southeastern Spain, 21 (91%) of 23 Griffon Vultures trapped alive had blood lead >20 µg/dL and two of them had >150 µg/dL (García-Fernandez et al. 2005). High blood lead levels (>20 µg/dL) had been previously observed in six other Griffon Vultures (García-Fernández et al. 1995). Egyptian Vultures from the Canary Islands (Spain) are sedentary, unlike the continental birds which migrate to Africa in winter. This difference makes the Canary Islands population more vulnerable because they feed on rabbit carcasses shot in winter. The presence of lead shot

was detected in 5.3% of pellets collected in January and 1.3% of those collected in November. Moreover, five (21.7%) of 23 birds had >20 µg/dL of lead in blood, and one had >50 µg/dL (Donázar et al. 2002). Gangoso et al. (2009) found elevated blood lead levels (>20 µg/dL) in 10 (7.3%) Egyptian Vultures from the Canary Islands (n=137 nestlings and adults), and one of these birds showed a concentration of 178 µg/dL. Moreover, they analyzed bones of 28 Egyptian Vultures found dead in the Canary Islands; one had >20 µg/g of lead in dry weight.

Several studies have been conducted to evaluate lead exposure in European raptors by tissue analysis of birds admitted to wildlife rehabilitation centers. Hontelez et al. (1992) found one Common Buzzard (*Buteo buteo*) (n=28) in the Netherlands with 22.5 µg/g in dry weight of bone. Jager et al. (1996) found 11 Common Buzzards (n=80) with outlying total burden of lead in liver of >20 µg and kidney (>6 µg) in the Netherlands, and elevated liver lead levels were also found in Common Buzzards from Denmark (Clausen and Wolstrup 1979). One case of lead poisoning in a Honey Buzzard (*Pernis apivorus*) was also described in the Netherlands (Lumeij et al. 1985). Pain and Amiard-Triquet (1993) found >15 µg/g of lead in dry weight of liver in three Common Buzzards (n=85), one Northern Goshawk (*Accipiter gentilis*) (n=1), and two Eurasian Sparrowhawks (*Accipiter nisus*) (n=30) from France. In the UK, Pain et al. (1995) found two Common Buzzards (n=56) and two Peregrine Falcons (*Falco peregrinus*) (n=26) with >15 µg/g of lead in dry weight of liver, and levels >6 µg/g in six other species, including Merlin (*Falco columbarius*) (6 of 63) and Golden Eagle (2 of 7). In Germany, two Northern Goshawks among 62 birds found dead or moribund had liver lead levels of 51 and 6.5 µg/g wet weight, respectively (Kenntner et al. 2003). In Italy, Battaglia et al. (2005) found two Common Buzzards (n=18) with >20 µg/g of lead in dry weight of liver. In Spain, Pérez-López et al. (2008) found one Common Buzzard (n=44) with a liver lead level of 18.1 µg/g dry weight. Lead shot ingestion has been studied by analysis of regurgitated pellets in several additional species of birds of prey from Doñana (Spain) (Mateo et al. 2007a; Table 5).

Nocturnal raptors are also exposed to lead shot, but few studies have been done. One Eurasian Eagle Owl (*Bubo bubo*) (n=42) from Central Spain showed 185 µg/g of lead in dry weight of bone (Mateo et al. 2003) and another from southeastern Spain (n=9) had 43 µg/g of lead in dry weight of bone (García-Fernández et al. 1997). One Long-eared Owl (*Asio otus*) was found dead of lead poisoning in Madrid (Spain) close to a pigeon shooting range (Brinzal 1996), and one Barn Owl (*Tyto alba*) was found in northern Spain with 73 µg/g of lead in wet weight of liver (González et al. 1983).

REGULATORY ACTIONS ON LEAD SHOT

The use of lead shot for hunting has been regulated in 14 countries of Europe (Table 6). All except one of these countries are within the European Union (EU), but no common EU regulation exists on lead ammunition. Despite the role of the EU in the regulation of chemical substances, including lead (Thomas and Guitart 2005), the European Commission (EC), responsible for designing, implementing and managing policy and legislation within the EU, has not taken any action on lead ammunition. The Ornis Committee, that makes decisions to implement the Birds Directive (79/409/EEC) initiated by the EC, has only recommended to member states to take their own measures (Beintema 2004).

The international conventions promoting the regulation of lead shot use for hunting have been reviewed by Thomas and Owen (1996), Beintema (2004) and Thomas and Guitart (2005). The Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention) and the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) of the Convention on the Conservation of the Migratory Species of Wild Animals (CMS, the Bonn Convention) have been the most explicit about enforcing the ban of lead shot. Paragraph 4.1.4 of the Action Plan of AEWA stated that "Parties shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000." All the countries with some regulation about lead ammunition are parties of the Bern Convention and all but one are parties of the AEWA. Moreover, the Declaration on Risk Reduction for Lead was adopted in 1996 by the Environment Ministers from the Organisation for

Table 6. Summary of international agreements and regulations on lead ammunition in Europe by 2007. See text for explanation of agreements.

Country	International Agreements							Shot pellets		
	EU[a]	OECD[b]	CMS[c]	AEWA[d]	Bern[e]	CBD[f]	Ramsar sites[g] Surface (ha)	Waterfowl & wetlands	Upland game	Bullets
Albania	-	-	+	+	+	+	83,062	-	-	-
Andorra	-	-	-	-	+	+	-	-	-	-
Armenia	-	-	-	-	+	+	492,239	-	-	-
Austria	+	+	-	-	+	+	122,372	-	-	-
Azerbaijan	-	-	-	-	+	+	99,560	-	-	-
Belarus	-	-	+	-	-	+	283,107	-	-	-
Belgium	+	+	+	+	+	+	42,938	(+)[h]	(+)	-
Bosnia & Herzegovina	-	-	-	-	-	+	10,911	-	-	-
Bulgaria	+	-	+	+	+	+	20,306	-	-	-
Croatia	-	-	+	+	+	+	86,579	-	-	-
Cyprus	+	-	+	-	+	+	1,585	(+)	-	-
Czech Republic	+	+	+	+	+	+	54,656	-	-	-
Denmark	+	+	+	+	+	+	2,078,823	+	+	-
Estonia	+	-	-	-	+	+	225,960	-	-	-
Finland	+	+	+	+	+	+	799,518	+	-	-
France	+	+	+	+	+	+	828,803	+	-	-
Georgia	-	-	+	+	-	+	34,480	-	-	-
Germany	+	+	+	+	+	+	843,109	(+)	(+)	(+)
Greece	+	+	+	+	+	+	163,501	-	-	-
Hungary	+	+	+	+	+	+	235,430	(+)	-	-
Iceland	-	+	-	-	+	+	58,970	-	-	-
Ireland	+	+	+	+	+	+	66,994	-	-	-
Italy	+	+	+	+	+	+	59,796	-	-	-
Latvia	+	-	+	+	+	+	148,363	(+)	-	-
Liechtenstein	-	-	+	-	+	+	101	-	-	-
Lithuania	+	-	+	+	+	+	50,451	-	-	-
Luxembourg	+	+	+	+	+	+	17,213	-	-	-
Macedonia	-	-	+	+	+	+	21,616	-	-	-
Malta	+	-	-	-	+	+	16	-	-	-
Moldova	-	-	+	+	+	+	94,705	-	-	-
Monaco	-	-	+	+	+	+	10	-	-	-
Montenegro	-	-	-	-	-	+	20,000	-	-	-
The Netherlands	+	+	+	+	+	+	818,908	+	+	-
Norway	-	+	+	-	+	+	116,369	+	+	-
Poland	+	+	+	-	+	+	145,075	-	-	-
Portugal	+	+	+	+	+	+	73,784	-	-	-
Romania	+	-	+	+	+	+	682,166	-	-	-
Russia	-	-	-	-	-	+	10,323,767	-	-	-
San Marino	-	-	-	-	-	+	-	-	-	-
Serbia	-	-	+	-	+	+	53,714	-	-	-
Slovakia	+	+	+	+	+	+	40,697	-	-	-
Slovenia	+	-	+	+	+	+	8,205	-	-	-
Spain	+	+	+	+	+	+	281,768	(+)	-	-

Country	International Agreements							Shot pellets		
	EU[a]	OECD[b]	CMS[c]	AEWA[d]	Bern[e]	CBD[f]	Ramsar sites[g] Surface (ha)	Waterfowl & wetlands	Upland game	Bullets
Sweden	+	+	+	+	+	+	514,506	+	+	+
Switzerland	-	+	+	+	+	+	8,676	+	-	-
Turkey	-	+	-	-	+	+	179,482	-	-	-
Ukraine	-	-	+	+	+	+	744,651	-	-	-
United Kingdom	+	+	+	+	+	+	917,988	(+)	-	-

[a] http://europa.eu/, [b] http://www.oecd.org/, [c] http://www.cms.int/, [d] http://www.unep-aewa.org/, [e] http://europa.eu/scadplus/leg/en/lvb/l28050.htm, [f] http://www.cbd.int/, [g] http://www.ramsar.org/, [h] (+) Only implemented in some regions or in some protected areas.

Economic Co-operation and Development (OECD). The purpose of this Declaration was to advance national and co-operative efforts to reduce the risk from exposure to lead, and one of the priority actions was to restrict the use of lead shot in wetlands (Beintema 2004). Two other international agreements, the Convention on Biological Diversity (CBD) and the Convention on Wetlands (the Ramsar Convention), identify the conservation of critical habitats for migratory birds, but do not make specific recommendations to ban lead shot (Thomas and Guitart 2005).

The regulatory actions adopted by European countries have been diverse in the extent and form of application (AEWA 2008). Denmark started with the ban on the use of lead shot for target shooting over wetlands in 1981, for hunting in Ramsar areas in 1985, and for shooting over small lakes and for target shooting over agricultural land in 1986. Moreover, from 1986, a maximum of 28 g of lead in each cartridge was allowed (Clausen 1992). Denmark enforced a total ban on the use and possession of lead shot in 1996 (Kuivenhoven et al. 1998, Kanstrup 2006). In Greenland, lead shot is being used, but the ban will be implemented in the next few years (AEWA 2008). The Netherlands totally banned the use of lead shot in all its territory in 1993, and possession has been illegal since 1998 (Kuivenhoven et al. 1998, Beintema 2000). Norway banned lead shot for waterfowl hunting in 1991 and has extended this to all types of hunting (Beintema 2001, Kanstrup and Potts 2008). Finland banned lead shot for waterfowl hunting in 1996 (Scheuhammer and Norris 1996). Lead shot was banned first in Sweden for waterfowl hunting within Ramsar areas (Scheuhammer and Norris 1996), for goose and duck hunting in 1998; in 2002 the Swedish government introduced a ban on lead ammunition to be fully implemented in 2008 (2002 for wetlands, 2006 for lead shot everywhere, and 2008 for bullets) (AEWA 2005). In the Flemish region of Belgium, waterfowl hunting with lead shot has been forbidden in Ramsar areas since 1993, and in 1998 this ban was extended to all EU Bird Directive areas (Beintema 2001). A total ban on the use of lead shot was adopted in 2003 in protected areas, and this will be extended to the remainder by 2008 (AEWA 2005). In the Walloon region, the restriction applies to hunting in wetlands, although coated lead pellets ('cartouches à plomb nickelés') are still allowed (AEWA 2008). In Switzerland, a ban on the use of lead shot in shallow water areas and wetlands was introduced in 1998 (Beintema 2001). Latvia banned lead shot for waterfowl hunting at the Natural Park Lake Engure in 1998 and this was later extended to other nature reserves (Beintema 2001). In the UK, different regulations have been adopted by the different countries. In 1999, England banned shooting with lead shot on or over any area below high-water mark of ordinary spring tides, specific sites of special scientific interest, or certain waterbird species. The same regulation was adopted by Wales in 2002. Scotland banned lead shot for shooting on or over wetland areas in 2005. In Northern Ireland, there is a voluntary ban, but a statutory ban is proposed for 2008/2009 (AEWA 2008). Spain banned the use and possession of lead

shot in Ramsar areas and other protected wetlands in 2001, and this was extended in 2007 to all the Natura 2000 wetlands. Before that, the use of lead shot for hunting in wetlands was initially banned in the regions of the Balearic Islands in 1995 and Castilla-La Mancha in 1999. France banned lead shot for hunting in wetlands in 2006 (J.-Y. Mondain-Monval pers. comm.). That implementation was stimulated by the experiences of North American hunters on the use of non-toxic shot (Mondain-Monval 1999). Several regions of Germany have banned lead shot for hunting waterfowl near waterbodies: Baden-Württemberg, Bavaria, Berlin, Brandenburg, Mecklenburg-West Pomerarnia, Lower Saxony, North Rhine-Westfalia and Thuringia (AEWA 2005); while Schleswig-Holstein extended the ban to waterfowl shot in terrestrial habitats (N. Kenntner pers. comm.). Moreover, the federal state Government of Brandenburg prohibited the use of any lead ammunition, including lead bullets for game hunting in the federal forests in the year 2005 (AEWA 2005, Kenntner et al. 2007). At a national scale, the German Federal Government and hunter's associations made in 1993 a recommendation to use non-toxic shot for waterfowl hunting in wetlands (Beintema 2001). Hungary has banned lead shot for hunting in Ramsar areas and other wetlands since 2005 (AEWA 2005, Kanstrup and Potts 2008). Lead shot is banned in wetlands in Cyprus (AEWA 2008). In the Russian Federation, there are some restrictions on waterfowl hunting in some areas that will reduce lead poisoning in waterbirds (Beintema 2001). Portugal prepared a ban of lead shot for all hunting in Ramsar areas for 2007/08 and plans to extend this to all waterbird hunting in 2008/09 (D. Rodrigues pers. comm.). The phasing out of lead shot use is in progress in the Czech Republic (by 2010), Slovakia (by 2015), and Croatia and Italy (AEWA 2005, 2006, 2008, Kanstrup and Potts 2008).

These advances in the regulation of the use of lead ammunition in Europe have been slow, and the result is a patchy distribution of countries where lead shot input into the wetlands has been stopped, other countries where lead shot can be used in some of the wetlands, and others with no regulation as yet (Table 6). The EU should take a stronger position on this issue to protect the African-Eurasian migratory flyway because this is a problem originated by the developed countries where lead hunting ammunition has been intensively used for decades. As a first step, the Federation of Associations for Hunting and Conservation of the EU (FACE) and BirdLife International (FACE-BirdLife 2004) havesigned an agreement as part of the EC's Sustainable Hunting Initiative under the auspices of the Birds Directive. Both organizations ask for the phasing out of the use of lead shot for hunting in wetlands throughout the EU as soon as possible, and no later than 2009. Similarly, the International Council for Game and Wildlife Conservation (CIC 2007) recommend to the authorities in countries where lead shot is still used for hunting in wetlands to begin a process of phasing out such use as soon as possible, and at the latest by 2010.

Little action has been taken to phase out lead shot for upland game hunting. Driven shooting of partridges and pheasants produces significant accumulation of lead shot in the soil of intensively hunted estates, indicating that the same regulations as in wetlands should be applied. Based on the Precautionary Principle of the Rio Declaration on Environment and Development, the input of lead into these upland hunting estates should cease before the damage has been produced (Thomas 1997), and this damage has already been revealed in several studies. In the adoption of such regulations, the exposure to humans through the consumption of lead-exposed birds (Guitart et al. 2005) or game meat with embedded lead pellets or bullet fragments (Johansen et al. 2001, 2004; Mateo et al. 2007b) should also be considered.

ACKNOWLEDGMENTS

I wish to thank N. Kenntner, J.-Y. Mondain-Monval and D. Rodrigues for information about the status of the regulatory actions adopted in their countries, and to the UNEP/AEWA Secretariat for the submission of the draft of the last update report on the use of non-toxic shot. I also thank U. Hofle for help with the English revision.

LITERATURE CITED

AEWA. 2005. Third Session of the Meeting of the Parties to the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), 23-27 October 2005, Dakar, Senegal. [Online.] Available at www.unep-aewa.org

AEWA. 2006. Fourth Meeting of the Standing Committee, 20-21 November 2006, Bonn, Germany. [Online.] Available at www.unep-aewa.org

AEWA. 2008. 8th Meeting of the Technical Committee, 3-5 March 2006, Bonn, Germany. [Online.] Available at www.unep-aewa.org

ALLOUCHE, L. 1983. Alimentation comparée du Canard Chipeau *Anas strepera* et de la Foulque Macroule *Fulica atra* pendant leur hivernage en Camargue. Rapport Diplôme d'Études Approfondies, Montpelier, France.

AMIARD-TRIQUET, C., D. J. PAIN, AND H. T. DELVES. 1991. Exposure to trace elements of Flamingos living in a Biosphere Reserve, the Camargue (France). Environmental Pollution 69:193-201.

ANCORA, S., N. BIANCHI, C. LEONZIO, AND A. RENZONI. 2008. Heavy metals in Flamingos (*Phoenicopterus ruber*) from Italian wetlands: The problem of ingestion of lead shot. Environmental Research 107:229-236.

ANGER, H. 1971. Gamebird diseases. The Game Conservancy Trust Annual Review 2:51-53.

ARCANGELI, G., A. MANFRIN, G. BINATO, R. DE NARDI, S. VOLPONI, M. VASCELLARI, F. MUTINELLI, AND C. TERREGINO. 2007. Avvelenamento da piombo in uccelli selvatici. Obiettivi & Documenti Veterinari 9:39-45.

AYAŞ, Z., AND D. KOLANKAYA. 1996 Accumulation of some heavy metals in various environments and organisms at Göksu Delta, Türkiye, 1991-1993. Bulletin of Environmental Contamination and Toxicology 56:65-72.

BATTAGLIA, A., S. GHIDINI, G. CAMPANINI, AND R. SPAGGIARI. 2005. Heavy metal contamination in Little Owl (*Athene noctua*) and Common Buzzard (*Buteo buteo*) from northern Italy. Ecotoxicology and Environmental Safety 60:61-66.

BAYLE, P., F. DERMAIN, AND G. KECK. 1986. Trois cas de saturnisme chez le Flamant Rose *Phoenicopterus ruber* dans la region de Marseille. Bulletin de la Societé Linneane de Provence 38:95-98.

BECK, N., AND P. GRANVAL. 1997. Ingestion de plombs de chasse par la Bécassine del Marais (*Gallinago gallinago*) et la Bécassine Sourde (*Lymnocryptes minimus*) dans le nord-ouest de la France. Gibier Faune Sauvage 14:65-70.

BEER, J. V., AND P. STANLEY. 1965. Lead poisoning in the Slimbridge wildfowl collection. Wildfowl 16:30-34.

BEINTEMA, N. 2001. Lead Poisoning in Waterbirds. International Update Report 2000. Wetlands International, Wageningen, The Netherlands.

BEINTEMA, N. 2004. Non-toxic shot: a path towards sustainable use of the waterbird resource. Technical Series No. 3. UNEP/AEWA Secretariat, Bonn, Germany.

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

BEYER, W. N., D. J. AUDET, G. H. HEINZ, D. J. HOFFMAN, AND D. DAY. 2000. Relation of waterfowl poisoning to sediment lead concentrations in the Coeur d'Alene River Basin. Ecotoxicology 9:207-218.

BEZZEL, E., AND H.-J. FÜNFSTÜCK. 1995. Alpine Steinadler *Aquila chrysaetos* durch bleivergiftung gefährdet? Journal für Ornithologie 136:294-296.

BIRDLIFE INTERNATIONAL. 2004. Birds in Europe: Population Estimates, Trends and Conservation Status. BirdLife International, Wageningen, The Netherlands.

BIRKHEAD, M. 1982. Causes of mortality in the Mute Swan *Cygnus olor* on the River Thames. Journal of Zoology 198:15-25.

BIRKHEAD, M. 1983. Lead levels in the blood of Mute Swans *Cygnus olor* on the River Thames. Journal of Zoology 199:59-73.

BONET, A., C. OLIVARES, M. L. PICÓ, AND S. SALES. 1995. L'acumulació de perdigons de plom al Parc Natural del Fondó d'Elx (Alacant): distribució espacial i propostes d'actuació. Butlletí de la Instució Catalana d'Història Natural 63:149-166.

BONET, A., B. TERRONES, AND J. PEÑA. 2004. El Hondo, a la cabeza en cantidad de perdigones de plomo depositados. Quercus 221:66-67.

BORG, K. 1975. Viltjukdomar. L.T.'s Forlag Helingoorg.

BRINZAL. 1996. S.O.S. Venenos: Búho Chico. Quercus 124:45.

BUTLER, D. A. 2005. Incidence of lead shot ingestion in Red-legged Partridges (*Alectoris rufa*) in Great Britain. Veterinary Record 157:661-662.

BUTLER, D. A., R. B. SAGE, R. A. H. DRAYCOTT, J. P. CARROLL, AND D. POTTS. 2005. Lead exposure in Ring-necked Pheasants on shooting estates in Great Britain. Wildlife Society Bulletin 33:583-589.

CALVERT, H. S. 1876. Pheasants poisoned by swallowing shot. The Field 47:189.

CAMPREDON, P. 1984. Régime alimentaire du canard siffleur pendant son hivernage en Camargue. L'Oiseau et R.F.O. 54:189-200.

CERRADELO, S., E. MUÑOZ, J. TO-FIGUERAS, R. MATEO, AND R. GUITART. 1992. Intoxicación por ingestión de perdigones de plomo en dos Águilas Reales. Doñana, Acta Vertebrata 19:122-127.

CHAPMAN, A., AND W. J. BUCK. 1893. Wild Spain. Gurney and Jackson, London, UK.

CIC. 2007. Migratory Bird Commission Recommendation. Phasing out of Lead Shot for Hunting in Wetlands. 54th General assembly, 2-5 May 2007, Belgrade, Serbia. [Online.] Available at www.cic-wildlife.org

CLAUSEN, B. 1992. Lead poisoning control measures in Denmark. Pages 68-70 *in* D. J. Pain (Ed.). Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop, Brussels, Belgium, 13–15 June 1991. International Waterfowl and Wetlands Research Bureau Special Publication 16, Slimbridge, UK.

CLAUSEN, B., AND C. WOLSTRUP. 1979. Lead poisoning in game from Denmark. Danish Review of Game Biology 11:1-22.

CORDEL-BOUDARD, C. 1983. Le saturnisme chez les Anatidés en Dombes. Thèse Docteur Vétérinaire. Ecole Nationale Vétérinaire de Lyon, France.

DANELL, K. 1980. The detrimental effects of using lead shot for shooting waterfowl. Rapport Institutionen för Viltekologi 4: 1-51.

DANELL, K., AND A. ANDERSSON. 1975. Blyhagelforekomst i andmager. Statens Naturvarksverk 538:1-23.

DANELL, K., A. ANDERSSON, AND V. MARCSTROM. 1977. Lead shot dispersed by hunters – ingested by ducks. Ambio 6:235-237.

DEL BONO, G. 1970. Il saturnismo degli ucelli acquatici. Annali della Facolta di Medicina Veterinaria de Pisa 23:102-151.

DI MODUGNO, G., A. CAMARDA, AND N. ZIZZO. 1994. Avvelenamento da piombo in Cigni Reali (*Cygnus olor*) di passo nella peninsola Salentina. Zootecnica International, 15-16: 90-94.

DONÁZAR, J. A., C. J. PALACIOS, L. GANGOSO, O. CEBALLOS, M. J. GONZÁLEZ, AND F. HIRALDO. 2002. Conservation status and limiting factors in the endangered population of Egyptian Vulture (*Neophron percnopterus*) in the Canary Islands. Biological Conservation 107:89-97.

DURANEL, A. 1999. Effets de l'ingestion de plombs de chasse sur le comportament alimentaire et la condition corporelle du Canard Colvert (*Anas platyrhynchos*). Thèse Docteur Vétérinaire. Ecole Nationale Vétérinaire de Nantes, France.

ERNE, K., AND K. BORG. 1969. Lead poisoning in Swedish wildlife. Ecological Research Committee Bulletin 5:31-33.

FACE-BIRDLIFE (2004). Agreement between BirdLife International and the Federation of Associations for Hunting and Conservation of the EU on the Directive 79/409/EEC. [Online.] Available at www.face-europe.org

FALANDYSZ, J., H. ICHIHASHI, K. SZYMCZYK, S. YAMASAKI, AND T. MIZERA. 2001. Metallic elements and metal poisoning among White-tailed Sea Eagles from the Baltic south coast. Marine Pollution Bulletin 42:1190-1193.

FALANDYSZ, J., B. JAKUCZUN, AND T. MIZERA. 1988. Metals and organochlorines in four female White-tailed Eagles. Marine Pollution Bulletin 19:521-526.

FALK, K., F. MERKEL, K. KAMPP, AND S. E. JAMIESON. 2006. Embedded lead shot and infliction rates in Common Eiders *Somateria mollissima* and King Eiders *S. spectabilis* wintering in southwest Greenland. Wildlife Biology 12:257-265.

FERRANDIS, P., R. MATEO, F. R. LÓPEZ-SERRANO, M. MARTÍNEZ-HARO, AND E. MARTÍNEZ-DURO. 2008. Lead-shot exposure in Red-legged Partridge (*Alectoris rufa*) on a driven shooting estate. Environmental Science and Technology 42:6271-6277.

FIGUEROLA, J., R. MATEO, A. J. GREEN, J.-Y. MONDAIN-MONVAL, H. LEFRANC, AND G. MENTABERRE. 2005. Interspecific and spatial variability

in the ingestion of grit and lead shot by waterfowl. Environmental Conservation 32:226-234.

FISHER, I. J., D. J. PAIN, AND V. G. THOMAS. 2006. A review of lead poisoning from ammunition sources in terrestrial birds. Biological Conservation 131:421- 432.

FRANK, A., AND K. BORG. 1979. Heavy metals in tissues of Mute Swans (*Cygnus olor*). Acta Veterinaria Scandinavica 20:447-465.

FRANSON, J. C., T. HOLLMÉN, R. H. POPPENGA, M. HARIO, M. KILPI, AND M. R. SMITH. 2000. Selected trace elements and organochlorines: Some findings in blood and eggs of nesting Common Eiders (*Somateria mollissima*) from Finland. Environmental Toxicology and Chemistry 19:1340-1347.

GALASSO, C. 1976. Caso di avvelenamento da piombo in una Pittima Reale (*Limosa limosa*). Rivista Italiana di Ornitologia 46:117.

GANGOSO, L., P. ÁLVAREZ-LLORET, A. B. RODRÍGUEZ-NAVARRO, R. MATEO, F. HIRALDO, AND J. A. DONÁZAR. 2009. Long-term effects of lead poisoning on bone mineralization in Egyptian Vultures (*Neophron percnopterus*) exposed to ammunition sources. Environmental Pollution 157:569–574.

GARCÍA-FERNÁNDEZ, A. J., E. MARTÍNEZ-LÓPEZ, D. ROMERO, P. MARÍA-MOJICA, A. GODINO, AND P. JIMÉNEZ. 2005. High levels of blood lead in Griffon Vultures (*Gyps fulvus*) from Cazorla Natural Park (southern Spain). Environmental Toxicology 20:459-463.

GARCÍA-FERNÁNDEZ, A. J., M. MOTAS-GUZMÁN, I. NAVAS, P. MARÍA-MOJICA, A. LUNA, AND J. A. SÁNCHEZ-GARCÍA. 1997. Environmental exposure and distribution of lead in four species of raptors in southeastern Spain. Archives of Environmental Contamination and Toxicology 33:76-82.

GARCÍA-FERNÁNDEZ, A. J., J. A. SÁNCHEZ-GARCÍA, P. JIMÉNEZ-MONTALBÁN, AND A. LUNAS. 1995. Lead and cadmium in wild birds in southeastern Spain. Environmental Toxicology and Chemistry 14:2049-2058.

GARCÍA, J. T., AND J. VIÑUELA. 1999. El plumbismo: una primera aproximación en el caso del Milano Real. Pages 213-220 *in* J. Viñuela, R. Martí, and A. Ruiz (Eds.). El Milano Real en España. Sociedad Española de Ornitología/ BirdLife, Madrid, Spain.

GIONFRIDO, J. P., AND L. B. BEST. 1999. Grit use by birds: a review. Current Ornithology 15:89-148.

GONZÁLEZ, J. L. 1991. El Aguilucho Lagunero (*Circus aeruginosus*) en España. ICONA-CSIC, Madrid, Spain.

GONZÁLEZ, L. M., AND F. HIRALDO. 1988. Organochlorine and heavy metals contamination in the eggs of the Spanish Imperial Eagle (*Aquila adalberti*) and accompanying changes in eggshell morphology and chemistry. Environmental Pollution 51:241-258.

GONZÁLEZ, M. J., M. C. RICO, M. C. FERNÁNDEZ-ACEYTUNO, L. M. HERNÁNDEZ, AND G. BALUJA. 1983. Contaminación xenobiótica del Parque Nacional de Doñana. II. Residuos de insecticidas organoclorados, bifenilos policlorados (PCBs) y metales pesados en Falconiformes y Strigiformes. Doñana, Acta Vertebrata 10:177-189.

GUILLEMAIN, M., O. DEVINEAU, J.-D. LEBRETON, J.-Y. MONDAIN-MONVAL, A. R. JOHNSON, AND G. SIMON. 2007. Lead shot and Teal (*Anas crecca*) in the Camargue, Southern France: Effects of embedded and ingested pellets on survival. Biological Conservation 137:567-576.

GUITART, R., S. MAÑOSA, V. G. THOMAS, AND R. MATEO. 1999. Perdigones y pesos de plomo: ecotoxicología y efectos para la fauna. Revista de Toxicología 16:3-11.

GUITART R, J., SERRATOSA, AND V. G. THOMAS. 2002. Lead-poisoned wildfowl in Spain: a significant threat for human consumers. International Journal of Environmental Health Research 12:301-309.

GUITART, R., J. TO-FIGUERAS, R. MATEO, A. BERTOLERO, S. CERRADELO, AND A. MARTÍNEZ-VILALTA. 1994a. Lead poisoning in waterfowl from the Ebro delta, Spain: Calculation of lead exposure thresholds for Mallards. Archives of Environmental Contamination and Toxicology 27:289-293.

GUITART, R., M. TORRA, S. CERRADELO, P. PUIG-CASADO, R. MATEO, AND J. TO-FIGUERAS. 1994b. Pb, Cd, As, and Se concentrations in livers of dead wild birds from the Ebro delta, Spain. Bulletin of Environmental Contamination and Toxicology 52:523-529.

HERNÁNDEZ, M. 1995. Lead poisoning in a free-ranging Imperial Eagle. Supplement to the Journal of Wildlife Diseases 31 (3), Newsletter.

HERNÁNDEZ, M., AND A. MARGALIDA. 2008. Pesticide abuse in Europe: effects on the Cinereous Vulture (*Aegypius monachus*) population in Spain. Ecotoxicology 17: 264-272.

HOFFMANN, L. 1960. Le saturnisme fleau de la sauvagine en Camargue. Terre et Vie 107**:** 120-131.

HOLLAND, G. 1882. Pheasant poisoned by swallowing shot. The Field 59:232.

HOLLMÉN, T., J. C. FRANSON, R. H. POPPENGA, M. HARIO, AND M. KILPI. 1998. Lead poisoning and trace elements in Common Eiders *Somateria mollissima* from Finland. Wildlife Biology 4:193-203.

HOLT, G., A. FROESLIE, AND G. NORHEIM. 1978. Lead poisoning in Norwegian waterfowl. Nord Veterinaermed 30:380-389.

HONTELEZ, L. C. M. P., H. M. VAN DEN DUNGEN, AND A. J. BAARS. 1992. Lead and cadmium in birds in The Netherlands : a preliminary survey. Archives of Environmental Contamination and Toxicology 23:453-456.

HOVETTE, C. 1971. Le saturnisme en Camargue. Union Internationale des Biologistes du Gibier. Actes du X^{e} Congrès, Paris, France.

HOVETTE, C. 1972. Le saturnisme des anatidés de la Camargue. Alauda 40:1-117.

HOVETTE, C. 1974. Le saturnisme des anatidés sauvages. L'Institut Techniche de l'Avicurture, 211:1-4.

IMRE, Á. 1994. Vadkacsák sörét eredetú ólommérgezése. Magyar Állatorvosok Lapja 49: 345-348.

IMRE, Á. 1997. Fácánok sörét eredetu ólommérgezése. Magyar Allatorvosok Lapja 119: 328-330.

JÅGAS, T. 1996. Lead levels and lead poisoning in Swedish *Anseriformes* birds. Ekotoxikologi Nº 47. Uppsala Universitet, Uppsala, Sweden.

JAGER, L. P., F. V. J. RIJNIERSE, H. ESSELINK, AND A. J. BAARS. 1996. Biomonitoring with the Buzzard *Buteo buteo* in the Netherlands: Heavy metals and sources of variation. Journal für Ornithologie 137:295-318.

JOHANSEN, P., G. ASMUND, AND F. RIGET. 2001. Lead contamination of seabirds harvested with lead shot: Implications to human diet in Greenland. Environmental Pollution 112:501-504.

JOHANSEN, P., G. ASMUND, AND F. RIGET. 2004. High human exposure to lead through consumption of birds hunted with lead shot. Environmental Pollution 127:125-129.

KALISIŃSKA, E., W. SALICKI, AND A. JACKOWSKI. 2006. Six trace metals in White-tailed Eagle from northwestern Poland. Polish Journal of Environmental Studies 15: 727-737.

KALISIŃSKA, E., W. SALICKI, K. M. KAVETSKA, AND M. LIGOCKI. 2007. Trace metal concentrations are higher in cartilage than in bones of Scaup and Pochard wintering in Poland. Science of the Total Environment 388:90-103.

KALISIŃSKA, E., W. SALICKI, P. MYSŁEK, K. M. KAVETSKA, AND A. JACKOWSKI. 2004. Using the Mallard to biomonitor heavy metal contamination of wetlands in north-western Poland. Science of the Total Environment 320:145-161.

KANSTRUP, N. 2006. Non-toxic shot-Danish experiences. Page 861 *in* C. G. Boere, C. A. Galbraith, and D. A. Stroud (Eds.). Waterbirds around the World. The Stationery Office, Edinburgh, UK.

KANSTRUP, N., AND D. POTTS. 2008. Lead shot: significant new developments with relevance to all hunters. CIC-News, 4 February 2008. [Online.] Available at www.cic-wildlife.org

KELLY, A., AND S. KELLY. 2004. Fishing tackle injury and blood lead levels in Mute Swans. Waterbirds 27:60-68.

KENNTNER, N., Y. CRETTENAND, H.-J. FÜNFSTÜCK, M. JANOVSKY, AND F. TATARUCH. 2007. Lead poisoning and heavy metal exposure of Golden Eagles (*Aquila chrysaetos*) from the European Alps. Journal of Ornithology 148:173-177.

KENNTNER, N., O. KRONE, R. ALTENKAMP, AND F. TATARUCH. 2003. Environmental contaminants in liver and kidney of free-ranging Northern Goshawks (*Accipiter gentilis*) from three regions of Germany. Archives of Environmental Contamination and Toxicology 45: 128-135.

KENNTNER, N., G. OEHME, D. HEIDECKE, AND F. TATARUCH. 2004. Retrospektive untersuchung zur bleiintoxikation und exposition mit potenziell toxischen schwermetallen von Seeadlern *Haliaaetus albicilla* in Deutschland. Wogelwelt 125:63-74.

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.

KENNTNER, N., F. TATARUCH, AND O. KRONE. 2005. Risk assessment of environmental contaminants in White-tailed Sea-eagles (*Haliaeetus*

albicilla) from Germany. Pages 125-127 *in* K. Pohlmeyer (Ed.). Extended Abstracts of the XXVIIth Congress of the International Union of Game Biologists, Hannover 2005. DSV-Verlag, Hamburg, Germany.

KEYMER, I. F. 1958. A survey and review of the causes of mortality in British birds and the significance of wild birds as disseminators of disease. Veterinary Record 70: 713-720.

KEYMER, I. F., AND R. S. J. STEBBINGS. 1987. Lead poisoning in a Partridge (*Perdix perdix*) after ingestion of gunshot. Veterinary Record 120:276-277.

KIM, E. Y., R. GOTO, H. IWATA, Y. MASUDA, S. TANABE, AND S. FUJITA. 1999. Preliminary survey of lead poisoning of Steller's Sea Eagle (*Haliaeetus pelagicus*) and White-tailed Sea Eagle (*Haliaeetus albicilla*) in Hokkaido, Japan. Environmental Toxicology and Chemistry 18: 448-451.

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

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., 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.

KUIVENHOVEN, P., J. VAN VESSEM, AND E. VAN MAANEN. 1998. Saturnisme des oiseaux d'eau. Rapport d'actualisation internationale 1997. Bulletin Mensuel de l'Office National de la Chasse 229 : 28-31.

LAMBERET, M. 1995. Enquête sur le saturnisme des Anatides en France métropolitaine. Bilan de la saison 1993/94. Rapport de stage BTA GFS – ONC.

LEFRANC, H. 1993. Enquête sur le saturnisme des Anatides en France métropolitaine. Bilan de la saison 1992/93. Rapport de stage BTA GFS – ONC.

LLORENTE, G. A. 1984. Contribución al conocimiento de la biología y la ecología de cuatro especies de anátidas en el delta del Ebro. Tesis Doctoral, Universidad de Barcelona, Barcelona, Spain.

LOCKE, L. N., AND M. FRIEND. 1992. Lead poisoning of avian species other than waterfowl. Pages 19–22 *in* D. J. Pain (Ed.). Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop, Brussels, Belgium, 13-15 June 1991. International Waterfowl and Wetlands Research Bureau Special Publication 16, Slimbridge, UK.

LUMEIJ, J.T., H. HENDRIKS, AND A. TIMMERS. 1989. The prevalence of lead shot ingestion in wild Mallards (*Anas platyrhynchos*) in the Netherlands. Veterinary Quarterly 11: 51-55.

LUMEIJ, J. T., AND H. SCHOLTEN. 1989. A comparision of two methods to establish the prevalence of lead shot ingestion in Mallards (*Anas platyrhynchos*) from The Netherlands. Journal of Wildlife Diseases 25**:**297-299.

LUMEIJ, J.T., W. T. WOLVEKAMP, G. M. BRONDIETZ, AND A. J. SCHOTMAN. 1985. An unusual case of lead poisoning in a Honey Buzzard (*Pernis apivorus*). Veterinary Quarterly 7:165-168.

MACDONALD, J. W., C. J. RANDALL, H. M. ROSS, G. M. MOON, AND A. D. RUTHVEN. 1983. Lead poisoning in captive birds of prey. Veterinary Record 113:65-66.

MARTÍNEZ-HARO, M., R. GUITART, G. LLORENTE, AND R. MATEO. 2005. Seasonal and annual fluctuations of lead poisoning in waterfowl in the Ebro delta, Spain. Pages 146-147 *in* K. Pohlmeyer (Ed.). Extended Abstracts of the XXVIIth Congress of the International Union of Game Biologists, Hannover 2005. DSV-Verlag, Hamburg, Germany.

MATEO, R. 1998. La intoxicación por ingestión de perdigones de plomo en aves silvestres: aspectos epidemiológicos y propuestas para su prevención en España. Tesis Doctoral, Universitat Autònoma de Barcelona, Bellaterra, Spain.

MATEO, R., J. BELLIURE, J. C. DOLZ, J. M. AGUILAR-SERRANO, AND R. GUITART. 1998. High prevalences of lead poisoning in wintering

waterfowl in Spain. Archives of Environmental Contamination and Toxicology 35:342-347.

MATEO, R., A. BONET, J. C. DOLZ, AND R. GUITART. 2000a. Lead shot densities in a site of grit ingestion for Greylag Geese *Anser anser* in Doñana (Spain). Ecotoxicology and Environmental Restoration 3:76-80.

MATEO, R., R. CADENAS, M. MÁÑEZ, AND R. GUITART. 2001a. Lead shot ingestion in two raptor species from Doñana, Spain. Ecotoxicology and Environmental Safety 48:6-10.

MATEO, R., J. C. DOLZ, J. M. AGUILAR-SERRANO, J. BELLIURE, AND R. GUITART. 1997a. An outbreak of lead poisoning in Greater Flamingos *Phoenicopterus ruber roseus* in Spain. Journal of Wildlife Diseases 33:131-134.

MATEO, R., J. ESTRADA, J-Y. PAQUET, X. RIERA, L. DOMÍNGUEZ, R. GUITART, AND A. MARTÍNEZ-VILALTA. 1999. Lead shot ingestion by Marsh Harriers *Circus aeruginosus* from the Ebro delta, Spain. Environmental Pollution 104:435-440.

MATEO, R., A. J. GREEN, C. W. JESKE, V. URIOS, AND C. GERIQUE. 2001b. Lead poisoning in the globally threatened Marbled Teal and White-headed Duck in Spain. Environmental Toxicology and Chemistry 20:2860-2868.

MATEO, R., A. J. GREEN, H. LEFRANC, R. BAOS, AND J. FIGUEROLA. 2007a. Lead poisoning in wild birds from southern Spain: A comparative study of wetland areas and species affected, and trends over time. Ecotoxicology and Environmental Safety 66:119-126.

MATEO, R., AND R. GUITART. 2000. The effects of grit supplementation and feed type on steel-shot ingestion in Mallards. Preventive Veterinary Medicine 44:221-229.

MATEO, R., R. GUITART, AND A. J. GREEN. 2000b. Determinants of lead shot, rice, and grit ingestion in ducks and coots. Journal of Wildlife Management 64:939-947.

MATEO, R., R. GUITART, AND A. MARTÍNEZ-VILALTA. 1997b. Lead shot pellets in the Ebro delta, Spain: Densities in sediments and prevalence of exposure in waterfowl. Environmental Pollution 96:335-341.

MATEO, R., R. MOLINA, J. GRÍFOLS, AND R. GUITART. 1997c. Lead poisoning in a free ranging Griffon Vulture (*Gyps fulvus*). Veterinary Record 140:47-48.

MATEO, R., M. RODRÍGUEZ-DE LA CRUZ, D. VIDAL, M. REGLERO, AND P. CAMARERO. 2007b. Transfer of lead from shot pellets to game meat during cooking. Science of the Total Environment 372:480-485.

MATEO, R., AND M. A. TAGGART. 2007. Toxic effects of the ingestion of lead polluted soil on waterfowl. Proceedings of the International Meeting of Soil and Wetland Ecotoxicology, Barcelona, Spain.

MATEO, R., M. A. TAGGART, A. J. GREEN, C. CRISTÒFOL, A. RAMIS, H. LEFRANC, J. FIGUEROLA, AND A. A. MEHARG. 2006. Altered porphyrin excretion and histopathology of Greylag Geese (*Anser anser*) exposed to soil contaminated with lead and arsenic in the Guadalquivir Marshes, SW Spain. Environmental Toxicology and Chemistry 25: 203-212.

MATEO, R., M. TAGGART, AND A. A. MEHARG. 2003. Lead and arsenic in bones of birds of prey from Spain. Environmental Pollution 126:107-114.

MATHIASSON, S. 1986. Lead in tissue and gizzards of Mute Swan *Cygnus olor* from the Swedish west coast, with remarks on other heavy metals and possible additive and synergetic effects. Vår Fågelvärld Supplement 11:111-126.

MAUVAIS, G., AND L. PINAULT. 1993. Le saturnisme des anatidés (Anatidae) sur le site du Lac de Grand-Lieu (Loire-Atlantique). Gibier Faune Sauvage 10:85-101.

MERKEL, F.R., K. FALK, AND S. E. JAMIESON. 2006. Effect of embedded lead shot on body condition of Common Eiders. Journal of Wildlife Management 70:1644-1649.

MEZIERES, M. 1999. Effets de l'ingestion de plombs de chasse sur la reproduction du Canard Colvert (*Anas platyrhynchos*). Thèse Docteur Vétérinaire. Ecole Nationale Véterinaire de Nantes, France.

MONDAIN-MONVAL, J.-Y. 1999. Programme d'education à la chasse à tir, l'approche nord-américaine. Bulletin Mensuel de l 'Office National de la Chasse 246:26-35.

MONDAIN-MONVAL, J.-Y., L. DESNOUHES, AND J.-P. TARIS. 2002. Lead shot ingestion in waterbirds in the Camargue (France). Gibier Faune Sauvage 19:237-246.

MOORE, J. L., W. L. HOHMAN, T. M. STARK, AND G. A. WEISBRICH. 1998. Shot prevalences and diets

of diving ducks five years after the ban on use of lead shotshells at Catahoula Lake, Louisiana. Journal of Wildlife Management 62:564-569.

MÖRNER, T., AND L. PETERSSON. 1999. Lead poisoning in woodpeckers in Sweden. Journal of Wildlife Diseases 35:763-765.

MUDGE, G. P. 1983. The incidence and significance of ingested lead pellet poisoning in British wildfowl. Biological Conservation 27:333-372.

MUDGE, G. P. 1984. Densities and settlement rates of spent shotgun pellets in British wetland soils. Environmental Pollution 8: 299-318.

MULLER, K., O. KRONE, T. GOBEL, AND L. BRUNNBERG. 2001. Akute bleoontoxication bei zwei Seeadlern (*Haliaeetus albicilla*). Tierarztliche Praxis Ausgabe K: Kleintiere-Heimtiere 29:209-213.

NOER, H., J. MADSEN, AND P. HARTMANN. 2007. Reducing wounding of game by shotgun hunting: effects of a Danish action plan on Pink-footed Geese. Journal of Applied Ecology 44:653-662.

OCHIAI, K., K. JIN, M. GORYO, T. TSUZUKI, AND C. ITAKURA. 1993. Pathomorfologic findings of lead poisoning in White-fronted Geese *Anser albifrons*. Veterinary Pathology 30:522-528.

O'HALLORAN, J., P. F. DUGGAN, AND A. A. MYERS. 1988a. Biochemical and hematological values for Mute Swans *Cygnus olor*: Effects of acute lead poisoning. Avian Pathology 17:667-678.

O'HALLORAN, J., A. A. MYERS, AND P. F. DUGGAN. 1988b. Lead poisoning in swans and sources of contamination in Ireland. Journal of Zoology 216:211-223.

OLNEY, P. J. S. 1960. Lead poisoning in waterfowl. Wildfowl 11:123-134.

OLNEY, P. J. S. 1968. The food and feeding habits of Pochard. Biological Conservation 1: 71-76.

OWEN, M. 1996. A review of the migration strategies of the Anatidae: Challenges for conservation. Gibier Faune Sauvage 13:123-129.

PAIN, D. J. 1990a. Lead shot ingestion by waterbirds in the Camargue, France: An investigation of levels and interspecific differences. Environmental Pollution 66: 273-285.

PAIN, D. J. 1990b. Lead poisoning of waterfowl: a review. Pages 172-181 *in* G. V. T. Matthews (Ed.). Managing Waterfowl Populations. International Waterfowl and Wetlands Research Bureau. Slimbridge, UK.

PAIN, D. J. 1991a. Lead shot densities and settlement rates in Camargue marshes, France. Biological Conservation 57:273-286.

PAIN, D. J. 1991b. L'intoxication saturnine de l'avifaune: Une synthèse des travaux français. Gibier Faune Sauvage 8:79-92.

PAIN D. J. 1992. Lead poisoning in waterfowl: A review. Pages 7-13 *in* D. J. Pain (Ed.). Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop, Brussels, Belgium, 13-15 June 1991. International Waterfowl and Wetlands Research Bureau Special Publication 16, Slimbridge, UK.

PAIN, D. J., AND C. AMIARD-TRIQUET. 1993. Lead poisoning in raptors in France and elsewhere. Ecotoxicology and Environmental Safety 25:183-192.

PAIN, D. J., C. AMIARD-TRIQUET, C. BABOUX, G. BURNELEAU, L. EON, AND P. NICOLAU-GUILLAUMET. 1993. Lead poisoning in wild populations of Marsh Harrier *Circus aeruginosus* in the Camargue and Charente-Maritime, France. Ibis 135:379-386.

PAIN, D. J., C. AMIARD-TRIQUET, AND C. SYLVESTRE. 1992. Tissue lead concentrations and shot ingestion in nine species of waterbirds from the Camargue (France). Ecotoxicology and Environmental Safety 24:217-233.

PAIN, D. J., C. BABOUX, AND G. BURNELEAU. 1997. Seasonal blood lead concentrations in Marsh Harriers *Circus aeruginosus* from Charente-Maritime, France: Relationship with the hunting season. Biological Conservation 81:1-7.

PAIN, D. J., I. CARTER, A.W. SAINSBURY, R. F. SHORE, P. EDEN, M. A. TAGGART, S. KONSTANTINOS, L.A. LAKER, A.A. MEHARG, AND A. RAAB. 2007. Lead contamination and associated disease in captive and reintroduced Red Kites *Milvus milvus* in England. Science of the Total Environment 376:116-127.

PAIN, D. J., AND G. I. HANDRINOS. 1990. The incidence of ingested lead shot in ducks of the Evros delta, Greece. Wildfowl 41:167-170.

PAIN, D. J., A. A. MEHARG, M. FERRER, M. A. TAGGART, AND V. PENTERIANI. 2005. Lead concentrations in bones and feathers of the globally threatened Spanish Imperial Eagle. Biological Conservation 121:603-610.

PAIN, D. J., J. SEARS, AND I. NEWTON. 1995. Lead concentrations in birds of prey in Britain. Environmental Pollution 87:173-180.

PATTEE, O. H., AND S. K. HENNES. 1983. Bald Eagles and waterfowl: the lead shot connection. Pages 230–237 *in* 48th North American Wildlife Conference. The Wildlife Management Institute, Washington, DC, USA.

PENNYCOTT, T. W. 1998 Lead poisoning and parasitism in a flock of Mute Swans (*Cygnus olor*) in Scotland. Veterinary Record 142:13-17.

PERCO, F., S. FOCARDI, C. FOSSI, AND A. RENZONI. 1983. Intossiczione da piombo in due Cigni Reali della Laguna di Marano (Nord-Est Italia). Avocetta 7:105-116.

PÉREZ-LÓPEZ, M., M. HERMOSO DE MENDOZA, A. LÓPEZ BECEIRO, AND F. SOLER RODRÍGUEZ. 2008. Heavy metal (Cd, Pb, Zn) and metalloid (As) content in raptor species from Galicia (NW Spain). Ecotoxicology and Environmental Safety 70:154-162.

PERRINS, C. M., G. COUSQUER, AND J. WAINE. 2003. A survey of blood lead levels in Mute Swans *Cygnus olor*. Avian Pathology 32:205-212.

PETERSEN, B. D., AND H. MELTOFTE. 1979. Forekomst af blyhagl i vestjyske vådområder samt i kråsen hos danske ænder. Dansk Ornitologisk Forenings Tidsskrift 73:257-264.

PINAULT, L. 1996. Evaluation de l'exposition au plomb des canards en France: résultats d'une enquête conduite de 1992 à 1995 en sept sites. Rapport d'étude, Ecole National Vétérinaire de Nantes, France.

PIROT, J.-Y. 1978. Régime alimentaire de la Sarcelle d'été, *Anas querquedula* L., pendant son transient en Camargue. Rapport Diplôme d'Études Approfondies, Paris, France.

PIROT, J.-Y., AND J. P. TARIS. 1987. Le saturnisme des anatides hivernant en Camargue: réactualisation des données. Gibier Faune Sauvage 4:83-94.

POOLE, C. 1986. Surgical treatment of lead poisoning in a Mute Swan (*Cygnus olor*). Veterinary Record 119:501-502.

POTTS, G. R. 2005. Incidence of ingested lead gunshot in wild Grey Partridge (*Perdix perdix*) from the UK. European Journal of Wildlife Research 51:31-34.

RAMO, C., C. SÁNCHEZ, AND L. HERNÁNDEZ SAINT-AUBIN. 1992. Lead poisoning of Greater Flamingos *Phoenicopterus ruber*. Wildfowl 43:220-222.

RODRIGUES, D., M. FIGUEIREDO, AND A. FABIÃO. 2001. Mallard *Anas platyrhynchos* lead poisoning risk in central Portugal. Wildfowl 52:169-174.

RODRIGUES, D., M. FIGUEIREDO, A. FABIÃO., M. C. VAZ, G. SARMENTO, J. FRANÇA, AND J. BACELAR. 2005. Lead poisoning in Portuguese waterfowl. Pages 170-171 *in* K. Pohlmeyer (Ed.). Extended Abstracts of the XXVIIth Congress of the International Union of Game Biologists, Hannover 2005. DSV-Verlag, Hamburg, Germany.

RODRIGUEZ, R., AND F. HIRALDO. 1975. Régimen alimenticio del Calamón *Porphyrio porphyrio* en las Marismas del Guadalquivir. Doñana Acta Vertebrata 2:201-213.

RODRIGUEZ-RAMOS, J., V. GUTIERREZ, U. HÖFLE, R. MATEO, L. MONSALVE, E. CRESPO, J. M. BLANCO. 2009. Lead in Griffon and Cinereous Vultures in Central Spain: Correlations between clinical signs and blood lead levels. Extended Abstract *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.2009.0213

ROSE, P. M. 1995. Western Palearctic and South-West Asia Waterfowl Census 1994. IWRB Publication 35.

SANDERSON, G. C. 1992. Lead poisoning mortality. Pages 14-18 *in* D. J. Pain (Ed.). Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop, Brussels, Belgium, 13-15 June 1991. International Waterfowl and Wetlands Research Bureau Special Publication 16, Slimbridge, UK.

SANDERSON, G. C., AND F. C. BELLROSE. 1986. A review of the problem of lead poisoning in waterfowl. Illinois Natural History Survey Special Publication 4:1-34.

SCHEUHAMMER, A. M., AND S. L. NORRIS. 1996. The ecotoxicology of lead shot and lead fishing weights. Ecotoxicology 5:279-295.

SCHRICKE, V., AND H. LEFRANC. 1994. Enquête sur le saturnisme des anatides en France métropolitaine. Bilan de la saison 1992/93. Bulletin Mensuel de l'Office National de la Chasse 192:2-15.

SEARS, J. 1988. Regional and seasonal variations in lead poisoning in the Mute Swan *Cygnus olor* in relation to the distribution of lead and lead

weights in the Thames area, England. Biological Conservation 46:115-134.

SEARS, J., AND A. HUNT. 1991. Lead poisoning in Mute Swans, *Cygnus olor*, in England. Wildfowl Supplement 1:383-388.

SILEO, L., AND S. I. FEFER. 1987. Paint chip poisoning of Laysan Albatross at Midway atoll. Journal of Wildlife Diseases 23:432-437.

SIMPSON, V. R., A. E. HUNT, AND M. C. FRENCH. 1979. Chronic lead poisoning in a herd of Mute Swans. Environmental Pollution 18:187-202.

SMIT, T., T. BAKHUIZEN, C. P. H. GAASENBEEK, AND L. G. MORAAL. 1988a. Voorkomen van loodkorrels rondjachthutten en kleiduivenbanen. Limosa 61:183-186.

SMIT, T., T. BAKHUIZEN, AND L. G. MORAAL. 1988b. Metallisch lood als bron van loodvergiftiging in Nederland. Limosa 61:175-178.

SOLER-RODRÍGUEZ, F., A. L. OROPESA-JIMÉNEZ, J. P. GARCÍA-CAMBERO, AND M. PÉREZ-LÓPEZ. 2004. Lead exposition by gunshot ingestion in Red-legged Partridge (*Alectoris rufa*). Veterinary and Human Toxicology 46:133-134.

STREET, M. 1983. The assessment of mortality resulting from the ingestion of spent lead shot by Mallard wintering in south-east England. *In* Proceedings of the XI Congress of the International Union of Game Biologists. Trujillo, Spain.

SVANBERG, F., R. MATEO, L. HILLSTRÖM, A. J. GREEN, M. A. TAGGART, A. RAAB, AND A. A. MEHARG. 2006. Lead isotopes and lead shot ingestion in the globally threatened Marbled Teal (*Marmaronetta angustirostris*) and White-headed Duck (*Oxyura leucocephala*). Science of the Total Environment 370:416-424.

TAMISIER, A. 1971. Régime alimentaire des Sarcelles d'hiver, *Anas crecca* L., en Camargue. Alauda 39:261-311.

TAVECCHIA, G., R. PRADEL, J.-D. LEBRETON, A. R. JOHNSON, AND J.-Y. MONDAIN-MONVAL. 2001. The effect of lead exposure on survival of adult Mallards in the Camargue, southern France. Journal of Applied Ecology 38:1197-1207.

THOMAS, G. J. 1975. Ingested lead pellets in waterfowl at the Ouse washes. England 1968-1973. Wildfowl 26:43-48.

THOMAS, G. J. 1982. Lead poisoning in waterfowl. Pages 260-268 *in* Managing Wetlands and their Birds: A Manual of Wetland and Waterfowl Management. International Waterfowl and Wetlands Research Bureau, Slimbridge, UK.

THOMAS, V. G. 1997. Attitudes and issues preventing bans on toxic lead shot and sinkers in North America and Europe. Environmental Values 6:185-199.

THOMAS, V. G., AND R. GUITART. 2005. Role of international conventions in promoting avian conservation through reduced lead toxicosis: Progression towards a non-toxic agenda. Bird Conservation International 15:147-160.

THOMAS, V. G., AND M. OWEN. 1996. Preventing lead toxicosis of European waterfowl by regulatory and non-regulatory means. Environmental Conservation 23:358-364.

TIRELLI, E., N. MAESTRINI, S. GOVONI, E. CATELLI, AND R. SERRA. 1996. Lead contamination in the Mallard (*Anas platyrhynchos*) in Italy. Bulletin of Environmental Contamination and Toxicology 56:729-733.

TROST, R. E. 1981. Dynamics of grit selection and retention in captive Mallards. Journal of Wildlife Management 45:64-73.

USFWS. 1975 Issuance of annual regulations permitting the sport hunting of migratory birds. Final Environmental Statement. U. S. Fish and Wildlife Service, Washington, DC, USA.

VEIGA, J. 1985. Contribution à l'etude du regimen alimentaire de la Bécassine Sourde *Lymnocriptes minimus*. Gibier Faune Sauvage 2:75-84.

WIUM-ANDERSEN, S., AND N. E. FRANSMANN. 1974. Dor andefulge af at spise blyhagl? Feltornithologen 16:14.

ZECHNER, L., T. STEINECK, AND F. TATARUCH. 2005. Bleivergiftung bei einem Steinadler (*Aquila chrysaetos*) in der Steiermark. Egretta 47:157-158.

ZUUR, B. 1982. Zum vorkommen von bleischrotkornern im magen von wasservölgen am Untersee. Ornithologische Beobachter 79:97-103.