Effectiveness of regulations intended to reduce the use of lead shotgun ammunition in and over coastal intertidal and riparian habitats in Scotland

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SUMMARY

The use of lead shot for hunting in wetlands is banned in many countries because ingestion of spent shot causes lead poisoning of wildfowl. In Scotland (UK), the Environmental Protection (Restriction on Use of Lead Shot) (Scotland) (No. 2) Regulations 2004 were introduced to reduce the exposure of wildfowl to lead shot by making its use in wetlands unlawful. We assessed the degree to which the regulations are being complied with by wildfowlers by conducting analyses of the shot metal type contained within shotgun cartridges discarded in coastal intertidal and riparian habitats across Scotland. Despite efforts to encourage compliance with the regulations, which had been in force for 17-18 years at the time of the surveys, about half of the cartridges used appeared to have contained lead gunshot, indicating unlawful use. Hence, efforts to restrict the use of lead ammunition in coastal and riparian wetlands by regulation, with the intention of reducing the risk of lead poisoning of waterfowl, have had limited effectiveness so far.

BACKGROUND

Exposure to lead derived from shotgun and rifle ammunition used for hunting continues to cause poisoning and deaths of a wide range of wild animal species, especially birds (Pain, Mateo & Green 2019). Poisoning of wetland birds, especially wildfowl, by ammunition-derived lead ingested as spent shotgun pellets has been recognised for over 100 years (Wetmore 1919). Consequently, legal restrictions on the use of lead shotgun ammunition in wetlands have been in force in over 33 countries; in some cases, for several decades (Thomas, Kanstrup & Fox 2019). The United Kingdom (UK) government is a Contracting Party to the Agreement on the Conservation of African-Eurasian Migratory Waterbirds and is therefore under a legal obligation to eliminate the use of lead shotgun ammunition in and over UK wetlands (AEWA 1999, 2002, 2008). In Scotland, the Environmental Protection (Restriction on Use of Lead Shot) (Scotland) (No. 2) Regulations 2004 came into force in 2005, making it an offence to use lead shotgun ammunition in Scotland on or over wetlands. Other restrictions with similar intended results apply in England, Wales and Northern Ireland.

In England, compliance with the relevant regulations has been monitored in several shooting seasons by purchasing carcasses of wild-shot ducks from retailers, recovering shotgun pellets embedded in them and identifying their principal metal type (Cromie *et al.*, 2002, 2010, 2015, 2022). This method is appropriate in England because the regulations there prohibit the shooting of all Anatidae (ducks and geese), Eurasian coot *Fulica atra* and common moorhen *Gallinula chloropus* with lead ammunition, regardless of which habitat they were in or over when shot. The same approach to monitoring compliance cannot be used in Scotland because the regulations there apply only to wetland areas, rather than to quarry species. Hence, waterfowl may be killed lawfully in Scotland using lead ammunition, providing that they are shot on or over habitats not defined as wetlands.

The regulations in Scotland define wetlands according to characteristics set out in Article 1.1 of the Ramsar Convention (Ramsar Convention Secretariat 2013). Some areas, such as temporary wetlands and wetlands within peatlands, are difficult to classify unambiguously and there is no definitive published map of Scotland showing all the areas where the use of lead ammunition for hunting is prohibited under the regulations. However, it is uncontested that all areas of foreshore in Scotland below the high-water mark of ordinary spring tides on coasts and along rivers are classified as wetlands under the regulations. The principal quarry species of hunters, who are usually referred to as wildfowlers in the UK, in these

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habitats are ducks and geese. The principal objective of our study was to assess compliance with the wetland lead regulations by wildfowlers on coastal intertidal and riparian habitats in Scotland 17-18 years after the regulations came into force. We did this by estimating the proportion of discarded spent shotgun cartridges recovered from the foreshore and along rivers which had contained different types of shot.

ACTIONS

Regulation of the use of lead shot in Scottish wetlands

Often referred to as the Lead Shot Regulations, the provisions of the Environmental Protection (Restriction on Use of Lead Shot) (Scotland) (No. 2) Regulations 2004, came into effect in Scotland on 31st March 2005 and continue to be in force at the time of writing. This statutory instrument's introduction, and that of similar measures in the other UK countries, followed previous unsuccessful efforts to phase out the use of lead ammunition in wetlands by voluntary means (Stroud 2015).

Efforts to enforce and encourage compliance with the regulations

UK shooting and countryside management non-governmental organisations have consistently encouraged wildfowlers to comply with the lead regulations throughout the UK and, since the mid-1990s, have provided their members with information on the availability and efficacy of non-lead shotgun ammunition (e.g. BASC 2009). However, monitoring of lead concentrations in samples of blood from live-captured wildfowl at Caerlaverock (Dumfries & Galloway, Scotland) during the 2010/2011 winter showed that 41% of birds (n = 145) had elevated concentrations (>20.0 µg/dL) (Newth *et al.* 2012), despite 6 years having elapsed since the regulations came into force in Scotland. Studies of proportions of wild-shot ducks killed in England using lead shotgun ammunition showed that compliance with the lead regulations there has remained low (Cromie *et al.*, 2002, 2010, 2015, 2022). The blood lead results from Caerlaverock suggested that the same might also be true in Scotland. However, at that time there had been no direct studies of the types of ammunition used in Scottish wetlands. Some shooting and countryside management organisations responded to these indications of low compliance in 2013 with the 'Use Lead Legally' campaign which was intended to encourage wildfowlers to comply with the lead regulations in all UK countries. This initiative was widely reported in the shooting media and in the magazines of shooting organisations (BASC 2013). We have not found any evidence of efforts by the police or other authorities to enforce the lead regulations in Scotland and are not aware of any prosecutions being taken for infringements.

Collection of discarded cartridge cases

Our objective was to assess the effectiveness of the statutory instrument by estimating the proportions of lead and non-lead shotgun cartridges used on and over coastal intertidal and riparian habitats by collecting the discarded cases of fired cartridges. Two of the authors (REG and DO-E) used personal contacts with potential co-workers who make regular visits to coastal intertidal and riparian habitats in Scotland to identify a group of co-workers willing to collect discarded cartridge cases. Some wildfowlers collect and remove their fired cartridge cases, which would then not be available for our surveyors to find. The extent to which this occurs has not been quantified, but we assumed that the proportion of fired cases discarded was similar for different shot metal types. Collections were made in the wildfowl shooting seasons (1st September – 20th February) of 2021/2022 and 2022/2023. Cartridge cases were dried and placed in bags and labelled with the date and place of collection as a six-figure Ordnance Survey grid reference (accurate to 100 m). Surveyors were asked not to publicise or otherwise draw attention to their survey work.

Identification of shot type

All cartridge case collections were sent to one of the authors (REG) who transcribed the inscriptions printed by cartridge manufacturers on the outside of the cylinder of the case (or cup). These inscriptions were checked against information on products listed on manufacturers' websites to identify the principal type of metal from which the shot in a cartridge were made. Some cartridge cases had no legible inscription, either because the wildfowler had loaded shot into a plain case (self-loading) or because the inscription had been abraded away by exposure to sediment and weathering. These cases were recorded as having contained shot of an unknown type. Cartridge cases have a brass head enclosing the primer and powder charge. REG scored the amount of corrosion of the brass head of each cartridge case by eye on an ordinal scale ranging from zero (no corrosion visible) to 5 (surface of the brass head entirely corroded or head missing with traces of corrosion on the plastic case). This was done as soon as possible after the cartridge cases were received and retained examples of typical cartridges with each of the scores were checked in each scoring session to ensure consistency. Examples of cartridge cases with each of the scores are shown in Figure 2. We assumed that the corrosion score was an ordinal proxy variable for the time elapsed since the cartridge was fired and its case was discarded, but the relationship between corrosion score and time elapsed was not quantified.

Characteristics of collection sites

We used a mapped database (NatureScot 2022) to identify areas protected by various designations within 100 m of each collection site grid reference. We also used a portal provided by ArcGIS Pro (2022) to identify collection sites within 100 m of Crown Estates Scotland Assets. We then summarised all the collection information by Ordnance Survey (OS) 1-km grid squares, with each collection site being assigned to the 1-km square in which its six-figure grid reference lay.

Statistical analysis

The parameter we wished to estimate was the proportion of discarded cartridge cases which had probably contained lead shot. Because some cases had contained shot of an unknown type, we calculated values using three methods: Method A ($P_{Pb/A}$) – the proportion of lead cartridges, assuming that those with unknown shot types had all contained non-lead shot; Method B ($P_{Pb/B}$) – lead cartridges as a proportion of those with all known shot types; and Method C ($P_{Pb/C}$) – the proportion of lead cartridges assuming that those with unknown shot types had all contained lead shot. Methods A and C give minimum and maximum values for the proportion with lead respectively. Method B gives an intermediate value, which we took to be the consensus estimate. It was evident from the data on dates and places of collection, cartridge case brands and corrosion scores that wildfowlers had often discarded several cartridge cases at a collection site of the same type and at the same time. For this reason, our observations are obviously pseudo-replicated, but the degree of pseudo-replication is difficult to quantify formally because cartridge cases from the same gun and shooting day might well have been discarded at different places within a 1-km grid square. It would be misleading to calculate the precision of estimates of the proportions of cases containing lead and non-lead ammunition by assuming that each individual case record represented a statistically independent observation. Instead, we used a bootstrap procedure in which the results from each of the *n* 1-km grid squares from which cases were collected were assumed to be independent of results from the other squares. We took a bootstrap sample of data on cartridge types by summing cartridge case numbers across *n* squares selected at random, with replacement, from the dataset of *n* observed squares. We calculated the proportions of lead cartridge cases for each bootstrap sample. We repeated this procedure for 10,000 bootstrap samples, ranked the bootstrap values of proportion of lead cases from lowest to highest and took the bounds of the central 9,500 values to define the 95% confidence limits of the overall proportion. The problem of unquantified pseudo-replication made it impractical to conduct a valid statistical test for variation in the proportion of lead cartridges among sampled grid squares.

We described the relationship between $P_{Pb/B}$ and the corrosion score by fitting a logistic regression model to the data for individual cartridge cases with known metal types with lead ammunition (=1) or non-lead (=0) as the binary dependent variable and the corrosion score as the sole independent variable. We used the bootstrap approach described above to obtain 95% confidence limits for the regression coefficient and the values of $P_{Pb/B}$ for each corrosion score unit.

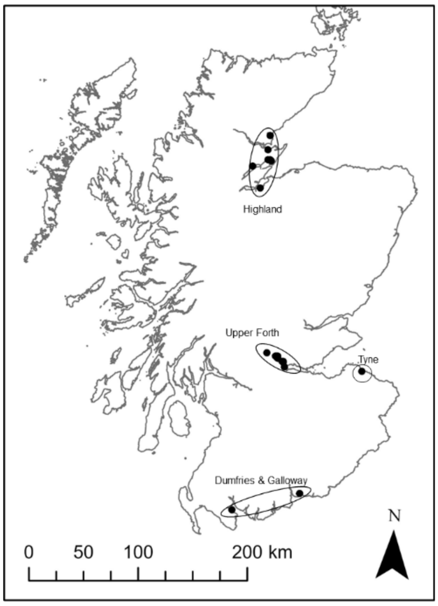

Figure 1. Locations (circles), in Scotland (UK), of centres of 1-km Ordnance Survey squares from which discarded cartridge cases were collected from coastal and riparian habitats. Ellipses show the four regions where collections were made, as shown in Table 1.

CONSEQUENCES

Compliance with the lead regulations

We collected 365 discarded cartridge cases from twenty-one 1-km Ordnance Survey grid squares (Table 1; Figure 1). We found no cases from cartridges containing known-type shot other than lead and steel. We found that a minimum of 167 of the cases we collected (46%) had apparently contained lead shotgun pellets. This is our Method A estimate of the proportion of cases containing lead shot (Table 2). It assumes that all of the 46 cartridge cases for which the shot type was unknown had contained non-lead shot. The

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Method B estimate, assuming that the same proportions of unknown-type and known-type cases contained lead, was 52%. If we assume that all the unknown-type cases contained lead shot (Method C), the estimate was 58% (Table 2). Hence our worst-case and best-case estimates of compliance with the lead regulations (i.e., when non-lead shot was used) produce the range 42% to 54%.

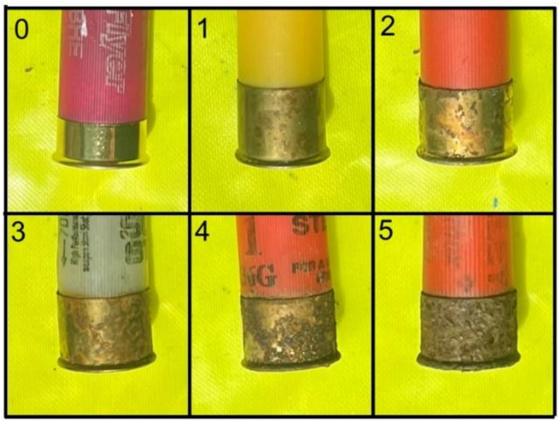

Figure 2. Examples of discarded cartridge cases with each of the six corrosion scores 0 – 5.

There is additional uncertainty associated with all three of the estimates because of the limited number of cartridges collected. We quantified this using confidence limits obtained by bootstrapping by 1-km grid squares. Considering the three methods we used to make the estimates (Methods A, B and C), we recommend taking the lower 95% confidence limit for Method A and the upper 95% confidence limit for Method C to represent the confidence interval (0.362 to 0.671) of the Method B consensus estimate of the proportion of cases which had contained lead shot (Table 2).

Recent trend in compliance with the lead regulations

Although our sampling only covered 2021 – 2023, the cartridge cases collected included some that appeared to have been recently fired and others with substantial corrosion of the brass head of the case, which we took to indicate that they had probably been fired some considerable, but undefined, time before collection. In the few cases where observations of shooting indicated that a batch of cases was the result of shooting within a day or two of collection, the brass heads were all uncorroded (score 0). Assuming the amount of corrosion to be a proxy ordinal variable for the time elapsed since the cartridge was fired, we estimated the trend in the proportion of lead cartridges of those of known type ($P_{Pb/B}$) in relation to corrosion score using logistic regression analysis. The fitted logistic regression model gave no indication of a positive trend of $P_{Pb/B}$ in relation to corrosion score (Figure 3): logit($P_{Pb/B}$) = 0.5478 – 0.1420*SCORE, as would be expected if compliance had increased over time. The 95% bootstrap confidence interval for the regression coefficient (-0.1420) overlapped zero (-0.2663 to 0.0794). Hence, our results provide no evidence that the proportion of cases that contain lead had changed over time during the unknown period during which the collected cartridge cases had been fired.

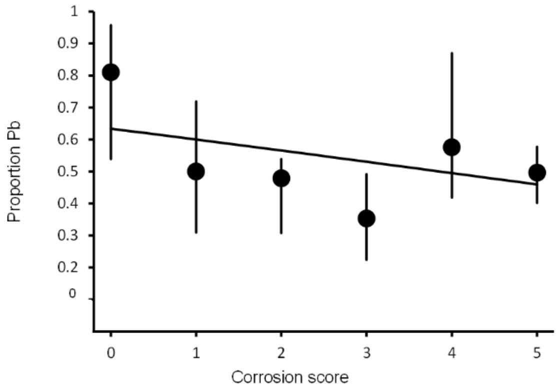

Figure 3. Proportions of discarded cartridge cases which had probably contained lead ammunition, based on cases with known shot type ($P_{Pb/B}$, see text), in relation to the corrosion score of the brass head of the case. Plotted points are $P_{Pb/B}$ values for each score and vertical lines represent their 95% bootstrap confidence intervals. Lower values of the corrosion score indicate less corrosion, which is assumed to indicate more recent use. The $P_{Pb/B}$ values are 0.81, 0.50, 0.48, 0.35, 0.58, and 0.50 for scores 0 to 5 respectively and the sample sizes for these scores are 39, 21, 11, 20, 24 and 98. The curve shows the fitted logistic regression model.

DISCUSSION

As far as we are aware, our study is the first attempt to quantify compliance with the Environmental Protection (Restriction on Use of Lead Shot) (Scotland) (No. 2) Regulations by wildfowlers in Scotland since they came into force in 2005. The regulations in Scotland are based entirely upon the type of habitat in or over which shooting occurs, so measuring the proportions of ducks shot using lead, as has been done repeatedly in England, is not a valid method in Scotland.

Our survey method is subject to four caveats regarding the extent to which its results can be taken to represent the true proportion of cartridges containing lead shot discharged on or over coastal and riparian habitats as a whole. First, we did not sample from all of the coastal and riparian habitats in Scotland. A wider-ranging survey with stratified random sampling based upon the distribution of

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wildfowling effort would be needed to improve substantially upon our results. We do not know of reliable data on the geographical distribution of wildfowling to use in the design of such a survey.

Second, our method is based upon discarded cartridge cases. If wildfowlers who fire lead cartridges are more or less likely to collect spent cartridges and remove them, our estimates would be biased. Given that using lead shot in these habitats is unlawful, wildfowlers might be more likely to remove spent lead than non-lead cartridges to avoid offences being detected. If that were the case, our estimates of compliance might be higher than the true value. Third, most of the sites we surveyed are designated as protected areas (Table 1) and several have professional staff visiting them regularly in the wildfowling season to manage and monitor their status. This monitoring might deter some wildfowlers from illegal use of lead shot and cause our results to overestimate the true mean level of compliance for monitored and unmonitored coastal and riparian sites as a whole. We were careful not to publicise our own surveys locally in advance, so as to avoid any possibility that wildfowlers would respond to them by changing the type of cartridges they used or the extent to which they removed the fired cases.

Finally, some wildfowlers may self-load shot into previously fired cartridge cases marked with brand information indicating that they had originally contained shot of a type different from that self-loaded. Our discussions with wildfowlers suggest that this occurs, but it is probably a rare practice.

A separate issue from potential biases of our survey results for coastal intertidal and riparian habitats is that our study deliberately avoided all other types of wetlands (e.g. inland freshwater bodies and wetlands) where shooting is covered by the lead regulations. We did this because there is no published map showing all the areas of Scotland to which the lead regulations apply. However, we believe that all wildfowlers know that coastal intertidal and riparian habitats are classed as wetlands and that shooting with lead ammunition on or over them is therefore unlawful. Compliance with the lead regulations in other wetlands might be higher or lower, but we suggest that it would be understandable if compliance was lower in non-coastal wetlands because wildfowlers might reasonably believe that their non-coastal shooting site, which would actually be classed as a wetland under the complicated Ramsar definition, was not a wetland and therefore not covered by the regulations.

Although our use of corrosion of brass cartridge heads is only a crude proxy for time elapsed between firing and collection, our study provides no evidence that there has been any marked recent increase in compliance, as indicated by a decline in the use of lead cartridges in our study areas. It is possible that differences among cartridge brands in the composition of the metal used for the heads and differences among areas in the environmental conditions to which spent cases are exposed might obscure a real time trend. A more robust approach to estimating trends might seem to be to conduct repeated surveys and only to monitor the shot types of uncorroded cases. However, publication of repeated surveys might then increase the degree to which lead cartridges are selectively removed by wildfowlers, which would bias the results.

Our study indicates that approximately half of the shotgun cartridges discharged recently in the sampled areas of coastal intertidal and riparian habitats in Scotland had contained lead ammunition, contrary to the lead regulations and 17-18 years after they came into force. Compliance in these habitats in Scotland may be higher than has been repeatedly observed in surveys of wild-shot ducks in England, where approximately 70% of birds are shot unlawfully using lead ammunition (30% compliance; Cromie *et al.*, 2002, 2010, 2015, 2022; Stroud *et al.* 2021). However, we conclude that efforts by shooting groups to encourage compliance with the regulations in Scotland seem to have had limited effectiveness so far in changing the practice of wildfowlers in Scotland after 18 years.

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Table 1. Locations of 1-km Ordnance Survey (OS) grid squares including coasts and rivers in Scotland from which discarded shotgun cartridge cases were collected. Numbers of discarded cases identified as having contained lead shot, steel shot and those for which the metal type could not be identified are shown. Identities of designations of sites overlapping each 1-km square are indicated by superscript letters after the site name (see key below table).

Area	Site	OS 1-km	Lead	Steel	Unknown
Highland	Alness Bay[a,+]	NH6367	0	7	1
Highland	Culloden[b]	NH7047	1	2	4
Highland	Tarbat - Nigg Bay[a]	NH7773	13	15	1
Highland	Nigg Bay[a]	NH7973	10	13	6
Highland	Nigg Bay[a]	NH8072	0	7	0
Highland	Tain[c,f]	NH7782	1	0	0
Highland	Loch Fleet[c,i]	NH7995	1	0	0
Upper Forth	Bridge of Allan[g]	NS7696	2	0	0
Upper Forth	Mouth of Devon	NS8493	3	2	0
Upper Forth	Tullibody Inch[d]	NS8592	11	16	1
Upper Forth	Tullibody Inch[d]	NS8691	3	1	0
Upper Forth	near Cambus[d]	NS8593	32	7	3
Upper Forth	near Alloa[d]	NS8692	26	17	3
Upper Forth	Forth Riverbank[d]	NS8693	3	0	0
Upper Forth	Clackmannanshire Bridge - Higgins Neuk[d]	NS9187	6	5	4
Upper Forth	Higgins Neuk – Dunmore[d]	NS9088	21	14	4
Upper Forth	Kennet Pans[d]	NS9188	1	0	0
Upper Forth	Skinflats[d]	NS9283	2	1	0
Tyne	Hedderwick Sands[d]	NT6379	6	5	4
Dumfries & Galloway	Crook of Baldoon[k]	NX4452	0	3	0
Dumfries & Galloway	Caerlaverock[e,h,+]	NY0667	25	37	15
All	All	All	167	152	46

Key to designations: SPAs & Ramsar sites: a=Cromarty Firth, b=Inner Moray Firth, c=Dornoch Firth and Loch Fleet, d=Firth of Forth, e=Solway Firth; SACs: f=Dornoch Firth and Morrich More, g=River Teith, h=Solway Firth; NNRs: i= Loch Fleet; Country Parks: j=John Muir; LNRs: k=Wigtown Bay; Crown Estates Assets: +

Table 2. Proportions of collected cartridge cases which probably contained lead shot, estimated using three methods with contrasting assumptions (see text). Bootstrap 95% confidence limits are shown. The consensus estimate is that from Method B. The confidence interval of the consensus estimate is explained in the text.

Method	Proportion of cases containing lead shot	Lower C.L.	Upper C.L.
Minimum ($P_{Pb/A}$)	0.458	0.362	0.525
Known cases ($P_{Pb/B}$)	0.524	0.430	0.627
Maximum ($P_{Pb/C}$)	0.584	0.505	0.671
Consensus	0.524	0.362	0.671

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