Sampling of red grouse carcasses in Britain indicates no progress during an intended five-year voluntary transition from lead to non-lead shotgun ammunition

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SUMMARY

The 2024/2025 shooting season for red grouse *Lagopus scotica* in Britain was the last during a five-year voluntary transition period proposed by shooting and rural organisations in 2020, during which it was suggested that shooters of all live quarry switch from the use of lead to non-lead shotgun ammunition. We purchased carcasses of red grouse and dissected them to recover shotgun pellets for chemical analysis. All of the 78 carcasses from which shot were recovered contained lead shotgun pellets. One carcass had both lead and bismuth pellets. Samples of grouse meat had, on average, concentrations of lead that were substantially higher than is permitted in meat from farmed animals and poultry, even though shotgun pellets were removed from the meat before analysis. Lead levels were similar to those from grouse sampled five and 12 years before the beginning of the transition. X-rays of 12 carcasses revealed small (mostly 0.2 – 0.5 mm diameter) fragments in most of them, in addition to whole shot. Lead concentration in the meat was strongly correlated with the number of these fragments, which are too small to be detected and potentially rejected by scavenging animals and predators. We conclude that most of the lead found in meat from red grouse carcasses results from fragmentation of shotgun pellets impacting the birds' bodies. The intended voluntary five-year transition has been unsuccessful in relation to red grouse.

BACKGROUND

The use of lead ammunition for game shooting is currently lawful in Britain, except on wetlands. Consideration has been given by the appropriate UK authorities as to whether the use of lead ammunition for shooting game causes sufficient harm that it should be restricted by new regulations. The UK Health and Safety Authority has recently concluded that there are risks that are currently not adequately controlled, both to the environment and to the health of those vulnerable people who consume large quantities of game meat (Health & Safety Executive 2024). However, UK shooting and rural organisations have suggested that a voluntary alternative to regulation could be used to remove the use of lead shotgun ammunition. In 2020, nine of these organisations jointly called for a complete voluntary transition from the use of lead to non-lead shotgun ammunition for all shooting of game animals, to be completed within five years 'in consideration of wildlife, the environment and to ensure a market for the healthiest game products at home and abroad' (BASC 2020a).

Red grouse (*Lagopus scotica*) are shot in large numbers in the UK (about 650,000 are killed annually: Aebischer 2019), principally in moorland areas, which have different management practices from lowland shoots where most other gamebirds are shot. Since 2020, a citizen-science research project (Environmental Research Institute 2024) has monitored annually the proportions of common pheasant (*Phasianus colchicus*) carcasses sold in Britain from which lead and non-lead shotgun pellets have been recovered, but there has been no systematic monitoring of the progress of the intended transition for red grouse shooting. In this paper, we report on the types of shotgun ammunition recovered from red grouse carcasses purchased from food retailers across Britain and the concentration of lead in their meat.

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ACTIONS

Proposal for the voluntary transition

Nine UK shooting and rural organisations issued a joint statement on 24th February 2020 calling for a complete voluntary transition by shooters, within five years, from the use of lead to non-lead shotgun ammunition for shooting of live quarry. The signatory organisations were the British Game Alliance (BGA), British Association for Shooting and Conservation (BASC), Countryside Alliance, Country Landowners' Association, Game & Wildlife Conservation Trust (GWCT), The Moorland Association, The National Gamekeepers' Organisation, Scottish Land & Estates and the Scottish Association for Country Sports. The BGA (later British Game Assurance) ceased to operate in 2023. Some of its previous activities are now conducted by Aim to Sustain (A2S) and Eat Wild, both of which support the voluntary transition.

Efforts by shooting and rural organisations to promote the transition for grouse shooting

BASC has promoted the transition to non-lead shot by publishing articles on the phasing out of lead shotgun ammunition in its magazine *Shooting and Conservation*, which is sent to all its 150,000 members. We examined 116 items that mentioned the transition in all thirty issues of *Shooting and Conservation* published since 2020 but found no advisory material or information on its progress specific to grouse moors (BASC 2024b). Most items were not specific to the shooting of any individual gamebird species. BASC staff have briefed thousands of members and non-members on the issues associated with moving away from lead shot and have also run training days in which participants use non-lead shot for clay pigeon shooting (BASC 2020b). GWCT followed up the joint statement by providing information to members and others on the ballistics of alternative ammunition types. The information detailed the Danish experience with non-lead shot after their 1996 statutory ban on lead shotgun ammunition and plans by the food retailer Waitrose & Partners to switch to selling only game meat products from animals killed using non-lead ammunition. To the best of our knowledge, both BASC and GWCT have provided accurate and useful technical information about the transition on their websites (BASC 2024a; GWCT 2024).

Only one of the nine signatory organisations, The Moorland Association, is concerned principally with the management of shooting in areas where red grouse are the main gamebird quarry. The Scottish Gamekeepers Association, many of whose members are involved in managing grouse shoots, was invited to sign up to the voluntary transition in 2020 but declined as they considered that there was insufficient evidence of harm to public health and the environment to justify a transition to non-lead ammunition (Scottish Gamekeepers Association 2022). The Moorland Association has expressed continued support for the transition and, while its website has little content about it, there is a link to the Upland Standards (Grouse) 2024 document prepared by A2S to specify good management practices on grouse moors (The Moorland Association 2024). The Moorland Association's website says that these standards provide 'peace of mind to …. the general public, game stockists and food retailers'. However, none of the A2S standards concern the use of lead or non-lead shot, although there is a recommendation (Recommendation 1.12) therein that 'sustainable or lead-free ammunition is used'. In response to our queries about how The Moorland Association has encouraged its members to transition to non-lead ammunition and whether any of its members had registered their shoots as lead-free, its Chief Executive Officer replied saying that he could not respond with regard to lead-free registers, but that grouse moors have been at the forefront of the transition away from lead shotgun ammunition and an unspecified number of them had been using lead-free ammunition for several years (A. Gilruth, pers. comm. 21st January 2025).

The BGA initiated a register of lead-free shoots in 2021 to facilitate access of game dealers and food retailers to game shot using non-lead ammunition. We were uncertain about which organisation, if any, is now operating this register after BGA ceased to operate in 2023. A2S took over many of the BGA's activities, so we wrote to A2S and Eat Wild requesting information about the numbers of moorland shoots currently registered on lead-free registers. A2S replied to say that they decided not to continue the BGA's Lead Free Register. Eat Wild replied on 14 November 2024 to say that they hoped to provide us with information from the Lead Free Register maintained by their partner organisation Back British Game (Back British Game 2024). We received no information about numbers of moorland shoots on the register and were later informed that it is now defunct (L. Clutterbuck, Eat Wild Chief Executive Officer, pers. comm., 5th December 2024).

CONSEQUENCES

Sampling of red grouse carcasses

In August – October 2024, we purchased 128 whole or oven-ready grouse carcasses from 11 businesses (92 carcasses from seven online retailers and 36 from four butchers' shops). Based upon information provided by the retailer, 44 (34%) carcasses originated from shoots in Scotland, 24 (19%) from the Northern Pennines of England and 60 (47%) from unknown locations.

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Processing of carcasses

We used a Dongmun MiniBlock DIG360 portable two-dimensional X-ray unit with Rayence DR plate (55 kV, 0.6 mAs) to image 12 of the carcasses along dorsoventral and lateral axes before dissecting them. This was done for illustrative purposes and to facilitate the subsequent recovery of shot by dissection, but analyses conducted using the images are described in a later section.

Using kitchen equipment, co-authors removed as much meat from each carcass as possible and examined thin slices of tissue and broken bones for shotgun pellets and pellet fragments. It was not our objective to recover every pellet present in the carcasses, but rather to obtain at least one pellet from as many carcasses as possible. All pellets recovered from a carcass were placed in a sample tube with a unique label. Methods used are described in full by Green *et al.* (2021; 2022a; 2023) and Environmental Research Institute (2024).

Meat from each carcass was cut into small pieces, mixed, and divided into ~30 g portions to obtain a random sample of meat from the bird. Each portion was placed into an individual labelled zip-seal polythene bag, flattened then sealed. We then held the bag up to a light source and looked for any pellets missed during dissection, which would be visible in silhouette, but none were found. We placed the bag inside another bag and into a freezer. All equipment was thoroughly cleaned between carcasses.

Identification of the principal metallic element in shotgun pellets recovered from carcasses

We recovered 142 shotgun pellets and large pellet fragments from 78 (61%) of the carcasses (one to six pellets and fragments per carcass). The average weight of pellets was 110 mg (range 39 – 156 mg). Almost all recovered items were near-spherical, indicating that they were nearly whole pellets. We recovered no shot or fragments from 50 (39%) of the carcasses, as is typically the case for gamebird carcasses (see Green *et al.* 2024a and Environmental Research Institute 2024 for the probable reasons for this). We placed each pellet recovered into a vial containing concentrated nitric acid to dissolve the metals, undertook a series of dilutions, and then used an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES; Agilent 5900 with SPS4 autosampler) to estimate metal concentrations and thereby the proportion of the mass of each pellet comprised of the metallic elements (lead, iron, bismuth, tungsten, copper and zinc) known to be used in making shotgun pellets. Previous tests of our analysis method have shown that it quantifies the proportion of total pellet mass comprised of these elements with sufficient precision to identify the principal metallic element (Green *et al.* 2021, 2024a), which we took to be the element which comprised at least 50% of its initial mass.

Lead was the principal metallic element in 140 of the 142 (99%) shotgun pellets analysed (average percentage by mass, 98%). Two pellets were composed principally of bismuth (56.3 and 62.9% bismuth), with these low percentages probably being due to incomplete dissolution, as indicated by the cloudy appearance of the solution. The two bismuth pellets recovered were from a carcass from which four lead pellets were also recovered. Hence, the proportion of carcasses with pellets recovered from which at least one lead pellet was recovered was 100% (Clopper-Pearson 95% binomial confidence limits; 95 - 100%). The proportion of carcasses from which at least one bismuth pellet was recovered was 1.3% (95% binomial confidence limits; 0.03 – 7%).

Lead concentrations in meat samples

We thawed the frozen samples of meat in the laboratory and examined them by flattening the sample within its bag, and then uplighting it with a large flatbed 44W LED work light to find and remove any whole shot not already detected and removed during dissection of the carcasses in co-authors' kitchens. This was done to ensure that the meat samples analysed did not include any shotgun pellets. We found one pellet in a meat sample in the laboratory that had been missed during dissection. Two other pellets had already been recovered from that carcass. We included this pellet in the analyses of pellet metal types described in the previous section. We removed each sample from its bag, weighed it, dried it to constant mass, weighed it again and then milled it to a fine powder. We took 0.4g from each milled sample and microwave digested it in a mixture of nitric acid (3.5ml) and hydrogen peroxide (1.5 ml). We then analysed the samples, certified reference material and blank digests using an inductively coupled plasma optical emission spectrometer (ICP-OES; Agilent 5900). We expressed the concentration of lead in meat (mg/kg) as dry weight (d.w.) and wet weight (w.w.).

In Table 1, we compare median lead concentrations in the meat of red grouse from the present study with those from previous studies of lead concentrations in the meat of red grouse and with lead concentrations in meat from carcasses of common pheasants from which lead and iron shotgun pellets had been recovered. Although the use of arithmetic mean concentrations is appropriate when making quantitative assessments of risks to human and animal health from long-term dietary exposure to ammunition-derived lead (Pain *et al.* 2022), we used median values and non-parametric confidence intervals and tests because they are relatively insensitive to the effects of non-normally

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distributed data and positive skewness often seen in meat concentration data (Siegel & Castellan 1988). All of the results presented are expressed in terms of the mass of lead per unit mass of meat from which all whole or near-whole shotgun pellets had been removed before analysis.

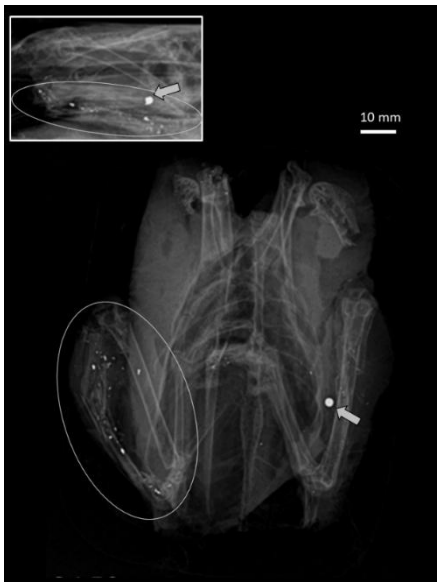

Figure 1. X-rays (main panel) showing a view from the ventral aspect (anterior, top; posterior bottom) of an oven-ready carcass of a red grouse before dissection. The grey arrow indicates a shotgun pellet measuring 2.45 mm diameter, which was recovered during dissection and measured with callipers. It was later found by ICP-MS analysis to be composed principally of lead. The grey ellipse shows an area of the right leg with a group of radio-dense fragments associated with the fractured right tibiotarsus, the smallest of which fragments are approximately 0.2 mm in diameter. The inset panel shows a lateral view of part of the same carcass (dorsal, top; ventral, bottom) showing the same group of radio-dense features.

There was no significant variation among the median wet weight lead concentrations derived from the three studies of red grouse collected in 2008, 2015 and 2024 (Pain *et al.* 2010; 2022), (Table 1: Kruskall-Wallis test, KW = 1.38, d.f. = 2, $p = 0.50$), indicating no significant evidence of change in lead levels after the beginning of the voluntary transition in 2020. There was also no significant difference between the median meat lead concentration from our 2024 study of red grouse and meat lead levels in common pheasant carcasses collected in 2022 from which lead shot were recovered (Green *et al.* 2024b, Table 1: Wilcoxon test; $p = 0.94$). Meat lead concentrations from pheasant carcasses collected in 2022 from which only iron shot were recovered were much lower than those for both pheasants and grouse known to have been killed using lead shot (Green *et al.* 2024b). The confidence interval of the median for the pheasants killed using iron shot did not overlap those for the pheasants or grouse killed using lead shot (Table 1).

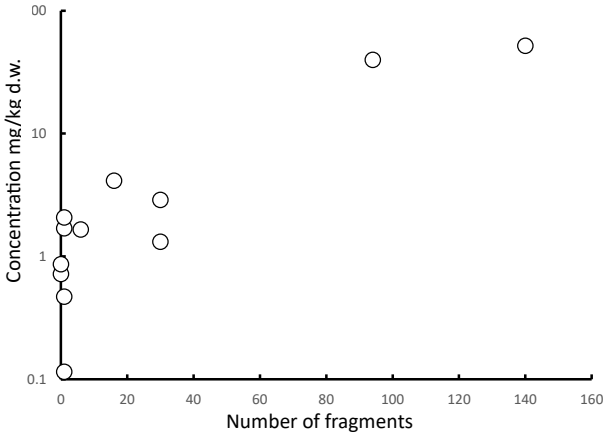

Figure 2. Average concentration of lead (mg/kg d.w.) in samples of meat from 12 wild-shot red grouse killed using lead shotgun ammunition in relation to the number of small radio-dense fragments visible on X-radiographs of the carcass. The vertical axis is on a logarithmic scale.

The concentration of lead in grouse meat was positively correlated with the number of shot recovered from each carcass (Spearman rank correlation coefficient; $r_S = 0.45$; $p < 0.0001$). The median meat lead concentration for categories of carcasses with different numbers of shot recovered increased progressively with increasing numbers of shot (Table 1). The lead concentration in meat from 76% of red grouse carcasses we sampled exceeded the maximum level (ML) for lead in the meat of farmed animals and poultry of 0.1 mg/kg w.w. set by European Union, Regulation (EU) 2023/915. Half of our grouse meat samples from carcasses from which no pellets were recovered had lead concentrations that exceeded the EU ML (Table 1). The EU ML is a useful threshold for separating lead concentrations in meat likely to arise from general background environmental exposure to lead, such as that experienced by farmed animals kept outside and wild-shot pheasants killed using iron shot, from those arising from elevated environmental exposure or embedded fragments, as indicated by results from a previous study of pheasant meat (Table 1; Green *et al.* 2024b).

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Table 1. Comparison of median concentrations of lead in mg/kg dry weight (d.w.) and wet weight (w.w.) per unit weight of meat in samples from wild-shot red grouse and common pheasants obtained in the UK from the present study[1], Pain *et al*. (2022)[2], Pain *et al*. (2010)[3], and Green *et al*. (2024b)[4]. Except in Pain *et al.* (2022), the type of metal composing the shot used to kill the bird was determined by analysing shot recovered from the carcass. The percentage of samples whose wet weight concentration of lead exceeded the maximum level (ML) permitted in meat from farmed animals and poultry under an EU regulation (which also applies in the UK) is also given. LCL= lower 95% confidence limit of the median; UCL= upper 95% confidence limit of the median; ND = not determined.

Species	Shot metal type	Sampling year	*N* shot recovered	mg/kg d.w. Median (CI)	mg/kg w.w. Median (CI)	>ML % of carcasses	*N* carcasses
Red grouse[1]	Lead	2024	0	0.372 (0.257-0.655)	0.102 (0.072-0.181)	50	50
Red grouse[1]	Lead	2024	1	1.720 (0.947-3.919)	0.491 (0.263-1.118)	89	46
Red grouse[1]	Lead	2024	>=2	3.000 (1.654-9.062)	0.880 (0.513-2.363)	97	32
Red grouse[1]	Lead	2024	All	1.327 (0.947-2.399)	0.373 (0.257-0.656)	76	128
Red grouse[2]	ND	2015	All	1.969 (1.242-3.754)	0.597 (0.367-1.167)	78	40
Red grouse[3]	Lead	2008	All	ND	0.257	70	20
Common pheasant[4]	Lead	2022	All	1.665 (0.729-2.927)	0.393 (0.217-0.877)	74	27
Common pheasant[4]	Iron	2022	All	0.224 (0.197-0.253)	0.072 (0.060-0.082)	9	23

Concentration of lead in meat in relation to X-ray counts of radio-dense fragments

On the X-ray images of all 12 grouse carcasses, we observed circular objects that we presumed to be whole, or nearly whole, shot. We measured the diameter of 18 spherical pellets recovered from these 12 carcasses to the nearest 0.01 mm with dial callipers and found their average diameter and range (2.54 mm: 2.34 – 2.78 mm) to be typical of #6 shot. There were also small, irregular-shaped, radio-dense objects visible on 10 of the 12 carcasses (Figure 1). Our ICP-OES analysis of shot recovered from these carcasses showed that they were all composed principally of lead. By comparing the imaged size of the fragments to that of the near-whole shot, we estimated that the smallest fragments recognisable on the images were about 0.2 mm in diameter.

We counted the fragments visible in the ventral and lateral images of each carcass. The two totals agreed closely, except in a few cases where a small part of the carcass was missing from one of the views. We took the larger of the two counts as our estimate of the number of radio-dense fragments. The average count of fragments per imaged carcass was 26.7 (range 0 – 140). The average count of near-whole shot per carcass was 3 (range 0 – 8). There was a significant positive relationship between the count of fragments and that of shot (Kendall rank correlation coefficient, $\tau = 0.57$, $p < 0.025$). The dry weight concentration of lead in meat was positively related to both the count of fragments and that of shot (fragments; $\tau = 0.74$, $p < 0.005$: shot; $\tau = 0.66$, $p < 0.005$). However, the relationship between lead concentration and fragment count was more strongly positive than that between lead concentration and the count of shot. Partial correlation analysis indicated that the effect of fragment count was larger than that of shot when the effect of the other variable was partialled out (Kendall partial rank correlations: fragments; $\tau = 0.59$, $p < 0.0025$: shot; $\tau = 0.43$, $p < 0.025$). The same results were obtained for wet weight lead concentrations. Hence, the high concentrations of lead in the meat of red grouse from which near-whole shot were removed before chemical analysis were probably attributable to the presence of small fragments of lead embedded in the meat.

DISCUSSION

All of the red grouse carcasses we obtained in 2024 (the last shooting season of the intended five-year voluntary transition from lead to non-lead shotgun ammunition) from which pellets were recovered had been shot using lead shotgun ammunition. The meat from the grouse carcasses sampled in 2024 was contaminated with lead to a similar degree to that of red grouse sampled in the UK in 2008 and 2015, long before the beginning of the voluntary transition in 2020. Previous studies of the concentration of lead in the meat of wild-shot pheasants in the UK also showed

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no indication of a reduction after the beginning of the transition (Pain *et al.* 2022). Our meat concentration results for red grouse are similar to recent values for pheasants shot in the UK using lead ammunition (Table 1; Green *et al.* 2024b) and to those for a large number of small game animal species shot in Europe (Pain *et al.* 2022). Meat from pheasants shot using iron shotgun pellets had much lower levels of lead (Table 1; Green *et al.* 2024b), which were mostly consistent with having arisen from background exposure. There was substantial variation among carcasses in the concentration of lead in meat, which was most strongly correlated with the number of small fragments visible on X-rays. This correlation suggests that most of the lead found in meat from red grouse carcasses results from fragmentation of shotgun pellets when they strike the birds. Similar results have been obtained for wild-shot pheasant carcasses using three-dimensional X-ray microtomography (Green *et al.* 2022b).

The UK shooting and rural organisations who issued the joint statement in 2020 calling for a complete voluntary transition from lead to non-lead shotgun ammunition have continued to support that policy. However, we found little evidence of publicly visible efforts to promote the voluntary transition specifically on red grouse shoots, compared with work by BASC and GWCT to promote the transition for gamebird shooting more generally. We have not seen any evidence so far that any red grouse shoots are, or ever have been, listed on a lead-free register.

The Moorland Association, which is the organisation most closely involved in the management of grouse moors, also expressed strong support for the voluntary transition. In 2022, the Chair of The Moorland Association issued a statement (The Moorland Association 2022) which said: '*That commitment [to the transition] is unwavering', 'There is growing evidence of shoots moving away from lead'* and *'Suggesting a ban…, is not supported by our evidence of active transition underway*'. Based upon this strong statement, it might be expected that quantitative evidence of change in practice on moorland shoots had already been obtained and that it showed that the voluntary transition from lead to non-lead ammunition was progressing as rapidly or more rapidly for red grouse shooting than it has been for pheasants. We are not aware of any such evidence. The results reported in this paper indicate that almost all red grouse continue to be shot using lead ammunition, even as the end of the transition period approaches. The monitoring information for pheasant shooting in the 2023/2024 and 2024/2025 shooting seasons also indicates that a high proportion of carcasses had been shot using lead ammunition (Green *et al*. 2024b; Green *et al.* in review). Hence, the five-year voluntary transition from lead to non-lead shotgun ammunition has been unsuccessful for the shooting of both species.

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