An updated response to concerns raised by Mr Ian Bell, Chief Executive Officer of the British Association for Shooting and Conservation, about the accuracy of conclusions drawn by the SHOT-SWITCH monitoring programme.

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Background

On the 24th of February 2020, nine UK game shooting and countryside organisations issued a joint statement expressing their wish to end, on a voluntary basis and within five years, the use of lead and single-use plastics in shotgun ammunition used by hunters. We are the principal investigators of the SHOT-SWITCH monitoring programme which was established in 2020 to monitor the intended transition from lead to non-lead shotgun ammunition over a five-year period (the shooting seasons of 2020/2021 to 2024/2025) by testing wild-shot common pheasants offered for sale across Britain and determining whether they were killed using toxic lead or non-lead shotgun ammunition. The scope and methods of the programme are described in ERI (2023). Results from the first three seasons of the programme have been reported in a peer-reviewed scientific journal (Green et al. 2021; 2022; 2023).

On 28th March 2023 Mr Ian Bell, the Chief Executive Officer of the British Association for Shooting and Conservation (BASC), which is one of the UK's largest shooting NGOs and a signatory of the joint statement, wrote a letter to one of us (REG) about the most recent SHOT-SWITCH report (Green et al. 2023). The letter expressed 'significant concerns' about the accuracy of the paper's conclusions. We thank Mr Bell for raising these concerns thus creating the opportunity for us to further explain the evidence, and also for permitting us to use his name in our response. This is an updated version of our previous response, released on 19 April 2023. The document has been updated to include relevant research findings from an unpublished study commissioned by BASC of which we were previously unaware.

The concerns and our responses

Concern

Mr Bell expressed doubts that any valid estimates can be made using SHOT-SWITCH data because of 'the small sample size'.

Response

We do not accept this as a valid concern. The sample of carcasses is actually quite large for the stated purpose of estimating a proportion. The confidence intervals for the estimated proportion of wild-shot pheasants killed using lead are given in all three of the SHOT-SWITCH publications (Green et al. 2021; 2022; 2023). These intervals are narrow. Carcasses were obtained from over 60 businesses spread across Great Britain in each season, so allowing for potential pseudo-replication caused by more than one carcass being obtained from the same business would only widen the intervals to a marginal degree. So far, the number of carcasses with non-lead shot has been too low for robust implementation of methods which could be used to allow for this potential pseudo-replication.

Concern

Mr Bell noted that no shotgun pellets were recovered from 34% of the pheasant carcasses examined by SHOT-SWITCH researchers in the 2022/2023 season, but that the paper calculated the proportion of wild-shot pheasants killed using lead ammunition based only on the 66% of carcasses with shot recovered and identified. Mr Bell suggested that one of the possible valid interpretations of the study is that some of the pheasants from which no shot were recovered were not killed by lead or non-lead ammunition, but were killed by some other unspecified method. In his letter, he wrote that our '… conclusion either suggests that 121 of the sampled pheasants were not killed by shotgun pellets at all or it is based on a miscalculation. Considering that all carcasses ended up in the food chain, the latter seems far more likely.' We provide evidence below about the possibility raised by Mr Bell that some of the pheasants examined were not killed by shotgun pellets, even though he considers this to be unlikely.

Response

We assume here that Mr Bell is suggesting that some of the pheasant carcasses examined by the SHOT-SWITCH study from which shot were not recovered were not from free-ranging birds killed by shooting. We cannot exclude this possibility entirely, but, in any case, it would not influence the validity of the study's conclusions. The objective of SHOT-SWITCH is to estimate the proportions of wild-shot pheasants killed using lead and non-lead ammunition. SHOT-SWITCH co-workers attempted to obtain only carcasses wild-shot pheasants, but if they inadvertently obtained some carcasses killed by something else, this would have no effect on the estimated proportion of wild-shot birds killed using lead ammunition because those carcasses would not contain any shot and would therefore not be used in the calculation.

We can exclude the possibility that anything other than a small proportion of the carcasses examined were not killed by shooting. Most of the SHOT-SWITCH carcasses examined in the 2022/2023 shooting season were examined carefully prior to and during dissection to check for the presence or absence of wounds indicating that the bird had probably been shot. The researchers looked for perforations of the skin and muscle tissue likely to have been caused by the passage of shot. Wounds of this type were found in 93% of the carcasses checked (Table 1). No signs of wounding were recorded in 4.6% of carcasses from which shot were recovered, which indicates that it is possible for a bird to be killed by shot without there being any easily detectable wounds. The percentage of carcasses with no signs of wounding was significantly higher for carcasses from which no shot were recovered (Table 1; Fisher exact test, two-tailed $P = 0.027$), but wounding was recorded from the majority of the carcasses with no shot recovered (88%). We note that most of the carcasses examined were prepared as oven-ready birds from which the head, neck and viscera had been removed. Hence, the carcass of a bird killed by pellets striking only the head, neck or abdomen could easily have no embedded pellets or wounds in the remaining parts of the carcass.

X-ray studies of wild-shot gamebirds killed using lead ammunition have shown that 87% of carcasses had embedded shot or small radio-dense metallic fragments or both and that the concentration of lead in gamebird meat was considerably elevated above background levels in carcasses with no embedded shot. Most of these had lead concentrations above the EU Maximum Residue Level for other meats of 100 ppb w.w. (see Figure 10 of Pain et al. 2010). These findings support the hypothesis that most gamebirds presumed to have been shot because of the information provided to the purchaser have indeed been shot.

We conclude that the inclusion of a substantial number of pheasants not killed by shooting in the carcasses examined by SHOT-SWITCH is excluded by the data on wounding and, in any case, this issue would not affect the calculation of the proportion of wild-shot birds killed using lead ammunition, though it might be relevant to public health concerns.

Concern

Mr Bell pointed out that the types of ammunition used to kill the wild-shot pheasants examined by the SHOT-SWITCH study were not known for carcasses from which no pellets were recovered. Mr Bell argued from this that, in the 2022/2023 season, the proportion of wild-shot pheasants killed using lead ammunition could feasibly be as low as 62% (if every wild-shot bird examined from which no pellet was recovered was killed using non-lead shot) or as high as 96% (if every wild-shot bird examined from which no pellet was recovered was killed using lead shot). In support of this argument, Mr Bell mentioned that some shooters who are experienced with steel ammunition ‘might’ argue that pheasants killed by steel shot were more likely to have no shotgun pellets present in the carcass than those killed using lead shot. This could occur if steel shot are more likely to pass through the bird’s body than are lead shot. If that was true, the real percentage of pheasants killed using steel shot would be higher than that estimated by SHOT-SWITCH. However, it is not clear whether these experts have any evidence for this. Mr Bell concluded that the authors of the SHOT-SWITCH paper ‘casually discarded’ information on the uncertainty attached the proportions of pheasants killed using lead and non-lead ammunition, largely because they failed to address this concern.

Response

We agree with Mr Bell that this issue has not been addressed quantitatively so far in any of the three published papers about the SHOT-SWITCH studies. However, that is not because we have ‘casually disregarded’ it. The first version of the manuscript of Green et al. (2023) submitted to the journal in January 2023 included a lengthy quantitative section examining the evidence concerning this potential source of bias, but it was felt by the editor and reviewers that the section was peripheral to the paper’s main objectives and it was therefore removed from the manuscript, with the agreement of the authors. We thank Mr Bell for giving us a reason to present the assessment of this potential bias at greater length here.

The proportions of SHOT-SWITCH carcasses with no shot recovered which were killed using lead and non-lead ammunition are not as uncertain as Mr Bell suggested. They are constrained to a substantial extent by evidence of three kinds: (a) the frequency distribution of numbers of pellets recovered per carcass from SHOT-SWITCH carcasses and (b) the proportions of carcasses in which pellets are detected and not detected in other studies using X-radiography, (c) results from an experimental study regarding the distance that lead and steel shotgun pellets penetrate when fired into blocks of ballistic gel.

In considering evidence of the first type, the numbers of pellets recovered per carcass from SHOT-SWITCH carcasses, it is important to recognise that skinning and dissecting a pheasant carcass using the methods described in ERI (2023) does not always detect all of the pellets present in the carcass, even though the researchers searched carefully. We know this because one of us (REG) cut each of a few carcasses from which no shot had been recovered by dissection into small pieces and placed them in a metal bucket partly-filled with water. In some cases, when the contents of the bucket were swirled around, a single pellet was heard rolling around on the bottom of the bucket and was then recovered. In addition, SHOT-SWITCH researchers were told that it was not necessary to find and recover all of the pellets that might be present in a carcass.

The observed frequency distribution of numbers of pellets recovered per carcass shows a striking feature for all three types of shot (lead, steel and bismuth) recovered by the SHOT-SWITCH study so far. Many more carcasses had just one pellet recovered than any other number and the frequency of pellet counts tended to decline rapidly and progressively as pellet number increased (Figure 1). It can be seen intuitively that this pattern suggests the possibility that many carcasses of wild-shot pheasants might be expected to have no pellets recovered, as was observed to be the case. The key observation though is that the frequency distribution of pellet numbers per carcass is broadly similar for lead and steel shot.

The hypothesis proposed by Mr Bell and the shooting experts is that a steel shot is more likely to pass through the bird's body and not be embedded in the carcass than a lead shot (see above). If that hypothesis is correct, we would expect that the count of recovered pellets would decline more rapidly with increasing pellet number per carcass for steel than for lead and that the arithmetic mean number of pellets recovered per carcass should be lower for steel than for lead. There is no sign of a difference in this expected direction in Figure 1. In fact, carcasses of pheasants from which shot were recovered tended to have a higher number of steel shot per carcass than lead shot per carcass (Table 2). The difference between the means for steel and lead is not statistically significant (t_{625} = 1.77; two-tailed P = 0.077), but it is much more likely that the mean is higher for steel than for lead than that it is higher for lead than steel. Hence, this observation runs counter to Mr Bell's hypothesis that steel is more likely to pass through a bird's body than lead, and provides no support for it whatsoever. It is not possible to draw any valid conclusions for bismuth shot because only four carcasses containing bismuth shot, which is expensive and appears to be rarely used, have been detected so far. However, some information about this issue for bismuth shot is available from the second type of evidence.

The second type of evidence uses X-radiography to identify the presence of shotgun pellets in carcasses of wild-shot birds. This method has the advantage over dissection that all shot present will have been detected. We know of two studies in which both numbers of shotgun pellets were counted by X-radiography, and the principal type of metal that the shot were composed of was also identified. Pain et al. (2010) X-rayed 22 wild-shot pheasants obtained in Great Britain in the 2008/2009 shooting season. They detected shot in 12 of them (54.5%). This percentage is slightly but non-significantly lower than that observed for carcasses of wild-shot pheasants dissected in the SHOT-SWITCH study (65.1% for the 2020/2021, 2021/2022 and 2022/2023 seasons combined), which suggests that at least some shot were detected by dissection in most of the SHOT-SWITCH carcasses where it was present. The principal metal type of all shot tested was lead. Kanstrup & Balsby (2019) X-rayed carcasses of common pheasants and mallards shot in Denmark in the 2016/2017 shooting season. This was 20 years after the use of lead shotgun ammunition for hunting was banned in Denmark. Only 1.7% of the pheasant carcasses with any shot present were found to have been killed using lead shot and most of the carcasses contained only embedded steel and/or bismuth shot (Table 4). The percentage of pheasants with any type of shot detected by X-radiography was 85.5% (Table 4). Results for mallards were broadly similar (Table 4). The percentage of pheasants with shot detected on X-rays was significantly higher for the Danish study, in which birds were killed predominantly with non-lead shot, than in the British study, where the birds were killed using lead ammunition (Fisher exact test, two-tailed P = 0.012). If non-lead shot were more likely than lead shot to pass through the bird's body without any embedded shot being left behind, the difference would be expected to be in the opposite direction to that observed. This comparison cannot be used to compare the proportions of carcasses with embedded shot separately for lead, steel and bismuth because the proportions of different shot types used to kill the pheasants without any embedded shot in the Danish study could not be determined.

Results from experiments using ballistic gel (type (c)) were not included in the first version of this document (released 19 April 2023), because we were unaware (at that time) of a relevant unpublished report, which we obtained recently after it was cited in a published paper (Ellis & Miller 2023). The study was conducted at Cranfield University (Champion 2021) and the report on it completed on 3 August 2021. The research was commissioned by BASC under Project No. P16577. The experiments reported compared distances to which lead and steel shotgun pellets (of different brands and sizes) penetrated blocks of ballistic gel, which is designed to resemble the tissue of quarry animals. The study compared several types of steel shot with several types of lead shot. The shot sizes of the two metal types chosen for direct comparison differed in the way that BASC has recommended for hunters switching from lead to steel shot. The current recommendation is to increase shot size by two increments when switching from lead to steel. For that reason, No.5 lead shot was compared with No.3 steel shot (Champion 2021). In one set of experiments, pellets were fired into bare gel blocks from various distances and the penetration distance measured. There was a consistent tendency for lead shot to penetrate further into the gel when compared to the recommended size steel shot. If these gel blocks accurately replicated results for real pheasants, we would interpret this as indicating that lead shot would be more likely (than steel shot) to pass through a bird's body and leave no embedded shot to be recovered. However, a real pheasant's body is covered by skin and feathers and it is likely that this changes the degree of penetration. To address this, Champion (2021) also conducted another set of experiments in which the surface of the gel block was covered by a piece of feathered pheasant skin before firing. When this was done, there was no indication of any consistent difference in penetration between lead and steel shot. We interpret this as indicating that lead shot would be no more and no less likely than steel shot to pass through the body of a real pheasant and that researchers would fail to recover any pellets from wild-shot pheasant carcasses with approximately equal probability. An ideal analysis would also take into account differences in the mean number of shot striking the pheasant, but we were unable to do this using the information available.

Hence, all three types of information considered here provide no support for the hypothesis proposed by Mr Bell that carcasses of pheasants killed using non-lead shot are less likely than those killed using lead shot to have at least one shot recovered from them by dissection. Types (a) and (b) indicated the opposite tendency to that proposed by Mr Bell and the BASC-commissioned type (c) study indicated no difference. We regret that we were unable to include an account of the type (c) evidence in our previous note on this topic. The study was not mentioned by Mr Bell in his letter even though it was completed 20 months earlier. Instead, he cited only anecdotal reports of possible differences between shot types.

Concern

Mr Bell's principal concern was that the SHOT-SWITCH conclusions were based on 'miscalculation' and that was substantial uncertainty arising from not knowing the cause of death or the type of shot used to kill birds with no shot recovered.

Response

Based upon the materials described above, this concern does not appear valid, but below we check our published results using an alternative approach which allows for a possible difference among shot types in the proportion of carcasses from which shot are recovered, as was suggested by Mr Bell. To do this, we considered the frequency distributions on numbers of shot recovered per carcass in more detail (Figure 1). We fitted statistical models to the observed distributions. The simplest of these was the Poisson model in which the probability P_x that a carcass has x pellets recovered from it is given by:

$P_x = e^{-m} m^x/x!$.

We fitted this model to the data on the number of carcasses with one or more pellets recovered iteratively, so that the mean number of pellets recovered for those carcasses with at least one pellet matched the observed mean. For both lead and steel pellets, there was a clear difference between the fitted Poisson distribution and the observed distribution (Figure 2). The Poisson model predicted too few carcasses with low numbers of pellets (i.e. 1) and high numbers (4 or more) (Figure 2). This observation suggests that the parameter m, which is assumed to be a constant in the Poisson model, actually varies within the population under consideration. We modelled this effect by assuming that the natural logarithm of m varied according to a normal distribution. We fitted the two parameters of this distribution (the mean and standard deviation) by maximizing the log-likelihood of the observed data. The fitted models using this method (shown in gold in Figure 2) improve the fit to the observed data (shown in blue). The fitted models can be used to estimate the expected proportion of carcasses with no shot recovered P_0. P_0 was estimated to be 0.458 (45.8%) for lead shot and 0.260 (26.0%) for steel shot. These values of can be used to adjust the observed total number of carcasses with shot of a particular type recovered C_o to an expected total C_e if the shot type had been identifiable in all carcasses dissected. The was done by calculating:

$C_e = C_o/(1\text{-}P_0)$.

Proportions of carcasses from pheasants shot using each ammunition type were then obtained by summing the C_e across ammunition types and dividing the C_e for each type by this sum. There were too few observations of pheasants killed using bismuth shot to estimate a value of P_0 for this shot type, so we calculated alternative values of C_e assuming that P_0 for bismuth was either the same as that for lead or was the same as that for steel. Table 4 shows the results and compares them with equivalent estimates of the proportion of wild-shot pheasants killed using lead ammunition from SHOT-SWITCH publications, based solely upon data for carcasses with at least one pellet recovered. The results of the two types of calculations are very similar.

Conclusion

We conclude that the evidence presented above indicates that the various concerns raised in Mr Bell's letter about the most recent SHOT-SWITCH results (Green et al. 2023) do not provide any support for the suggestion that the true proportion of wild-shot pheasants killed in Great Britain using lead ammunition is much different from the results presented in the SHOT-SWITCH publications. We further note that, even if Mr Bell's suggestion that the true percentage of pheasants killed using lead ammunition in 2022/2023 might be as low as 62%, which we do not think is consistent with available data, the proportions calculated on the same basis as that proposed for each of the three seasons of SHOT-SWITCH monitoring do not indicate any statistically significant or even an appreciable change in practice over time (Figure 3; Fisher exact test, two-sided $P = 0.772$). Hence, the conclusion about the principal objective of the SHOT-SWITCH study, which is to monitor change in practice, remains the same as that in the published reports: there has been very little change so far during the first three seasons of the proposed transition.

References

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Table 1. Numbers of common pheasant carcasses examined for wounds for which wounds were recorded and for which no wounds were detected in relation to whether shot were recovered from the carcass or not. Results are from birds obtained in Great Britain in the 2022/2023 shooting season.

	Number of carcasses			
Shot recovered?	Wounds recorded	No wounds	Total examined	% wounded
No	81	11	92	88.0
Yes	187	9	196	95.4
All	268	20	288	93.0

Table 2. Mean numbers of shotgun pellets recovered per carcass of common pheasants obtained in Great Britain in the shooting seasons of 2020/2021, 2021/2022 and 2022/2023 in relation to the principal type of metal in the shot. Means are calculated only for those carcasses from which at least one pellet was recovered, since metal type could not be determined for carcasses with no shot recovered.

Quantity	Lead	Steel	Bismuth
Arithmetic mean	2.02	2.85	1.00
Lower 95% C.L.	1.89	1.77	-
Upper 95% C.L.	2.15	4.23	-
Number of carcasses	614	13	4

Table 3. Numbers of common pheasant and mallard shot in Denmark in the 2016/2017 shooting season from which shotgun pellets of each type were detected by X-radiography. Results for pheasant carcasses with some meat removed before examination were excluded. Data are from Table 1 of Kanstrup & Balsby (2019).

Quantity	Pheasant	Mallard
Total birds examined	200	202
Birds with steel shot only	96	124
Birds with bismuth shot only	65	7
Birds with lead shot only	2	5
Birds with steel and bismuth shot	2	0
Birds with bismuth and lead shot	1	0
Birds with unknown shot only	5	12
All birds with shot	171	148
% of birds examined with shot	85.5	73.3
% birds with shot which had only steel and/or bismuth	95.3	91.9

Table 4. Numbers of wild-shot common pheasant carcasses from which at least one shotgun pellet was recovered in Great Britain in the shooting seasons of 2020/2021, 2021/2022 and 2022/2023. The percentage of carcasses from which at least one pellet was recovered which had at least one lead pellet is shown (% Lead S-S), as calculated in publications of results from the SHOT-SWITCH project together with percentages of carcasses with lead shot calculated by an alternative method (% Lead new) described in the text. *Both lead and steel shot were recovered from one carcass. +Two values are given because the value of P_0 cannot be estimated for bismuth shot. The first value assumes that P_0 is the same for lead and bismuth and the second that P_0 is the same for steel and bismuth.

	Number of carcasses					
Season	Lead	Bismuth	Steel	Total with shot recovered	% Lead S-S	% Lead new
2020/2021	179*	0	2*	180	99.4	99.2
2021/2022	214	0	1	215	99.5	99.7
2022/2023	221	4	10	235	94.0	95.1/95.8+

Figure 1. Numbers of common pheasant carcasses obtained in Great Britain in the shooting seasons of 2020/2021, 2021/2022 and 2022/2023 with different numbers of recovered shotgun pellets per carcass in relation to the principal type of metal in the recovered shot.

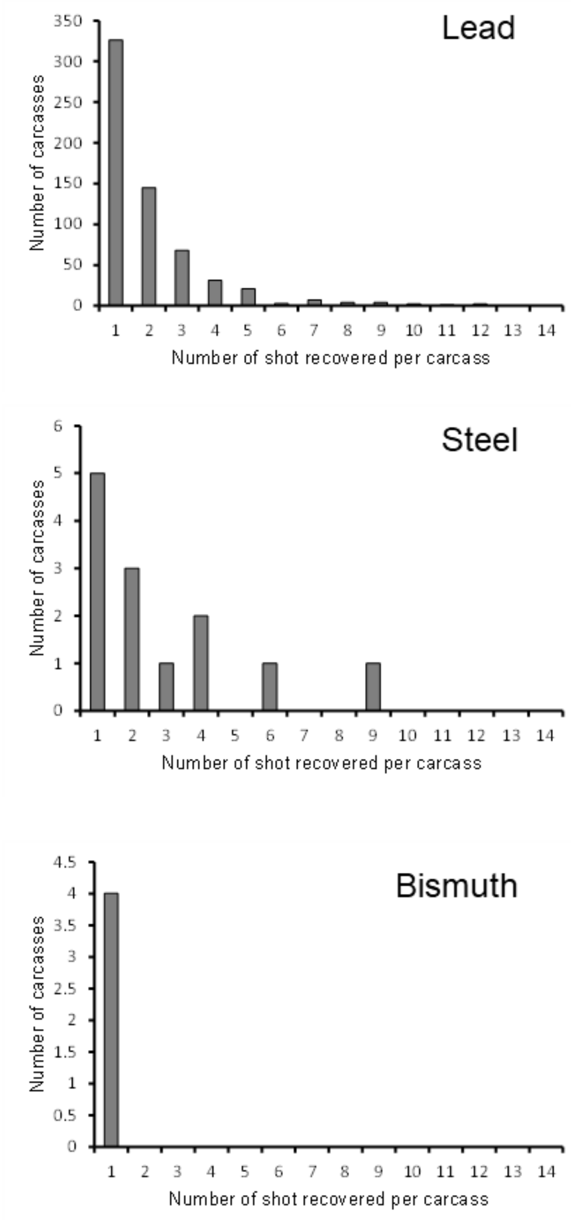

Figure 2. Cumulative distributions of numbers of shotgun pellets recovered per common pheasant carcass in relation to the principal type of metal in the shot. The distributions shown by blue curves are those observed for carcasses obtained in Great Britain in the shooting seasons of 2020/2021, 2021/2022 and 2022/2023 combined. These are the same data as those presented in Figure 1. Red curves show the expected cumulative distributions under a Poisson model. Gold curves show the expected cumulative distributions under a mixture model in which the parameter *m* of the Poisson distribution varied among individuals and had a log-normal distribution. See text for details.

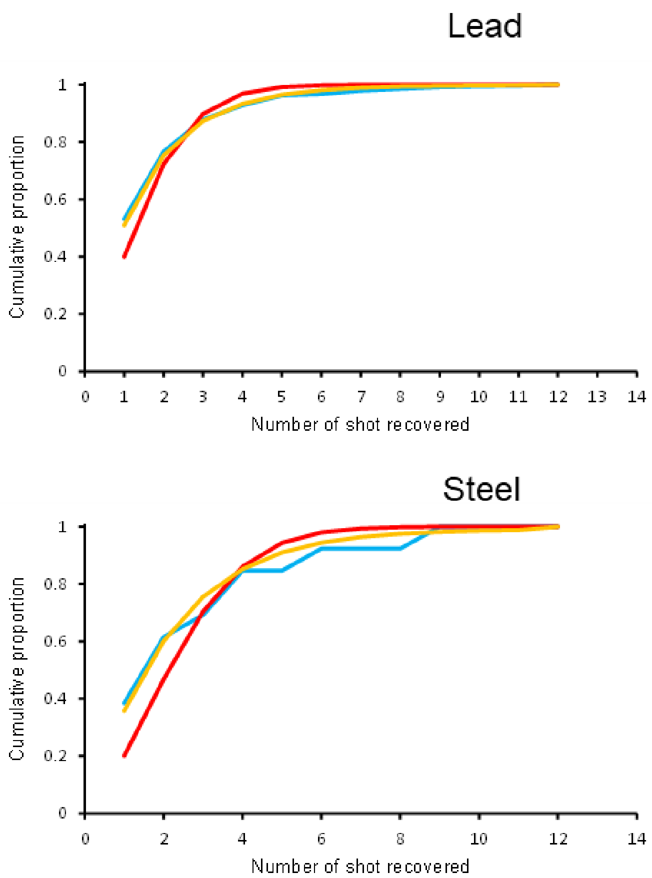

Figure 3. Percentages of all common pheasant carcasses obtained in Great Britain in the shooting seasons of 2020/2021, 2021/2022 and 2022/2023 from which at least one lead shotgun pellet was recovered. Vertical lines represent Clopper-Pearson 95% confidence intervals. Carcasses from which no pellets were recovered were included in this calculation for the purpose of illustration, but we suggest that this is not good practice (see text).