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Non-lead rifle ammunition: Danish hunters' attitudes

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Abstract

Background: Lead particles from hunting rifle ammunition become embedded in the tissue of shot animals and pose a health risk to predators and scavengers that eat discarded offal or parts of non-retrieved carcasses of shot game animals, as well as to humans who consume game. Copper and copper–zinc alloys are the most widely used alternatives to leaded ammunition. In Denmark, there has been a growing awareness of the toxic environmental effects of lead ammunition and the Danish government, supported by the Danish Hunters' Association, announced in November 2020 a forthcoming ban on the use of lead-based bullets for hunting purposes intended to take effect in 2023. The question that remains to be addressed is how the Danish hunting community perceives lead ammunition as a problem and non-lead alternatives as a solution, and whether the willingness to change demonstrated by the hunters' representatives reflects the attitude of the individual hunters. We studied this in a survey targeting 6000 randomly selected Danish rifle hunters, mapping their knowledge and concerns regarding lead rifle ammunition as well as their use of lead and non-lead ammunition.

Results: We found that approximately one-fifth of the use of rifle ammunition for hunting in Denmark in 2019 was non-lead. Hunters' knowledge of and concern for the adverse impacts of lead ammunition and the opportunities to switch to non-lead alternatives were generally limited. However, some showed an open-minded attitude and we found that such knowledge and concern increased the likelihood of hunters deciding to use non-lead ammunition. Hunters mainly got their information from hunting organizations and colleagues and expressed a distinct lack of information and guidance on the topic from ministerial authorities responsible for hunting administration.

Conclusions: Some hunters have already changed to use non-lead rifle ammunition completely or in part, and others show an open attitude to discussing the issue and receiving more information particularly from hunting authorities. Some hunters demonstrated a critical or negative attitude towards a change. Communication of the adverse impacts of leaded ammunition in terms of the risk of lead poisoning to wildlife and humans and the opportunities of switching to the existing efficient and safe alternatives is essential regardless of the formal approach and will be crucial for the effectiveness of the regulation announced by the Danish government.

Keywords: Copper ammunition, Hunter resistance, Lead ammunition, Regulation, Transition, Voluntary

Background

The adverse impacts of the use of leaded ammunition in hunting and the possibility of replacing it with non-lead ammunition are well described [1]. For many years, the primary concern was on lead gunshot, but in recent years, the environmental, human and animal health consequences from the dispersal of lead from rifle ammunition have come into focus. Lead particles become embedded in the tissue of shot animals [2, 3] and risk poisoning predators and scavengers that eat discarded offal or parts of non-retrieved carcasses of shot game animals, as well as human consumers who eat game [4, 5]. Several studies document high amounts of lead from ammunition among, e.g., white-tailed eagles (*Haliaeetus*

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albicilla) and golden eagles (*Aquila chrysaetos*) and consequently higher mortality [6–8] and sub-lethal impacts including behavioral changes [9].

Several types of non-lead and non-toxic rifle bullets are produced and marketed, among which copper and copper–zinc alloys are the most widely used. At present, the retail market offers a wide variety of non-lead rifle ammunition designed for a wide range of applications [10–12]. For practical hunting use, the common non-lead types meet the same standards of efficacy and safety as leaded ammunition [13–15].

Worldwide, only a few countries have introduced regulation of leaded rifle ammunition. In 2019, California introduced a ban on all lead hunting ammunition, just as some federal states in Germany (e.g., Schleswig Holstein, Baden-Württemberg and Saarland) have regulated the use of lead rifle ammunition. In other European countries, regulation is only sporadic and targets specific areas, such as national parks and wildlife management areas [16]. There is a significant resistance to change promoted mainly by the international ammunition industry and hunting community although the denial of problems and unwillingness to discuss solutions has not been universal [17].

Although there is no actual ban on lead-based rifle ammunition in Denmark, there is a growing interest in the problem of such ammunition poisoning wildlife and posing risks to humans who consume game meat, and some hunters have switched from lead to non-lead ammunition. Within the Danish hunting community and hunting media, the risk of lead in rifle ammunition and the possibility of using non-lead alternatives have occasionally been debated (e.g., Kanstrup [18]; Knudsen [19], Sand [20]). However, at the governmental level, there has until now been no explicit position or communication on the consequences of leaded rifle ammunition and the possibility of replacing lead ammunition with non-lead alternatives. Although the Danish regulation of leaded gunshot for hunting may have created a certain awareness of the adverse impact of lead in ammunition among hunters, it is likely, that Danish hunters' concern for the environmental impact of leaded rifle ammunition and their awareness of the possibility of changing to non-lead alternatives, in general, are weak and that only a minority of hunters, therefore, have switched to non-lead ammunition. In 2019, Aarhus University initiated this national survey to test this hypothesis and to explore the influence of socio-demographic variables on the hunters' knowledge, concern and use of ammunition, the relationships between knowledge and concern, and the influence of these variables on the choice of ammunition, and not least, to clarify what sources hunters get their information from or expect to get it from. The survey included Danish rifle hunters' attitudes to the environmental and health consequences of using lead ammunition, their use of alternatives, and factors likely to affect their choice of rifle ammunition.

Method

The study was conducted as an electronic questionnaire during the period October 2019 to February 2020. The questionnaire (Additional file 1) was accessible from all major browsers, smartphones and tablets and was sent to 6000 rifle hunters randomly selected from the Danish National Hunting Register consisting of approximately 165,000 hunters. The selection followed a standard approach undertaken by the Danish Environmental Protection Agency (EPA), based on a randomizing generator referring to the unique registration number of all hunters. Socio-economic variables such as the hunters' age, gender, place of residence, school/professional education, and income for which there exists reference data [21] were included in the questionnaire to evaluate representativeness of the sample or to survey to which degree some of these background parameters influence the primary study variables, i.e., the hunters' knowledge and concerns regarding potential adverse impacts of leaded ammunition, their knowledge and potential reservations concerning essential properties of non-lead rifle ammunition (e.g. safety, ballistics and price), and their use of ammunition. The parameter "knowledge" was chosen to assess the level of objective information that hunters had about the two types of ammunition, whereas "concern" was included to evaluate to which degree such knowledge was subjected to reflections of positive and/or negative aspects of both types, hence to reflect an attitude. Furthermore, the questionnaire included the hunters' use of ammunition to test whether this related to their knowledge and concern. Respondents were given the opportunity to add additional textual information to some open-ended questions and to add general comments at the end. The latter was included to capture any aspect not included in the questionnaire, for example attitudes toward the questionnaire per se, and the experiences of respondents of whom many have extensive experience.

The study was executed in collaboration with the Danish Ministry of Environment and subject to procedures of ethics, protection of participants, anonymity, and safe storage of personal data at the same level as similar research and advisory activities under a present joint collaboration agreement between the Ministry and Aarhus University.

Prior to the submission of the questionnaire, two pilots were tested on two groups of 8 and 34 hunters, respectively. The first group was recruited among personal contacts of the project team. The second was suggested

by members of the first group. The first pilot was circulated as a pdf by e-mail and the second as an electronic questionnaire. Respondents in both pilots were asked to comment on clarity and function of questions as well as on the overall impression of scope, content, structure, relevance, and balance of the study and the practical use of the electronic setup. Based on the results of the pilots, the questionnaire was modified accordingly.

The questionnaire was first distributed on October 11, 2019 to 3000 randomly selected rifle hunters. Individualized URL's were circulated by the Danish Environmental Protection Agency (EPA) via e-Boks which is a trusted Nordic provider of secure platforms and digital postboxes for all citizens. Due to an error in the URL, the questionnaire was re-distributed to the same sample on October 14, 2019. A closer analysis revealed that out of the 3000 randomly selected rifle hunters, 2778 met the criteria to be included in the study in terms of valid hunting license and the required permission to hunt with a rifle. As of December 2019, 1257 (45%) had answered the questionnaire sent to the first group. No reminder letter was sent to this group.

Assuming the error in the URL might have had a negative effect on the number of responses we decided to circulate the questionnaire to an additional second sample of hunters. Again 3000 rifle hunters were randomly selected and a new circulation with a URL was sent out on December 12, 2019. Out of the 3000, 2801 qualified to be included in the study by holding a valid hunting license and permission to hunt with a rifle. On February 1, 2020, 946 (33.8%) from the second sample had completed and submitted the questionnaire. On February 3, 2020, a reminder was sent out to all those who had not responded. On February 17, 2020, the registration of responses was closed with a total number of responses of 1422 (51%). The total number of electronic responses from the two samples qualified for inclusion was 2679. In addition to the responses to the electronic questionnaire, 22 recipients stated by e-mail that they for various reasons did not find themselves eligible (e.g., because of age) to answer the survey. Including these emailed responses which were not included in the data analysis, the total response rate of the two circulations was 2701 (48%) out of a total of 5579 qualified recipients. Response rates for surveys targeting the hunting community in Denmark have been variable, ranging between 27 and 79% [21–23].

The two samples in the present study did not differ significantly regarding the variables included in the study (see rationale and statistical testing approach in the data processing section). We, therefore, merged the two samples ($n = 2679$) into one pool as the basis for the further analysis.

Several variables were included in the study to analyze the sample representativeness. As the survey did not have access to basic information about Danish rifle hunters, respondents' age, sex, and place of residence were compared to all hunting license holders registered in 2019[1] and—where possible—with Seismonaut [23]. The educational backgrounds of respondents were compared with all Danes (see Table 1 for actual distribution). Compared to all hunting license holders, there was an underrepresentation of hunters < 34 years among the respondents in this study (as in Seismonaut [23]), as well as an overrepresentation of hunters in the 35–64 years age range in this study (Table 1). The mean age of the respondents in the sample was 54.6 years, almost the same as the 55.2 years that appeared in Seismonaut [23], compared to 52.2 years among all hunting licenses.

Ninety-seven percent of all respondents were male, which is an overrepresentation, compared to all hunting licensees (92%). This was most pronounced in the oldest category of respondents as only 1% of respondents > 64 years of age were female. In total women appeared to be underrepresented. In Seismonaut [23], 94% of respondents were male. A comparison of postal codes of respondents versus all hunters showed a rather similar distribution of places of residence between the two groups, although there seemed to be a slight underrepresentation of respondents from the Copenhagen region. This was not tested statistically.

The vast majority of respondents reported their level of formal education (school/professional). There was no comparable dataset available pertaining to the educational characteristics/background/experience of Danish hunters. However, a comparison with the Danish population in general[2] revealed that our sample was overrepresented in the category 'vocational education' and underrepresented in the category 'primary school' as the most recently completed education. This corresponds to previous studies of Danish hunters [21]. The same applies to gross income, where the respondents in this survey revealed a an underrepresentation of income below DKK 300,000 per year and a corresponding overrepresentation in the high-income classes as also demonstrated by Hansen [21].

We compared annual game bags reported by respondents with the equivalent mandatory reports of all Danish hunters[3] and found a clear tendency for the respondents to bag more animals than the average Danish hunter,

[1] Basic data achieved from EPA.

[2] Basic data achieved from Statistics Denmark (https://www.dst.dk/da/).

[3] Basic data achieved from the official Danish Wildlife Bag Statistics (https://fauna.au.dk/jagt-og-vildtforvaltning/vildtudbytte/).

Table 1 Three groups of socio-economic variables to compare respondents with other groups of hunters or Danes: Top: Age [a Kolmogorov–Smirnov test showed that the average age of respondents were slightly higher than that of all hunters ($D=0.082$, $p<0.001$)]

Age intervals (years)	Respondents	Seismonaut [23]	All hunters
16–34	9	11	16
35–64	66	61	61
65–99	25	28	24

Place of residence	Respondents	All hunters
Copenhagen area	7	11
North Sealand	5	5
Bornholm	1	1
East Sealand	16	16
Funen and islands	10	9
South Jutland	16	16
North West/Mid Jutland	15	13
East Jutland	17	17
North Jutland	12	11

	Respondents	Danes
Basic school	8	25
High school (gymnasium)	3	10
Vocational	42	30
Short academic education	8	5
Medium academic education	16	15
Bachelor	6	2
Long academic education	13	10
Phd/scientist	1	1
Do not know	4	2

Middle: Formal education (not tested). Bottom: Place of residence (not tested). All numbers refer to percentages.

demonstrating an overrepresentation of particularly active hunters among the respondents. This was supported by the fact that 60% of respondents reported that they were members of a hunting organization versus 50% of hunters in general [23].

Overall, we assessed the data to be representative of Danish hunters, although with a few exceptions. First, there seemed to be an overrepresentation of particularly active hunters, i.e., hunters that have a larger annual bag and who are more likely will be organized than the average hunter. This is unsurprising, since those hunters who do not currently hunt or who are less active are presumably less likely to respond, meaning that the sample will exhibit a bias. Second, the average age of respondents seemed to be slightly higher than average hunters which may be because hunters begin their hunting career with shotgun hunting and tend to develop to hunting with a rifle at a slightly later stage. Finally, there was an underrepresentation of women compared to the frequency of women among hunters in general. However, according to the low number of participating women, this factor has only limited relevance to the study. It was, therefore, disregarded in the discussion/analysis.

Additional comments given by some respondents were subject to a thematic analysis where we established eight themes and quantified comments according to statement keywords.

Data processing

Merging of the two samples

The two samples in the present study did not differ significantly regarding the key variables included in the study (Kolmogorov–Smirnov test for continuous variables, respondents' age: KS = 0.70, $p=0.0711$; game bag: KS = 0.655, $p=0.785$; level of knowledge: KS = 0.329, $p=0.999$; level of concern: KS = 0.607, $p=0.855$), (Chi-square tests for discrete variables; sex: $X_1^2=0.011$, $p=0.915$; education: $X_8^2=9.922$, $p=0.271$; use of lead-free ammunition $X_1^2=0.011$, $p=0.773$). We, therefore, merged the two samples ($n=2679$) into one pool as the basis for the further analysis.

Knowledge

To test whether the sources of information from which the hunters expected to get their information on leaded and non-lead ammunition, were also the sources from which they actually got their information, we used a $\chi 2$ test. Since each hunter could indicate multiple expected and real sources of information, the expected values estimated as row sum * column sum were corrected with the factor: SUM observed/SUM expected to ensure that number of expected and observed observations were equal. Only data from hunters who had reported knowledge > 0 of lead and non-lead ammunition were included here.

Concern and knowledge

To test the association between knowledge about and concern for adverse impacts of the use of lead ammunition, we used a $\chi 2$ test. Concern had four levels (3 graded levels: "Not concerned", "Slightly concerned", "Much concerned" and one "Don't know") and knowledge had three graded levels ("No knowledge", "Some knowledge", "Extensive knowledge").

Choice of non-lead ammunition in relation to knowledge and concern

To test whether the hunters' knowledge about and concern for impacts of lead ammunition affected the likelihood of using unleaded ammunition, we used a generalized linear model. This model followed a multinomial distribution as the extent of use of non-lead ammunition had three categories of reply: "No use", "Occasionally" and "Exclusively". In addition to awareness and concern, the model included age and sex. The model, therefore, looked like this: Use = age + sex + awareness + concern. The generalized linear model tested the probability of more frequent use of non-lead among those with higher levels of knowledge about/concern for the adverse impacts of lead ammunition. Education might also affect the probability of using non-lead ammunition. However, age differed significantly between education categories (General linear model $F_{8,2670} = 23.4$, $p < 0.001$). We, therefore, tested education in a separate model: Use = education + sex + awareness + concern.

Reasons given for using non-lead ammunition

The hunters gave different reasons for the use of non-lead ammunition. For each hunter we counted the number of reasons for using non-lead ammunition. We tested the relation between the sum and specific reasons for using non-lead ammunition to identify the reasons which primarily contributed to the decision to use non-lead ammunition. The model used was: Use = Consumer + Scavengers + Environment + Perception + Hunting in Germany + Precision + Efficiency + Age + sex. Beside the seven possible reasons for choosing non-lead ammunition, the model also included age and sex to account for the variation that these variables may contribute with. We tested this model using a generalized linear model with a Poisson distribution.

All generalized linear models were calculated in PROC GENMOD, general linear models in PROC GLM, Kolmogorov–Smirnov tests were calculated in PROC NPAR-1WAY, and Chi-square test were calculated in PROC FREQ in SAS ver 9.4.

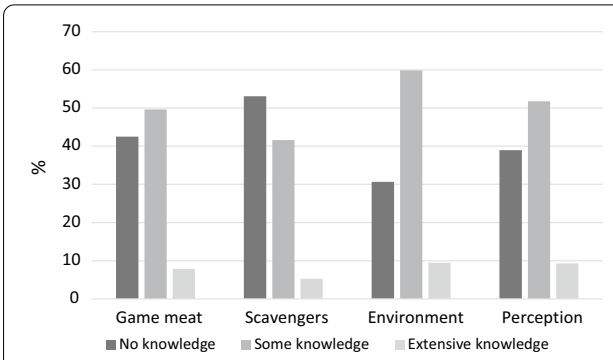

Fig. 1 Respondents' knowledge of impacts of lead ammunition relating to the four different themes (see text)

Results

Out of 5579 qualified recipients of the survey, 2701 (48%) responded. Of these, 22 responded by email and did not provide data via the electronic questionnaire. Hence, 2679 responses contributed to the dataset.

Knowledge

Respondents reported their knowledge of the possible adverse impacts of lead in rifle ammunition in relation to four topics: "Human consumers of game meat", "Predators/scavengers", "The environment", and "Public perception of hunting". On average only 8.0% marked that they had "Extensive knowledge" on all four topics, while almost half stated to have "Some knowledge" on the four listed topics. The topic about which hunters reported most knowledge was adverse impacts of lead ammunition on the environment (Fig. 1). The topic about which hunters reported the least knowledge related to the poisoning of the predators and scavengers.

Regarding sources of knowledge on the impacts of lead ammunition, the respondents indicated hunting colleagues (16.8%) and associations (23.2%) as the main source, while universities (5.0%) and social media (5.6%) scored lower (Fig. 2). Hunting authorities (19.3%) and to

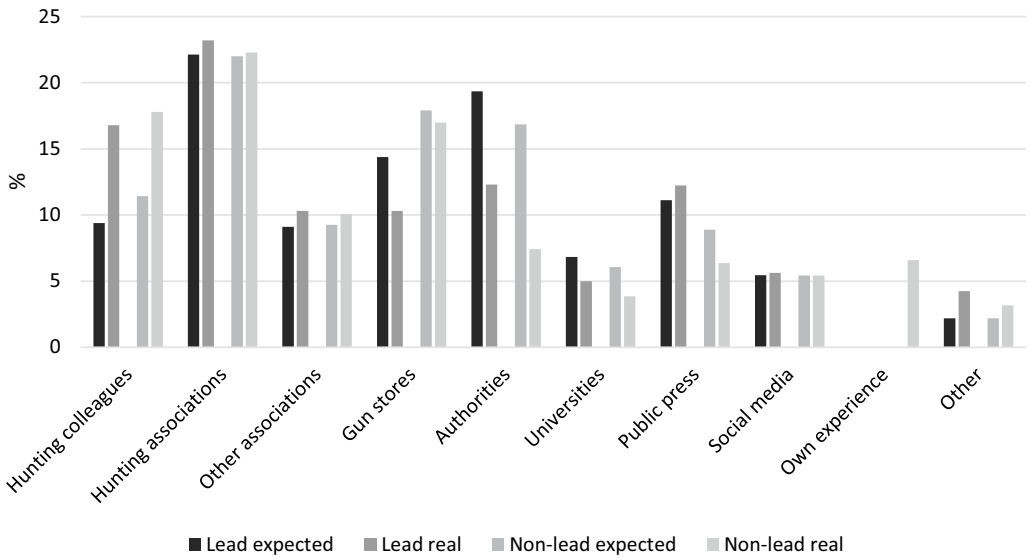

Fig. 2 Sources from which respondents expected to get their information on the impact of lead in rifle ammunition and non-lead rifle ammunition compared to the sources from which they actually obtained this information. "Own experience" was not optional concerning lead ammunition and had no expected option in the non-lead question

Table 2 Statistical output concerning the number of observations, χ2 values, and differences between the hunters' real use and their expected use of sources of information on the impact of lead and on knowledge on non-lead ammunition

Source of information	Lead			Non-lead		
	Observations	χ^2	Difference real/expected	Observations	χ^2	Difference real/expected
Hunting colleagues	981	380.6	449.7	792	239.8	332.1
Hunting organizations	1356	2.2	53.1	991	4.6	65.1
Other organizations	603	6.6	60	448	1	20.7
Hunting stores	603	68.8	− 241	756	0.3	14.2
Authorities	719	150.5	− 412.7	330	170.7	− 337.5
Universities	292	35.2	− 120.4	172	45.2	− 113.7
Newspapers	715	8.7	74.8	284	5.5	− 42.6
Social media	329	0.4	11.4	242	1.7	19.2
Other	249	126.3	125.1	141	19.1	43.3

some extent universities (6.8%) were expected to play a more significant role in knowledge transfer than they actually did with reported sources of knowledge differing significantly from expected sources ($\chi^2_9 = 779.2$, $p < 0.001$, Fig. 2).

Respondents ($N = 2679$) reported their knowledge of non-lead rifle ammunition (categories: "No knowledge", A little knowledge", "Some knowledge", and "Extensive knowledge") and provided information on expected and real sources for such information (Fig. 2). Expected and real sources of knowledge differed significantly ($\chi^2_9 = 487.8$, $p < 0.001$). Once again, hunting associations (22%) and hunting colleagues (18%) were the most important sources but compared to the figures for knowledge about lead ammunition, gun stores played a more significant role.

In total, the difference between values for the sources from which hunters expected to get their information and the sources that they actually get it from were statistically significant. Statistical output concerning the number of observations, χ^2 values, and differences between the hunters' real use and their expected importance of nine sources of information about lead and non-lead ammunition are shown in Table 2.

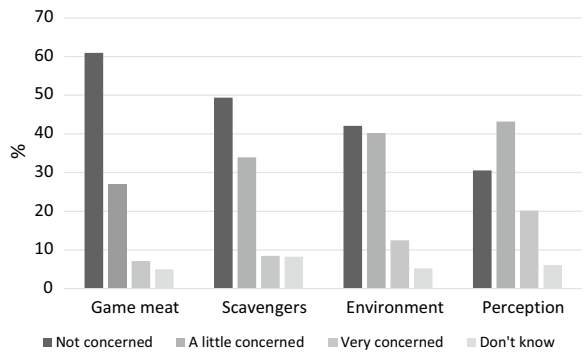

Fig. 3 Respondents' concern for the impacts of lead ammunition relating to four different themes

The differences between observed and expected sources of information on both lead and non-lead ammunition showed that more information than expected was obtained from hunting colleagues, whereas less information than expected was obtained from the authorities and to some extent also universities. The same goes for hunting stores, but only in relation to lead ammunition. For the other sources, there were only slight discrepancies between the expected and the actual level of information.

Concern for impacts of lead ammunition

Respondents indicated their level of concern for the potentially adverse impacts of lead in rifle ammunition relating to the same four themes as for knowledge (see above) (Fig. 3).

In total, 82% of the responses were in the categories "Not concerned" and "A little concerned". Most respondents were concerned for the "Public perception of hunting" (20.2% "Very concerned"). The risk to "Human consumers of game meat" caused less concern (60.9% "Not concerned" and 7.1% "Very concerned"). A rather constant but small number of respondents indicated that they did not know if they were concerned (average 6.1% for all four themes).

Concern, knowledge and the use of non-lead ammunition

We analyzed values for knowledge and concern relating to the four themes: "Human consumers of game meat", "Predators/scavengers", "The environment", and "Public perception of hunting". All showed a significant association (Table 3), meaning that knowledge and concern were dependent. In this case, it meant that respondents who expressed the highest degree of knowledge also expressed the highest degree of concern. The statistical output suggested that hunters were most concerned about the public perception of hunting and least concerned about the risk to human consumers of game meat contaminated by lead ammunition.

Table 3 Statistical output (χ^2 test) for the analysis relationship between hunters' knowledge of and their concern for potential adverse impacts of leaded rifle ammunition relating to the four themes: "Human consumers of game meat", "Predators/scavengers", "The environment", and "Public perception of hunting"

Impact themes	df	χ^2	*p*
Game meat	6	264.9	< 0.001
Scavengers	6	368.6	< 0.001
Environment	6	484.9	< 0.001
Perception	6	774.3	< 0.001

Table 4 Statistical output of the tests (generalized linear model) of possible variables that might impact the use of non-lead ammunition

Variable	df	χ^2	*p*	Slope
Level of knowledge	1	26.7	< .0001	0.116
Level of concern	1	54.2	< .0001	0.134
Age	1	9.7	0.0018	− 0.0095
Sex	1	0,1	0.748	

The degree of knowledge and concern significantly influenced the use of non-lead ammunition. Those reporting higher levels of knowledge and concern were more likely to use non-lead ammunition (Table 4). This means that knowledge as well as concern increased the tendency of hunters to use non-lead ammunition. The significant negative estimate of age demonstrated that young hunters are more likely to use non-lead ammunition than older ones. Sex had no significant impact. The tests indicated that education did not influence the likelihood of using non-lead ammunition.

Use of ammunition

1.853 (69%) respondents reported that they did not use non-lead rifle ammunition, while 450 (17%) used it occasionally, and 376 (14%) exclusively. The distributions of reasons for not using or using non-lead ammunition are illustrated in Figs. 4 and 5, respectively.

The motivation for using non-lead ammunition, to a certain degree, reflected the concerns that respondents had for the possible negative impact of lead ammunition ("Concern, knowledge and the use of non-lead ammunition"). To clarify which aspects contributed most to the extent of the use of non-lead ammunition, we tested the sum for the number of reasons for using non-lead ammunition in relation to the individual aspects that

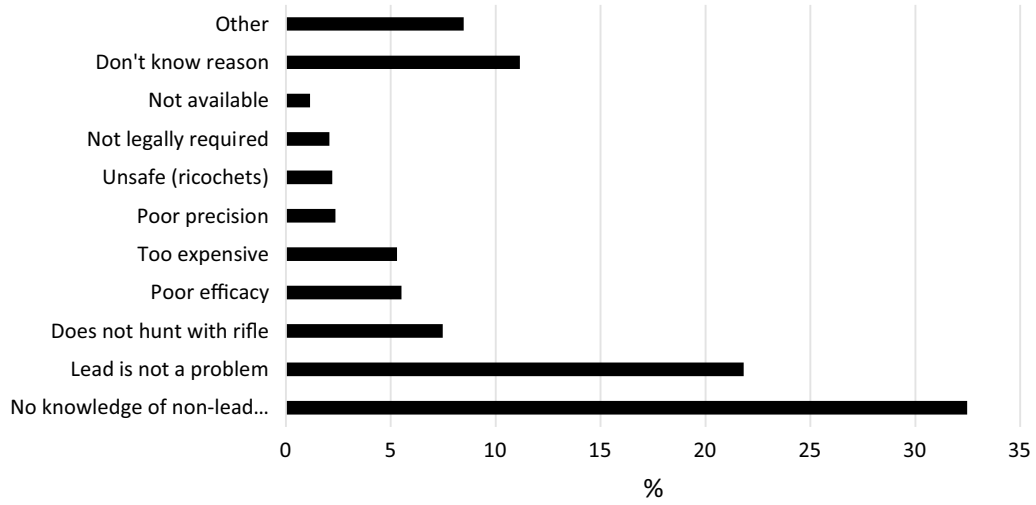

Fig. 4 Reasons not to use non-lead rifle ammunition ($n = 1853$). Respondents could give multiple answers

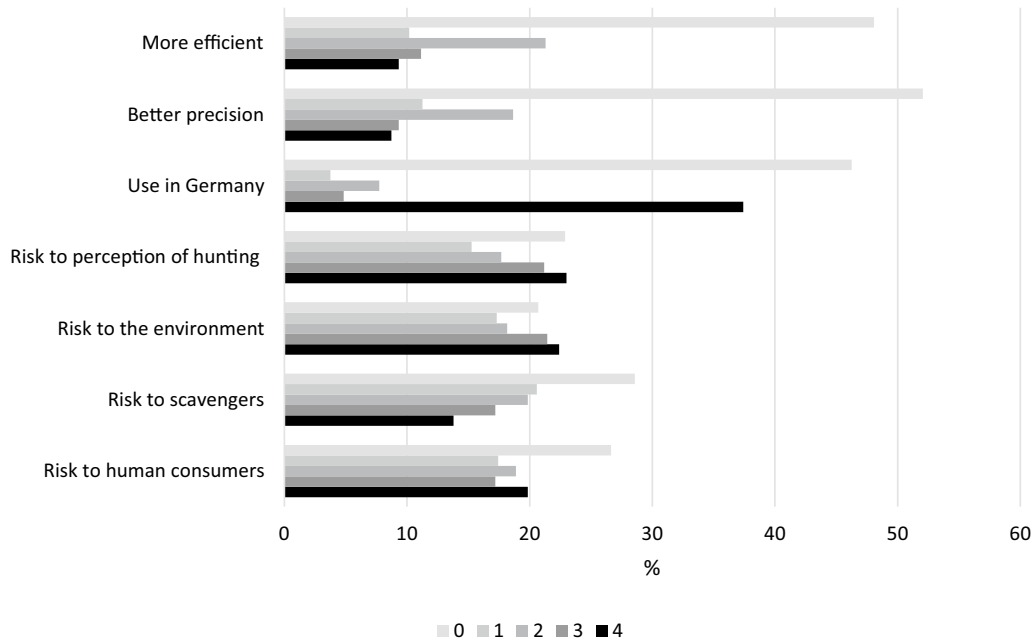

Fig. 5 Reasons to use non-lead rifle ammunition ($n = 826$). Respondents could quantify answers on the scale from 0 (no importance) to 4 (highest importance)

contributed to the sums. This was also tested with a generalized linear mixed model. In this model, the sum was assumed to follow a Poisson distribution. All aspects showed a significant positive relation to the extent of use (Table 5).

According to the parameter estimates (slope), "Damage to the environment" and "The perception of hunting" made the largest contribution. The impact of hunters being introduced to non-lead rifle ammunition in Germany showed a lower contribution to their choice of ammunition, based on the slope estimate. However, this factor was the most significant, which indicates its impact is quite clear compared to the other parameters. The impact of hunting in Germany upon the use of non-lead ammunition was supported by the fact that 73.2% of 213 respondents who hunted in Germany in 2018,

Table 5 Statistical output of tests to compare the importance of different variables and the hunters' choice of using non-lead ammunition

Variable	df	χ^2	*p*	Slope
Risk to human consumers	1	53.91	< .0001	0.0907
Scavengers	1	16.08	< .0001	0.0562
Environment	1	65.30	< .0001	0.1136
Perception	1	82.94	< .0001	0.1024
Hunting in Germany	1	168.15	< .0001	0.0745
Improved precision	1	20.93	< .0001	0.0549
More efficient	1	45.23	< .0001	0.0824

reported that they used non-lead ammunition whereas this was only 27.2% for other respondents.

Respondents reported their use of rifle rounds per year for hunting and training, indicating a mean use of around 6.6 (73% lead; 27% non-lead) rounds per year for hunting and 69.5 (79% lead; 21% non-lead) for training.

Additional comments

The questionnaire gave respondents the opportunity to add their own general or specific comments and reflections. The comments were classified in different themes (Fig. 6). In total, 377 respondents gave additional comments. Some had comments on the relevance or construction of the study or otherwise expressed a negative attitude to the survey (9%). Some argued that lead ammunition is not a problem (14%) while, others supported a ban on leaded rifle ammunition (4%). A rather large group (total 31%) expressed a positive and open attitude to change, however, many had reservations, such as the importance of non-lead ammunition living up to standards of efficacy and safety. Some respondents (7%) stated that they would switch to non-lead when their existing stock of lead ammunition was exhausted. Finally, there was a group (12%) requesting more information including access to the project report. A rather large group gave comments that were of no direct relevance for the survey, for example that they did not at present have a rifle or have the opportunity to hunt (22%).

Discussion

One-fifth of the 2019 use was non-lead

Almost one-third (31%) of the respondents stated that they used non-lead rifle ammunition occasionally or exclusively. Game bag statistics further reveal that respondents were more active in their hunting pursuits than the average hunter in Denmark, and thus, have more practical experience of hunting, including rifle hunting. Higher levels of knowledge of the adverse impacts of leaded ammunition correlates to an increased likelihood of using unleaded ammunition. Hence, the proportion of respondents who stated that they use non-lead ammunition is not representative of all hunters but must be considered a maximum figure. The same is likely to be the case for the figures provided by the respondents regarding ammunition use, which for hunting was distributed as 73% on lead and 27% on lead-free ammunition and for

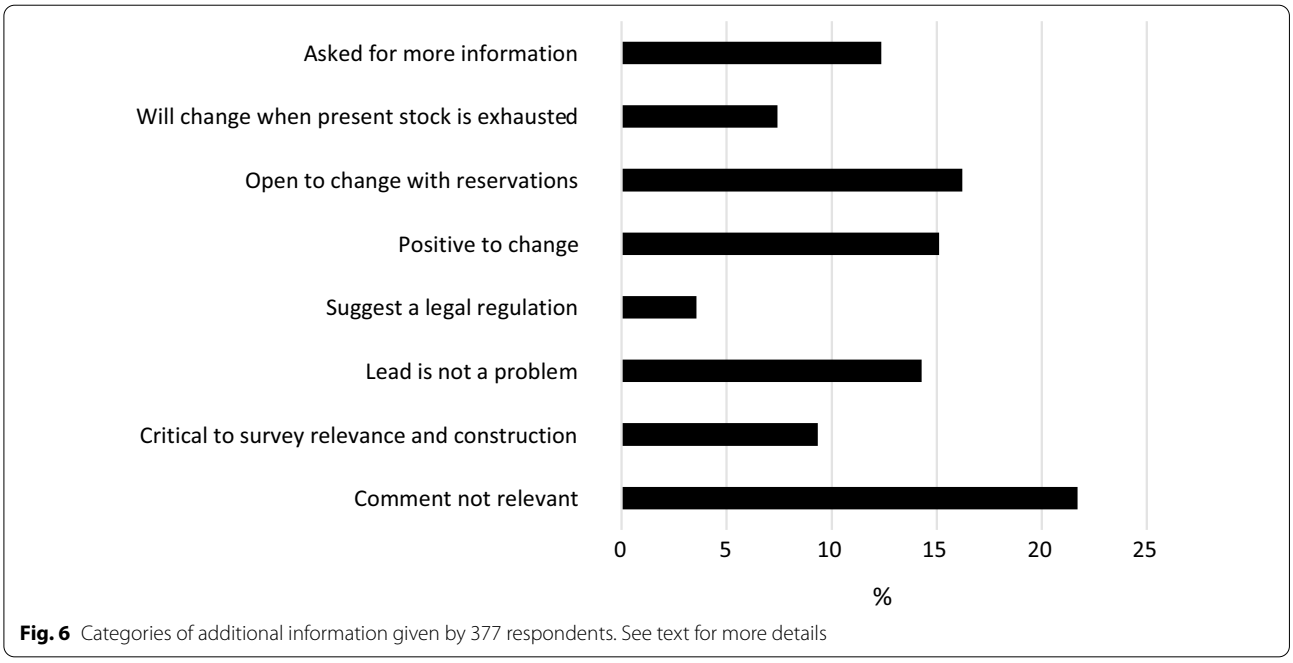

Fig. 6 Categories of additional information given by 377 respondents. See text for more details

training as 79% and 21%, respectively. Furthermore, the figures were above the levels found by questioning Danish gun stores indicating that 10–15% of sales over the years 2017–2019 were non-lead, however, the amount is clearly increasing (Kanstrup, unpublished data). Based on the present study and information from the gun stores it is likely that 15–25% of the rifle ammunition currently used for hunting and related training in 2019 in Denmark is unleaded.

Knowledge, concern, and use are interconnected

Our study demonstrates that the more hunters know about lead ammunition and non-lead alternatives, and the more concerned they are about the impacts of lead ammunition, the higher the tendency is for them to use non-lead ammunition. This highlights the importance of communication and learning as tools for change as demonstrated in other studies [24].

Knowledge and concern predominantly related to "The perception of hunting" and "The environment". This is interesting, because these two themes are poorly covered by literature, whereas the risks to "Human consumers of game meat" and "Predators/scavengers" are well documented at least in the scientific literature [4, 5]. However, comparatively fewer hunters drew on scientific sources for their information on the subject, hence, their knowledge and concern will to a higher degree rely on information from hunting colleagues and hunting associations. Information exchanged between hunters may be intuitive rather than based on research and empirical data. Although Danish hunters' associations and media have been open to discussing the impact of lead in rifle ammunition, the scientific information has not yet reached the wider hunting community. The information has not specifically addressed risks to human health and scavengers but rather the negative implications of hunting being associated with the dispersal of a toxic substance that society in general is in the process of phasing out. This may explain why hunters mostly regard lead in rifle ammunition as a concern for the public perception of hunting.

Before November 2020, i.e., when this study was carried out, Danish authorities had no explicit position on the consequences of leaded rifle ammunition. The website of the Veterinary and Food Administration currently provides the following information: "*Game animals shot with lead ammunition can contain high concentrations of lead—especially in the meat around the bullet hole. Children under seven years of age and pregnant women should therefore avoid eating meat from the area around the bullet hole*" [25]. Implicitly, this formulation issues no warning to people other than children and pregnant women against eating meat from any part of the shot animal, including meat from the area around the bullet hole. This contradicts widely accepted guidelines recommending that particularly children up to the age of seven, pregnant women and women of childbearing age should abstain from eating game meat that has been hunted with lead ammunition due to their specific sensitivity towards the toxic effects of lead [26]. It further contradicts the Swedish guidelines to which the Danish administration makes an explicit website reference. Swedish authorities recommend hunters "*to cut and discard the wound channel after the bullet, meat that looks affected or bloodstained, and at least ten cm of visible unaffected meat around the wound canal. This meat should not be used as food for humans or animals*" [27].

Our study showed that authorities play an important potential role as a source of awareness building for Danish hunters. The scarce and misleading information that has been and still is available from the food authorities may well be one reason for the limited level of knowledge and concern expressed by respondents in this study, particularly in terms of the risk that lead ammunition poses to human health. This suggests that increased focus on the risks associated with human consumption of game meat shot with leaded ammunition could be instrumental in a future communication strategy and raise more concern among hunters if communicated more effectively and less misleadingly. Hunters are, themselves, consumers of game meat as are their families including children and young women. Hunters are the primary producers of game meat for the public food market and it is in the interest of hunters to provide game meat products that are safe for consumers thereby also enhancing the long-term positive reputation of recreational hunting in the public [17]. X-ray photos demonstrating "a snowstorm" of lead fragments in carcasses of killed deer [2] often elicit a strong and spontaneous reaction among hunters and others that are not aware of this phenomenon (authors' personal observation) and could be an illustrative communication tool. Another argument for change could be the more general subject of political sustainability and the public perception of hunting which was the most concern-raising element among respondents. This may primarily be an intuition, however, it is scientifically well established that hunting with lead ammunition is not sustainable [28]. The Danish regulation of leaded gunshot pellets for hunting has established the narrative of the adverse impact of lead in ammunition among hunters [29]. This could be included in a general strategy for future communication on leaded ammunition and the possible transition to non-leaded rifle ammunition.

The study identified a group of respondents who reported a high amount of knowledge but at the same time little concern about the impact of lead rifle

ammunition. Additional comments from these hunters demonstrated that some of them found the risk negligible not least compared to other lead sources (including lead in military ammunition, and fireworks). Some stated that non-lead rifle ammunition is just as toxic as lead ammunition, hence, a transition would only exchange one potential problem with another. Some criticized the project team for "wasting" their (and that of the "respondents") time on a survey like this and found the whole discourse on lead in rifle ammunition to be an attempt to discredit hunters and, in the long term, develop an anti-hunting ploy as also demonstrated in the other studies [30, 31]. This combination of dismissing the potential problem with lead ammunition and at the same time dismissing non-lead types was also observed in the discourse among hunters during the Danish phase-out of lead shotgun pellets in the 1980s [29] and in similar processes in the other countries [32]. This indicates the existence of (i) a group of hunters who are unlikely to switch from lead to non-lead rifle ammunition voluntarily, and (ii) a group of hunters who are unlikely to comply even with legal regulations on the subject, as it was seen also in the process of phasing out lead shotgun pellets [33]. A transition process and the mechanisms to provide such a process must, therefore, be seen in a broader perspective and should include factors beyond those investigated in this study. Some may be rather fundamental and connected to the personal ideology of hunters. There are indications that some societies over the recent decades have witnessed a turn towards a neoliberal paradigm making regulatory conservation approaches problematic while simultaneously making voluntary programs the default policy option [30]. It is conceivable that some hunters are exponents of such a development and that the political conditions for programs for phasing out lead in ammunition today are fundamentally different from what was the case in the initial processes of regulating lead shot for waterbird hunting in the 1980s and 1990s both in North America and an array of European countries.

A rather large group of respondents demonstrated an open attitude towards a transition from lead to non-lead rifle ammunition. 27% of all respondents offered their e-mail addresses to receive further information on the subject and to participate in future follow-up studies. Some demonstrated willingness to discuss the whole issue of lead in rifle ammunition, while simultaneously expressing various reservations, including concern for lethality, safety, availability and price of non-lead ammunition types. Furthermore, respondents expressed that the actual amount of information they receive from authorities, etc., was lower than expected which demonstrates a potential for more communication. Hence, there seems to be a large potential to improve the communication of information about the transition from lead to non-lead rifle ammunition including detailed information covering the specific concerns of hunters all of which have been thoroughly covered by research of direct relevance to Danish hunters [34]. This applies to the efficacy of non-lead bullets investigated in Northern Europe including Germany [35], Scandinavia [14] and Denmark [13] availability [36, 37] including availability on the Danish retail market where a wide range of lead-free rifle ammunition is already available to suit most Danish hunting applications [19]. In terms of the overall budget of hunters, the cost of ammunition plays a minor role. However, the price of ammunition appears to be an essential concern for hunters in their considerations of changing to use non-lead types. In this study, extra costs were given as a reason for not using non-lead rifle at a level of c 5% of answers given by respondents (Fig. 4), which was similar to the percentage of respondents with concerns for the poor efficacy of non-lead ammunition. It is well established that non-lead rifle ammunition is available at prices comparable to equivalent leaded ammunition [12, 36]. Regarding safety, research generally suggests that it is not the material (lead or non-lead) that is decisive for the ricochet tendency but rather the bullet shape and construction [38].

Future perspectives

Non-lead rifle ammunition was first introduced to the Danish market in around 2013 and this study suggests that approximately one-fifth of the consumption in 2019 was non-lead. This change has until now occurred without any legal encouragement, apart from the formal regulation of lead rifle bullets in Germany which evidently has a knock-on effect in Denmark, because Danish hunters who hunt in German regions with regulations on lead rifle ammunition get acquainted with non-lead ammunition and tend to also use it in Denmark. However, by November 2020, the Danish government announced a legal regulation of leaded rifle ammunition to come into force in 2023. Therefore, speculation about to what extent a transition could occur without a legal regulation in Denmark, i.e., based only on a voluntary transition supported by an extended outreach strategy, appears with the recent governmental initiative to be a purely theoretical endeavor. Nevertheless, the traditional components of a non-regulative approach, not least solid communication, is still needed to facilitate and improve the rate of success of an effective regulative phase-out of leaded rifle bullets.

Our study shows that young hunters are more likely to switch from leaded to lead-free ammunition than older ones. Furthermore, some hunters plan to switch

to non-lead ammunition when their existing stock of lead ammunition is exhausted. Both findings suggest that the shift will accelerate even without a legal regulation. The elimination of lead ammunition in some private hunting districts in 2020 will further contribute both in the form of ammunition used in these districts and the impact that such an initiative will have on hunters' choice of ammunition for hunting in other areas. The broad request from many respondent hunters to receive more information about our study as well as the hunters' willingness to learn from each other demonstrate a potential for improving communication from all relevant bodies. Improved information and knowledge will motivate concern and, thus, stimulate the transition whether it is voluntary or regulative. However, information and knowledge alone are unlikely to lead to changes of attitude and behavior, as described in the "information deficit model". Successful governance relies on more than just one-way information and should ensure communication in the broadest possible capacity embracing that information, its content of technical knowledge and the consequences of that knowledge are understood by, reflected on, debated and, where relevant, commented on by key target audiences.

Segerson [39] found the concept of voluntary approaches in environmental protection programs to encompass three types: (i) unilateral initiatives, under which polluters voluntarily take actions to reduce pollution without any government involvement; (ii) negotiated agreements, under which a regulatory agency negotiates with polluters over the terms of an agreement involving obligations on both sides, and (ii) public voluntary programs, under which the government unilaterally determines both the rewards and obligations of participation and eligible polluters are encouraged to participate. Regardless of the impact of regulation in Germany, the approach taken until now in Denmark seems to belong to unilateral initiatives driven only by the hunters themselves with no or only little contribution from Danish authorities. According to this it is, however, overall likely that the establishment of a negotiated agreement between the Danish government and the hunting community could lead to a further and significant transition from the use of lead to non-lead rifle ammunition based solely on a voluntary approach. However, several factors would limit the success of such a program in terms of a full transition including a free-rider behavior of a rather large group of hunters that disregards the adverse impacts of lead ammunition and, at the same time, regards the whole discourse and possible regulation to be an anti-hunting ploy. Furthermore, the group of hunters who will transition to non-lead ammunition once their present stocks of leaded ammunition are exhausted could hinder a quick transition. Finally, voluntary programs to phase-out lead ammunition as seen in Europe and North America during the past 2 decades have been largely unsuccessful and ineffective [24, 30, 32, 34].

The consistent approach taken by Danish authorities to phase-out leaded gunshot in the 1990s has been successful and has posed no risk to the future of hunting [29, 40]. Although Denmark is one of Europe's smallest countries, it holds a high proportion of hunters with multifaceted hunting traditions resembling those of larger European countries, e.g., Germany, UK, and France. The Danish success of phasing out leaded gunshot pellets, including almost 40 years of accumulated knowledge, experience, and communication are, therefore, a valid and representative contribution to the international discourse in the years to come.

Lead is toxic and our understanding of the adverse impacts of this form of lead exposure on wildlife and humans will change little with further eco-toxicological research. The issue is now socio-political [41]. This increases the demand for knowledge about the mechanisms that govern human behavior, i.e., an increased effort within the socio-scientific disciplines. There is a growing need for an effort that transcends the classical research sectors. Such an interdisciplinary approach will provide a deeper understanding of the factors predicting and affecting perception and compliance with the established regulations and acceptability of any future changes to practice.

Conclusions

This study demonstrates that many Danish hunters are not yet aware of the adverse impacts of lead in rifle hunting ammunition and neither do they know about the possibilities to changing to alternative, non-toxic types. At the same time, some hunters have already changed completely or in part as approximately one-fifth of the rifle hunting ammunition used in Denmark in 2019 was non-lead. Others show an open attitude to discussing the issue and receiving more information particularly from hunting authorities. Nevertheless, a group of hunters demonstrated a critical or negative attitude towards a change.

Knowledge is a key to concern for lead's impact and the possibility of using alternatives and both knowledge and concern increase the likelihood of hunters changing to use non-lead rifle ammunition. Introduction to the use of non-lead rifle ammunition via hunting in Germany further stimulates Danish hunters to use non-lead ammunition also for hunting in Denmark. Hunters requested more information from hunting authorities, and a transition is likely to succeed if campaigned efficiently by authorities and hunters' organizations.

The study identifies essential elements of communication in a transition program, including information on the problem in terms of, for example the risks that lead rifle ammunition poses to human consumers as well as the solution in terms of efficacy and safety of non-lead ammunition types that are widely available. Communication of this information is essential in the regulative approach as announced by the Danish government in November 2020 whereby lead in rifle ammunition will be banned by 2023. A clear strategy to maintain and improve the communication with the hunters is essential for the success of such initiative.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12302-021-00485-z.

Additional file 1. Questions included in the questionnaire study: Non-lead rifle ammunition: Danish hunters' attitudes.

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Authors' contributions
NK conceptualized and directed the study, analyzed and interpreted the data, drafted, revised and finalized the manuscript. TJSB undertook statistical analysis and data interpretation. KAM designed data collecting software and administered the technology. HPH supported conceptualization, undertook data interpretation and critical revision of manuscript. All the authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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Not applicable.

Consent for publication
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The authors declare that they have no competing interests.

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