Lead Poisoning and Illegal Hunting of Migratory Swans:

from biological effects to conservation conflict

Submitted by Julia Louise Newth to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Biological Sciences, April 2019.

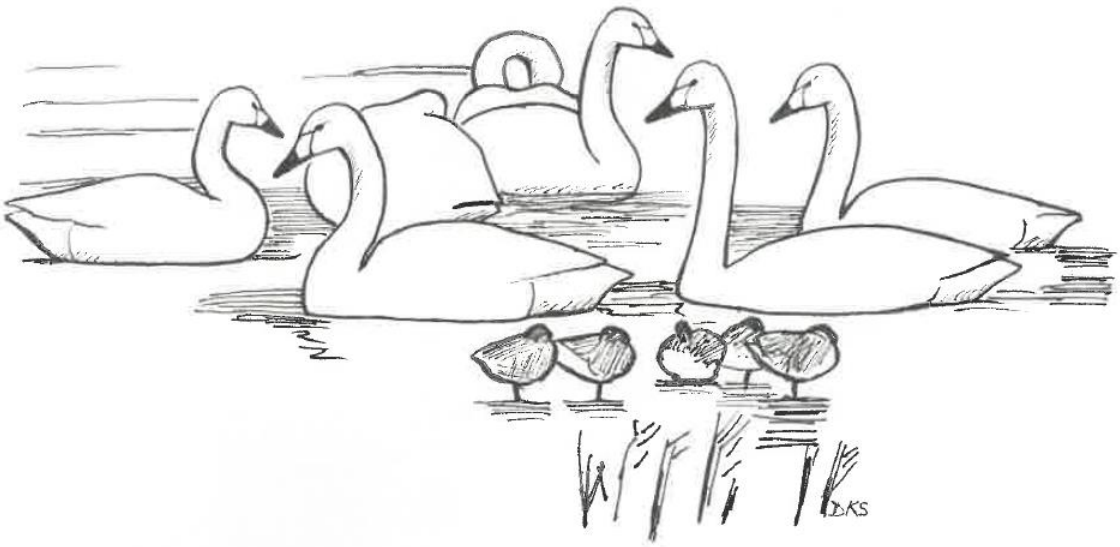
I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

(Signature) ……

“Real change comes when people are enabled to use their thinking and their energy in a new way, using a different system of thought, different language, and having fresh visions of the future.”

Dr Scilla Elworthy

Peace builder



Abstract

Conflicts between people over protecting biodiversity are ubiquitous, damaging and among the most challenging problems facing wildlife conservation worldwide. Such conflicts typically emerge from 'biodiversity impacts' when there are disagreements about the management and allocation of natural resources. They are characterised by their inherent multi-layered complexity and their negative impacts on biodiversity, livelihoods and human wellbeing. A shift towards a greater understanding of the human causal drivers of complex conservation issues as well as their ecological impacts is urgently needed to prevent and de-escalate conflicts and halt potentially catastrophic biodiversity loss. I explore the ecological and socio-psychological contexts of two complex conservation issues – the illegal killing of Bewick's swans *Cygnus columbianus bewickii* in the Russian Arctic (regarded as a biodiversity impact at risk of emerging as a conflict) and the poisoning of waterbirds from lead ammunition in the UK (currently in a 'destructive' phase of conflict) – using approaches and methodologies from the natural and social sciences and psychology. I also provide novel insights into their management and wildlife management more broadly.

I first examine the lesser known impacts of blood lead levels on the physiology of wild birds. I determine that sub-lethal impacts of lead on the body condition of Icelandic-breeding whooper swans *Cygnus cygnus* occur at the lower end of previously established clinical thresholds. Despite partial restrictions on the use of lead ammunition in the UK, I found a high prevalence of lead poisoning within this swan population. I recommend that previously suggested thresholds for adverse clinical effects should be revised downwards for free-living wildfowl. These findings reaffirm the importance of reducing contamination of the environment with lead shot and thus the availability and exposure of lead to waterbirds.

Next, using Q-methodology, I examined the perspectives of ammunition users around the use of lead ammunition and its potential impacts on wildlife and humans. Disagreements on the risks arising from the use of lead ammunition and appropriate mitigation measures continue to strain relationships between conservation and shooting stakeholder groups in the UK. I identified two

statistically and qualitatively distinct perspectives ('Open to change' and '*Status quo*') among ammunition users, and areas of consensus between these. I argue that the clarification of views held presents an opportunity for the shooting community and other stakeholders to take forward discussions and potentially forge new solutions for this long-running conflict.

To identify effective management approaches for reducing the illegal hunting of Bewick's swans in the Russian Arctic, I examined the risk of accidental hunting and the drivers of deliberate hunting using responses to a questionnaire survey. I found an overall inability of hunters to visually distinguish between three swan species and conclude that the risk of Bewick's swans being hunted arises in part when they are mistaken for the whooper and mute swan *Cygnus olor*, both of which are afforded weaker legal protections than the Bewick's swan in certain areas. Additionally, a significant proportion of hunters were ignorant of the protective laws. I therefore recommend technical solutions that inform hunters about species identification and protective laws. The clarification and mitigation of this issue at the earliest opportunity will help prevent it from emerging as an intractable conservation conflict between conservationists and resource users.

Next, using the Theory of Planned Behaviour, I assessed the drivers for deliberate hunting. Hunters were more likely to harbour hunting intentions if they held negative attitudes towards protective laws and positive or neutral attitudes towards hunting Bewick's swans, perceived few or no practical barriers to hunting them, and believed that the behaviour was socially acceptable. Wider ecological, recreation, legal and economic motivations were also identified. Future conservation interventions should therefore target social and psychological conditions that influence hunters' attitudes, social norms and perceived behavioural control.

Finally, I collate the findings of this thesis and use an established conflict typology to partition the varying dimensions and thematic features of the lead shot conflict and identify characteristics of the illegal hunting issue that may facilitate its emergence as a conservation conflict. I suggest that conflict management approaches can be applied to complex biodiversity impacts to prevent their transition to conflict.

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Contents

Table and Figures

Author's declaration for co-authored manuscripts

Chapters 2, 3, 4, and 5 have been published or written for publication as co-authored academic papers. All studies herein (Chapters 2, 3, 4 and 5) were conceived by myself. All authors contributed critically to the drafts and gave final approval for publication.

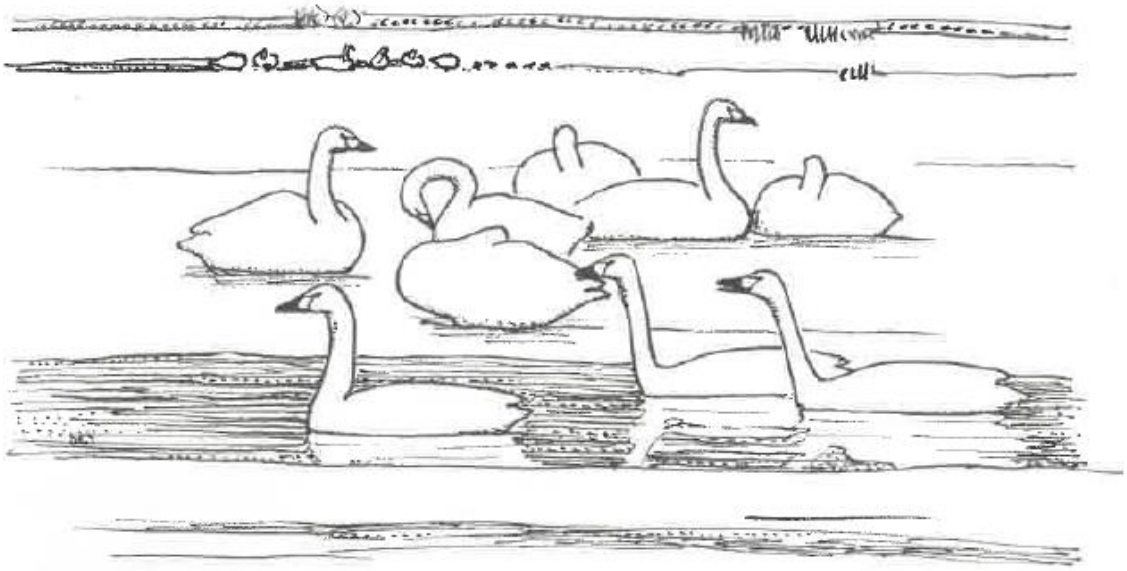
For Chapter 2, data was collected by myself and other staff and volunteers from the Wildfowl & Wetlands Trust (WWT). Blood lead samples were analysed by Gareth Norton and Claire Deacon at the University of Aberdeen. I analysed the data with guidance from Geoff Hilton (GH), Eileen Rees (ECR), Ruth Cromie (RLC), Stuart Bearhop (SB) and Robbie McDonald (RM), and led the writing of the manuscript.

For Chapter 3, I designed the methodology with input from RM, Alice Lawrence, RLC and John Swift. I then collected the data. I prepared the data for analysis with Emily Strong. I analysed the data and led the writing of the manuscript.

I designed the studies for Chapters 4 and 5 with Ana Nuno (AN) and Igor Semenov. The fieldwork was undertaken by Anton Chistyakov and Galina Mikhaylova. I then processed the data and undertook analysis with input from RM, SB, AN, Kevin Wood and ECR. Finally, I led the writing of the manuscript.

Chapter 1

INTRODUCTION



Chapter 1: Introduction

Conservation conflicts in a dynamic world

Our world is facing a rapid loss of species and habitats, resulting from a suite of anthropogenic pressures including exploitation of natural resources, pollution, climate change and land-use change (Foden et al. 2013; Maxwell et al. 2016; Tilman et al. 2017; Hoegh-Guldberg et al. 2018). Indeed, an accelerated decline in biodiversity driven by human-induced changes in the Anthropocene, has caused the extinction of species at a rate that has not been seen since the last global mass-extinction event approximately 66 million years ago (the Cretaceous–Paleogene extinction) (Rockström et al. 2009). Anthropogenic impacts on biodiversity have been exacerbated by an increasing human population and the subsequent demand for, and commercial exploitation of, natural resources which have increasingly positioned conservation in conflict with human activities (Redpath et al. 2013; Margalida et al. 2014). In these cases, 'biodiversity conflicts' emerge from 'biodiversity impacts' (Young et al. 2010), typically arising from disagreements about the management and allocation of natural resources associated with wildlife and habitats (Marshall et al. 2007). More broadly, 'conservation conflicts' (which encompass biodiversity conflicts) occur between humans *"when parties clash over differences about conservation objectives and when one party asserts, or at least is perceived to assert, its interests at the expense of another"* (Redpath et al. 2015b). Rather than being characterised by disputes between people, biodiversity or 'human-wildlife' impacts occur under circumstances where *'people, consciously or unconsciously, impact negatively on biodiversity, or alternatively, where wildlife or other aspects of biodiversity impacts negatively on the wellbeing or livelihoods of people'* (Young et al. 2010). Conservation conflicts may involve diverse actors including engaged stakeholders from conservation, industry, business and government and wider public, as well as the media (Hodgson et al. 2019). They are wide-ranging and commonly relate to the intensification of agriculture and forestry practices, land abandonment and development, natural resource extraction, water catchment and other land uses such as recreation and hunting (Young et al. 2005; Buchanan 2013). Such conflicts may culminate in various degrees of impact and arise across diverse spatio-temporal scales, ranging from large-scale

disputes between multinational companies or governments and local stakeholders over mineral extraction (e.g. Buchanan, 2013), to local conflicts between land managers and conservation groups over wildlife management (Young et al. 2005). Conflict over protecting biodiversity now presents one of the most significant challenges to wildlife conservation worldwide (Peterson et al. 2013; Hodgson et al. 2019). In today's context of increasing resource scarcity (Day et al. 2009), it is predicted that conflicts will increasingly come to characterise biodiversity conservation in the future (Peterson et al. 2013). A shift towards a greater understanding of the human causal drivers of conflict as well as their ecological impacts, is urgently needed to mitigate future conflicts and halt potentially catastrophic biodiversity loss (Young et al. 2010).

Conflict patterns and processes

An understanding of the underlying processes of conflict and how they may evolve over time can inform their management and prevent their escalation. Patterns in conflict stages have been identified and visualised as a 'conflict curve' (Figure 1.1).

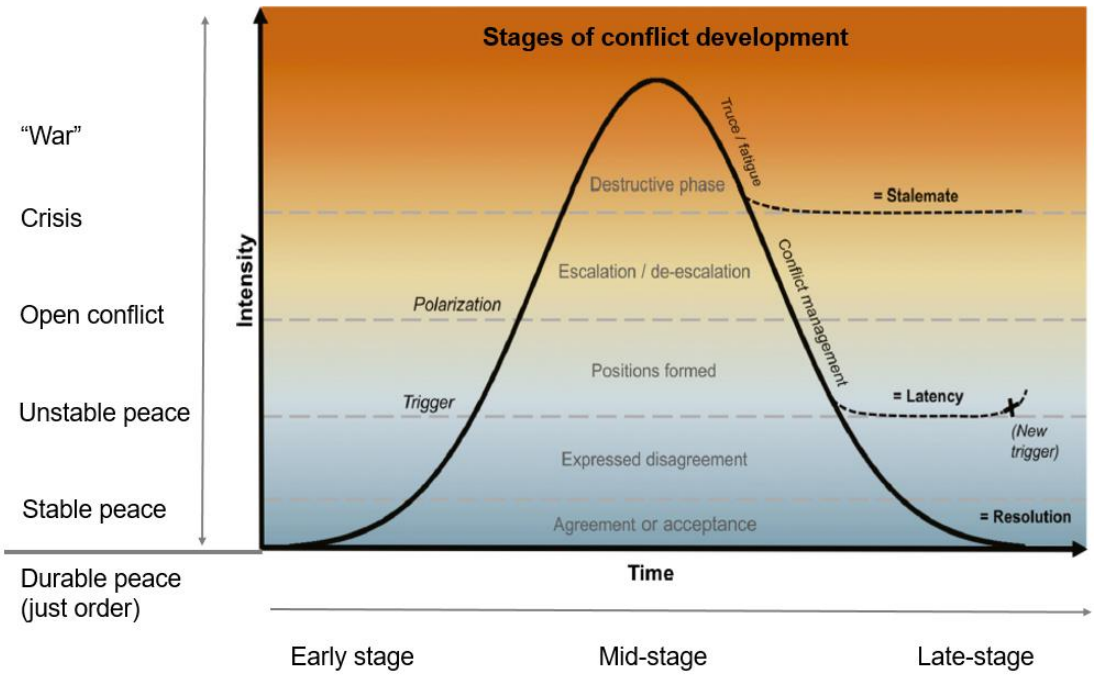


***Figure 1. 1**: Processes (italicised text) and outcomes (bold text) of conflict visualised as a 'conflict curve' (Adapted from Crowley et al. 2017 using Swanström & Weissmann 2005 and Lund 2009).*

As depicted in the conflict curve, conflicts become destructive when they escalate and span long periods of time. The first stage of a conflict may manifest as ‘stable peace’, where tension between the stakeholders is low and some level of co-operation may exist (Swanström & Weissmann 2005). Conflicts may then progress from periods of ‘stable peace’, to ‘unstable peace’ (when tensions between parties is such that peace no longer seems guaranteed), ‘open conflict’ (when the conflict is defined and the parties have taken measures to deal with it), ‘crisis’ (when action of a higher intensity or gravity is taken), and finally, to ‘war’ (when there is widespread and intense conflict) (Swanström & Weissmann 2005). At this point, the conflict is now in a ‘destructive’ phase where damaged relationships and harmful outcomes prevail (Crowley et al. 2017; Figure 1.1). Unable to sustain such intensity, destructive conflicts tend to stagnate while remaining unresolved or may enter unending ‘cycles of latency and escalation’ (Crowley et al. 2017). Conflicts may evolve in this way by two facilitating processes: ‘polarisation’ and ‘escalation’ (Crowley et al. 2017). Polarisation occurs when disagreements are framed in simplistic binary ‘for or against’ terms, implying that only a win-or-lose scenario is possible (Redpath et al. 2013; Crowley et al. 2017), and that positions are mutually exclusive (Minteer & Collins 2005). Opportunities to identify common ground may be missed as a consequence. Escalation refers to increasing conflict intensity and complexity arising from the involvement of more people, interests and issues (Crowley et al. 2017). This may culminate in a self-perpetuating circular debate which can lead to hostilities between conflict actors, thus reducing opportunities for meaningful dialogue (Crowley et al. 2017). Numerous conservation conflicts follow these general patterns and processes and various approaches are taken to deconstruct them.

The role of ecological knowledge in conflict

Access to information is fundamental to the democratic process and is regarded as a precondition for informed discussion (Linnell 2013). Conflicts can occur when information is lacking (Young et al. 2010). In one case, a lack of scientific data was believed to be a key contributing factor in the escalation of an emerging conflict around the presumed killing of livestock by griffon vultures *Gyps fulvus* in south-west Europe (Margalida et al. 2014). Although some attributed a reported increase in livestock killing to a shortage in the availabilty of carcasses for

vultures to scavenge on, there was little emipirical data to support this and proposals for the provision of supplementary feeding sites (Margalida et al. 2014). Ecological information can help us quantify the impacts of humans on wildlife, the impacts of wildlife on humans, the mechanisms within systems where impacts occur and the relative efficacy of mitigation strategies (Dalerum 2014; Redpath & Sutherland 2015). Mason et al. (2018a) used mixed-effect models to examine the drivers of historical spatio-temporal dynamics on the numbers and distribution of Greenland barnacle geese *Branta leucopsis* on Islay, thereby demonstrating the roles of habitat modification and climate change in the emergence of conflict between goose conservation and agriculture. This led to the identification of aspects of the conflict that were more amenable to human control, such as local habitat management (Mason et al. 2018a). In other cases, a knowledge deficit may simply be a conservation problem in need of a solution, rather than a source of conflict between stakeholders.

Ecological data may help move a debate forward when perceptions differ. Redpath et al. (2015b) examined the highly political and persistent conflict relating to the impact of hen harriers *Circus cyaneus* on red grouse *Lagopus lagopus scoticus* in the UK's uplands. Arguments between those with interests in hunting and conservation revolve around the magnitude of impact on grouse populations and the illegal persecution of hen harriers. Further ecological research found that in some cases, raptor predation could make intensive forms of grouse/moorland management uneconomic, and these findings moved the debate narrative from one about impact to that about appropriate management strategies (Thirgood & Redpath 2008). While the science has changed the nature of the debate, this deep-seated conflict has not been resolved, partly due to social and political barriers (Thirgood & Redpath 2008).

Although ecological information may not resolve a controversy, it may play an important role in decision-making processes (Redpath & Sutherland 2015). In a study exploring how knowledge uncertainties influenced a mussel fishery in the Dutch Wadden Sea, Floor et al. (2018) identified several aspects of knowledge generation that contributed to the management of conflict between the fishery and conservationists. Research projects were perceived by the authors to play strategic, procedural and instrumental roles. All actors used research as a

strategic tool in their pursuit of finding ‘better knowledge’, with results increasing the depth of their scientific arguments. Scientists were made jointly responsible for fishing permit decisions and the research projects provided important meeting grounds for discussion (Floor et al. 2018). Uncontested knowledge was used to form the basis of co-operation within a legal framework (Floor et al. 2018).

Despite opportunities for a positive contribution to conflict management, the utility of ecological information in transforming conflicts is often limited (Kirkpatrick & Turner 1997; Heberlein & Ericsson 2008; Linnell 2013). The Information Deficit Model (Kahan et al. 2012) whereby communication of knowledge is deemed sufficient to help raise awareness and bring about change, has become dominant among conservation biologists and policy makers (Beck 2011) in the fields of resource use and protected natural areas (e.g. Floor et al. 2016). However, scientific facts alone rarely change attitudes and values or culminate in behaviour change (Sarewitz 2004; McKenzie-Mohr et al. 2012; Floor et al. 2016; St John et al. 2018). The ‘linear model of expertise’ (Beck 2011), which determines that the knowledge debate must first be resolved in order to achieve agreeable decisions and policy, is now in doubt (e.g. Floor et al. 2018). Furthermore, ecological information may in itself be a source of conflict when it is misunderstood or perceived in conflicting ways (Young et al. 2010). Indeed, Hodgson et al. (2019) argue that the way in which research based-knowledge is used and interpreted by opposing parties, rather than the knowledge itself, has a key role in conflicts. Research can be used to legitimise and reinforce certain world views and to support political actions (e.g. Hodgson et al. 2019). Uncertainties about knowledge can fuel debates about knowledge (Floor et al. 2018). Given that socio-ecological systems are dynamic, complex and composed of multiple interacting agents, uncertainties can be large and varied (Nuno et al. 2014). Perceptions about incomplete knowledge can give rise to disputes about whether there is sufficient knowledge to support decision-making (Floor et al. 2018). Disagreements can occur when people dispute conflicting information, particularly when they are derived from different knowledge systems and different ‘ways of knowing’ (Floor et al. 2016). Knowledge forms are diverse, encompassing scientific knowledge and local, lay and traditional knowledge (Linnell 2013). Scientific knowledge is often given greater weight than other forms of knowledge and this can culminate in power struggles (Linnell 2013). Recent

authors have argued that integrating these different forms of knowledge could benefit attempts to manage or resolve conservation conflicts (Gutiérrez et al. 2016).

Conflicts can arise even when there is close co-operation between scientists, managers and resource users, and when there is legislation and mechanisms in place to facilitate the input of various knowledge forms (e.g. traditional ecological knowledge; Manseau et al. 2005). For example, published estimates of beluga whale *Delphinapterus leucas* numbers in the Canadian Beaufort Sea derived from scientific surveys, conflicted with higher estimates derived from the personal observations of local hunters over the years (Manseau et al. 2005). Although the limitations of the surveys were outlined by the scientists, the published estimates became the focus of the discussions on the health of the population (Weaver 1991). Subsequent surveys produced much higher population estimates leading to the conclusion that there were in fact more whales than had been originally estimated from surveys (Manseau et al. 2005). Although the legitimacy and value of a range of knowledge forms has been widely recognised within the key international conservation agreements (e.g. Convention on Biological Diversity, 2019) and intergovernmental forums (e.g. the Arctic Council; Brhlíková 2017) in recent years, the integration of diverse knowledge systems remains problematic and a source of contention in many cases (Linnell 2013). Conflicts relating to information may not simply be due to contrary, or a lack (perceived or otherwise) or misunderstanding of information. The deliberate dissemination of misinformation may be used as a tool in struggles for power and legitimacy (Skogen & Krange 2003; Lewandowsky et al. 2013; Linnell 2013). For example, misinformation has played a central role in the politics of large carnivore conservation in Europe and has been used to exaggerate or downplay the risks that wolves *Canis lupus* pose to human safety (Skogen & Krange 2003).

The need for interdisciplinary approaches

> *"Management decisions for natural resources are not made in a vacuum; the environmental and ecological conditions as well as the socio-economic and political contexts affect goals, the choice of interventions, their feasibility, and which outcomes are obtained"* – Nuno et al. (2014).

Traditionally, the field of conservation has been rooted in the natural sciences and the skills and interest of practitioners has focused on understanding and conserving the needs of wildlife rather than humans (Madden & Mcquinn 2014; Bennett et al. 2017b). Furthermore, conservationists sometimes make important assumptions about human attitudes and behaviour when managing conflict (Dickman 2010). For example, it may be assumed that impacts on wildlife are directly related to the level of conflict, that the level of conflict evokes a proportionate response, or that altering the response to the conflict will have a proportionate response (Dickman 2010). These understandings and assumptions can culminate in certain approaches to conflict management (Treves et al. 2009). Indeed, efforts by conservation biologists to address conflicts have been, and largely still are, tailored towards technical solutions that aim to alter human behaviour by changing the external environment (Baynham-Herd et al. 2018). These may include physical solutions (e.g. use of fences to separate predators from wildlife; Woodroffe et al. 2014), economic incentives (e.g. compensatory payments for losses due to wildlife or financial incentives to dissuade people from killing wildlife illegally; Karanth et al. 2013), legal action (e.g. stricter enforcement measures for laws that protect wildlife and more stringent punishment for violation of regulations; Baynham-Herd et al. 2018), and direct, biological methods (e.g. lethal control of invasive populations that threaten native wildlife; Howald et al. 2009, or retaliatory killing; Mariki et al. 2015). Although positive conservation outcomes can arise from such practices, alone they are usually insufficient for addressing the complex psychological and social dimensions that underpin conservation conflicts (Madden & Mcquinn 2014).

More often than not, such confrontations are rooted in a deeper conflict between people and groups rather than solely between people and wildlife (Madden & Mcquinn 2014). On the surface, many conflicts appear to be linked to impacts on biodiversity such as the impact of carnivores on livestock (van Eeden et al. 2017), the impact of protected areas on livelihoods (Brockington & Wilkie 2015), and the impact of illegal killing on wildlife (Sándor & Anthony 2018). However, conflicts are in fact multi-layered and derive from a deeper cognitive level (Adams et al. 2003), influenced by power relations (Raik et al. 2008), world views, attitudes, beliefs and values that are rooted in larger societal and historical issues such as poverty and inequality (Vedeld et al. 2012; Duffy et al. 2016) and governance

processes (Lute et al. 2018). Moreover, there are often multiple linkages and interactions between these elements (Ives & Kendal 2014; Bunnefeld et al. 2017). A myriad of social and psychological demands such as status and recognition, dignity and respect, empowerment, freedom and control, personal fulfilment, expectation, identity, belonging and social, emotional, cultural and spiritual security, may all play a crucial role in influencing conflict (Satterfield 2002). Indeed, of the six broad conflict categories to have been identified (Table 1.1; Young et al. 2010; Redpath et al. 2013, 2015b), only one ('conflicts over information') is driven by ecological factors.

Table 1. 1*: Typology of conflict. The typology identifies six broad, and sometimes overlapping, categories of conflict. The typology partitions the varying dimensions of conflict and identifies the key themes that characterise them. (Adapted from Young et al. 2010 and Redpath et al. 2015b).*

Type of conflict	Theme
Conflicts of interest	When two parties want different things from the same habitat or species
Conflicts over beliefs and values	Where differences exist over normative perceptions (e.g. what species should be conserved and what human behaviour should be allowed)
Conflicts over process	When conflicting parties take different approaches to decision-making and fairness
Conflicts over information	When data are lacking, misunderstood, or perceived in different ways by different stakeholders
Structural conflicts	Relate to social, legal, economic and cultural arrangements
Interpersonal conflicts	Relate to differences in personality between parties (individuals or groups), including issues of communication and mistrust

The substantial influence of societal factors on conflicts may be evident in people's response to a species. Such responses may be shaped by attitudes and belief systems. For instance, the widely held and deep seated negative attitudes towards bats has long been fostered by the mythology that links them to

vampirism (Prokop et al. 2009; Dickman 2010). In another example, many large predators and other animals that sometimes attack humans suffer persecution linked to beliefs that such attacks are related to sorcery (e.g. summoning spirits in the form of animals) and human-to-animal shapeshifting, leading to conflicts with conservationists and contributing to the poor conservation status of these species (Sousa et al. 2018). Human perceptions of particular animals may also shift over time alongside their influences (Manfredo & Dayer 2004; Gordon 2017). There is increasing recognition that preferences for conservation programmes or policies may depend on what in nature is 'valued' and why (Ives & Kendal 2014; Lute et al. 2016). Carnivores, for example, often provoke strong emotions, ranging from extreme love, admiration and respect, to fear and hatred (Linnell 2013). Knight et al. (2011) argues that a lack of consideration of values by those managing ecological systems can lead to conflict and poor ecological outcomes. However, while there is often a wide diversity of views within and between stakeholder groups, research often shows that a wide platform of common ground concerning environmental and social values exists (Linnell 2013).

Imbalances of power and feelings of vulnerability can also escalate conflict. For example, rural communities may feel aggrieved when they perceive that the protection of wildlife stems largely from powerful, urban 'elites' (Skogen et al. 2008; Dickman 2010). Conflicts may consist of various struggles that may not be immediately obvious, particularly when they are examined in isolation. One case study describes a conflict in Kenya which was initially perceived to be instigated when a local authority and a conservation body intended to implement plans that would affect how a forest was being used by the indigenous Loita Maasai (Kronenburg García 2017). The author concluded that one important layer was overlooked in the various interpretations of the conflict; the struggle within the leadership of the Loita Maasai, and this was crucial for providing a valid explanation for two conflicts when they were considered together (Kronenburg García 2017). Issues of distrust between actors may also serve to antagonise and intensify conflict (Dickman 2010; Young et al. 2016a). This complex cocktail of ecological, cultural, socio-political and personal factors has led to some conservation conflicts being characterised as 'wicked problems' (Mason et al. 2018b). 'Wicked problems' are difficult problems that are hard to define,

immersed in socially complex systems with interdependencies, and lack clear solutions with often no determinable stopping point (Rittel & Webber 1973).

Under these circumstances, the development of mutually supported solutions that can be sustained beyond the short-term requires an in-depth understanding of both the ecological *and* underlying socio-psychological, economic, political and historical components of conflict (Young et al. 2010; Bunnefeld et al. 2017). By their very nature and definition, conservation conflicts cannot be fully understood nor managed from a single paradigm, but require an interdisciplinary approach that draws on several realms including the natural sciences, social sciences and humanities (Manfredo & Dayer 2004; Naidoo et al. 2006; White et al. 2009b; Redpath et al. 2013). Developing a broader understanding of patterns and processes underlying conservation conflicts is critical to enable people to move from conflict towards coexistence using appropriate measures (Dickman 2010).

The perils of simple solutions to complex problems

Despite this inherent complexity, limited approaches to tackling conflicts in conservation persist (Dickman 2010; Madden & Mcquinn 2014). Conflicts are therefore often presented superficially as surface manifestations while, as described above, conservationists and wildlife managers who are predominantly more familiar with the purely ecological aspects of conservation may not be equipped or have the capacity to deal with issues that require interdisciplinary methods and approaches (St. John et al. 2014; Bennett et al. 2017b). Even the most well-intentioned efforts will only address superficial aspects of conflicts if poorly designed, therefore limiting the receptiveness of stakeholders to change and commitment to conservation goals (Reed 2008; Madden & Mcquinn 2014). Furthermore, a reluctance to tackle problematic conflict issues with all their various entanglements and their perceived drain on resources, may hinder progress (Leong et al. 2011). Complex conflicts therefore are often treated as conventional cause and effect problems (Mason et al. 2018b) and given overtly simplistic short-term solutions (Dickman 2010) that culminate in the exclusion of relevant stakeholders from the solutions process (Madden & Mcquinn 2014). Without an interdisciplinary approach, ‘solutions’ are likely to be only temporary (Madden & Mcquinn 2014) and likely ineffective, and conservation outcomes

impeded (Peterson et al. 2013). This is demonstrated by the conflict between shooting and conservation interests over red grouse and hen harrier conservation, which has, for most of its history, focussed on the ecological dimensions (Elston et al. 2014; St John et al. 2018). So far, this approach has failed to find solutions and reduce conflict (St John et al. 2018) while the critical social elements considered to be at the core of the dispute have received less attention (Hodgson et al. 2018). Indeed, poorly or unmanaged conflicts are believed to be one of the most widespread and intractable challenges confronting the conservation of many wildlife species around the world (Dickman 2010; Redpath et al. 2013; St John et al. 2018). Destructive and costly, they may present obstacles to effective conservation and management of wildlife, and impact severely on economic development, social equality and resource sustainability (Redpath et al. 2013; Madden & Mcquinn 2014). Furthermore, with increasing pressure on the world's natural capital and increasing calls for biodiversity conservation, it is argued that the importance and magnitude of conflicts are only likely to increase along with their negative impacts on biodiversity, human livelihoods and wellbeing (Young et al. 2010; Margalida et al. 2014).

Exploitation of wildlife as a source of conflict

Since AD 1500, 75% of all the plant, amphibian, reptile, bird and mammal species known to have gone extinct were harmed by overexploitation and agricultural activity (Maxwell et al. 2016). Overexploitation refers to *"the harvesting of species from the wild at rates that cannot be compensated for by reproduction or regrowth"* (Maxwell et al. 2016). Impacts on wildlife populations are related to the rate and efficiency of exploitation and the variable resilience to exploitation by target populations (Peres 2010). Today, overexploitation of species through overfishing and illegal hunting, threatens the sustainable management of ecosystems and the conservation of threatened species globally (Gavin et al. 2010; Mateo-Tomás et al. 2012). Overexploitation for commerce, recreation or subsistence, affects 72% (6,241) of species listed by the IUCN Red List of Threatened Species as threatened or near-threatened (Maxwell et al. 2016). Indeed, overexploitation presents one of the most serious threats to mammals and birds in the tropics, leading to 'empty forest syndrome' (Wilkie et al. 2011).

Ecological impacts include population declines and extinctions (Rosser & Mainka 2002), and reduced genetic diversity and ecosystem function (Gavin et al. 2010), while human societies face degradation and loss of ecosystem services (Ripple et al. 2016).

As the impacts of overexploitation and other unsustainable hunting practices have been realised, persistent and ubiquitous conflicts between people over the management of wildlife have arisen (e.g. Redpath et al. 2015b; St John et al. 2018). In many cases, hunting has promoted good practice in the management of quarry species, the controlling of pests and for the conservation of habitats (Kanstrup et al. 2018). For example, an initiative called the Conservation Reserve Program (CRP) instigated by the hunting organisation Ducks Unlimited, incentivised farmers in the Prairie Pothole region of the U.S. to restore wetlands and plant cover that was beneficial to wildlife, culminating in the conversion of 1.9 million ha of cropland and increasing duck nest success by 46% (Reynolds et al. 2001). Environmental law has also largely traditionally supported the fundamentals for *sustainable hunting* whereby hunting does not jeopardise the conservation status of species (quarry or otherwise) and does not cause a deterioration of habitats where it occurs (Kanstrup et al. 2018). Managing and controlling species is a widely acknowledged part of conservation management (Williams & Madsen 2013), and there is broad acceptance that hunting is a legitimate, sustainable use of wildlife resources (Kanstrup et al. 2018). However, disputes around the sustainability of certain hunting practices have developed between those representing hunting and conservation interests (noting that these groups are heterogeneous and not always mutually exclusive). Indeed, Young et al. (2005) identified hunting activity as one of three main threats that can lead to conflicts between human activities and biodiversity conservation. In recent years, hunting-related conflicts have revolved around a range of topics, including legal and illegal overexploitation (e.g. Veríssimo & Campbell 2015; Duffy et al. 2016), species population targets (e.g. Williams & Madsen 2013), large-scale habitat management for hunting (Young et al. 2005), and lethal control methods (e.g. Newth et al. 2015; Appendix 1). Two important conservation issues that affect multiple wild bird species on a global scale and where conflict between resource users and conservationists has emerged from their biodiversity impacts are (1) illegal killing, and (2) lead poisoning from ammunition.

Illegal killing of wild birds

The term 'illegal killing of wild birds' refers to *"any form of deliberate action, such as catching, trapping, injuring, removing or persecution of birds and their eggs, outside the legal regulations of the aforementioned law"* (BirdLife International 2016a). Illegal killing is a significant threat that impacts on the viability of wild bird populations (BirdLife International 2016a). Indeed, overexploitation is one of the main drivers of extinction for birds globally (BirdLife International 2013), and the most important threat after habitat loss for migratory birds (Kirby et al. 2008; Brochet et al. 2016). Every year, millions of birds are estimated to be killed/illegally taken in the Mediterranean region, North Africa and the Middle East (Brochet et al. 2016). Birds are exploited in various ways. They may be taken for use as pets or display (an estimated 37% of all bird species) or hunted for food (14%) and sport (4%) (Brochet et al. 2016), with illegal use often unsustainable (BirdLife International 2013).

Concern about the impacts of illegal killing on wild birds has prompted studies to understand further the scale, scope and causal drivers, though they remain sparse. Examples include studies of illegal killing of birds in Northern and Central Europe and the Caucasus (Brochet et al. 2017), the Mediterranean (Brochet et al. 2016), Portugal (Fairbrass et al. 2016) and the lesser white-fronted goose *Anser erythropus* in Kazakhstan (Jones et al. 2017). Identifying drivers for sensitive issues relating to illicit behaviours such as illegal killing is hampered by many challenges, including the lack of willingness of perpetrators to reveal information or identify themselves through fear of retribution (Keane et al. 2008; Gavin et al. 2010). Furthermore, illegal killing is often driven by a complex range of motivations, influenced by social, economic and ecological conditions (Von Essen et al. 2014). Several studies and reviews have informed initiatives to reduce conflict between poachers and conservationists. Recent examples include recommendations and activities to reduce the illegal killing of protected species in three EU Mediterranean countries (Italy, Greece and Spain; BirdLife International 2016a), the killing of the great cormorant *Phalacrocorax carbo* which despite protection has been persecuted by fishers across Europe (Cowx 2013), and interventions to improve the conservation status of the illegally hunted eastern imperial eagle *Aquila heliaca* population in Hungary (BirdLife

International 2016b). In recognition that the illegal killing of protected wild bird species remains a significant conservation issue, several treaties have developed initiatives which have adopted a ‘zero tolerance approach’ to address this threat. Recent examples include ‘the Roadmap towards eliminating illegal killing, trapping and trade of birds’ (European Commission 2012), ‘the Tunis Action Plan for the eradication of illegal killing, trapping and trade of wild birds’ (Council of Europe 2013), and a Resolution on ‘the Prevention of illegal killing, taking and trade of migratory birds’ (UNEP-CMS 2014a; 2017a). Despite policy and conservation efforts to reduce the illegal killing of wild birds, the challenging nature of understanding and addressing such sensitive or taboo behaviours means that many conflicts continue unabated (Redpath et al. 2015b). Another axis of hunting that may cause conflict relates to spent lead ammunition, a by-product of legal (and in some cases illegal) shooting activity, which has negative impacts on species of conservation concern.

Poisoning of wild birds from lead ammunition

The poisoning of birds following the ingestion of lead ammunition (i.e. shotgun pellets, bullets, and fragments), causes significant morbidity, mortality and suffering in waterbirds and terrestrial birds worldwide (Pain et al. 2015, 2019a). Waterbirds and predatory or scavenging birds are particularly susceptible, in part due to their feeding ecology. Waterbirds are poisoned following ingestion of spent lead shot along with grit and food in areas that are hunted over (Figure 1.2; Newth et al. 2013; Appendix 2). Ingested shot is mechanically eroded in the gizzard and dissolved by stomach acids before toxic salts are absorbed into the blood stream and deposited in soft tissues and bone (Franson & Pain 2011). Predatory and scavenging birds are exposed to embedded lead ammunition in their prey or carrion (Pain et al. 2009; Figure 1.2). Pain et al. (2019a) concluded that lead poisoning of birds is likely to occur wherever lead ammunition is used and a pathway of exposure exists.

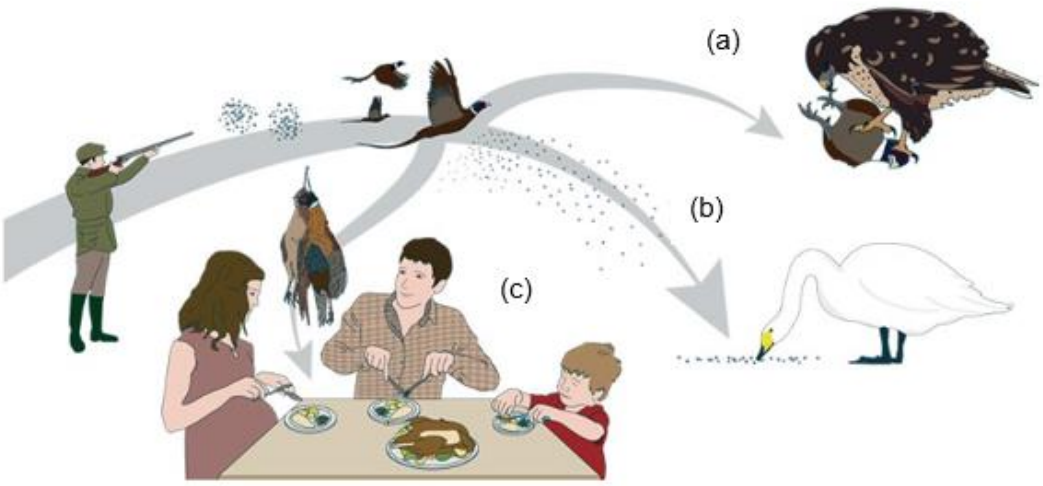


Figure 1. 2*: Three exposure routes to birds and humans of lead ammunition: (a) indirect (secondary) ingestion when feeding on prey and carrion (most relevant to predatory and scavenging species), (b) direct ingestion of lead shot with food and grit (most relevant to waterbirds), and (c) direct ingestion for humans through the consumption of lead shot embedded in game meat. Adapted from Delahay & Spray (2015).*

Lead affects numerous physiological and biochemical systems, including vascular, nervous, haematopoietic, renal and reproductive systems (as reviewed in Pain et al. 2015, 2019a). The behaviour and symptoms of lead poisoned animals is consistent with extended suffering (Kanstrup et al. 2018) and this is particularly evident in Anatidae (Pain et al. 2015). More recently, evidence has emerged to suggest that numbers and trends of waterbird populations are associated with the ingestion of lead shot (Pain et al. 2019b). For example, Green & Pain (2016) found that inter-specific variation in mean population growth rate was significantly negatively correlated with the prevalence of lead shot ingestion for eight duck species, including the common pochard *Aythya ferina* which is globally threatened. Beyond waterbirds, perhaps most prominent is the case of the California condor *Gymnogyps californianus*, which was nearly driven to extinction by lead poisoning from lead-based ammunition (Finkelstein et al. 2012). In addition to impacts on wildlife, there is a growing body of research on the impacts of eating game shot with lead on human health (Figure 1.2; Arnemo et al. 2016).

In response to the risks to humans and wildlife from exposures to lead ammunition sources, 33 countries worldwide have imposed legislative restrictions on its use (Stroud 2015; Kanstrup 2018; Kanstrup et al. 2018). Currently, two countries (Denmark and the Netherlands) have total bans on the use, trade and possession of lead shot (Kanstrup 2006; Avery & Watson 2009). In the UK, there are partial restrictions on the use of lead shot. Lead shot was banned over the foreshore and specified (wetland) Sites of Special Scientific Interest (SSSI), for hunting wildfowl, coot *Fulica atra* and moorhen *Gallinula chloropus* in all areas in England in 1999 (HMSO 1999, 2002a, 2003) and Wales in 2002 (HMSO 2002b), and for hunting over wetlands in Scotland in 2004 (HMSO 2004) and Northern Ireland in 2009 (HMSO 2009). However, Newth et al. (2013) found that the proportion of waterbirds dying from lead poisoning in England did not vary after the introduction of legislation (Appendix 2). Furthermore, lead poisoning has continued to affect a wide range of waterbirds long after legal restrictions were introduced (Newth et al. 2013). For example, elevated levels of lead (i.e. values >20µg/dL) were found in 34% of waterbirds tested at four sites during the 2010/11 winter (Newth et al. 2013). Waterbirds continue to be exposed to lead shot when they; forage on agricultural land over which it is legal to shoot with lead shot (Newth et al. 2013), feed on lead shot that has been illegally discharged (compliance with the current regulations restricting the use of lead shot in England has been shown to be poor; Cromie et al. 2015), and ingest residual lead from historical shooting (Newth et al. 2013).

Species and conservation issues in focus

The migratory Northwest European Bewick's swan *Cygnus columbianus bewickii* and the Icelandic-breeding whooper swan *Cygnus cygnus* (Figure 1.3) are both impacted by illegal shooting (Newth et al. 2011; Appendix 3) and lead poisoning following the ingestion of lead shot (Newth et al. 2013; Appendix 2).

Figure 1. 3*: Illustrations of a whooper swan (left) and Bewick's swan (right).*
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Being long-lived with slow rates of reproduction (Brazil 2003; Rees 2006) they are particularly vulnerable to additive mortality (Peres 2010). Wood et al. (2018a) suggest that a decline in mean survival rates of ringed Bewick's swans recorded between the 1980s and 2010s may in part be connected to known causes of mortality such as illegal shooting and lead poisoning.

The Northwest European population of Bewick's swan breeds in the European Russian Arctic and winters in north-west Europe (Rees 2006), and since the mid-1990s, has faced a substantial decline in numbers (Rees & Beekman 2010; Nagy et al. 2012). As a consequence, the species is currently classified as endangered in Europe (BirdLife International 2015). Although the Northwest European Bewick's swan is protected under national and international laws throughout its migratory flyway (Rees 2006), it is frequently subject to illegal hunting (Newth et al. 2011 – Appendix 3; Nagy et al. 2012; Mineyev & Mineyev 2014). More than a third of live Bewick's swans x-rayed between the 1970s and early 2000s carried

shot-in embedded gunshot in their body tissue (Newth et al. 2011; Appendix 3) (Figure 1.4).

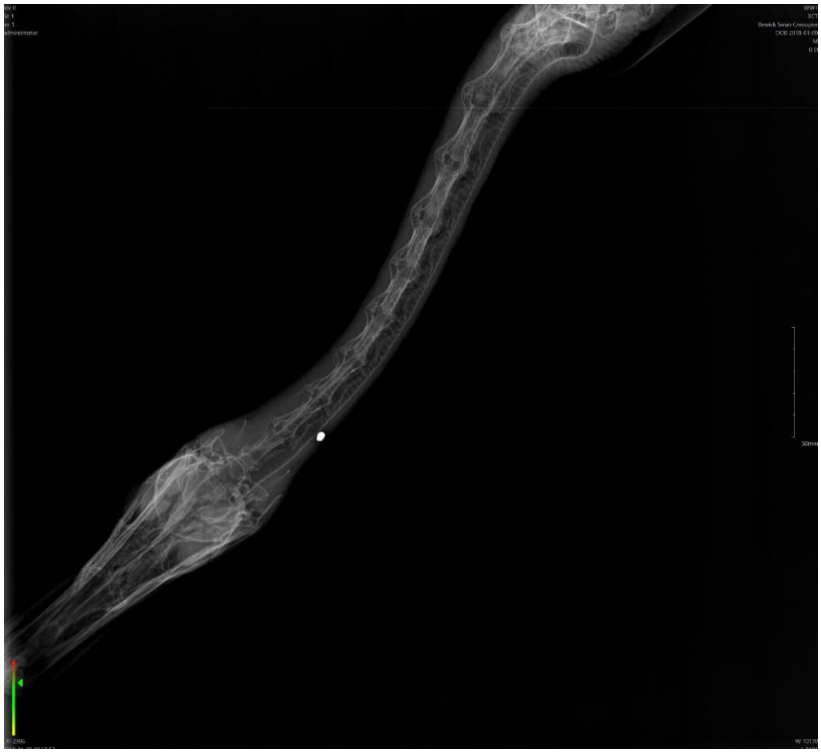

Figure 1. 4*: An x-ray of a wild, living Bewick's swan named 'Croupier' with one shotgun pellet embedded in his neck. Croupier was caught and x-rayed at WWT Slimbridge on 9th January 2018. Photo © Julia Newth/WWT.*

Illegal hunting therefore is regarded as a potentially high threat for the Northwest European population (Nagy et al. 2012) and urgent action to address this issue has been recommended in the Bewick's Swan Single Species Action Plan (adopted by UNEP-AEWA; Nagy et al. 2012). However, little is known currently about the causal human drivers for the hunting of the Bewick's swan.

The poisoning and death of migratory swans from lead ammunition in Britain and Ireland is well documented (e.g. Brown et al. 1992; O'Connell et al. 2008; Newth et al. 2013; Appendix 2) and ingested lead shot is frequently found in lead poisoned swans (e.g. O'Connell et al. 2008; Newth et al. 2013). In one study which examined the mortality of 2,365 wild waterbirds recovered at sites across Britain between 1971 and 2010, lead poisoning accounted for the deaths of 27% of whooper swans and 23% of Bewick's swans, the most of any other species group sampled (n=28) (Newth et al. 2013; Appendix 2). Icelandic-breeding

whooper swans which migrate to wintering sites in Britain and Ireland every autumn (Brazil 2003), are known to be particularly susceptible to lead poisoning following the ingestion of lead shot. Despite partial restrictions on the use of lead shot in the UK, elevated levels of lead were recorded in the blood of up to 43% of live whooper swans tested at sites in England and Scotland during the 2010/2011 winter (Newth et al. 2013; Appendix 2). Previously, elevated lead levels (then defined as >25µg/dL) were recorded in 44–70% of whooper swans caught at wintering sites in Britain and Ireland (O'Connell et al. 2008). Swans and geese frequently forage on agricultural land, over which it remains legal to shoot with lead (with the exception of wetlands and specified SSSIs in Scotland and Northern Ireland) (Newth et al. 2013; Appendix 2). Furthermore, swans may require particularly large quantities of grit when feeding on more indigestible foods such as cereals, and are therefore perhaps more likely to ingest spent lead shot (O'Connell et al. 2008).

The risks to birds (and humans) arising from the use of lead ammunition and proposed mitigation measures have formed the basis of a long running conflict in the UK and in other countries worldwide. Simplified, the 'lead debate' has primarily been conducted between those advocating the retention of lead shot for shooting and those favouring stricter controls or an entire phase out of lead ammunition and its replacement with non-lead alternatives (Cromie et al. 2015; Newth et al. 2015 – Appendix 1; Kanstrup et al. 2018). In Europe, a recent public consultation about a proposal made by the European Union's Chemicals Agency to restrict lead shot use and possession in wetlands produced diverse perspectives from a range of stakeholders (ECHA 2017, 2018a). Within the UK, stakeholder groups have become polarised, preventing collaborative working and the agreement of common solutions (Cromie et al. 2015). Although this lead shot conflict is rooted in the natural sciences, specifically ecology and toxicology, it is defined by a range of political and sociological barriers, few of which have been studied in this context to date (exceptions include Cromie et al. 2010, 2015; Newth et al. 2015).

The Thesis

Research objectives

Despite calls for a more broadly interdisciplinary approach to address biodiversity impacts and conservation conflicts, the utility of this approach remains largely conceptual (Pooley et al. 2017) and untested (Gutiérrez et al. 2016). In this thesis, I aim to: (i) examine empirically the ecological and socio-psychological contexts of two prominent and complex conservation issues – illegal killing and lead poisoning – using approaches and methodologies from the natural and social sciences and psychology, and (ii) provide novel insights into their management and wildlife management more broadly. Specifically, I will examine the ecological impacts and social conflict relating to the poisoning of waterbirds from lead shot in the UK and the human drivers for the illegal hunting of the Northwest European Bewick's swan in the Russian Arctic. To date, both issues have been approached primarily from an ecological perspective, with a focus on prevalence and impacts on birds (e.g. Evans et al. 1973; Newth et al. 2011, 2013 – Appendices 3 & 2). However, gaps in understanding relating to the complex human, and to a lesser extent, ecological dimensions, are hampering the ability of stakeholders to set agreed priorities and effectively address the issues. Conservation measures recommended in species action plans such as the Bewick's Swan Action Plan (Nagy et al. 2012) require a range of approaches to be effective. Therefore, my objectives are to:

(a) Assess the impact of blood lead levels on the body condition of wild whooper swans wintering in Britain (Chapter 2)
(b) Identify the perspectives of UK shooting participants on the use of lead ammunition and its potential impacts on wildlife and people (Chapter 3)
(c) Examine the risk of the misidentification and accidental killing of Bewick's swans in the European Russian Arctic (Chapter 4)
(d) Understand the drivers for the deliberate hunting of Bewick's swans in the European Russian Arctic (Chapter 5)

Conflict stage

The lead shot issue can be regarded as being in a ‘destructive’ phase of conflict (Figure 1.1), primarily because it is an acrimonious and politicised decades-old dispute, characterised by very public disagreements, and drawing in numerous actors, interests and issues (Cromie et al. 2015; Crowley et al. 2017). This phase has been attained through polarisation and escalations, related to the publishing of new science suggesting that lead poisoning remains a problem for birds (e.g. Newth et al. 2013 – Appendix 2; Cromie et al. 2015), and various political interjections (e.g. the publication of recommendations to the UK government from the Lead Ammunition Group; 2015a). While currently in a feedback loop of latency and escalation, this conflict shows little sign of abating and progress towards solutions that satisfy all actors is slow, although urgency created by recent policy developments (e.g. ECHA 2018b) is beginning to open up the debate around the issue.

According to current knowledge (Newth et al. 2011; Appendix 3), the illegal hunting issue can be regarded as a complex human-wildlife impact with the potential to transition into a conflict. However, the problem has come to light only in recent years and to date, little practical on the ground action has been taken to understand or tackle the human dimension. A deeper understanding of these aspects is required to inform and implement effective management measures that mitigate an escalation to conflict.

Structure

My thesis is structured as multiple, discrete academic papers, in which I have aimed to make connected but distinct research contributions that are relevant to social and natural scientific audiences and informative for species conservation. Following this general introduction, I explore the ecological and sociological components of the lead shot issue. First, I examine the sub-lethal impacts of lead poisoning on whooper swans (Chapter 2). While research on the impacts of lead shot on wild birds has primarily focused on acute poisoning leading to mortality, much less is known about its sub-lethal impacts, although recent studies indicate a range of potentially significant effects (Kanstrup et al. 2018). Here, I investigate

the prevalence of lead exposure in wild whooper swans and identify the threshold at which blood lead levels are associated with initial reductions in body condition. With this chapter, I aim to provide additional and novel evidence on lesser-known impacts that contribute to the scientific dimension of the lead debate. In Chapter 3, I move away from the ecological realm, instead using Q-methodology (Brown 1996b) to explore the social perspectives of shooting participants in the UK on the use of lead ammunition and its potential impacts on wildlife and people. Although the risks arising from the use of lead ammunition and potential mitigation measures have prompted conflict between stakeholder groups, relatively little is known of the perspectives of individual ammunition users, despite their critical role in adding lead to the environment and their pivotal place in any potential changes to practice. I argue that the articulation of views held by shooters in this study presents a foundation for renewing discussions between the conflict actors and to potentially forge new solutions and adaptation of practices. The incidence of embedded shotgun pellets (indicating illegal shooting) in live Bewick's and whooper swans caught and x-rayed in Britain between winters 1970/71 and 2007/08 is described in Appendix 3 (Newth et al. 2011). Next, I explore both the accidental and intentional causal drivers of hunting Bewick's swans in the Russian Arctic using questionnaire surveys of hunters in the Nenets Autonomous Okrug and Arkhangelsk Oblast. Chapter 4 examines the potential for hunters to accidentally shoot Bewick's swans when they mistake them for two morphologically-similar and sympatric swan species with weaker legal protection. Using an adapted socio-psychological model (the Theory of Planned Behaviour; Ajzen 1985), Chapter 5 examines factors that predict hunting intention while also exploring the wider ecological, legal, recreation and economic motivations. I conclude with recommendations for conservation interventions and suggest that the approach used in this study may be applied to inform the effective design, prioritisation and targeting of interventions that improve compliance and reduce biodiversity impacts.

The thesis concludes with a discussion (Chapter 6) which identifies the key themes and contributions of this research to the conservation conflict field, and its potential application in the management of human-wildlife impacts and conservation conflicts.

Chapter 2

Widespread exposure to lead affects the body condition of free-living whooper swans *Cygnus cygnus* wintering in Britain

Chapter 2: Widespread exposure to lead affects the body condition of free-living whooper swans *Cygnus cygnus* wintering in Britain

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Abstract

Lead poisoning, through the ingestion of spent lead gunshot, is an established cause of morbidity and mortality in waterbirds globally, but the thresholds at which blood levels begin to affect the physiology of birds in the wild is less well known. Here we determine the prevalence of lead exposure in whooper swans and, for the first time, identify the level of blood lead associated with initial reductions in body condition. Blood lead elevated above background levels (i.e. >20 µg/dL) was found in 41.7% (125/300) of swans tested. Blood lead was significantly negatively associated with body condition when levels were ≥44 µg/dL (27/260 = 10%). Our findings that sub-lethal impacts of lead on body condition occurs at the lower end of previously established clinical thresholds, and that a relatively high proportion of individuals in this population may be affected, reaffirms the importance of reducing contamination of the environment with lead shot.

Introduction

Lead is a highly toxic heavy metal that acts as a non-specific poison and is known to affect all physiological systems in animals (e.g. Pokras et al. 2009; EFSA 2010; Franson & Pain 2011; Johnson et al. 2013). Absorption of relatively large amounts of lead may cause rapid mortality from acute lead poisoning with few associated signs of poisoning at post-mortem. By contrast, the absorption of smaller amounts of lead, including through chronic, low level exposure, may result in a wide range of sub-lethal physiological, biochemical and behavioural impairments (e.g. Demayo et al. 1982; Scheuhammer 1987; Pain et al. 2009; Franson & Pain 2011). Lead affects the function of the central and peripheral

nervous systems and may cause muscular paralysis resulting in impaction of the oesophagus, proventriculus, gizzard and the intestines, and subsequent weight loss, reduced body condition and an increased risk of starvation (Beyer et al. 1998; Pattee & Pain 2003). Severe loss of body weight in birds therefore, is widely identified as a characteristic sign of chronic lead poisoning and may cause extreme emaciation prior to death (Quortrup & Shillinger 1941; Jordan & Bellrose 1951; Anderson 1975; Pattee et al. 1981; Beyer et al. 1988; Wobeser 1997; Pattee et al. 2006). Clinical changes related to body condition and associated with lead poisoning in birds include muscle atrophy, most notably breast muscle, and loss of subcutaneous or visceral fat (Jordan 1953; Beyer et al. 1998). In a review of experimental studies spanning 35 years, Sanderson and Bellrose (1986) concluded that change in body mass was the most appropriate indicator for assessing levels of lead poisoning in birds. While the dose-response relationship can be affected by a wide range of biological and environmental factors in birds, field and experimental studies have shown that birds often die approximately 2–3 weeks after ingesting lead gunshot, often in an extremely emaciated condition (e.g. Irby et al. 1967; Barrett & Karstad 1971; Szymczak & Adrian 1978; Wobeser 1981; Sanderson & Bellrose 1986; USFWS 1986; Locke & Thomas 1996; Beyer et al. 1998; De Francisco et al. 2003). However, the effects of lead poisoning on body weight may vary considerably and absence of weight loss and other atypical signs of lead poisoning have been recorded in affected birds (Trainer & Hunt 1965; Cook & Trainer 1966; Sanderson & Irwin 1976; Marn et al. 1988). For example, in cases of acute poisoning, birds may die rapidly in apparently good body condition (Cook & Trainer 1966; Scheuhammer & Norris 1996).

Lead poisoning is a well-documented cause of morbidity and mortality in waterbirds (Mateo 2009), which ingest anglers' weights (UNEP-AEWA 2011) or spent lead gunshot, either inadvertently when mistaken for food particles or more actively as grit which is retained in the muscular gizzard to aid mechanical breakdown of food. Once in the gizzard, the shot are ground into smaller particles and lead salts absorbed into the bloodstream. Lead poisoning has been recorded in wild swans globally (e.g. Ochiai et al. 1992; Blus 1994; O'Halloran et al. 2002; Perrins et al. 2003; O'Connell et al. 2008; Nam & Lee 2011; Newth et al. 2013), with poisoning of mute swans (*Cygnus olor*) attributed to the ingestion of

discarded lead fishing weights (Perrins et al. 2003), whereas migratory whooper swans (*Cygnus cygnus*) and Bewick's swans (*Cygnus columbianus bewickii*) more commonly ingest spent lead gunshot (Spray & Milne 1988; O'Connell et al. 2008; Newth et al. 2013). Migratory swans feeding in areas shot-over with lead gunshot are thus particularly susceptible to lead exposure. In a study investigating the mortality of 2,365 waterbirds recovered across Britain between 1971 and 2010, lead poisoning accounted for the deaths of 27.3% of whooper swans and 23% of Bewick's swans (Newth et al. 2013). Elevated blood lead levels (i.e. >20 µg/dL; Franson & Pain 2011) were recorded in 43% of live whooper swans caught in Britain in the 2010/11 winter (Newth et al. 2013). Previously, O'Connell et al. (2008) recorded elevated lead levels (then defined as >25 µg/dL) in 44–70% of live whooper swans caught at wintering sites in Britain and Ireland.

Field studies have shown reduced survival (Tavecchia et al. 2001; Guillemain et al. 2007) and a range of sub-lethal effects in wildfowl following ingestion of lead gunshot. Evidence also suggests that sub-lethal lead poisoning can increase the likelihood of mortality from other factors, such as flying accidents in wild mute swans (Kelly & Kelly 2005) and the susceptibility to being hunted in a wide range of wildfowl (Bellrose 1959; Heitmeyer et al. 1993; Demendi & Petrie 2006). However, the relationship between blood lead levels and body condition in free-living wildfowl, including swans, has yet to be quantified. Identifying thresholds for tissue lead concentrations at which measureable physiological effects occur is important for determining the impacts of lead on individuals and populations. Franson and Pain (2011) considered that blood lead levels of >20 µg/dL in Anseriformes exceeded background levels. These concentrations have been considered as indicative of lead gunshot ingestion (O'Halloran et al. 1988) and are consistent with adverse physiological effects. Anseriformes were found to have subclinical poisoning whereby impairment of normal biological functioning occurs but is not sufficiently severe to develop apparent signs at 20–<50 µg/dL, signs of clinical poisoning (including weight loss) at 50–100 µg/dL and of severe clinical poisoning at >100 µg/dL (Franson & Pain 2011). However, these thresholds were largely determined from studies of captive birds that had been dosed with lead in experimental and controlled settings and included a limited number of studies of wild birds. Tissue lead residues associated with

physiological injury, clinical signs and death due to lead poisoning may vary between individuals (Pain 1996; Pattee et al. 2006; Johnson et al. 2013) and species (Pattee & Pain 2003; Franson & Pain 2011), for a range of ecological and biological reasons.

Body condition is an indicator of the energetic state of an animal, especially its energy reserves (fat and protein) relative to the skeletal body size of the animal (Gosler 1996; Krebs & Singleton 1993; Schulte-Hostedde et al. 2001), and is assumed to affect individual health and fitness (Peig & Green 2009). Fat storage can greatly influence migration strategies (Pierce & McWilliams 2004), over-winter survival (Rogers & Reed 2003) and clutch size (Christians 2000) in avian species. This study therefore aims to quantify, for the first time, the blood lead levels that have a significant influence on individuals' body condition in a population of free-living birds. The effects of age, sex, timing of blood sampling, wintering location and breeding status on susceptibility to lead poisoning are also considered. This analysis comes at a time when there is a global policy focus on the effects of lead ammunition on both wildlife and human health (Watson et al. 2009; Bellinger et al. 2013; Bernhoft et al. 2014; UNEP-CMS 2014b).

Methods

Study sites and sample collection

Whooper swans were caught between winters 2010/11 and 2013/14 in Britain; at Martin Mere, Lancashire (51° 58' 98" N, 2° 25' 02" W) and at Caerlaverock, Dumfriesshire (54° 58' 02" N, 3° 25' 02" W). Blood samples were taken from individual birds for lead level analysis; blood lead concentrations usually reflect recent exposure to lead, i.e. within the preceding 35–40 days (O'Halloran et al. 1988). A blood sample was taken under Home Office license from the medial metatarsal vein of each bird with a 2-mL syringe using a 23-gauge needle as part of on-going broader health studies. Sub-samples of any excess blood were then transferred into a 1.5-mL tube containing lithium heparin and chilled at 4°C until analysis.

The swans were also sexed (by cloacal examination), ringed, aged (as either adults or juveniles by plumage characteristics) and weighed. Skull and tarsus length were measured for use in conjunction with body mass to determine the body condition of the birds.

Blood analysis

A sub-sample of 0.1 g was taken from each blood sample and 0.5 ml of concentrated nitric acid added. Samples were left over-night, after which 1.0 ml of hydrogen peroxide was added to each sample. The samples were then digested using a microwave digester (MARS, CEM), with a final incubation at 95˚C for 30 mins. The digests were made up to 5 ml by mass with milliQ water. Samples were then analysed for lead using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500 series), and as an internal standard, a continuous concentration of 10 µg/l rhodium, prepared in 1% nitric acid, was introduced into the sample stream via a T-piece.

Several methods were used to ensure quality control. Blanks (digests without blood, processed using the methods outlined above) were used to assess background levels of lead and the limit of detection (LOD). Spikes (digests without blood, processed using the methods outlined above, with a known concentration of calibration standard added to them), were used to assess any fluctuation in lead during the preparation process. Certified Reference Material (bovine liver, National Institute of Standards and Technology SRM 1577b) was also used to determine accuracy and precision of the results.

Standard additions of samples were conducted prior to analysis to check that there were no interferences. All samples were randomised and analysed in four batches. The sample data were divided by the internal standard to account for any drifting of the instrument and the standards were re-analysed every 30 samples, with results used to construct a calibration curve.

Condition Indices

In this study, body condition is taken as a measure of the energy capital accumulated in the body as a result of feeding, which is assumed to be an indicator of an animal's health and quality (Peig & Green 2009). In most cases, the energy capital refers to the size of energy reserves such as fat and protein (Krebs & Singleton 1993; Gosler 1996; Schulte-Hostedde et al. 2001) relative to the skeletal body size of the animal. Fats are the major form of energy storage in birds and the first stores mobilised for energetic purposes (Blem 1990). Given the difficulties involved in measuring fat stores and other nutrients directly in live birds, it is common to use a surrogate estimate of body condition (Ardia 2005). Mass corrected for skeletal body size reflects physiological energy stores (Brown 1996a) and is a commonly used measure of condition (Ardia 2005).

Three steps were undertaken to obtain a scaled mass index of body condition (hereafter, body condition index) for individual birds, following Peig and Green (2009). First, the single linear body measurement that correlated most strongly with body mass was determined in a sample of 300 birds and found to be skull length (Pearson correlation: $r = 0.65$, $P < 0.05$). Tarsus length was less strongly correlated ($r = 0.47$, $P < 0.05$). Skull length, therefore, was used to calculate the scaled body mass index for each bird, as this variable best explained that fraction of mass associated with skeletal size. Ln-transformed skull length was regressed against ln-transformed body mass using standardised major axis regression to obtain and compare the slope estimates of this relationship within and between age and sex categories. Slope estimates did not differ significantly ($P = > 0.05$) and thus the scaling relationship was deemed to be comparable between and within groups. Therefore, the slope estimate (b_{SMA}) of ln-transformed skull length when regressed against ln-transformed body mass was determined for all birds. Finally, the scaled body mass index ($\widehat{M}_i$) in kg for each individual was calculated as:

$$\widehat{M}_i = M_i \left(\frac{L_o}{L_i}\right) b_{SMA}$$

where M_i and L_i are the body mass (kg) and skull length (mm) of individual i respectively, and L_o is the arithmetic mean skull length (174.6 mm) for the whole sample.

Statistical analysis

The body condition index values did not differ significantly from a normal distribution (Shapiro-Wilk test, P = 0.148). A scatter plot of blood lead level and body condition index values suggested a non-linear trend and a possible threshold response. Piecewise linear regressions fit different linear models to different ranges of the explanatory variable, and are thus described by multiple regression slopes and breakpoints – or thresholds – which are values of the explanatory variable at which the regression slope changes (Toms & Lesperence 2003; Ficetola & Denoel 2009; Sonderegger et al. 2009). Piecewise regressions have been used to model thresholds at which the toxic effects of lead in humans occurs (e.g. Schwartz 1993; USEPA 2000). A general linear model (GLM) with Gaussian error distribution and identity link functions was therefore used to fit a piecewise linear regression to identify (a) any significant deleterious effect of blood lead level (the explanatory variable) on the swan's body condition (the response variable), and (b) the threshold at which blood lead level was found to have a significant impact on body condition, if this was indeed the case. Piecewise regressions require a sensible initial estimate of the threshold, or "breakpoint" (Muggeo 2003; Toms & Lesperence 2003) as the algorithm may otherwise converge to a local maximum rather than a global maximum if the initial estimate of the breakpoint is a long way from the true breakpoint (Eigenbrod et al. 2009). The model was run using an estimated breakpoint of 20 µg/dL based on a visual inspection of the data and following the work of Franson and Pain (2011) suggesting that 20 µg/dL represents above background blood lead levels.

The model also included the following explanatory variables: sex, age, site, breeding status and timing of sampling, represented by four events (an event identification code served as a proxy, whereby sampling events occurring within two days of each other were grouped). Sex, age, year, month and site are known to have a significant influence on the body condition of migratory swans (Bowler 1994, 1996; Morgan 2010). Adult birds that were observed associating with cygnets during the winter that they were sampled were classed as 'breeders'. Age (0 = cygnet, 1 = adult), sex, event (event 1 included birds sampled on 10th/11th February 2011, event 2 = 13th/14th February 2013, event 3 = 12th December 2013 and event 4 = 5th/6th March 2014), site (Martin Mere,

Caerlaverock) and breeding status (0 = not bred, 1 = bred) were treated as categorical variables. During the three-winter study period, more than one blood lead sample was taken from 36 birds. The first sample taken for each of these birds was included in the model.

Many factors such as the bird's age, sex, breeding condition and diet, along with the extent and duration of exposure to lead, influence lead absorption and distribution within the body and consequent physiological impacts (reviewed in Franson & Pain 2011). Body mass and fat reserves of migratory swans generally increase through the winter (Bowler 1996) so impacts of lead on body condition may be greater in the weeks shortly after arrival in the wintering range when the birds are at their leanest (Hohman et al. 1995). First-order interactions between the response variable (blood lead level) and the explanatory variables were therefore included in the initial model. An interaction between sex and breeding status was also included as females are more likely than males to be affected by lead during the egg-laying period (Krementz & Ankney 1995; Scheuhammer 1996; Franson & Pain 2011). Non-significant interactions and then variables ($P > 0.05$) were excluded sequentially from the piecewise regression, starting with the least significant, to ensure that the final model was parsimonious. The drop1 function was used to generate P values by dropping each term in sequence and testing the change in residual deviance with an analysis of deviance test.

All statistical analyses were performed in R version 3.1.2 (R Development Core Team 2015) with the piecewise regression using the 'segmented' package.

Results

A total of 300 blood samples were collected from 260 live whooper swans (including 36 individuals sampled more than once), between winters 2010/13 and 2013/14 inclusive (Table 2.1). Lead was detected in all blood samples, with levels ranging from 5.6 to 132.9 µg/dL. Elevated blood lead levels (i.e. >20.0 µg/dL) were found in 41.7% of swans tested (Table 2.1).

***Table 2. 1**: Summary of blood lead levels for whooper swans caught at two sites in Britain during winters 2010/11 to 2013/14 (N = number of blood samples taken each winter. 36 swans were sampled more than once during the study period).*

Site	Winter	N	Median	Mean (SD) blood lead (µg/dL)	Range	% swans with >20 µg/dL[1]
Caerlaverock, Scotland	2010/11	135	17.6	26.4 (23.6)	5.6 – 132.9	40.0
	2012/13	30	15.1	19.4 (11.5)	8.9 – 65.9	40.0
	2013/14	58	16.6	20.0 (16.5)	6.6 – 119.4	27.6
Martin Mere, England	2010/11	29	20.0	20.9 (8.0)	6.2 – 45.2	48.3
	2012/13	39	24.3	24.5 (7.4)	8.7 – 45.0	66.7
	2013/14	9	17.9	19.1 (12.5)	7.2 – 49.0	33.3
Total		**300**	**18.1**	**23.5 (18.4)**	**5.6 – 132.9**	**41.7**

[1] *Franson and Pain (2011) considered that blood lead levels of >20* µg/dL *in Anseriformes exceeded background levels.*

Lead effects on body condition

The piecewise linear regression indicated that blood lead had no significant effect on body condition of whooper swans wintering in Britain at concentrations below 44 µg/dL SE = 16.2 (233/260 birds were below this threshold; t = 0.517, P > 0.05, regression slope = 0.004, 95% CI of slope = -0.011 to 0.020) (Table 2.2; Figures 2.1 & 2.2). Above this threshold, blood lead had a negative effect on body condition (t = -2.301, P < 0.05, regression slope = -0.016, 95% CI of slope = -0.030 to -0.002). Blood lead elevated above 44 µg/dL was found in 10% (27/260) of swans tested in Britain between winters 2010/11 and 2013/14. No other breakpoints were detected.

***Table 2. 2**: Parameter estimates of a piecewise linear regression for whooper swans wintering in Britain. The estimated breakpoint in blood lead level at and above which blood lead was found to have a negative impact upon body condition was 44 µg/dL.*

Parameter	**Estimate**	**SE**	***t***	***P***	
Intercept	8.248	0.342	24.147	<0.0001	
Blood lead	0.004	0.008	0.517	0.606	
Age (adult)	0.826	0.140	5.917	<0.0001	
Sex (male)	0.751	0.391	1.923	0.056	
Sex x bred:					
-Sex (female) x bred (non-breeder)	0.302	0.293	1.032	0.303	
-Sex (male) x bred (non- breeder)	-0.574	0.295	-1.950	0.053	
Slope	**Estimate**	**SE**	***t***	**CI (95%) lower**	**CI (95%) upper**
<44 µg/dL	0.004	0.008	0.517	-0.011	0.020
>44 µg/dL	-0.016	0.007	-2.301	-0.030	-0.002

The reference factor levels are Age (juvenile), Sex (female), and Bred (breeding bird).

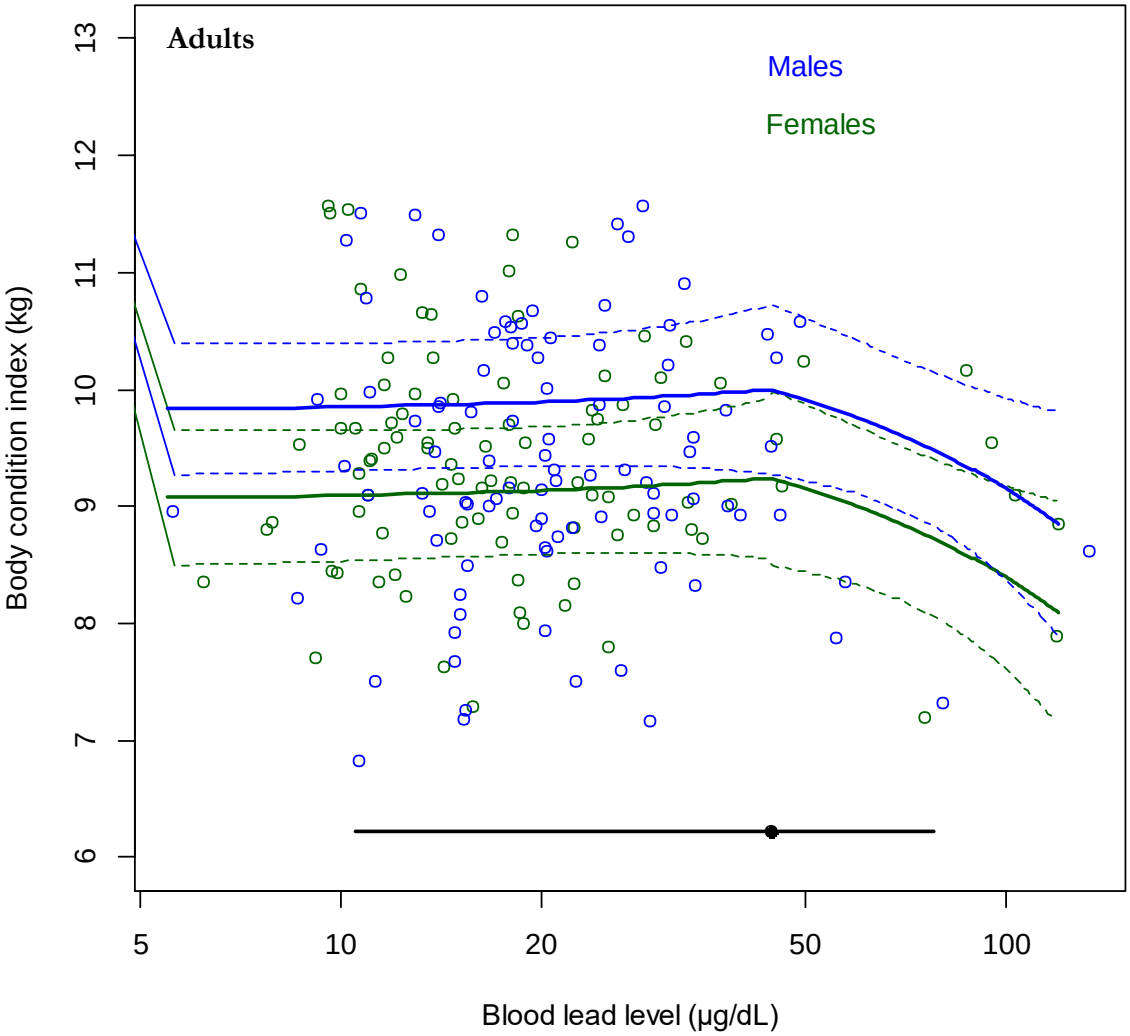

***Figure 2. 1**: Piecewise linear regression showing the relationship (represented as two segmented lines) between the body condition index (kg) and log-blood lead values (µg/dL) of male (blue) and female (green) adult birds. Upper and lower 95% CI's are represented by dashed lines. CI's for the breakpoint (44 µg/dL) is represented as a solid black line.*

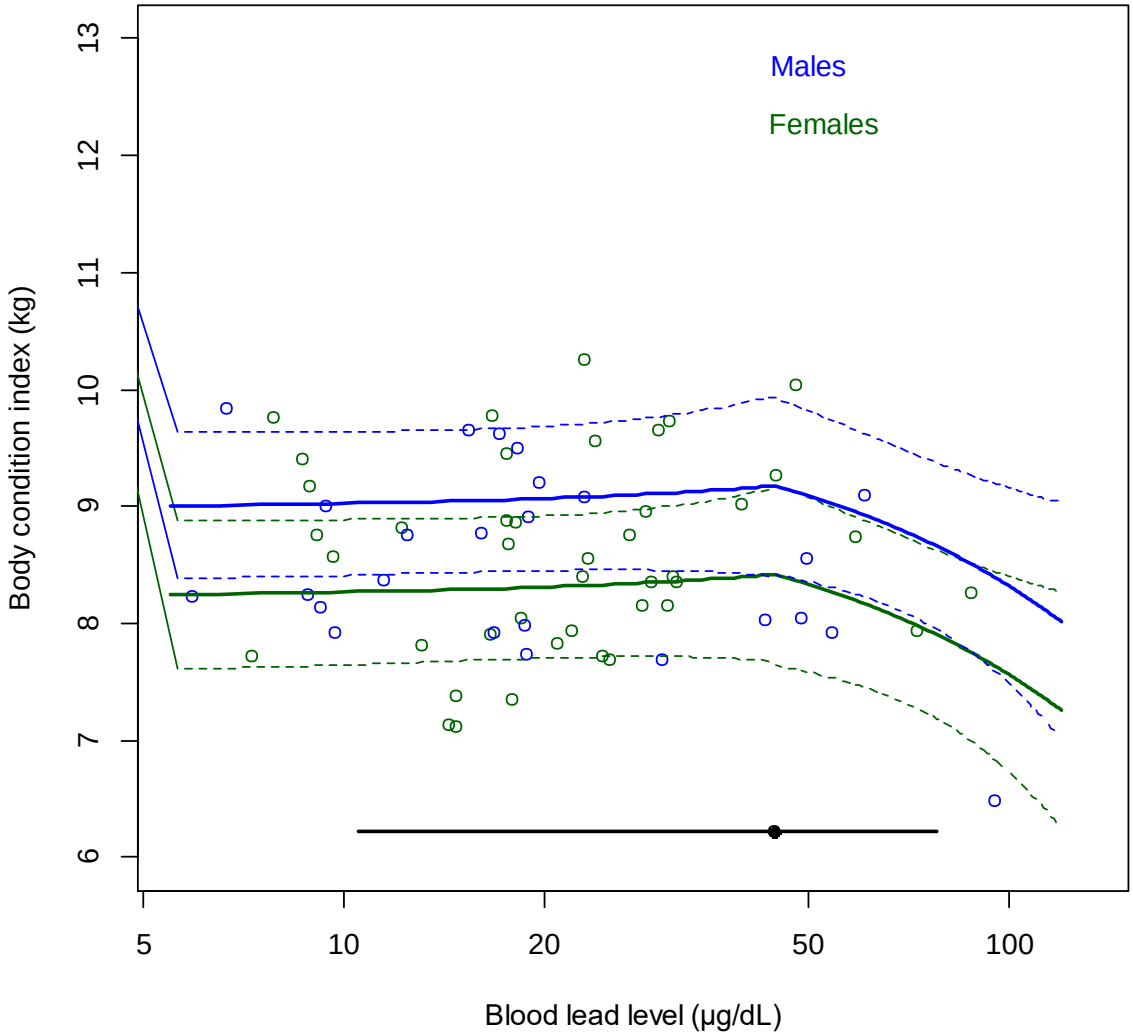

***Figure 2. 2**: Piecewise linear regression showing the relationship (represented as two segmented lines) between the body condition index (kg) and log-blood lead values (µg/dL) of male (blue) and female (green) cygnets. Upper and lower 95% CI's are represented by dashed lines. CI's for the breakpoint (44 µg/dL) is represented as a solid black line.*

Effects of other variables on body condition

Body condition varied significantly with the age of the bird (piecewise linear regression, $P < 0.001$) (Tables 2.2 & 2.3) with adult birds being in better condition than cygnets. Male birds were in apparently better condition than females (Table 2.2 & 2.3), with this relationship approaching significance ($P = 0.056$). Site, the

timing of sampling (event) and breeding status did not have significant effects on body condition (P < 0.05) and were therefore omitted from the final model.

***Table 2. 3**: Body condition index (kg) of whooper swans caught at Caerlaverock and Martin Mere in Britain between the 2010/11 and 2013/14 winters.*

Age	Sex	N	Median	Mean (SD)	Range
Adults (>2 years)	Male	97	9.3	9.4 (1.1)	6.8-11.6
	Female	96	9.3	9.4 (0.9)	7.2-11.6
		193	***9.3***	***9.4 (1.0)***	***6.8-11.6***
Juveniles (<1 year)	Male	25	8.4	8.5 (0.8)	6.5-9.8
	Female	42	8.6	8.6 (0.8)	7.1-10.3
		67	***8.6***	***8.6 (0.8)***	***6.5-10.3***
Total		**260**	**9.1**	**9.2 (1.0)**	**6.5-11.6**

Discussion

The presence of lead in the blood of whooper swans was found to have a significant detrimental impact on their body condition when levels were ≥44 µg/dL. The range of blood lead levels within which Anseriformes are predicted to exhibit clinical signs of poisoning (including weight loss), and leading to probable death if lead exposure were to continue, has previously been estimated at between 50–100 µg/dL (Franson & Pain 2011). However, lead tissue thresholds are largely determined from studies of captive birds that have been dosed with lead in experimental and controlled settings (Franson & Pain 2011). Our results indicate that blood lead at the lower end of clinical thresholds is associated with significant impairment of normal biological functioning in free-living swans sufficient to have a measureable impact on body condition. Wild birds may be subject to more natural stressors such as inadequate diets and cold weather than birds in experimental studies, which may make them more susceptible to the effects of lead toxicosis (Kendall & Scanlon 1984; Blus et al. 1991; Franson & Pain 2011). Care should be exercised when interpreting threshold tissue concentrations indicative of exposure and poisoning in wild birds, as the toxic

effects of lead may vary between species and individuals (Franson & Pain 2011) and sites according to a range of factors. In addition to ambient environmental conditions, nutritional status, genetic predisposition and concurrent disease conditions can be influential (Pain 1996; Pattee & Pain 2003; Pattee et al. 2006; Johnson et al. 2013). The level and duration of lead exposure may also influence its effects; birds exposed to relatively low levels of lead on a sustained basis may suffer similar physiological effects but with lower blood lead concentrations, than birds acutely exposed to higher levels of lead for a shorter period of time (Franson & Pain 2011). Birds with acute poisoning can appear to be in good condition, without pronounced weight loss as their health may deteriorate rapidly before losing appreciable amounts of weight (Cook & Trainer 1966; Scheuhammer & Norris 1996). The present study found blood lead levels elevated above background (i.e. >20 µg/dL; Franson & Pain 2011) in 41.7% of swans tested. Our results suggest that previously suggested thresholds for adverse effects should be revised downwards. This would follow trends in the thresholds for blood lead concentrations demonstrated to be associated with adverse effects on human health which are now one sixth or less of those thought to be protective of human health in the 1960s (Green & Pain 2012).

Sub-lethal impacts associated with reduced body condition may have an important impact on fitness. Birds poisoned by lead suffer from muscle atrophy, most notably breast muscle, and loss of subcutaneous or visceral fat (Jordan 1953; Beyer et al. 1988). Fat accumulation prior to migration has been shown to influence migration, survival (e.g. Haramis et al. 1986; Owen & Black 1989) and breeding success (e.g. Ankney & Macinnes 1978) in other wildfowl species. Long-distant migrants are dependent upon fat reserves to meet migration energy requirements. Fat reserves developed by whooper swans at wintering sites in Britain prior to spring migration serve to fuel a journey of ~1,000 miles to summer breeding grounds in Iceland (Pennycuick 1996). Birds with reduced body condition and fitness may also be more susceptible to disease and other mortality factors, and weaker birds may be at increased risk of predation (Scheuhammer & Norris 1996; Kelly & Kelly 2005; Newth et al. 2013) and being shot by hunters (Bellrose 1959; Heitmeyer et al. 1993; Demendi & Petrie 2006). If survival probabilities of whooper swans is related to winter body mass as has been found in other species (Haramis et al. 1986), then survival of birds exposed to relatively

high lead concentrations may be reduced relative to those exposed to lower levels. Arriving on the breeding grounds with sufficient fat reserves may also influence the ability of a pair to defend a breeding territory and to breed successfully (Nilsson 1979). The quantity of stored fat may also directly affect egg production in females thus affecting breeding success as demonstrated in other migratory birds (Harvey 1971; Ankney & Macinnes 1978; Drent & Daan 1980).

While this analysis suggests a negative impact of lead on one indicator of bird health (i.e. body condition according to our definition; Peig & Green 2009), multiple other sub-lethal and lethal impacts are likely to apply. There is no lead level threshold whereby 'no effect' occurs (CDC 2005; Franson & Pain 2011). For example, lead at very low concentrations may inhibit the activities of several enzymes needed for the production of haemoglobin (Redig et al. 1991; Grasman & Scanlon 1995; Pain et al. 2009). Lead also affects the circulatory system and may have immunosuppressive effects (e.g. Scheuhammer 1987; Trust et al. 1990; Redig et al. 1991; Rocke & Samuel 1991; Fair & Myers 2002; Franson & Pain 2011; Vallverdú-Coll et al. 2015). Given the high prevalence of lead poisoning in the Icelandic-breeding whooper swan population and the range of lethal and sub-lethal effects detected, population impacts of lead poisoning are possible. Following bans on the importation, sale and use of lead angling weights (between 0.06 and 26.5g) in England and Wales in 1987, the incidence of lead poisoning cases in mute swans started to fall and the population started to increase (Perrins et al. 2003). Further analysis of the sub-lethal impacts of lead, current ingestion rates and an understanding of population dynamics and processes are required to assess the full range of individual and population level impacts of lead poisoning on wild swans (Scheuhammer & Norris 1996).

There is extensive evidence implicating lead ammunition as the main source of lead poisoning in wild waterbirds (e.g. Locke & Thomas 1996; Mateo 2009; Newth et al. 2013). It is likely that most of the whooper swans found with elevated levels of lead in their blood in this study were exposed to and ingested lead from spent lead gunshot when foraging within the preceding 35–40 days of sampling (O'Halloran et al. 1988). Newth et al. (2013) found lead shot in the gizzards of 74.9% of waterbirds that were diagnosed as having died of lead poisoning at sites

in Britain (including Caerlaverock and Martin Mere) between 1971 and 2010. The substitution of lead shot with non-toxic alternatives would reduce the availability and exposure of lead to swans and is widely regarded as the long term solution for protecting waterbirds from lead poisoning and reducing environmental pollution (Beintema 2001; Mateo 2009; Cromie et al. 2012; Newth et al. 2013, 2015). In November 2014, the contracting parties (including the UK) to the UN Environment Programme's Convention on Migratory Species, adopted Resolution 11.15, the guidelines of which call for a rapid phase out of the use of lead ammunition in all habitats and its replacement with non-toxic alternatives (UNEP-CMS 2014b). The replacement of lead shot with non-toxic shot is particularly important in areas where whooper swans feed as lead poisoning is commonly caused following the ingestion of spent lead shot when swans are foraging (Spray & Milne 1988; O'Connell et al. 2008; Newth et al. 2013). In the UK, whooper swans frequently forage on agricultural land (Hall et al. 2012) over which it is legal to shoot with lead shot (with the exception of wetlands and specified conservation areas, depending on UK country-specific legislative details) (Newth et al. 2013). Our findings that sub-lethal impacts of lead on body condition occurs in free-living British wintering whooper swans at the lower end of previously established clinical thresholds, and that a relatively high proportion of individuals in the population may be affected, reaffirms the importance of reducing contamination of the environment with lead shot.

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Chapter 3

Perspectives of ammunition users on the use of lead ammunition and its potential impacts on wildlife and humans

Chapter 3: Perspectives of ammunition users on the use of lead ammunition and its potential impacts on wildlife and humans

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Abstract

Recent national and international policy initiatives have aimed to reduce the exposure of humans and wildlife to lead from ammunition. Despite restrictions, in the UK lead ammunition remains the most widespread source of environmental lead contamination to which wildlife may be exposed. The risks arising from use of lead ammunition and the measures taken to mitigate these have prompted intense and sometimes acrimonious discussion between stakeholder groups, including those advancing the interests of shooting, wildlife conservation, public health and animal welfare. However, relatively little is known of the perspectives of individual ammunition users, despite their role in adding lead to the environment and their pivotal place in any potential changes to practice. Using Q-methodology, we identified the perspectives of ammunition users on lead ammunition in an effort to bring forward evidence from these key stakeholders. Views were characterised by two statistically and qualitatively distinct perspectives: (1)*'Open to change'* – comprised ammunition users that refuted the view that lead ammunition is not a major source of poisoning in wild birds, believed that solutions to reduce the risks of poisoning are needed, were happy to use non-lead alternatives and did not feel that the phasing out of lead shot would lead to the demise of shooting, and (2)*'Status quo'* – comprised ammunition users who did not regard lead poisoning as a major welfare problem for wild birds, were ambivalent about the need for solutions and felt that lead shot is better than steel at killing and not wounding an animal. They believed opposition to lead ammunition was driven more by a dislike of shooting than evidence of any harm. Adherents to both perspectives agreed that lead is a toxic

substance. There was consensus that involvement of stakeholders from all sides of the debate was desirable and that to be taken seriously by shooters, information about lead poisoning should come from the shooting community. This articulation of views held by practitioners within the shooting community presents a foundation for renewing discussions, beyond current conflict among stakeholder and advocacy groups, towards forging new solutions and adaptation of practices.

Introduction

There is international recognition of the risks presented by lead to the health of humans and wildlife (Green & Pain 2015; Pain et al. 2015; Stroud 2015; Arnemo et al. 2016). Following regulation to remove lead in the environment from other sources such as paint and petrol (Stroud 2015), recent policies have aimed to reduce the exposure of humans and wildlife to lead from ammunition (UNEP-CMS 2014b; Stroud 2015; IUCN 2016). Over the last 50 years, lead ammunition (primarily shot) has been subject to legislative and other forms of regulation in 33 countries worldwide (Stroud 2015; Kanstrup 2018; Kanstrup et al. 2018). Currently, two countries have total bans on the use, trade and possession of lead shot: Denmark introduced legislation in 1996 (Kanstrup 2006) and the Netherlands in 1993 (Avery & Watson 2009). Partial and total restrictions on the use of lead ammunition for hunting have culminated in a range of experiences from different jurisdictions (Kanstrup 2018). In Denmark, the proposed ban initially received a negative reception from hunters. Resistance was motivated by concerns about safety and the quality and expense of the alternatives to lead shot, compounded by tensions between stakeholders and a lack of organisational leadership (Kanstrup 2015, 2018). Hunter attitudes became more positive with a widening appreciation of the environmental impacts of lead shot and the introduction of a new generation of shot types (Kanstrup 2018). In the UK, partial restrictions on the use of lead ammunition, particularly over wetlands and foreshores, have been introduced to reduce morbidity and mortality of wildlife in England in 1999 (HMSO 1999, 2002a, 2003), Wales in 2002 (HMSO 2002b), Scotland in 2004 (HMSO 2004) and Northern Ireland in 2009 (HMSO 2009). Despite these restrictions, lead ammunition remains the most widespread and

common source of environmental lead contamination to which wildlife might be exposed in the UK (Pain et al. 2015).

The 'lead debate'

The risks arising from use of lead ammunition and the measures taken to mitigate these have prompted intense discussion between stakeholder groups (Newth et al. 2015). Shooting is a long-standing activity with established practices and traditions and is undertaken for a variety of purposes, including sport, pest management and hunting for food. Shooting therefore involves heterogeneous communities of participants (Kanstrup 2018). Furthermore, stakeholder groups in discussions about lead extend beyond shooting, encompassing organisations advancing wildlife conservation, public health and animal welfare (Cromie et al. 2015). This discussion, as played out among membership organisations and vocal commentators in public arenas, is dominated by a 'lead debate' between those advocating retention of the *status quo* (predominantly shooting and countryside management organisations) and those favouring stricter controls or phasing out of lead ammunition and replacement with non-toxic alternatives (predominantly wildlife conservation organisations). This 'lead debate' has become polarised in the UK and sits within a wider landscape of mistrust and tension between shooting and conservation organisations, despite their holding many conservation goals in common. There may also be a perception that moves to phase out the use of lead ammunition are 'anti-hunting' and part of a wider attack on shooting and other legitimate field sports, leading to ratcheting up of regulation and restrictions (Cromie et al. 2015; Thomas 2015).

As with other environmental conflicts, the 'lead debate' has been characterised by contested interpretations of the scientific evidence, and can now be regarded as a socio-political issue (Arnemo et al. 2016). Evidence from the natural sciences alone is often insufficient to resolve conflicts (Haas 2004; Hulme 2009; Saltelli et al. 2015) and this appears to be true in this case (Arnemo et al. 2016). Indeed, Byrd (2002) argues that without addressing the socio-political dynamics driving the public discourse behind such conflicts, interventions based solely on science are likely to polarise people and result in politically unviable management plans. The origins of many conflicts are related to values, changing attitudes and

power relations (Raik et al. 2008) that have roots in social and cultural history (Redpath et al. 2013).

The perspectives of ammunition users

Although the 'lead debate' could be characterised as an apparently 'intractable conservation conflict' (Redpath et al. 2013), played out by large organisations, relatively little is known of the perspectives of individual ammunition users, despite their critical roles in a) adding lead to the environment, and b) adopting, or not adopting, any potential changes to practice. Efforts by statutory agencies and shooting and countryside management organisations to improve user compliance with regulations (e.g. through awareness-raising activities such as the "Use Lead Legally" campaign), have been largely unsuccessful. Compliance with existing regulation remains generally poor in England (e.g. 77% of ducks were shot with lead shot in winter 2013/14; Cromie et al. 2015), some thirteen years after the introduction of regulations (HMSO 1999), indicating that at least some shooting participants have not 'bought-in' to the legislation or guidance.

The success or otherwise of conservation interventions may depend upon whether and how the opinions of relevant individual stakeholders are understood and catered for (Redpath et al. 2013; Madden & Mcquinn 2014; Bennett et al. 2017a) and whether or not proposed solutions are perceived as appropriate (Zabala et al. 2018). Understanding the viewpoints and values of individuals with respect to issues important for conservation has multiple benefits (Curry et al. 2013; Zabala et al. 2018), including: identification of barriers or alignments (Frantzi et al. 2009), improved assessment of the effectiveness of policy and plans, improvement of public participation and stakeholder dialogue (Cuppen et al. 2010) and the facilitation of critical reflection (Zabala et al. 2018), as well as an opportunity to resolve contentious issues (Durning 2005).

Q-methodology in conservation conflicts

Q-methodology uses a combination of quantitative and qualitative techniques to identify and explore subjective attitudes, viewpoints and perspectives on a given topic (Stephenson 1953; Watts & Stenner 2012). It combines the transparency of

a structured quantitative technique with the richer understanding of a qualitative approach (Zabala et al. 2018). For contentious issues, Q-methodology may facilitate agreeable and compromise policy solutions in several ways. It may help decision-makers to: (1) clarify issues, through deeper understanding of the sometimes hidden interests and beliefs of stakeholders, (2) identify competing definitions of problems and solutions and reveal commonalities between them, and (3) as a consequence, forge new solutions (Durning 2005). Within conservation conflict scenarios, Q-methodology has identified shared and opposing discourses relating to the management of large, terrestrial wildlife (e.g. Bredin et al. 2015; Price et al. 2017; Zabala et al. 2018), with the aim of reaching acceptable solutions. Although some conservation conflicts might be well-suited to the application of Q-methodology, such use remains relatively uncommon and the method has rarely been used to explore diversity of viewpoints *within* potentially heterogeneous stakeholder groups. In this context, Q-methodology might help clarify the views of individual stakeholders within the shooting community, i.e. ammunition users, who are instrumental to the success of guidance and legislation and help guide organisations and commentators participating in debate. Enhanced dialogue may prevent misunderstandings about perspectives and motivations of those with differing viewpoints and encourage discourse about the issue so that mutually agreeable compromises might be reached (Durning 2005).

Here, using Q-methodology, we aim to identify the perspectives of ammunition users in relation to the substance of the ‘lead debate’ in an effort to bring forward evidence from these key stakeholders, who have influence over and are most affected by the issue.

Methods

A Q-study involves a relatively small number of purposively selected participants (usually 20–40 people) who are asked to rank, in order, a number of opinion statements about a specific topic (Cairns 2012). The rankings, known as ‘Q-sorts’, are then analysed statistically using factor analysis to explore patterns or shared perspectives towards a topic. These ‘factors’, or social perspectives, are

then interpreted with the aid of contextual information gained through post-sort interviews with all participants (Cairns 2012).

Constructing the narrative for the debate (the "concourse")

A concourse which contains expressions of potentially varied perspectives of the topic (Webler et al. 2009) was constructed using a 'semi-naturalistic approach' (Robbins & Krueger 2000; Cairns 2012), whereby opinion statements were drawn from a combination of semi-structured interviews with seven informed individuals (Webler et al. 2009) and through review of written materials (Stainton Rogers 1995). The interviewees were purposively selected for their considerable professional knowledge of lead ammunition in relation to wildlife health, human health and shooting. They were not asked to rank statements for analysis. Written materials that included the broad subjects of lead ammunition, related impacts on wildlife and humans, associated politics, and non-toxic/non-lead ammunition, were selected for review. The scope was limited to information relevant to the UK only. Materials included published papers, perspectives and reports, articles in shooting and conservation magazines, content from shooting and conservation blogs, websites and forums, texts of international agreements and minutes of meetings and transcripts of parliamentary debates related to the issue of lead shot. This multi-source approach was used to capture, as far as possible, the diversity of opinion and to provide a breadth of personal and organisational perspectives. A total of 243 statements written and released between January 2009 and June 2017 were selected and constituted the original concourse. The concourse was considered complete when the addition of new statements did not present any new opinions (Cairns 2012).

Constructing the Q-set

The concourse was refined to a manageable number of statements (termed the Q-set; Table 3.1) so that they could be sorted by the participants in the Q-sort stage.

***Table 3. 1**: Factor arrays for the two study factors. Factor 1 represents the 'Open to change' perspective while Factor 2 represents 'Status quo'. A factor array (i.e. an estimate of the factor's viewpoint) was identified by combining a weighted average of all the individual Q-sorts that loaded significantly on a particular factor. Statement numbers from the Q-set are presented in brackets followed by their corresponding factor array score which relates to a scale of agreement (e.g. -5 = most disagree; 0 = neutral; +5 = most agree). For example, (17, +5) indicates that statement 17 is strongly agreed with.*

	Statement	Factor	
		1	**2**
1	Stakeholder opinions from all sides of the lead poisoning debate should be included in any decision-making process.	2	3
2	Lead shot is better than steel at killing and not wounding an animal.	0	5
3	Supermarkets should clearly state that their wild game meat products might contain lead.	2	0
4	Lead ammunition harms the image of shooting.	1	-3
5	Steel shot is more likely to ricochet from hard surfaces than lead.	2	4
6	The phasing out of lead shot will lead to the demise of shooting.	-5	1
7	The financial impacts of any further restrictions on lead could be very damaging to shooting related interests.	-3	0
8	Lead ammunition is not a major source of lead poisoning in wild birds.	-3	1
9	There is no evidence that lead poisoning causes bird populations to decline.	-3	1
10	Current game meat handling techniques are enough to address any risks to humans from lead shot.	-1	2
11	Shooters' pastimes and activities are being eroded.	-4	2
12	If shooters saw birds dying from lead poisoning they would think twice about using lead ammunition.	4	0

	Statement	Factor	
		1	**2**
13	The scientific evidence of the impacts of lead on waterbirds is robust.	1	-2
14	The shooting community probably does more for wildlife and habitats than any other group in the UK.	0	5
15	A large number of wildfowl die from lead poisoning each year.	0	-3
16	The risks to wild birds from lead ammunition have been exaggerated.	-3	3
17	Lead is a toxic substance.	5	3
18	Those with political power to influence the issue are biased in favour of keeping lead shot.	-1	-4
19	Lead poisoning is a major welfare problem for wild birds.	0	-4
20	Shooters and non-shooters have the same aim of having sustainable numbers of birds in the British countryside.	3	4
21	Steel shot damages shotgun barrels.	-1	1
22	There needs to be greater awareness within the shooting community about the harm lead poisoning does.	4	0
23	To be taken seriously, information about lead poisoning needs to come from within the shooting community.	1	1
24	There should be better enforcement of current regulations restricting the use of lead shot.	1	-2
25	Opposition to lead ammunition is driven more by a dislike of shooting than any evidence of harm.	-2	4
26	If use of non-toxic ammunition makes people more aware of good range judgement then they will shoot better.	-1	-3
27	Steel and lead shot are comparably priced.	-1	-2
28	More research should be done on the performance of non-toxic ammunition.	0	3

	Statement	Factor	
		1	**2**
29	Eating game killed by lead ammunition has adverse effects on human health.	-2	-5
30	The most effective solution to reduce the risks of lead would be to replace lead shot with non-toxic alternatives.	2	-1
31	There are no safe levels of lead exposure.	1	-2
32	More guidance on different ammunition types, and techniques for their use, would reduce concerns about non-toxic shot.	2	0
33	Those selling game meat for human consumption are not very aware of possible lead contamination in their meat.	-1	-4
34	There is clearly a need for solutions to reduce the risks of lead poisoning.	3	0
35	The risks to human health from lead ammunition have been exaggerated.	-2	3
36	There should be better observance of current regulations restricting the use of lead shot.	4	-2
37	Current restrictions on using lead shot in England and Wales are not sufficient to address lead poisoning in waterbirds.	1	0
38	If you have to shoot at shorter ranges it's not as sporting or fun.	-4	-1
39	Shooting at closer range with non-toxic shot damages the meat.	-2	-1
40	Using plastic wads with non-toxic shot can cause problems with livestock.	0	2
41	Non-toxic shot is widely available.	3	2
42	The shooting community and cartridge manufacturers need to work together and come up with a viable alternative to lead shot.	0	4
43	Ballistically, alternatives to lead shot that are fit for purpose already exist.	3	-1
44	Current human health advice is enough to reduce the risks of lead shot to humans.	-1	2

	Statement	Factor	
		1	**2**
45	Sooner or later, lead shot will be banned.	0	-2
46	Using non-toxic shot would have a negative financial impact on me.	-2	1
47	Non-toxic shot is ineffective against clay targets.	-5	-3
48	Regulations are essential to reducing lead poisoning in waterbirds.	3	-3
49	Lead poisoning in birds is not a big enough problem to justify current regulations.	-4	1
50	Accumulated spent lead shot in intensively shot locations should be removed from the soil to reduce environmental contamination.	-2	-4
51	Shooting organisations are afraid they will look weak if they support a ban on lead shot.	1	-1
52	I am happy to use non-lead ammunition.	4	-1
53	A wider range of non-toxic cartridges would become available if there was a ban on lead.	2	-1
54	Some 'non-toxic' alternatives to lead have greater toxicity than lead.	-3	0
55	Robust scientific evidence should determine how we use lead shot.	5	2
56	If we stopped using lead shot we'd have more birds to shoot.	-4	-5

An unstructured strategic sampling approach was followed to ensure that the variability of the concourse was captured by the Q-set (Webler et al. 2009). Each statement was printed onto a card in a common format and read in detail several times by members of the research team who were familiar with the topic (though none had participated in the interviews to construct the concourse). Group discussions explored possible meanings of each statement. The statements were assigned to clearly defined themes and sub-themes that emerged inductively from the concourse. The categories provided a means of grouping statements that had broad similarities (Webler et al. 2009). When no new themes emerged it was surmised that major themes had been identified (Thomas 2003). The

statements were further reduced following Fisher's experimental design principles (Brown 1980), whereby similar statements within each theme were eliminated to avoid repetition. The final Q-set constituted 56 statements and was created by selecting a number of statements from each theme and sub-theme in order to encompass the spectrum of aspects discussed in the debate. A range of views within each theme was maintained (Stainton Rogers 1995; Cotton 2015). In order to minimise reflexivity (i.e. researcher interference) in the study design (Webler et al. 2009), verbatim statements were included where possible with minimal editing and paraphrasing of the statements employed only for the purposes of increasing clarity and brevity (Stainton Rogers 1995; Cotton 2015). The final Q-set was checked by eight informed individuals from both the shooting and conservation communities (Stainton Rogers 1995; Cotton 2015). Finally, pilot testing with five individuals helped refine the Q-sort process and ensured that instructions were clear and well understood.

Participant selection

Participants from the shooting community were selected through purposive sampling, instead of random sampling of a large number of participants. Q-method aims to identify the comprehensive diversity of perspectives that exist, rather than to determine how those perspectives are distributed across a population (Armatas et al. 2017). Therefore, participants from the shooting community were selected for their familiarity with the issue (Webler et al. 2009). Based on previous studies (Cromie et al. 2010) and discussions with those from the community, views were deemed likely to vary according to how shooters predominantly accessed their shooting, their primary target quarry species and their familiarity with non-toxic shot (indicated by frequency of use), albeit acknowledging that there is likely some overlap between categories. These additional criteria were therefore used to identify participants within the shooting community (Table 3.2).

***Table 3. 2**: Summary of the characteristics of survey participants. Based on previous studies (Cromie et al. 2010) and discussions with those from the community, it was hypothesized that viewpoints were likely to vary according to how shooters predominantly accessed their shooting, their primary target quarry species and their familiarity with non-toxic shot (indicated by frequency of use), albeit acknowledging that there is likely some overlap between categories.*

Characteristics	Response (number of respondents)
Use of non-toxic shot	Very Frequently/Frequently (14), Occasionally (11), Rarely/Very Rarely (3), Never (1), Unknown (1)
Main quarry species	Wildfowl (10), Terrestrial (13), Mixed (5), Deer (1), Unknown (1)
Main access to shooting	Syndicate/Club (11), Local contacts (9), Shoots alone (1), Employment (2), Mixed methods, including commercial (3), Mixed methods, excluding commercial (2), Unknown (2)
Age	25–34 (3), 35–44 (6), 45–55 (6), 55–64 (9), 65+ (5), Unknown (1)
Gender	Male (30), Female (0)
Occupation	Business/Industry/Construction (9), Farming/Land management (4), Conservationist/Researcher (4), Game management (4), cartridge supplier (1), Rural commentator/Journalist (2), Retired (6)

Although some participants were known to each other, efforts were made to incorporate individuals from a breadth of distinct and separate friendship groups, whose members were unknown to each other. This was to reduce undue social influence within the sample, thus improving the likelihood that a diversity of views could be captured.

Administering the Q-sort

Q-sorts were undertaken between August 2017 and February 2018. Participants were asked to rank the 56 Q-statements according to how strongly they agreed or disagreed with each (Brown 1996b). To facilitate this process, participants

were given a deck of randomly numbered cards (with each card containing one statement from the Q-set), instructed to read all 56 statements and sort them first into three categories; Agree, Disagree and Neutral/Unsure/Not applicable (Cotton 2015). The status of statements could be changed during subsequent sorting if desired. Statements were then sorted along a scale from 5 (agree most strongly) to -5 (disagree most strongly), where 0 is neutral (statements have zero salience), and with a fixed number of statements along the scale (Watts & Stenner 2012). A pyramid shaped grid, known as an array, is used as it requires respondents to rank the statements in a forced quasi-normal distribution (Curry et al. 2013; Figure S3.1, Appendix 4). This encourages the participants to evaluate each statement carefully and helps them to reveal their preferences (Webler et al. 2009). Participants in the Q-sort were encouraged to interpret the statements in the context of others when sorting (Webler et al. 2009; Cairns 2012). Once the statements had been ranked, each participant was asked to identify the areas in the grid that demarcated agree from disagree and neutral. Following the Q-sort, each participant was asked in an interview to elaborate on how they had interpreted the most salient statements (those placed at both extreme ends of the continuum on the array), their reasoning for ranking the statements in their unique way, and whether they felt that their perspective had been captured within the Q-set (Brown 1980; Van Exel & de Graaf 2005). The interviews provided information which, along with the factor analysis, helped give the Q-sorts meaning. During the interview, participants engaged in a short discussion on whether they felt solutions were required to reduce the risks of people and wildlife ingesting lead ammunition and, if so, to propose suggestions. Potential barriers to implementing change were also discussed. Those that did not believe solutions were required were asked to explain their reasoning. Participants also provided additional socio-demographic information through the completion of a short questionnaire. Each participant gave their informed consent to participate before they were surveyed. The anonymity of participants was protected and the study and its methodology were approved by the College of Life and Environmental Sciences (Penryn) Ethics Committee at the University of Exeter (reference 2016/1498).

Statistical analysis

The 30 Q-sorts were analysed using centroid factor analysis and subjected to a Varimax rotation in PQMethod (Schmolck 2014). An unrotated factor was considered significant when: (1) its Eigenvalue exceeded one (Kaiser-Guttman criteria: Guttman 1954; Kaiser 1960, 1970), (2) the cross-product of its two highest loadings exceeded twice the standard error of the correlation matrix (i.e. > ±0.27, Humphrey's Rule; Brown 1980), and (3) there were two or more significant factor loadings following extraction (Brown 1980) (Table S3.1, Appendix 5). Factor loadings (i.e. the extent to which an individual Q-sort exemplifies the pattern for a defined factor) were regarded as significant when ≥ ±0.34 at the $p < 0.01$ level (Brown 1980) (Table S3.1, Appendix 5), where:

Significant factor loading = 2.58 x (1/ √ number of items in Q-set)

Factors selected using this criteria (Table S3.1, Appendix 5) were then rotated (Schmolck 2014). Q-sorts that load significantly on the same factor (e.g. see Table 3.3) show a similar sorting pattern suggesting similar and/or shared viewpoints among participants (Watts & Stenner 2012).

***Table 3. 3**: The rotated factor matrix. The loadings indicate the extent to which each Q-sort is associated with each of the study factors following rotation. * indicates which factor each Q-sort is significantly loaded on (i.e. ≥±0.34 at p < 0.01). For example, sorts 3 and 5 significantly load on to Factor 1 and contribute to the weighted average derived from the array which exemplifies Factor 1 (Table 3.1; Figure S3.1, Appendix 4). Q-sorts 1 and 30 are confounded, i.e. they significantly load on to both factors.*

Sort number	Factor 1	Factor 2
1	0.6684	-0.4248
2	0.2244	*0.7025
3	*0.5362	0.2377
4	0.0096	*0.8426
5	*0.6077	0.1417
6	*0.4084	-0.0330
7	*0.5248	-0.0383
8	*0.4316	0.2421
9	*0.5574	0.2656
10	*0.6947	0.2477
11	-0.1989	*0.7495
12	*0.6766	-0.0755
13	0.0146	*0.6006
14	*0.6967	0.1362
15	*0.7434	0.0074
16	0.0532	*0.5185
17	0.0065	*0.6312
18	*0.3381	0.1736
19	0.2259	*0.7108
20	*0.6856	-0.0933
21	*0.3842	0.3290
22	0.2094	*0.5258
23	-0.0807	*0.7516
24	0.2837	*0.6375
25	-0.1903	*0.7204
26	*0.5973	0.0711
27	*0.6639	-0.0979
28	*0.6313	-0.2830
29	*0.5579	0.1875
30	0.4762	0.4972
% explained variance	**22.7**	**20.2**
Eigenvalue	**6.8**	**6.1**

A single, typical Q-sort (termed a factor array) was created for each rotated factor by combining a weighted mean of all the significantly loading Q-sorts (Brown 1980; Watts & Stenner 2012) (Table 3.3; Figure S3.1, Appendix 4). Interpretations of the factor arrays were made by holistically examining the way items were patterned within each and by drawing distinctions between them (Stenner et al. 2003). In order to minimise researcher bias that may arise during the interpretation process, a protocol (known as a 'crib sheet') for analysing factor arrays developed by Watts & Stenner (2012) was systematically and rigorously followed for each array. This ensured that a methodical approach to factor interpretation was applied consistently in the context of each factor and helped to deliver genuinely holistic factor interpretations by forcing engagement with every statement in the factor arrays (Watts & Stenner 2012). A 'reflexive' approach (Galdas 2017) was also adopted which ensured critical self-reflection about preconceptions, relationship dynamics and the analytical focus, throughout the process.

Results

A total of 36 people were approached; 30 (83.3%) actually participated (two individuals declined, two initially agreed to participate but later withdrew, and two did not respond to the invitation). Detail of the composition of the participants is provided in Table 3.2. Two factors were extracted (Table 3.3) and according to the following selection criteria, represented the most plausible summary of the Q-sorts (Watts & Stenner 2012) (Table S3.1, Appendix 5): Eigenvalues exceeded 1.0 (Kaiser-Guttman criteria: Guttman 1954; Kaiser 1960, 1970), the cross-product of each factor's two highest loadings exceeded twice the standard error of the correlation matrix (i.e. > ±0.27, Humphrey's Rule; Brown 1980), and there were two or more significant factor loadings (i.e. ≥ ±0.34) following extraction (Brown 1980). Together both factors accounted for 43% of the rotated explained variance (Table 3.3) which falls at the lower end of the range of explained variance that would ordinarily be considered acceptable (35–40% or above; Kline 1994; Watts & Stenner 2012). In total, 28 of the 30 Q-sorts significantly loaded onto one of the two factors and two sorts were confounded as they loaded significantly onto both factors. Here, we aim to understand and explain the perspective exemplified by each factor and shared by participants whose sorts

have significantly aligned with them. Statement numbers from the Q-set are presented in brackets followed by their corresponding factor array score. For example, (17, +5) indicates strong agreement with statement 17 (see Table 3.1 for array scores associated with each statement and factor). Pertinent comments made by participants during the post-sort interviews are also used to support interpretation.

Factor 1: Open to change

Résumé: *This group of ammunition users believed that lead is toxic; refuted the view that lead ammunition is not a major source of poisoning in wild birds; believed that solutions are needed, and the phasing out of lead shot will not lead to the demise of shooting. They are content to use non-lead ammunition.*

Factor 1 has an Eigenvalue of 6.8 and explains 22.7% of the study variance. A total of 17 participants significantly loaded on this factor.

Evidence and impacts

> *"I think we're all aware that lead is a toxic substance. It's been taken out of petrol, it's been taken out of pencils. And now, in certain circumstances, it's been taken out of shotgun ammunition."* – Participant 5.

This perspective was characterised by a strong belief that lead is toxic (17, +5) and some agreement that there are no safe levels of lead exposure (31, +1). It refutes the views that lead ammunition is not a major source of poisoning in wild birds (8, -3) and that it has no impact on bird populations (9, -3). Scientific evidence of the impacts of lead on waterbirds was perceived to be robust (13, +1). This position did not believe that the risks to wild birds from lead ammunition have been exaggerated (16, -3) nor that opposition to lead ammunition is driven more by a dislike of shooting than any evidence of harm (25, -2). Eating game killed by lead ammunition was not thought to have adverse effects on human health (29, -2). However, the risks to human health from lead ammunition were not perceived to have been exaggerated (35, -2).

Solutions

> *"I am very happy to use non-lead ammunition. It's not an opinion; I use it, it works, and therefore I'm in complete agreement with it."* – Participant 12.

This viewpoint recognised the need for solutions to reduce the risks of lead poisoning (34, +3). It strongly agreed that if shooters saw birds dying from lead poisoning, they would think twice about using lead ammunition (12, +4), and that there was a need for greater awareness within the shooting community about the harm lead poisoning does (22, +4). There was also strong support for better observance of current regulations restricting the use of lead shot (36, +4) and the need for robust scientific evidence to determine how lead shot is used (55, +5). This view strongly disagreed that lead poisoning in birds is not a big enough problem to justify current regulations (49, -4).

Regulations were seen as essential for reducing lead poisoning in waterbirds (48, +3). This position supported the replacement of lead shot with non-toxic alternatives as the most effective solution for reducing the risks of lead (30, +2). There was strong agreement with the statement "I am happy to use non-lead ammunition" (52, +4) and agreement that guidance on different ammunition types, and techniques for their use, would reduce concerns about non-toxic shot (32, +2). According to this view, alternatives to lead shot that are fit for purpose (in ballistic terms) already exist (43, +3). Therefore, there was ambivalence about whether the shooting community and cartridge manufacturers need to work together to develop a viable alternative to lead shot (42, 0). Using non-toxic shot was not believed to have a negative financial impact on the individual (46, -2). There was neither agreement nor disagreement with the notion that lead shot is better than steel at killing and not wounding an animal (2, 0). There was some disagreement that current human health advice is sufficient to reduce the risks of lead shot to humans (44, -1) and that current game meat handling techniques are enough to address any risks to humans from lead shot (10, -1).

Cultural and sporting aspects

> *"I don't see any reason why the phasing out of lead shot will lead to the demise of shooting... Indeed, in some senses, if we lost lead shot, or gave up lead shot, we might be in a stronger position to promote what we do, because it is such a controversial issue."* – Participant 14.

This position strongly disagreed with the view that shooters' pastimes and activities are being eroded (11, -4). There was strong disagreement that shooting at shorter ranges is not as sporting or fun (38, -4). The financial impact of any further restrictions on lead was not perceived to be very damaging to shooting related interests (7, -3). This position adhered to the view that shooting organisations are afraid they will look weak if they support a ban (51, +1). There was strong disagreement that the phasing out of lead shot would lead to the demise of shooting (6, -5), and there was uncertainty that lead shot will be banned in the future (45, 0).

Factor 2: Status quo

Résumé: *This group of ammunition users believed that lead is toxic but did not regard lead poisoning a major welfare problem for wild birds; opposition to lead ammunition is driven more by a dislike of shooting than evidence of any real harm**;** there is ambivalence about the need for solutions and they are unhappy with the non-toxic alternatives.*

Factor 2 has an Eigenvalue of 6.1 and explains 20.2% of the study variance. In total, 11 participants significantly loaded on this factor.

Evidence and impacts

> *"If it was right what they're saying, why are there not people picking up birds all across the countryside?"*
>
> *"In the shooting world we're up against so much opposition. A lot of people just don't like what we do, they don't like shooting…"* – Participant 25.

This perspective agreed that lead is a toxic substance (17, +3) but disagreed that there are no safe levels of lead exposure (31, -2). Lead ammunition was not perceived to be a major source of lead poisoning in wild birds (8, +1) and lead poisoning was not regarded as a major welfare problem for wild birds (19, -4). The scientific evidence of the impacts of lead on waterbirds was not believed to be robust (13, -2) and the risks to wild birds from lead ammunition were thought to have been exaggerated (16, +3). It was strongly agreed that opposition to lead ammunition is driven more by a dislike of shooting than any evidence of harm (25, +4). There was strong disagreement that eating game killed by lead

ammunition has adverse effects on human health (29, -5). Furthermore, the risks to human health from lead ammunition were perceived to have been exaggerated (35, +3).

Solutions

> *"It's been overlooked, the fact that lead is the cleanest killing ammunition out there."* – Participant 25.

There was ambivalence about the need for solutions to reduce the risks of lead poisoning (34, 0) although agreement that robust scientific evidence should determine how lead shot is used (55, +2). This view did not agree that there should be better observance of the current regulations restricting the use of lead shot (36, -2). There was some agreement that lead poisoning in birds is not a big enough problem to justify current regulations (49, +1). Regulations were not deemed essential for reducing lead poisoning in waterbirds (48, -3). This position disagreed with the suggestion that the most effective solution to reduce the risks from lead would be to replace lead shot with non-toxic alternatives (30, -1). There was some disagreement with the statement "I am happy to use non-lead ammunition" (52, -1) and that alternatives to lead shot that are fit for purpose already exist (43, -1). It was strongly agreed that lead shot is better than steel at killing and not wounding an animal (2, +5) and that steel is more likely to ricochet from hard surfaces than lead (5, +4). There was strong support for the shooting community and cartridge manufacturers working together to develop a viable alternative to lead shot (42, +4). This view strongly disagreed that accumulated spent lead shot in intensively shot locations should be removed from the soil (50, -4). There was strong disagreement that those selling game meat for human consumption are not very aware of possible lead contamination in their meat (33, -4) and there was satisfaction that current human health advice is sufficient to reduce risks of lead shot to humans (44, +2). Current game handling techniques were deemed to be sufficient to address any risks to humans from lead shot (10, +2).

Cultural and sporting aspects

> *"So they [the gamekeepers] are managing the habitats so they are not only beneficial to the pheasants but also all the other wildlife that's there as well."* – Participant 4.

This position strongly adhered to the view that the shooting community probably does more for wildlife and habitats than any other group (14, +5). There was agreement with the notion that shooters' pastimes and activities are being eroded (11, +2) and that the phasing out of lead shot will lead to the demise of shooting (6, +1). There was uncertainty about whether the financial impacts of any further restrictions on lead could be very damaging to shooting related interests (7, 0). There was strong disagreement that those with political power are biased in favour of keeping lead shot (18, -4). This view did not believe that lead shot will be banned in the future (45, -2).

Consensus among perspectives

> *"Well, if you've got to have a discussion, you need to have the people who are against it and the people who are for it, so you can have a balanced debate."* – Participant 25.

There were five statements of statistically significant consensus across both factors (Table 3.4).

***Table 3. 4**: Statements with statistically significant consensus across both factors. These are items whose rankings do not distinguish between factors, i.e. the study factors have ranked these statements in the same or similar ways (where p > 0.05). Both the Q-sort value and normalised factor scores (the z scores) are shown. It should be noted that the authors noticed some difficulty with participants' interpretation of statement 56. It was clear in the follow up interviews that some took this statement to refer to lead's impacts on wild bird populations while others linked it with reared game bird populations. There is therefore likely some ambiguity with the interpretation of this statement in this analysis.*

	Statement	**Factor 1 Rank (*z* score)**	**Factor 2 Rank (*z* score)**	**Differential *z* score**
1	Stakeholder opinions from all sides of the lead poisoning debate should be included in any decision-making process	2 (0.820)	3 (0.968)	-0.148
21	Steel shot damages shotgun barrels	-1 (0.022)	+1 (0.156)	-0.134
23	To be taken seriously, information about lead poisoning needs to come from within the shooting community	+1 (0.423)	+1 (0.212)	0.211
41	Non-toxic shot is widely available	+3 (0.830)	+2 (0.573)	0.257
56	If we stopped using lead shot we'd have more birds to shoot	-4 (-1.828)	-5 (-2.084)	0.256

Both parties indicated that lead poisoning was a shared problem; the involvement of stakeholders from all sides of the debate was desirable and there was consensus that to be taken seriously by shooters information about lead poisoning should come from the shooting community. It was agreed that some challenges associated with the non-toxic alternatives (steel shot damages shotgun barrels) remain, though the alternatives were believed to be widely available. Key statement positions that define the two factors and consensus statements are illustrated in Figure 3.1.

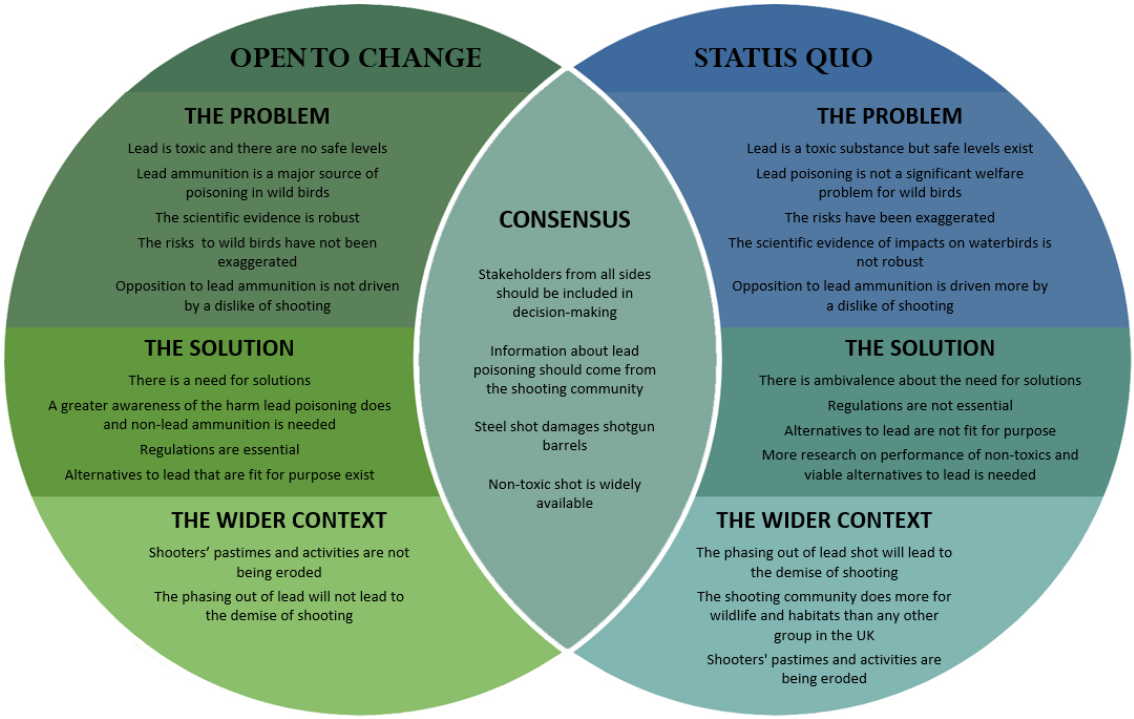

***Figure 3. 1**: A Venn diagram depicting views on some key statements that defines two subject positions derived from a Q-method study of ammunition users. Topics of consensus between the two positions are highlighted in the centre. For each perspective, statements were allocated to three themes that emerged inductively from the Q-set: the problem, the solution and the wider context. Taking a holistic approach advocated by Q-method (Watts & Stenner 2012), statements that reflected a breadth of factor scores, from -5 to +5, within each factor array were extracted, and statements related to topics regarded by the authors as most prevalent within the 'lead debate' were prioritised for inclusion. Statements with statistically significant consensus across both factors (see Table 3.4) were included in the 'Consensus' section. For brevity and illustrative purposes, these statements were summarised and included in this Venn diagram. This figure therefore represents a 'snap-shot' of each perspective rather than a comprehensive view.*

Discussion

The risks of lead ammunition use to human and wildlife health and the measures taken to mitigate these have long been debated in the UK, culminating in a current conflict primarily enacted between groups representing shooting and conservation interests (Cromie et al. 2015; Newth et al. 2015). While this conflict between groups is well known, we have explored the diversity of perspectives among ammunition users, the critical group for their role in releasing lead into the environment and adopting any related changes to shooting practice. Durning (2005) proposed that Q-methodology can be deployed to help resolve conflicts and forge solutions for contentious policy issues in three main ways: 1. Clarifying perspectives, 2. Identifying competing problem definitions and solutions, and 3. Forging new solutions. Here, we discuss the contribution of this study to each of these, summarising and exploring the links between each perspective's definition of the problem and preferred solutions (Derry 1984; Weiss 1989).

Clarifying perspectives

The views of individual ammunition users about the 'lead debate' were characterised by two statistically and qualitatively distinct perspectives: (1)'Open to change' – those that refuted the view that lead ammunition is not a major source of poisoning in wild birds, believed that solutions to reduce the risks of poisoning are needed, were happy to use non-lead alternatives and did not feel that the phasing out of lead shot would lead to the demise of shooting, and (2)'*Status quo*' – those who did not regard lead poisoning as a major welfare problem for wild birds, were ambivalent about the need for solutions and felt that lead shot is better than steel at killing and not wounding an animal. Opposition to lead ammunition was driven more by a dislike of shooting than evidence of any harm. To understand fully the complexity and nature of perspectives, they should be placed within their wider socio-economic and cultural contexts. Both therefore are discussed within the context of views about the future of shooting in the British landscape.

The two perspectives had contrasting views about the future of shooting. The '*Status quo*' perspective was framed by fears that the phasing out of lead shot

would lead to the demise of shooting and that shooters' pastimes and activities were being eroded. These fears were compounded by the feeling that opposition to lead shot is driven by a dislike of shooting. This perspective reflects a prevailing message in the printed shooting media in recent years, which has suggested that a ban on lead shot represents 'the thin end of the wedge' with a call for all attacks on shooting to be resisted (Cromie et al. 2015). Such concerns were also reflected in comments made during the interviews and suggest that some may perceive their shooting heritage as a whole to be under threat, for example:

> *"People with political influence are using banning of lead shot in the hope therefore that people will give up shooting. So it's the sprat to catch the mackerel. The thin end of the wedge."* – Participant 13.

Moreover, this shooting heritage was believed to make an important contribution to the conservation of British wildlife. This sense of pride in the 'shooting life' was a strong theme in the post-sort interviews:

> *"The shooting community wants the wildlife to succeed…My grandfather was a tenant farmer, he told me that you're only here for a short period and you're only the steward of the land in your lifetime, and you have an obligation to leave it looking better than you found it."* – Participant 13.

Conversely, 'Open to change' disagreed that shooters' pastimes and activities were being eroded and that the phasing out of lead shot would lead to the demise of shooting:

> *"I don't agree that the phasing out of lead shot would lead to the complete demise of shooting. I think the phasing out of lead shot will have short-term impacts on shooting."* – Participant 12.

Identifying competing definitions of the lead problem

Problem definition provides the foundations for the construction of policy and its implementation, as well as influencing which stakeholders take part in the decision-making process (Weiss 1989). We found contrasting definitions of the problem among ammunition users. Although both perspectives agreed that lead is toxic, the extent of its toxicity was disputed: 'Open to change' believed that lead is a genuine problem and there are no safe levels of lead, whereas '*Status quo*' believed that the lead problem is exaggerated and safe levels exist. Such contrasting definitions of the 'lead problem' was manifested in differing views on its impacts and the need for (and preferred) solutions.

For ‘Open to change’, the scientific evidence on the impacts of lead on waterbirds was believed to be sound and the evidence was trusted (i.e. not considered exaggerated, nor influenced by a wider dislike of shooting sports). Conversely, those aligned to ‘*Status quo*’ were less inclined to believe the evidence, which was not regarded as robust and was perceived to have been exaggerated. This distrust of the evidence is again likely compounded by the strong sense that opposition to lead ammunition is driven more by a dislike of shooting than evidence of harm. Mistrust of scientists often stems from a questioning of their motives rather than their expertise or integrity (Wissenschaft im Dialog 2017). Multiple factors may contribute to distrust of science, including religious beliefs, level of education, political affiliation and socio-economic status (Kahan 2002; Kabat 2017). Distrust is a key barrier to collaboration (Ansell & Gash 2007) and to the resolution of conservation conflicts (Young et al. 2016a), and therefore may have serious implications for conservation, the success of which often relies on effective collaboration.

In the post-sort interviews, several ammunition users linked their disbelief about the impacts of lead with their own personal experiences, notably that they had never knowingly encountered a lead poisoned bird, nor had been aware of any impacts on their own health following a lifetime of eating game:

> *“But here I am, I’ve been eating game for, I don’t know, 72 years, and I’m still here. So it’s ineffective on me.”* – Participant 19.

Neither perspective believed that lead shot was harmful to human health. Mortality of wild birds from lead poisoning often goes undetected (Cromie et al. 2010; Newth et al. 2013). Unlike wildlife diseases such as botulism, large scale die-offs of wild birds from lead poisoning are rare events (Pain 1991). Furthermore, sub-lethal impacts of lead on the physiological systems of birds (Franson & Pain 2011; Newth et al. 2016) and humans (EFSA 2010; Arnemo et al. 2016) may not be obvious (Cromie et al. 2015).

It should also be considered that when conservation issues are politicised, individuals may selectively understand the science in accordance with their own value-based demands (Sarewitz 2004; Kahan et al. 2011; Chamberlain et al. 2012) and this may partly explain the polarity in viewpoints in this study.

Preferred solutions

'*Status quo*' was ambivalent about the need for a solution to reduce the risks of lead shot, perhaps unsurprisingly given the view within this group that lead poisoning is not a significant problem. A previous survey of British shooters found that a key reason for non-compliance with the current lead shot restrictions was that 'lead poisoning is not a sufficient problem to warrant restrictions' (Cromie et al. 2010). There was also support for this sentiment within '*Status quo*', associated with little enthusiasm for suggested solutions such as awareness-raising, better observance or enforcement of the current regulations and further regulations to replace lead shot with non-toxic alternatives. In contrast, as well as agreeing that lead was a significant problem, 'Open to change' recognised the need for solutions to reduce the risks of lead poisoning. Regulations were seen as essential and there was some support for the replacement of lead shot with non-toxic alternatives. This view strongly agreed that shooters would think twice about using lead ammunition if they saw birds dying from poisoning and that greater awareness of the issue would help:

> *"I just can't imagine that anybody, whether they were shooters or not, would think that it's acceptable to see birds being poisoned or dying. If they saw it, I think it would upset them."* – Participant 10.

In recent years, the 'lead debate' has been punctuated by numerous national laws (HMSO 1999, 2002a, 2002b, 2003, 2004, 2009) and international agreements (UNEP-CMS 2014b, 2017b; IUCN 2016; UNEA 2017; Kanstrup et al. 2018) which have called, to varying degrees, for the replacement of lead ammunition with non-toxic alternatives. Views on non-lead alternatives notably differed between the two perspectives. Those in 'Open to change' were more likely to be happy to use non-lead options, felt that they were fit for purpose and therefore saw little need for further research to develop a viable alternative. They believed that the availability of further information on non-lead ammunition would reduce concerns. A previous survey found that 41% of British shooters felt that more guidance about the non-lead options would help improve compliance with current restrictions (Cromie et al. 2010). However, those in '*Status quo*' were generally not happy to use non-lead ammunition, did not feel that the alternatives were fit for purpose and strongly believed that lead shot was better than steel at killing and not wounding an animal. A dislike of the alternatives was also a key

reason that British shooters gave for not complying with the current regulations in England (Cromie et al. 2010) and concerns about the effectiveness of non-lead shot relative to lead has been reported in shooting communities elsewhere (Kanstrup 2006, 2015, 2018). There was a strong belief among those in '*Status quo*' that more research should be done to develop a viable alternative. It seems logical that those who were more content with the non-lead alternatives, reflecting the perspective of 'Open to change', are more likely to support the replacement of lead shot with these alternatives while those who were not, are less likely to support this suggested solution. There was some support from those within 'Open to change' for the notion that shooting organisations are afraid they will look weak if they support a ban on lead shot. This may reflect the pressure that membership-oriented shooting organisations are under to provide both leadership and to reflect their memberships' views and supporting a ban may feed into a narrative of giving in to the opposition.

Commonalities

Though the two perspectives differed on many issues, there was consensus that to be taken seriously information about lead poisoning should come from within the shooting community:

> *"Yes. If you want to hear bad news, you want to hear it in the pub, from your mates, rather than in the media, at a press conference directed at you. You want to be in the room, and you want to be in ownership of leading the way out of what the issue might be."* – Participant 22.

This indicates that such sources would have greater credibility among shooters. In Denmark, critical advocates within the hunting community persuaded other hunters of the benefits of non-toxic ammunition using evidence from hunter-led research (Newth et al. 2015; Kanstrup 2018). In principle, both perspectives supported using robust scientific evidence to guide lead shot policy and management and agreed that opinions from all sides of the 'lead debate' should be included in the decision-making process. Effective participation may improve relationships by increasing trust and sharing perspectives and ultimately reduce conflicts (Ansell & Gash 2007; Redpath et al. 2013). Both perspectives believed that shooters and non-shooters have the same aim of having sustainable numbers of birds in the British countryside:

> *"I feel as though my view would be the same as a non-shooter. We want to see the same thing, we don't want to see the decline in wildlife at all. We'd rather see the uprising of it."* – Participant 17.

Forging solutions

Conflicts are often over-simplified as they become entrenched and polarised, losing the nuanced perspectives that may exist among the parties. Furthermore, individuals within a polarised stakeholder group do not necessarily hold uniform opinions on wildlife management (Chamberlain et al. 2012; Rust 2017). Here, use of Q-method has allowed access to a complex issue, enabling the perspectives of ammunition users, as the key group of actors, to be clarified, competing definitions of the problem and preferred solutions to be identified and commonalities to be revealed. Critically, these perspectives arise solely from within the shooting community of ammunition users. In a conflict commonly depicted as between those in favour of shooting versus those opposed, we reveal that a diversity of views on lead ammunition is held within the shooting community itself. Further studies are required to assess the prevalence of the views identified. The variables influencing the views outlined within this paper merit further examination using interdisciplinary methods from the social sciences and psychology. A deeper understanding of factors predicting the use of lead and non-lead ammunition would be beneficial for addressing non-compliance with the current regulations and acceptability of any future changes to practice. Given that the lead debate is dynamic and influenced by various socio-economic and political factors (Cromie et al. 2015), this study may form a useful foundation for a longitudinal study whereby changes in perspectives on the issue across time can be explored.

The views of women shooting participants were not captured within this study as women were not specifically targeted during participant recruitment. Studies have shown that women exhibit relatively stronger environmental concern and behaviour than men (Vicente-Molina et al. 2018), and therefore targeted work to assess the perspectives of women in relation to the lead shot issue merits further examination. Overall, the clarification of views held by ammunition users presents an opportunity for the shooting community to take forward discussions and potentially forge new solutions.

Acknowledgements

We are extremely grateful to all participants and advisors from the shooting community for their trust, time and contribution to this study.

Additional Supporting Information:

Figure S3.1 (Appendix 4): Exemplar factor array
Table S3.1 (Appendix 5): Selection criteria for unrotated factors

Chapter 4

Conservation implications of misidentification and killing of protected species

Chapter 4: Conservation implications of misidentification and killing of protected species

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Abstract

Killing protected species mistaken for morphologically-similar quarry species, or species with weaker protection, can hinder their conservation. Despite policy aims to reduce threats from illegal killing, information is lacking on susceptible species, conservation impacts and the identification accuracy of hunters. We examined the ability of hunters (n=232) in Arctic Russia to identify the endangered Northwest European Bewick's swan *Cygnus columbianus bewickii* using photographs. Only 14% (n=33) identified this species correctly and distinguished it from sympatric and congeneric whooper swans *C. cygnus* and mute swans *C. olor*, with 15% of individuals admitting to accidentally hunting a Bewick's swan in the previous three years. We conclude that there is a risk of Bewick's swans being shot accidentally when mistaken for similar species with less legal protection. Improving hunters' skills in discerning protected from legitimate quarry species is likely to be an effective tool for conservation of morphologically-similar species.

Introduction

Accidentally killing protected species mistaken for legitimate quarry species presents a problem to threatened wildlife (AEWA 2015). For populations subject to legal hunting, accurate identification is important to ensure sustainable exploitation and avoid impacts on non-target species (European Commission 2008; Christensen et al. 2017). The ability of hunters to shoot selectively may vary with species, environmental conditions and hunter experience (European Commission 2008). Examples of avian species affected by shooting mortality

include the critically endangered slender-billed curlew *Numenius tenuirostris* (Gallo-Orsi et al. 2002) and the vulnerable lesser white-fronted goose *Anser erythropus* (Jones et al. 2008; AEWA 2015). More widely, misidentification of wildlife species may reduce ability or willingness to engage in monitoring and conservation (Robinson et al. 2016), have implications for public health (e.g. distinguishing poisonous and non-poisonous species) and have serious conservation impacts (e.g. removal of native species when mistaken for invasive) (Somaweera et al. 2010).

Despite international attention (e.g. European Commission 2008; AEWA 2015; Madsen et al. 2015), information on birds susceptible to misidentification and potential impacts on these species is surprisingly lacking (AEWA 2015). Though scarce, evaluations of hunters' species-identification skills have mixed outcomes. One study assessing hunters' ability to identify five quarry goose species in Denmark found that 14.5% of 2,160 identifications were incorrect (Christensen et al. 2017). While most hunters on the Mississippi Flyway were able to recognise common waterfowl, females of taxa rarely encountered were frequently misidentified (Wilson & Rohwer 1995). Globally, few countries grant hunting licenses on the condition of passing a species identification test. In northern Europe, there are notable exceptions including Denmark (Danish Hunters' Association 2003), Norway (Directorate for Nature Management Trondheim 2018), Sweden (Svenska Jagareforbundet 2005), Finland (Hunters' Central organization 2018), Germany (Deutscher Jagdschutz-Verband 2003), the Netherlands, Belgium and Luxembourg (Koninklijke Nederlandse Jagers Vereniging 2004).

We examined the ability of hunters in the Russian Arctic to identify correctly the endangered Northwest European Bewick's swan *Cygnus columbianus bewickii* (BirdLife International 2015), which has been protected from hunting under national and international legislation throughout its range since 1954 and 1976, respectively (Rees 2006), but is still hunted illegally (Gurtovaya 2000; Newth et al. 2011; Nagy et al. 2012; Mineyev & Mineyev 2014). In their Russian Arctic breeding grounds, Bewick's swans may be confused with mute swans *C. olor* (AEWA 2015), and in particular, whooper swans *C. cygnus*, which are similar in

appearance (Figure 4.1) and distribution (Rees 2006; Mineyev & Mineyev 2011, 2014).

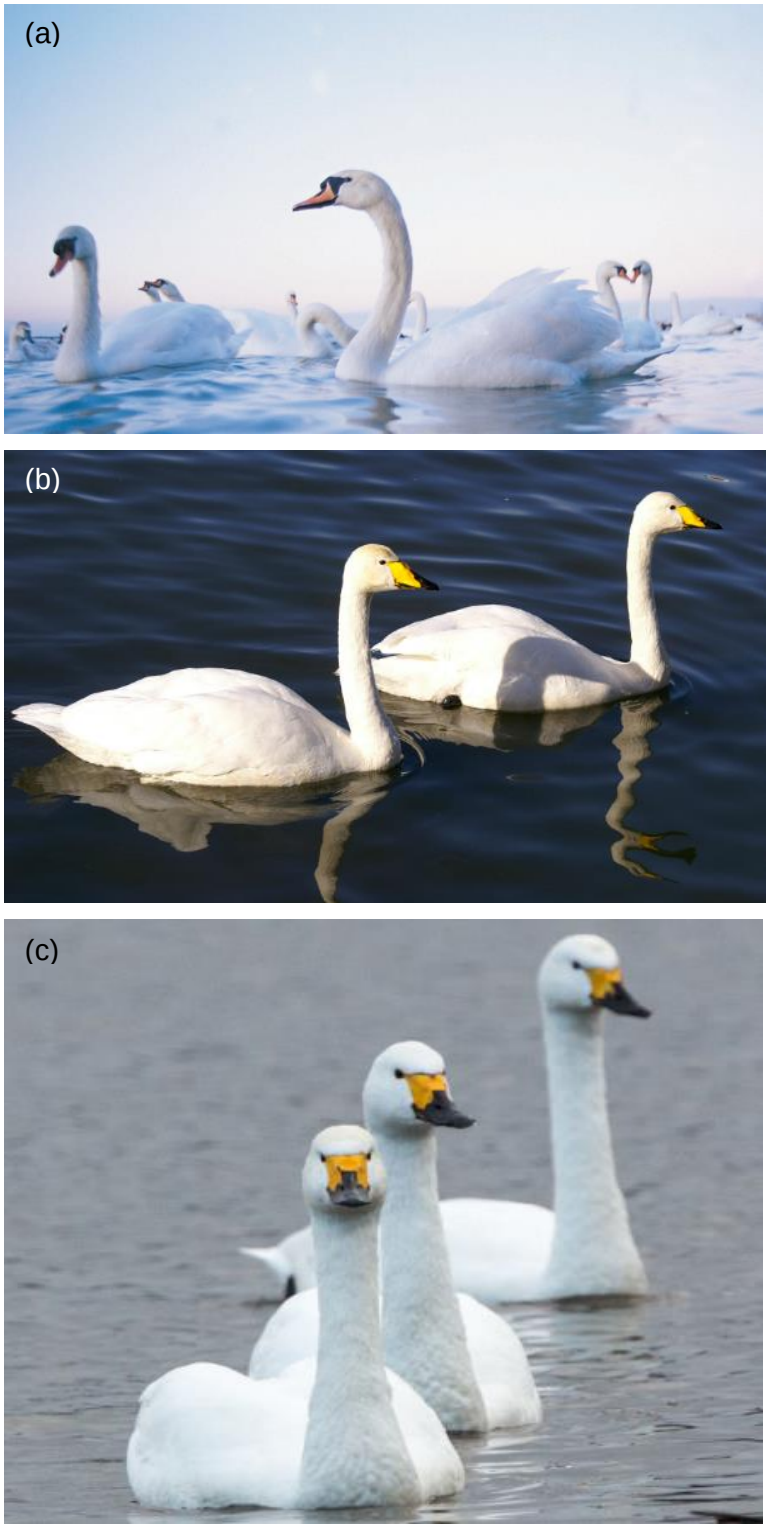

Figure 4. 1*: Photographs of adult (a) mute swans, (b) whooper swans and, (c) Bewick's swans used to assess species identification accuracy (photo credit: WWT).*

Bewick's swan has been included in the Red Data Book of the Russian Federation (and previously the Soviet Union) since 1978, giving it legal protection from hunting across Russia (Mineyev & Kondratiev 2001). The species is additionally listed in Red Data books for its breeding and moulting areas in the Nenets Autonomous Okrug (NAO) (Gurtovaya & Litvin 2006) and the Arkhangelsk Oblast (AO) (Novoselov 2008), emphasising its protected status in these regions. Further south, it is also protected across staging and wintering areas, yet embedded shot was detected in 31% of individuals x-rayed between winters 1970/71 and 2008/09, highlighting the frequent occurrence of shooting this species within the flyway (Newth et al. 2011). Such shooting may have a significant impact on Bewick's swan survival rates (Wood et al. 2018a) and is considered a potentially high threat for the population (Nagy et al. 2012; AEWA 2015). Although whooper swans and mute swans are omitted from huntable species lists in the NAO and AO (Mineyev & Mineyev 2014), their absence from the Russian Red Data Book means that they have weaker legal protection. Moreover, although whooper swans are included in the regional Red Data Book of the AO (Novoselov 2008), they are not included for the NAO (Gurtovaya & Litvin 2006). Mute swans are not listed for either region. The penalty for killing these two species therefore is less severe, and the legal deterrent weaker, than for Bewick's swans (Decree of the Ministry of Natural Resources and Ecology of Russian Federation No. 107 28.04.2008).

We predicted that Bewick's swans are shot at when deliberately targeted, when mistaken for one of the two morphologically-similar and sympatric swan species or through inaccurate targeting of quarry species in close proximity. Given the prevalence of Bewick's swans carrying shot, and that they spend c. 40% of the year in northern Russia (May – September inclusive; Rees 2006), we tested the ability of a large sample of hunters in European Arctic Russia to distinguish the Bewick's swan from two other swan species and examined the influence of socio-demographic variables on identification success. Thus we explored the potential role of species misidentification in the illegal killing of Bewick's swans and prospective mitigation measures.

Methods

Hunters from seven settlements in European Arctic Russia (six in the NAO; one in the AO; Figure 4.2) were surveyed between 27 June and 16 July 2016.

Figure 4. 2*: Study regions in the Russian Arctic. Grey shading denotes the Nenets Autonomous Okrug (NAO) and white shading, Arkhangelsk Oblast (AO). In AO, only hunters on the mainland (and not the island of Novaya Zemlya) were surveyed.*

The population of the NAO is ethnically diverse, comprising Russians, indigenous Nenets, Komi and other nationalities, while that of the AO is predominantly Russian (Russian Federal State Statistics Service 2015). Identities of settlements and participants are not reported to preserve anonymity. Settlements were selected on the basis of: (i) proximity to areas used by Bewick's swans when

summering on the tundra or during migration (Mineyev 1991; Rees 2006), (ii) ethnic heterogeneity of the populations (ensuring all main ethnicities were sampled across the settlements), and (iii) ease of access. Questionnaires were administered by three trained facilitators, all Russian speakers, in interviews with participants at a time and location of their convenience. Only those regarding themselves as 'hunters' were asked to participate. For each settlement, 2.5% of the total population (based on numbers for 2015; range = 10–88 participants per settlement) was included in the survey.

Given the sensitive nature of illegal killing, snowball sampling was used to recruit participants (Newing et al. 2011). Although it is not possible to make statistical inferences from the sample to the population using this method, information can be gathered from groups that are ordinarily less easily accessed, and influential factors may be identified. Recruitment continued until a sufficient number of individuals had been identified to meet the desired sample for each settlement. All participants were aged 18 years or over. Survey methods were approved by the College of Life and Environmental Sciences (Penryn Campus) Ethics Committee at the University of Exeter (reference 2016/1496) and each respondent gave their free and informed consent prior to participation.

The questionnaire comprised 52 questions; question wording and methods were refined following a pilot survey of 50 inhabitants from one settlement in the NAO between 24 June and 1 July 2015. Only interviews conducted in 2016 are used in the analyses (S4.1, Appendix 6). Participants were asked about their socio-demographic status, residence, hunting frequency and hunter identity (i.e. reason for regarding oneself as a 'hunter'), and knowledge about Bewick's swan ecology and the laws protecting them (Table S4.1, Appendix 7; European Commission 2008; Robinson et al. 2016; Christensen et al. 2017).

To test respondents' ability to distinguish between three swan species, they were shown (in turn) a colour photograph (sized 29 x 20 cm) of an adult Bewick's swan, whooper swan and mute swan (each printed on a separate sheet), and asked to identify each one by their Russian or colloquial name (S4.1, Appendix 6, Q7). The participants had the opportunity to view all three photographs at the same time. Previous studies (e.g. Keane et al. 2011) have found visual tools useful for

ascertaining species identification. Respondents were also asked whether they had hunted Bewick's swans in the region within the previous three years (S4.1, Appendix 6, Q12).

Statistical analysis

All analyses were conducted in R 3.1.1 (R Development Core Team 2016). A generalized linear model (GLM) with binomial error distribution and logit link function was used to assess the effects of the explanatory variables on the hunters' ability to identify a Bewick's swan (0 = incorrect, 1 = correct). Generalized Variance Inflation Factors (GVIFs) checked for multi-collinearity between explanatory variables. All variables (Table S4.1, Appendix 7) were within acceptable norms (i.e. GVIFs < 3) (Thomas et al. 2013) and therefore were retained in the global model.

An Information Theoretic approach was applied (Burnham et al. 2011). Full sub-set model selection was performed using the MuMIn package in R (R Development Core Team 2016), to test all possible combinations of effects (Table S4.1, Appendix 7). Models were ranked according to the value of Akaike's information criteria, corrected for small sample size (AICc). The model with the lowest AICc value was regarded as our best supported model and the relative likelihood, Akaike weight, and evidence ratio were also used to assess support. R^2_{mod} values (Tjur 2009) assessed the percentage of the variance in hunters' ability to identify Bewick's swans explained by each model. Model averaging across our best supported models (i.e. those where ΔAICc $\leq$ 2.0) was undertaken using the MuMIn package (R Development Core Team 2016), to estimate the effect sizes associated with each variable. Chi-squared tests determined whether or not hunters' ability to identify swans differed significantly across species. To assess whether hunters' ability to identify each species differed from that expected by chance (i.e. random selection), we used a 2-sample binomial test for equality of proportions.

Results

A total of 252 people were approached and 8% (n=20) declined to participate. 232 questionnaires were completed and used in the analysis. Respondents came from eight ethnic groups (Table S4.1, Appendix 7) and 98% (n= 228) were male. 14% (n=33) of the respondents correctly identified (named) a Bewick's swan from its colour photograph (Table 4.1).

Table 4. 1: *Identification accuracy and the probability of accurate identification expected following random selection, of three swan species by 232 hunters in the Russian Arctic.*

Species	Identification accuracy (n)	Probability of accurate identification following random selection (n)	2-sample binomial test for equal proportions (χ^2)	*P* value
Identification of Bewick's swan only	0.14 (33)	0.33 (77)	22.03	< 0.001
Identification of whooper swan only	0.14 (33)	0.33 (77)	22.03	< 0.001
Identification of mute swan only	0.12 (27)	0.33 (77)	29.76	< 0.001
Identification of both Bewick's and whooper swans	0.07 (16)	0.17 (39)	9.98	< 0.001
Identification of both Bewick's and mute swans	0.05 (12)	0.17 (39)	14.89	< 0.001
Identification of both whooper and mute swans	0.06 (13)	0.17 (39)	13.54	< 0.001
Identification of all three swan species	0.05 (11)	0.17 (39)	16.34	< 0.001

Identification accuracy was similar for whooper swans (14%; n=33) and for mute swans (12%; n=27), and hunters' ability to identify swans did not differ significantly between species (X^2_2 = 0.894, P = 0.64 for 3 species) (Table 4.1). No other species aside from Bewick's, whooper and mute swans were suggested by the participants during the identification test. Those able to identify Bewick's swans were significantly more likely also to be able to identify whooper swans (16 of 33; 49%) than those that were not (17 of 199; 9%) (X^2_2 = 33.81, P = < 0.001)**.** A 2-sample binomial test for equality of proportions indicated that identification accuracy was, in every case, worse than that expected by chance (Table 4.1).

Identification accuracy was best explained by a model (of averaged effects associated with our best supported models; i.e. those models where ΔAICc ≤ 2.0), including employment sector, the distance of hunters' settlement to the nearest key Bewick's swan site, region of residence, hunting frequency, hunter identity, knowledge of Bewick's swan migration and monogamy, perceptions of population trends, knowledge of protective laws and age (Tables 4.2 & 4.3).

Table 4. 2: *A summary of effects on the ability of 232 hunters in the Russian Arctic to correctly identify a Bewick's swan. We present model averaged effects associated with our best-supported models (i.e. all models where ΔAICc ≤ 2.0; Table 4.3). A GLM with a binomial error distribution and logit link functions was used to assess the effects of the explanatory variables on the ability of hunters to identify a Bewick's swan (0 = incorrect identification, 1 = correct identification).*

Parameter*	**Estimate**	**SE**	***Z***	***P***
Intercept	*-2.047*	*350.075*	*0.006*	*0.995*
Employment (unlikely to involve interaction with natural environment)	-1.238	0.488	2.522	0.012
Employment (other†)	-1.670	0.685	2.424	0.015
Distance to nearest key Bewick's swan site	-0.555	0.452	1.224	0.221
Hunting frequency‡	-0.022	0.147	0.149	0.882
Knowledge of migration (correct)	0.039	0.196	0.198	0.843
Region of residence (Nenets Autonomous Okrug)	0.072	0.259	0.278	0.781
Unsure of population trends for Bewick's swans	1.239	350.074	0.004	0.997
Perceive Bewick's swan population is increasing	1.271	350.075	0.004	0.997
Perceive Bewick's swan population is stable	1.336	350.078	0.004	0.997
Age	0.017	0.143	0.120	0.905
Knowledge of monogamous behaviour (correct)	0.013	0.153	0.086	0.931
Knowledge of laws protecting Bewick's swans (correct)	0.027	0.215	0.125	0.901
Knowledge of laws protecting Bewick's swans (incorrect)	0.068	0.355	0.186	0.852
Hunter identity: reason for regarding oneself as a hunter (did not know)	0.003	0.189	0.015	0.988
Hunter identity: reason for regarding oneself as a hunter (appreciation of the natural world)	0.024	0.139	0.173	0.863

*The reference factor levels are: Employment (likely to involve interaction with the natural environment); knowledge of migration (incorrect); region (Arkhangelsk Oblast); perceive Bewick's swan population is decreasing; knowledge of monogamous behaviour (incorrect); knowledge of laws protecting Bewick's swans (did not know), and hunter identity (reasons for regarding oneself as a hunter are not related to an appreciation of the natural world).
†Includes pensioners, the unemployed and respondents for whom employment sector is unknown.
‡Number of days spent hunting per annum.

***Table 4. 3**: A comparison of the relative support and explanatory power of our best-supported models relating to the ability of 232 hunters in the Russian Arctic to correctly identify a Bewick's swan. K refers to the number of parameters within the model. Model parameters: i = intercept, E = employment sector, D = Distance of settlement to the nearest key Bewick's swan site, Hf= hunting frequency, Km = knowledge of migration, Ppop = perception of population trend, A = age, Kp = knowledge of monogamous behaviour, Kl = knowledge of laws, Hi = hunter identity and R = region of residence. The best supported models (for which model-averaging of parameter estimates was undertaken; Table 4.2) are indicated in bold.*

Model	***K***	**AICc**	**ΔAICc**	**Relative Likelihood**	**Akaike weights**	**Evidence ratio**	**R^2_{mod} (%)**
i + E + D	**3**	**186.467**	**0.0**	**1.00**	**0.2068**	**1.00**	**5.8**
i + E	**2**	**188.040**	**1.6**	**0.46**	**0.0942**	**2.20**	**4.2**
i + E + Hf + D	**4**	**188.152**	**1.7**	**0.43**	**0.0890**	**2.32**	**6.1**
i + Km + E + D	**4**	**188.205**	**1.7**	**0.42**	**0.0867**	**2.38**	**5.8**
i + E + D + R	**4**	**188.215**	**1.7**	**0.42**	**0.0863**	**4.40**	**6.0**
i + E + R	**3**	**188.236**	**1.8**	**0.41**	**0.0854**	**2.42**	**4.9**
i + E + Ppop + D	**4**	**188.307**	**1.8**	**0.40**	**0.0824**	**2.51**	**8.0**
i + E + A + D	**4**	**188.33**	**1.9**	**0.39**	**0.0815**	**2.54**	**6.0**
i + E + D + Kp	4	188.441	2.0	0.37	0.0071	2.68	5.9
i + E + D + Kl	4	188.995	2.5	0.28	0.0584	3.54	6.6
i + E + D + Hi	4	189.217	2.7	0.25	0.0523	3.95	6.1

Those able to identify Bewick's swans correctly were significantly more likely to be employed in a sector that involved interaction with the natural environment than those that were not (33% and 13%, respectively; Table 4.2). Identification accuracy was highest among those employed in reindeer herding and the fishing industry (38% and 33%, respectively). Respondents living in closer proximity to key Bewick's swan sites were also more likely (albeit marginally so) to be able to identify Bewick's swans (Table 4.2). Those who spent fewer days hunting per year were marginally *more* likely to be able to identify a Bewick's swan, as were those with greater knowledge of Bewick's swan migration and monogamy (Table 4.2). Participants noting an appreciation of the natural world as a reason for regarding themselves as hunters were more likely to be able to identify a Bewick's swan. Bewick's swan identification accuracy was more likely to be higher among those living in the NAO than in AO (Table 4.2). Those with knowledge that Bewick's swans were protected by law were marginally less likely to be able to identify the species. Perception of population trends was a poor predictor of identification accuracy (SE = 350; Table 4.2).

Overall, 12% (n=27) of participants admitted to hunting what they believed to be a Bewick's swan in the previous three years, 15% (n=35) admitted to accidentally hunting them, 72% (n=168) stated that they had not hunted Bewick's swans, and 0.8% (n=2) did not want to answer the question. Of those able to identify a Bewick's swan correctly (n=33), 12% (n=4) admitted to hunting the species and 18% (n=6) admitted to accidentally hunting them. Most (82%; n=190) respondents were aware that it was not legal to hunt Bewick's swans while 8% (n=19) thought that it was permissible and 10% (n=23) did not know.

Discussion

Photographs of the Northwest European Bewick's swan, a protected species susceptible to illegal shooting (Newth et al. 2011), were generally not distinguished from photographs of two other swan species with lower legal protection by hunters in parts of the Russian Arctic. Poor identification accuracy for Bewick's, whooper and mute swans (14%, 14% and 12%, respectively) suggests an overall inability by hunters to separate these species. Hunters familiar with the identifying features of Bewick's swans were significantly more

likely to identify whooper swans than those that were not. Given the physical similarities between these particular swans, specific knowledge is required to distinguish them. Accurate distinction of morphologically-similar species may challenge even the most experienced ornithologist. This has important implications for the effectiveness of conservation rules and for understanding sources of uncertainty surrounding their implementation (Hunt 2013).

Low identification rates may be attributable to subtle specific differences (Christensen et al. 2017). In addition to sharing similar morphological traits, Bewick's and whooper swans also exhibit similar behaviour (including vocalizations) and ecology (Rees 2006), co-exist at certain times in sizeable numbers (Rees 2006; Mineyev & Mineyev 2011, 2014), and use similar habitats. Given that whooper and mute swans are afforded weaker legal protections than Bewick's swans in Russia, with lower penalties incurred for their killing, it is plausible that they are targeted for shooting. Enforcement of severe penalties serve as a deterrent and, among other measures, reduce the illegal killing of protected wildlife (e.g. Martin et al. 2013). Moreover, penalties are a key tool deployed by the Russian Government to deter poaching (e.g. Federal Law No. 91 07.05.2013). Both whooper and mute swans may be included on hunting lists and shot in other regions of Russia (Solokha & Gorokhovsky 2017). Under these circumstances, it seems likely that Bewick's swans are shot on being mistaken for whooper and mute swans. Mute swans are less likely to coincide with Bewick's swans during the summer because they occur in lower numbers in the arctic tundra (Mineyev & Mineyev 2014). Those living in the AO were not as likely to identify a Bewick's swan correctly in comparison to those living in the NAO. The risk of hunters who are aware of protective laws mistakenly shooting Bewick's swans when whooper swans are targeted is perhaps lower in the AO, as here whooper swans are also listed in the regional Red Data Book (i.e. afforded the strongest legal protection), whereas in the NAO they are not. Higher penalties are therefore incurred for the hunting of whooper swans in the AO which may serve as a deterrent and reduce the likelihood that they are targeted for hunting in the first place. Furthermore, hunters in the AO may regard that legal protections simply encompass swan species with yellow and black bills, thus making the ability to distinguish Bewick's from whooper swans less relevant. It is likely that shooting is the main method of hunting for all three swan species.

Higher identification accuracy was found for hunters employed in sectors more likely to involve interaction with the natural environment and among those living closer to key Bewick's swan sites. These hunters are perhaps more likely to encounter Bewick's swans and thus be familiar with their identifying characteristics. Among American duck hunters, highest identification accuracy occurred for species regularly seen in the field (Wilson & Rohwer 1995). Hunting frequency also plays an important role and has been found to depend upon the training and experience of the hunter (e.g. European Commission 2008). In this study however, those spending more days hunting annually were significantly less likely to be able to identify Bewick's swans. The number of years rather than days spent hunting may be more influential in this case.

Identification accuracy may be higher under field conditions than from photographs, because other cues are available to hunters such as the comparative size, behaviour and occurrence of swans in the area (Austen et al. 2016; Christensen et al. 2017). Given that Bewick's and whoopers swans are particularly similar morphologically, size differences may be one of several distinguishing features used to identify them. However, adverse field conditions including weather, lighting and observation distance can in turn reduce the ability of hunters to recognise species (European Commission 2008), so inspecting a photo closely, without time constraints and in a well-lit room, might be expected to improve some aspects of identification accuracy. We should also consider that, as in other wildfowl (Wilson & Rohwer 1995; Christensen et al. 2017), identification of juveniles is likely to be less accurate than for adult birds because interspecific differences in morphology are more subtle at that age (Wilson & Rohwer 1995; Christensen et al. 2017). Finally, those unable to identify Bewick's swans may not have been aware of their existence and this warrants further investigation.

We conclude that the risk of Bewick's swans being shot arises in part when they are mistaken for two morphologically-similar swan species, particularly when they spatially and temporally coincide. Interventions may help reduce the accidental shooting of misidentified species, for instance by informing hunters of the consequences of accidental shooting for wild bird populations and improving their identification abilities (AEWA 2015; Madsen et al. 2015). Hunters should be

encouraged by government agencies, hunting organisations, hunting tourism agencies and respected and influential community leaders and groups, to avoid shooting a bird unless they are confident of its identity (European Commission 2008; AEWA 2015). Government-supported proficiency tests and traditional ways of educating would ensure that an adequate level of knowledge is reached (AEWA 2015; Madsen et al. 2015). Identification keys, which help to reduce the risk of confusion (e.g. Poyarkov et al. 2011)**,** are a useful resource (European Commission 2008; AEWA 2015). Financial, practical and communications support from government agencies and hunting bodies for the design and dissemination of resources for hunters, is likely to be required for a successful awareness-raising campaign. For example, the Italian Hunters' Association (AssociaWhzione Cacciatori Migratoristi Acquatici) was instrumental in preparing and distributing visual guides for hunters which addressed the possible confusion of Ruff *Philomachus pugnax* and Ferruginous Duck *Aythya nyroca* with morphologically-similar species (AEWA 2015)**.** While most hunters in this survey understood that it was not permissible to hunt Bewick's swans, 18% thought that it was legal or did not know. Some hunters therefore may benefit from further information on protection accorded to different species. Printed and digital memos for hunters that comprise a visual guide on protected and quarry species, information on areas where hunting is forbidden and penalties for non-compliance, may be an effective method of dissemination. Overall, 15% of participants admitted to having accidentally hunted what they believed to be a Bewick's swan in the previous three years. Given that the ability of hunters to distinguish between the swan species was poor, it is possible that some of those reporting to have hunted a Bewick's swan may have in fact hunted a whooper or mute swan and *vice versa*. However, of those able to identify a Bewick's swan correctly, 18% admitted to accidentally hunting the species. It should also be considered that 8% of hunters asked to participate in the survey declined to take part, some of whom may have done so in fear of incriminating themselves if they had hunted a Bewick's swan previously. The number of hunters who admitted hunting a Bewick's swan may therefore be an underestimate. Further investigation should determine the risk of birds being accidentally shot when in close proximity to inaccurately targeted quarry species. In some circumstances, it may be necessary for governments to strengthen the legal protection of non-protected species at high risk of being mistaken for protected species (e.g.

Knobel 2015), or to amend opening and closing dates of hunting seasons when both protected and non-protected species coincide (European Commission 2008). Countries that are signatories to multilateral environmental agreements can utilise relevant guidance and resolutions (e.g. AEWA Resolution 6.4: Conservation and Sustainable Use of Migratory Waterbirds; AEWA 2016) that provide frameworks within which interventions can be initiated and undertaken and political support can be garnered. Given that illegal shooting of Bewick's swans occurs throughout their range (Rees & Bowler 2002), measures should be implemented at other sites where accidental shooting is considered a risk (AEWA 2015). Given that 12% of hunters admitted to the non-accidental hunting of (what they believed to be) a Bewick's swan previously, further studies are required to establish whether this species is at significant risk from purposeful as well as accidental hunting, and if so, the motivations for such behaviour. Understanding the role and impact of hunters within the wider social-ecological landscape is crucial for reducing the uncertainty of implementing regulations for conserving wildlife (Hunt 2013). Improving hunters' skills in discerning protected from quarry is likely to be an effective tool for conservation of morphologically similar species.

Acknowledgements

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Additional Supporting Information:

S4.1 (Appendix 6): Survey questions for Russian hunters used in Chapter 4
Table S4.1 (Appendix 7): Independent variables used in the global model

Chapter 5

Predicting intention to hunt protected wildlife: a case study of Bewick's swans in the European Russian Arctic

Chapter 5: Predicting intention to hunt protected wildlife: a case study of Bewick's swans in the European Russian Arctic

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Abstract

Understanding human behaviour is critical for addressing some of the world's most pressing conservation issues such as habitat loss, climate change and overexploitation. However, complex social-ecological processes present unique challenges for managing human behaviours, particularly those involving illicit activities. Illegal killing of wildlife is a major conservation issue which requires insight into the drivers of human behaviour to be addressed effectively. Here we adapt an established socio-psychological model, the Theory of Planned Behaviour (TPB), to assess reasons for hunting Bewick's swans *Cygnus columbianus bewickii* in the European Russian Arctic, using responses from hunters to a questionnaire survey. Wider ecological, legal, recreational and economic motivations were also explored. Of 236 hunters who participated overall, 14% harboured intentions to hunt Bewick's swans. Behavioural intention was predicted by all components of the TPB: attitude towards behaviour, perceived behavioural control and subjective norms. The inclusion of *attitude towards protective laws* and *descriptive norm* increased the model's predictive power. Understanding attitudes towards protective laws can help guide the design of agreeable conservation measures that reduce non-compliance. We conclude that conservation interventions should target the socio-psychological conditions that influence hunters' attitudes, social norms and perceived behavioural control. These may include activities that build trust, encourage support for conservation, generate social pressure against poaching, use motivations to prompt change and strengthen local peoples' confidence to act. The approach used in this study may be applied to inform the effective design,

prioritisation and targeting of interventions that improve compliance and reduce the illegal killing of wildlife.

Introduction

Success in tackling threats to biodiversity relies on our capacity to anticipate such threats and understand how they might be affected by conservation interventions (Wood et al. 2018b). Demands for conservation to become more predictive have culminated in the emergence of models for ecological forecasting that predict key conservation outcomes (Sutherland 2006), such as abundance and distribution of animals, demographic rates and interactions between individuals and species (Wood et al. 2018b). There have also been increasing calls for frameworks that develop understanding of human behaviour (e.g. Redpath et al. 2018). The ability to predict human behaviour is vital for addressing some of the world's most pressing conservation issues such as habitat fragmentation, climate change and overexploitation (Lande 1998; Thomas et al. 2004; Nuno & St. John 2015). Therefore, increasing attention is being dedicated to studying drivers of human behaviour that detrimentally affect the conservation of species and habitats (Nuno & St. John 2015). However, understanding the complex processes that characterise human behaviours presents challenges, particularly where behaviours encompass illicit activities.

The achievement of conservation goals is often undermined by illegal behaviours (Solomon et al. 2015) such as logging in protected areas (Lee et al. 2015) and the illegal killing of wildlife (Keane et al. 2008), and such acts can have wide-ranging impacts on socio-ecological systems (Solomon et al. 2015). Illegal killing of wildlife threatens biodiversity globally and affects the conservation of threatened species (Gavin et al. 2010; Brochet et al. 2016). The ecological consequences of such killing include population declines and extinctions, and reduced genetic diversity, species richness and ecosystem function (Gavin et al. 2010). Ramifications for human societies of illegal killing of wildlife range from the degradation and loss of ecosystem services (e.g. Ripple et al. 2016) to escalations in conservation conflicts (e.g. Carter et al. 2017; St John et al. 2018). Overexploitation is a key cause of bird extinctions worldwide (BirdLife International 2013), with illegal killing posing a significant threat for migratory

birds that is second only in importance to habitat loss and degradation (Bairlein 2016; Brochet et al. 2016). Growing recognition of the illegal killing of birds as a conservation issue has prompted the adoption of numerous international species action plans (Nagy et al. 2012), conservation interventions (Jones et al. 2017) and policy instruments (e.g. European Commission 2012; Council of Europe 2013; UNEP-CMS 2014b, 2017b).

The effective targeting of conservation interventions to discourage illegal killing and other environmentally harmful behaviours relies upon their drivers being robustly identified (Vlek & Steg 2007; St. John et al. 2010). Illegal killing is often driven by a complex range of motivations which may be influenced by diverse social, economic and ecological conditions across varying social and spatiotemporal scales (Von Essen et al. 2014; Carter et al. 2017). Rather than simply being a way to harvest game, hunting may provide opportunities to realise a number of social, psychological, emotional, physical and other benefits (Hrubes et al. 2001). However, identifying drivers for sensitive issues relating to illicit or socially taboo behaviours presents many challenges, not least the lack of willingness of perpetrators to identify themselves or reveal information through fear of retribution (Keane et al. 2008; Gavin et al. 2010; St John et al. 2011). Illegal behaviour therefore is frequently subject to high uncertainty (Nuno et al. 2013), and baseline information about prevalence, perpetrators and underlying drivers is often difficult to obtain. Under these circumstances, use of indicators that predict behaviour reliably can be of great value (St John et al. 2011). A number of tools and frameworks have been employed to measure and predict sensitive behaviours (e.g. Stern 2000; Nuno & St. John 2015). In recognition that humans are not purely rational beings making considered and informed decisions within static economic frameworks (St. John et al. 2010; Fairbrass et al. 2016), social-psychological models have increasingly been applied to predict behaviour and environmental rule-breaking (St John et al. 2011).

One such framework and a widely used social-psychological model, is the Theory of Planned Behaviour (TPB, Ajzen 1985; Figure 5.1). According to this theory, the most important determinant of a behaviour is the intention to engage in that behaviour (Armitage & Conner 2001). Behavioural intentions are influenced by three key attributes: (1) attitude towards the behaviour, (2) perceived social

pressure or group level influences to perform or not perform the behaviour (termed the “subjective norm”) and, (3) perceived capability to perform the behaviour (“perceived behavioural control”) (Ajzen & Cote 2008). The efficacy of the TPB in predicting intention and behaviour has been supported by several meta-analyses and reviews of studies using the theory (e.g. Armitage & Conner 2001; Miller 2017) including those examining psycho-social determinants of pro-environmental behaviours (Bamberg & Möser 2007). Conservationists and natural resource managers have applied the TPB to predict intentions to hunt (Hrubes et al. 2001) and kill wildlife illegally (Rossi & Armstrong 1999; Marchini & Macdonald 2012; Steinmetz et al. 2014; Fairbrass et al. 2016; Castilho et al. 2018).

Although there is broad empirical support for the TPB (Ajzen & Cote 2008), for some behaviours and circumstances the inclusion of additional elements may increase its predictive power (e.g. Marchini & Macdonald 2012; Fairbrass et al. 2016). For example, assessment of “descriptive norms”, which reflect a perception of whether other people perform the behaviour (Cialdini et al. 1990), increased the predictive utility of the TPB in a study examining the intention to hunt jaguars in Amazonia and the Pantanal (Marchini & Macdonald 2012). While contextual factors such as laws and government regulations can also influence environmental behaviour (Stern 2000), little is known about the role of attitude towards rules in predicting the intention to violate them and the route by which this may occur (e.g. directly or through elements of the TPB). Effectiveness of environmental regulations is partly dependent upon people’s willingness to comply (Winter et al. 2001), which in turn is likely influenced to some extent by attitude towards the regulations (Keane et al. 2008). Here, we use an extended version of the TPB model to explore potential predictors for the intention of individuals to hunt endangered Northwest European Bewick’s swan *Cygnus columbianus bewickii* in the European Russian Arctic (Figure 5.1).

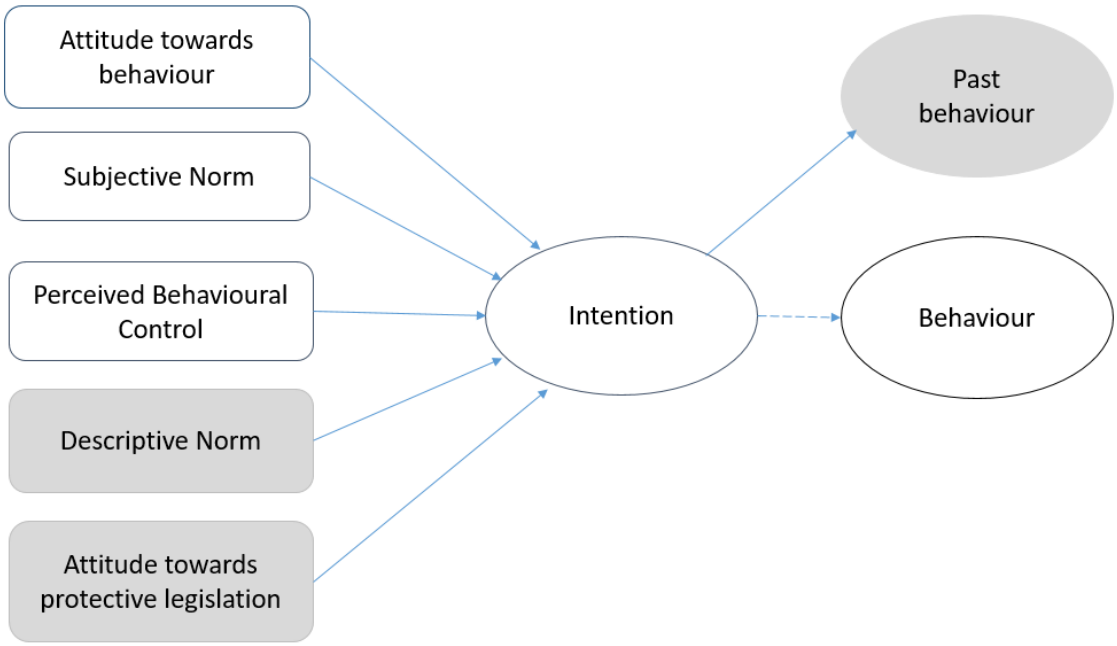

Figure 5. 1*: Adapted model of the Theory of Planned Behaviour (TPB) which includes attitude towards protective laws and descriptive norm (reflecting an individual's perception of whether other people perform the behaviour in question; Cialdini et al. 1990) as predictors of behaviour. Clear boxes indicate variables included in Ajzen's (1985) original model of TPB. Grey shading indicates additional variables investigated. Solid lines indicate relationships that were examined in this study.*

Despite being protected under national and international legislation throughout its migratory range (Rees 2006), the Bewick's swan population in the European Russian Arctic (BirdLife International 2015) is nevertheless subject to exploitation and killing (Newth et al. 2011; Nagy et al. 2012; Mineyev & Mineyev 2014). Some 31% of live Bewick's swans x-rayed between the 1970s and early 2000s carried embedded gunshot in their body tissue (Newth et al. 2011). Illegal shooting is regarded as a potentially high threat for this population (Nagy et al. 2012) and may impact significantly on survival (Wood et al. 2018a). Newth et al. (2019) found that there was a risk of Bewick's swans being accidentally shot on their breeding grounds in the European Russian Arctic, partly because they were mistakenly taken for morphologically-similar whooper swans *C. cygnus* or mute swans *C. olor,* which have weaker legal protection in this region, and also because some hunters were unaware of protective legislation. Overall, 15% of

hunters claimed they had accidentally hunted a Bewick's swan while a further 12% admitted to non-accidental hunting (Newth et al. 2019).

In accordance with the TPB, we hypothesised that those who harbour intentions to hunt Bewick's swans are more likely to have positive attitudes towards this behaviour, believe that there is social support for this behaviour (subjective norm), and perceive that there are no, or few, barriers to undertaking this activity (perceived behaviour control). We expect the predictive utility of the TPB model to improve with the inclusion of: (i) attitude towards protective laws (where those with hunting intentions are more likely to hold negative attitudes towards such laws), and (ii) descriptive norm (with those intending to hunt being more likely to believe that this behaviour is a 'norm' in their locality). We predict that those intending to hunt swans are more likely to have hunted them previously. Perceived motivations for hunting are also explored and discussed in relation to typologies that aim to deconstruct, understand and predict illegal hunting (Von Essen et al. 2014). These include recreational satisfaction, gamesmanship, commercial gain, household consumption, poaching as a traditional right, disagreement with or lack of enforcement of wildlife regulations (Muth & Bowe 1998), and ignorance of either conservation law or ecology (Von Essen et al. 2014). An understanding of the determinants for hunting behaviours can help identify and prioritise effective interventions for encouraging behaviours that contribute to species conservation (e.g. Steinmetz et al. 2014) and these will also be discussed.

Methods

Study area and participants

A total of 256 people were approached and 8% (n=20) declined to participate in the survey (Appendix 8). Overall, 236 hunters from seven settlements in the European Russian Arctic – six in the Nenets Autonomous Okrug (NAO) and one in Arkhangelsk Oblast (AO) – were surveyed between 27 June and 16 July 2016 (Figure 4.2). The human population of the NAO comprises Russians, indigenous Nenets and Komi and other nationalities, while that of the AO is predominantly Russian (Russian Federal State Statistics Service 2015). To ensure anonymity,

the identity of participants and settlements are not reported. Settlements were selected for their proximity to areas used by Bewick's swans (Mineyev 1991; Rees 2006), their ease of access, and the ethnic heterogeneity of the population across the settlements. Questionnaires were delivered in Russian by three trained facilitators during interviews with participants at a time and place of their convenience. Those regarding themselves as 'hunters' were asked to partake in the survey. For each settlement, 2.5% of the total population (based on numbers in 2015; range 10–88 participants per settlement) was included in the survey. Given the sensitive nature of illicit behaviours, snowball sampling was used to recruit participants (Newing et al. 2011), whereby recruitment continued until a sufficient number of individuals had been identified to meet the desired sample for each settlement. All participants were aged 18 years or over. Survey methods were approved by the College of Life and Environmental Sciences (Penryn) Ethical Review Committee at the University of Exeter (reference 2016/1496) and each respondent gave their informed consent prior to participation.

Survey design

Participants were asked about their intention to hunt Bewick's swans over the next three years (Table 5.1). Questions relating to all three components of the TPB predicted to influence intention to hunt were included in the survey (Figure 5.1; Table 5.1).

***Table 5. 1**: Responses by 201 hunters in the European Russian Arctic to a survey in 2016 on the illegal hunting of Bewick's swans. The Theory of Planned Behaviour (TPB; Ajzen 1985) was used as a framework to predict hunting intention. Statements related to the following elements of the TPB: attitude towards the behaviour, subjective norm and perceived behavioural control. The framework was extended to include attitude towards protective laws and descriptive norm (which reflects an individual's perception of whether other people perform the behaviour in question; Cialdini et al. 1990), both of which are also expected to influence hunting intention.*

Variable (from adapted TPB)	Statement	Response*	% (n= no. of respondents)
Behavioural intention	I intend to hunt Bewick's swans in the {area} in the next 3 years	Disagree Agree	83.6% (n=168) 16.4% (n=33)
Attitude towards hunting	For me the hunting of a Bewick's swan in this area would be:	Bad Neutral Good	29.4% (n=59) 6.2% (n=133) 4.5% (n=9)
Perceived behavioural control	There is nothing stopping me from using guns and ammunition to hunt Bewick's swans in this area	Disagree Neutral Agree	56.7% (n=114) 5.5% (n=11) 37.8% (n=76)
Subjective norm	People who are important to me think that it is OK to hunt Bewick's swans in this area	Disagree Neutral Agree	35.8% (n=72) 30.3% (n=61) 33.8% (n=68)
Descriptive norm	Bewick's swans are hunted near my village	No Yes I don't know	37.8% (n=76) 36.3% (n=73) 25.9% (n=52)
Attitude towards protective legislation	Local people should be authorised to hunt Bewick's swans in the {region} under some circumstances	Disagree Neutral Agree	22.4% (n=45) 19.4% (n=39) 58.2% (n=117)

*The following categories were collapsed: agree/strongly agree (=agree); disagree/strongly disagree (=disagree); very good/good (=good); very bad/bad (=bad).

Additionally, participants were asked whether the hunting of Bewick's swans is typical or normal in their locality (i.e. descriptive norm; White et al. 2009a), and their attitude towards legislation protecting Bewick's swans (indicated by views on whether local people should be authorised to hunt Bewick's swans under some circumstances) (Table 5.1). Responses were analysed in an adapted

model of the TPB (Table 5.1; Figure 5.1). Those that agreed or strongly agreed that local people should be authorised to hunt Bewick's swans in their area were asked under which circumstances this would be permissible (S5.1, Q9a; Appendix 8). Hunters were also given the opportunity to describe any perceived barriers to hunting Bewick's swans (S5.1, Q12a; Appendix 8). According to the TPB, behavioural intention predicts behaviour. Due to practical barriers (i.e. the substantial time and cost of accessing participants living in remote settlements), we were not able to return to measure directly the hunting behaviour of individuals, or indirectly using specialized questioning techniques (Nuno & St. John 2015), after they were surveyed and had declared their hunting intentions. Past behaviour therefore was used as a proxy for 'behaviour' (Marchini & Macdonald 2012), whereby each hunter was asked directly whether they had hunted Bewick's swans in the region in the past three years (S5.1, Q16; Appendix 8; see also Newth et al. 2019).

Given the sensitive nature of illegal killing, indirect questions explored perceived motivations for hunting swans to give participants an opportunity to reveal information without the risk of incriminating themselves. Participants were asked to use a 5-level Likert scale (from very likely to very unlikely) to indicate their views on the likelihood of people in their area hunting Bewick's swans for legal, ecological, recreational and subsistence reasons (S5.1, Q13; Appendix 8), drawing on and developing drivers for illegal killing identified by Muth & Bowe (1998). This enabled the identification of general as well as socio-psychological causal factors (Muth & Bowe 1998; Von Essen et al. 2014). An open-ended response question asked participants to suggest *"other reasons for hunting Bewick's swans in this area"* (S5.1, Q14; Appendix 8), in order to capture additional motivations. Participants were also asked about their socio-demographic status, specifically their gender, age group, ethnicity, place of residence and occupation (S5.1, Qs1–6; Appendix 8).

Treatment of data

Participants were divided into two groups: (1) those who agreed they intended to hunt Bewick's swans, and (2) those who disagreed. When responding to questions, fewer people selected categories on the extreme ends of the Likert

scale (i.e. categories 1 and 5; S5.1, Appendix 8) and therefore the following response categories were collapsed: strongly agree/agree (=agree); strongly disagree/disagree (=disagree); very good/good (=good); very bad/bad (=bad).

Statistical analysis

All analyses were conducted in R 3.1.1 (R Development Core Team 2016). A generalized linear model (GLM) with a binomial error distribution and a logit link function was used to assess the effects of the explanatory variables on hunters' intention to hunt Bewick's swans within the next three years (0 = disagree, 1 = agree) (Table 5.1). Generalized Variance Inflation Factors (GVIFs) checked for multi-collinearity between explanatory variables. All variables were within acceptable norms (i.e. GVIFs < 3) (Thomas et al. 2013) and were therefore retained in the global model. An Information Theoretic approach (Burnham et al. 2011) was applied to select the most parsimonious models using the MuMIn package in R (Barton 2018). Models were ranked according to the value of Akaike's information criterion, corrected for small sample sizes (AICc). The relative likelihood, Akaike weight, and evidence ratio were also used to assess support. R^2 values (Tjur 2009) assessed the percentage of the variance in hunters' intention to hunt Bewick's swans explained by each model. We undertook model averaging across our best supported models (i.e. those where ΔAICc $\leq$ 3.0) using the MuMIn package to estimate the effect sizes associated with each variable. A Fisher's Exact Test examined the association between past hunting behaviour and intention to hunt in the future. Responses to open-ended questions which examined additional motivations for hunting, barriers to hunting and circumstances under which hunting would be acceptable, were explored using inductive thematic analyses, where themes that emerged from the data were identified (Braun & Clarke 2006).

Results

The 236 participants surveyed came from a breadth of ethnic groups (n=8), with two being substantially represented (i.e. Russian: 65% and Nenets: 25%) (Table S5.1; Appendix 9). Overall, 14% (n=33) of participants agreed that they intended to hunt Bewick's swans in the next three years. Those who were 'neutral' regarding their intention to hunt Bewick's swans (n=33) were omitted; their inclusion in an ordinal logistic regression (where disagree = -1, neutral = 0 and agree = +1) caused multi-collinearity between the explanatory variables and thus the predictors hypothesised to influence hunting intention (Figure 5.1) could not be tested within the same model. Two hunters did not provide answers to certain questions and were thus also removed from the TPB analysis. Therefore, responses from 201 hunters were included in the adapted TPB model.

Predicting intention to hunt and hunting behaviour

Intention to hunt Bewick's swans was best explained by a model that included all three predictors from the TPB (attitude towards the behaviour, subjective norm and perceived behavioural control), and two additional predictors (descriptive norm and attitude towards protective laws) which, as hypothesised, increased the model's predictive power (Tables 5.2 & 5.3).

***Table 5. 2**: Comparison of the relative support and explanatory power of our best-supported models for predicting the intention to hunt Bewick's swans in the European Russian Arctic, based on a survey of 201 hunters. K refers to the number of parameters within the model. Model parameters: i = intercept, Att = attitude towards hunting Bewick's swans, PBC = perceived behavioural control, SN = subjective norm, Au = attitude towards protective legislation and DN = descriptive norm. The best supported models (for which model-averaging of parameter estimates was undertaken; Table 5.3) are indicated in bold.*

Model	*K*	AICc	ΔAICc	Relative Likelihood	Akaike weights	Evidence ratio	R^2
i + Att + PBC + SN + Au + DN	**6**	**133.3**	**0.0**	**1.00**	**0.54**	**1.00**	**0.43**
i + PBC + SN + Au + DN	**5**	**135.4**	**2.1**	**0.36**	**0.19**	**2.80**	**0.38**
i + Att + PBC + SN + DN	**5**	**135.5**	**2.2**	**0.34**	**0.18**	**2.95**	**0.38**
i + Att + PBC + SN + Au	5	138.3	5.0	0.08	0.0455	11.89	0.36
i + Att + SN + Au + DN	5	138.8	5.4	0.07	0.0358	15.11	0.35

***Table 5. 3**: Predicting the intention of 201 hunters to hunt Bewick's swans in the Russian Arctic using the Theory of Planned Behaviour (TPB). The table presents a summary of model averaged effects associated with our three best-supported models (i.e. all models where ΔAICc ≤ 3.0). A GLM with a binomial error distribution and logit link functions was used to assess the effects of the explanatory variables on the intention hunters to hunt Bewick's swans in the next three years (intention to hunt: 0 = disagree, 1 = agree).*

TPB variable	Parameter	Estimate	SE	*Z*	*P*
	Intercept	3.564	1.172	3.022	0.003
Attitude towards behaviour (hunting)	For me the hunting of a Bewick's swan in this area would be: (good)	2.164	1.542	1.399	0.162
	For me the hunting of a Bewick's swan in this area would be: (neutral)	0.398	0.635	0.622	0.534
Perceived behavioural control	There is nothing stopping me from using guns and ammunition to hunt Bewick's swans in this area (agree)	0.646	0.525	1.224	0.221
	There is nothing stopping me from using guns and ammunition to hunt Bewick's swans in this area (neutral)	2.860	0.912	3.115	0.002
Subjective norm	People who are important to me think it is ok to hunt Bewick's swans in this area (agree)	1.676	0.676	2.462	0.014
	People who are important to me think it is ok to hunt Bewick's swans in this area (neutral)	-1.295	0.973	1.322	0.186
Attitude towards protective legislation	People who are important to me think it is ok to hunt Bewick's swans in this area (agree)	1.216	1.156	1.048	0.295
	People who are important to me think it is ok to hunt Bewick's swans in this area (neutral)	-0.440	1.366	0.320	0.749
Descriptive norm	Bewick's swans are hunted near my village (no)	-2.011	0.783	2.552	0.011
	Bewick's swans are hunted near my village (yes)	-0.232	0.603	0.382	0.703

*The reference factor levels are: attitude towards behaviour (bad); perceived behavioural control (disagree); subjective norm (disagree); attitude towards protective legislation - hunting should be authorised (disagree) and descriptive norm (I don't know).

Attitude towards protective legislation was a significant predictor of intention to hunt and those holding a negative attitude (i.e. favouring a relaxation of the law under certain circumstances) were more likely to harbour hunting intentions (Tables 5.1 & 5.3). Circumstances deemed acceptable for hunting Bewick's swans were identified by 115 hunters and included: if limited quotas for hunted swans were in place (with suggested quotas ranging from 1–15 swans per individual per hunting season) (n=69), when the swan population needed to be regulated (i.e. when numbers were perceived to be too numerous) (n=19), if there were licenses and rules in place for swan hunting (n=13), and for subsistence (n=9) (Figure 5.2).

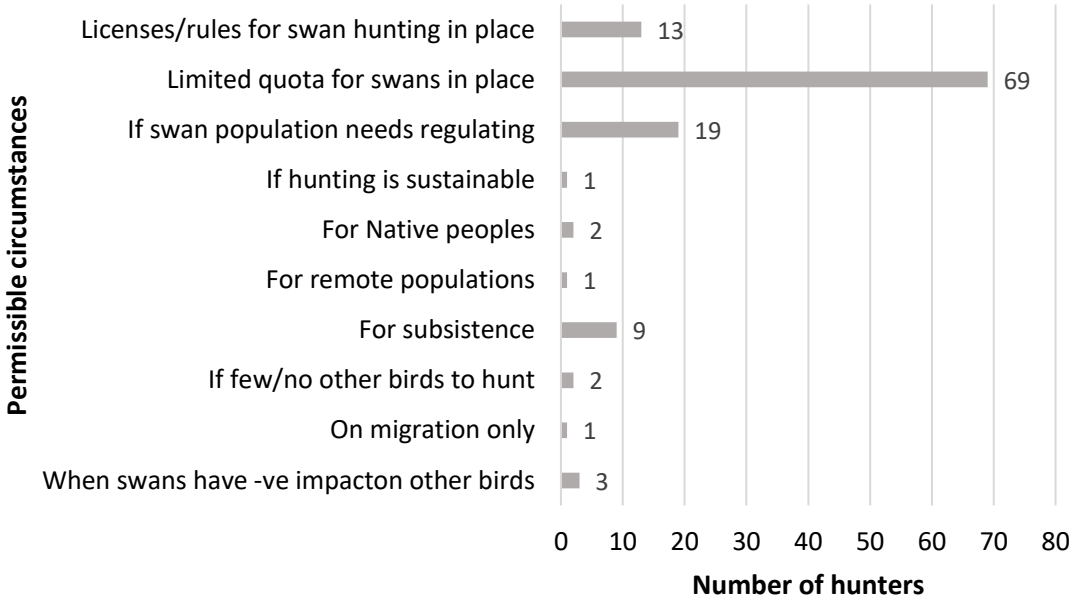

Figure 5. 2: *Circumstances under which hunting of Bewick's swans is regarded as permissible. Responses came from 115 of 149 hunters surveyed in the European Russian Arctic who agreed or strongly agreed that hunting should be authorised for local people under certain circumstances, and who offered suggestions (S5.1; Q9a; Appendix 8). The topics represent themes that emerged from an inductive thematic analysis of open-ended responses (Braun & Clarke 2006).*

Attitude towards hunting Bewick's swans and perceived behavioural control also emerged as significant predictors of hunting intention; those holding positive or neutral attitudes towards hunting were more likely to intend to hunt, as were those who agreed or felt neutral about the concept that there was nothing stopping them

from exploiting the species. Nevertheless, most hunters (57%) agreed that there were barriers to shooting Bewick's swans, including law (n=68) and law enforcement (n=14), absence of desire (n=8) and one's own conscience (associated with pity for the swans, liking the Bewick's swan, regarding the swan as beautiful, and as one participant described, *"inner moral conviction"*, n=16) (Figure 5.3).

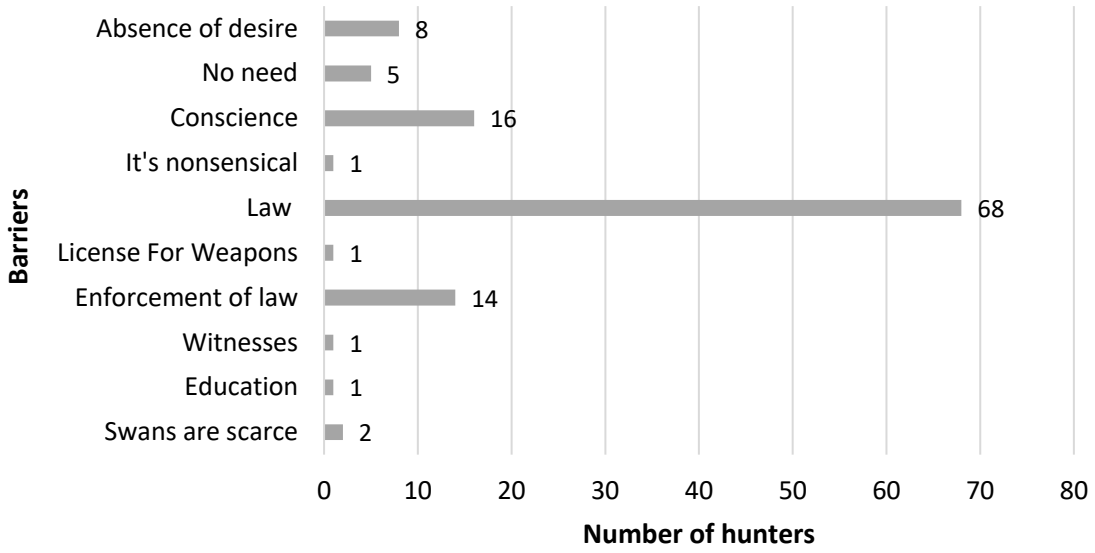

Figure 5. 3*: Perceived barriers to hunting Bewick's swans according to 117 hunters surveyed in the European Russian Arctic in 2016 (who responded to the open-ended question "Are there any barriers to shooting Bewick's swans in this area?" S5.1, Q12a; Appendix 8). Categories emerged during an inductive thematic analysis of responses (Braun & Clarke 2006).*

The subjective norm influenced intentions to hunt Bewick's swans; those perceiving that people important to them condoned such behaviour were more likely to harbour hunting intentions. Hunting intention was also predicted by descriptive norm; hunters were less likely to harbour hunting intentions when they believed that this behaviour was not a social norm in the locality (Table 5.3). Individuals who admitted hunting Bewick's swans previously were more likely to intend to hunt them in the future (41%; 11/27) than those that had not (7%; 12/171) (OR = 0.1, 95% CI: 0.03-0.31; Fishers Exact $P < 0.001$).

Perceived motivations for hunting Bewick's swans

Respondents perceived that people in their area hunted Bewick's swans for ecological, recreational, subsistence and legal motivations (Figure 5.4; S5.1, Q13; Appendix 8).

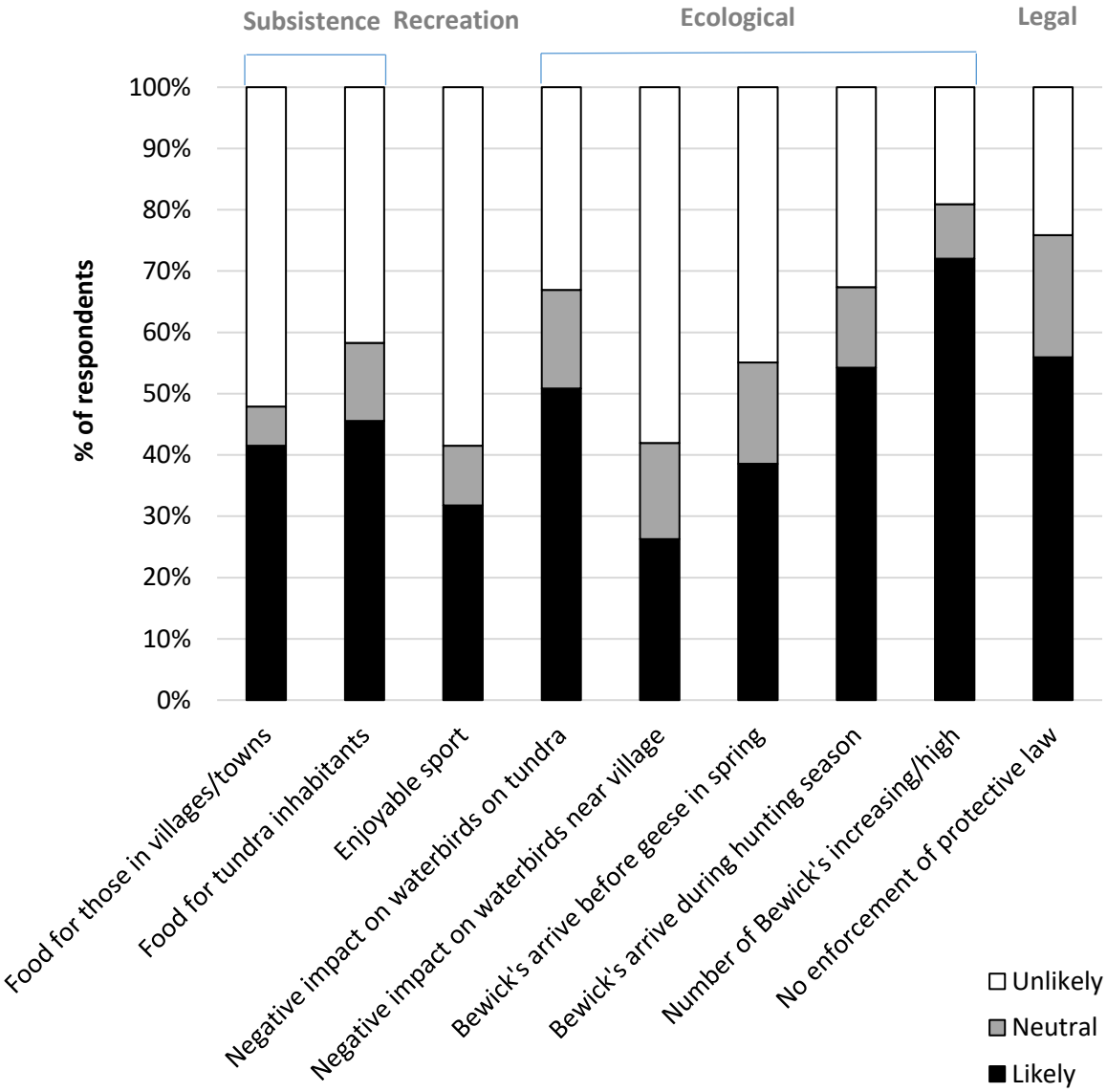

Figure 5. 4*: The views of 236 hunters in the European Russian Arctic on the likelihood of people in their area hunting Bewick's swans for legal, ecological, recreational and subsistence reasons (from very likely to very unlikely, S5.1, Q13; Appendix 8). One respondent provided no answer when asked for their view on "food for tundra inhabitants" (i.e. human inhabitants) as a motivation for hunting Bewick's swans (therefore 235 participants gave their view on this particular aspect).*

The following motivations were believed to be the most likely for hunting Bewick's swans: the number of Bewick's swans is increasing/high (72% of respondents, n=170, regarded this as a likely motivation), no enforcement of protective legislation (56%, n=132), Bewick's swans arriving during the hunting season (54%, n=128) and Bewick's swans having a negative impacts on breeding waterbirds on the tundra (51%, n=120). In total, 26 hunters identified additional motivations, including: swans being present in the absence of other birds to hunt, swans being easier to shoot as they fly slowly, swan skins for clothes, curiosity (related to the meat or the sporting experience), lack of awareness that the swans are protected and misidentification of Bewick's swans for other swan species (Table S5.2, Appendix 10).

Discussion

Biodiversity loss is largely driven by human behaviours and thus identifying predictors of behaviour is critical for informing effective conservation measures (Vlek & Steg 2007; St. John et al. 2010). Here, we examined the utility of an adapted socio-psychological model (the TPB; Ajzen 1985) for predicting the deliberate illegal hunting of Bewick's swans in the European Russian Arctic. Behavioural intention was predicted by all components of the TPB; attitude towards the behaviour (i.e. illegal hunting), perceived behavioural control and subjective norm. This study supports our hypotheses and presents evidence that inclusion of attitude towards protective laws and descriptive norms in an adapted TPB model increases its predictive power, suggesting that both should be considered when exploring drivers of non-compliance.

Factors predicting hunting intention and behaviour

Hunters were more likely to harbour hunting intentions if they held a negative attitude towards protective laws. The perceived legitimacy and acceptability of rules affects their acceptance by resource users (Keane et al. 2008). Those with a positive or neutral attitude towards hunting Bewick's swans were also more likely to intend to hunt them. Attitude towards hunting has been found in previous studies to be the strongest predictor of hunting intention (Rossi & Armstrong 1999). Social pressure was also influential and those intending to hunt Bewick's

swans were more inclined to believe the behaviour was socially acceptable. Humans have a natural tendency to respond to social norms or shared understandings about what is regarded as appropriate behaviour (Steinmetz et al. 2014) and are consequently reluctant to deviate from the norm (Schultz 2011). Those who agreed that there were no practical barriers preventing them from hunting were also more likely to intend to hunt, as were those who felt ambivalent about the existence of such barriers. Although Bewick's swans are protected by law (Mineyev & Kondratiev 2001; Gurtovaya & Litvin 2006; Novoselov 2008), the NAO and AO form a geographically vast and isolated area, making law enforcement challenging.

Measuring illegal hunting behaviour of hunters following their participation in the survey was not possible and therefore the validity of the model predicting future hunting behaviour could not be verified. However, we present evidence that suggests our indicator of intention to hunt Bewick's swans is related to self-reported past hunting behaviour. First, relationships between intention and the predictors aligned with that expected based on the TPB (Marchini & Macdonald 2012). Second, there was a significant relationship between intention to hunt and past hunting behaviour, suggesting that hunting intention may also be a valid proxy for future hunting behaviour (Marchini & Macdonald 2012), as proposed by the TPB (Ajzen 1985). Furthermore, this relationship may indicate that the hunting of Bewick's swans is habitual for some hunters and this warrants further investigation. It should be noted that behavioural decision-making models such as the TPB rely on self-reporting, which allows the possibility of social desirability bias (Armitage & Conner 2001). Given the sensitive nature of killing Bewick's swans, it is likely that this illegal behaviour was under-reported.

The model explained 43% of variation in hunting intention, which is consistent with previous research aiming to predict hunting intentions (e.g. 38%; Rossi & Armstrong 1999). Unexplained variance may partly reflect the complex nature of human behaviour (Schultz 2011). The TPB assumes that behaviour is the product of rational, elaborative thought (Manfredo 2008; Miller 2017). It cannot therefore fully account for human complexity as it omits the role of emotions, identity and other variables that influence behaviour (Manfredo 2008; Jacobs et al. 2014) such as moral considerations and norm activation theory (Kaiser 2006; Miller 2017),

which uses awareness of consequences of a behaviour, ascription of responsibility and personal norm to predict pro-social behaviour (Schwartz 1977).

Wider motivations

Recreational drivers included sport and sporting challenge/experience, as acknowledged by Muth & Bowe (1998) who identified recreational satisfaction, thrill seeking and gamesmanship as motivations for illegal hunting. Subsistence drivers included food and skins to make clothes and generate money, supporting economic drivers such as household consumption and commercial gain noted by Mancini et al. (2011). Legal (lack of enforcement) and ecological factors were perceived to be the most likely motivations for illegal hunting. Illegal hunters may only adhere to the law when law enforcement is present (e.g. rules and knowledge thereof and enforcement personnel) (Von Essen et al. 2014), although this is likely to be context-dependent. Lack of knowledge of protective laws was also noted as a likely motivation and has previously been identified as an important factor underlying illegal hunting (e.g. Von Essen et al. 2014). In a complementary study, 18% (n=42/232) of hunters in the NAO and AO believed that it was permissible to hunt Bewick's swans or did not know whether or not they were protected (Newth et al. 2019). Perceived ecological drivers included the swans having a negative impact on other waterbirds. Swans are perceived by some to disrupt the breeding success of huntable waterbird species (Gurtovaya 2000). The misidentification of Bewick's swans for other swan species, likely implying accidental shooting, was also noted and is supported by Newth et al. (2019).

Implications for conservation

Our findings suggest that to reduce the illegal hunting of Bewick's swans, conservation interventions should target social and psychological conditions that influence hunters' attitudes, social norms and behavioural control. This requires activities that (i) build trust (Stern 2008) through participatory techniques, (ii) encourage support for Bewick's swan conservation (Yaffee & Wondolleck 2000) through awareness-raising about their ecology, population status and the impacts of poaching, and offering opportunities for public participation in conservation, (iii)

promote the benefits of conservation to motivate change (Schultz 2011), (iv) consider ethics and reasons surrounding dislike of protective laws (Tyler 1990), and (v) strengthen perceived behavioural control and confidence and power to act (Kaplan 2000). Using the TPB to identify predictors of wildlife poaching, Steinmetz et al. (2014) designed a community outreach programme encompassing these elements, and poaching of five ungulate and one rodent species in a reserve in Thailand declined by 76% within three years of targeted interventions. A review of case-studies that used the TPB found that two-thirds had recorded a degree of desired behaviour change following intervention (Hardeman et al. 2002). Persuasive communication campaigns involving respected community leaders and institutions may help to redefine the social norm and increase social pressure against hunting Bewick's swans while reducing pressure to hunt them. Past studies have shown that when behaviours become socially unacceptable they become less common (e.g. Cialdini et al. 2006). Conversely, widespread support for environmental protection and conservation has been found to culminate in positive behavioural change (Schultz 2011). Ultimately, engaging with local communities that are best placed to conserve wildlife is essential to prevent poaching and conserve endangered wildlife (Challender & MacMillan 2014). We have found that attitude towards laws protecting wildlife can be an important additional predictor of intention to violate those same laws. Such knowledge may be useful for informing the design of agreeable conservation measures that reduce non-compliance and conflict between stakeholders.

Targeting ecological and legal (lack of enforcement) motivations through community engagement and law enforcement, respectively, may be beneficial. For example, perceptions about the negative impact of swans on other waterbirds could be countered through interventions that increase tolerance towards wildlife (Liu et al. 2011). However, increasing knowledge through such communication alone (as in the Information Deficit Model; Kahan et al. 2012) rarely results in behaviour change (McKenzie-Mohr et al. 2012). Efforts to educate and raise awareness should include motivational elements, such as self-interest, values and social responsibility (Stern 2000; Schultz 2011). However, given many hunters lacked knowledge of protective laws (Newth et al. 2019), and ignorance of the law was perceived as a likely motivation for hunting, increasing knowledge

about the law may in this case yield benefits. Law enforcement (e.g. through patrolling) may also reduce poaching (e.g. Hilborn et al. 2006), although without changes in underlying social norms, people often revert to past habits when enforcement stops or fails (Steinmetz et al. 2014). Conversely, outreach aims to alter the social conditions around the poacher and thus seeks changes that are internally motivated (Steinmetz et al. 2014) and which are consequently more stable (de Young 2000). In conclusion, the approach used in this study can be applied to inform the effective design, prioritisation and targeting of interventions that should improve compliance with regulations and species protection.

Acknowledgements

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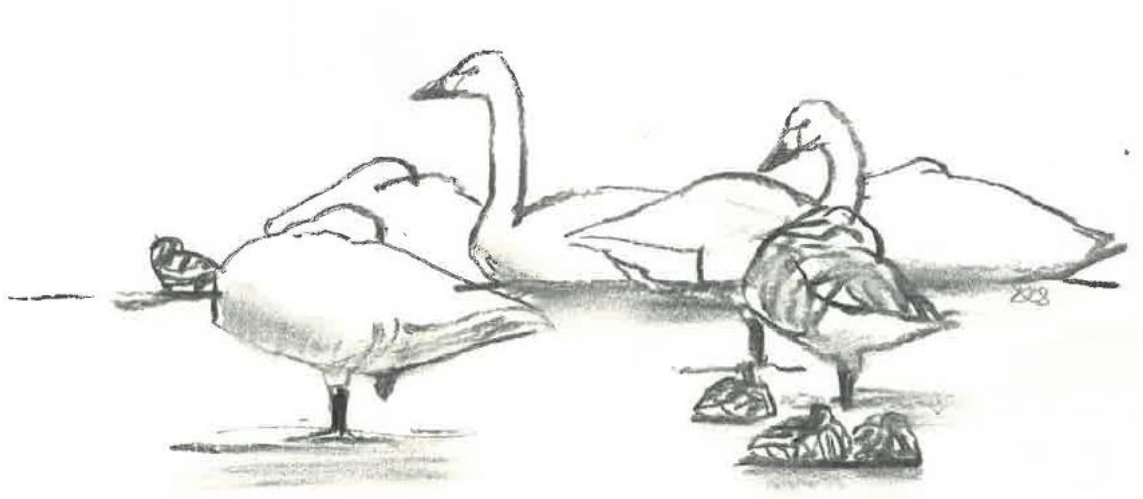
Additional Supporting Information:

S5.1 (Appendix 8): Survey questions for Russian hunters
Table S5.1 (Appendix 9): Socio-demographic characteristics of hunters
Table S5.2 (Appendix 10): Motivations for hunting Bewick's swans

Chapter 6

DISCUSSION



Chapter 6: Discussion

Conservation conflicts currently present one of the most significant challenges facing wildlife conservation around the world (Hodgson et al. 2018) and are likely to only increase in frequency (Young et al. 2010). Their intractability is characterised by their inherent, multi-layered complexity or 'wickedness' (Mason et al. 2018b) and their negative impacts on biodiversity, livelihoods and human wellbeing (Baynham-Herd et al. 2018). Such conflicts are notoriously destructive and costly and undermine effective conservation (Veríssimo & Campbell 2015). Derived from deeper cognitive levels, conflicts may be influenced by a myriad of often interacting social and psychological elements that stem from societal, political and historical issues (Redpath et al. 2015b; Bunnefeld et al. 2017). Conservation conflicts and biodiversity impacts with human complexity, such as those involving illegal behaviours, are therefore best viewed through an interdisciplinary lens, and tackled using approaches and methodologies drawn from multiple disciplines beyond ecology alone, such as the social sciences, psychology, economics, humanities (White et al. 2009b) and peace studies (Gutiérrez et al. 2016). The employment of effective tools for understanding and managing drivers, patterns and processes that underpin conflicts is crucial to achieve progression from conflict to co-existence (Dickman 2010). When applied to human-wildlife impacts in complex settings, this approach may prevent their transition into conflict.

Conflicts and biodiversity impacts are often most intense around practices that require the direct use of biodiversity such as hunting (Veríssimo & Campbell 2015). My exploration of conflict and impacts herein has focused on two issues relating to hunting practices: the illegal hunting of Bewick's swans in the Russian Arctic (regarded as a biodiversity impact at risk of emerging as a conflict) and the lead poisoning of waterbirds from lead ammunition in the UK (currently in a 'destructive' phase of conflict) (Figure 1.1). Our understanding of both issues to date has largely focused on their prevalence and immediate impacts on waterbirds (e.g. Newth et al. 2011; Newth et al. 2013; Appendices 3 & 2). In this thesis, I aimed to (i) examine empirically the ecological and socio-psychological contexts of both issues, using approaches and methodologies from the natural and social sciences and psychology, and (ii) provide novel insights into their

management and wildlife management more broadly. Specifically, my objectives were to:

(a) Assess the impact of blood lead levels on the body condition of wild whooper swans wintering in Britain (Chapter 2)
(b) Identify the perspectives of UK shooting participants on the use of lead ammunition and its potential impacts on wildlife and people (Chapter 3)
(c) Examine the risk of the misidentification and accidental killing of Bewick's swans in the European Russian Arctic (Chapter 4)
(d) Understand the drivers for the deliberate hunting of Bewick's swans in the European Russian Arctic (Chapter 5)

For this final chapter, I review my findings in relation to these research aims and objectives and discuss the key theoretical and applied contributions of this research. I use an established conflict typology (Table 1.1) to partition the varying dimensions and thematic features of the lead shot conflict and identify characteristics of the illegal hunting issue that may potentially facilitate its emergence as a conservation conflict. I consider the strengths and limitations of the approach and methodologies used, and finally conclude by suggesting relevant avenues for future research.

The lead poisoning of waterbirds: an entrenched conservation conflict

The ecological and socio-psychological contexts: summary of findings

Although lead poisoning through the ingestion of spent lead shot is an established cause of morbidity and mortality in waterbirds (Pain et al. 2015, 2019), the thresholds at which blood lead levels begin to affect the physiology of wild birds are less well known. Identifying these thresholds is important for determining the impact of lead on individuals and populations (Franson & Pain 2011). The relationship between blood lead levels and body condition in free-living wildfowl had not previously been quantified. In Chapter 2, I determined that sub-lethal impacts of lead on the body condition of Icelandic-breeding whooper swans occur at the lower end of previously established clinical thresholds (≥44 µg dL), and that a relatively high proportion of the population may be affected (10%). I therefore

recommended that previously suggested thresholds (e.g. 50–100 µg/dL; Franson & Pain 2011) for adverse clinical effects (largely derived from experimental studies with captive birds), should be revised downwards for free-living wildfowl. The wider implications of sub-lethal impacts associated with reduced body condition such as impacts on fitness, survival (e.g. Haramis et al. 1986; Owen & Black 1989) and breeding success (e.g. Ankney & Macinnes 1978) were discussed. I suggested that migratory species such as whooper swans that depend on fat reserves to meet their migration energy requirements, may be particularly impaired by reduced body condition. In addition, my findings suggest that despite partial restrictions on the use of lead ammunition, a high prevalence of lead poisoning within this swan population exists, with elevated blood lead levels (i.e. values >20µg/dL) found in 41.7% of birds tested. These findings reaffirm the importance of reducing contamination of the environment with lead shot and thus the availability and exposure of lead to waterbirds. I therefore supported recommendations made by other bodies and policy instruments (e.g. UNEP-CMS 2014b,c; 2017b; IUCN 2016; ECHA 2018b) for the substitution of lead shot with non-toxic alternatives as a solution for protecting waterbirds from lead poisoning.

My research addresses an ecological knowledge gap and makes a positive contribution to conflict management by quantifying a sub-lethal impact on wild birds, identifying mechanisms within the system where the impact occurs, and proposing mitigation strategies (Dalerum 2014; Redpath et al. 2015b). Moreover, information collected on the prevalence of lead poisoning (as indicated by blood lead levels) in this swan population can be grouped with past (e.g. O'Connell et al. 2008; Newth et al. 2013 – Appendix 2) and future data, to evaluate the efficacy of mitigation strategies. The sub-lethal impacts of lead poisoning do not necessarily manifest in visible clinical signs and indeed lead poisoning has been labelled 'the invisible disease' (Friend 1989). In interviews I held with ammunition users, several linked their disbelief about the impacts of lead on wildlife with the fact that they had never knowingly encountered a lead poisoned bird (Chapter 3). My findings therefore contribute not only to the scientific body of research but also to the substance of the public lead debate.

However, although additional ecological knowledge can contribute to the discourse and move a debate forward when views differ (Redpath et al. 2015b), it is unlikely by itself to transform conflict (Linnell 2013). Despite decades of scientific study investigating the impacts of lead ammunition on wildlife (e.g. Newth et al. 2013 – Appendix 2; Pain et al. 2015, 2019b), disagreements on the risks arising from the use of lead ammunition and appropriate mitigation measures continue to strain relationships between conservation and shooting stakeholder groups in the UK (Cromie et al. 2015; Newth et al. 2015 – Appendix 1). There remains no consensus on solutions (Cromie et al. 2015) and thus the impacts perpetuate (Chapter 2). Besides a few notable and recent exceptions (e.g. in the UK, Cromie et al. 2010; 2015; Newth et al. 2015 – Appendix 1; and globally, Arnemo et al. 2016; Andreotti et al. 2018; Pain et al. 2019a), there has been little investigation of the fundamental socio-economic and political aspects that have likely underpinned this conflict for decades. Chapter 3 therefore examined the perspectives of ammunition users, around the use of lead ammunition and its potential impacts on wildlife and humans. Despite ammunition users being pivotal actors in this conflict for their roles in adding lead to the environment, and adopting, or not adopting, any potential changes to practice, their views had not previously been explored in detail. Current literature on conflict management highlights the need to understand conflict as perceived by the key actors (Redpath et al. 2013, 2015b). Using a method (Q-method; Brown 1996b) that originates from the discipline of psychology but which has recently been applied in conservation (as reviewed by Zabala et al. 2018), we identified two statistically and qualitatively distinct perspectives ('Open to change' and '*Status quo*') among ammunition users, and areas of consensus between these. Q-method allowed access to a complex issue and enabled the perspectives of ammunition users to be clarified, the competing definitions of the problem and preferred solutions to be identified and commonalities to be revealed, all of which may contribute to conflict resolution (Durning 2005). As with many conflicts that become entrenched and polarised, they become over-simplified, losing the nuanced perspectives that may exist. The lead shot conflict is no exception, being commonly depicted in the media as between those in favour of shooting versus those opposed. However, I reveal that a diversity of views on the issue is held within the shooting community itself and here suggest that those arguing the case for retaining lead shot are most likely to be aligned to the '*Status quo*' perspective.

Those in favour of replacing lead with non-toxic alternatives may include ammunition users with views closer to the 'Open to change' perspective. I argue that the clarification of views held presents an opportunity for the shooting community and other key stakeholders to take forward discussions and potentially forge new solutions for this long-running conflict.

Deconstructing the lead conflict

In order to identify additional approaches that might be useful for understanding and managing the lead conflict, I will now partition some of its key characteristics and themes using an established typology (Table 1.1) and in reference to the conflict literature. As typical of many conservation conflicts, the lead conflict is characterised by multiple features and dimensions and these will be discussed as possible sources of contention and targets for future management. The features discussed below are identified from this body of work only and are not comprehensive. I found evidence to suggest that the lead shot conflict may incorporate *'conflicts over information'* and '*process'* and '*interpersonal conflict'* (Table 1.1; Young et al. 2010; Redpath et al. 2015b).

I identified evidence for potential *'conflicts over information'* between those aligned to '*Status quo*' and those creating and supporting the ecological research (often researchers from conservation organisations e.g. Group of Scientists 2013, 2014). This was characterised by a disbelief of the scientific evidence among those aligned to '*Status quo*', most likely fuelled by distrust, contradictions between the evidence and personal knowledge or experience, and perceived uncertainties over the science.

There was consensus between the two perspectives identified that robust scientific evidence should guide policy on lead shot (Chapter 3). However, those aligned to the '*Status quo*' perspective appeared to distrust the evidence on the risks and impacts of lead ammunition on wildlife and humans, not perceiving it as robust and believing it was exaggerated (Chapter 3). In this case, apparent distrust of the evidence may reflect distrust of those who support or create the evidence rather than the evidence itself. This perspective held the view that opposition to lead ammunition was driven more by a wider dislike of shooting

rather than evidence of any real harm, with the suggestion that conservation actors are driven primarily by an alternative agenda. Wider sentiments of distrust of those in favour of phasing out lead shot were also captured in interviews with ammunition users (Chapter 3). Scientists are sometimes perceived to be at the root of conflicts (Alphandéry & Fortier 2001) or seen by some as imposing management options (Chaineux & Charlier 2003). There was consensus across both perspectives that information about lead poisoning should come from the shooting community for it to be taken seriously, thus reaffirming the distrust of ammunition users towards knowledge providers from outside of their community. Multiple factors may contribute to the distrust of science (Kahan 2002; Kabat 2017), and it forms a key barrier to collaboration (Ansell & Gash 2007) and the resolution of conservation conflicts (Young et al. 2016a). Distrust also indicates that stakeholders are polarised, a characteristic of entrenched and 'destructive' conflicts (Crowley et al. 2017). The polarisation of parties in this conflict has also been described previously by others (Cromie et al. 2015; Newth et al. 2015 – Appendix 1).

Conflicts over information perhaps most commonly arise when scientific knowledge is not aligned to local stakeholder knowledge (Redpath et al. 2015b). This may apply to the lead shot conflict as doubts expressed about the robustness of the evidence was often supported by personal knowledge and experiences. For instance, neither perspective agreed that lead shot was harmful to human health, with several participants citing their own health experiences of eating lead shot game to support their views. When one form of knowledge is refuted and challenged, understanding between parties can be hindered (Redpath et al. 2015b).

Complex socio-ecological systems are often associated with particularly large and diverse uncertainties (Harwood & Stokes 2003; Fulton et al. 2011; Nuno et al. 2014). Uncertainties about the current knowledge expressed by the '*Status quo*' cohort, in itself is likely to fuel the debate about knowledge (Floor et al. 2018). Lack of certainty over scientific results may not simply arise through distrust or misinterpretations, but also when there are knowledge gaps which may stem from difficulties in quantifying certain impacts (e.g. Young et al. 2010). Perceptions that knowledge is incomplete can cause disputes about whether there is sufficient

knowledge to support decision-making (Floor et al. 2018). Indeed, '*Status quo*' adhered to the view that there is not enough evidence to justify current regulations on lead shot (Chapter 3). Pain et al. (2019b) highlight that in some countries, there has been considerable debate about the effects of ingested lead ammunition on the size and trends of bird populations, and an absence of robust information is sometimes cited as a reason for political inaction (e.g. Truss 2016).

The importance of communication to the lead debate was acknowledged by the 'Open to change' perspective, which supported the need for greater awareness within the shooting community about the harm lead poisoning does and guidance on different ammunition types and techniques for their use. It is likely that interpretations of the evidence among ammunition users may be influenced by how the information is communicated and reconstructed (Hodgson et al. 2019; Chapter 1), although evidence for this is not derived from this research. Many conservationists would argue that after decades of peer reviewed research (numerous reviews include Scheuhammer 1987, Watson et al. 2009; Franson & Pain 2011; Pain et al. 2015, 2019b), there are few anthropogenic threats to wild birds that are as well evidenced than lead poisoning from lead ammunition. However, to date the scientific evidence has largely been published in scientific journals, many of which are not freely nor easily accessible, while interpretations of the research outcomes have been communicated to shooting audiences through either vocal conservation campaigners or the shooting media. Following a review of 72 articles about the lead issue published in the UK's field sports media between July 2010 and July 2015, Cromie et al. (2015) found that dismissing the evidence and discrediting the messengers was a popular narrative. This demonstrates a typical characteristic of conflicts where information has been weaponised by actors through the deliberate dissemination of misinformation (Skogen & Krange 2003; Lewandowsky et al. 2013; Linnell 2013) or by discrediting claims of opposing actors (Verma et al. 2017). Furthermore, the media can hinder conflict management when it seeks to highlight and sensationalise disputes (Barua 2010). Individuals aligned to 'Open to change' could play a key bridging role between the scientific evidence and the broader shooting community, particularly given that this group trusted the evidence and believed that awareness-raising was necessary.

My findings also suggest that *'interpersonal conflicts'* play a role (Chapter 3). Interpersonal conflicts relate to personality differences between stakeholders, including issues of trust and communication such as those outlined above. Interpersonal conflicts may arise from certain perceptions of groups and individuals. In this case, negative perceptions about those favouring the phase out of lead shot were recorded, with fears that evidence supporting impacts of lead shot is driven primarily by an 'anti-shooting' agenda (Chapter 3). The personal nature of this conflict comes at a price for those involved. Friend (2009) reflects on the personal costs of a parallel conflict around the use of lead shot in the U.S. leading up to its ban for waterfowl hunting:

> *"Little of what we have presented here reflects the bitterness that characterized much of the struggle to transition to the use of nontoxic shot for waterfowl hunting in the US. Nor does it reflect the heavy personal costs to those who championed the use of nontoxic shot, among them state and federal employees, outdoor columnists, members of the general public, academicians, researchers, and others."*

The influence of wider societal factors (Dickman 2010) also emerged, with support among those aligned to '*Status quo*' for the notion that shooters' pastimes and activities are being eroded and that the phasing out of lead shot will lead to the demise of shooting (Chapter 3). This may reflect a long held perception in the shooting and wider field sports communities that hunting is under threat in the UK (Cromie et al. 2015), likely in part due to the spilling over of conflicts that engage the same conservation and shooting stakeholders (e.g. Thirgood & Redpath 2008).

'Conflicts over process' are likely to feature in this conflict with these findings suggesting the existence of different approaches to decision-making. In recent years, various national laws (HMSO 1999, 2002a, 2002b; 2003, 2004, 2009) and international agreements (UNEP-CMS 2014b, 2017b; IUCN 2016; Kanstrup et al. 2018) have called, to varying degrees, for the replacement of lead ammunition with non-toxic alternatives. However, those aligned to '*Status quo*' were less likely to support this action and disagreed that regulations were essential for reducing lead poisoning in waterbirds (Chapter 3).

The illegal hunting of Bewick's swans: a complex human-wildlife impact

The socio-psychological context: summary of findings

Prior to this research, our understanding of the illegal hunting of Bewick's swans had relied largely on ecological research, specifically the prevalence of wounded birds (Evans et al. 1973; Newth et al. 2011 – Appendix 3). Chapters 4 and 5 therefore explored the role and potential impact of hunters in the European Russian Arctic within the wider socio-ecological landscape. To identify the best management approaches and to avoid potential conflict, two aspects were investigated; the risk of accidental hunting (Chapter 4) and the drivers of deliberate hunting (Chapter 5). Hunters admitted to killing Bewick's swans both accidentally (15% of those surveyed) and non-accidentally (12%) (Chapter 4).

I found an overall inability of hunters to visually distinguish between the three swan species (Chapter 4). I conclude that the risk of Bewick's swans being hunted arises in part when they are mistaken for the sympatric and congeneric whooper and mute swan, both of which are afforded weaker legal protections than the Bewick's swan in some areas (Chapter 4). Here I identified the likely existence of an important dimension that contributes to the impact of hunting on swans. When approaching the management of a 'conflict', it is important to clarify whether an issue is indeed a conflict (Young et al. 2016b) or simply a human-wildlife impact (Young et al. 2010; Redpath et al. 2015a), as alternate strategies may be required to address each. Technical solutions may be sufficient to address human-wildlife impacts, while more complex and interdisciplinary tools may be needed to address conservation conflicts (Young et al. 2016b). I therefore suggest technical options for reducing the accidental hunting of Bewick's swans such as informing hunters of the consequences of accidental shooting for wild bird populations and improving identification abilities using identification keys, proficiency tests and traditional ways of educating. While most hunters surveyed understood that Bewick's swans were protected, a significant proportion (18%) were ignorant of the law, and this was perceived to be a likely motivation for hunting. Although increasing knowledge through communication is rarely sufficient to cause behaviour change by itself (McKenzie-Mohr et al. 2012), a lack of information in this case is likely to be a barrier to compliance. Therefore, I

recommend that further information on the protected status of the Bewick's swan may be beneficial for some hunters. Clarifying and mitigating this human-wildlife impact at the earliest opportunity will help avoid this issue developing into a complex conservation conflict between hunters and conservationists (Young et al. 2016b). The accidental killing of species when they are mistaken for legitimate quarry species or those with weaker legal protections is a problem for threatened birds worldwide (AEWA 2015; Jones et al. 2017) and thus the approach taken and recommendations suggested in this study have wider relevance and applicability for the conservation of protected species.

Next, I assessed the drivers for deliberate hunting (Chapter 5). Conservation interventions that successfully target illegal killing and other environmentally harmful behaviours rely upon their drivers being identified correctly (Vlek & Steg 2007; St. John et al. 2010). Here, I examined the utility of an adapted socio-psychological model (the Theory of Planned Behaviour; TPB, Ajzen 1985) for predicting hunting intention. Hunters were more likely to harbour hunting intentions if they; (i) held negative attitudes towards protective laws and positive or neutral attitudes towards hunting Bewick's swans, (ii) perceived few or no practical barriers to hunting them, and (iii) believed that the behaviour was socially acceptable. I presented evidence that the inclusion of attitude towards protective laws and descriptive norms in an expanded TPB model increased its predictive power, suggesting that both should be considered when exploring drivers of non-compliance in the future. Indeed, understanding attitudes towards protective laws can help inform the design of agreeable conservation measures that reduce non-compliance. Wider ecological, recreation, legal and economic motivations were also identified. Where human-wildlife impacts involve human complexity, technical solutions may not be sufficient to deliver long-term solutions. In this case, I conclude that future conservation interventions should target social and psychological conditions that influence hunters' attitudes, social norms and perceived behavioural control. I propose activities that build trust, encourage support for swan conservation, generate social pressure against poaching, use motivations to prompt change, and strengthen perceived behavioural control. Additionally, I suggest that targeting specific ecological and legal (lack of enforcement) motivations through community engagement and law enforcement, respectively, may be beneficial. This chapter demonstrates the

utility of an adapted socio-psychological model for understanding the drivers of the illegal killing of wildlife, an issue that threatens biodiversity and affects the conservation of threatened species globally (Gavin et al. 2010; Brochet et al. 2016). This approach may be applied to inform the effective design, prioritisation and targeting of interventions that improve compliance in other settings. Furthermore, this research responds to calls for conservation to become more predictive (Sutherland 2006) and increasing demands for frameworks that develop understanding of human behaviours that impact detrimentally on wildlife conservation (Manfredo et al. 1995; Nuno & St. John 2015; Redpath et al. 2018). The deliberate hunting of Bewick's swans has potential to be a source of contention that escalates and emerges as a conflict between conservationists and resource users.

Potential to emerge as a conflict

'*Conflicts over information'* and '*beliefs and* '*values'* and *'conflicts of interest'* (Table 1.1) may potentially trigger the emergence of a conservation conflict in the future. *'Conflicts over information'* may arise from differing views of stakeholders about the population status and trends of the Bewick's swan and their perceived impact on other waterbirds. There was a perception among hunters that the Bewick's swan population was high or increasing and this was regarded as a likely motivation for hunting the species (Chapter 5). This contradicts scientific evidence that indicates a substantial decline in numbers of Bewick's swans in the Northwest European population (38% between 1995 and 2010; Rees & Beekman 2010; Nagy et al. 2012). Due to the low proportion of hunters surveyed that could distinguish Bewick's swans from the other swan species (Chapter 4), the perceived population increase may in some cases arise when all swan species are grouped together. Furthermore, this perception may be compounded by the rising numbers of whooper and mute swans recorded in the region in recent years (Mineyev & Mineyev 2014). This reinforces the need to improve the species identification abilities of hunters. Some believed that Bewick's swans were hunted as they were aggressive and had a negative impact on breeding waterbirds on the tundra (Chapter 5). Although there is substantial evidence that swans exhibit aggression towards other waterbird species, this perception conflicts with

evidence that suggests swans do not spend more time than other waterbirds engaged in aggressive interactions (Wood et al. 2017).

'Conflicts over beliefs and values' and *'conflicts of interest'* surrounding differing perceptions of Bewick's swans as a resource, something to conserve or both, may lead to conflict. Perceived motivations for hunting swans included food and sport (Chapter 5). However, recreational and subsistence reasons are unlikely to be considered justifiable by many of those supporting the legal protection of swans and this may prompt conflict between these parties if not managed carefully. Furthermore, the majority (58.2%) of hunters agreed that local people should be authorised to hunt Bewick's swans under certain circumstances, thus likely providing another source of conflict with those that support the legislation and with non-local commercial hunters or hunting tour operators. This may be intertwined with *'conflicts over process'* whereby current regulations are regarded by some as not fair. Although these findings suggest areas of disagreement between stakeholders and potential flashpoints for future conflict, conflict would only arise if one actor asserts, or at least is perceived to assert, its interests at the expense of another (Redpath et al. 2015b).

Management approaches

The identification of features and themes above can inform targeted management approaches (Redpath et al. 2013) that may prevent (i) the continued destructive cycle of latency and escalation experienced by the lead shot conflict and, (ii) the emergence of the illegal hunting issue as a conservation conflict where damaged relationships and harmful outcomes occur. Success in conflict management may occur *'when the outcome is acceptable to both sides and when neither party asserts its interests to the detriment of others'* (Redpath et al. 2013). Often conflicts are managed to achieve various outcomes rather than be resolved (Gutiérrez et al. 2016). Although biodiversity impacts and conflicts often require different courses of action (Gutiérrez et al. 2016), the application of conflict management approaches to complex impact issues may facilitate the avoidance of conflict. Indeed, the best ways to resolve conflicts is to prevent them arising in the first place (Young et al. 2005).

Distrust between opposing parties is a key feature identified in conflicts over information and interpersonal conflicts and is most likely impeding the ability of parties to collaborate and reach common agreement in the case of the lead shot conflict (Redpath et al. 2013; Young et al. 2016a). This highlights the importance of building and sustaining strong institutional and interpersonal trust between stakeholders (Young et al. 2016a). Trust is likely to encourage engagement (Redpath et al. 2013) and empirical evidence demonstrates that increased trust through fair processes makes conflict resolution more likely (Young et al. 2016a). The lead shot conflict could be seen as an opportunity or reason for the stakeholders to engage with each other with perceived legitimacy (Young et al. 2016a). Deliberative and participatory processes can facilitate dialogue and lead to a deeper understanding of different perspectives and viewpoints, therefore increasing trust between actors (Young et al. 2010). However, to succeed, trust building efforts require the allocation of considerable time, resources and effort and may require a willingness to share power in decision-making and implementation of measures (Young et al. 2016a). In 2010, the UK government invited key stakeholders from conservation, human health and shooting interests to advise on the impacts of lead ammunition on wildlife and human health. However, the lead conflict was already entrenched and parties were polarised and thus the five year deliberations concluded without agreement and with the acrimonious departure of several shooting stakeholders (Lead Ammunition Group 2015b) who did not agree with the chair's recommendations (Swift 2015). Earlier engagement between parties and a deeper understanding of stakeholder perspectives using interdisciplinary approaches may have helped mitigated this conflict.

Participation may also help reduce the interpersonal conflicts, or conflicts of interest and values identified herein (Beierle & Konisky 2001; Young et al. 2010). Engagement may be encouraged by highlighting the shared nature of the conflict and identifying shared positions. There was consensus among both perspectives of ammunition users that stakeholder opinions from 'all sides of the lead poisoning debate' should be included in any decision making process and that both shooters and non-shooters hold the same aim of having sustainable numbers of birds in the British countryside. It would therefore be beneficial to explore the views of conservationists to identify the potential for a shared vision

relating to sustainability (Cromie et al. in review). The ‘Open to change’ perspective is likely to be closely aligned to the views of certain conservation stakeholders and this may create a space for dialogue among these parties. Shared positions could form good starting points from which to facilitate dialogue and lead to a win-win situation for all stakeholders (Redpath et al. 2013). Developing neutral third-party agreements to which scientists adhere can be beneficial when there is scepticisms of scientists and the science (Redpath et al. 2013) as appears to be the case in the lead shot conflict.

Conflict management relies on agreement between parties about the parameters of the impact on biodiversity (Young et al. 2010). Science has been used to define the problem, offer solutions and inform management and policy decisions. However, conflicts of information relating to distrust, knowledge uncertainties or conflicting information identified in the lead shot and illegal hunting studies may benefit from the bringing together of stakeholders to co-produce knowledge with the aim of reaching a shared understanding of the issues (Hage et al. 2010). Furthermore, all stakeholders, including scientists, should recognise their own potential roles in the conflict (Carss 2003; Young et al. 2010). Improving the quality of information available will require stronger interdisciplinary input in order to further understand the perceptions, role and potential contributions of actors involved (Weiss 1989; Young et al. 2010).

Where a lack of information potentially contributes to a misunderstanding of the issue, as is likely in the illegal hunting case, active communication of knowledge may reduce the risk of conflict. All information should be communicated simply but effectively to reduce the risk of misunderstandings (Young et al. 2010). Potential conflicts of interest and those relating to beliefs or values identified in the illegal hunting study may benefit from the opening of dialogue, if necessary with an independent facilitator, between the parties with the aim of reaching mutual understanding and areas of common agreement. Stakeholders in the Russian Arctic would benefit from early engagement as this is more likely to lead to effective and durable decisions, allowing this human-wildlife impact to be addressed before parties enter conflict and become polarised (Reed 2008; Redpath et al. 2013). Equitable, participatory processes should be implemented along with ongoing efforts to build and maintain trust between parties (Redpath

et al. 2015b). The need for these conflict avoidance strategies is particularly urgent now that evidence indicating a biodiversity impact has been brought forward and is being openly discussed by some stakeholders.

Although broad approaches for conflict management may have value, it should be noted that each conflict is different in terms of scale, culture and intensity and therefore management tools will need to be tailored to each individually (Young et al. 2005).

Application of research findings

Lead poisoning of waterbirds

Research undertaken for Chapter 3 involved direct engagement with members of the shooting community and therefore opened opportunities to facilitate dialogue and mutual understanding. Although this was not the aim of my research, several positive spin-off benefits have occurred, including a stakeholder meeting, the invitation to present my findings to several hunting groups in the UK and to the European Federation for Hunting and Conservation's (FACE) Lead Ammunition Working Group in Denmark, which meets twice per year to discuss important policy developments related to ammunition. During the six year period that this thesis was undertaken (2013–2019), global policy initiatives to restrict the use of lead shot have accelerated (Figure 6.1). Findings from Chapter 2 (Newth et al. 2016) have informed the UK's Lead Ammunition Group (Lead Ammunition Group 2018) and proposals for a restriction on lead shot in Europe (RAC/SEAC 2018).

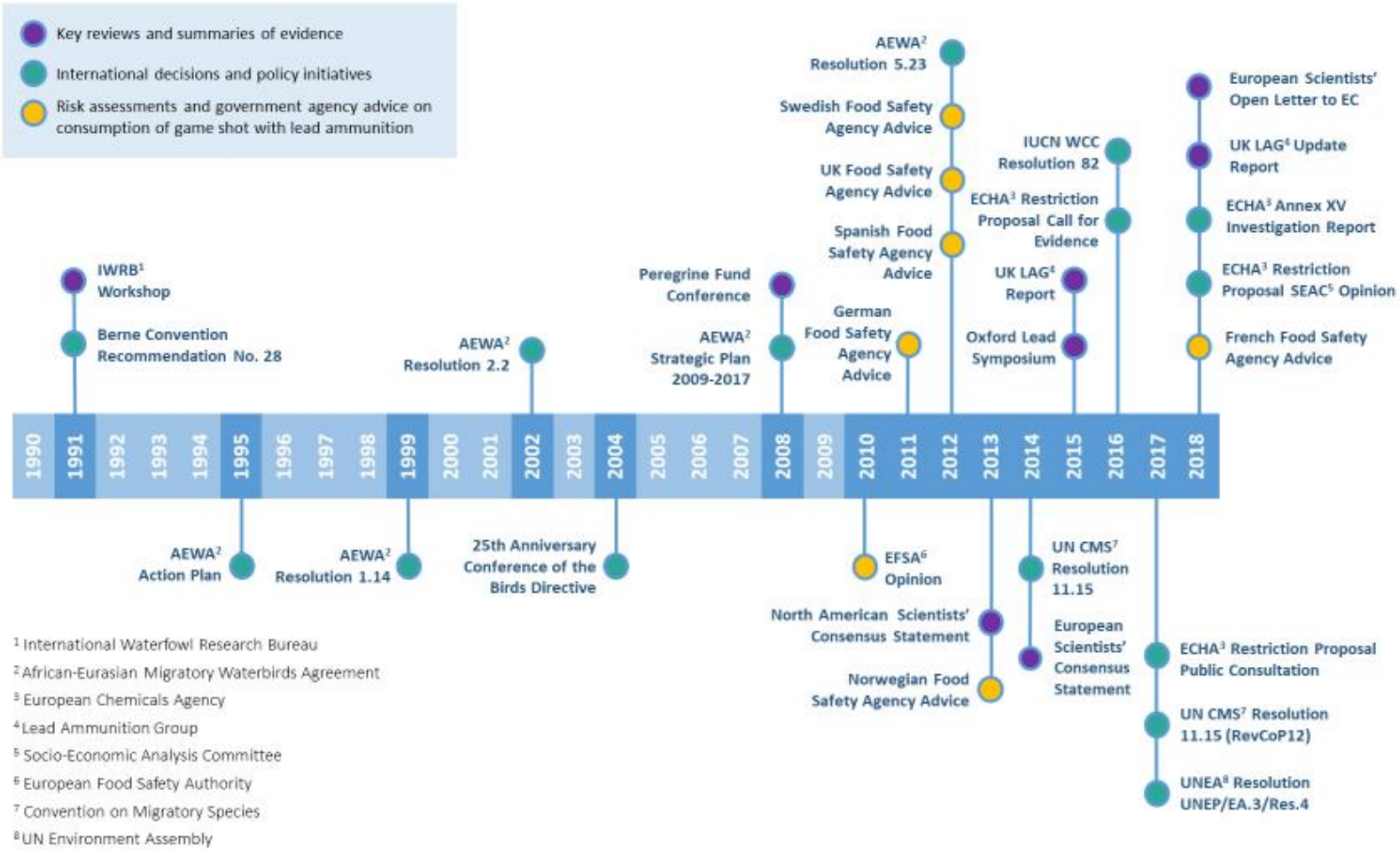


***Figure 6. 1**: Increasing focus on lead ammunition over time – timeline illustrating some of the key reviews of evidence, policy initiatives and publication of European food safety agency advice (Cromie et al. in review).*

Illegal hunting of Bewick's swans

Research from the natural (Newth et al. 2011 – Appendix 3) and social-psychological (Chapters 4 & 5) sciences have enabled a deeper understanding of the extent and human causal drivers of the illegal hunting of Bewick's swans. This has informed the design and targeting of conservation measures that may help prevent this issue being escalated into yet another intractable conservation conflict. The evidence obtained has instigated a deliberative participatory process involving several meetings and two workshops in the Nenets Autonomous Okrug (NAO), with representatives from Russian and British (the Wildfowl & Wetlands Trust) conservation organisations, indigenous and community groups, hunting tourism agencies, educational institutions and government bodies. As a consequence, a resolution with a commitment to reduce the illegal hunting of the Bewick's swan in the NAO was agreed by all parties. A follow up workshop (Figure 6.2) formalised these efforts into an initiative called the 'Swan Champion Project' which aims to reduce illegal hunting in Arkhangelsk Oblast as well as the NAO through a number of activities suggested by attendees (Swan Champion Project 2018).

Figure 6. 2*: Members of the Swan Champion Project at a workshop in Nar'Yan-Mar, Russia, in March 2018.*

To address the knowledge gaps relating to the protective status of the Bewick's swan and the misidentification of swan species (Chapter 4), a 'Memo for Hunters in the NAO' (Appendix 11) has been created. The Memo provides a visual guide of protected and huntable waterbirds, information about penalties for violating protective laws and a map which identifies 'no hunting zones' in this region. To encourage activities that promote swan conservation among hunters (as recommended in Chapter 5), the Memo also includes guidance on how to report sightings of ringed birds. Printed versions of the Memo will be distributed by the Department of Natural Resources, Ecology and Agro-development Complex of the NAO, to 3,000 hunters across the region in spring 2019, and digital (website and phone compatible) versions are available for download on the Department's website. The creation of the Memo was a collaborative effort and thus ownership of the initiative has been shared and trust between the stakeholders has been maintained. Future activities to create awareness of the swans, their population and legal status, and encourage social pressure to discourage hunting and support swan conservation (as recommended in Chapters 4 & 5), include a travelling swan exhibition which will reach remote communities, an online, interactive migration platform for children, a swan conservation film and a phone application for hunters. The project will involve community-led co-ordination and implementation as well as efforts for equitable contribution and decision-making power for the Nenets peoples. Participatory efforts thus far will be built on with regular meetings and workshops to strengthen trust.

Limitations and further research

Applied limitations

The work in this thesis demonstrates the value of applying interdisciplinary approaches to further our understanding of the various dimensions inherent to conflict and human-wildlife impacts and to inform their management. However, reaching and implementing solutions is often problematic. Any resolution process works within legal and political realities in addition to the scientific, ethical and practical considerations, and these may limit the management options available (Redpath et al. 2015b). In complex and unpredictable socio-ecological systems such as these, a number of personal, capacity and institutional barriers may

reduce the capacity of conservationists to achieve their outcomes (Nuno et al. 2014). In the case of the lead shot conflict, there are additional important factors not captured within this thesis that are likely to form barriers for moving towards a non-toxic future and thus perpetuate conflict between stakeholders. Some of these are described by Cromie et al. (2015) and include commercial interests and the political power of the field sports lobby, including the gun and ammunition industries.

The illegal hunting study can be regarded as an initial exploration of a complex human-wildlife impact, with the full appreciation that important knowledge gaps on how this behaviour sits within the economic and political landscape remain. Although I have suggested dialogue and trust-building approaches to resolve certain characteristics of both the lead shot and illegal hunting issues, engagement cannot be considered a panacea and comes with its own difficulties and limitations. Indeed, parties may not be willing to engage and may actively attempt to undermine the process (Redpath et al. 2015). In relation to the lead shot conflict, deep divisions and mistrust between some conservation and shooting stakeholders may limit opportunities to build trust and make participatory processes untenable.

The likely increase in magnitude and intensity of conservation conflicts in the future presents a great challenge for the conservation sector. Balancing the need to tackle emerging and ongoing complex ‘wicked’ issues with the limited resources available for conservation is problematic. Although conflicts often require individual approaches to manage them, the utility of drawing approaches and insights from detailed studies such as those explored herein for managing multiple conflicts, should be explored further.

Methodological limitations

Specific methodological limitations relating to each analysis are outlined within Chapters 2, 3, 4 and 5. Therefore, here I will discuss the broader limitations associated with this work and suggest further areas of potential academic enquiry.

The social and ecological dimensions have been studied in isolation and therefore, the relationships between these elements have not been explored. Future research could focus on the integration of these components, the estimation of uncertainty and the exploration of management options with relevant stakeholders (Redpath et al. 2015b) using holistic approaches such as Management Strategy Evaluation (MSE: Bunnefeld et al. 2011), Bayesian Belief Networks (Marcot et al. 2006), and Adaptive Management (Gutiérrez et al. 2016; Bainbridge 2017). Feedbacks between components and trade-offs between decisions could also be considered (Nuno et al. 2014). Understanding uncertainty, whether related to natural systems or human behaviour is important for the conflict management process (Milner-Gulland & Rowcliffe 2007). For example, uncertainty may impede our understanding of impacts and this not only affects confidence in estimates, but can be used for inaction or even as an argument against a certain stance, as identified in the lead shot conflict.

Although my findings suggest the presence of or potential for certain types of conflict (according to an established conflict typology; Table 1.1), targeted exploration of these will help verify their nature and confirm appropriate approaches required to find solutions (Redpath et al. 2015b). It should be noted that in some cases, conflicts and human-wildlife impacts may be difficult to categorise as they often occur in unique and complex settings (Young et al. 2010). I hope that this work will open the door to further academic enquiry, particularly relating to the human dimension of both issues.

Concluding remarks

Conservation conflicts are ubiquitous, persistent, damaging and among the most challenging problems facing biodiversity conservation. Our challenge as conservation biologists and practitioners is to help manage conflicts and prevent their emergence from human-wildlife impacts, and this relies on understanding their various dimensions. This research draws on interdisciplinary approaches and methodologies to examine two issues that impact on the conservation of waterbirds: the illegal hunting of Bewick's swans in the Russian Arctic and the lead poisoning of waterbirds from lead ammunition in the UK. I empirically examined their lesser known ecological and socio-psychological contexts and determined multiple characteristics and themes characteristic of 'wicked problems' for their complexity. This complexity means that such issues are often presented superficially as surface manifestations. The lead shot conflict is often framed by the media as between the conservation and shooting communities, yet I found diverse opinions on the subject among ammunition users. Apparently physiologically healthy birds may mask sub-lethal impacts such as reduced body condition. Unseen social pressure may play a key role in enabling the illegal hunting of Bewick's swans. It is therefore imperative to probe the many layers that lie beneath the surface of conflicts and human-wildlife impacts. Indeed, such 'wicked problems' should be approached as complex, nuanced problems. However, I am aware that this requires a capacity to employ appropriate interdisciplinary methods and approaches which may not be available to those specialising in ecological disciplines. Furthermore, the prospect of tackling a problematic conservation issue with all its various entanglements and perceived drain on resources may not be appealing. Treating these complex problems with simple, technical, 'sticking plaster solutions' may seem like the straightforward solution. However, this approach is often a false economy and can culminate in the escalation of a conflict that is then seemingly impossible to resolve and may take much time and effort to claw back from. Conflict management approaches can be applied to de-escalate the lead conflict and prevent the illegal hunting issue from emerging as a conflict. Inevitably, the delivery of long-term solutions for problematic conservation issues, whether human-wildlife impacts or conflicts, require the correct interdisciplinary toolkit, sufficient time and importantly, good will and energy among parties to work together and reach consensus.

Appendices

Appendix 1: Lead shot in Europe: conflict between hunters and conservationists

Newth JL, Cromie RL, Kanstrup N. 2015. Lead shot in Europe: conflict between hunters and conservationists. Pages 177–179 in R. J. Gutiérrez, K. A. Wood, and J. C. Young, editors. Conflicts in Conservation: Navigating towards solutions. Cambridge University Press, Cambridge, UK.

Box 12

Lead shot in Europe: conflict between hunters and conservationists

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Lead shot is a widely used, effective and cheap ammunition. During shotgun shooting, the majority of spent lead shot falls to the ground where it can be ingested by birds because they mistake it for food or grit.

Lead poisoning in birds from lead shot was first recorded in the 1870s and is now well documented as a source of morbidity and mortality in wild birds around the world (Mateo, 2009). Predatory and scavenging birds, primarily raptors, also ingest lead embedded in prey or carrion. Conflict arises between those who wish to continue using lead shot for hunting and those who wish to replace lead shot with non-toxic alternatives for all shooting in order to protect birds and ecosystems from the toxic effects of lead (herein termed 'conservationists', accepting that hunters may be conservationists too).

Research on lead poisoning encouraged the development of shared positions of agreement by hunters and conservationists. In 1991, an International Wetlands Research Bureau (IWRB) conference in Brussels representing experts in lead poisoning, government agencies, NGOs, conservation and hunting organisations, and arms and ammunition manufacturers led to statements supporting phased removal of lead shot used over wetlands and prompted the first of several resolutions of the African–Eurasian Waterbirds Agreement, which precipitated national legislation in many countries.

International hunting bodies, such as the European Federation of Associations for Hunting and Conservation (FACE) and the International Council for Game and Wildlife Conservation (CIC), have also promoted the phasing out of lead in ammunition. However, although there is some acceptance within national hunting communities that lead shot poisons birds, there is disagreement about its scale and potential solutions.

Case study England: Conservationists argue that English legislation introduced in 1999 aimed at restricting the use of lead over wetlands fails to protect birds, including wildfowl, feeding in terrestrial areas. Compliance with legislation has been poor and difficult to enforce (Cromie *et al.*, 2010), and has not reduced lead poisoning (Newth *et al.*, 2012). Proposals that allude to further restrictions on lead shot use over terrestrial habitats have been met by strong resistance from many in the shooting community. Motivations for non-compliance with legislation include: perception that lead poisoning was not a sufficient problem to justify the restrictions; non-lead alternatives were expensive, not widely available and not as effective as lead; and restrictions were not enforced (Cromie *et al.*, 2010). Restrictions were also perceived as a means to phase out lead shot completely and perhaps as

'being used' by conservationists to end bird hunting completely. Conservationists see shooters as obstructing efforts to reduce lead poisoning. These perceptions have contributed to mutual mistrust. Prior to, and since, the introduction of legislation in England, conservationists have not worked with hunters to persuade them of the benefits of non-toxic shot and few advocates within the shooting community have supported the use of non-toxic shot.

Case study Denmark: Denmark began regulating lead shot in 1985 and in 1996 it became illegal to use lead shot for all shooting. Initially, Danish shooters shared similar fears about the cost and efficacy of non-toxic shot. However, some key advocates from this community were crucial in persuading other hunters of the benefits of non-toxic shot (Kanstrup, 2006). The success of steel shot for clay pigeon shooting allayed shooter concerns by demonstrating that there were suitable, safe, relatively cheap alternatives to lead. Research by the Danish Hunters Association also demonstrated the efficacy of steel shot for killing birds. When steel shot embedded in trees was deemed unacceptable to foresters, the development of softer alternatives such as bismuth was prompted, despite the comparatively higher cost. As was the case in England, many Danish hunters were concerned that phasing out of lead shot would lead to the end of hunting, but this has not occurred and the number of hunters and the annual bag have not changed significantly. Furthermore, an initial concern that there was an increased risk of irreparable gun damage by steel shot proved unfounded. Scientific studies conducted by hunters demonstrated the efficacy of alternative shot and have reassured the hunting community. Moreover, the general 'image' of shooting within Danish society has been maintained.

These examples illustrate contrasting approaches to lead poisoning having varying success. Denmark successfully reduced environmental lead contamination by enacting legislation that banned the use of lead shot by garnering support of hunters for use of non-toxic alternatives. Danish success can be linked to a few advocates within the hunting community who persuaded other hunters of the benefits using evidence from hunter-led research. All stakeholders were involved in the transition process in the early stages and thus trust between them was maintained. In England, a country of strong traditions, the absence of hunter advocates for non-toxic shot and support for non-toxic shot polarised stakeholders. Partial restrictions have had poor compliance, largely because shooters are not convinced either of the problem or the benefits of non-toxic shot. The engagement of a trusted third party, respected by stakeholders, is needed to facilitate negotiations to resolve the conflict.

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Newth, J. L., *et al.* (2012). Poisoning from lead gunshot: still a threat to wild waterbirds in Britain. *Eur. J. Wildl. Res.*, 59, 195–204.

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Appendix 2: Poisoning from lead gunshot: still a threat to wild waterbirds in Britain

Newth JL, Cromie RL, Brown MJ, Delahay RJ, Meharg AA, Deacon C, Norton GJ, O'Brien, MF, Pain DJ. 2013. Poisoning from lead gunshot: still a threat to wild waterbirds in Britain. European Journal of Wildlife Research 59:195–204. doi: 10.1007/s10344-012-0666-7

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ORIGINAL PAPER

Poisoning from lead gunshot: still a threat to wild waterbirds in Britain

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Abstract Lead is a highly toxic metal known to be an important cause of morbidity and mortality in waterbirds and terrestrial birds worldwide. The risk to birds of poisoning from lead has resulted in the introduction of legislation in many countries, such as UK restrictions on the use of lead in angling weights and lead gunshot. In this study, we examined data on current and historical trends in lead poisoning in British waterbirds and related these to the introduction of legislation restricting the use of lead. Our results indicate that lead poisoning has continued to affect a wide range of British waterbirds long after legal restrictions were introduced. Elevated levels of lead (i.e. >20.0 μg/dL) were found in the blood of 34 % (n=285) of waterbirds tested at four sites in Britain during the 2010/2011 winter and accounted for the deaths of at least 10.6 % (n=2,365) of waterbirds recovered across Britain between 1971 and 2010 and 8.1 % (n=1,051) between 2000 and 2010, with lead gunshot being the most likely source of poisoning. The proportion of birds dying from lead poisoning in England did not vary significantly after the introduction of legislation, accounting for 13.7 % of non-infectious causes of death between 1971 and 1987 (n=204), 20.8 % (n=360) between 1988 and 1999 and 11.8 % (n=423) between 2000 and 2010, despite a significant change in lead-related mortality in mute swans found during the same time period, 25 % (n=12) between 1971 and 1987, 4.6 % (n=65) between 1988 and 1999 and 2 % (n=100) between 2000 and 2010. Existing legislation needs review and extension to ensure the delivery of international commitments and a broad-scale transition to the use of non-toxic shot and angling materials in all environments.

Keywords Lead poisoning · Lead gunshot · Legislation · Waterbirds · Britain

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Introduction

Lead is a highly toxic metal that can affect virtually every physiological system in animals (Pokras and Kneeland 2009; EFSA 2010; Franson and Pain 2011). Poisoning caused by lead is a widely accepted and well-documented global problem for humans, domestic animals and wildlife and remains an important cause of morbidity, mortality and suffering in waterbirds and terrestrial birds (Pain 1996; Scheuhammer and Norris 1996; Beintema 2001; Mateo 2009; Pain et al. 2009). In Britain, lead poisoning has been studied since the 1960s and reported in many species of waterbird (Olney 1960; Thomas 1980; Birkhead 1982; Mudge 1983; Perrins et al. 2003; O'Connell et al. 2008).

Waterbirds are poisoned following ingestion of spent lead gunshot, either inadvertently or when mistaken for food particles or grit (Hall and Fisher 1985; Pain 1990b; Moore et al. 1998; Gionfriddo and Best 1999; Mateo and Guitart 2000). Predatory and scavenging birds, primarily raptors, are also exposed to embedded lead ammunition (gunshot, bullets or fragments thereof) in their prey or carrion (Pain et

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al. 2009). A high proportion of both legally and illegally shot birds can carry embedded shot. For example, studies have revealed shot in 25 and 36 %, respectively, of first year and adult live-trapped pink-footed geese (*Anser brachyrhynchus*) (Noer and Madsen 1996) and 31 % of protected Bewick's swans (*Cygnus columbianus bewickii*) (Newth et al. 2011). Some raptors may therefore be exposed to lead across the migratory routes of their prey.

Although more recent examples are not available, in the early 1990s in the UK, an estimated 160 tonnes of lead shot equating to about 1.6 billion individual shot was deposited in wetlands alone (Pain 1992). As lead gunshot generally degrades only slowly (except under acidic conditions; Rooney et al. 2007) and may persist for tens or hundreds of years, this represents a substantial accumulation of this heavy metal in the sediments and soils of hunted habitats around the world.

The risk to birds from poisoning from lead gunshot has resulted in many countries imposing legislative restrictions on its use (Avery and Watson 2009). In Europe, much legislation has resulted from a request for the phasing out of lead shot over wetlands within the action plan and subsequent resolutions of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA 1999, 2002, 2008). As a signatory to AEWA, the UK responded by banning the use of lead shot over the foreshore and specified (wetland) Sites of Special Scientific Interest (SSSIs); for hunting wildfowl, coot (*Fulica atra)* and moorhen (*Gallinula chloropus*) in all areas in England in 1999 and Wales in 2002; and for hunting over wetlands (for any type of shooting activity) in Scotland in 2004 and Northern Ireland in 2009 (HMSO 1999, 2002a, b, 2003, 2004, 2009). However, in England, there is evidence of non-compliance with the restrictions with 68 % (n=40) of ducks purchased from game outlets in 2001/2002 and 70 % (n=492) purchased between 2008 and 2010 having been shot illegally with lead (Cromie et al. 2002; Cromie et al. 2010). In addition to compliance issues, restrictions do not extend to all habitats used by waterbirds, and hence many species remain at risk of ingesting lead.

Despite restrictions on its use, waterbirds in the UK have continued to be poisoned by lead. Elevated blood lead levels (i.e. >20.0 μg/dL) were recorded in 79.7 % of whooper swans (*Cygnus cygnus*) caught at wintering sites in England 5 to 6 years after the introduction of legislation, and in 61.4 % of this species in Scotland, 1 year following legislation, with ingestion of spent lead shot attributed as the most likely cause (O'Connell et al. 2008).

The purpose of the present study was to provide further information on current and historical trends in lead poisoning in British waterbirds. Firstly, we investigated blood lead levels in live birds caught during the 2010/2011 winter, and the incidence of lead-poisoning-induced mortality of birds found dead between 1971 and 2010. Secondly, we examined variation in the incidence of lead-poisoning-induced mortality in waterbirds in England between three-time phases (1971–1987, 1988–1999 and 2000–2010) to investigate whether there was a detectable change in the temporal trend in lead-related mortality in relation to the introduction of legislation restricting the uses of lead in angling weights in 1986 (HMSO 1986, as amended 1993; EA 2012) and in ammunition in 1999 (HMSO 1999, as amended 2002 and 2003). The findings of this study provide evidence to help inform the development of UK Government policy on the risks to wildlife health from exposure to lead ammunition, and possible management measures.

Methods

Study sites and sample collection

Blood lead levels in waterbirds wintering in Britain during winter 2010/2011

All live birds tested for blood lead levels were caught at or near to four Wildfowl & Wetlands Trust (WWT) centres in Britain: Slimbridge, Gloucestershire (51°58′98″ N, 2°25′02″ W), Welney, Norfolk (52°31′50″ N, 0°16′98″ E) and Martin Mere, Lancashire (51°58′98″ N, 2°25′02″ W) in England and Caerlaverock, Dumfriesshire (54°58′02″ N, 3°25′02″ W) in Scotland. A total of 285 birds were caught between 16th December 2010 and 24th February 2011 (Table 1) in decoy-type 'swan-pipes' (275 birds) or by cannon-netting (10 birds). These included a dabbling species (pintail, *Anas acuta*), diving species (pochard, *Aythya ferina*) and grazing species (whooper and Bewick's swans), all of which are known to have been previously affected by lead poisoning (Mudge 1983; Pain 1990a, b, 1992).

Sightings of Bewick's swans identified by bill pattern recognition techniques (at Slimbridge) and whooper swans identified by coded leg-rings were analysed to assess the length of time spent at WWT sites prior to testing. Given that blood lead concentrations usually reflect recent exposure to lead, i.e. within 35–40 days of testing (O'Halloran et al. 1988a), swans seen at WWT reserves more than 40 days prior to testing were deemed likely to have been exposed to lead in the vicinity of the reserves.

Birds were sexed (by plumage characteristics or cloacal examination), ringed, aged (as either adults or juveniles by plumage characteristics) and weighed, and their skull, tarsus and wing lengths were measured.

A blood sample was taken from the medial metatarsal vein of each bird with a 2-mL syringe using a 23-gauge needle as part of on-going broader health studies. Samples of 500 μl of blood were then transferred into a 1.5-mL tube containing lithium heparin and chilled (at 4 °C) until analysis.

Table 1 Summary of blood lead concentrations (in micrograms per decilitre) for target species of waterbirds sampled at WWT reserves in Britain during winter 2010/2011 and outputs of a general linear regression showing interspecies differences (with Bewick's swan as the reference level)

Species	Blood lead concentration (μg/dL) summary statistics			Blood lead concentration model outputs			Elevated blood lead levels (% >20 μg/dL)
	N	Median	Range	Model coefficient	*t* statistic	*P* value	
Bewick's swan	39	5.9	1.6–62.6	0			12.8
Whooper swan	177	18.2	5.6–132.9	−0.007	−0.03	0.98	42.9
Pochard	29	15.0	4.3–38.4	−0.022	−0.09	0.93	20.7
Pintail	40	10.3	3.5–196.0	0.439	2.44	0.02	25.0
Overall	285	15.4	1.6–196.0				34.0

The proportion of each species with elevated lead levels (i.e. values >20.0 μg/dL) is also shown

Mortality from lead poisoning of waterbirds recovered at sites in Britain between 1971 and 2010

Between 1971 and 2010, *postmortem* examinations were routinely carried out on waterbirds found dead during regular (near daily) patrols by reserve wardens and other staff in the vicinity of WWT centres: at Arundel, West Sussex (50° 51′41.35″ N, 0°32′59.31″ W), Llanelli, Carmarthenshire (51°40′01.10″ N, 4°07′20.08″ W), London Wetland Centre (51°28′37.94″ N, 0°14′9.343″ W), Washington, Tyne and Wear (54°53′52.73″ N, 1°28′47.70″ W), Slimbridge, Welney, Caerlaverock and Martin Mere. Dead wild birds were recovered on a less frequent ad hoc basis at other sites. Post mortem examinations were not always possible for carcasses that had been scavenged or predated or for those that had decomposed to such an extent that tissue analysis was not possible. Only birds whose cause of death was determined were included in this analysis.

The primary cause of death was determined for 2,365 wild waterbirds recovered at sites across England, Scotland and Wales during this time period. A total of 28 different species of waterbird were represented from the six subfamilies Anatinae (724 birds), Anserinae (1,358 birds), Aythyinae (151 birds), Merginae (17 birds), Oxyurinae (2 birds) and Tadorninae (113 birds).

Laboratory analyses

Blood analysis

A subsample of 0.1 g was taken from each 0.5 mL blood sample, and 0.5 mL of concentrated nitric acid added. Samples were left overnight, after which 1.0 mL of hydrogen peroxide was added to each. The samples were then digested using a microwave digester (MARS, CEM) initially at 55 °C for 10 min, then at 75 °C for 10 min, and finally at 95 °C for 30 min. The digests were made up to 5 mL by mass with Milli-Q water. Samples were then analysed using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500 series), and as an internal standard, a continuous concentration of 10 μg/l Rh, prepared in 1 % nitric acid, was introduced into the sample stream via a T-piece.

Several methods were used to ensure quality control. Blanks (digests without blood, processed using the methods outlined above, in 'Blood analysis') were used to assess background levels of lead and its limit of detection (LOD= 0.275 μg/L). Spikes (digests without blood, processed using the methods outlined above, in 'Blood analysis', with a known concentration of calibration standard added to them) were used to assess any fluctuation of lead during the preparation process. A certified reference material (in this case, bovine liver) (National Institute of Standards and Technology SRM 1577b) was also used to validate results. The recovery for the certified reference material was 0.117±0.007 (mean±s.e.m) with an average percentage recovery of 90.8 %.

Standard additions of samples were conducted prior to analysis to check that there were no interferences. All samples were randomised and analysed in one batch. The sample data were divided by the internal standard to account for any drifting of the instrument and the standards were re-analysed every 30 samples and used to construct an external calibration curve.

Birds with blood lead exceeding 20.0 μg/dL were considered to have an elevated concentration above background levels, indicative of lead ingestion (O'Halloran et al. 1988a) and consistent with adverse physiological effects (Franson and Pain 2011).

Post mortem analysis

Pathological findings that are characteristic of lead poisoning include impaction of the gizzard and oesophagus with food, very little body fat, low body weight, atrophy of gizzard and liver, enlarged gall bladder and green staining of the vent. Birds which exhibited these signs and the presence of lead (shot, angling weights or fragments thereof) in the gizzard

and/or intestines and/or had elevated lead levels in kidney tissues (i.e. >25 μmol/kg in dry matter) were determined to have died from lead poisoning.

For each bird tested, 2 g (wet weight) of kidney tissue was digested in a solution of perchloric, nitric and sulphuric acid. The samples were then made up to 12 mL with de-ionised water. A dry matter analysis was performed on each sample. An aliquot of the received samples was dried for 4 h at 100 °C and then reweighed. Lead concentrations were determined by atomic absorption spectrophotometry, using a GBC908 Atomic Absorption Spectrophotometer in flame mode (F-AAS). As tissue analysis was not conducted routinely on all birds at post mortem examination, some cases of lead poisoning without characteristic pathology are likely to have been missed.

Treatment of the data and statistical analyses

Blood lead data

A general linear regression model was used to partition the variation in log-transformed blood lead levels (the response variable), relative to species, site, sex and age (the factors). A general linear model (GLM) with binomial error distributions and logit link functions was used to identify any significant variation in the probability of elevated (i.e. values >20.0 μg/dL) blood lead levels (the response variable) relative to species, site, sex and age (the factors).

Mortality data

A GLM with binomial error distributions and logit link functions was used to investigate interspecific differences in lead poisoning mortality of all birds (whose cause of death was known) recovered at sites across Britain (including WWT centres), between 1971 and 2010.

There was variability in data collection effort over time at sites away from WWT centres (see 'Mortality from lead poisoning of waterbirds recovered at sites in Britain between 1971 and 2010'). Therefore, to investigate any association between the introduction of legislation in England, specifically restrictions in use of lead in angling weights in 1986 (HMSO 1986, as amended 1993; EA 2012) and in ammunition in 1999 (HMSO 1999, as amended 2002 and 2003), and the temporal trend in lead-related mortality rates amongst waterbirds, an additional GLM with binomial error distributions and logit link functions was used to examine only data derived from birds recovered at WWT centres in England. Dead bird surveillance efforts at WWT centres remained relatively consistent over time (with near daily patrols) and hence data collected during each time period were considered comparable. This model investigated variation in the frequency of mortality from lead poisoning (the response variable), relative to species, time period (1971–1987 vs 1988–1999 vs 2000–2010), site, sex and age (the factors). WWT centres were established in different years (at Slimbridge in 1946, Welney and Caerlaverock in 1970, Martin Mere and Washington in 1975, Arundel in 1976, Llanelli in 1991 and London Wetland Centre in 2000), and so site was included in the model to account for this.

For this additional analysis, we calculated mortality rates attributed to lead poisoning as proportions of all mortality events associated with non-infectious causes. We omitted all cases of mortality relating to infectious disease (plus avian botulism) from these analyses as outbreaks of such conditions varied substantially and would confound a consistent assessment of the relative importance of lead poisoning in space and time. This subset of data is hereafter referred to as the 'non-infectious data subset'. The model was run once for all species and separately for three species (mute swan, whooper swan and mallard) that had sufficiently large sample sizes (i.e. >100 birds) to permit species-specific analyses. All statistical analyses were carried out using MINITAB (version 14) and GenStat (version 14.1) software packages.

Results

Blood lead levels in waterbirds wintering in Britain during winter 2010/2011

Interspecific comparison

Single blood samples were collected from 285 live birds during the 2010/2011 winter. Lead was detected in all blood samples, with levels ranging from 1.6 to 196.0 μg/dL (Table 1). There was a significant interspecific variation in blood lead levels ($F_{3,\ 274}$=3.34, P<0.05), with the highest median blood lead levels found in whooper swans and the lowest in Bewick's swans (Table 1). The widest variation in blood lead levels was recorded in pintails and whooper swans (Table 1). Elevated blood lead levels (i.e. >20.0 μg/dL) were found in 34 % of all birds tested and ranged from 12.8 % in Bewick's swans to 42.9 % in whooper swans but did not vary significantly between species (logistic regression, P>0.1) (Table 1).

Twenty whooper swans found to have elevated blood lead levels had been previously leg-ringed. Of these, 17 (85 %) had been sighted at Martin Mere (five birds) or Caerlaverock (12 birds), more than 40 days prior to testing there. Seven of the birds tested at Caerlaverock had been sighted in fields near to the reserve during the same winter and five of those had used these sites within 40 days of testing. Of five Bewick's swans caught at Slimbridge with elevated blood lead levels, three had been recorded at the reserve (using bill pattern recognition techniques), more than 40 days prior to testing.

Site comparison

Blood lead levels varied significantly between sites ($F_{3, 274}$= 9.76, P<0.001) as did the proportion of birds with elevated blood lead levels: 45.2 % of birds caught at Martin Mere (n= 62), 41.4 % of birds at Caerlaverock (n=145), 13.2 % of birds at Slimbridge (n=68) and 0 % of birds at Welney (n=10) (χ_3^2=11.72, P=0.008).

Age and sex comparisons

Neither blood lead levels nor the proportion of birds with elevated blood lead levels varied significantly with age and sex (GLMs, P always >0.05).

Mortality from lead poisoning

Waterbirds recovered at sites across Britain between 1971 and 2010

Lead poisoning accounted for mortality in 251 (10.6 %) of 2,365 individual waterbirds (whose cause of death was determined), recovered at sites across Britain (including WWT Centres) from 1971 and 2010 inclusive. Of these, 74.9 % (n=188) had lead shot in varying states of dissolution in their gizzards. In addition, fragments of lead angling weights were present in the gizzards of three mute swans (*Cygnus olor*) that were also entangled in fishing tackle. A total of 14 species of waterbird were affected: mute swan, whooper swan, Bewick's swan, Canada goose (*Branta canadensis*), Western greylag goose (*Anser anser*), pink-footed goose, mallard (*Anas platyrhynchos*), northern pintail, gadwall (*Anas strepera*), common teal (*Anas crecca*), European pochard, tufted duck (*Aythya fuligula*), common shelduck (*Tadorna tadorna*) and shoveler (*Anas clypeata*). There was a significant interspecific variation in the proportion of birds that had died from lead poisoning (GLM: χ_{27}^2=147.60, P< 0.001). Those species with the highest proportion of deaths recorded from lead poisoning included whooper swans (27.3 %), Bewick's swans (23 %), Canada geese (16.7 %) and pochard (16.7 %) (Fig. 1). Amongst the 1,051 individual waterbirds recovered at sites around Britain between 2000 and 2010 and whose cause of death was known, lead poisoning accounted for mortality in 85 (8.1 %).

Other variables associated with lead poisoning mortality

When sources of variation in the frequency of mortality from lead poisoning were analysed using the non-infectious data subset (i.e. those recovered at WWT centres in England between 1971 and 2010 inclusive, see 'Mortality data'), adult birds (of over 2 years) were found to be significantly more likely to be recorded as dying from lead poisoning than juvenile birds (<1 year) (17 %, n=780, and 7.2 %, n= 153; χ_1^2=9.77, P=0.002). However, the probability of birds dying from lead poisoning did not vary significantly relative to site and sex (GLM: P always >0.05).

Three species (mute swan, whooper swan and mallard) had sufficiently large sample sizes (i.e. >100 birds) to permit species-specific analyses. When investigated separately, adult whooper swans found at WWT centres in England were significantly more likely to be recorded as dying from lead poisoning than juvenile birds (51.5 %, n=101, and 26.1 %, n= 23; GLM: χ_1^2=5.62, P=0.01). Also, female whooper swans were more likely to be recorded as dying from lead poisoning than males (56.6 %, n=76, and 33.9 %, n=56; GLM: χ_1^2= 5.54, P=0.01). No such age and sex effects were detected in mallards and mute swans (GLM: P always >0.05).

Lead-related mortality accounted for 13.7 % of deaths, unrelated to infectious disease, between 1971 and 1987 (n= 204), 20.8 % between 1988 and 1999 (n=360) and 11.8 % between 2000 and 2010 (n=423). However, once variation associated with other factors (species, site, sex and age) was taken into account, the probability of birds dying from lead poisoning did not vary significantly between the three time phases (GLM: P>0.1). However, a significant time effect was observed for the proportion of mute swans dying of lead poisoning (GLM: χ_2^2=8.36, P=0.01), which varied from 25 % (n=12) between 1971 and 1987 to 4.6 % (n=65) between 1988 and 1999 and 2 % (n=100) between 2000 and 2010. Significant temporal variations in lead-related mortality rates were not detected for whooper swans or mallards (GLM: P always >0.05).

Discussion

Despite legislation aimed at reducing the impact of lead on wildfowl in the UK, it continues to poison and kill waterbirds. Elevated levels of lead (i.e. >20.0 μg/dL) were found in 34 % of waterbirds tested at four sites in Britain during the 2010/2011 winter ranging from 12.8 % of Bewick's swans to 42.9 % of whooper swans. In addition, lead poisoning accounted for the deaths of at least 8.1 % of waterbirds, recovered across Britain between 2000 and 2010. Lead shot was found in varying states of mechanical grinding and dissolution in the gizzards of 74.9 % of waterbirds that were diagnosed as having died of lead poisoning between 1971 and 2010, the disease accounting for the death of 10.6 % of waterbirds during this period.

Post mortem data presented in this paper are likely to underestimate the true impact of lead poisoning on waterbirds for a number of reasons. For example, some birds may have died from lead poisoning without exhibiting typical pathology in which case the cause of death may have been attributed to something else (Beyer et al. 1998). Also, lead

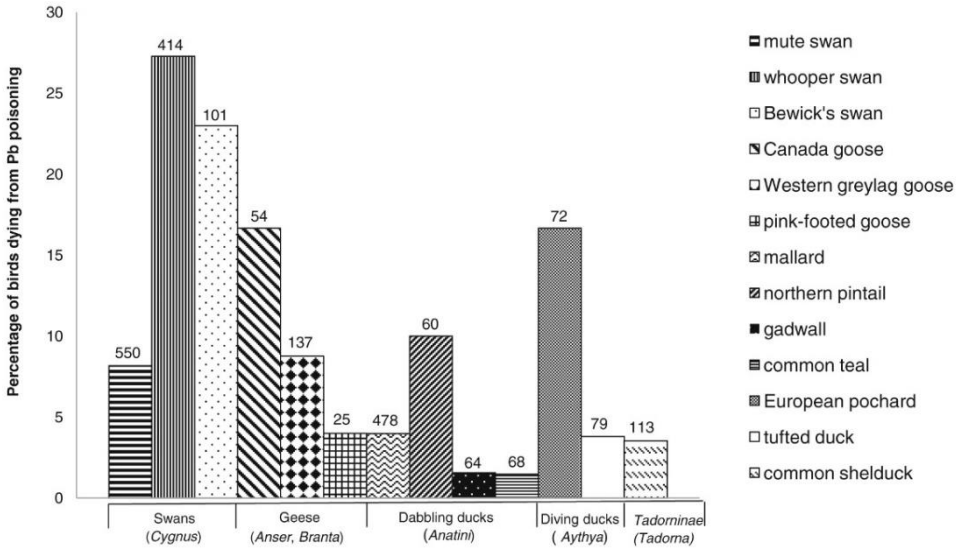

Fig. 1 Mortality from lead poisoning amongst waterbirds recovered at sites in Britain between 1971 and 2010. Sample sizes are indicated, and species for which less than 20 birds were available were omitted

poisoning may cause sublethal impacts on physiology and behaviour (Scheuhammer 1987; Pain et al. 2009) and so may contribute to premature death from other causes such as concurrent disease, starvation, predation and flying accidents (Scheuhammer and Norris 1996; Kelly and Kelly 2004). Furthermore, while large-scale die-offs occasionally occur, mortality from lead poisoning is generally less conspicuous and exhibited as day to day mortality which may result in the frequent and largely invisible losses of small numbers of birds that subsequently remain undetected (Stutzenbaker et al. 1986).

Moribund birds generally become increasingly reclusive, and after death, carcasses are not likely to be seen before being scavenged (Stutzenbaker et al. 1986; Pain 1991) and are thus likely to be under-represented in the post mortem dataset. Lead poisoning is understandably known as 'the invisible disease' (Pain 1991).

Interspecific variation in lead poisoning

In Britain, lead poisoning has been reported in a wide variety of waterbirds, including the 14 species recorded herein and others including goldeneye (*Bucephala clangula*), moorhen and snipe (*Gallinago gallinago*) (Thomas 1975; Mudge 1983). Many bird species feeding in an area where shooting with lead ammunition occurs illegally or legally are at some risk of exposure and potentially poisoning, but this is likely to be influenced by interspecific differences in behaviour.

In the present study, rates of mortality attributable to lead poisoning varied significantly between species, with whooper swans being more likely to be recorded as dying from lead poisoning (27.3 % of birds recovered in Britain between 1971 and 2010) and exhibiting the highest median blood lead levels (18.2 μg/dL). Lead poisoning was also diagnosed as having caused the deaths of 23 % of Bewick's swans and 16.7 % of Canada geese and pochard recovered in Britain between 1971 and 2010.

Swans and geese commonly forage on agricultural land, over which it is legal to shoot with lead gunshot (with the exception of wetlands and specified SSSIs, depending on UK country-specific legislative details). High mortality rates have been recorded in Canada geese in the USA, poisoned by lead gunshot ingested during foraging in crop fields (Szymczak and Adrian 1978). Whooper and Bewick's swans may require particularly large quantities of grit when feeding on more indigestible foods such as potatoes, corn and barley and are thus perhaps more likely to ingest spent gunshot (O'Connell et al. 2008). The poisoning and death of Bewick's, mute and whooper swans from lead in Britain and Ireland is well documented (O'Halloran et al. 1988b; O'Halloran, unpublished results; Brown et al. 1992; O'Connell at al. 2008), and lead gunshot have been frequently found in lead-poisoned swans (Owen and Cadbury 1975; Mudge 1983; Spray and Milne 1988; O'Halloran et al. 1988a, b; O'Halloran unpublished results; O'Connell et al. 2008).

Spent lead gunshot are also accessible to diving ducks such as pochard, when they gather food items from lake bottoms and sediments which are too compact for lead items to sink out of reach (Olney 1968; CWS 2001). During the winter, pintail may exploit fields that are temporarily available through flooding (JNCC 2012) which lie outside of

permanent wetlands and that are hunted over with lead shot. Other studies elsewhere have found a particularly high prevalence of lead poisoning in pochard and pintail (e.g. values nearing or above 70 %; Mateo et al. 1997, 1998).

Spatial variation in lead poisoning

Blood lead concentrations and the proportion of birds with elevated levels (i.e. >20.0 μg/dL) varied significantly amongst sites in the present study. The highest proportions of birds with elevated levels of lead in the blood were from Martin Mere (45.2 %) and Caerlaverock (41.4 %), most likely to have resulted from current shooting with lead in areas surrounding these wetland sites (see 'Sources of lead' below), along with some residual lead from historical shooting (prior to the sites coming into WWT management in 1975 and 1970, respectively). This is consistent with previous studies which also recorded elevated lead levels (i.e. >1.21 μmol/L) in adult whooper swans caught at both sites (Spray and Milne 1988; O'Connell et al. 2008). In areas of high exposure (e.g. heavily hunted areas), the likelihood of picking up spent gunshot and repeated exposure increases (Pattee and Hennes 1983).

Location and timing of lead ingestion

Blood lead concentrations tend to reflect recent exposure of within 35–40 days of testing (O'Halloran et al. 1988a). The presence of lead in the blood of birds caught in the present study between December and February, having mostly arrived in Britain during the autumn (Rees et al. 1997; Kershaw et al. 1998; Kershaw 2002; Olgilvie 2002; Rees and Bowler 2002; Rees et al. 2002), is therefore consistent with exposure in Britain. Following arrival in Britain, long-distance winter movements are generally limited amongst Bewick's swans (Rees and Bowler 2002) although whooper swans may move between Britain and Ireland within a winter season (McElwaine et al. 1995). Sightings of swans (identified by bill pattern recognition techniques or leg rings) indicated that three of five Bewick's and 85 % (n=20) of whoopers found with elevated lead levels in the present study had been seen at WWT reserves more than 40 days prior to testing, suggesting that at least some lead is likely to have been ingested in the vicinity of reserves. Pochard are known to move from Northern Europe to Britain within the same winter although in small numbers (Keller et al. 2009). Within-winter movements for other waterbird species are less well understood (Owen and Black 1990) and hence the provenance of elevated lead levels in these species is less easily attributed.

Twelve of the 14 species of waterbird found dead from lead poisoning throughout Britain in the present study may have visited other countries during the preceding year (but is unlikely to be the case for Canada goose and mute swan). However, poisoned birds often die within 3 weeks (De Francisco et al. 2003) and sometimes within a few days of shot ingestion (Beintema 2001). Also, given the potentially debilitating nature of lead poisoning, affected birds may be less able to successfully migrate long distances. On balance, the evidence suggests that many birds dying of lead poisoning in Britain are likely to have ingested lead in Britain.

Sources of lead

In Britain, lead is still legally deposited in areas accessible to waterbirds, and thus many species remain at risk of exposure and ingestion, particularly those that graze on shot-over agricultural land. Although lead shot is still widely available and used extensively and legally for many shooting activities, birds are also likely to have ingested lead gunshot deposited following their illegal use. A recent study found that in the 10th and 11th seasons since the introduction of restrictive legislation in England (HMSO 1999, as amended in 2002 and 2003), 70 % of ducks sold by game suppliers throughout the country had been illegally shot using lead, with no apparent improvement since similar research was conducted in 2002 (Cromie et al. 2002; Cromie et al. 2010). Although questionnaire surveys of shooting participants found a good understanding of the spirit of the law, 45 % of the respondents indicated that they sometimes or never complied with the legislation (Cromie et al. 2010). To date, there has only been one prosecution relating to the legislation in England (R -v- Quince, Harrogate Magistrates Court, 16th May 2011), and this was a secondary offence, the primary offence being illegal shooting of a swan. The enforcement of local restrictions is difficult; lead shot is still legally available for use in other types of shooting, most of which occurs on privately owned land in England (Quy 2010). In the USA and Canada, compliance with legislation appears to be high which has been attributed to the support of waterfowl hunters and conservation police officers for the non-toxic shot programme (Anderson et al. 2000; Stevenson et al. 2005).

Lead gunshot may take tens or hundreds of years to break down and so can remain accessible to feeding waterbirds long after deposition (Mudge 1984; Rooney et al. 2007). While some of the lead recently ingested by waterbirds in Britain may have been deposited historically (Rocke et al. 1997; Quy 2010), it is perhaps more likely that the majority was deposited recently. Recently deposited lead gunshot is likely to be more readily available to waterbirds than historically deposited shot which may become increasingly inaccessible over time as it becomes incorporated into the substrate. However, rates of incorporation are likely to vary widely in space and time, dependent on prevailing local conditions. Research from the USA showed that of 1,345 mallard containing ingested shotgun pellets in the fifth and sixth year after a ban on the use of lead gunshot for waterfowl hunting, 68 % of birds contained only non-toxic shot

(Anderson et al. 2000). Given that the level of compliance was unknown (although it was assumed to be high; Anderson et al. 2000), this suggests that most shot ingested were those most recently deposited.

Efficacy of legislation in reducing lead-related mortality of waterbirds in England (HMSO 1986, as amended 1993; HMSO 1999, as amended 2002 and 2003; EA 2012)

The results of the present study indicate that lead poisoning continues to affect a wide range of waterbirds, long after restrictions on the use of lead shot came into force in Britain. Restrictions have worked in some countries. After a national ban on lead shot for waterfowl hunting in the USA in 1991, there was a relatively rapid decline in the rate of lead shot ingestion (Anderson et al. 2000). Consequently, 1.4 million of 90 million ducks in one year (1997) were estimated to have been spared from fatal lead poisoning (Anderson et al. 2000). The prevalence of elevated blood lead in American black ducks (*Anas rubripes*) wintering in Tennessee declined by 44 %, 6 to 8 years after the ban on lead shot (Samuel and Bowers 2000), and average bone lead concentrations in dabbling ducks and American black ducks in Canada decreased significantly following the establishment of a national regulation in 1997 prohibiting the use of lead shot for waterfowl hunting (Stevenson et al. 2005).

Results from the present study showed that the proportion of birds dying from lead poisoning in England (calculated from the noninfectious data subset) did not vary significantly after the introduction of legislation restricting the use of lead in ammunition, despite an anticipated reduction in lead deposition and subsequent exposure. Perhaps, this is not surprising given the observed lack of compliance with legislation reported in previous studies (Cromie et al. 2002 and Cromie et al. 2010) and the continued legal use of lead in areas used by waterbirds, where restrictions do not currently apply.

The proportion of mute swans dying of lead poisoning in England (calculated from the noninfectious data subset) was found to significantly change over time: from 25 % (1971–1987) to 4.6 % (1988–1999) and 2 % (2000–2010). In the 1970s and 1980s, lead angling weights were a major cause of mortality for mute swans in the UK (Birkhead 1982; Birkhead and Perrins 1986) probably because of their habit of frequenting urban rivers and lakes where fishing activity is high. These results support other evidence that legislation restricting the sale and use of lead fishing weights has had an effect in reducing lead poisoning in this species (Sears and Hunt 1991; Perrins et al. 2003).

Removing the threat of lead poisoning in waterbirds

Phasing out the use of lead shot is now widely recognised as a long-term solution for protecting waterbirds from lead poisoning, and across the world, a variety of regulations have been introduced to assist with this goal (Beintema 2001; Mateo 2009). The use of lead gunshot is banned for waterfowl hunting in the USA and Canada and banned completely in the Netherlands, Denmark and Norway (Avery and Watson 2009).

Considering the failure of current legislation in protecting waterbirds from lead poisoning in Britain, we suggest that the most practical and effective solution is likely to be an extension of current restrictions on the use of lead shot to cover all shooting. Non-toxic alternatives are widely available and their use would be consistent with the habitat goals and the 'wise use' and 'sustainable use' of wetlands principles of the Ramsar Convention (Ramsar 1971) and of the Convention on Biological Biodiversity (CBD 1992). Certain management practices (e.g. the provision of grit to reduce shot ingestion, cultivation of the soil to redistribute surface shot to deeper layers or the regulation of water levels to dissuade birds from feeding in particularly contaminated areas) should be considered in areas where lead gunshot densities are high and which are used by high concentrations of waterbirds. Such management techniques are, however, costly and time-consuming and can only be implemented on a local scale.

Given the long migrations that a number of these waterbird species undertake, during which political boundaries are repeatedly crossed, an international approach with measures taken across the distributional ranges is important if tackling the threat of lead poisoning is to be effective. A renewed commitment from international conventions, national legislation and the hunting community is needed to achieve a broad-scale transition to the use of non-toxic gunshot and angling materials in all environments and thus reduce unnecessary bird mortality and morbidity and environmental pollution.

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Appendix 3: Incidence of shotgun pellets in Bewick's swans Cygnus columbianus bewickii and whooper swans Cygnus cygnus wintering in the UK

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Incidence of embedded shotgun pellets in Bewick's swans *Cygnus columbianus bewickii* and whooper swans *Cygnus cygnus* wintering in the UK

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ABSTRACT

The migratory whooper swans (*Cygnus cygnus*) and Bewick's swans (*Cygnus columbianus bewickii*) have been protected by national and international legislation throughout their migratory ranges since the mid 20th century, yet illegal shooting of both species still occurs. X-rays taken of wild caught swans at several sites in the UK were inspected to determine: (1) the incidence of embedded pellets in live birds, (2) inter-specific differences in the level of illegal shooting, and (3) trends in the prevalence of shot-in pellets between the 1970s and the 2000s. A significantly higher proportion of Bewick's swans (31.2%) contained shot-in pellets than whooper swans (13.6%). The likelihood of a bird having been shot increased with its age for both species. The proportion of Bewick's swans with embedded shot was higher during the 1970s and 1980s than in the 1990s and 2000s but the incidence remains high, with 22.7% of Bewick's swans X-rayed in the 21st century containing shot. The prevalence of whooper swans with embedded shot did not change significantly over time (14.9% with pellets in the 1980s compared with 13.2% with pellets in the 2000s). As the swans follow different migration routes, the results not only have implications for consistent and effective implementation of legislation, but show that illegal shooting must be addressed at both national and international levels.

1. Introduction

Unsustainable hunting has caused declines and even extinctions in wildfowl populations (Kear et al., 2005). It is of particular concern in long-lived species with delayed onset of breeding and low annual productivity, which are sensitive to increases in adult mortality (Perrins, 1991; Pianka, 1970). Such species include the migratory geese and swans which breed at high latitudes, but migrate to winter across Eurasia and North America where there's an open hunting season on many wildfowl populations during the winter months. Although the hunting of migratory birds has decreased significantly in Europe since the 1950s (McCulloch et al., 1992), and several populations have been protected by being removed from the quarry list (Kear et al., 2005), illegal hunting continues for some species. Birds may also be shot illegally for other reasons such as crop protection. Bag statistics are regularly recorded for legal wildfowling activity in a number of countries, and in North America hunting regulations have been designed to be flexible in order to take account of variations in population size for quarry species (Fox, 2005). Given the illicit nature of taking protected species, however, levels of illegal hunting are more difficult to determine and remain largely unknown.

In addition to bag statistics, taking X-rays of live-caught birds has been used to provide some indication of hunting levels for quarry species, and to measure levels of wounding in waterfowl. Earlier studies have shown that 28–62% of geese (Elder, 1950, 1955; Grieb, 1970; Jonsson et al., 1985; Noer and Madsen, 1996; Noer et al., 2007; Norman, 1976) and 25–35% of sea ducks (Falk et al., 2006; Hicklin and Barrow, 2004; Noer et al., 1996, 2007) carry embedded shotgun pellets. Analyses not only provided estimates of pellet infliction rates on different populations but assessed the impacts of carrying pellets on the survival of individuals. For instance, pellet-carrying pink-footed geese (*Anser brachyrhynchus*) had significantly lower annual survival rates (0.765) than non-carriers (0.869) (Madsen and Noer, 1996) and the relative survival of shot adult mallards (*Anas platyrhynchos*) was 19% lower than for those without pellets in their tissues (Tavecchia et al., 2001). Embedded shot did not, however, have a significant effect on survival rates for teal (*Anas crecca*) (Guillemain et al., 2007). For the pink-footed goose, 36% of adult birds were found with pellets, which on correcting for a lower survival of pellet carriers corresponded to an additional annual mortality of 7% for the adult population (Madsen and Noer, 1996).

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The migratory whooper swans (*Cygnus cygnus*) and Bewick's swans (*Cygnus columbianus bewickii*) which winter in the UK have been protected from shooting under national and international legislation throughout their ranges since 1954 and 1976, respectively (Rees, 2005, 2006; Robinson et al., 2004a), yet X-rays taken of birds caught for ringing on the wintering grounds have revealed that a high proportion of live birds carry shotgun pellets in their body tissues. Evans et al. (1973) found that 34% of live Bewick's swans X-rayed in the early 1970s had embedded shot, similar to levels found in legal quarry species such as pink-footed geese (Elder, 1955; Noer and Madsen, 1996), with adult birds (>2 years) more likely to contain shot than juvenile or sub-adult (yearling) swans. Preliminary studies by Rees et al. (1990) similarly showed that whooper swans wintering in Britain carry shotgun pellets which, given the geographic distribution of the population, must have been inflicted in Britain, Ireland or Iceland.

This paper aims to analyse the number of embedded pellets recorded in X-rays taken of live-caught Bewick's swans and whooper swans, for an inter-specific comparison of illegal shooting levels for two protected species wintering in Britain which have very different distributions and migratory routes. Variation in the levels of illegal shooting is also determined by analysing trends in the proportions of birds carrying pellets over several decades; for Bewick's swans X-rayed since 1970, and for whooper swans X-rayed since 1988. Incidence of embedded shot (i.e., whether or not the birds have pellets in their tissues), and also the number of pellets recorded, is analysed in relation to the age, sex, size and condition of the birds, to identify any patterns of targeting by poachers. For instance, selective hunting of juveniles affects age ratios (but not sex ratios) of wigeon (*Anas penelope*) in winter (Mitchell et al., 2008). Potential consequences of carrying embedded pellets for the health of the birds is determined by analysing the swans' body condition in relation to whether or not a bird has been shot and the number of pellets recorded. As the location of illicit shooting could not be determined from the X-ray analysis, the frequency and location of dead swans reported as having been shot is also described to provide a broad indication of where the birds may be most at risk. The results are discussed in relation to the migration routes followed by the two species.

2. Methods

2.1. Study populations

The Northwest European Bewick's swan population, which breeds on the arctic tundra of European Russia, makes a 3200 km migration to wintering sites across Northwest Europe (Delany et al., 1999; Rees et al., 1997; Fig. 1). Large concentrations (up to 50% of the population) occur at staging sites in Estonia and the Gulf of Finland in both spring and autumn and most of the population is thought to stage at the White Sea in spring (Luigujoe et al., 1996; Nolet et al., 2001; Rees et al., 1997). The Icelandic-breeding whooper swan has a much shorter migration; about 94% of the population winters in Britain and Ireland, and the rest remain in Iceland (Rees et al., 2002; Worden et al., 2009; Fig. 1). As most of the Icelandic whooper swans' migration is over the Atlantic Ocean there are no major staging sites separate from the breeding or wintering areas (McElwaine et al., 1995; Rees et al., 2002; Newth et al., 2007).

2.2. X-raying live birds

The swans were caught in decoy-type 'swan-pipes' at four sites in Britain. Bewick's swans were X-rayed at Slimbridge, Gloucestershire (51°43′98″N, 2°25′02″W) and at Welney, Norfolk (52°31′50″N, 0°16′98′E); whooper swans were X-rayed at Caerlaverock, Dumfriesshire (54°58′02″N, 3°25′02″W), and both species at Martin Mere, Lancashire (53°37′50″N, 2°52′02″W). A total of 1018 X-rays were taken of 735 individual Bewick's swans between winters 1970/71 and 2008/09 inclusive, and 474 X-rays of 397 whooper swans between 1988/89 and 2007/08 (Table 1). Following capture the swans were placed in plastic 'swan jackets' for sexing (determined by cloacal examination), ringing and taking X-rays (Evans et al., 1973; Evans and Kear, 1972). The swans were also aged using plumage characteristics, weighed and their skull, tarsus and wing lengths were measured (Evans and Kear, 1978). Only swans recorded in their first or second winter could be aged precisely; minimum age was determined for birds first seen as adults.

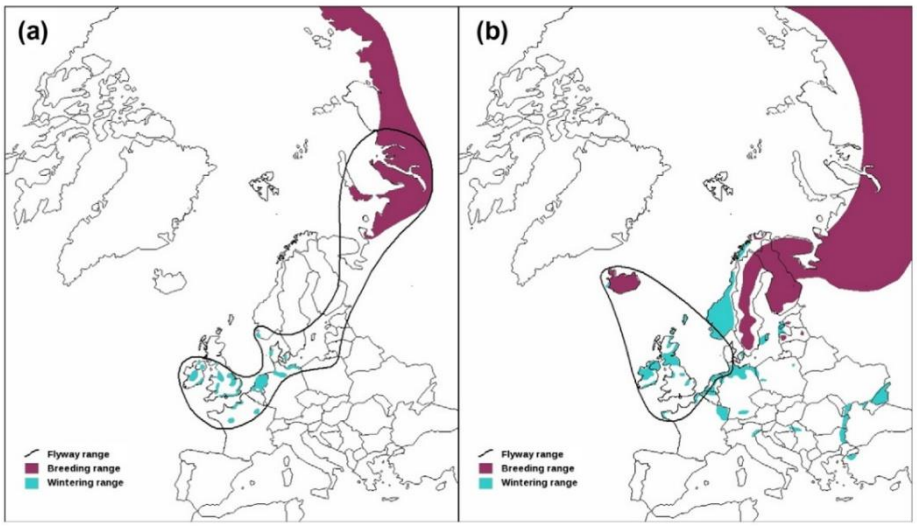

Fig. 1. Distribution of (a) the NW European Bewick's swan population and (b) the Icelandic whooper swan population (from Robinson et al. (2004a,b)).

Table 1
Number of Bewick's swans and whooper swans X-rayed at wintering sites in the UK, and the total number of X-rays taken. This includes 66 re-captured birds (54 Bewick's swans and 12 whooper swans) represented more than once in different age categories and 35 Bewick's swans represented across timeframes.

Timeframe	Winters	Site	No. individuals X-rayed (No. X-rays)	No. X-rays of adults (%)	No. X-rays of yearlings (%)	No. X-rays of cygnets (%)
Bewick's swans						
1970s	1970/71–1975/76	Slimbridge	390 (537)	335 (62.4)	80 (14.9)	122 (22.7)
1980s	1988/89–1989/90	Slimbridge	80 (94)	65 (69.1)	7 (7.4)	22 (23.4)
1990s	1990/91–1999/00	Slimbridge	208 (288)	174 (60.4)	39 (13.5)	75 (26.0)
	1990	Martin Mere	50 (50)	35 (70.0)	4 (8.0)	11 (22.0)
	1994	Welney	1 (2)	2	0	0
2000s	2000/01–2008/09	Slimbridge	44 (47)	25 (53.2)	8 (17.0)	14 (29.8)
Total			735 (1018)	636 (62.5)	138 (13.6)	244 (24.0)
Whooper swans						
1980s	1988/89–1989/90	Caerlaverock	131 (150)	104 (69.3)	25 (16.7)	21 (14.0)
2000s	2006/07–2007/08	Caerlaverock	90 (121)	90 (74.4)	13 (10.7)	18 (14.9)
	2006/07–2007/08	Martin Mere	176 (203)	152 (74.9)	14 (6.9)	37 (18.2)
Total			397 (474)	346 (73.0)	52 (11.0)	76 (16.0)

As Bewick's swans wintering at Slimbridge are identified by their natural black and yellow bill markings and also have a high level of winter site fidelity (Rees, 1987), the minimum age of an individual, and hence the minimum number of seasons that an individual had been exposed to shooting, included observations made of the swans prior to their being caught for ringing.

During the 1970s, Bewick's swans were X-rayed using a Watson MX1 portable machine at 65 kV potential and 15 mA, at a focal distance of 52.3 cm, and using Kodak R.P./D.X- Kodak R.P./D.X-omat radiographic film (30.5 cm × 38.1 cm) (Evans et al., 1973). From the 1980s onwards both species were X-rayed using a PLH Medical K6 Electronic portable machine, at 70 kV potential and 10 mA, at a focal distance of 75 cm, and using Mediphot X-ray HDC-UVB high contrast, blue sensitive radiographic film (30.0 cm × 40.0 cm). Exposure time was 1.2 s on each occasion.

After X-ray development, the total number of pellets embedded in the tissues was counted for each X-ray plate. Although pellets were readily identifiable as distinct, light dots, pellet composition (for instance, whether made of lead or steel) could not be determined from the X-ray alone. Information on materials used in the pellets can only be confirmed by extracting and analysing them, which was not have been easy to achieve or appropriate for live birds. Lead may be more likely than steel to deform on impact but this is not conclusive; during the 1970s and 1980s, when use of lead shot was almost universal, most pellets were found to be circular on the X-ray plates (Fig. 2). It therefore was not possible from inspection of the X-rays to determine the location of illegal shooting based on the type of shot used. Similarly it was not possible to assess compliance with the ban on using lead shot when shooting over wetlands, introduced in the UK and several other European Union countries during the 1990s; however, this paper aims to determine long-term changes the level of illegal shooting rather than the type of shot used.

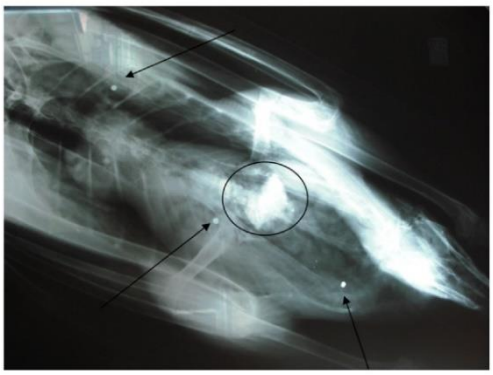

Fig. 2. X-ray of a Bewick's swan with embedded shotgun pellets (arrows) and showing the gizzard (oval).

Pellets classed from their location on the X-ray plate as being in the digestive tract or in the gizzard were considered to have been ingested by the birds as grit. The gizzard is visible on the X-ray (Fig. 2), and ingested pellets can be readily identified not only by their location in the gizzard but by their shape and size as they are eroded by the muscular action of the gizzard and by the presence of grit. Grit is semi radio-opaque, so pellets in the gizzard can also be identified by their reduced clarity where they overlap with the grit. One Bewick's swan and seven whooper swans found to have ingested pellets, but with no evidence for embedded (shot-in) pellets in their tissues, were classed as not being shot.

2.3. Post-mortem data

The primary cause of death was recorded for ringed Bewick's swans recovered from 1970 to 2009 and for ringed whooper swans recovered from 1980 to 2009. The two main data sources were *post-mortem* examination carried out routinely for swans found dead in the vicinity of Wildfowl & Wetlands Trust (WWT) centres in the UK (Brown et al., 1992) and reports to the British Trust for Ornithology (BTO), the Icelandic Institute for Natural History and the Bird Ringing Centre Moscow for birds recovered elsewhere (Rees et al., 2002; Rees and Bowler, 2002). Although the sample is likely to be biased by regional variation in reporting of shot birds, the cause of death recorded on recovery was analysed to identify some of the areas where illicit shooting has occurred.

2.4. Treatment of the data

The number of embedded pellets was determined for each individual swan each time that it was X-rayed. In analyses of (1) the proportion of birds with pellets, and (2) the number of pellets per bird, within each timeframe (i.e., year, decade or overall), birds that were captured on more than one occasion were included as a single observation only, with the highest pellet count recorded for each individual being included in the analysis. Increases in the number of pellets recorded for re-captured individuals were analysed separately to provide further information on the timing of illegal shooting, within and across decades.

To assess inter-specific differences in the incidence of embedded pellets in the swans' body tissues and the effects of time period (decade), sex, minimum age and (minimum age)^2 on the incidence of embedded pellets we used Generalised Linear Mixed Models

(GLMMs) with binomial error distributions and logit link functions. Decade rather than year was used because there was a large gap in the timing of X-rays taken for whooper swans (i.e., late 1980s, then not again until the early 2000s). GLMMs were also used to test, for each species separately, whether the presence or absence of pellets (included as a binary response variable) varied significantly with the age, sex, size and body condition of the swans and the time period (year for Bewick's swans; decade for whooper swans) in which the X-rays were taken. GLMMs with a poisson error distribution and logarithm link function similarly tested for a significant association between the same variables and the number of pellets recorded per bird. Bird identity was included as a random factor to allow for the inclusion of the same bird in >1 year. Decade and sex were treated as categorical variables. Trends in the level of illegal shooting were considered in further detail by analysing the proportion of cygnets found to have been shot each year (using a Generalised Linear Model (GLM) for Bewick's swans and, because there were fewer years' data available, an Analysis of Variance (ANOVA) for whooper swans), on the basis that these birds would have been shot at ⩽6 months before being X-rayed. Percentages were arcsine transformed prior to analysis.

Body size was included as an explanatory variable in the models to test whether larger birds were more likely to be targeted or hit; body condition was included on the basis that birds in poorer condition may be slower to respond to the presence of poachers. Size was calculated using Principal Component Analysis (PCA) to determine the first principal component (PC1) of the mean skull and mean tarsus measures recorded for individual swans (following Choudhury et al., 1996; Coleman et al., 2002). PC1s for cygnets, yearlings and adults were calculated separately to allow for increasing body size over the first 2 years of a swan's life (Evans and Kear, 1978). Body condition measures were the residual values obtained on regressing the swans' mass against their body size (PC1 of skull and tarsus; Green, 2001). Previous studies have shown that the body mass of migratory swans is relatively stable in mid-winter (Evans and Kear, 1978); maximum mass recorded for each individual in December–January in winters in which they were X-rayed therefore was used to determine body condition in the years in which the birds were X-rayed.

Whether the presence of embedded pellets had a significant deleterious effect on the swan's body condition was determined by including the swan's body condition as the dependent variable in GLMMs, specifying a normal distribution and identity link function, and with bird identity as a random factor. Decade, minimum age, the quadratic function of age (i.e., (minimum age)^2), sex, decade, whether or not the swan had embedded pellets, and interaction terms were included as explanatory variables in the initial model. Age treated as a categorical variable (0 = cygnet, 1 = yearling, 2 = adult) was tested in a separate model but the results (which also proved significant) are not reported here as minimum age provided a better fit to the body condition data. The quadratic function for minimum age was included to test in particular for any curvilinearity in the relationship between body condition and age, with birds potentially in better condition in their prime. The number of pellets recorded was also included as an independent variable to assess whether the pellet loading was significant. Non-significant variables were excluded sequentially from the GLMMS to ensure that the final models were parsimonious.

MINITAB and GenStat (version 12) software packages were used for analysis. Means are given ±SE values throughout.

3. Results

Of the Bewick's swans X-rayed, most (93% of individuals) were X-rayed at Slimbridge whereas 56% of whooper swans were X-rayed at Caerlaverock and 44% at Martin Mere (Table 1). There was no significant difference in the proportion of Bewick's swans of different age classes X-rayed in each decade ($\chi^2_6 = 7.49$, $P > 0.05$). For whooper swans, the proportion did vary, with a relatively high incidence of yearlings X-rayed in the 1980s ($\chi^2_2 = 7.46$, $P < 0.05$, Table 1), but there was no different in the proportion of adult to sub-adult whooper swans X-rayed in the 1980s compared with the 2000s ($\chi^2_1 = 1.49$, $P > 0.05$). In the 2000s, when whooper swans were X-rayed at both Caerlaverock and at Martin Mere, differences between sites in the percentage of birds found to contain shot (Caerlaverock: 17.8%, $n = 90$; Martin Mere 10.8%, $n = 176$) were not significant ($\chi^2_1 = 2.54$, $P = 0.11$, n.s.).

3.1. Inter-specific comparison

Overall, 31.2% (SE 3.3, $n = 735$) of Bewick's swans and 13.6% (SE 3.4, $n = 397$) of whooper swans were found to be carrying pellets, rising to 43.2% (SE 4.6, $n = 438$) and 16.3% (SE 4.3, $n = 288$) for adult birds, respectively. There was a significant inter-specific difference in the incidence of embedded pellets for the years in which both species were X-rayed (1988, 1989, 2007 and 2008) (GLMM: $F_{1,552} = 10.32$, $P < 0.001$), and the incidence of pellets also increased with the age of the bird (GLMM: $F_{1,552} = 33.46$, $P < 0.001$; Fig. 3) but there was no significant difference between the sexes in the likelihood of a bird being shot (GLMM: $F_{1,552} = 2.79$, $P = 0.095$, n.s.).

For adult swans with pellets, the number of pellets recorded for individual birds did not differ between species (mean = 2.9 ± 0.2 pellets for Bewick's swans, mean = 2.2 ± 0.3 pellets for whooper swans; Mann–Whitney U test, $W = 23046.5$, $P = 0.1210$, n.s.). Most shot birds received 1–3 pellets but up to 30 pellets were recorded in Bewick's swans (one bird at Slimbridge in 1991) and up to 11 pellets in whooper swans (one bird at Caerlaverock in 2007; Fig. 4).

3.2. Increase in the number of pellets per bird

Of 176 Bewick's swans and 61 whooper swans captured and X-rayed on more than one occasion, 48 (27.3%) and 2 (3.3%) respectively were recorded with more pellets when caught subsequently. There was evidence that illegal shooting occurred at wintering sites in Britain; of 39 Bewick's swans re-captured within the same winter at Slimbridge, 5.1% (two individuals) were recorded with a higher pellet count when X-rayed on the second occasion. A total of 25 whooper swans were X-rayed more than once in the same winter of which one bird X-rayed at Caerlaverock had one additional pellet when X-rayed again.

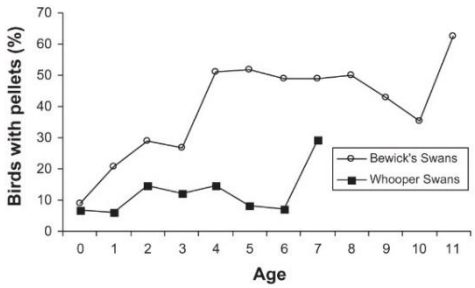

Fig. 3. Percentage of birds with embedded pellets in relation to their age (in years) for Bewick's swans X-rayed between 1970 and 2008 and for whooper swans X-rayed between 1988 and 2007.

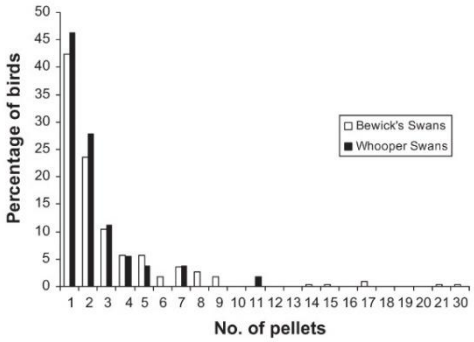

Fig. 4. Pellet count frequency in Bewick's and whooper swans, recorded as the percentage of swans of each species found to at least one embedded pellet.

3.3. Trends over time

The proportion of Bewick's swans recorded as shot each year varied significantly between the years (Fig. 5) and across the decades (1970s = 34.1%, 1980s = 38.8%, 1990s = 27.1%, and 2000s = 22.7%), with the incidence of pellets increasing significantly with the age of the bird (GLMM: $F_{1,961} = 69.61$, $P \leqslant 0.001$; Fig. 3) and decreasing over time (GLMM: $F_{1,961} = 12.52$, $P \leqslant 0.001$; Fig. 5). Moreover, more Bewick's swans were found to have incurred pellets when re-captured during the 1970s than during the 1980s ($\chi^2_1 = 2.60$, $P = 0.11$, n.s.) and the 1990s ($\chi^2_1 = 10.01$, $P = 0.002$); there was no such increase in pellet count for the small number ($n = 2$) of Bewick's swans re-captured in the 2000s (Fig. 6).

The proportion of whooper swans recorded as shot varied little between the years (Fig. 5) and across the two decades: 14.5% of those X-rayed in the 1980s and 13.2% of those X-rayed in the 2000s ($F_{1,438} = 0.01$, n.s. for time period). Moreover, there was no difference in the proportion of birds with increased pellet count on re-capture between the 1980s and 2000s, with only one bird having an increase in pellet count in each decade (Fig. 6). The proportion of shot cygnets recorded each year was analysed to provide a more definitive indication of trends in illegal shooting, but no significant differences were found for Bewick's swans (GLM: $R^2 = 0.32$, $F_{1,18} = 1.1$, $P = 0.314$, n.s.) or for whooper swans (ANOVA: $F_{1,3} = 0.68$, $P = 0.497$, n.s.).

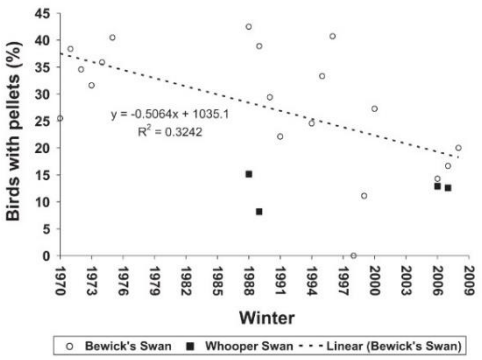

Fig. 5. Incidence of shotgun pellets for Bewick's swans X-rayed between 1970 and 2008 and for whooper swans X-rayed between 1988 and 2007.

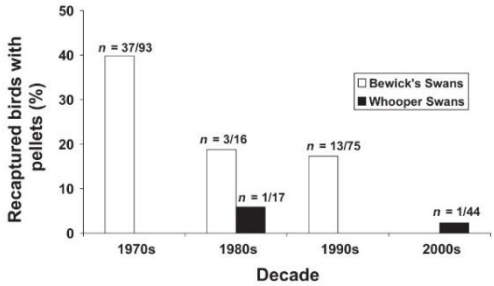

Fig. 6. Percentage of Bewick's and whooper swans with an increased pellet count on re-capture (n = number of birds shot/number of birds X-rayed more than once).

3.4. Variables associated with the presence or absence of embedded shot

For Bewick's swans, the minimum age of the swan and also the decade in which the bird was X-rayed were significantly associated both with the incidence of embedded shot (GLMM: $F_{1,961} = 69.61$, $P < 0.001$ for minimum age; $F_{1,961} = 12.52$, $P < 0.001$ for decade) and with the number of pellets recorded (GLMM: $F_{1,790} = 21.06$, $P < 0.001$ and $F_{1,790} = 14.62$, $P < 0.001$ respectively). Body size was associated with the number of embedded pellets found for Bewick's swans (GLMM: $F_{1,790} = 4.84$, $P = 0.028$) but not for whooper swans (GLMM: $F_{1,237} = 1.75$, $P = 0.186$, n.s.). Minimum age of the bird proved significant for whooper swans (GLMM: $F_{1,438} = 10.23$, $P < 0.001$ for incidence of shot; $F_{1,438} = 14.06$, $P < 0.001$ for number of pellets per birds) (Fig. 3), but sex and body condition did not have a significant effect on the likelihood of a bird having embedded pellets for either species.

3.5. Effects of embedded pellets on the swans' body condition

The body condition of the swans varied significantly with the sex and minimum age of the bird, and the swans' condition also varied across the decades (GLMM: $F_{1,624} = 129.31$, $F_{1,624} = 160.74$ and $F_{3,624} = 6.44$ respectively for Bewick's Swans; $F_{1,237} = 89.23$, $F_{1,237} = 28.59$ and $F_{1,237} = 17.64$ for whooper swans; $P < 0.001$ in each case). For Bewick's swans, condition was highest in the 1980s (mean residual = 0.40 ± 0.11) and lowest in the 2000s (-0.46 ± 0.23), with whoopers showing a similar pattern (0.34 ± 0.10 and -0.52 ± 0.08 in the 1980s and 2000s). The presence or absence of embedded pellets did not have a significant effect on whooper swan body condition, or on Bewick's swan condition when all birds were considered, but it approached significance for adult Bewick's swans (GLMM: $F_{1,375} = 2.98$, $P = 0.085$, n.s.) with swans with pellets apparently in poorer condition than those without pellets for adults of both sexes (Fig. 7). Bewick's swan cygnets with embedded pellets conversely appeared to be in better condition than those without pellets (Fig. 7), but only the sex of the bird was significantly associated with its body condition on analysing cygnet data only (GLMM: $F_{1,165} = 14.36$, $P < 0.001$ for sex; $F_{1,165} = 2.39$, $P = 0.124$, n.s. for pellets versus no pellets). The number of pellets recorded was not significantly associated with body condition, so was excluded from the final model.

3.6. Numbers reported killed by poachers

The cause of death was determined for just 98 of 202 ringed Bewick's swans found dead since 1970 and 361 of 962 ringed whooper swans found dead since 1980. Of these, 17 Bewick's

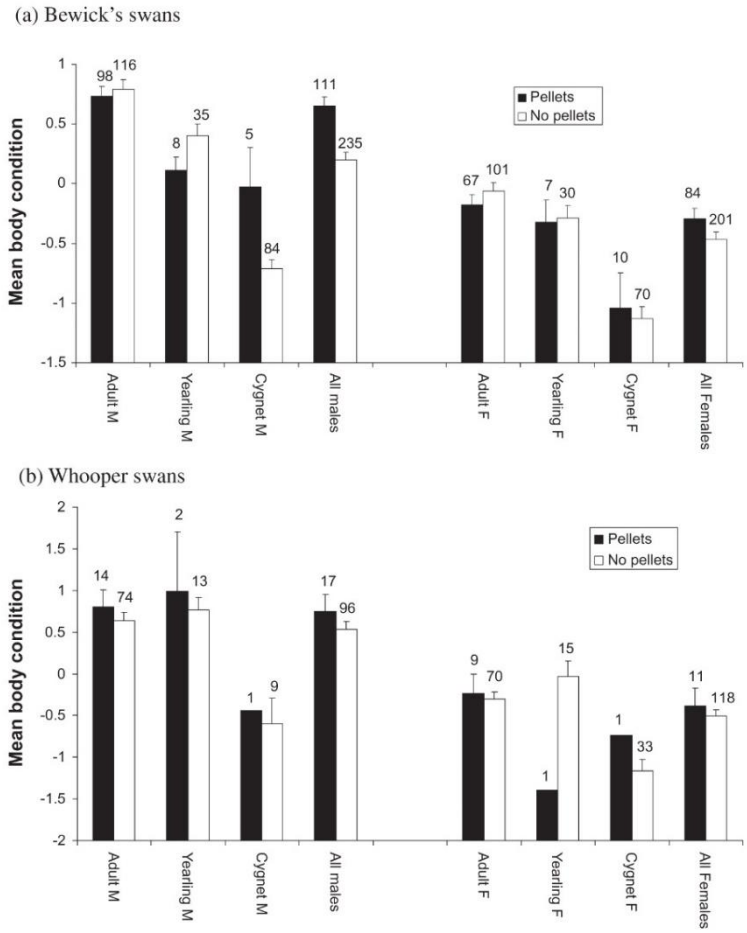

Fig. 7. Mean body condition (calculated as the residuals from regressing mid-winter mass with body size) recorded for swans with and without embedded shotgun pellets for (a) Bewick's swans and (b) whooper swans. For whooper swans, there was only one bird recorded with pellets for cygnet males, cygnet females and yearling females (n = number of birds recorded with mean body condition).

swans (17.3% of birds where the cause of death was known; 8.4% of all recoveries) and 30 whooper swans (8.3% of birds where the cause of death was known; 3.1% of all recoveries) were reported as having been shot. For Bewick's swans where the cause of death was known, the proportion found to have been shot across the decades was 15.8% (n = 6/38) in the 1970s, 14.3% (n = 5/35) in the 1980s, 26.3% (n = 5/19) in the 1990s and 16.7% (n = 1/6) in the 2000s. For whooper swans, the proportions were 23.9% (n = 11/46) in the 1980s, 7.0% (n = 14/200) in the 1990s and 4.3% (n = 5/115) in the 2000s. Of the Bewick's swans reported shot, 12 were found in Russia, one in Estonia and four in Britain. Of the whooper swans, 20 were shot in Iceland, five in Britain, two in Ireland and one in France.

4. Discussion

The Icelandic whooper swan population and the Northwest European Bewick's swan population are legally protected from hunting throughout their migratory ranges under national legislation (since 1885 in Iceland, 1954 in the UK, 1964 in Russia and 1976 in the Republic of Ireland) and international legislation (under 1979 EU Birds Directive and the 1999 African–Eurasian Waterbird Agreement), yet high levels of illegal shooting persist for both species. Overall, 31.2% of Bewick's swans and 13.6% of whooper swans X-rayed contained shot-in pellets, including 10 (22.7%) of 44 Bewick's swans and 35 (13.2%) of 266 whooper swans X-rayed in the 21st century. The particularly high incidence of pellets in Bewick's swans is similar to that recorded for quarry species such as the pink-footed goose, with 41% and 36% of geese X-rayed in Britain and Denmark found to be carrying pellets (Elder, 1955; Noer and Madsen, 1996). It is also similar to data recorded for six species of duck caught and X-rayed at Slimbridge between 1980 and 1982: 17.6% of mallard (*Anas platyrhynchos*; n = 91), 27.1% of pintail (*Anas acuta*; n = 108), 25.0% of pochard (*Aythya ferina*; n = 116), 14.9% of tufted duck (*Aythya fuligula*; n = 107), 25.8% of shoveler (*Anas clypeata*; n = 31) and 26.3% of gadwall (*Anas strepera*; n = 19) had embedded pellets (WWT unpubl. data), with the relatively low incidence for mallard perhaps reflecting a relatively localised, non-migratory group. The high level of embedded shot

found in Bewick's swans probably reflects their comparatively long overland flight across Europe to breeding grounds in arctic Russia, whereas most of the whooper swans' ~800 km migration is an overseas flight from Britain or Ireland to Iceland. Bewick's swans also cross more political boundaries and compliance with legislation may be better in some countries than others. Thus illegal shooting needs to be addressed at both national and international levels.

The likelihood of being shot appeared to increase with age for both species, reflecting the greater time that older birds have been exposed to the risk of shooting. Potentially lower survival rates of younger pellet carriers may also explain the differences in pellet frequency across age cohorts. Although survival rates of shot pink-footed geese have been found not to vary between age classes (Madsen and Noer, 1996), Merkel et al. (2006) found that juvenile common eiders (*Somateria mollissima*) with embedded lead shot were more likely to have a poorer body condition than pellet carrying adult birds. For Bewick's swans, however, there was some indication of body condition being lower in adults with pellets, but not for cygnets with pellets, which may perhaps reflect the cygnets having carried the pellets for a relatively short time. Previous studies have demonstrated a relationship between body size and pellet incidence, whereby larger birds have a greater surface area for pellets to hit (Elder, 1955; Evans et al., 1973; Hoffman, 1965). The likelihood of having been shot was not associated with body size for the swans in our study, though the number of embedded pellets was significantly higher for larger Bewick's swans suggesting that if a bird is targeted then size may affect the extent to which it's peppered with shot.

With such high levels of wounding, significant shooting mortality seems likely. Earlier studies report that pink-footed geese and mallards carrying pellets in their tissues have a significantly lower survival than non-carriers (Madsen and Noer, 1996; Tavecchia et al., 2001). Illegal shooting is an established cause of death in both swan species; earlier studies reported that 7.4% of adult Bewick's swans (Brown et al., 1992) and 13% of whooper swans (Rees et al., 2002) were illegally shot or deliberately taken by man. *Post-mortem* data analysed for this study indicated that illegal shooting caused the death of 8.4% of 202 Bewick's swans recovered since the 1970s (17.3% of 98 birds where the cause of death was known) and 3.1% of 962 whooper swans recovered since the 1980s (8.3% of 361 birds where the cause of death was known), though it should be noted that there is probably a bias in reporting rates, with shot birds more likely to be reported than swans dying of disease or exhaustion during migration. Further analysis is needed to determine the impact of illegal shooting on the survival of the migratory swans, including an assessment of whether illegal shooting provides additive or compensatory mortality to that of birds dying of other causes (Fox et al., 2006).

4.1. Trends over time

The prevalence of pellets in Bewick's swans varied over the decades but remained high throughout the study. However, higher proportions of shot birds were recorded during the 1970s and 1980s than in the 1990s and 2000s and significantly more Bewick's swans had an increase in pellet count on re-capture in the 1970s than in the 1990s. This apparent reduction in levels of illegal shooting may perhaps be due to legislative messages being communicated and absorbed more effectively, for instance with fewer hunters being unaware of the protected status of swan species.

Protective legislation has had some success in reducing illegal shooting for other waterfowl species. The establishment of hunting restrictions and hunting-free zones within EU Special Protection Areas in Denmark was linked to a reduction in illegal shooting of mute swans (*Cygnus olor*), with suggestions of increasing legislative compliance since 1979 EU Birds Directive (Andersen-Harild et al., 2002). The Greenland white-fronted goose (*Anser albifrons flavirostris*) population doubled following shooting restrictions and site protection on both wintering and breeding grounds (Fox et al., 2006). There is evidence that hunting levels have declined for other species in Europe, with McCulloch et al. (1992) demonstrating a significant overall decrease in hunting for most of 20 migratory species surveyed since 1950, with changes thought to be at least partly attributable to a real decline in addition to changes in reporting the shooting of species which are now protected. More recently, in southern Europe, there has been a significant decrease in the proportion of birds admitted to rehabilitation centres due to shooting and an increase in those admitted due to impacts with infrastructure since the mid 1990s, with the number of hunting licenses also decreasing during this time (Martínez-Abraín et al., 2009).

Despite indications that levels of illegal shooting have reduced for Bewick's swans, complacency should not prevail. Illegal shooting levels were comparatively low in the whooper swan population, but there was little variation between the 1980s and 2000s in the proportion of shot birds. This suggests that adherence to protective legislation has not improved in the range countries of this population (i.e., Britain, Ireland and Iceland) since the 1980s, although the extent to which legislation has influenced the frequency of wounding cannot be determined as there are no pre-legislative X-ray data available for swan species.

4.2. Location of illicit shooting

Despite the high levels of illegal shooting, determining 'hot-spot' areas where the birds are at risk is more difficult, although there is evidence to suggest that birds are shot throughout their ranges. Some birds X-rayed more than once in a winter were found with an increased pellet count on re-capture, revealing that both species have been shot at wintering sites in Britain. WWT-ringed Bewick's swans have also been found shot dead in Estonia and Russia, whilst shot whooper swans have been recovered in Iceland, France and Ireland. Although Morozov (2006) suggested that violation of hunting regulations is rife in Russia, the precise locations of illegal shooting hot-spots remain unclear for both flyways. Whether and where accidental shooting occurs, with swans potentially being hit inadvertently when in mixed flocks with quarry species of geese, also needs to be determined.

4.3. Conservation implications

Although illegal shooting of Bewick's swans has declined since the 1970s it remains a threat for both Bewick's and whooper swans. Given the long migrations undertaken, during which political boundaries are repeatedly crossed, a flyway approach is important if tackling the level of illegal shooting is to be effective. International collaboration in coordinating research and conservation activity is required for the successful reduction of poaching, as demonstrated for other hunted species, particularly as adherence to national and international legislation is likely to vary between countries. In particular, the threat may be reduced through stricter enforcement of legislation at the national level and by increasing public awareness of the issue. Improved engagement with hunting organisations across the flyways is needed to ensure that hunters are fully aware of which species are protected, to provide training in bird identification where this is found to be needed, to identify areas where the birds are most at risk, and to determine and address any other reasons (e.g. crop protection) for illegal shooting.

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Appendix 4: Exemplar factor array (Chapter 3)

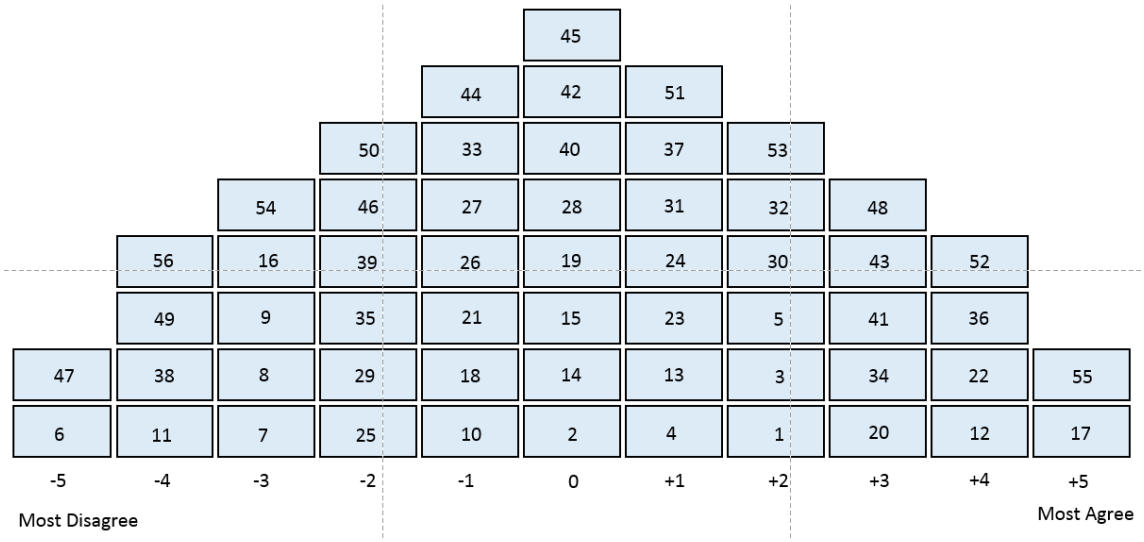


Figure S3.1: The exemplar array for Factor 1 incorporating views of ammunition users in the UK on the risks arising from use of lead ammunition and mitigating measures. The array was created by combining a weighted average of all significantly loading Q-sorts.

Appendix 5: Selection criteria for unrotated factors (Chapter 3)

Table S3.1: Selection criteria for two unrotated factors derived from a Q-method study of ammunition users. Criteria for factor selection were met for Factors 1 and 2: combined they explained 43% of the explained variance (Kline 1994; Watts & Stenner 2012), Eigenvalues exceeded 1.0 (Kaiser-Guttman criteria: Guttman 1954; Kaiser 1960, 1970), the cross-product of each factor's two highest loadings exceeded twice the standard error of the correlation matrix (i.e. >±0.27, Humphrey's Rule; Brown 1980), and there were two or more significant factor loadings (i.e. ≥ ±0.34) following extraction (Brown 1980).

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Unrotated % explained variance	25	18	3	1	3
Unrotated Eigenvalues	7.4	5.4	1.0	0.3	1.0
Humphrey's Rule	0.48	0.44	0.09	0.04	0.09
Number of Q-sorts significantly loaded onto unrotated factors	25	16	1	0	2

Appendix 6: Survey questions for Russian hunters used in Chapter 4

S4.1: Survey questions used in the interviews with participants. Grey highlighted text relates to instructions for the facilitator and was not disclosed to the participant.

Questionnaire for hunters in the Arkhangelsk Oblast and Nenets Autonomous Okrug, Arctic Russia

(A) Do you regard yourself as a hunter?
Please circle relevant answer

i. Yes
ii. No
iii. I don't know

[If the respondent answers YES, proceed with the interview. If the respondent answers NO or DON'T KNOW, explain that this survey is intended for hunters, thank them for speaking with you and FINISH HERE]

If YES:
Why do you regard yourself as a hunter?

_____
_____
_____
_____
_____

First I'm going to ask you some questions about yourself.

Section 1: Socio-demographic variables

1. Gender: Male / Female *Please circle relevant answer*

2. Age: *Please circle relevant answer*
   (a) 18-24
   (b) 25-34
   (c) 35-44
   (d) 45-54
   (e) 55-64
   (f) 65+

3. Ethnicity:

4. Place of residence (name of community/village):

5. Sector of occupation: *Please circle relevant answer*
   a) Industry
   b) Agriculture (Reindeer herding)

c) Fish industry
d) Transport and communications
d) Building industry
e) Trade and catering
f) Medicine
g) Education and culture
h) Housing and utilities
i) Administration
j) Tourism
k) Other: please explain:

6. How many days do you hunt? *Please state number of days*

a) In the spring season _____ days
b) In the fall season _____ days
c) During a year _____ days

Section 2: Knowledge about Bewick's swans

Now I am going to ask you some questions about swans.

7. Can the respondent identify the three swan species?

[Show respondent a photograph of each swan (on three cards labelled A, B and C). Ask them to identify each swan species and record whether they can/cannot identify each in the table below.]

Can the respondent identify the swan on the following cards? Under each card, write YES or NO.

Card A	Card B	Card C

Any notes about identification?

8. In the last 10 years, have numbers of Bewick's swans in your area [insert name of area]
Please circle relevant answer
(a) Increased
(b) Decreased
(c) Remained the same
(d) I don't know

9. During their lives, Bewick's swans have:
Please circle relevant answer
(a) The same partner
(b) More than one partner

(c) I don't know

10. Bewick's swans:
    Please circle relevant answer
    (a) Stay in Russia all year
    (b) Spend time outside of Russia for part of the year
    (c) I don't know

Section 3: Legal knowledge

11. Is it currently allowed to hunt Bewick's swans in the [insert region]?
    Please circle relevant answer
    (a) Yes
    (b) No
    (c) I don't know

Section 4: Behaviour

Please reiterate to respondent that all answers will remain **anonymous** and **confidential**

12. In the past 3 years, I have hunted Bewick's swans in the [insert region]
    Please circle relevant answer
    (a) Yes
    (b) Yes, but accidentally
    (c) No
    (d) I don't want to answer

Thank you very much for your time and participation. Do you have any comments or questions?

Appendix 7: Independent variables used in the global model (Chapter 4)

Table S4.1: Independent variables used in the global model. Data was collected during the survey of 232 hunters living in the NAO and AO in 2016.

Variable	Type of variable	Level
Socio-demographic		
Age	Categorical	18–24 (=1); 25–34 (=2); 35–44 (=3); 45–54 (=4); 55–64 (=5); 65+ (=6)
Ethnicity*	Categorical	Russian; Nenets; Komi; Other (Georgian, Ukrainian, Pomor, Mordvin and Udmurt); No answer
Employment sector*	Categorical	- Those likely to involve interactions with the natural environment (reindeer herding, conservation, the fish industry, tourism, nomadism and meteorology); - Those unlikely to involve such interactions (housing and utilities, transport and communications, trade and catering, the building industry, administration, emergency services, industry, education and culture and medicine); - 'Other' (including pensioners, the unemployed and those for whom employment sector was unknown).
Region of residence	Categorical	Nenets Autonomous Okrug; Arkhangelsk Oblast

Knowledge/perceptions about Bewick's swan ecology and protective laws		
Perceptions of trends in Bewick's swan population over the previous ten years	Categorical	Population increase; Population decrease; Population remained the same
Knowledge of monogamous behaviour among Bewick's swans	Categorical	Answered incorrectly (=0); Answered correctly (=1)
Knowledge of their migration	Categorical	Answered incorrectly (=0); Answered correctly (=1)
Knowledge of laws protecting Bewick's swans	Categorical	Answered incorrectly; Answered correctly; Did not know
Hunting identity/habits		
Hunter identity: reason for regarding oneself as a 'hunter'†	Categorical	Due to an appreciation of the natural world; Not due to an appreciation of the natural world; Did not know
Hunting frequency‡	Continuous	Number of days per year spent hunting (the maximum value was used when a range was given)
Distance to Bewick's swans		
Distance of settlement to nearest key Bewick's swan site	Continuous	Number of kilometres calculated from location of settlement to key Bewick's swan sites identified in Mineyev 1991; Nolet et al. 2001; Rees 2006 and Nagy et al. 2012

*We grouped the respondents' employment sector into three categories. Ethnicity for five individuals that identified themselves as Georgian, Ukrainian, Pomor, Mordvin or Udmurt, were classified as 'other'.
†An inductive thematic analysis (Braun & Clarke 2006) was undertaken on responses to the question, "why do you regard yourself as a hunter?" (hereafter referred to as 'hunter identity'). This involved the identification of themes that emerged from the data.
‡A measure of hunting frequency was derived from a question that asked how many days per year respondents spent hunting.

Appendix 8: Survey questions for Russian hunters used in Chapter 5

S5.1: Survey questions used in interviews with 236 hunters in the European Russian Arctic.

Questionnaire for hunters in the Arkhangelsk Oblast and Nenets Autonomous Okrug, Arctic Russia

(A) Do you regard yourself as a hunter?

Please circle relevant answer

i. Yes
ii. No
iii. I don't know

[If the respondent answers YES, proceed with the interview. If the respondent answers NO or DON'T KNOW, explain that this survey is intended for hunters, thank them for speaking with you and FINISH HERE]

If YES:
Why do you regard yourself as a hunter?

First I'm going to ask you some questions about yourself.

Section 1: Socio-demographic variables

1. Gender: Male / Female *Please circle relevant answer*

2. Age: *Please circle relevant answer*
   (a) 18-24
   (b) 25-34
   (c) 35-44
   (d) 45-54
   (e) 55-64
   (f) 65+

3. Ethnicity:

4. Place of residence (name of community/village):

5. Sector of occupation: *Please circle relevant answer*
   (a) Industry
   (b) Agriculture (Reindeer herding)
   (c) Fish industry
   (d) Transport and communications
   (e) Building industry
   (f) Trade and catering
   (g) Medicine
   (h) Education and culture
   (i) Housing and utilities
   (j) Administration
   (k) Tourism
   (l) Other: please explain

6. Your occupation: *Please circle relevant answer*
   (a) Full time job
   (b) Seasonal work
   (c) Currently unemployed
   (d) Pensioner
   (e) Student
   (f) Other: please explain

Section 2: Perceptions about hunting activity

Next I am going to ask you a few questions about hunting activity in your area.

7. Bewick's swans are hunted near my village
   Please circle relevant answer
   (a) Yes
   (b) No
   (c) I don't know

8. Bewick's swans are hunted on the tundra
   Please circle relevant answer

   (a) Yes
   (b) No
   (c) I don't know

Section 3: Attitude towards protective laws

Now I would like to ask your opinion about regulations protecting Bewick's swans in the {insert area}. Please tell me how much you either agree or disagree with the following statement, where 1 is strongly disagree, and 5 is strongly agree.

9. Local people should be authorized to hunt Bewick's swans in [insert region] under some circumstances

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly agree

   (a) If AGREE or STRONGLY AGREE, under which circumstances do you think this should be permissible?

Section 4: Attitude towards hunting Bewick's swans

Now I would like to ask how you feel about hunting Bewick's swans. On a scale of 1 to 5, how do you feel about the following statements:

10. For me the hunting of a Bewick's swan in this area would be

1	2	3	4	5
Very bad	Bad	Neutral	Good	Very good

(a) If the respondent answers **"GOOD"** or "**VERY GOOD"**, please ask them to explain **Why**:

Section 5: Social context

I am now going to read some statements. On a scale of 1 to 5, how do you feel about the following statements:

11. People who are important to me think that it is ok to hunt Bewick's swans in this area

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly agree

Section 6: Practicalities

With the following statements, please tell me how much you either agree or disagree with each, where 1 is strongly disagree, and 5 is strongly agree.

12. There is nothing stopping me from using guns and ammunition to hunt Bewick's swans in this area

1	2	3	4	5
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

(a) Are there any barriers to shooting Bewick's swans in this area?

Section 7: Motivations for hunting

I am now going to read some statements about possible motivations for hunting Bewick's swans in [insert region]. Please rate each statement from 1 to 5 where 1 is 'very unlikely' and 5 is 'very likely'.

13. People in this area hunt Bewick's swans because:		Very unlikely	Unlikely	Neutral	Likely	Very likely
(a)	Bewick's swans provide food for those in villages/towns	1	2	3	4	5
(b)	Bewick's swans provide food for inhabitants of the tundra (Reindeer herders)	1	2	3	4	5
(c)	It is an enjoyable sport	1	2	3	4	5
(d)	People think Bewick's swans have a negative impact on other breeding waterbirds on the tundra	1	2	3	4	5
(e)	People think Bewick's swans have a negative impact on other breeding waterbirds near the village	1	2	3	4	5
(f)	People think that the number of Bewick's swans in the area is increasing / high	1	2	3	4	5
(g)	Bewick's swans usually arrive during the hunting season	1	2	3	4	5
(h)	Bewick's swans often arrive before the geese in the spring	1	2	3	4	5
(i)	There is no enforcement of protective laws	1	2	3	4	5

14. Do you think there are any other reasons for hunting Bewick's swans in this area?
    Please circle relevant answer
    (a) Yes
    (b) No
    (c) I don't know

If you have answered **YES**, please explain further

Section 8: Behavioural intentions

[Please reiterate to respondent that all answers will remain **anonymous** and **confidential**]

Please tell me how much you either agree or disagree with the following statement, where 1 is strongly disagree, and 5 is strongly agree.
You don't have to give your opinion if you don't want to, but if you feel comfortable then please proceed.

15. I intend to hunt Bewick's swans in [insert region] in the next 3 years
    Please circle relevant answer

1	2	3	4	5
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

Now I am now going to ask two direct questions. Again, you don't have to answer these if you don't want to, but if you feel comfortable then please proceed.

16. In the past 3 years, I have hunted Bewick's swans in [insert region]
    Please circle relevant answer
    (a) Yes
    (b) Yes, but accidentally
    (c) No
    (d) I don't want to answer

Thank you very much for your time and participation. Do you have any comments or questions?

Appendix 9: Socio-demographic characteristic of hunters (Chapter 5)

Table S5.1: Socio-demographic characteristics of 236 hunters surveyed in the European Russian Arctic in 2016.

Variable	Category (no. of respondents)
Gender	Female (4) Male (232)
Ethnicity	Nenets (60) Russian (154) Komi (14) Georgian (1) Mordvian (1) Pomor (1) Udmurt (1) Ukrainian (1) No Answer (3)
Age category	18-24 (13) 25-34 (55) 35-44 (63) 45-54 (56) 55-64 (37) 65+ (12)
Sector of occupation	Industry (12) Agriculture (Reindeer herding) (17) Fish industry (6) Transport and communications (21) Building industry (16) Trade and catering (22) Medicine (2) Education and culture (12) Housing and utilities (35) Administration (15) Tourism (2) Emergency services (13) No Answer (35) Other (28)
Occupation	Full time job (169) Seasonal work (12) Currently unemployed (17) Pensioner (33) Student (4) Other (1)

Appendix 10: Motivations for hunting Bewick's swans (Chapter 5)

Table S5.2: Responses from 26 hunters when asked to suggest motivations for hunting Bewick's swans in the European Russian Arctic. The words and phrases represent themes that emerged from an inductive thematic analysis of responses (Braun & Clarke 2006) that were translated from Russian into English.

Theme	**Response**
No geese during hunt	If the goose has not arrived
More meat	Swans contain more meat
Experience	For the sake of the experience
Varied diet	For a variety of food, diet products
Interrupts sleeping	If the birds stop me from sleeping
Curiosity about meat	Interest (if the person has never tasted meat of swan)
Stupidity	Stupidity and greed
Swan like a wolf / Misidentification of species	The stories of hunters that "Swan is worse than the wolf" creates a certain attitude to the swan. The swan hunters do not distinguish swans, and then shoot Bewick's swans.
Skins for clothes	Skins are used to make vests
Swan like a wolf	Swan has a wolf lifestyle. The fish die because of them, the other birds fly away. Swan behaviour is very aggressive and individualistic. They don't allow other animals to live near themselves normally
Alcohol	Alcohol
Monetary	Money (for sale)
Skins for clothes	Manufacture of insoles from down the ventral portion of swan skins
Curiosity about meat	Curiosity, a desire to try his meat
More meat	The swan has much meat
Not aware swans are protected	People do not know that swans are in the Red Book: many believe that they are not in the Red Book
Sports challenge/experience	Sporting interest (excitement)
Stupidity	Dullness and stupidity
Varied diet	For a varied diet
More meat / Swans fly slowly	Because swans have more meat than the geese; they fly slowly
Fun	For fun
Mischief	Mischief
Curiosity	Curiosity
Sports challenge/experience	Interest to win (outwit) swan
Food	A small part for food
No birds during hunt	The absence of other birds during the hunt. Seduction

[1]*"Swan like a wolf"* refers to the perception that the swans' behaviour is "*very aggressive and individualistic*" and they "*don't to allow other animals to live near them"*.

Appendix 11: Memo for Hunters in the Nenets Autononmous Okrug

Правильная охота имеет ряд запретов и ограничений

Цивилизованный охотник должен знать правила охоты своего региона и уметь отличать охотничьи виды от редких и охраняемых видов птиц.
В соответствии с Правилами охоты, составленными на основании традиционных способов и сроков охоты:

- Нельзя нарушать устанавливаемые местными органами власти сезонные сроки и нормы добычи дичи, а также границы особо охраняемых территорий (зеленых зон, заказников, заповедников, национальных парков).
- Запрещена охота на виды птиц, не указанные в разрешении (лицензии) на охоту и не относящиеся к охотничьим видам. Перечень видов, отнесённых к объектам охоты, приведен в Правилах охоты (ПРИКАЗ от 16 ноября 2010 г. N 512)
- На гусей и уток разрешается только охота с гладкоствольным оружием или с ловчими птицами. Нарезное и пневматическое оружие, луки, арбалеты, рогатки, любые самоловные орудия добычи, химические отравляющие и взрывчатые вещества для охоты запрещены. Запрещена ночная охота на птиц с использованием фонарей и прожекторов. Запрещена охота с применением автомототранспортных средств, за исключением охоты с плавсредств (лодки) с выключенным мотором.
- Весенняя охота на гусей и селезней разрешается только из укрытий (шалашей, скрадков). При этом весной запрещена ходовая охота (с подхода, с подъезда). Весной запрещен отстрел самок уток. Не разрешена весенняя охота на водоплавающих с собаками и с ловчими птицами, за исключением применения подружейных собак для отыскивания раненой пернатой дичи (подранков) и подачи добытой пернатой дичи;
- Во время охоты на водоплавающую дичь разрешено использование подсадных уток и манных гусей наряду с традиционными манками, чучелами и профилями. Не допускается применение на охоте любых электронных звуковоспроизводящих устройств, как специализированных электроманков, так и кустарных комбинаций с применением обычных звуковоспроизовдящих устройств.
- Запрещены разорение гнезд и сбор яиц диких птиц.

Этика охотника

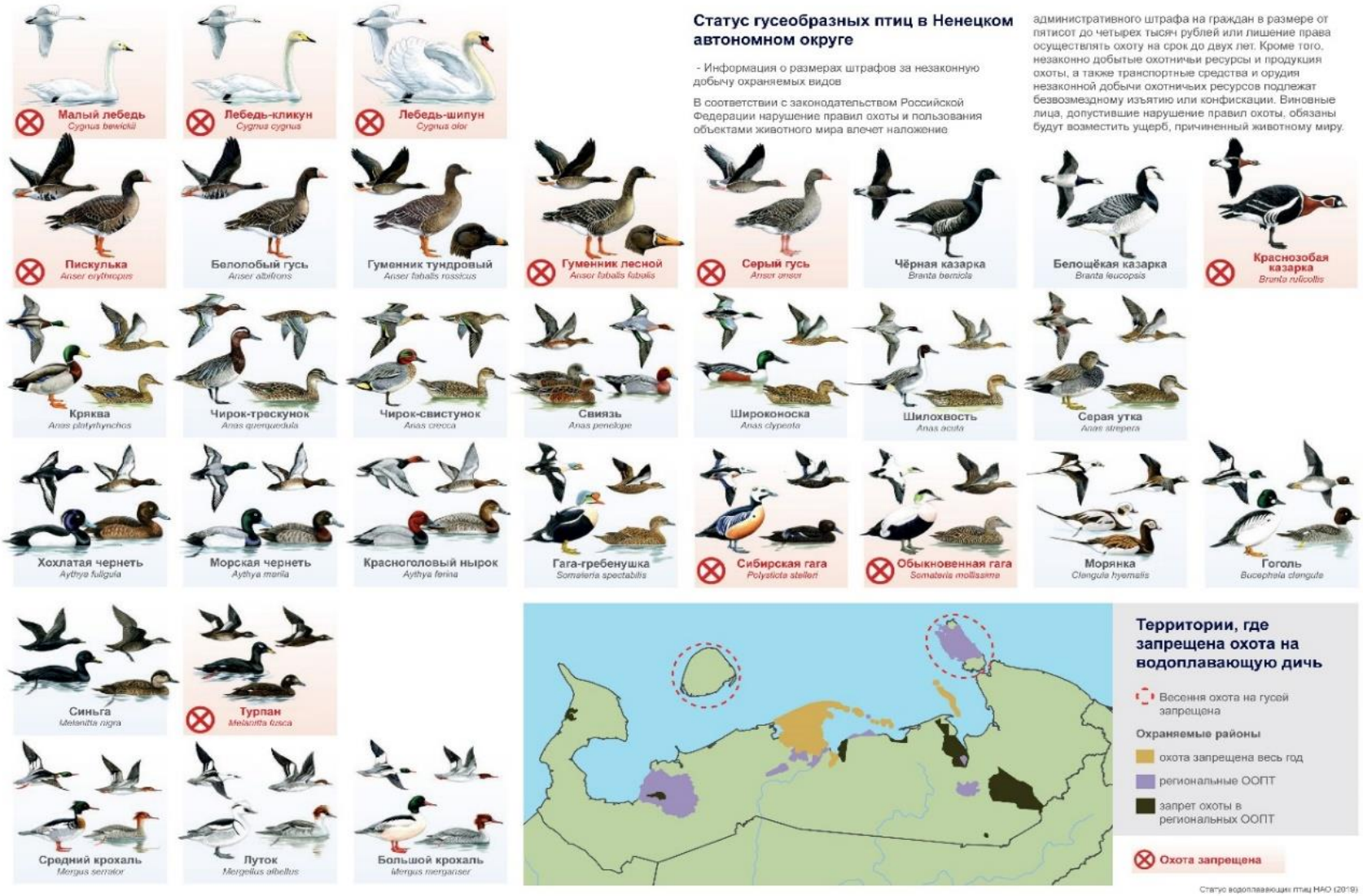
Кроме оформленных законодательно правил охоты, существуют неписанные законы, соответствующие традициям и этическим нормам поведения на охоте:

- Никогда не стреляйте по птицам и другим животным просто для забавы. Охота – это или способ добычи пропитания, или ответственное увлечение, спорт со строгими правилами.
- Никогда не стреляйте на расстояние более 40 метров, особенно влет. Вероятность удачного выстрела незначительна, а шанс подранить птицу очень велик.
- При охоте на уток используйте дробь не крупнее № 5. На дистанции до 30 метров во все охотничьи сезоны даже кряква нормально бьется дробью № 7. При охоте на гусей никогда не используйте дробь крупнее № 1 и тем более картечь. Помните, что стрельба крупной дробью приводит к многочисленным подранкам.
- На стреляйте летящую птицу, если у вас мало шансов найти её после выстрела – в высокой траве, в прибойной полосе, в болоте и т.д. Сделайте все возможное, чтобы подстреленная вами птица была добита и подобрана.
- Неэтично охотиться на птиц, по каким-либо причинам временно не способных к полёту: линяющих гусей и уток, молодых, не до конца оперённых птиц (хлопунцов), а также добывать птиц, находящихся в бедственном положении (попавших в сеть, замерзающих в полынье и т.д.).
- К открытию летне-осенней охоты нередко некоторые выводки не успевают подняться на крыло. Охотник не только не должен стрелять по хлопунцам, но и помнить, что при них обычно находится самка, отвлекающая опасность на себя. При этом она имитирует раненую, плохо летающую птицу, подает голос и садиться на воду поблизости от охотника. Добыть такую птицу – позор для настоящего охотника.
- Не стреляйте весной по утиной стае, а также в сумерках по налетающей паре уток, т. к. велик риск убить самку. Добыча самки весной равносильна убийству целого выводка молодых уток.
- Будьте осторожны при стрельбе в сумерках, особенно в местах, где регулярно встречаются виды, внесенные в Красную книгу. Велик риск спутать их с обычными охотничьими видами. Выбирайте для охоты другие места.
- Пристрелка оружия разрешена в сезон охоты в охотугодьях при соблюдении мер безопасности. Но необходимо учитывать, что свинцовая дробь загрязняет водоемы и может приводить к гибели птиц и серьезным заболеваниям человека. Никогда не тренируйтесь в стрельбе над водоемами или болотами!
- Соблюдайте основные требование техники безопасности на охоте! Не стреляйте в сумерках по неясно видимому силуэту или на звук. Помните, что при стрельбе по целям на воде велика вероятность рикошета. Всегда обращайтесь с оружием так, как будто оно заряжено!

Статус гусеобразных птиц в Ненецком автономном округе

- Информация о размерах штрафов за незаконную добычу охраняемых видов

В соответствии с законодательством Российской Федерации нарушение правил охоты и пользования объектами животного мира влечет наложение административного штрафа на граждан в размере от пятисот до четырех тысяч рублей или лишение права осуществлять охоту на срок до двух лет. Кроме того, незаконно добытые охотничьи ресурсы и продукция охоты, а также транспортные средства и орудия незаконной добычи охотничьих ресурсов подлежат безвозмездному изъятию или конфискации. Виновные лица, допустившие нарушение правил охоты, обязаны будут возместить ущерб, причиненный животному миру.

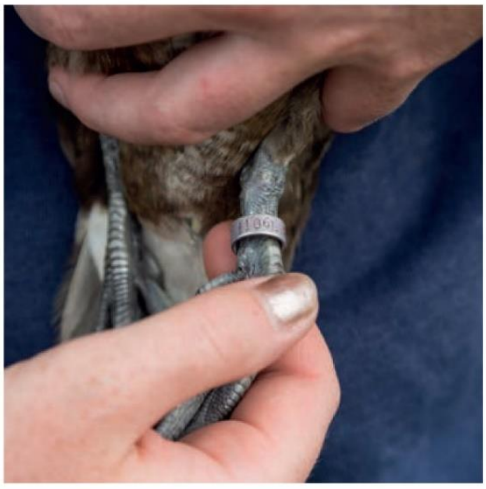


Чтение птичьего кольца

Если вы добыли окольцованную или меченую птицу, сообщите по адресу: Центр кольцевания птиц, Москва, 117312 или по электронной почте **bird.ring.rus@gmail.com**

Ваш вклад в сбор информации будет особенно полным и интересным, если вы укажете:

- номер кольца (перепишите все, что написано на кольце: цифры и буквы)
- дату (число, месяц, год),
- место (область, район, ближайший населенный пункт),
- обстоятельства обнаружения кольца (птица добыта на охоте, найдена мертвой, найдено только кольцо и т.д.).



По всем вопросам, касающихся охоты и охраны водоплавающих птиц, Вы можете обращаться в Департамент природных ресурсов, экологии и агропромышленного комплекса НАО:
www.dprea.adm-nao.ru
Нарьян-Мар, ул. Выучейского, дом 36
+7 (81853) 2-38-55

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“The male swan calls his beloved partner,
He sings to her his love song,
There at the silent river
they set their nesting place,
It's inconspicuous, invisible,
their small miracle.
Their nest is hidden by the Summer,
by the grass which is like emerald.
Some time later, the young swans,
which are so similar to each other,
will sail next to their parents,
dressed in grey coats of fluff.
It will take a long time for them
to reach the swan's beauty.
They become white like ice
and they cry with pride in their throat
But so far their father is guarding
And the mother is trying to be silent
And the sky above them
is singing a quiet, quiet song...”

Alexei Pichkov, Nenets Poet