The potential for reintroduction of Eurasian lynx to Great Britain: a summary of the evidence

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Executive Summary

1. There are estimated to be around 50,000 Eurasian or European lynx (*Lynx lynx*), distributed across Europe, Siberia and central Asia, with around 9,000 individuals in Europe. IUCN Red List conservation status for lynx is 'Least Concern'.

2. Lynx are solitary, territorial carnivores of about 20 kg weight. Home range sizes vary from 200-2800 km^2 for males and 100-800 km^2 for females and are largest at high latitudes and smallest where high densities of prey and productive habitats occur. Typical densities are in the range of 0.5-1.5 lynx per 100 km^2. There is little range overlap between same sex individuals but male ranges overlap those of several females. Juvenile lynx can disperse up to 428 km from their natal areas at 9-11 months of age. Males disperse further than females, particularly in expanding populations. However, dispersal is limited by natural and anthropogenic barriers including major roads.

3. Based on IUCN Red List criteria and population viability analyses, a population of lynx should have at least 250 individuals to be viable for a period of at least 100 years. Within Britain, a sufficient area of contiguous woodland habitat to support this number of animals only occurs in the Scottish Highlands, although the suitability of these woodlands in terms of understory vegetation and structure still requires investigation.

4. Across the current European lynx range, population growth and expansion has been greatest in remnant populations while growth of most reintroduced populations has stagnated and populations remain small. Most European populations occur partly outside protected areas in multi-use landscapes dominated by woodlands and with relatively low human population densities. The main factors limiting population growth are illegal killing, traffic accidents and legal harvesting.

5. Lynx are considered to be roe deer specialist and roe deer would likely form an important part of the diet of lynx in Britain. However, muntjac might be equally predated if they coexisted with reintroduced lynx. Lynx are also likely to prey on red, fallow and sika deer but to a lesser extent, and depending on their relative availabilities within lynx home ranges. There is a need for better, spatially-explicit estimates of current prey densities across Britain.

6. Lynx are very efficient predators of roe deer, even at low roe deer densities. As a result, they can have a marked impact on low density roe deer populations, especially in low productivity environments in Scandinavia. In Britain, local roe deer densities would probably be reduced by reintroduced lynx where they co-exist but the full impact cannot be predicted from the data currently available.

7. Lynx may influence deer vigilance behaviour, with knock-on effects on deer stalking success. Empirical evidence from Scandinavia suggests lynx recolonization has not affected roe deer habitat selection but anecdotal evidence from central Europe suggests roe deer may be harder to shoot. Behavioural studies of lynx prey are needed.

8. Alternative prey of reintroduced lynx in Britain could include rabbits, brown and mountain hares, woodland grouse, wildcat, red squirrel, red fox and pine marten as well as domestic pets, sheep, goats and reared game birds. However, the available evidence

suggests that lynx do not actively select livestock or these other species, but kill them when preferred prey is scarce. Thus the impact of lynx on other wildlife and livestock will depend on their relative abundances compared to preferred prey species.

9. Evidence indicates that sheep predation is most serious where sheep range freely in or adjacent to woodlands inhabited by lynx. In Britain, lynx would be unlikely to use close-cropped open hill ground where sheep range but it is not clear whether lynx would pose a risk to hill sheep grazing on heather moorland.

10. In Europe, 54-97% of lynx mortality is human related. Illegal killing is considered to be the primary threat to lynx, accounting for 30-50% of all mortality. Conflict with hunters over the perceived threat posed to roe deer by lynx is believed to contribute to this, particularly in reintroduced lynx populations in central Europe. By comparison, conflict over sheep predation is low except in Norway and to a lesser extent the Alps and Jura, where husbandry practices predispose livestock to high predation rates.

11. Vehicle-collisions are another significant cause of lynx mortality and limit recolonisation in the fragmented habitats of central Europe. Collision risks would probably also be high for lynx in large parts of Britain with its extensive road network. This has negative implications for animal welfare and population expansion. Human and road densities in the Scottish Highlands are comparable to those in areas where lynx currently occur.

12. The main tools used to manage lynx populations and conflicts in Europe and Fennoscandia are legal hunting and compensation schemes for predated livestock. Lynx are protected under the EU Habitats Directive but lawful population control is carried out in some non-EU countries or under derogation. Compensation schemes are widely implemented but are costly and can be controversial.

13. The reintroduction of lynx to any part of Britain would require a non-native species licence from the relevant statutory authority. A license application requires a risk assessment of the biological, animal welfare and socio-economic impacts, as well as evidence of thorough public consultation and plans for post-release monitoring and communication. Criteria for success must also be defined. All costs of reintroduction, including independent monitoring, should be borne by the licence applicant.

14. Carnivore reintroductions are extremely lengthy, costly and complex processes and should only be undertaken where there is a high probability of success. The human dimensions are likely to be as important for success as the ecological aspects. However even well planned reintroductions carry no guarantee of success and therefore a viable exit strategy and appropriate budget must be in place from the outset.

15. It is clear that further work on habitat quality, prey availability and social acceptability are required to inform any assessments of reintroduction of lynx to Britain. In particular, positive public and stakeholder attitudes in areas surrounding reintroduction sites are vital, over sufficiently large areas that a viable population would be tolerated. The financial, practical management, ethical and welfare implications of reintroducing lynx need to be carefully considered, particularly where areas of suitable habitat are considered too small to support contiguous viable populations.

Introduction

Lynx distribution and status

The Eurasian or European lynx (*Lynx lynx*) is the largest of the four lynx species and has one of the widest distributions of any cat, ranging from western Europe to the Pacific coast of Siberia and the Himalayas (Fig. 1; von Arx *et al.*, 2004). It occurs where prey are abundant in both forested areas of Europe and Siberia and in more open habitats in central Asia. The main strongholds of Eurasian lynx (hereafter referred to as lynx) today are in southern Siberia, Mongolia and China and the global population is believed to be over 50,000 individuals (Breitenmoser *et al.*, 2015). Although status and trends in many Asian countries are unclear due to insufficient data, the conservation status of lynx is 'least concern' on the IUCN Red List of Threatened Species (Breitenmoser *et al.*, 2015).

Lynx were once widespread throughout their range, but in many areas their populations declined due to deforestation, habitat fragmentation, loss of prey and direct control to protect livestock. Consequently by the early 20th century they had been extirpated from most of Europe except Fennoscandia, the Baltic, Carpathians and Balkans (Linnell *et al.*, 2009; Schmidt *et al.*, 2011). However, since the 1950s, the recovery of European woodlands and roe deer (*Capreolus capreolus*) populations, together with changes in public attitudes and at least 15 reintroduction programmes (Linnell *et al.*, 2009; von Arx *et al.*, 2009), have allowed lynx numbers in Europe to at least partially recover (Schmidt *et al.*, 2011). There are now 11 breeding populations of lynx with a permanent presence across 23 European countries (Table 1) and the total European population size is estimated at 9,000 - 10,000 individuals (Kaczensky *et al.*, 2012; Chapron *et al.*, 2014). However, all the reintroduced populations remain small (Table 1) and none are yet considered viable (von Arx, Breitenmoser-Würsten & Breitenmoser 2009; Chapron *et al.* 2014). As with most large carnivore species, lynx live at low population densities and have large home ranges. Consequently, European protected areas are not sufficiently large to maintain viable populations exclusively within their boundaries, so populations occur partly outside protected areas in multi-use landscapes with relatively low average human population densities (22-74 inhabitants /km^2; Linnell, Swenson & Anderson 2001; Chapron *et al.* 2014).

Lynx ecology

The lynx is primarily nocturnal with activity peaks corresponding to those of its prey, primarily at dawn and dusk outside polar areas (Heurich *et al.*, 2014). In Europe, the main prey of lynx are small ungulates such as roe deer and chamois (*Rupicapra rupicapra*), but they also take other smaller species such as hares (*Lepus spp.*), rabbits (*Oryctolagus cuniculus*), red foxes (*Vulpes vulpes*), rodents and game birds (Jędrzejewski *et al.*, 1993; Nowicki, 1997; Jobin *et al.*, 2000; Odden *et al.*, 2006). Lynx can kill larger prey such as red deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), moose (*Alces alces*) or livestock, taking individuals up to 3-4 times their own size (Okarma *et al.*, 1997; Pedersen *et al.*, 1999; Odden *et al.*, 2006). Lynx actively hunt using dense cover to stalk, or opportunistically ambush,

their prey (Jędrzejewski *et al.*, 2002). Frequency of hunting depends on the size of prey items, with lynx returning to larger kills over an average of 3-5 consecutive nights (Jędrzejewski *et al.*, 1993; Okarma *et al.*, 1997; Jobin *et al.*, 2000).

Generally, adult lynx are around 1m long, 0.75m tall and weigh 12-37 kg, averaging about 18 kg for adult females and 22 kg for adult males. The lynx is well adapted to the cold and to deep snow, having long legs, large paws and thick fur. Outside of the breeding season lynx are solitary, except for females with young. The mating season is in February-March with the birth season in late May. Litter size is typically 2-3 cubs (Gaillard *et al.*, 2014). Females rear the cubs alone, and cubs stay with their mother till the following mating season before dispersing (Schmidt, 1998). Lynx usually breed for the first time at 2-3 years of age. Longevity in the wild can be up to 15 years but is normally much less (von Arx *et al.*, 2004), with only about half of juveniles reaching adulthood (Breitenmoser-Würsten *et al.*, 2007). The main causes of mortality are anthropogenic, particularly illegal killing, vehicle collisions and legal hunting (Andrén *et al.*, 2006; Ryser-Degiorgis, 2009), although the role played by infectious diseases is not yet well understood and may be under-estimated (Schmidt-Posthaus *et al.*, 2002).
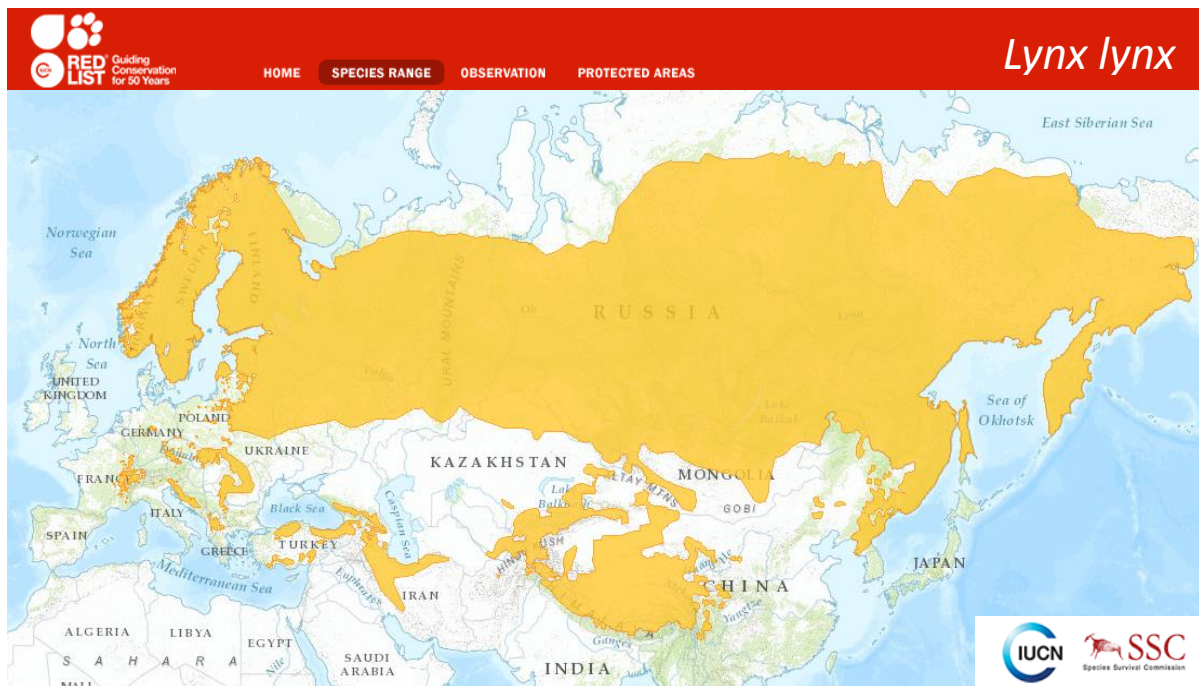

Fig. 1. Global distribution of Eurasian lynx (Breitenmoser *et al.*, 2015).

Table 1. European lynx populations showing their size and status. Based on data from Kaczensky *et al.* 2012 and Chapron *et al.* 2014. (Pop. trend - population trend, either Inc. - increasing, Dec. - decreasing or Stable - not changing. NA - data are not available).

Population	Countries	Origin	Estimated pop. size	Pop. trend	Range km^2
1. Scandinavian	Norway, Sweden	Remnant	1,800–2,300	Stable	470,100
2. Karelian	Finland	Remnant	2,400–2,600	Inc.	92,000
3. Baltic	Estonia, Latvia, Lithuania, Poland	Remnant	1,600	Stable	82,300
4. Carpathian	Bulgaria, Czech, Hungary, Poland, Romania, Serbia, Slovakia	Remnant	2,300–2,400	Stable	112,600
5. Balkan	Albania, FYR Macedonia, Kosovo	Remnant	40–50	Dec.	4,500
6. Dinaric	Croatia, Bosnia-Herzegovina, Slovenia	Reintroduced	120–130	Stable/Dec.	20,200
7. Bohemian-Bavarian	Austria, Czech, Germany	Reintroduced	50	Stable/Dec.	5,600
8. Alpine	Austria, France, Italy, Slovenia, Switzerland	Reintroduced	130	Stable	9,300
9. Jura	France, Switzerland	Reintroduced	110	Inc.	9,400
10. Vosges-Palatinian	France, Germany	Reintroduced	19	Stable/Dec.	1,400
11. Harz Mountains	Germany	Reintroduced	10	NA	300

Methods

We reviewed the available evidence to address 7 questions posed by the British Deer Society (Table 2), each of which is dealt with as a subsection of the Results section below. For the review process, we identified relevant articles in the peer-reviewed and, to a lesser extent, 'grey' literature using the 'Web of Science' (WoS) online citation indexing database (Thomson Reuters, 2015) and 'Google Scholar'. Searching on the terms "Eurasian lynx", "European lynx" or "Lynx lynx" but excluding "Canada lynx" and "Iberian lynx", WoS yielded 978 English language papers from the fields of zoology, biodiversity and conservation, ecology, forestry and behavioural sciences. Searches were further refined using additional search terms appropriate to specific questions, for example in WoS, the terms "mov* or dispers*" were used to identify articles including the words 'movement', 'moving', 'dispersal', 'disperser' or 'dispersing'. In addition, we manually added relevant papers and reports which were cited in key articles but not highlighted by our search terms.

Table 2. Overview of questions posed by BDS and addressed in the Results section.

1)	Over what areas could we expect lynx to normally range, how are their ranges organised relative to each other, what distances might be covered during extreme movements and what triggers extreme movements?
2)	What would reintroduced lynx most likely kill and or eat, and what impacts could their predation have on deer populations?
3)	How many lynx might Great Britain sustain, where would they most likely be located, and at what densities? (To include an appraisal of environmental suitability where available).
4)	What other interactions can we expect with British wildlife or domestic stock? (For example, species of conservation importance, such as wild cat, capercaillie, red squirrel, mountain hare and pine marten, and also pest/nuisance vertebrates including invasive non-native species).
5)	How might lynx reintroduction affect deer management and the interests of the deer stalking community? (To include changes in effort required to manage deer populations, changes in shooting opportunities, risks to stalkers).
6)	What regulates and influences lynx population growth on the North Eurasian continent, would this likely be the same in UK, and if not, what might we expect? (To include information on the consequences of natural population regulation for lynx, and on approaches to lynx management on the continent).
7)	What processes must be undertaken in order to lawfully reintroduce lynx to England, Scotland and Wales? (To include a brief description of the licensing and consultation process, including risk assessment, risk mitigation and likely timelines).

Results

1) Over what areas could we expect lynx to normally range, how are their ranges organised relative to each other, what distances might be covered during extreme movements and what triggers extreme movements?

Ranging behaviour

Lynx are generally solitary, territorial animals. Both males and females defend territories, with those of males being larger than females. There is little range overlap between individuals of the same sex but male home ranges usually overlap those of 1-3 females (Breitenmoser *et al.*, 1993; Schmidt *et al.*, 1997; Linnell *et al.*, 2001b). Recorded home range sizes vary 10-fold across Europe (Herfindal *et al.*, 2005a) and are largest where habitat productivity and prey availability are lowest. Annual home range sizes are typically 200-2800 km^2 for males and 100-800 km^2 for females (Linnell *et al.*, 2001b; von Arx *et al.*, 2004; Herfindal *et al.*, 2005a). Hetherington & Gorman (2007) estimated the available prey biomass in the Scottish Highlands and Southern Uplands based on deer dung counts at Forestry Commission sites in these areas. From these, Hetherington *et al.* (2008) assumed that home range sizes in Scotland would be relatively small and comparable with those in

environmentally similar areas in Switzerland (approximately 70-250 km^2; Breitenmoser *et al.* 1993; Herfindal *et al.* 2005b).

Daily activity and movement of lynx vary depending on season, sex, age, density and species of available prey and time since last kill (Jędrzejewski *et al.*, 2002; Podolski *et al.*, 2013). Daily movement can vary from zero to 30 km, with males travelling furthest during the mating season and females travelling furthest while caring for new-born cubs (Schmidt, 1998; Jędrzejewski *et al.*, 2002; Andersen *et al.*, 2005). Typically the straight-line distance moved per day is in the order of 2-5 km for females and 6-15 km for males (Pedersen *et al.*, 1999; Sunde *et al.*, 2000; Jędrzejewski *et al.*, 2002). Movement distances increase in response to lower prey availability (Schmidt, 2008) and hunting success (Jędrzejewski *et al.*, 2002), being greatest on days when lynx fail to kill prey and least on days following a new kill (Schmidt, 1999; Jędrzejewski *et al.*, 2002; Krofel *et al.*, 2013).

Lynx dispersal

Dispersal in lynx is generally associated with sub-adults leaving their natal area at 9-11 months of age. Radio- and GPS-tracking studies suggest dispersal distances of between 2 and 428 km, with male lynx dispersing further than females (Schmidt, 1998; Sunde *et al.*, 2000; Kramer-Schadt *et al.*, 2004; Zimmermann *et al.*, 2005; Samelius *et al.*, 2012). Average dispersal distances in Poland were 60 km for males and 7 km for females (Schmidt, 1998), whereas in Switzerland, where dispersal is limited by natural and anthropogenic barriers such as mountain ranges, major rivers and water bodies, and major roads (Zimmermann & Breitenmoser, 2007; Zimmermann *et al.*, 2007), it averaged 42 km (Kramer-Schadt *et al.*, 2004). By contrast, dispersal distances of male and female lynx in Scandinavia averaged 148 and 47 km respectively, partly due to much larger home range sizes (Samelius *et al.*, 2012). Dispersal distances over 150 km seem to be specific to expanding populations in Scandinavia (Andersen *et al.*, 2005; Samelius *et al.*, 2012). Illegal killing appears to limit dispersal outside protected areas (Müller *et al.*, 2014; Kowalczyk *et al.*, 2015; Magg *et al.*, 2015). In addition, dispersal may be limited where lynx density is already high (Zimmermann *et al.*, 2005). Long distance movements by 2 adult lynx (55 km by a male and 120 km by a female) have been reported from Poland, associated with infection with rabies virus and a poaching injury (Schmidt 1998).

Dispersal also occurs in the context of reintroductions, following release. In the Vosges Mountains, France, 21 lynx were released. Those individuals that were tracked successfully, made exploratory movements of 5-37 km within an area of 84–566 km^2 during the first 3 months (n=8), before settling in smaller areas close to the release site (n=5) or, in one case, approximately 50 km away (Vandel *et al.*, 2006). Dispersal of reintroduced individuals appears to be limited by the same natural and anthropogenic barriers that limit dispersal of young. In Switzerland, dispersal barriers helped to establish a core population by keeping released individuals within a confined area, whereas in Austria, dispersing animals spread in different directions and so did not establish a social system, leading to the failure of the reintroduction (Linnell *et al.*, 2009; von Arx *et al.*, 2009).

Knowledge gaps

To better predict home range sizes and population densities of reintroduced lynx in Britain, habitat suitability mapping exercises need to be complemented with better spatially-explicit estimates of prey densities. Models which predict roe deer densities based on factors such as climate, altitude and vegetation productivity are now available at the European scale (incorporating data from Britain) and may contribute towards this (Melis *et al.* 2009; Alexander *et al.* 2014) but other prey species also need to be included. Moreover, it will be necessary to adjust predictions of local prey density following implementation of local and regional land-use policies that influence prey density.

2) What would reintroduced lynx most likely kill and or eat, and what impacts could their predation have on deer populations?

Lynx diet

Over 30 prey species have been recorded in the diet of lynx (Odden *et al.*, 2006) but small ungulates are their main prey throughout most of Europe (Breitenmoser *et al.*, 2010). Where lynx and roe deer coexist in Europe, roe deer are widely acknowledged to be their preferred prey species (Jędrzejewski *et al.*, 1993; Odden *et al.*, 2006; Breitenmoser *et al.*, 2010; Andrén & Liberg, 2015), accounting for 50-99% of prey biomass (Nowicki, 1997; Okarma *et al.*, 1997; Jobin *et al.*, 2000; Mayer *et al.*, 2012). However, in some areas where lynx coexist with both chamois and roe deer, chamois are the preferred prey of lynx despite lower densities (Jobin *et al.*, 2000; Breitenmoser *et al.*, 2010).

Given the widespread distribution and increasing number of roe deer in Britain (Ward, 2005; Noble *et al.*, 2012; Wäber *et al.*, 2013), it seems clear that roe deer would form an important component of the diet of reintroduced lynx in Britain. However, patterns of roe deer population change are unlikely to be consistent across the whole of Britain, so the contribution that roe deer make to lynx diet may vary between locations and over time. As lynx do not currently coexist with muntjac (*Muntiacus reevesi*) or Chinese water deer (*Hydropotes inermis*), the two other principal small ungulate species in Britain, data on their predation or relative preference by lynx are unavailable. However, across the Palaearctic region where lynx coexist with 10 different ungulate species, lynx appear to show strong prey selection for the smallest ungulate species present (Jędrzejewski *et al.*, 1993). Therefore, given the body sizes of muntjac and Chinese water deer, we can speculate that lynx reintroduced to Britain would prey on both these species where they co-occurred.

Lynx also prey on larger ungulates such as wild and semi-domestic reindeer (Pedersen *et al.*, 1999; Odden *et al.*, 2006; Mattisson *et al.*, 2014), red deer (Jędrzejewski *et al.*, 1993; Nowicki, 1997; Okarma *et al.*, 1997), and even moose (Odden *et al.*, 2006) but where preference data are available it is clear that these species are less preferred than roe deer (Jędrzejewski *et al.*, 1993). Red deer accounted for 1-72% of prey biomass consumed across study sites in Europe and Russia, depending on the availability of other prey (Nowicki, 1997).

Male lynx tend to kill red deer more frequently than females, and in general juvenile and adult female red deer are killed more often than mature stags (Jędrzejewski *et al.*, 1993; Okarma *et al.*, 1997; Belotti *et al.*, 2014; Gervasi *et al.*, 2014). Lynx may have a greater tendency to take large ungulates in the absence of competition from other large carnivores such as wolves, or where large ungulates are relatively more common than small ungulates (Jędrzejewski *et al.*, 1993; Nowicki, 1997).

In the British context, lynx are only likely to prey on red deer where they occur within or adjacent to forestry and woodland areas (i.e. areas preferred by lynx), and where roe deer, their preferred prey, are less abundant. Evidence from Russia suggests predation rates of sika (*Cervus nippon*) may be higher than red deer, although this could reflect differences in relative abundance rather than preference (Nowicki, 1997). Furthermore, the smaller body size of red deer in Britain than in Europe may influence relative lynx predation rates and reduce avoidance of stags. On the basis of the evidence for red deer and sika, fallow (*Dama dama*) would also be potential prey for lynx where they co-occur, although the limited range overlap of this species with lynx in Europe means data are not available to support this supposition.

Based on evidence from Europe, reintroduced lynx in Britain could also be expected to prey on a variety of wildlife including small mammals and birds, as well as domestic pets, domestic livestock and reared game birds. These are discussed in detail in answer to question 4 below.

Impact on deer populations

There has been much debate about the effects of lynx predation on red and, particularly, roe deer populations (e.g. Okarma *et al.*, 1997; Molinari-Jobin *et al.*, 2002; Gervasi *et al.*, 2012; Heurich *et al.*, 2012; Andrén & Liberg, 2015). Theoretically, non-selective stalking predators should exert a stronger effect on prey populations than more selective coursing predators (Gervasi *et al.*, 2012). Certainly, lynx show no selection for different age or sex classes or condition of roe deer (Okarma *et al.*, 1997; Molinari-Jobin *et al.*, 2002; Andersen *et al.*, 2007), with a solitary adult lynx killing around 30-70 individuals annually (Jobin *et al.*, 2000; Nilsen *et al.*, 2009). Among those killed are many prime aged adults which reduces the normally high adult survival rates of roe deer (Heurich *et al.*, 2012; Melis *et al.*, 2013) and reduces population growth rates (Gervasi *et al.*, 2012). Predation of roe deer by lynx is additive to other types of mortality such as hunting, traffic accidents and other natural mortality (Andrén & Liberg, 2015). Furthermore, the lynx is a very efficient predator of roe deer, with kill rates only declining at roe deer densities below about 1 deer / km^2 (Nilsen *et al.*, 2009; Andrén & Liberg, 2015). Consequently, as roe deer density decreases a higher proportion of the population is predated by lynx, particularly in parts of Scandinavia with low environmental productivity and the most severe winters (Melis *et al.*, 2010). The impact of lynx predation on roe deer population growth can therefore be highly negative at low roe deer densities, as observed in some parts of Scandinavia (Gervasi *et al.*, 2012). Predation

impact decreases with increasing roe deer density but it is not clear to what extent these results can be extrapolated to British roe deer densities.

It is difficult to predict the potential impact of reintroduced lynx on British ungulate populations as it would be influenced by both predator and prey densities (Gervasi *et al.*, 2012) and while lynx densities are as yet unknown, roe deer densities and population growth rates are currently not available for all potential reintroduction sites in Britain (but see Wäber *et al.*, 2013). Furthermore, the impact is likely to vary between sites with differing roe deer densities and habitat productivity. Nonetheless, it is clear at the continental scale that roe deer densities are lower where lynx are present (Melis *et al.*, 2009) and have decreased where lynx have re-established (Heurich *et al.*, 2012; Andrén & Liberg, 2015). We could therefore expect a reduction in British roe deer densities in areas where lynx become established. It seems likely that muntjac (or other small deer) densities would also be reduced if lynx overlapped their range.

By comparison, reintroduced lynx would probably have a low impact on British red deer populations due to a combination of the generally high availability of roe deer, lower preference for and predation rates of red deer and selection for young non-reproductive individuals. Furthermore, the open hill habitat where economically important red deer populations occur in the Scottish Highlands is not the type of habitat typically occupied by lynx. In the absence of good information regarding predation of sika and fallow deer, we could speculate that, based on body sizes and habitat use, the population-level impact might be somewhat greater than in red deer but relatively low compared with roe deer.

Impact on deer behaviour

The reintroduction of lynx to Britain could also affect deer by influencing their behaviour. Behavioural responses of ungulate populations to perceived predation risks create a so-called "landscape of fear", with deer responses ranging from increased vigilance to avoidance of high risk areas (Ripple & Beschta, 2004; Manning *et al.*, 2009; Norum *et al.*, 2015). Avoidance of areas with a high predation risk has allowed the regeneration of trees in parts of Yellowstone National Park following the reintroduction of wolves (Ripple & Beschta, 2007). In Norway, sites where roe deer are killed by lynx have a higher canopy cover and spruce density than other locations used by roe deer (Norum *et al.*, 2015) yet roe deer do not appear to avoid habitats associated with high lynx predation risk. Recolonization by lynx has had little impact on roe deer habitat selection (Ratikainen *et al.*, 2007; Samelius *et al.*, 2013) and there are no reports of habitat recovery following the reintroduction of lynx in Europe. The observed lack of response to lynx predation may reflect the high kill success of this efficient stalking predator (Nilsen *et al.*, 2009), smaller prey group sizes or limited flexibility in prey habitat use (Samelius *et al.*, 2013). By contrast, coursing predators, such as wolves, create much greater disturbance and the dilution effect of large prey herds allow prey to respond by adapting their behaviour (Ripple *et al.*, 2001; Samelius *et al.*, 2013).

Knowledge gaps

We do not know the relative preferences of lynx for the different species of deer found in Britain because of the limited range overlap of these species with lynx and each other elsewhere. The impact of a viable reintroduced lynx population on the British roe deer population is also unknown due to a lack of information regarding current birth and death rates and the population growth rate for all potential reintroduction sites. In addition, predictions of the impacts of reintroduced lynx on deer behaviour and habitat use in Britain are limited by a lack of behavioural studies of roe deer responses to lynx recolonisation, from across a range of environmental conditions and densities of deer and lynx.

3) How many lynx might Great Britain sustain, where would they most likely be located, and at what densities? (To include an appraisal of environmental suitability where available).

Size of a viable population

The feasibility of reintroducing lynx to Great Britain is dependent on the availability of sufficient habitat and prey to sustain a viable population, and also depends on the tolerance of human communities in reintroduction areas. From an ecological perspective, a minimum viable population (MVP) must be large enough to maintain genetic diversity and be buffered against unpredictable events, such as environmental catastrophes and disease outbreaks, over the long-term (Wilson, 2004). Breitenmoser *et al.* consider an MVP of lynx to be a connected population of around 250 individuals based on IUCN Red List criteria (Breitenmoser *et al.*, 2001). Lynx population viability analyses suggest an MVP of 100-400 individuals would be required to have a 95% probability of persistence over 100 years, depending on the assumptions used, including founder population size (Wilson, 2004; Hetherington, 2005). MVP estimates of >200 seem more realistic than the 'optimistic' scenario that assumes high survival rates and consequently a smaller viable population size (Hetherington, 2005). None of the reintroduced lynx populations in Europe have reached this size yet (Table 1; von Arx *et al.*, 2009; Chapron *et al.*, 2014) but there has always been the hope that populations would expand and individuals would move between populations, although geographic isolation of habitat fragments may prevent this occurring in many situations (Kramer-Schadt *et al.*, 2004, 2005). As British lynx populations would be geographically isolated from their continental conspecifics and so need to be self-sustaining, they should occur in areas sufficiently large and contiguous to allow good genetic mixing.

Lynx habitat availability

Previous assessments of the potential for reintroduction have been carried out for Scotland (Hetherington, 2005; Hetherington & Gorman, 2007; Hetherington *et al.*, 2008), Wales (Goodger *et al.*, 2005) and Britain as a whole (Kitchener, 2001). An in-depth assessment of lynx habitat availability and connectivity within Scotland concluded that sufficient habitat existed to support around 400 individuals in the Highlands and a further 50 in the Southern

Uplands (including adjacent habitat in northern England), at estimated densities of 2.63 lynx 100/km^2 and 0.83 lynx 100/km^2 respectively based on assumed prey availability (Hetherington & Gorman, 2007; Hetherington *et al.*, 2008). These estimated lynx densities are comparable with the range of densities observed across Europe (0.25-3.2 lynx /100 km^2 depending on prey availability; von Arx *et al.* 2004). However, poor habitat connectivity is likely to restrict movement of lynx between these two areas of Scotland (Hetherington *et al.*, 2008), without which the Southern Upland population would have a low probability of long-term persistence.

Similarly detailed analyses have not been reported for other parts of Britain, including sites that might be considered for lynx reintroduction. However, from maps of British woodland distribution it is apparent that the majority of woodlands are relatively small (Fig. 2; Forestry Commission, 2011). This may be problematic where woods are separated by busy traffic infrastructure (Kramer-Schadt *et al.*, 2004) or are not well connected by semi-natural habitat as lynx show avoidance of areas of intensive human settlement and land use, including arable land (Basille *et al.*, 2009; Magg *et al.*, 2015). Hetherington *et al.* used rule-based spatially-explicit modelling to identify suitable patches of contiguous forest or semi-natural habitat in a GIS, based on parameter values from environmentally similar areas in Switzerland (Hetherington *et al.*, 2008). This excluded habitat patches considered not sufficiently large (< 45 km^2) or wooded (< 38 % forest cover) to support a female lynx home range (Hetherington *et al.*, 2008). From these values and the map in Fig. 2, it seems probable that only small areas of suitable habitat would exist in Britain outside those areas already identified in Scotland. If lynx actually need larger home ranges than assumed by Hetherington *et al*., then the availability of suitable areas would be even lower. Indeed, Kitchener (2001) concluded that insufficient contiguous woodland habitat occurred in Britain and quoted Swiss lynx expert Urs Breitenmoser as saying this was the main reason why lynx reintroduction should not be attempted in Britain (Kitchener, 2001).

In some regions lynx are known to also use open landscape, questioning the need for large areas of contiguous woodland when assessing habitat availability. Indeed, a high proportion of non-wooded semi-natural habitats occurred within lynx home ranges in the Swiss Jura, and fragmented forest with large amounts of edge habitat is favourable for roe deer (Schadt *et al.*, 2002). On this basis, it has been suggested that lynx could occur where sufficient prey populations exist in the south and south-west of England (Kitchener, 2001) although this has yet to be verified. Wales only has a relatively low woodland cover and small, but increasing, populations of deer (primarily fallow and roe) so was not considered to be currently suitable for lynx reintroduction (Goodger *et al.*, 2005). Although good spatial estimates of density of roe deer or other potential ungulate prey are lacking for most of Britain, there is evidence that deer distribution and abundance are increasing nationally (Ward, 2005; Noble *et al.*, 2012) so it seems unlikely that prey availability would be a limiting factor for lynx in Britain.
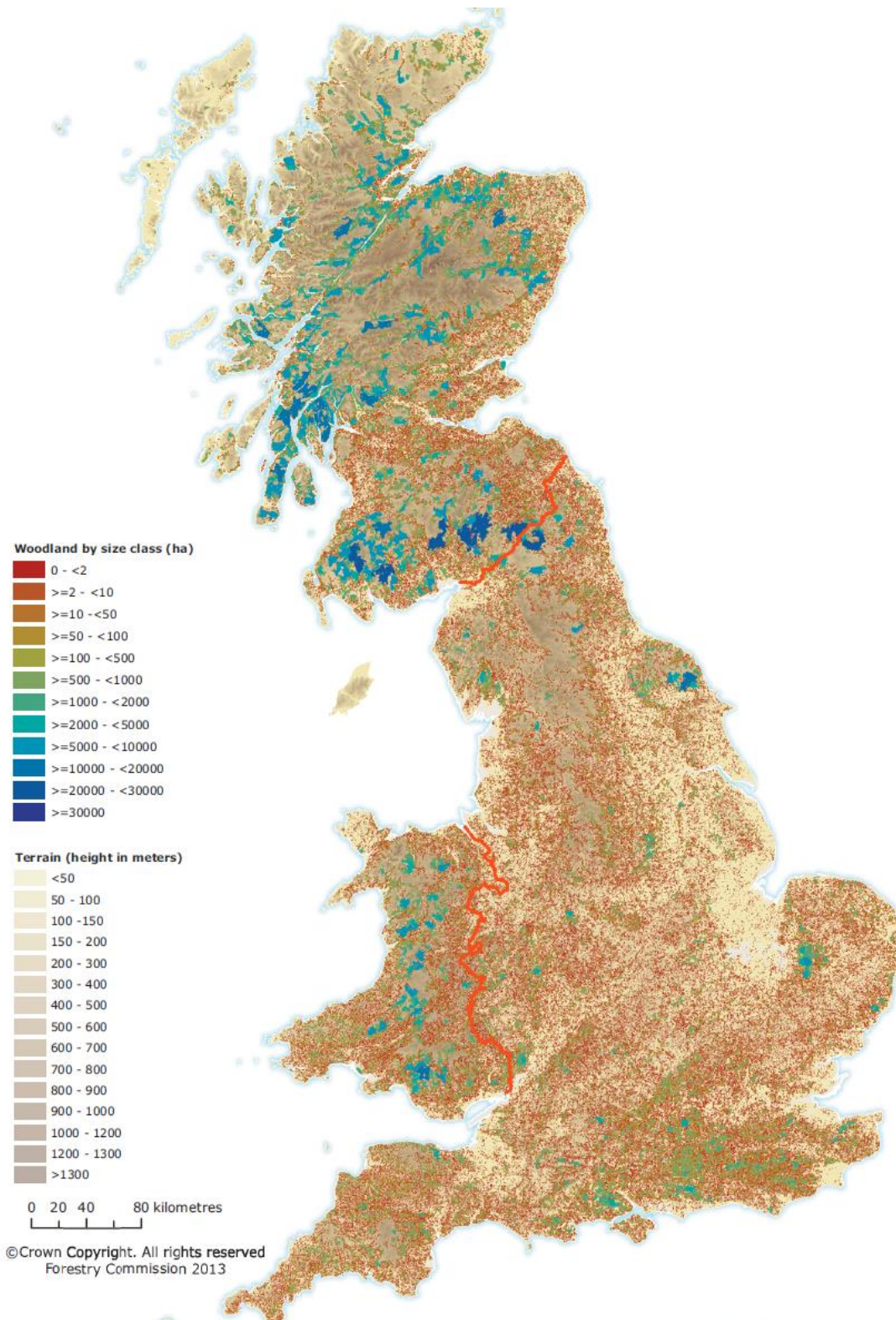
Fig. 2. Map of woodland distribution in Britain by area (Forestry Commission, 2011).

Knowledge gaps

There are many unknowns and assumptions associated with estimating MVPs (reviewed by Wilson, 2004; Hetherington, 2005). However, the similarity in estimates between authors, and their comparability with the MVP suggested by European experts (Breitenmoser *et al.*, 2001) suggest that the goal of any lynx reintroduction in Britain should be a minimum contiguous population of at least 250 individuals. We have focused our review on the understanding that any reintroduction should be in areas able to support this number of individuals. However, if lynx reintroduction was proposed in areas that could only support a smaller population, predicted to be non-viable over the longer term, then issues over managing such a situation and the associated ethics need wider and more in-depth discussion.

The size of lynx home ranges reintroduced to Britain cannot be precisely predicted (see question 1 above), yet is needed to estimate the area of habitat required and the size of the lynx population that could be supported. Furthermore, the availability and connectivity of suitable habitat needs to be assessed more widely across Britain and particularly in all areas of proposed lynx reintroduction. However, a key unknown to assessing habitat availability in Britain is the extent to which lynx would use non-wooded semi-natural habitats such as heather moorland, as this is not widely available within the current lynx range. While moorland is generally not associated with high roe deer densities except near woodland edges, it may nonetheless be important in providing lynx with movement corridors and so increase the overall availability of suitable habitat.

The suitability of habitat patches already identified in Scotland has not been investigated in terms of woodland structure. Lynx show high selectivity for microhabitat and require forest with structural diversity, good availability of cover for stalking prey and dense thickets or undergrowth for resting (Podgórski *et al.*, 2008). There is abundant evidence that heavy browsing by deer has reduced the density and cover of woodland understory vegetation in many parts of Britain (Gill & Fuller, 2007). Therefore, whether sufficient understory vegetation is available to meet the requirements of lynx in the Scottish habitat networks identified by Hetherington *et al.* and any proposed reintroduction sites elsewhere should be clarified. In addition, the suitability for lynx of dense coniferous plantation stands typical of British commercial forestry is unclear. Uncertainty also arises over the extent to which the suitability of woodland habitats may be reduced by human disturbance associated with recreational use.

Roe deer are increasingly occurring in peri-urban and sub-urban areas (Dandy *et al.*, 2011). Although lynx are shy of people, the extent to which they may be attracted to these areas and the consequences of this for lynx, roe deer and other alternative prey in the area needs further investigation.

4) What other interactions can we expect with British wildlife or domestic stock? (For example, species of conservation importance, such as wild cat, capercaillie, red squirrel, mountain hare and pine marten, and also pest/nuisance vertebrates including invasive non-native species).

Wildlife

A wide range of species have been recorded in the diet of lynx, including small and large ungulates, small and medium-sized carnivores, rabbits and hares, woodland grouse and other birds such as pigeons, magpies and occasionally passerines, rodents, insectivores, domestic cats and dogs, and domestic sheep and goats (Jędrzejewski *et al.* 1993; Nowicki 1997; Jobin, Molinari & Breitenmoser 2000; Odden, Linnell & Andersen 2006). However, most non-ungulate wildlife species contribute little to the lynx diet (Jobin *et al.*, 2000). Some rabbits, mountain hares and brown hares (lagomorphs) would undoubtedly be killed by reintroduced lynx in Britain where they occur in forest and woodland edge habitats. However, generally lagomorphs only form a significant part of the diet of lynx at the taiga edge where small ungulates are unavailable (Jędrzejewski *et al.*, 1993; Nowicki, 1997). Similarly tetraonid birds have only been shown to be important in boreal and mountain regions, accounting for 14-20% of prey items (Nowicki, 1997). British woodland grouse (capercaillie and black grouse) populations are small, occur at very low densities and are highly localised and therefore of conservation concern. It is considered unlikely that many individuals would be predated by lynx, particularly in areas where they coexist with roe deer. Nonetheless for vulnerable populations even small losses may be extremely serious. However, as black grouse and capercaillie are also vulnerable to predation by foxes and pine martens (Baines *et al.*, 2011), which may themselves be predated by lynx, it is not clear where the new balance would lie in predator-prey relationships altered by lynx reintroduction.

Red fox can account for up to 6% of the prey items of lynx (Jobin *et al.*, 2000) but more often are only rarely hunted, in common with other small-medium sized predators such as pine marten, badger and wildcat (Jędrzejewski *et al.*, 1993; Nowicki, 1997). The overall impact that lynx reintroduction may have on wildcats in Britain is uncertain although some wildcats, feral domestic cats and hybrids would probably be killed by lynx and lynx may directly compete with them for small prey items such as rabbits.

Other species of conservation interest such as red squirrel are likely to be killed by reintroduced lynx but in only very small numbers (Jędrzejewski *et al.*, 1993). We could also speculate that a few grey squirrel and North American mink may also be taken opportunistically where they coexisted with reintroduced lynx.

Although wild boar are reported in the diet of lynx (Nowicki, 1997), this species is taken considerable less often than would be expected from its availability (Jędrzejewski *et al.*, 1993). Lynx would therefore be unlikely to have much impact on populations of wild boar now becoming established in parts of Britain if they co-occurred.

Livestock

Predation of livestock by large carnivores is a major cause of conservation conflict globally and a barrier to increasing public acceptance of carnivores (Baker *et al.*, 2008; Odden *et al.*, 2013). Many in Britain would be concerned if lynx were reintroduced (or even seriously considered for reintroduction). Lynx are generally considered less of a threat to livestock than wolves or bears (Breitenmoser *et al.*, 2000). The areas where lynx predation of livestock causes conflict are the Alps and Jura (usually <100 animals killed per year) and in Fennoscandina where semi-domestic reindeer are killed as well as sheep (no. sheep killed: 25, 70-150 and 7,000-10,000 per year in Finland, Sweden and Norway respectively; Kaczensky *et al.* 2012).

Scandinavian studies suggest that lynx prefer wild prey (Mattisson *et al.*, 2014) and it appears that sheep are not actively selected but may be killed when encountered by lynx while searching for wild prey (Odden *et al.*, 2008). Consequently, densities of both sheep and wild ungulate prey influence sheep predation rates (Odden *et al.*, 2013; Gervasi *et al.*, 2014). There are large regional differences in sheep predation by lynx across Europe suggesting that differing husbandry practices (Linnell *et al.*, 2012) and inherent features of specific sites (Stahl *et al.*, 2001) make livestock in some areas more vulnerable than others. Free ranging extensive grazing systems expose domestic stock to the greatest predation risk (Mattisson *et al.*, 2014). The most extreme sheep-lynx predation conflict arises in Norway, where free range sheep graze unsupervised at high densities in lynx habitat (specifically forests and adjacent upland areas) throughout the summer months (Linnell *et al.*, 2001b; Odden *et al.*, 2002, 2008). By contrast, in Sweden, where sheep are kept within fields or fenced pastures, sheep predation is an order of magnitude lower (3.7 and 0.25 lynx-killed sheep / 1,000 sheep in Norway and Sweden respectively; Linnell *et al.*, 2001b). Management practices that separate lynx and sheep, such as keeping sheep in open, less preferred habitats away from woodland edges, as well as improved shepherding and use of guard dogs or electrified fencing, help to reduce predation risks (Stahl *et al.*, 2002; Odden *et al.*, 2008; Linnell *et al.*, 2012). In Britain, sheep predation would be most likely to occur where sheep range freely in or adjacent to woodlands inhabited by lynx. However, predation is likely to be low where sheep graze close-cropped open hill ground that lacks the cover required by lynx for stalking their prey.

Another potential conflict in Britain would be the predation by lynx of reared game birds such as pheasant and red-legged partridge. As game bird rearing on the scale practised in Britain does not occur within the lynx range elsewhere in Europe, this issue is not covered in the literature. It would seem logical to expect that where birds are reared in, or adjacent to, lynx habitat, predation is likely to occur, particularly by juvenile lynx. The extent of the potential impacts are unknown, but we can expect concern over lynx reintroduction from those with game bird interests.

There are a number of unknowns relating to the impact of reintroduced lynx on British wildlife. The extent to which lynx would prey on existing predators of British wildlife, such as foxes, is unknown. Given the impacts of foxes on some species of conservation interest (e.g. Baines *et al.*, 2011), this may determine whether the overall effect of lynx on species of conservation interest is positive or negative. Similarly, the likely effect of lynx on rear and release game birds will depend on the impact of lynx on other game bird predators, as well as the availability of alternative preferred prey and the extent to which lynx overlap spatially with the game birds.

It is difficult to predict how significant sheep predation would be in Britain because British sheep farming systems and husbandry practices are not directly comparable with those in areas where lynx currently occur. Whether lynx would prey on hill sheep grazing heather moorland is unknown as this habitat is not widely available within the current lynx range but predation risk is likely to be higher than on close-cropped open hill ground and to increase with proximity to adjacent woodland and forestry blocks. Studies of lynx predation in Norway compared with France and Sweden have shown that confining sheep in ordinary stock-fenced fields or keeping them out of the forest dramatically reduces predation losses (Stahl *et al.*, 2002; Odden *et al.*, 2013), but it is not clear how applicable these findings would be to the smaller, more fragmented forests and woodlands of Britain.

5) How might lynx reintroduction affect deer management and the interests of the deer stalking community? (To include changes in effort required to manage deer populations, changes in shooting opportunities, risks to stalkers).

The reintroduction of lynx to Britain could influence deer management and recreational stalking directly, as a result of a decreased deer populations, and indirectly, through possible behavioural changes and shifts in habitat use of deer populations. However, there are no reports of lynx attacks on humans in Europe (Wilson, 2004) and lynx are not a direct threat to people (Breitenmoser *et al.*, 2000). Stalkers therefore need not be concerned for their safety.

Effects on stalking opportunities

There is considerable discussion about whether competition for the same quarry between hunters and large carnivores is real or perceived (Melis *et al.*, 2010). Evidence from Germany and Sweden shows that roe deer hunting bags have decreased substantially in some areas since the return of lynx (Heurich *et al.*, 2012; Andrén & Liberg, 2015) and data from Norway suggest that roe deer hunting quotas are unsustainable in some areas where environmental productivity is low and lynx are present (Melis *et al.*, 2010). Lynx reintroduced to Britain would be more likely to affect the stalking of roe than red deer for the reasons given in answer to question 2 above. However, a lack of spatial estimates of both roe deer densities and hunting pressure on most populations of British roe deer makes

it difficult to predict how lynx reintroduction would affect stalking opportunities in the parts of Britain where lynx might be reintroduced. As indicated in question 2 above, in productive areas with relatively high density roe deer populations, lynx would probably have little impact on stalking opportunities. It is unclear how stalking opportunities would be affected in less productive areas of Britain.

To put lynx predation into the context of current roe deer harvesting, if we assume a lynx population of 250 individuals, of which 200 are adults, and we assume that each adult takes 50 roe deer per year, then the total number of roe killed by lynx would be 10,000 per year. This compares with a current annual roe deer cull in Scotland of approximately 30,000 deer shot per year (SNH, 2014).

Effects on stalking effort

The reintroduction of lynx may affect stalking and deer management through non-lethal effects on behaviour of ungulate populations in response to perceived predation risks (see question 2 above). If deer become more vigilant or avoid certain habitat types they may be harder to stalk. Hunters in the Alps and Germany have argued that behavioural changes induced by lynx have been substantial, making ungulates wilder and more difficult to hunt (Breitenmoser & Haller, 1993; Heurich *et al.*, 2012). However, clear evidence to support these assertions is lacking and they contradict empirical evidence from Scandinavia which suggests a lack of behavioural response by roe deer to lynx recolonisation (Ratikainen *et al.*, 2007; Samelius *et al.*, 2013). Furthermore, humans and lynx have different hunting modes, creating contrasting habitat risks for roe deer (Lone *et al.*, 2014). Roe deer face a higher predation risk from lynx and lower risk from human hunters with increasing cover, particularly where humans hunt from high seats and with rifles rather than stalking or drive hunting with shot guns where this is legal (Norum *et al.*, 2015).

Knowledge gaps

Roe deer stalking effort data and to a lesser extent harvest data are not currently widely collected using consistent methodologies across all of Britain. The availability of such baseline data would be required to measure changes in harvest or effort brought about by lynx reintroduction and feed into subsequent adaptive lynx management plans.

The effects of lynx predation on roe deer behaviour are as yet unclear. Whether these might vary depending on habitat type or densities of roe deer or lynx is unknown but this could contribute to inconsistencies between anecdotal evidence from central Europe and empirical evidence from Scandinavia. This makes it difficult to determine whether or not an increase in effort would be required to control deer populations in areas of Britain where lynx are present, or the extent to which any change in effort may be offset by reductions in deer population size brought about by lynx predation.

6) What regulates and influences lynx population growth on the North Eurasian continent, would this likely be the same in UK, and if not, what might we expect? (To include information on the consequences of natural population regulation for lynx, and on approaches to lynx management on the continent).

Population regulation in lynx

Lynx population growth and expansion have been strong in the indigenous remnant populations of Scandinavia, the eastern Baltic and Carpathian mountains over recent decades, but slow by comparison in reintroduced populations (Linnell *et al.*, 2009; Chapron *et al.*, 2014). Even after more than thirty years, all reintroduced populations remain small and most are either no longer growing or are declining in size (Table 1; Chapron *et al.*, 2014). Lynx are inherently slow breeders and relatively poor dispersers and in reintroduced populations this may be exacerbated by the small size and narrow genetic basis of founder populations (Linnell *et al.*, 2009). Furthermore, extreme habitat fragmentation in the human-dominated landscape of central Europe has hindered the geographic expansion of reintroduced populations and the establishment of a larger inter-connected network of sub-populations (Kramer-Schadt *et al.*, 2005; von Arx *et al.*, 2009).

The main factor limiting growth of both remnant and reintroduced lynx populations is mortality of anthropogenic causes. Together, poaching, traffic accidents exacerbated by habitat fragmentation and, to a lesser extent, legal harvesting account for 54-97% of all mortality (Ryser-Degiorgis, 2009). Widespread illegal killing has been a major factor limiting the growth rate of remnant populations (Andrén *et al.*, 2006; Kowalczyk *et al.*, 2015) and particularly the expansion of reintroduced populations (Linnell *et al.*, 2009; Breitenmoser *et al.*, 2010; Müller *et al.*, 2014). It could account for a third to a half of all lynx mortality (Andrén *et al.*, 2006; Breitenmoser-Würsten *et al.*, 2007; Kowalczyk *et al.*, 2015). Although the level of conflict over lynx predation of livestock is generally low compared with other large carnivores, conflict with deer hunters is particularly serious and is believed to contribute to the high rates of illegal killing (Breitenmoser *et al.*, 2010; Kaczensky *et al.*, 2012), particularly when poaching occurs during the ungulate hunting season (Andrén *et al.*, 2006). Vehicle collisions are the second most serious cause of mortality, accounting for 20-50% of deaths (Ryser-Degiorgis, 2009). Dense transport networks in central Europe cause particularly high rates of traffic-related lynx mortality (Kramer-Schadt *et al.*, 2004), especially among dispersing sub-adult lynx (Schmidt-Posthaus *et al.*, 2002). Legal harvesting of lynx is permitted by the authorities in some countries (see below) to limit the distribution and density of lynx in an attempt to reduce livestock predation (Herfindal *et al.*, 2005b).

In Britain, similar factors could also limit populations of reintroduced lynx. Conservation conflicts have a long history in Britain (Etheridge *et al.*, 1997; Redpath *et al.*, 2013) and we might anticipate conflicts related to the predation of roe deer, reared game birds and sheep. Sheep predation problems are most likely on lower ground and where sheep are grazed at relatively high densities in, or adjacent to, extensive woodlands with relatively low roe deer densities (Odden *et al.*, 2013; Gervasi *et al.*, 2014).

Additional mortality issues are likely to arise in relation to the particularly high densities of roads, traffic and human population in much of Britain relative to elsewhere in Europe. The average human population density in areas currently occupied by lynx in Europe is 22 inhabitants/km^2 (Chapron *et al.*, 2014). While much of Scotland, Wales and England north of a line from Preston to Newcastle have human densities low enough to be compatible with lynx persistence, only small pockets occur in the rest of England (UK Census 2011). Given the high proportion of mortality accounted for by traffic accidents, a reintroduced lynx population in southern England is likely to have a lower chance of success than in Scotland.

Lynx management

The main tools used to manage lynx populations and conflicts in Europe and Fennoscandia are legal hunting and compensation schemes for predated livestock (Kaczensky *et al.*, 2012). In some areas, payments or reporting premiums are also paid to hunters (Kaczensky *et al.*, 2012). Within the EU, lynx are protected under the Habitats Directive but legal hunting occurs in Sweden, Latvia and Finland under derogation (Kaczensky *et al.*, 2012). In Norway, which is not under EU law, lynx are currently managed through a quota hunting system that aims to stabilise their population density and attempts to limit predation of domestic sheep (Herfindal *et al.*, 2005b; Linnell *et al.*, 2010). Legal selective removal of so-called 'problem animals' is allowed in Norway, Switzerland and France (Kaczensky *et al.*, 2012) although its success is generally only temporary as predation arises due to landscape or management features of a specific site and new individuals moving into the vacant territory are likely to cause the same problem (Odden *et al.*, 2002; Stahl *et al.*, 2002).

Although compensation schemes for predator-killed livestock are widespread (Kaczensky *et al.*, 2012), they themselves can cause social conflict associated with difficulties in verification and perceived fairness (Zabel & Holm-Müller, 2008; Linnell *et al.*, 2012; Odden *et al.*, 2013). Alternatives are risk-based incentive systems which encourage active predation-prevention rather than focus on damage documentation (Odden *et al.*, 2013) and conservation performance payments, for example those which are paid in Sweden for carnivore reproduction in reindeer grazing areas (Swenson & Andrén, 2005; Zabel & Holm-Müller, 2008).

Knowledge gaps

It is as yet unclear what management options would exist in Britain to handle potential conflicts arising from lynx reintroduction. Any plans involving lethal control of the population would need careful design and require derogation from Europe. Similarly if compensation would be provided, consideration is needed for what kind of package would be appropriate and the possibility of tying it to predation-prevention incentives (Breitenmoser *et al.*, 2000). The cost of such a scheme and, if it would involve public money, an assessment of its value for money, would also need to be addressed.

Predictions of the likely consequences of collisions with road traffic would be required for any reintroduced lynx populations in Britain. Crossing motorways and dual carriageways

seems particularly difficult for lynx (Kramer-Schadt *et al.*, 2004) and, although speed limits on British motorways are lower than in some parts of central Europe, average traffic volumes are higher than in Germany (Department for Transport 2014). Although many studies report high traffic-related mortality (Schmidt-Posthaus *et al.*, 2002; Kramer-Schadt *et al.*, 2004; Breitenmoser-Würsten *et al.*, 2007), few specific details seem to be available which will make it difficult to quantify population-level impacts.

7) What processes must be undertaken in order to lawfully reintroduce lynx to England, Scotland and Wales? (To include a brief description of the licensing and consultation process, including risk assessment, risk mitigation and likely timelines).

Many early lynx reintroductions were poorly planned, took little consideration of animal welfare and were carried out in a very 'ad hoc' manner (Linnell *et al.*, 2009). Since then, detailed reintroduction guidelines have been produced and updated by the IUCN / Species Survival Commission which outline the necessary steps from planning, to design and risk assessment of a programme, and to release and subsequent monitoring (IUCN/SSC, 2013). In addition, there is a new Scottish Code for Conservation Translocations developed by the National Species Reintroduction Forum (NSRF), and associated best practice guidance (NSRF, 2014a, 2014b).

Although the guidelines are not legally binding, required licences will only be granted if they have been met. Free-living, wild lynx have not been present in the British Isles for at least 1400 years (Hetherington *et al.*, 2006) and, as they are unable to recolonise here naturally, they are considered to be outwith their native range. Therefore, for any reintroduction to occur, a non-native species licence is required from Natural England (NE), Scottish Natural Heritage (SNH) or Natural Resources Wales (NRW). A licence application would have to demonstrate proper public consultation and evidence gathering, as well as serious consideration of the socio-economic impacts of the introduction and impacts on the environment and the animals themselves (Natural England, 2015). Within Scotland, completion of a Translocation Project Form is mandatory for all reintroductions and translocations that require a licence from SNH. This form covers an assessment of the benefits, legislative considerations and risks, as well as details of the required risk mitigation, future monitoring and management (NSRF, 2014a). The risks include a wide range of biological, economic and animal welfare considerations. The criteria for assessing the success of the reintroduction must also be specified. Given the high profile of a lynx reintroduction, the stakeholder engagement process would likely be referred to NSRF whose 26 members represent a diverse range of stakeholders from across the land use, conservation and scientific communities. Additional licences would need to be sought from the relevant statutory bodies in the countries of donor populations and if the release of a non-native species affects a Natura site, a 'Habitats Regulations Appraisal' must be carried out before any licence can be issued (NSRF, 2014a). Animal health and welfare legislation must also be met.

Carnivore reintroductions are extremely lengthy, costly and complex processes (Kramer-Schadt *et al.*, 2005), requiring long-term commitments by all partners (Breitenmoser *et al.*, 2001). Gathering the necessary evidence to submit a non-native species licence application is likely to take time, particularly where public consultation is required and the relevant statutory agencies must then consider the application. The process undertaken during the Scottish beaver trial (Gaywood, 2015) provides an indication of what could be expected for a lynx reintroduction in Scotland and the time scale involved. The Scottish Government is due to make a decision regarding beaver reintroduction in 2015, 20 years after SNH began investigating the feasibility and desirability of reintroducing beaver to Scotland and 6 years after the first official trial release (Gaywood, 2015). In general, the licence applicant is expected to bear the costs of any reintroduction in Britain, and should have a sufficient budget to fund the exit strategy and any mitigation costs. However, the statutory authority may also incur costs associated with its obligation to monitor compliance with the conditions of the licence. The Scottish beaver trial has cost in the region of £2 million, being funded primarily by the licence holders Scottish Wildlife Trust and Royal Zoological Society of Scotland, but with SNH contributing almost 15% in relation to the monitoring programme (Gaywood, 2015). Future beaver management scenarios will entail further costs but the decision on how to balance these between private and public funding sources has yet to be made (Gaywood, 2015). If a reintroduction has been judged a success, the species then becomes an established part of the national fauna/flora and subsequent management and monitoring costs will fall to the statutory authorities or other parties responsible for such activities.

Discussion

Under the European 1992 Habitats and Species Directive (Directive 92/43) legislation, the UK is obliged to study the desirability of reintroducing species extirpated from their natural range, if this is likely to contribute to their conservation. Given the current large Eurasian range of lynx and the growth rate of remnant populations, coupled with multiple European reintroductions, it is questionable whether lynx conservation would benefit from a reintroduction to Britain. Indeed, the species action plans for carnivore conservation in Europe prioritise supporting natural recolonisation, augmenting currently non-viable populations and releasing animals to join up non-viable populations before carrying out releases into new areas (Breitenmoser *et al.*, 2000). Reintroductions of cat species generally play no significant conservation role at the global scale, although they may have local or regional benefits (Breitenmoser *et al.*, 2001). On the other hand, similar arguments regarding the global conservation benefits of reintroducing beaver to Britain could be made, yet the Scottish beaver trial and the licensing of beavers released in Devon have set a precedent suggesting that more local conservation benefits are sufficient justification for the reintroduction of former-native species to Britain.

A prerequisite to reintroduction is that conditions leading to a population's extirpation should no longer exist (IUCN/SSC, 2013). In the case of lynx, there have been strong recoveries in habitat and prey populations in Britain, although habitat fragmentation remains an issue, albeit to a lesser extent in the Scottish Highlands (Kitchener, 2001; Hetherington *et al.*, 2008). Human persecution probably contributed to the loss of lynx from Britain (Hetherington *et al.*, 2006) but although attitudes towards large carnivores are generally now more positive (Nilsen *et al.*, 2007; Heydon *et al.*, 2010), the extent to which lynx might experience renewed persecution following reintroduction in Britain is unknown. Therefore, some causes of extirpation may partially remain, although conditions are now more favourable than in the recent past.

There are undoubtedly pros and cons associated with a reintroduction of lynx to Britain and this feeds controversy. As the reintroduction of carnivores is an extremely complex and costly process (Breitenmoser *et al.*, 2001), a high probability of success is likely to be a prerequisite of a licence. The success of such a programme in Britain rests on the availability of sufficient prey and suitable habitat and, importantly, on the will of the people.

Good estimates of spatial variation in prey availability throughout Britain are currently not available but would be required for more accurate predictions of the size, density and viability of reintroduced lynx populations. Furthermore, to understand the potential impacts of lynx predation on roe deer populations in particular, estimates of current roe deer reproduction and mortality rates are needed for proposed reintroduction sites. The sustainability of a roe deer harvest in the presence of reintroduced lynx would need to be monitored, possibly by observing trends in population density over 5+ year timespans. Changes could be used as an indicator of roe deer population viability and feed into an integrated adaptive deer and lynx management plan.

To improve estimates of the availability of suitable habitat, spatial modelling of habitat connectivity, within the context of lynx space use, is needed in England and Wales while the quality of habitat identified in Scotland by Hetherington *et al.* (2008) needs investigating in more detail, particularly regarding the availability of woodland understory vegetation. Browsing by deer has reduced the density and cover of understory vegetation in many parts of Britain (Gill & Fuller, 2007). These habitat features are required by lynx for stalking prey and resting (Podgórski *et al.*, 2008). Furthermore, assessments of habitat availability need to consider the effects of future infrastructure and housing developments within local and national strategic development plans. The potential lynx habitat network identified in the Scottish Highlands should therefore be reappraised in the light of road improvement schemes such as those planned for major trunk routes between Perth and Inverness and also Aberdeen and Inverness, which would affect lynx habitat connectivity in the landscape.

Even if we assume that prey and habitat availability are sufficient to support a viable population in the Scottish Highlands (Hetherington & Gorman, 2007; Hetherington *et al.*, 2008), and that any lynx welfare issues are considered acceptable, it is not clear whether there is the social appetite for a population of the size required for long term viability

(assumed to be at least 250 lynx) among the inhabitants of the communities that would be most affected. In many areas where attitudes to carnivores have been studied, opinions of urban people are more positive than those of the rural population who must live alongside carnivores and face potential impacts on their livelihoods (Breitenmoser *et al.*, 2001; Ericsson & Heberlein, 2003). In some rural communities there can be a high social acceptability of illegal hunting of large predators (Gangaas *et al.*, 2013). Consequently it may be that the social carrying capacity of lynx in Scotland is considerably lower than the ecological carrying capacity. However, both of these will need to be higher than the predicted minimum viable population size if a reintroduction of lynx is to stand a reasonable chance of success. A survey of attitudes towards wolf reintroduction in the Highlands showed that while attitudes differed between rural (Glen Affric) and urban (Inverness) participants, they were nonetheless positive in both groups, while the attitudes of the farming subsample of rural participants were negative (Nilsen *et al.*, 2007). Interestingly the attitudes of individual farmers were far less negative than those of the organization that represents them (Nilsen *et al.*, 2007). It is therefore important to understand both the views of a representative sample of society, regarding the desirability of reintroduction in general, and those of the people likely to be directly affected when considering the specifics of a reintroduction such as site suitability and impact minimisation.

In the light of experience from reintroduction programmes in Europe (Breitenmoser *et al.*, 2001; Linnell *et al.*, 2009; von Arx *et al.*, 2009), it seems inevitable that lynx reintroduction in Britain would involve anthropogenically-caused mortality of some lynx. However, it is not clear whether the public are aware of this, or how socially acceptable this is. In the most recent reintroduction of lynx in Harz Mountains, Germany, 7 of the 24 released individuals died post-release (4 due to a combination of starvation and sarcoptic mange, 1 due to train collision, 1 of a broken leg and 1 unknown), while a further 2 had to be recaptured due to a lack of shyness towards people (Linnell *et al.*, 2009). A recent survey of the British public's attitude towards lynx reintroduction (Lynx UK Trust, 2015) is believed to show support for the idea, but more detailed surveys are required to understand perceptions of wider aspects of such a reintroduction. For example, attitudinal surveys should be designed to determine whether the public are prepared to accept risks associated with reintroduction into areas where there could be high levels of anthropogenically-caused mortality due to fragmented habitat, conservation conflicts or traffic accidents, or where high levels of post-release intervention are required to manage populations that are too small to be self-sustaining.

Lessons should be learned from earlier lynx reintroductions. These have been well reviewed (Breitenmoser *et al.*, 2001; Linnell *et al.*, 2009; von Arx *et al.*, 2009) and, where relevant, are incorporated in the IUCN guidelines (IUCN/SSC, 2013). What is abundantly clear from earlier reintroductions is that sufficient understanding of the social issues was often lacking and that planning requires in-depth consideration of these, in addition to the ecological issues. The successful reintroduction of lynx into Britain requires a number of knowledge gaps to be filled, relating to both ecological conditions and social attitudes and tolerance.

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