Biodiversity and Upland Management

A summary of research outputs supported or facilitated by the Environmental Change Programme of the Scottish Government's Portfolio of Strategic Research 2011-2016

Introduction

In this booklet, we summarise some of the research from the Scottish Government's Strategic Research Programme on wildlife and biodiversity and how these interact with management, with particular emphasis on the uplands which cover two thirds of Scotland's land area. Whilst they are important for wildlife, nature conservation and recreation, they are also managed for livestock, woodland, red grouse shooting and deer stalking. In recognition of these multiple objectives a number of policies such as Scotland's Land Use Strategy (*Getting the Best From Our Land*, 2011) and the Scottish Biodiversity Strategy (*2020 Challenge for Scotland's Biodiversity*, 2013) aim to foster sustainable environmental management to safeguard the biodiversity and the benefits they provide to society.

We describe some of the work recently undertaken to support the management of key upland species and components of biodiversity. We show in Chapter 1 how diversity of management can help to increase the *diversity of upland birds* at a landscape scale. Developing effective monitoring is important for Adaptive Management and in support of the '*Wildcat Conservation Action Plan*', and we used our spatial analysis skills to assess candidate priority areas and to inform a reliable monitoring framework (Chapter 2). We show in Chapter 3 how standardising record keeping can improve our ability to *detect changes in red deer body mass and reproduction* to support of the priorities for sustainable deer management identified in *'Wild Deer: A National Approach 2014 Review'*. Making use of good quality data is crucial if we are to manage conflicts such as those over *deer management and public access* (Chapter 4) and developing effective *monitoring of mountain hares* (Chapter 5) is essential as part of Scotland's obligation to sustainably manage this iconic, Annex V species. The practice of *muirburn* is an important wildlife management tool and our results demonstrate that vegetation recovery on wet heaths and blanket bogs is slow (Chapter 6). Technological advances in remote wildlife monitoring such as camera traps is an increasingly valuable way to *engage communities* with wildlife (Chapter 7).

Where an environment provides a wide range of *ecosystem services*, as exemplified by the uplands, maintaining local livelihoods as well as wider public benefits remains a challenge (Chapter 8). Work on understanding *long-term patterns in semi-natural habitats* has detected widespread homogenisation, decreasing plant diversity and increasing graminoid cover in several habitats across Europe, attributable to human activities and environmental change (Chapter 9). Montane habitats, including internationally important *Racomitrium* heath, show significant impacts of atmospheric *nitrogen deposition* on key ecosystem processes (Chapter 10). Climate-driven changes in upland habitats may require intervention to conserve the less mobile species, for example by *translocation* to other areas, which provides significant methodological challenges (Chapter 11). Mitigating climate change via woodland expansion also needs to consider wider impacts such as the finding that the abundance of *ticks* is higher in woodlands (Chapter 12).

The restoration of biodiversity and ecosystem processes through re-wilding must consider a broad range of impacts, be they benefits or costs, to biodiversity and ecosystem processes as demonstrated in the *beaver reintroduction* trial (Chapter 13), and other high profile initiatives such as the *Lynx reintroduction* (Chapter 14). Similarly, supporting scavenger species by, for example, *carcass placement* for the golden eagle also influences other aspects of the food web and wider ecosystem processes (Chapter 15) and scavenger activity is strongly influenced by the presence or absence of *predator control* (Chapter 16).

We need to continue working with relevant stakeholders to identify the upcoming issues and the appropriate monitoring to understand how the uplands respond to drivers of change so that sustainable management options can continue to be developed, tested and applied.

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CHAPTER 1

The consequences of upland management for avian diversity

Background

There is growing recognition that conservation of biodiversity and delivery of ecosystem services needs to be achieved alongside other socially and economically sustainable land uses. Recreational hunting, or sport shooting (hereafter hunting), is widespread, and although controversial, is a socially and economically important land use that influences many habitats and landscapes across Europe. In Scotland, management for hunting influences an estimated 50% of the land area. Land management for game birds and other hunted species involves a wide range of management practices which may have positive or negative effects on other bird species.

To assess the biodiversity impacts of management for hunting we carried out a literature review and surveys of breeding birds of conservation importance across Scottish upland land holdings (estates).

Approach

We reviewed the scientific literature to assess the positive and negative impacts of game bird management on non-game birds and other species across Europe. In addition we carried out field surveys of breeding birds during the spring at 26 estates with different management objectives (grouse shooting, deer stalking, sheep production and biodiversity conservation) across Scotland.

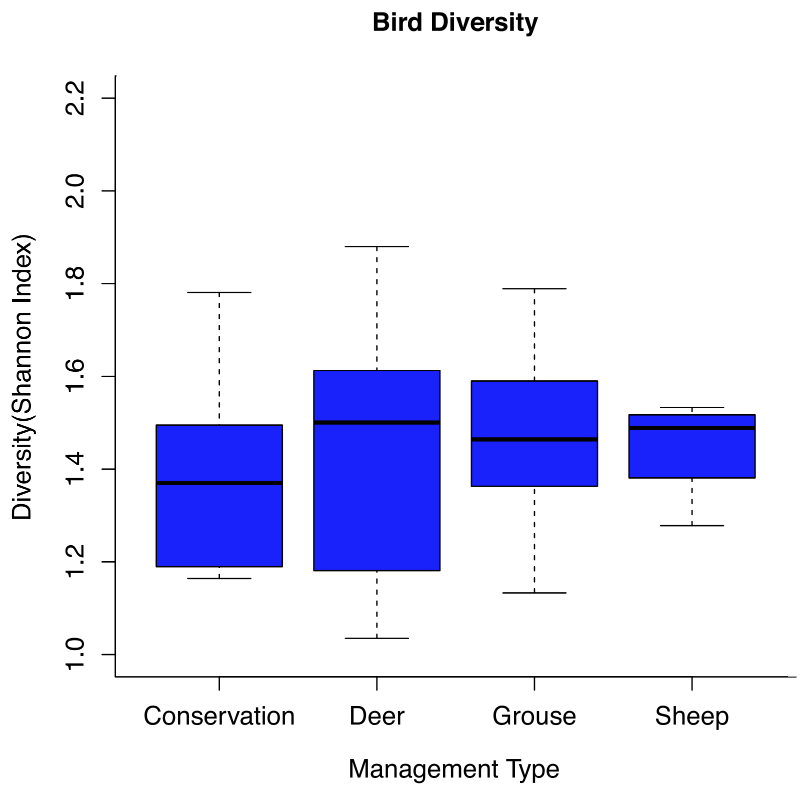

Fig. 1: Breeding bird diversity (Shannon index) of 26 upland estates with different dominant management objectives (grouse shooting, deer stalking, sheep production and biodiversity conservation). The thick black line shows the median value for each management type, the blue area of each plot show the 25-75% quartiles, and the dotted lines show the range of values recorded for each management type

Results

- The 32 scientific studies we found reported more than twice the number of positive than negative effects of game bird management on non-game bird species.
- Habitat management and legal predator control carried out for game bird management were generally either positive or neutral for non-game species, though the effects depended on the wider dominant land management.
- Illegal predator control, which can have profound effects on vulnerable or protected species, was the main documented negative effect of game management.
- An analysis of bird diversity across a range of upland moorlands in Scotland demonstrated that there was no statistical difference in avian diversity between land managed for hunting versus land managed for other objectives (Fig. 1).
- However, the composition of the species present did vary with management objectives, thus indicating that management influences the type of species present but not the overall level of diversity.

Conclusion

Management for hunting involves a number of practices that favour particular species, but can be detrimental to others. Both our review of the scientific literature and survey of breeding birds on Scottish upland estates support the idea that game management may be a potentially important tool for the conservation of biodiversity outside of protected areas, and that biodiversity at the landscape (regional and national) level might be maximised by encouraging a diversity of land use types alongside protected areas.

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CHAPTER 2

An assessment of the suitability of candidate wildcat conservation areas

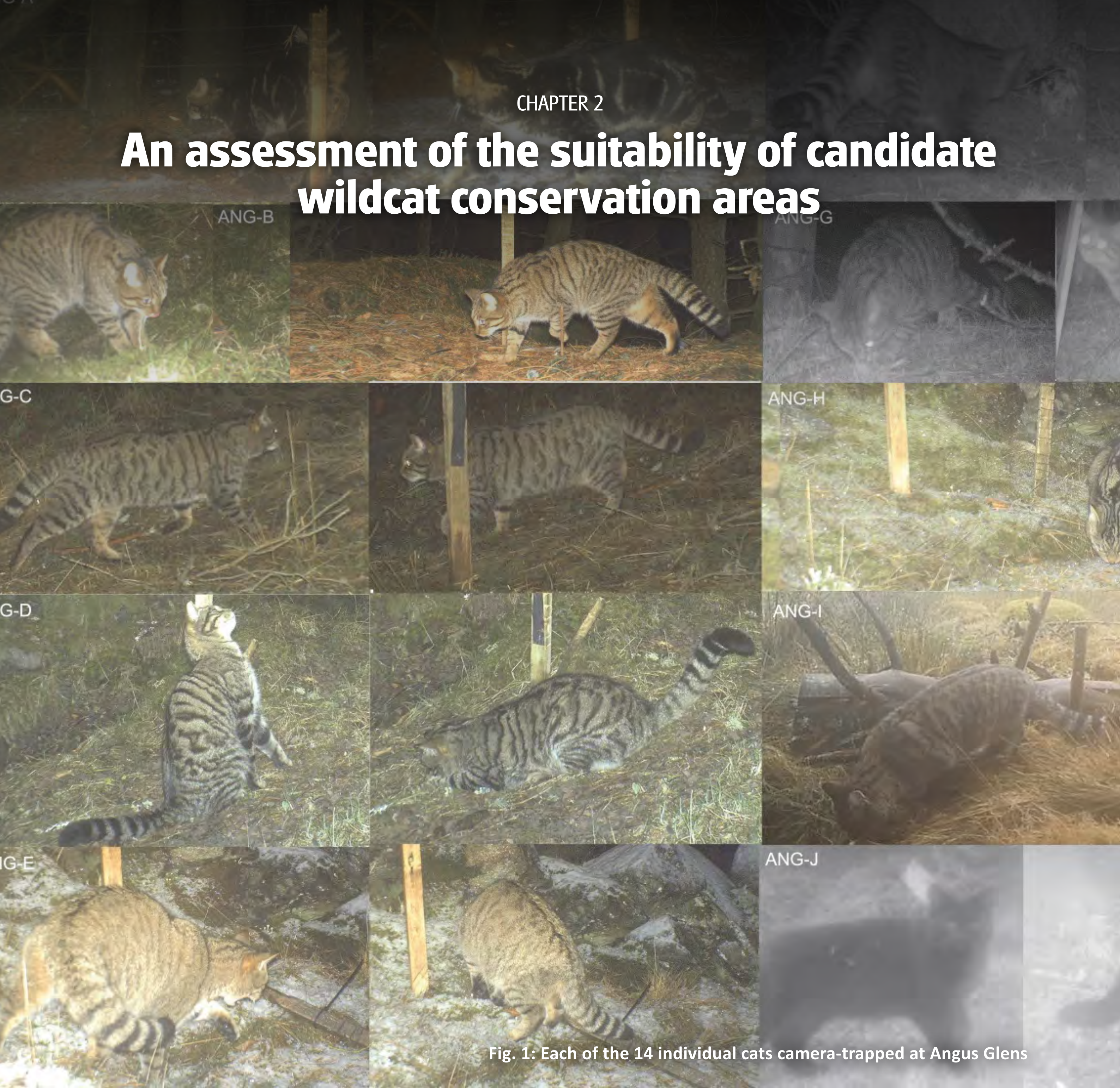

Fig. 1: Each of the 14 individual cats camera-trapped at Angus Glens

Background

The Scottish wildcat (*Felis silvestris*) is in urgent need of action to save the remaining small wild populations which are now restricted to fragmented areas of the Scottish Highlands. The Scottish Wildcat Action Plan aims to secure at least five stable populations. **The aim of this project was to determine the presence and number of wildcats in a set of candidate areas and assess whether these contained sufficient suitable habitat to maintain viable populations.**

Approach

We used population viability assessment to provide guidance on the minimum population size for a viable population. We combined this with a Geographic Information System-based analysis of the land cover in the candidate areas to determine the area of land that would

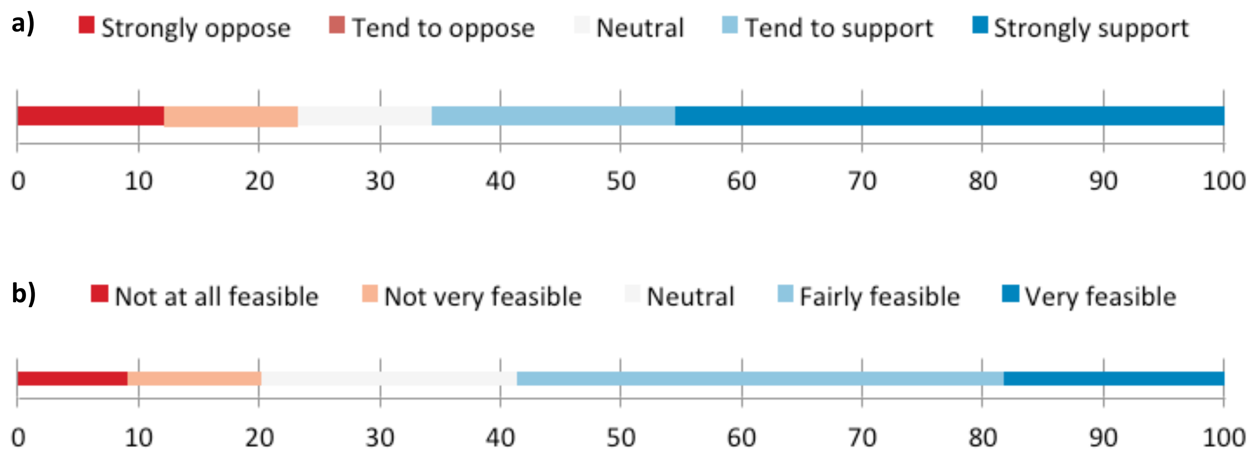

Fig. 2: a) 66% of respondents would be supportive ('tend to support' or 'strongly supportive') of a co-ordinated trap-neuter-release (TNR) programme and b) 59% of respondents think TNR is feasible ('Fairly' or 'Very') in their area

contain sufficient quality habitat for the viable population. We analysed data from a camera trap survey of each area to determine the size of the remaining wildcat populations in the candidate areas. In addition, we designed a questionnaire to assess attitudes towards wildcat conservation in the candidate areas (Littlewood, NA. *et al.*, 2014, Survey and scoping of wildcat priority areas. SNH Commissioned Report No. 768).

Results

- The analysis suggested that a population of 40 breeding wildcats (males and females; assuming an equal sex ratio at birth) was required to stand a >95% chance of surviving for 50 years. Nine areas were defined that contained sufficient high-quality habitat to be able to support 20 breeding female wildcats.
- Camera trap surveys at each of the nine candidate priority areas detected wildcats based on pelage characteristics at six of the sites. The highest density of wildcats was found in the Angus Glens site (Fig. 1). However, hair and faecal samples showed a broad spectrum of hybridisation with feral domestic cats across all sites.
- Questionnaires showed that most people supported wildcat conservation and the suggested specific conservation actions. However, releasing neutered feral cats elicited opposing views from respondents (Fig. 2).

Conclusions

Genetically distinct wildcats clearly exist in several areas but at very low densities; but there is also evidence for significant populations of hybrid wildcats. Five sites were recommended as priority areas for wildcat conservation based on the existence of wildcats and the presence of contiguous suitable habitat, taking into account barriers to movement and dispersal. Success for wildcat conservation will depend on stakeholder attitudes and acceptance of proposed wildcat management actions. The use of camera traps to monitor wildcat populations will require very substantial survey effort and, given current knowledge of wildcat ecology, may not be suitable for monitoring low density wildcat populations (Newey, S. *et al.*, 2015. Simulation study to inform the design of wildcat camera trap monitoring protocols. SNH Commissioned Report No. 899).

Acknowledgements: This project was funded by Scottish Natural Heritage.

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CHAPTER 3

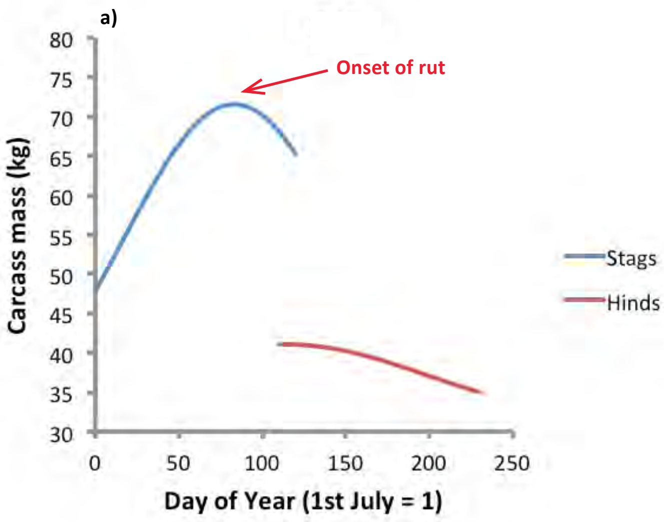
Effective use of larder data for sustainable red deer management

Background

Wild deer are an iconic species in the Scottish uplands with importance for rural economies and communities but can also have significant impact on their habitat. Deer management must therefore increasingly deliver to both public interest and private objectives. The sustainability of which will require us to predict population responses to future climate and land use change so that an adaptive management approach based on evidence can be implemented. **The aim of this project was to determine the key metrics that can be collected from culled red deer (*Cervus elaphus*) to detect how deer performance responds to both management and environmental change.**

Approach

A suite of metrics were collected from over 7,000 individual culled deer, in a standardised format, from over 20 participating open-hill sporting estates across the uplands. Metrics included date, location, sex, carcass mass, body length, estimated age, weight of kidneys and kidney fat, prevalence of some important parasites and, for females, pregnancy and lactation status. Jaw length provided a measure of skeletal size, annual rings in the molar cementum provided accurate ageing and ovary structures were examined to determine reproductive history. Much of the analysis so far has focussed on understanding the variation in two key measures: body condition and reproductive rates.



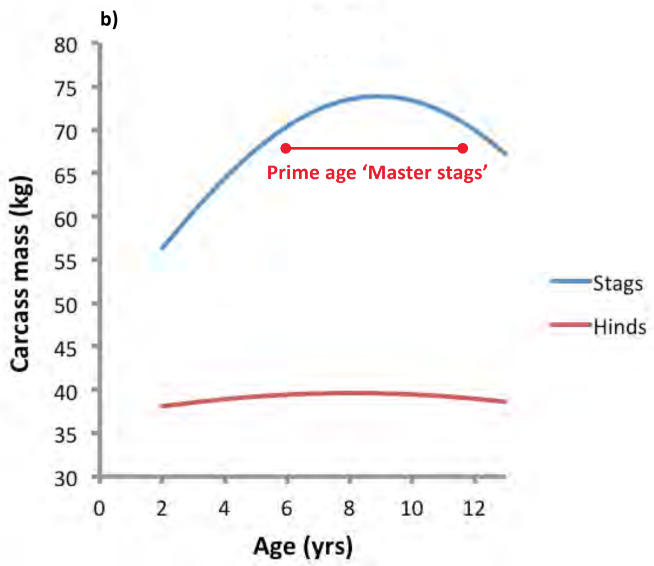


Fig. 1: Change in predicted average carcass mass with a) date and b) age for stags and hinds

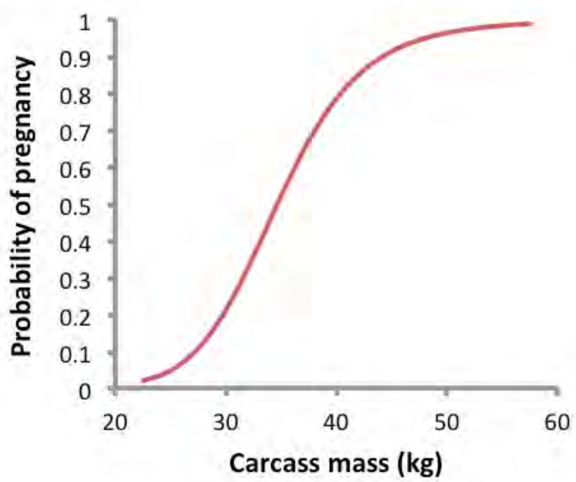


Fig. 2: Predicted probability of pregnancy with changing carcass mass for adult hinds

Results

- **Condition.** Carcass mass was strongly related to body condition but it also changes through the seasons (Fig. 1a). Furthermore, knowing the age of adult males is important because carcass weight peaks in prime age animals and then declines. However, this is not so important in adult females (Fig. 1b). Carcass weight was also related to skeletal size (jaw length explaining 12-15% of carcass mass variation). Kidney fat weight can also further contribute to a measure of condition but both jaw length and kidney fat are more difficult to measure in the larder.

- **Reproductive rates.** Pregnancy rates were higher when animals were in better condition with carcass mass the most important factor (Fig. 2). However, pregnancy rates in adult females were not strongly related to age or skeletal size. Kidney fat weight adds limited additional explanatory power (3-4%).

Conclusion

Standardised body mass recording by sporting estates would be a significant aid to effective adaptive management of our deer populations. For red deer, body mass is a good measure of condition but season also needs to be taken into account. Accounting for age is important in adult stag carcass mass but less so for hinds. Body mass is a key factor in determining reproductive rates. The collection of additional metrics, such as jaw length and kidney fat mass, may enhance monitoring but the additional collection effort may not be justified. Next steps should include further exploration of how variation in body mass relates to deer density, habitat and climate across the uplands.

Acknowledgements: This project was funded by Scottish Natural Heritage.

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CHAPTER 4

Investigating the causes of changes in deer distribution in relation to changes in sheep numbers and public access

Background

The uplands are important for a range of activities which support the rural economy - including hill farming, deer stalking, forestry and recreation. Recent drivers of change include increases in numbers of hillwalkers, pressure to reduce grazing on priority habitats such as native woodland and blanket bog, leading to reductions in red deer *(Cervus elaphus)* densities, and a decline in sheep numbers in many parts of Scotland. These changes can lead to conflicts between the legitimate objectives of landowners and the public benefits these landscapes provide. **A pilot study was conducted to investigate whether available management information can be used to detect changes in deer distribution and culling patterns to inform future research on the impact of human activity on wild animal populations.**

Approach

This pilot focused on a group of estates that formed part of a deer management group in Perthshire and contained a number of 'Munros' (mountains over 3000 ft a.s.l.) that are popular with hill walkers. We collated historical deer count and cull data and analysed this to assess temporal and spatial trends in deer numbers and to investigate the relationship between deer counts and sheep numbers derived from the agricultural returns (IACS). We then compared observed counts against predictions from a population model and predictions for density distributions from a Geographic Information System-based habitat preference model (DeerMAP: Irvine, R. J., et al. 2009. Journal of Applied Ecology 46, 344-352).

Results

- Over the whole study area, deer numbers have been increasing; in the core area the distributions of stags and hinds have changed (Fig. 1) and stag numbers have declined. Across a similar timeframe, sheep numbers have been reduced to very low levels except in the core area where numbers have been maintained.
- Deer are increasingly recorded on lower slopes (Fig. 2) and on the margins of the study area, possibly because the sheep reduction now allows deer access to these grazing areas.
- Within the core area, the spatial pattern of culling has also changed, with a decline in animals culled in the central ground and more

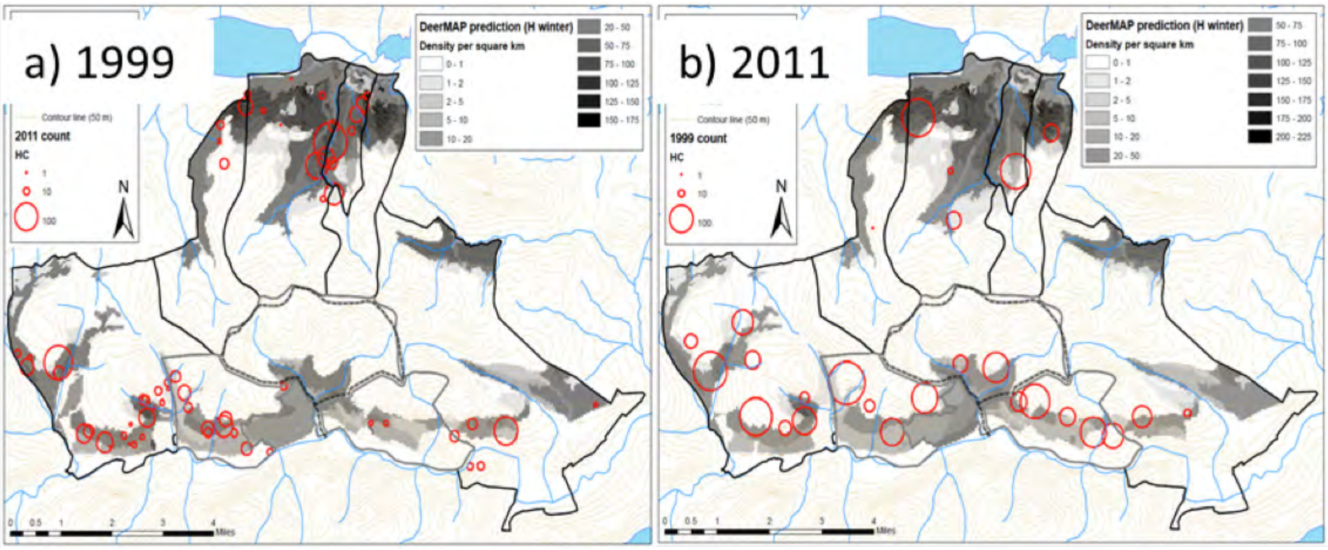

Fig. 1: DeerMAP prediction of deer distribution across the study area in winter in a) 1999 and b) 2011. The size of the red rings relates to the number of animals observed at that location

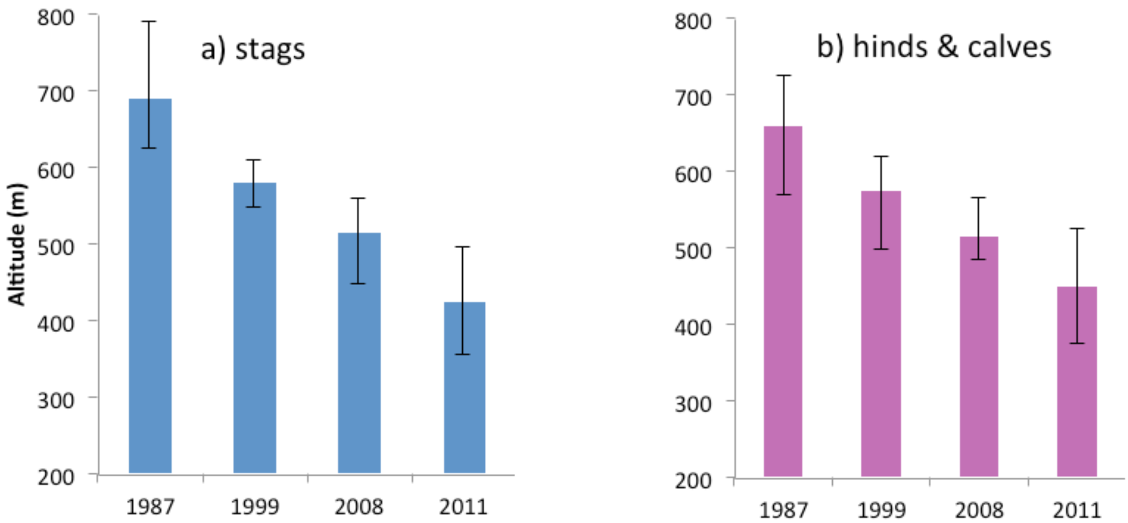

Fig. 2: Mean altitude (m) with standard errors at which (a) stags and (b) hinds and calves were counted for the entire study area in different years

now culled in the Western and Eastern sectors.

- Population modelling for the whole area indicates that the population should be in decline but actual deer numbers remain high. However, within the core area the models predict that there should be more deer than there are. This mismatch indicates that there remain factors affecting deer distribution that we have not yet accounted for.

Conclusions

Our analysis of the sort of management information usually available from estates indicates an unexplained change in deer distribution over time. Potential factors at play may include the effect of sheep removal that may have drawn deer away from the core areas. In addition, the extent to which hill walking has driven this change in deer (and in particular stag) distribution also needs to be tested. A further study is required to provide evidence to inform the perceived conflict between recreation and sustainable wildlife management. The full report is available from http://www.bds.org.uk/index.php/research/current-research-projects/13-current-projects/142-detecting-changes-in-deer-numbers.

Acknowledgements: Funding was received from the British Deer Society and North Chesthill Estates.

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CHAPTER 5

Developing monitoring methods for mountain hares to improve the evidence base for decision-making

Background

Estimating animal abundance or density is a central requirement in ecology and remains one of the most challenging areas of wildlife management. Methods of estimating animal numbers must be tailored to the survey objectives including ease of use, species and habitat (Fig. 1). Assessment of mountain hare abundance and density is necessary to meet the UK's EU legislative conservation obligations, inform conservation targets and for local management of their populations, which are an important game resource and prey for other species. However, no simple and widely applicable method has yet been developed and validated. In a collaboration between The James Hutton Institute, the Game & Wildlife Conservation (GWCT) and Scottish Natural Heritage (SNH) **we aim to establish and validate a reliable method for counting mountain hares so that future population trends can be rigorously monitored and managed.**

Approach

The project is simultaneously testing different methods of estimating hare numbers to compare them with the results of reliable, but expensive and logistically demanding – capture-mark-recapture (CMR) surveys. CMR involves live-trapping, marking, release and recapture of mountain hares (Fig. 1) which combined with information on trap locations can be used to obtain an estimate of density). In preparation, we used existing trapping data to optimise the trapping regime employed, by simulating predicted hare trapping and re-trapping success under a range of possible densities and distributions of mountain hares, number of trapping nights and trap arrangements (Table 1). The CMR survey based on these results is now

	Candidate trapping parameters entered into simulation	Chosen trapping parameters
Number of trapping spatial designs simulated	13	-
Number of traps	64 (8x8), 100 (10x10) or 4x(5x5)	100
Number of clusters	1,4	4
Spacing:		
Inter-trap	100,125,150,200 m	100 m
Cluster centres	600,700,800,900,1000 m	700 m
Trapping nights	12, 16	16
Area	490-1960 ha	640 ha
Walking distance to check traps	7.1 – 21.8 km	12.8 km

Table 1: The simulated candidate parameters of the trapping regime and the chosen trapping regime

Fig. 1: a) Mountain hare in short heathland b) Mountain hare in a cage trap for marking and release

underway and should obtain rigorous density estimates against which to compare and calibrate other methods, which include:

- Distance sampling; measuring their distance from walked transect lines to obtain density estimates;
- Night-time transect counts using powerful spotlights and thermal imaging equipment to detect active hares to obtain a simple count;
- Dung counts; counting faecal pellets from circular plots to give an estimate of the "standing crop" of faecal pellets, and by clearing and revisiting the plots to estimate dung accumulation.

Results

- Based on the simulation studies we use 100 traps arranged in 4 trapping grids to cover the entire study area, and trap for 16 nights over each four week period on each study site (Table 1).

Conclusions

The project is in its second year and using the selected trapping protocol we have so far completed surveys of six study areas. In the third and final year we plan to carry out surveys on four more study areas. Data will then be analysed and the findings used to advise on the most appropriate survey methods and what further work is needed.

Acknowledgements: We are grateful for the support of the estates that have allowed us to carry out this work on their ground. This project is funded by Scottish Natural Heritage.

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CHAPTER 6

Heath vegetation recovery after muirburn under different grazing regimes

Background

Muirburn, the rotational burning of heather moorland, is used to improve grazing for livestock, provide a better habitat for red grouse and reduce the fuel load to minimise wildfires. As deer and sheep frequently graze in areas where muirburn is practiced it is important to understand how the presence of grazers affects vegetation recovery after burning and whether grazing impacts differ between dry and wet heath. This interaction between grazing and muirburn may have implications for water cycling, carbon sequestration and, more generally, upland biodiversity. **We investigated how heather moorland vegetation recovers after muirburn with and without grazing by sheep and deer.**

Approach

Muirburn was carried out on an area of upland heather moorland grazed by sheep and deer at the James Hutton Institute's Glensaugh Research Station. Replicated 100 m x 100 m areas of both wet and dry heath were burnt and then monitored over the following three years. We fenced small plots within the burned areas to exclude grazing. Each year we measured the height of heather (*Calluna vulgaris*), blaeberry (*Vaccinium myrtillus*) and grass and recorded how the percentage cover of plant species changed (Fig. 1). Once the heather had begun to recover, heather utilisation (a measure of grazing on heather shoots) was compared between burned and adjacent unburned areas of moorland.

Fig. 1: Recording vegetation recovery after burning.

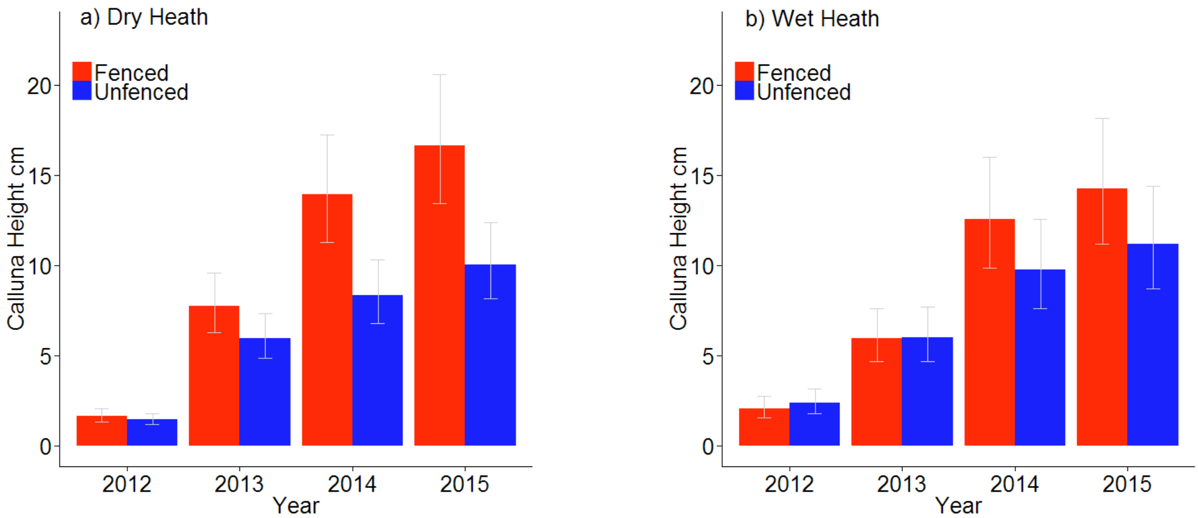

Fig. 2: The height of heather (*Calluna vulgaris*) on : a) Dry heath - fenced (ugrazed, red bars) plots show a greater increase over time than unfenced (grazed plots, blue bars); b) Wet heath - the growth of heather was slower and less affected by grazing.

Results

- Height of heather, grass and blaeberry increased over time since burning in all plots. However, after the first couple of years, heather height was significantly greater on dry heath and in the ungrazed (fenced) plots in both vegetation types (Fig. 2)
- Bare ground after burning was gradually replaced by vegetation but shrub cover (heather and blaeberry) increased much more on dry heath and more in the ungrazed plots in both vegetation types.
- Heather utilisation was lower on the grazed (unfenced) plots within the muirburn areas than on adjacent unburnt heath, although there was no significant difference between vegetation types

Conclusions

Clearly grazing reduces the recovery of plant biomass after muirburn, affecting both shrubs and grasses. However, dry heath recovers more quickly than wet heath - with greater vegetation height and faster increase in heather cover. Despite these observed differences between grazed and ungrazed plots, we did not detect any difference in heather utilisation between vegetation types. The results indicate that grazing can have an additive impact on recovery and although dry heath can recover quite quickly, heather on wet heath is slower to recover. Therefore the longer term effects of grazing on the recovery of wet heath need to be taken into account when considering vegetation responses to muirburn.

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CHAPTER 7

Engaging communities in biodiversity: the value of camera trapping

Fig. 1: We have innovated in using camera traps for small mammal recording. The technique is now used in biological recording, conservation monitoring and research.

Background

It is difficult for communities to value or protect aspects of nature that they are not aware of. Many animals are elusive or nocturnal and local residents often have no idea of the species that share their space. Technological developments such as camera traps provide a method for scientists, naturalists and the general public to detect and monitor a range of species that are often difficult to survey by other means. **The aim of this work was to explore how camera traps can be used to engage a diverse range of community groups in observing, recording and valuing their local wildlife.**

Approach

A number of projects have been undertaken by North East Scotland Biodiversity Partnership to engage the wider community in recording biodiversity. These involved loaning camera traps to community groups and volunteers and working with schools and ranger services to enable children to discover the secret world of wildlife that inhabits their school grounds and catchment.

Fig. 2: At four training courses, techniques have been demonstrated for getting the best performance out of camera traps.

Fig. 3: Local schools and communities have been engaged in using camera traps to discover animals that share their space.

We ran training courses for professionals and volunteers, both within the conservation sector and those involved in delivering outdoor education. We also developed a novel technique for camera trapping small mammals. Using social media and a range of other means we encouraged the use of camera traps to generate records for the North East Scotland Mammal Atlas.

Results

- Our schools project involved 14 primary schools and more than 250 children. Combining the use of technology with the discovery of a secret world has sparked an innate curiosity and helped to combat the disconnect with nature experienced by many children.
- Knowledge of the state of the region's mammals has greatly benefitted from the data now being collected by these schools and communities, with many new records generated for the forthcoming mammal atlas for North East Scotland, the first publication of its kind for the region.
- Our innovations in camera traps for small mammals (Fig. 1) are now being widely adopted, not least because they come with none of the animal welfare issues associated with small mammal trapping.

Fig. 4: Winners in the Schools Camera Trap Competition receiving their prizes from The James Hutton Institute's Chief Executive Iain Gordon.

Conclusions

Camera traps are now a standard tool for ecologists but, with encouragement and assistance, a much wider range of communities and individuals can utilise this technology to discover, appreciate and value local wildlife that might otherwise go unnoticed (Figs. 2 and 3). The themes of discovery and citizen science have underpinned our range of engagement initiatives. Individuals, schools (Fig. 4) and communities are now not only capturing photographs of elusive animals but also systematically *recording* local wildlife and thus contributing to a shared knowledge base. The project received interest from the highest levels of Scottish Government and was shortlisted for a Nature of Scotland award.

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Acknowledgements: This project was part funded by the North East Scotland Biodiversity Partnership.

CHAPTER 8

Quantifying ecosystem services in the uplands

Background

The hills and uplands of Scotland provide a wide range of ecosystem goods and services including the obvious provisioning services of food, fibre, fuel and water; but also regulating services such as climate regulation and flood regulation; and cultural services such as tourism, fishing, hunting and cultural heritage. Some of these goods and services can easily be quantified, whereas others, particularly the cultural services, are much more difficult. **We have been identifying and attempting to quantify the ecosystem goods and services provided by SRUC's Kirkton and Auchtertyre hill farm, evaluating them in monetary and non-monetary terms and assessing their importance.**

Approach

The case study site was SRUC's Hill and Mountain Research Centre at Kirkton and Auchtertyre, near Crianlarich. The estate covers some 2225 ha of land, from 170 m on the floodplain of the River Fillan to 1025 m a.s.l at the summit of Ben Challum. The range of ecosystem services provided by the estate were assessed and quantified, and where possible evaluated. Some of the data collected was by direct measurement while other

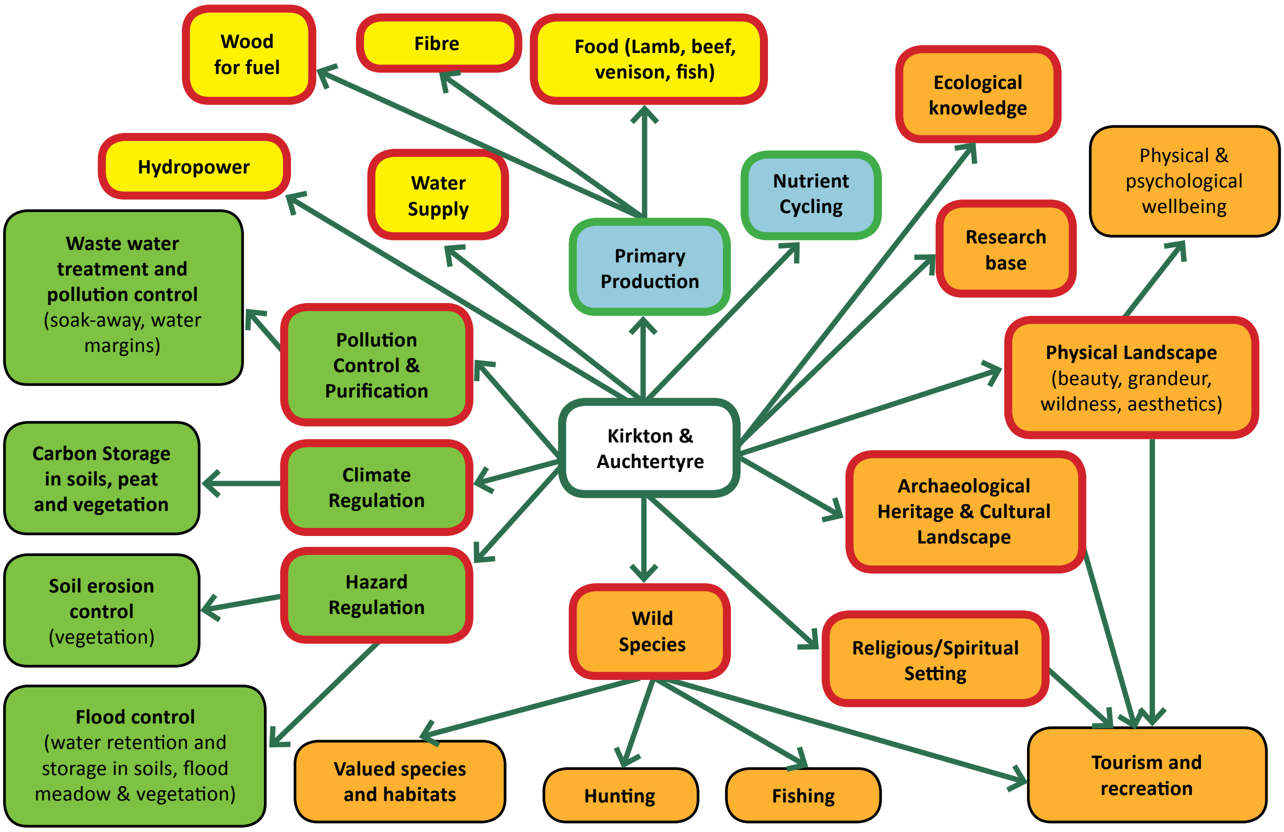

Fig. 1: Summary of the ecosystem goods and services provided by Kirkton and Auchtertyre farm (yellow -provisioning; blue - supporting; green - regulating; orange - cultural).

information was derived indirectly from indicators or informed estimates.

Results

Fig. 1 shows a summary of the ecosystem goods and services provided by the estate.

- In 2014/15 the total value of food (609 lambs, 242 ewes, 23 rams, 7 steers, 56 red deer, 5 roe deer) and fibre (2541kg of wool) sold from the estate was £57,183.
- The value of domestic water supply and waste water treatment was £3286; however, in addition the farm provided drinking water and waste water treatment for an estimated 11,300 residential guests at the farm tourism business plus around 8000 West Highland Way walkers who used the farm toilet facilities.
- The energy produced by the hydropower plant was estimated to be 2,287,800 KWh, with a potential value of £251,650 and a mitigation potential of 1153 tonnes of CO_2.
- The soils and vegetation contain an estimated 874,000 tonnes of CO_2, which is more than 1500 times the amount of CO_2 emitted by the farm each year.
- The farm has two SACs, eight priority habitats, and more than 300 plant species including 3 nationally rare and 16 nationally scarce plant species.

Conclusion

By using the Hill and Mountain Research Centre as a case study site we have been able to quantify and evaluate some of the ecosystem goods and services provided by the estate, showing the wide-ranging importance and value of the hills and uplands.

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CHAPTER 9

Drivers of long-term biodiversity change – key Scottish habitats in a European context

Background

Across the globe, different vegetation types vary in their sensitivity to different drivers of change. Increasing evidence of habitat changes driven by climate change, pollution and other human influences has highlighted the urgent need to understand varying habitat sensitivities in order to guide land management into the future. Long-term vegetation change data is increasingly being used to quantify changes and examine the impacts of different environmental drivers. Excellent long-term data exists for most major vegetation types (hereafter called habitats, in line with EU Habitats Directive) within Scotland and, by combining these with datasets on environmental change we can assess the importance of different factors in driving change, both within and across habitats. **The aim of this study was to set our Scottish data on long-term vegetation change, into the European context to assess commonality and differences in both habitat changes and the drivers of those changes.**

Approach

We teamed up with other scientists in the ALTER-Net European network to bring together 29 resurvey studies from 17 countries covering 5 major habitat types: alpine, forest, grassland, heathland and wetland, covering mean time periods of between 23 and 76 years between surveys. We synthesised common measurements from each study and summarised which drivers had been identified as causing change. Species richness and Shannon diversity were measured across all studies. A range of other measurements were made across different sub-sets of studies and these are all in the full report of this work (http://www.alter-net.info/about-alter-net/projects/env-history).

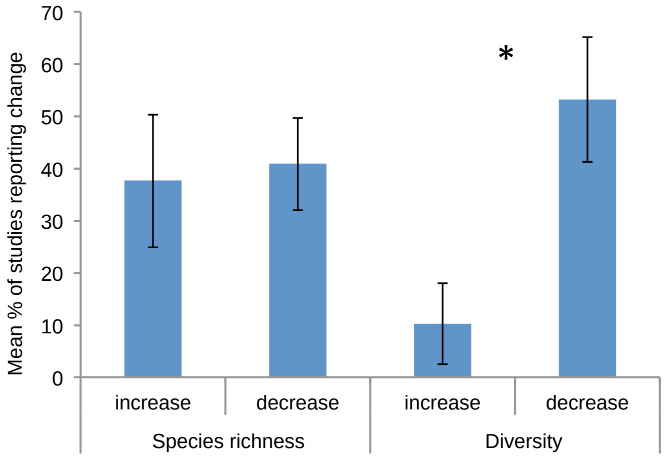

Fig. 1: Percentage of studies showing changes in species richness and diversity across all habitat types. Error bars show standard errors of the means. * indicates significant difference at P<0.05.

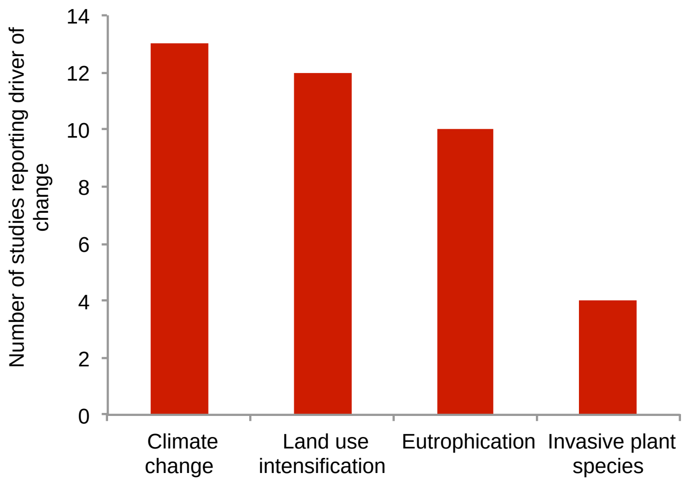

Fig. 2: Drivers of vegetation change reported in more than three studies across all habitat types.

Results

- The two most notable trends in vegetation change reported across all habitat types were the increase in the cover of graminoids (grass, sedge and rush species) and homogenisation.

- Homogenisation was particularly apparent in alpine habitats and forests, whereas increased graminoid cover was most commonly recorded in alpine habitats, grasslands and wetlands.

- Diversity declined significantly across all habitats combined (Fig. 1). Species richness showed no consistent directional changes across habitat types, but alpine habitats showed a trend for increasing species richness.

- Other commonly reported trends were decreased lichen cover and increases in the cover of thermophilic and mesophilic species, particularly in alpine habitats.

- Climate change was the most commonly reported driver of vegetation change (particularly in alpine habitats), closely followed by land use intensification (more important in forests, grasslands and heathlands) and eutrophication (forests) (Fig. 2).

Conclusion

Comparison of this small, European level synthesis with our more detailed research within Scotland shows that the main changes summarised above are consistent across many of our Scottish habitats, as is the importance of climate and land use change in driving the changes in vegetation composition. Homogenisation and declining species diversity have important implications for biodiversity conservation, much of which is defined at European level cascading down to individual countries. Identifying commonality of habitat changes and the impacts of different drivers across Europe will facilitate better European level targeting of both policy and management action.

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Acknowledgements: We thank ALTER-Net for funding this synthesis work and all the co-authors in the report for sharing their data.

CHAPTER 10

Cascading effects of nitrogen pollution on biodiversity and ecosystem function in alpine systems

Background

Racomitrium heath is a widespread alpine habitat dominated by the woolly fringe moss *(Racomitrium lanuginosum)*. These heaths are of international importance, supporting rare species such as the dotterel *(Charadrius morinellus)* and storing significant stocks of carbon. Due to its mountain summit location, *Racomitrium* heath is subject to high rainfall and prolonged cloud cover, and as a result is exposed to high levels of nitrogen deposition in many parts of its geographic range. **The aim of this work was to understand how the effect of nitrogen deposition and associated changes in vegetation influence key ecosystem functions such as decomposition, nutrient cycling and maintenance of carbon stocks.**

Approach

We selected 15 *Racomitrium* heaths ranging from north Wales to the northwest Highlands of Scotland that represented a nitrogen deposition gradient of 6.4 to 35.4 kg N ha^{-1} $year^{-1}$. At each site we sampled the vegetation, soil, mites, springtails and fungi. We also measured the nitrogen (N) and carbon (C) stored in both vegetation and soil, and measured the rate of moss decomposition.

Results

- Increasing N deposition increased the nutrient content of moss shoots (Fig. 1a), causing a dramatic increase in moss shoot decomposition (Fig. 1b, seven fold increase between the least and most polluted sites).

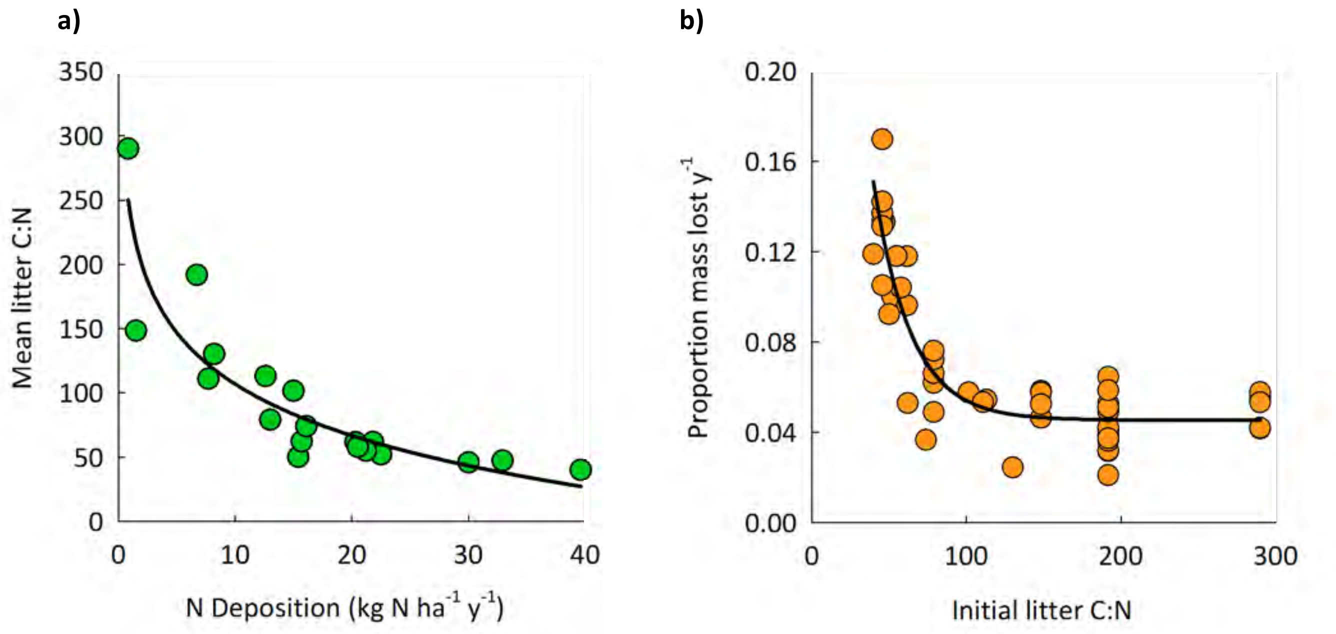

Fig. 1: a) Relationship between litter quality (mean C:N) and nitrogen deposition – lower C:N indicates higher quality litter which is more easily degraded. b) Relationship between litter decomposition rate (mass loss per year) and litter quality.

- Increased moss decomposition resulted in reduced moss cover and was associated with a shift to grass-dominated plant communities.
- N deposition was associated with a reduction in above ground C stocks. In contrast, soil C stocks were unaffected by N deposition and, overall, there was no detectable change in the total (above and below ground) C stock along the N deposition gradient.
- Deposited N accumulated in the soil, with an increase in the soil N pool and a decline in soil C:N along the N deposition gradient.
- Soil mite and springtail communities were not directly affected by N deposition but were found to be sensitive to the N deposition-related changes in habitat quality and food availability.
- The fungal communities associated with bryophyte shoots were found to be sensitive to N deposition, with reduced diversity at high deposition sites.

Conclusion

Racomitrium heath biodiversity and function is adversely affected by current rates of N deposition. Even small increases in deposition above background rates can cause dramatic increases in moss decomposition rates - a key ecosystem function. This has a cascading effect; altering plant community composition, the soil fauna and associated fungal communities. Although impacts on ecosystem carbon pools appeared limited, deposited N accumulates in *Racomitrium* heath soils, increasing the likelihood of N leaching to streams and rivers. Future work will need to ascertain to what extent these changes can be reversed by reductions in pollution.

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CHAPTER 11

Opportunities for translocating mountain species

Background

Climate change is already impacting on Scotland's biodiversity. In SNH's Climate Change Action Plan, one of the main 2012-2015 goals is to: *"Identify the consequences of climate change for protected places and the Natura network, and put in place adaptive measures" (p20)*. Measures available include reducing the impacts of other pressures such as pollution or inappropriate management, and increasing habitat connectivity. However, at some point it may be necessary to start moving species to new locations which may be suitable under a future climate. **This project tested the practicalities of such conservation translocations, in particular how we can best identify suitable recipient sites.**

Approach

We used the model species *Flavocetraria nivalis*, an arctic-alpine lichen species with its UK range restricted to the Cairngorms (Fig. 1).

Fig. 1: The target lichen *Flavocetraria nivalis*. In this photograph you can also see the wire loop used to hold the translocated lichen to the ground, and a small piece of red thread used to measure lichen growth.

We used data from a large scale field survey of the lichen's natural distribution to build a model that predicted suitability of recipient sites for translocated lichens. We tested the model in the Gairn catchment within the Cairngorms, examining whether the model was able to predict where the lichens did or did not survive.

Results

- The model developed from the survey data was quite poor at predicting where the lichens initially survived or died.

- Several factors improved the power of the predictive model. These included locally-recorded climatic data measured using small temperature loggers located at individual plots. This indicates the importance of local "micro-climatic" conditions, which can vary greatly over short distances in mountain environments.

- Time was also an important factor; as time went on the model was better able to predict lichen survival, most likely because delayed lichen mortality causes a lag-time over which the distribution of transplanted lichens matches that for natural populations.

Conclusion

Our results provide some important information for attempts to translocate non-mobile mountain species in particular. First of all they demonstrate the importance of long-term monitoring for accurate ecological decision-making. Secondly, and more importantly, selecting the appropriate micro-climatic location is clearly critical: small changes in the positioning of the lichen had large effects on survival. It is unlikely that this kind of small scale effect can be captured in a coarse-grained predictive model, typical of bioclimatic modelling. Expert knowledge may be an efficient and more effective tool for selecting recipient sites when translocating species sensitive to microhabitat variation.

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CHAPTER 12

The role of woodland expansion in shaping tick abundance over Scotland

Background

The Scottish landscape consists of a mosaic of many different habitats. The largest land use change that Scotland is currently experiencing is that of woodland expansion, promoted by government policy to enhance timber production, recreation and carbon sequestration to mitigate climate change and enhance biodiversity. However, one potential unwanted spin-off of woodland expansion might be an increase in the abundance of tick *(Ixodes ricinus)* and risk of infection of tick-borne diseases, due to increased numbers of deer, rodents and birds that are hosts to ticks. Tick abundance and the reported incidences of tick-borne disease such as Lyme borreliosis have been increasing in Scotland over the last few decades, and are now an increasingly urgent public health concern. **We aimed to answer the question: How do woodlands shape tick abundance patterns across Scotland?**

Approach

Using tick survey transects in a large-scale, long-term woodland planting experiment, we compared tick abundance in plots where trees (birch saplings) were planted in 2005, with plots where no trees were planted (heather). We conducted tick surveys in May, July and September between 2007 and 2014. We needed to be able to predict the pattern of tick abundance over Scotland, with a focus on the

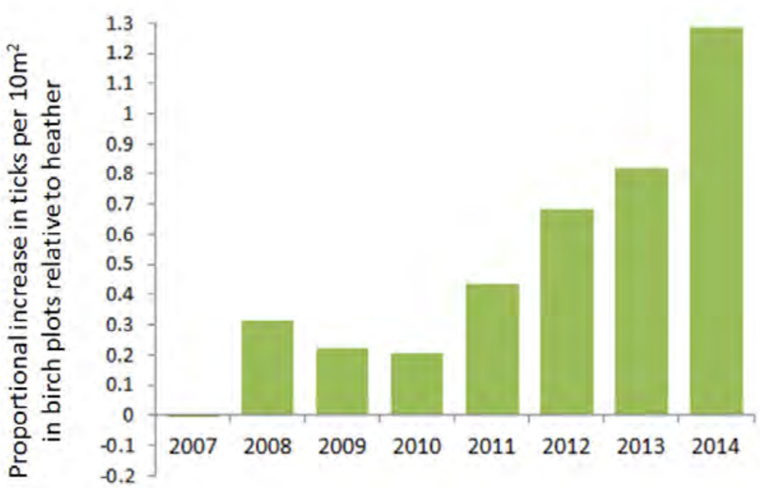

Fig. 1: The increase in ticks over time in unfenced experimental plots planted with birch saplings in 2005 compared with those in adjacent unplanted (heather) plots.

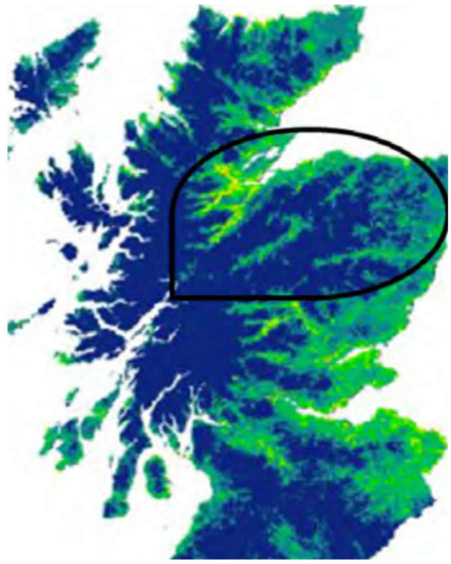

Fig. 2: Map showing areas of predicted higher tick abundance (green/yellow), with the most robust predictions inside the black perimeter.

importance of woodlands. For this we used tick abundance data from over 300 sites around Scotland and used statistical analysis to identify the environmental drivers of tick abundance. We then used the resulting algorithm produced from the statistics to extrapolate the tick abundances we might expect over Scotland, according to the habitat, climate and deer populations in each area. This was visualised using Geographic Information System as a map showing the predicted abundance of ticks over Scotland.

Results

- In the first year of surveying (2007), when the tree saplings were only 2 years old and no higher than the surrounding heather, there was no difference in tick abundance between birch and heather plots. Only 3 years after planting, there were already consistently more ticks in birch plots; and by 2014 there were 130% more ticks in birch than heather plots (Fig. 1).

- From the surveys of over 300 sites around Scotland, we found higher tick abundance in areas with more woodland cover, a warmer climate (higher annual temperatures and fewer days of frost in September) and higher deer abundance.

- The map of predicted tick abundance across Scotland predicts more ticks in low altitude (i.e. warmer) areas with a lot of woodland, such as Deeside, Speyside, Tayside and the glens of Inverness-shire (Fig. 2).

- We have most confidence in the predictions for Grampian and Inverness-shire, where we had more data. Data was poorest for the West Highlands, the Central Belt and southern Scotland, therefore the predictions are least robust in these areas.

Conclusion

This work shows that woodlands are generally associated with higher tick abundance than open habitats and the distribution of woodlands over Scotland shapes the patterns of tick abundance. Other factors, especially climate and hosts, also shape tick distribution, but woodland expansion has the potential to increase tick abundance if hosts such as deer are not controlled or the woodlands are not fenced to exclude deer.

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CHAPTER 13

The effects of beavers on woodlands

Photo: Steve Gardner, Scottish Beaver Trial

Background

The reintroduction of species to areas from which they have previously been extirpated can be a positive contribution to the enhancement of biodiversity. This is especially true when the species, such as the Eurasian beaver *(Castor fiber)*, is an ecosystem engineer with capacity to modify the habitat to produce other benefits to biodiversity and ecosystem services. Beavers were eradicated from Scotland by around the sixteenth century but a trial reintroduction was undertaken in 2009-2014 at Knapdale, Argyll, during which four family groups established lodges on four different lochs. As part of the trial, the multiple benefits and risks of beaver activity to, *inter alia* biodiversity, forestry, hydrology and local economy were assessed (www.snh.gov.uk/beavers-in-scotland). **Here we summarise the effects of beavers on woodland, asking to what extent they selected and affected trees of different species and how the trees responded.**

Approach

We labelled all 4,454 stems that were greater than 1.3m in height, in 111, 10 m x 4 m rectangular plots, centred at 2, 8, 18 and 28 m from the water's edge. Twice yearly from 2009 – 2013 we recorded signs of beaver damage on these stems and their responses. Also, at the end of the trial in 2014 two hundred and fifty five, 10 m diameter circular plots centred at 5, 15 and 25 m from the edges of the four main lochs were assessed for proportion of trees damaged by beavers.

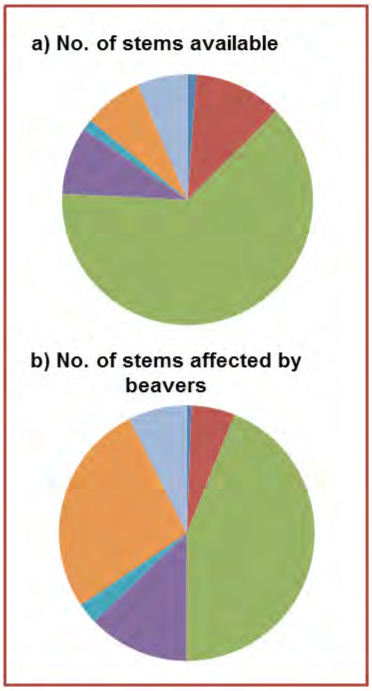

Fig. 1: The proportion of stems of each species a) available to beavers before the trial reintroduction and b) affected by beavers by November 2013. ● : Alder *(Alnus glutinosa)*, ● : Downy birch *(Betula pubescens)*, ● : Hazel *(Corylus avellana)*, ● : Ash *(Fraxinus excelsior)*, ● : Willow species *(Salix spp)* ● :Rowan *(Sorbus aucuparia)*.

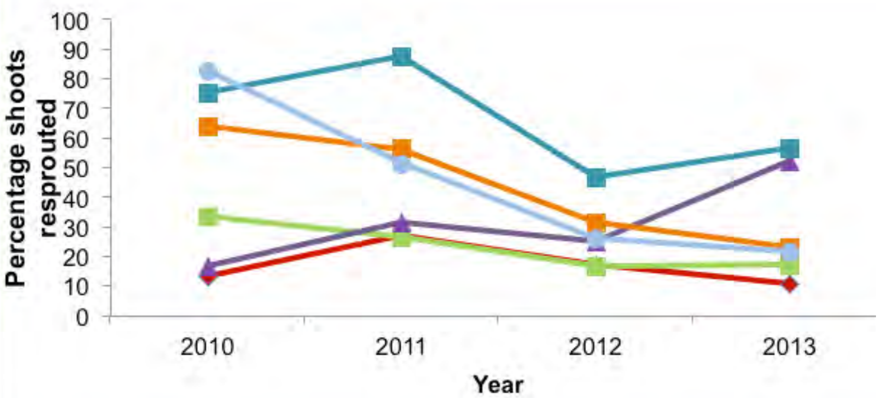

Fig. 2: The percentage of beaver affected trees that subsequently resprouted new shoots. Species represented by colours as in Figure 1.

Results

- Overall, 8.6% of trees in the area within 30m of the beaver lochs were gnawed or felled by beavers during the four year study; most effects were within 10m of the water's edge.
- The stem diameter of trees gnawed by beavers varied among species but was on average 4 cm and increased for most tree species across the four years of the study.
- Although birch was the species with most stems used by beavers due to its abundance in the area, in relation to availability they felled or gnawed more willow, followed by ash, rowan and hazel (Fig. 1). Coniferous species were only rarely affected by beavers.
- The preferred species showed greater recovery from beaver gnawing or felling by producing re-sprouted shoots, compared to un-preferred tree species (Fig. 2). Regrowth was generally quite slow. No re-sprouted shoot was eaten by a beaver during the course of the trial, but over 68% of the re-sprouts were eaten by deer present in the area.

Conclusion

Although a relatively small percentage of tree stems were gnawed or felled by beavers, they showed clear preferences and can cause local depletion of their preferred species, in this case the willows. The fact that they choose species with higher capacity for recovery, and only forage close to the water, can mitigate their effects on woodland. However, regrowth was slow and the utilisation of the re-sprouted shoots by deer indicated that a whole system approach must be taken and long-term effects considered when predicting the system responses and impacts of beavers elsewhere.

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

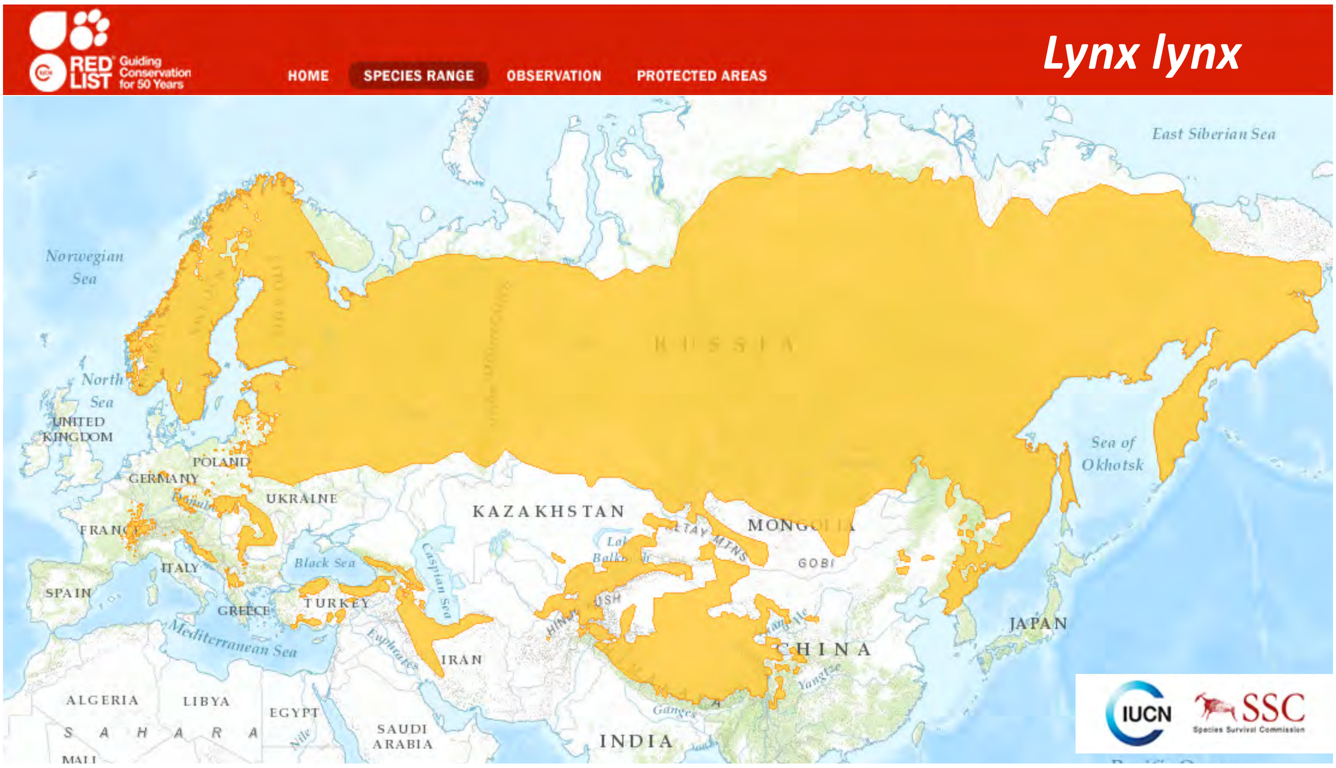

Fig. 1: Global distribution of Eurasian lynx (Breitenmoser U, *et al.*, 2015, *Lynx lynx*. The IUCN Red List of Threatened Species. http://www.iucnredlist.org/details/12519/0).

Background

The idea of re-introducing lynx *(Lynx lynx)* to Britain has featured widely in the media recently. There are now around 50,000 individuals distributed across Europe, Siberia and central Asia (Fig. 1), with around 9,000 in Europe. Lynx were probably last seen in Britain in medieval times. The IUCN Red List conservation status for lynx is 'Least Concern'. **Here we review some aspects of lynx ecology and evidence of potential impacts, particularly on deer, from elsewhere in Europe, and summarise the available evidence to determine the issues that would need to be addressed in any reintroduction application for the UK.**

Approach

We reviewed the available evidence to address a range of questions posed by the British Deer Society in relation to lynx reintroduction. The questions covered lynx ranging behaviour, predation habits, likely impact on UK deer species and their management, factors that affect the viability of lynx populations and the statutory obligations associated with such a reintroduction (see Table 2 in full report at http://www.bds.org.uk/index.php/research/current-research-projects/13-current-projects/159-the-potential-for-reintroduction-of-eurasian-lynx-to-great-britain)

Results

- In Europe, lynx home range sizes vary from 100-2,800 km^2 and typical densities are in the range of 0.5-1.5 lynx per 100 km^2. The main factors limiting population growth are illegal killing, traffic accidents and legal control.

- Population viability analyses indicate that a viable population should probably have at least 250 individuals (compare this with other European populations: Table 1).

Population	Countries	Origin	Estimated pop. size	Pop. trend	Range km²
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

Table 1: European lynx populations showing their size and status based on data from Kaczensky, *et al* (eds.), 2012. http://ec.europa.eu/environment/nature/conservation/species/carnivores/conservation_status.htm) and Chapron *et al.* 2014. Science, 346, 1517–1519. Pop. trend = population trend, either Inc. - increasing, Dec. - decreasing or Stable - not changing. NA - data are not available).

- Within Britain, an area of continuous suitable habitat sufficient to support a viable population only occurs in the Scottish Highlands, although the suitability of the associated woodlands in terms of understorey vegetation and habitat structure requires further investigation.
- Lynx are very efficient predators of roe deer and prefer these over other deer species and sheep. We could expect a reduction in roe deer densities in areas where lynx become established.
- Carnivore reintroductions are extremely lengthy, costly and complex processes and should only be undertaken where there is a high probability of success – which depends on public attitudes and tolerance, as much as on ecological aspects.

Conclusion

Further work on habitat quality, prey availability, disease risk and social acceptability is required to inform any assessments of reintroduction of lynx to Britain. The financial, practical management, ethical and welfare implications of reintroducing lynx need to be carefully considered, particularly where proposed reintroduction sites have an insufficient area of suitable habitat to support a viable population. However, even well-planned reintroductions carry no guarantee of success and therefore a viable exit strategy and appropriate budget need be in place from the outset.

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Acknowledgements: This project was funded by the British Deer Society.

CHAPTER 15

The impact of deer carcasses on soil nutrients and invertebrate communities

Background

Carcass placement is an approach that is used to support scavenger species of conservation concern and restore ecosystem functions as part of rewilding activities. Carrion is in limited supply in the Scottish uplands because deer are removed for venison and sheep densities have declined in response to changes in agricultural support. The practice of leaving out carcasses in these semi-natural habitats may benefit some scavenger species but it is not clear how this addition of nutrients affects the food web and nutrient cycling. **The aim of this study was to investigate how these nutrients are a) cycled in the soil and b) result in changes in invertebrate communities around carcasses that were either protected or exposed to scavengers.**

Approach

We selected seven heather moorland sites representing the main land management activities in the uplands (deer stalking, grouse shooting & nature conservation) and varying in the level of predator control. At each site there were three plots: the first with a carcass, the second with a carcass in a cage to prevent access by avian and mammalian scavengers and the third a control without a carcass. We sampled soil nutrients using ion exchange membranes and the

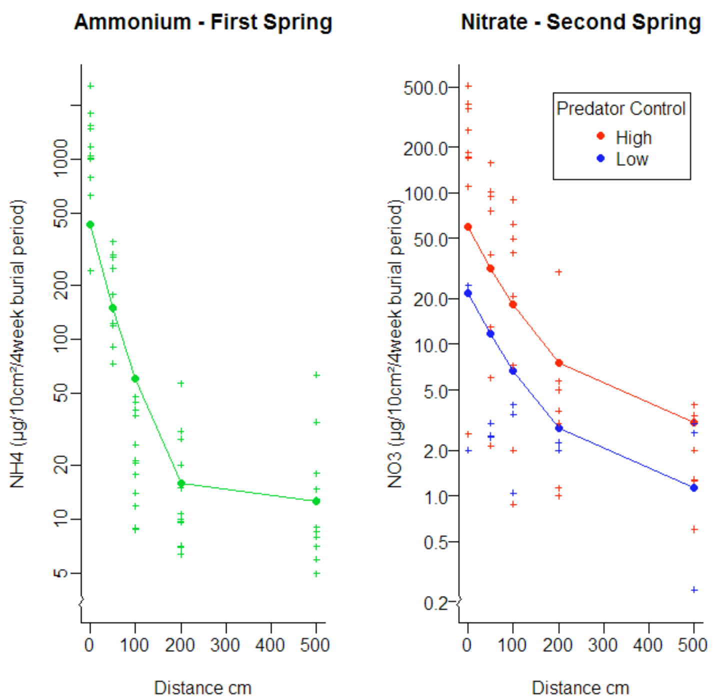

Fig. 1: Supply rate of ammonium during the first spring and nitrate during second spring after carcass placement. Sites were classified with respect to the importance of predator control as a management option: red observed (+) and fitted (•) values indicate relatively high predator control and blue values indicate sites with relatively low predator control activity.

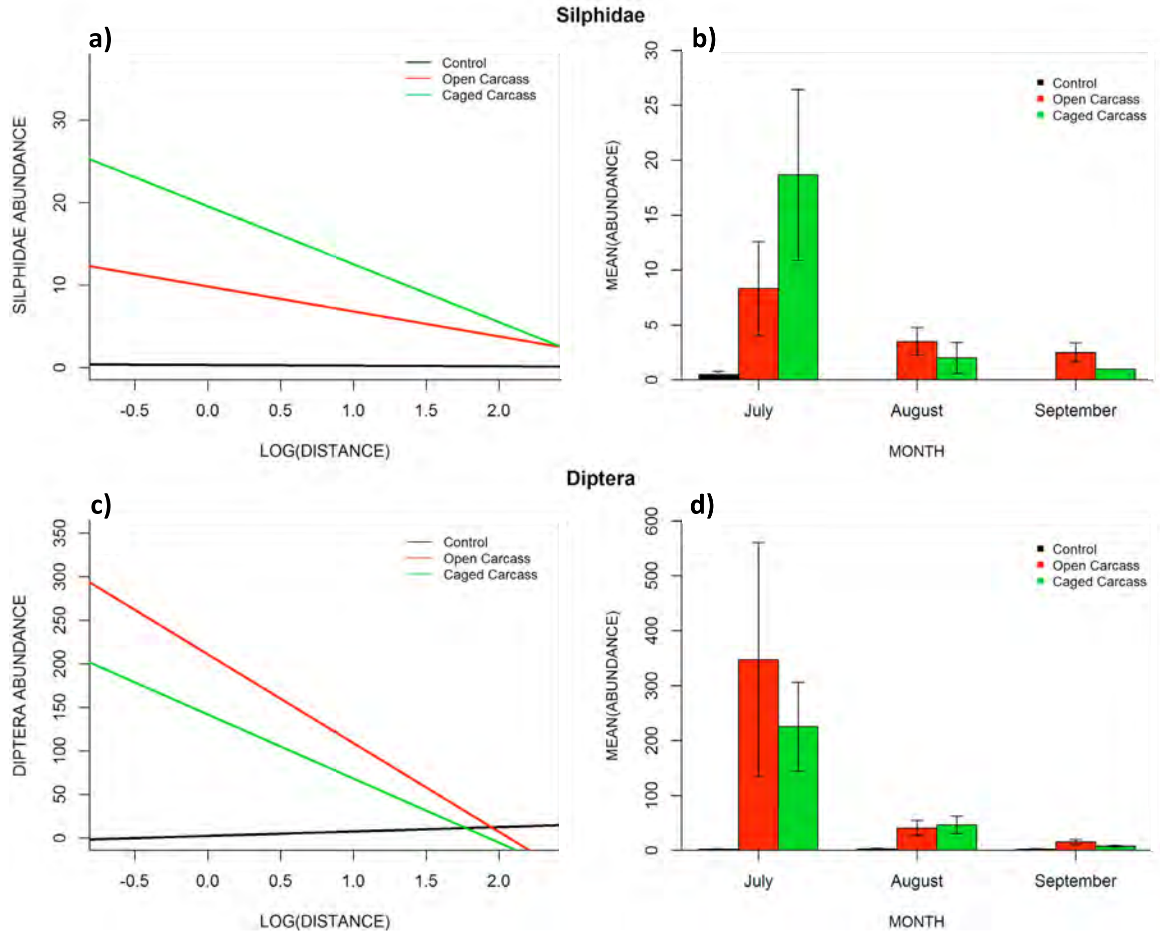

Fig. 2: Changes in abundance of *Silphidae* and *Diptera* with increasing distance from the carcass (a and c) and in caged and open carcasses compared with control areas (b and d).

invertebrate community using pitfall traps at a range of distances up to 5m from the carcass.

Results

- Supply rate of both nitrate and ammonium was greatest directly under the carcass and declined rapidly with distance.
- Ammonium supply rate was highest during the first spring after carcass placement whereas nitrate levels did not become elevated until the second spring and were higher at sites with high predator control (Fig. 1).
- Abundance of carrion beetles (family *Silphidae*) was significantly higher on the carcass plots than the controls and tended to be higher around the caged carcasses. The numbers were highest in July and returned to low levels for the rest of the year (Fig. 2) and declined to levels found in controls by 2 m from the carcass.
- Abundance of carrion specialist beetles (mainly *Thanatophilus rugosus* and flies of the family *Calliphoridae*) were 15% greater at carcasses compared to controls (Fig. 2).

Conclusion

Leaving carcasses on the hill clearly has a significant, albeit localised, impact on nutrient cycling and food webs. Nutrient cycling is slow in the cold wet conditions of the Scottish uplands with soil nitrate supply only becoming elevated around carcass sites in the second spring after carcass placement. Elevated nitrate levels could lead to changes in plant community composition over time (already observed at some sites), leading to greater heterogeneity in the pattern of vegetation in the uplands. Sites where carcasses were less exposed to scavengers showed higher levels of nitrates and greater abundances of scavenger invertebrates which in turn may provide a food source for insectivores. Further work is in progress to gain a better understanding of how the nutrient flow from carcasses is influenced by different land management regimes to determine the ecosystem benefits of this controversial practice.

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CHAPTER 16

The use of deer carcasses by avian and mammalian scavengers

Background

Declines in some scavenger species across Europe are thought to be due, in part, to a reduction in the amount of carrion in the landscape. This may be the result of a drop in livestock numbers due to changes to the EU Common Agricultural Policy combined with the removal of fallen livestock in compliance with EU regulations. In addition, in the Scottish uplands few deer carcasses are left for scavengers because most mortality is due to shooting and the carcass is removed for venison. In some places, there is increasing interest in placing out carcasses of wild or domestic herbivores to support the recovery of scavenger species. **The aim of this study was to explore the diversity of scavenger species in the Scottish uplands as part of a wider study looking at the environmental benefits of carcass placement**

Approach

Fresh adult female red deer carcasses were placed out on upland heather moorland during the winter shooting season. Study sites included three land holdings managed primarily for red grouse shooting and three managed primarily for biodiversity conservation. Camera traps were set up and used to monitor wildlife activity around each carcass for two years after carcass placement.

Results

- A wide range of bird and mammal species used deer carcasses, including crows, ravens, buzzards, golden eagles, red foxes, badgers, pine martens and otters (Fig. 1).
- Small mammals and passerines (e.g. meadow pipit) were also recorded, presumably benefitting from the increased abundance of invertebrates associated with decomposing carcasses.
- Short-eared owls and unidentified mustelids were also seen - these may have been benefitting from the increased abundance of small mammals.
- Carcasses that were regularly used by several scavenger species were consumed within a few weeks and tended to be on the conservation

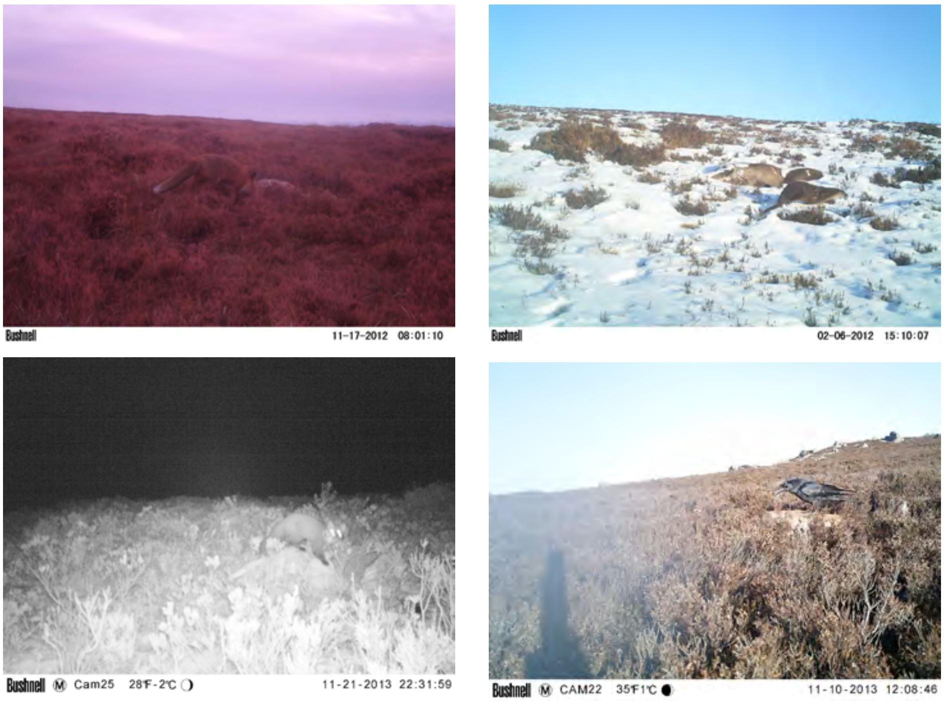

Fig. 1: Some of the mammal and bird species recorded using deer carcasses, clock-wise from top left; red fox, otter, raven and pine marten.

Species/Management	Sport	Conservation
Crow/Raven	+	+
Buzzard	-	+
Short-eared owl	+	+
Red fox	+	+
Pine marten	-	+
Stoat/weasel	-	+
Cat (unidentified species)	-	+

Table 1: Summary of scavenger species recorded at deer carcasses by camera trap at six study areas in the Scottish highlands over 2012-2014. 'Sport' indicates that these study sites (n=3) were on areas of heather moorland managed for red grouse shooting. 'Conservation' indicates the study sites (n=3) that were on areas of heather moorland managed for biodiversity conservation. A '+' sign denotes that the species was recorded, and '–' sign that the species was not recorded.

focussed landholdings, whereas carcasses that were visited by fewer scavenger species decomposed slowly and tended to be on land managed for shooting (Table 1).

Conclusion

The diversity of birds and mammals that make use of deer carcasses varied across the uplands, although it remains unclear how nutritionally important carcasses are to these scavenger species. Land management objectives appeared to influence the guild of vertebrate carrion feeders present and therefore influence carcass decomposition rates, with consequences for how nutrients from the carcass enter the upland food web.

Further analysis is needed to determine the relative impact of the direct benefits that carcasses provide to avian and mammalian scavengers versus the indirect benefits provided to other species such as invertebrate feeders (Chapter 15).

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Acknowledgements: We thank all the landowners who have contributed carcasses and allowed us to work on their land.

This booklet summarises some of the key findings on wildlife and biodiversity in relation to environmental management with emphasis on the Scottish uplands, that have arisen from the Scottish Government's Rural and Environment Science and Analytical Services Division's funded research programme "Environmental Change"which ran from 2011 to 2016 and involved researchers from

- Biomathematics and Statistics Scotland
- Royal Botanic Garden Edinburgh
- The James Hutton Institute
- Scottish Agricultural College

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