Report

Thirgood, S.; Scott, D.; Irvine, J.; Sibbald, A.; Palmer, S.; Gilbert, L.; Leckie, F.; Elston, D.. 2007 *Developing methodologies to monitor deer movements at the landscape scale.* NERC/Centre for Ecology and Hydrology, 156pp. (CEH Project Number: C02914) (Unpublished)

FLEXIBLE FUND

FINAL REPORT FOR THE PERIOD
JUNE 2005 TO DEC 2006

1. PROJECT INFORMATION

1.1 Project Title: Developing Methodologies to Monitor Deer Movements at the Landscape Scale.

1.2 Commission Number: MLU/952/04

1.3 Project Manager: Simon Thirgood

1.4 Project start and end dates: 1 June 2005 - 31 December 2006

1.5 Reporting period: 1 June 2005 – 31 December 2006

1.6 Project contractors (Institution and contact names):

Macaulay Institute (Simon Thirgood)

Centre for Ecology and Hydrology (David Scott)

Biomathematics and Statistics Scotland (David Elston)

2. EXECUTIVE SUMMARY

2.1 This is the final report of a Flexible Fund project entitled "Developing Methodologies to Monitor Deer Movements at the Landscape Scale". The objectives of the project were: (1) to critically review the methods currently used to monitor red deer movements in Scotland; (2) to review and explore innovative or novel techniques from similar and other fields worldwide and assess their potential suitability; (3) where appropriate, to design and conduct field trials of the most promising technologies, bearing in mind the relevant issues in Scotland; and (4) report and recommend on the cost and effectiveness of techniques available now and in the near future.

2.2 The project has delivered the following planned outputs: (1) a systematic and quantitative evaluation of existing literature and datasets and assessment of existing methods for monitoring red deer movements in Scotland; (2) a comprehensive review of technologies for monitoring animal movement and their potential for monitoring red deer movements in Scotland; (3) an Expert Workshop to review the findings from

Objectives 1 and 2 and to determine priorities for field evaluation of promising methodologies(Objective 3) and develop future research priorities for investigating landscape-scale deer movements; and (4) recommendations to deer managers and researchers regarding appropriate, logistically-feasible monitoring techniques.

3. INTRODUCTION AND BACKGROUND

3.1 The sustainable management of red deer in Scotland is becoming a critical issue for both biodiversity and rural livelihoods. The Scottish Highlands are managed for a range of different interests, including sport and natural heritage, which inevitably have different management goals, e.g. maximising revenue from deer stalking versus conserving the natural heritage. These contrasting goals obviously require very different deer management policies, eg. a sporting estate that wishes to maximise income may implement strategies to retain a large number of mature stags, whereas a conservation organisation that wishes to restore native woodland may want to reduce deer densities to as little as <5 deer/km^2. Over the past forty years, red deer numbers in Scotland have increased (Clutton-Brock et al 2004). Most red deer in Scotland are free-ranging across land management and economic boundaries. Policies instigated by one management unit can have an adverse impact on the goals of others, potentially causing conflict among neighbouring management units. In some cases this may compromise the government's natural heritage commitments, damage the economics of rural businesses and threaten the livelihoods of those involved with deer management.

3.2 The key biological question underpinning this conflict is "to what extent do red deer range across management boundaries?" Red deer movements may be opportunistic or permanent and may be important in the context of either daily or seasonal behaviour patterns. However, the extent of all such movements is frequently contested among land managers and there is a need for an independent evaluation of red deer movements in Scotland. It is within this biological and socio-economic context that we have evaluated methods for assessing landscape-scale movements of red deer. SEERAD and the Deer Commission for Scotland (DCS) viewed it as timely to re-appraise methods currently in use in Scotland and elsewhere to monitor deer movements, and to review world-wide the up-and-coming techniques that could be used to monitor wildlife populations. By identifying, developing and testing technologies and analytical methods for assessing deer movements at the landscape scale, it was hoped to make a significant contribution to the effective and sustainable management of red deer in Scotland.

3.3 The project had four main objectives:

(1) To critically review the methods currently used to monitor deer movements in Scotland.

(2) To review and explore innovative or novel technologies from similar and other fields worldwide and assess their potential suitability.

(3) Where appropriate, to design and conduct field trials of the most promising technologies, bearing in mind the relevant issues in Scotland.

(4) Report and recommend on the cost and effectiveness of techniques and technologies available now and in the near future.

Progress in achieving these objectives is outlined in the following section.

4. RESULTS

4.1 A report on the work addressing Objective 1 is attached as Annex 1 and consists of a quantitative and qualitative assessment of the suitability of existing methods for monitoring red deer movements at the landscape scale. This assessment was made by reviewing the literature relevant to red deer movements in Scotland and by analysing existing datasets. The datasets were monthly count data from West Affric and Creag Meagaidh estates, census data from the North Block of Rum, the Rum Round Island Census data, count data and calf-tagging data from various parts of Scotland supplied by the Deer Commission for Scotland, and GPS collar data collected on the Mar Lodge and Invercauld estates and on Cairngorm. Analysis of the data from West Affric, which includes counts on neighbouring estates, showed that carefully designed and rigorously applied direct counting methods can be used to obtain information about seasonal movements across estate boundaries. The Creag Meagaidh dataset, which comprised zonal counts within a single estate, could be used to obtain information about movements between zones within the estate. The DCS counts were in general too infrequent to indicate movements of animals between estates. The DCS calf-tagging data include information about individuals' locations at the time of birth and death, and are therefore limited in terms of understanding how animals move around during their lifetimes. However the calf-tagging data support the idea that stags move significantly further than hinds and show that some individuals move long distances from where they were born. Analysis of the GPS collar data indicates that with such technology it is possible to detect the difference between range shift and seasonal habitat use of individuals. However, analysis of the census data from Rum demonstrated that because of differences in the behaviour of individuals within groups, detection of group movements by GPS collaring would require large numbers of individuals to be collared, which is currently not a practical option due to the cost of collars and the logistics of catching deer. Following consultation with stakeholders, a computer model was developed to investigate whether traditional calf-tagging methods could be used to detect increased immigration from ‘source’ to ‘sink’ estates and therefore determine whether high cull rates did indeed create a ‘vacuum effect’. The model outputs indicated that calf-tagging methods would only be effective in revealing such patterns when the cull was severe and the rates of both tagging and recovery of tagged animals were high.

4.2 A report on the work addressing Objective 2 is attached as Annex 2 and consists of an evaluation of a wide range of both existing and novel technologies with potential for monitoring red deer movement, assessed against a set of criteria agreed with SEERAD at the start of the project. The report covers methods currently used to monitor movements of other species as well as deer, and some novel technologies not yet used on wildlife, and considers the potential of each method to provide high-quality information on red deer movements at the landscape-scale. The methods that are covered in the report fall into three main types: traditional ‘low-tech’ methods such as direct counts, pellet group counts and tagging; rather more ‘high-tech’ methods such as VHF radio-tracking and GPS satellite-tracking, electronic tagging and remote sensing, with an enhanced section on satellite imagery; and technologies that are relatively novel for wildlife, such as seismic detection, DNA genotyping and stable isotopes. A summary table is provided which shows the relative performance of each method against the various assessment criteria. The review of technologies concludes that, at present, there is no real benefit to moving away from the traditional counting methods. Most of the high-tech methods are very expensive and are generally more suited to tracking individuals than large numbers of animals. Some of the more novel methods, such as DNA finger-printing and stable isotope profiling, may be useful in the future when analytical methods have been developed further. However, these methods are limited in terms of the timescale over which they can provide answers and there are significant logistical problems related to the collection of samples, which may be difficult to overcome. In response to one of the recommendations of the Workshop, further enquiries were made into the feasibility of using satellite imagery to count deer. However, although the technology is developing rapidly, images with the level of resolution required are not commercially available at the moment and are unlikely to be an economical prospect for some time into the future.

4.3 A report on the work addressing Objective 3 is attached as Annex 3 and consists of a summary of the proceedings of an Expert Stakeholder Workshop, held on March 8-9 2006, at Douneside House, Tarland, Aberdeenshire. The workshop was attended by stakeholder representatives from the Deer Commission for Scotland, Scottish Natural Heritage, The National Trust for Scotland and Forest Enterprise. The findings of the research carried out to address Objectives 1 and 2 were presented to the participants on the first day of the Workshop and discussed. The second day was spent in two break-out groups, which were asked to identify priorities for further data analysis or field- testing of potential technologies. Summaries of the presentations, the ensuing discussion and the deliberations of the break-out groups are included in Annex 3. The calf-tagging modelling exercise (Annex 1, page 20) and the enhanced section on satellite imagery (Annex 2, page 37) both resulted directly from recommendations that were formulated by the Workshop.

4.4 In fulfilment of Objective 4, it is recommended that the most cost-effective way of monitoring landscape-scale movements of large numbers of red deer in Scotland, is to use carefully designed and rigorously conducted direct counts. Counts should be conducted by experienced observers from either vantage points or transects. Counts should be conducted on a zonal basis such that observations are made across management units whether these incorporate zones within estates or between adjacent estates. Counts must be rigorously conducted across multiple years to overcome stochasticity and detect long term trends. It is also critical that baseline data are collected for several years before management interventions such as major culls. It is recommended that counts are organised at the level of the Deer Management Groups. Finally, it is strongly recommended that, despite financial constraints, more attention is given to data management and data sharing, both within and between stakeholders.

5. CONCLUSIONS

5.1 The main conclusion of this study is that the most appropriate and cost effective method for monitoring red deer movements at the landscape scale in Scotland is by direct counting. Vantage point or transects counts of deer, applied on a zonal basis across management boundaries, can provide sufficiently detailed information on deer movement for management. Counts have the advantage that they require no expensive equipment and are familiar and therefore acceptable to managers. Counts must however be robustly designed, rigorously conducted over multiple years, with baseline data collected before management interventions.

5.2 Additional information on the directionality of movement can be detected through ear-tagging programmes. However, a computer simulation model has demonstrated that the proportion of animals ear-tagged and the proportion recovered both need to be large if ear-tagging is to be used to provide evidence of the occurrence of an increased level of immigration with a high degree of confidence.

5.3 GPS collars can provide valuable detailed data on individual deer movement and habitat use but there are considerable challenges in scaling up from individuals to populations. Despite improvements in GPS collar design and data download options there are still problems with reliability. GPS collars are also very expensive and this alone will preclude their use by most managers.

5.4 An exhaustive review indicates that there is no "silver-bullet" technology available now or in the immediate future that will provide reliable, cost-effective information about red deer movement to aid management. The only exception to this conclusion is the possible future use of remote sensing to count deer. At present the resolution of commercially available satellite imagery is inadequate however this is a rapidly developing market and it will be worth reviewing the situation in five years time.

6. COMMUNICATED OUTPUTS

6.1 Systematic and quantitative evaluation of existing literature, data and methods to assess red deer movement. (Annex 1)

6.2 Review of technologies and their application to monitor red deer movement in Scotland. (Annex 2)

6.3 Report of Stakeholder Workshop held at Douneside House, Tarland on 8th and 9th March 2006 (Annex 3)

6.4 Talk to Deer Commission for Scotland Research Meeting held at the Birnam Institute on 8th Sept 2006 (Powerpoint Presentation provided to DCS and available on request)

6.5 Popular article for *"Deer"* – the magazine of the British Deer Society to be submitted within six months of completion of contract.

7. RESOURCES

THE MACAULAY LAND USE RESEARCH INSTITUTE

DEVELOPING METHODOLOGIES TO MONITOR DEER MOVEMENTS AT THE LANDSCAPE SCALE

FINANCIAL	YEAR 1		YEAR 2		TOTAL
REPORT	Days	01/06/2005 to 31/03/06	Days	01/04/2006 to 31/12/06	
SALARIES					
Band 4 ERNIC Superannuation	17	2721 277	10	2,356 240	
Total		2998		2,596	£ 5,594
Band 5-SPD ERNIC Superannuation	17	2,107 215	5	749 87	
Total		2,322		836	£ 3,158
Band 5-SPD ERNIC Superannuation	1	17			
Total		17		-	£ 17
Band 5-SPD ERNIC Superannuation	34	4,284	4	726	
Total		4,284		726	£ 5,010
Band 5-SPD ERNIC Superannuation	37	4,692	6	1,020	
Total		4,692		1,020	£ 5,712
TOTAL SALARIES		14,313		5,178	£ 19,491
CONSULTANTS					£ -
					£ -
WORKSHOP		1,400			£ 1,400

TRAVEL					£ -
SUBCONTRACTS		9,196		12,260	£ 21,456
OVERHEADS		6,870		2,485	£ 9,355
TOTAL		£ 31,779		£ 19,924	£ 51,703

8. ACKNOWLEDGEMENTS

We are grateful to the following organisations and individuals who assisted with provision of data: The National Trust for Scotland – James Fenton, Simon Frank, Shaila Rao, Richard Luxmoore; Scottish Natural Heritage – Richard Kilpatrick, Peter Duncan; The Rum Project – Josephine Pemberton, Ian Stevenson; The Deer Commission for Scotland – Mike Daniels and The Macaulay Institute – Russell Hooper and Andrew Dalziel.

We are also grateful to the following organisations and individuals for providing technological insights: Blue Sky Telemetry – Ian Hurlbert; Lotek Wireless; Infoterra Ltd; NEODC; Sea Mammal Research Unit - Bernie McConnell; National Paintball Supplies Europe – John Cashmore; Biomark – Mark Owens; NERC Isotope Geosciences Lab – Rhiannon Stevens; Iso-analytical Ltd. – Steve Brookes; Edinburgh University – Sylvia Perez-Espona.

We thank the following for giving their time and expertise as participants at the Workshop: Mike Daniels and Josephine Pemberton – Deer Commission for Scotland, Jenny Bryce – Scottish Natural Heritage, Willie Lamont – Forest Enterprise, Helen Armstrong – Forest Research, Richard Luxmoore and Shaila Rao - National Trust for Scotland.

Finally we thank Mike Daniels, Josephine Pemberton and Steve Albon for their help, support and advice throughout.

ANNEX 1

SYSTEMATIC AND QUANTITATIVE EVALUATION OF EXISTING LITERATURE, DATA AND METHODS TO ASSESS RED DEER MOVEMENT

Contents

1. SUMMARY.

We have conducted a detailed review of the peer-reviewed and grey literature pertaining to deer movements in Scotland and the methods currently used to assess movement.

The following data sets were evaluated for their ability to provide information on landscape scale deer movements according to agreed criteria: (1) Glen Affric count data (2003-2005); (2) Creag Meagaidh census data (1992-2005); (3) Rum North Block census data (1974-2005); (4) DCS count data (1983-2004); (5) Mar Lodge count/cull data (1990-2005); (6) Macaulay Institute GPS data (Mar Lodge, Invercauld and Cairngorm); (7) DCS calf tagging data; (8) Run Round Island census data; and (9) calf tagging modelling study.

The West Affric data provided counts of animals on either side of the estate boundaries and could provide some estimates of seasonal movement patterns. However, consistent data were only available for 12 months and were compromised by different counting protocols between observers. The Creag Meagaidh data allowed deer movements between count zones within the estate to be detected, but because there was no comparable count data from neighbouring estates, it was not possible to detect movement across estate boundaries.

The Rum North Block census of individuals demonstrated a negative relationship between the similarity of group composition from one observation to the next, and the distance moved. Therefore, if a marked individual moves a large distance it is less likely that its previous companion animals will move with it. The GPS data demonstrated that it may be possible to detect the difference between range shift and seasonal habitat use, but because of the results from the Rum data, it would probably not be worth using GPS for detecting large-scale movement unless large numbers could be tagged.

The DCS count data, at the counting block scale, were too coarse to predict large-scale movements. Analysis at the estate scale might be informative, but considerable investment in proof-reading and formatting the data would be required. The DCS calf tagging data demonstrated that, depending on location, some individuals had moved a long distance from where they were marked as calves, although most had not. It was not possible to test whether local variations in density were responsible for the differences.

The calf-tagging modelling exercise demonstrated that tagging could be used to detect increased levels of immigration ‘source’ to ‘sink’ estates, although the power to detect such influxes will be low unless three conditions are met. These conditions are that the reduction cull in the sink estate is fairly severe, a high proportion of potential immigrants on the source estate are tagged and a high recovery rate of tagged animals is achieved on the sink estate. The probability of detecting increased immigration will generally be highest if the animals are moving in from larger estates and recovery is by sighting rather than by culling.

In conclusion, the following research/monitoring protocol to assess red deer movement was recommended, based on the findings from the various data sets/methods evaluated. Neighbouring estates should be divided into zones with all observers counting all the zones together. Training in and standardisation of counting protocols should be carried out, to ensure that data are comparable within and between counts. Baseline counts across the whole area of interest should be made prior to any changes in density in the potential sink area. This should be augmented by ear-tagging animals on the suspected source areas, to determine whether they start appearing in the sink area. If funds allow, supplementary GPS tagging of some individuals could be carried out in order to obtain more detailed movement data.

2. APPROACH

We used the following four-stage process to evaluate the suitability of methods that have already been used to monitor deer movements in Scotland, and assess their potential for monitoring movements at the landscape-scale:

- Critically review existing peer-reviewed and 'grey' literature on red deer movements in Scotland, using sources such as Web of Science, the internet, non-peer-reviewed reports and previous literature reviews (e.g. SEERAD core-funded literature review on deer and woodland, MLU/717/00).
- Carry out quantitative and qualitative analyses of available datasets on red deer, using an array of statistical and modelling approaches described below.
- Interpret the data analyses, in conjunction with the literature review, giving full consideration to the potential for each method to provide high-quality information on deer movements, suitable for implementing evidence-based management policies.
- Evaluate each method against the Agreed Assessment Criteria, for comparison with other methodologies that have not yet been used to collect deer movement data.

3. REVIEW OF LITERATURE RELEVANT TO THE MOVEMENT OF RED DEER

3.1. Introduction

Red deer are large, highly mobile animals whose movements often bring them into conflict with man (SNH 1994; Putman et al 2004). In Scotland, individual land-holdings seldom contain discrete deer populations and efficient management depends on cooperation amongst those exploiting a common stock. A relatively recent change in the pattern of land-ownership has resulted in more diverse deer management interests. Thus neighbouring land-holdings can have opposite deer management strategies. Concern about deer culling strategies and their impact on deer dispersal (SNH 1994) has brought about, at its worst, conflict between neighbouring land-holdings. There is, therefore, a need to understand landscape-scale red deer movements and the factors that influence them.

Darling (1937) lists four main types of factor that influence red deer movements: meteorological, biological, physiological and psychological. Meteorological factors, such as temperature, humidity, wind, rainfall, snow and frost, can potentially instigate movements and may also be stimuli in a physiological sense. Biological factors include disturbance from insects, predators and humans. Physiological factors include nutrition and reproduction, both strong motivators for movement. Searching for food is a major activity and deer may have to range widely to meet their nutritional requirements. The need to reproduce also influences movements in both sexes, though this is most marked in stags. Psychological factors include the urge to establish new territory. Darling (1937) argues that the psychological causes of movement, other than those linked to weather, disturbance and physiological factors, should be regarded as *choice.* Thus choice is present to some degree in all movements, except reflex ones, and "especially in those involving curiosity and problems of insight and foresight" (Darling, 1937). There are few, if any, studies that have looked directly at the psychological factors that motivate red deer to move. Such factors are clearly important, but our understanding of them is limited and constitute a gap in our knowledge of deer movements.

3.2 Movement of hinds and stags

Large-scale movements by red deer should be viewed in the context of how red deer are "normally" distributed over the landscape. In general, except during the rut, stags and hinds segregate, often into geographically distinct areas (Lowe 1966; Staines 1970; Jackes 1973; Clutton-Brock et al 1987). The basis of social organisation in hinds is a matriarchy, with a social unit consisting of a mature hind and her dependent offspring. Her mature daughters and their young usually have adjacent ranges, which overlap hers (Clutton-Brock 1974; Mitchell et al 1977; Staines 1991). However, as population density increases, the degree of spatial association between female kin declines (Albon et al 1992). Data from the North Block of Rum show that when local population density was high, individual hinds spent less time close to their relatives and more with unrelated animals. As the population increased, only young mothers and their youngest daughters were closely associated. When these daughters reached maturity and produced surviving female offspring, their association with their mother and sisters weakened. In a few cases this involved leaving the natal area and led to the establishment of new ranges, but in most cases, dispersal consisted of a gradual weakening of matrilineal bonds, combined with an increase in the time spent in groups with unrelated animals (Albon et al 1992).

In contrast, many young stags leave their natal area, the age of dispersal varying from one year old in forest plantations to two years or more on the open hill. The timing of this dispersal is usually at the rut, in late September through to November, or just before the calving period (Staines 1991), starting in mid-May. These periods also tend to be the peak times for road traffic accidents involving deer (Langbein & Putman 2006). Young stags form semi-permanent groups with unrelated animals, for varying periods. Stags do not settle for several years until they become mature, when seasonal ranges are then established (Staines 1991). Stags generally become more mobile at the time of the rut, as they move into the areas where the hinds are. The rutting areas of stags are traditional for particular populations and can be several kilometres from their summer and wintering areas (Darling 1937; Mitchell et al 1977; Langbein 1997).

Red deer have a strong hefting instinct (Lowe 1966; Mitchell et al 1977; Staines 1977; Catt & Staines 1987; Clutton-Brock & Albon 1989) and this is particularly the case for hinds, and to a lesser extent, mature stags. Experimental evidence from Glen Dye and Glenfeshie shows that when deer were deliberately disturbed, on reaching the edge of their "known" range they turned and ran back towards the centre of their range (Staines 1977; Staines & Scott 1994). The greatest disturbance that red deer face in Scotland is during the hunting season, and changes in localised range use at this time of year have been found (Staines 1970; Staines 1977; see also review by Staines & Scott 1994). However, Staines (1970; 1977) found that although distribution was modified for a day or so after shooting, there was no evidence of animals moving permanently to nearby areas during this period.

An initial tagging study by the Red Deer Commission (RDC) found that hinds were rarely recovered more than 2 km from their birthplace, whereas over 40% of stags were recovered more than 8 km away, with maximum distances of up to 22 km reported (RDC 1978). More recent tagging studies by the Deer Commission for Scotland (DCS), from elsewhere in Scotland, reveal a similar pattern, with stags recovered at about twice the distance from their birthplace than hinds (5 km cf. 3 km). However, some very long distances have been recorded, for example 57 km for a stag (DCS 1999) and 31 km for a hind (RDC 1988). Data from the West Grampians showed that 4% of hind recoveries were from sites of more than 16 km away from their site of tagging, compared to 17% of stags (RDC 1988). The distance moved has been shown to depend on tagging location, which suggests that topography or local deer density may be important (Daniels & McClean 2003). However, tag recovery rate was only about 25% and 61% of these recoveries were for hinds, thus some caution is required in interpreting these results, as the fate of the bulk of marked animals, especially stags, remains unknown.

Woodland deer populations distribute themselves in a similar manner to those on the open hill. Results from radio tracking red deer in a commercial forestry plantation at Glenbranter Forest, Argyll, are consistent with those reported above from calf marking in the open hill. In these woodland studies none of the 19 marked females dispersed (Hinge 1986; Catt & Staines 1987), but one hind was observed to make a single one-day excursion of just over 1 km out-with the boundary of her normal home range (Catt & Staines 1987). The deer population in the study area was almost exclusively hinds and dependent young, as adult stags were seen only during the rut. Of four young stags and one adult stag marked, four animals, including the adult, dispersed 12-18 km from their point of capture (Catt & Staines 1987). The fifth male was sighted as an adult 6 km from its capture point, but its last known location was 1 km away from its point of capture. The closest population of mature stags was one to two kilometres to the north, but there was no consistent direction of dispersal for the stags marked at Glenbranter.

From a deer management perspective, the results from these studies emphasise what is already well known, that hinds seldom leave their natal area and young males are more likely to emigrate. However, the advantage of long-term studies, such as the DCS calf tagging study, where more than 2300 calves have been tagged, and the work on Rum, is that they have demonstrated that a small proportion of females also emigrate and, at least in the case of Rum, this may be related to local population densities (Albon et al 1992).

Although most hinds and mature stags are hefted to their home ranges, large differences in the size of home ranges have been recorded. The largest so far reported (2400 ha) was on open hill in the eastern highlands (Staines 1977). Studies on Rum have recorded smaller home range sizes, ranging from 400 ha (Lowe 1966) down to 200 ha (Clutton-Brock et al 1982). Home ranges incorporate favourable resources, such as sheltered areas and feeding areas. The distribution and size of these resources within the landscape has been shown to influence the size of home ranges of red deer, and other mammals (Clutton-Brock & Harvey 1978; Clutton-Brock et al 1982; Catt & Staines 1987). Differences in range size between the sexes have also been reported, with stags generally, though not always (e.g. Clutton-Brock et al 1982), having larger ranges (Darling 1937; Staines 1970; Catt & Staines 1987; Langbein 1997).

3.3 The effect of density and management on movement

In open hill landscapes, deer populations can have distinct seasonal ranges, with higher ground used in summer and lower, more sheltered ground used in winter (Darling 1937; Parish 1971; Staines 1977; Watson & Staines 1978). In a study of red deer on Exmoor, two marked hinds moved to separate winter ranges, which stretched up to 7 km away from their summer range (Langbein 1997). However, these individual shifts in range only occurred in some of the years that the animals were followed. Thus, the obvious issue about how deer range over the landscape is that animals may use areas with differing ownership and, potentially, different management aims. These are most likely to concern the densities and sex of animals thought best for their requirements. Any large-scale perturbation on one estate, such as increasing or decreasing local deer densities, is thought likely to impact on deer densities and movements on neighbouring estates. Thus, if heavy culling creates an area of low density, the concern is that this area will be re-colonised by deer, principally stags, emigrating from other areas, the so called "vacuum effect" (SNH 1994).

The effect of an increasing population density on the rate of emigration and immigration has been investigated on the Isle of Rum (Clutton-Brock et al. 1982). Within the North Block, where there has been no culling since 1973, increasing hind density did not lead to increases in hind emigration but led to a reduction in the number of hinds immigrating (Clutton-Brock & Albon 1989). Increasing hind density also reduced stag immigration, with few if any stags settling in the areas with high hind density (Clutton-Brock & Albon 1989; Coulson et al 2004) thus increasing the degree of sexual segregation in the study area (Conradt et al 1999).

The effect of decreases in population density on red deer movement has also been assessed. The number of deer in Glen Dye was reduced from 846 in 1961 to 298 by 1968 (Staines 1978). In the initial population there were just over four times as many hinds as stags, whereas in the final year of the study there were only one and a half times as many hinds. Despite the high cull, the number of stags remained more stable than those of hinds, because of immigration.

The effects of reducing deer density were also investigated on Rum, in an experimental cull aimed at altering the relative density of stags and hinds outwith the North Block (Clutton-Brock & Thomson 1998; Clutton-Brock et al 2002). In one block, a cull reduced the density of hinds by 50% over two years. Following the reduction in hinds, the number of stags in this block increased by around 25% over 8 years (Clutton-Brock et al 2002). In a second block, stag numbers were reduced by 50%, though this required sustained culling over a number of years to achieve. A lower male density immediately attracted young stags from neighbouring areas, and it took 5 years to reduce the stag population to half its original number. However, once stag numbers were reduced, the number of hinds in this block increased by around 50% within 5 years. Both emigration and immigration by females on the island were rare, irrespective of density (Clutton-Brock et al 1997), and the increase was thought more likely to be due to recruitment (Clutton-Brock et al 2002). This work indicates that both stags and hinds respond to changes in the density of the opposite sex and, despite sex differences in habitat use, similar resources limit the numbers of animals (Clutton-Brock et al 2002).

Concerns over damage to the natural heritage have prompted some estate managers to reduce the density of all large herbivores. In the late 1980s there was a large reduction in deer at Creag Meagaidh National Nature Reserve (Putman et al. 2005). Counts undertaken at the start of the cull suggest that more hinds used the reserve than stags. The counts, taken in March and October, showed similar numbers of hinds, but there was a large increase in the number of stags at the October counts. Although deer densities were greatly reduced, initially there was no evidence of significant movements into the area (SNH 1994; Putman et al 2005). However, there is concern over recent population increases, with numbers having now returned to levels seen in the mid 1980s. Monthly counts show a marked seasonal pattern in numbers, and it appears that this is partially caused by transient individuals or recent immigrants, rather than a change in the performance of, or recruitment to, the resident deer population (Putman et al 2005). Hinds and their young are present in large numbers between June and December. The numbers of stags on the reserve are more stable throughout the year, although numbers increase for the rut in September and October, in line with maximum numbers of hinds. The age structure of stags at the time of the rut has also altered in recent years, primarily due to an increase in the number of younger stags. However, there are no equivalent data for hinds, as they are not aged in the counts. A similar result was reported at the RSPB reserve at Abernethy, with a significant decline in deer numbers over a few years followed by a subsequent increase in numbers, which was again associated with stags (Parlane 1999).

These studies demonstrate that reducing hind density can result in immigration of young stags. Clutton-Brock et al (2002) argue that in many parts of Scotland, hind densities are probably above the threshold at which male density starts to be affected and that reducing numbers of females would have little effect on the size of stag harvests. In fact, they suggest that there could be benefit in this, because immigration by stags is more likely at lower hind density. Putman et al (2005) suggest that changing deer densities in neighbouring estates could account for the number of transient animals using Creag Meagaidh. These authors argue that when densities are high, more deer access the reserve simply as a form of range expansion. They cite, as an example, that the numbers counted on the reserve dropped dramatically following high levels of winter mortality on neighbouring ground.

The likelihood of increased immigration of deer following a reduction in deer density is a concern to some estate managers. This has been examined in two instances. First, at West Affric Estate, there was concern that deer were moving into the estate from the north in response to reductions in density within the estate. A counting regime was instigated to try to determine whether this was happening. It confirmed that deer were using inaccessible corries to the north of the estate, which has increased the difficulty of reducing deer density further. There was no clear indication that deer were moving in from the north and more years of data may be needed (see data analysis in next section). However, it has been suggested that if deer density in the Northern Corries (close to the northern march) has increased, then this may act as a buffer to reduce immigration from the north (Fenton 2004). Therefore any study looking into deer movement may need to consider how deer ranging behaviour responds to different levels of culling pressure. In addition, this effect may increase the time delay in detecting any net movement and therefore count data must continue long after a change in management has occurred, if the effects are to be quantified.

A second example occurred on Mar Lodge Estate, where culls of 24% of the deer population have been achieved over several years. However, a helicopter count in 2001 indicated that the population was still of a similar size to that counted in 1995. This may be due to underestimates of the true population size during the earlier foot counts, or to immigration from neighbouring estates. However, foot counts have shown a decline in population size indicating that, although the population may have been undercounted, it has declined since 2001. In addition, neighbouring estates have not reported any reduction in density, which would have been expected if immigration was the source of the higher than expected numbers on Mar Lodge (Luxmoore 2002). Management changes since 2002 have aimed to split the estate into two zones. Regeneration of native pinewood is prioritised in the first zone and target densities of deer have been set at 5/km^2. Deer stalking is prioritised in the second zone, where target deer densities are 16/km^2. These data will provide an opportunity to look at movement within the estate, which given its size, is equivalent to movement between estates in other parts of Scotland. Three years worth of data are available but have yet to be analysed (Shaila Rao, pers. comm.).

3.5. Conclusions

The published reports do not provide a great deal of insight into the frequency of large-scale deer movements over the landscape, and across estate boundaries, nor do they give insights into the factors that predispose animals to make these movements. However, the evidence, so far, suggests that reducing local density may cause immigration from neighbouring ground where density is higher. The following section of this report investigates what we can learn about deer movements from existing data sets, that are either unpublished or have not been analysed in relation to these questions.

4. CRITERIA FOR ASSESSING DATA SETS FOR USE IN DETERMINING DEER MOVEMENTS

(agreed at meeting with SEERAD Project Officer 20 July, 2005)

Metadata.

- Description and definition of variables recorded.
- Description of methods used.
- Associated data on management history of the site and neighbouring sites

Consistency

- In methods used.
- In approach to missing or poor quality data.
- In timing of data collection (e.g. same period each year or same time of day).
- In duration over which data is collected (e.g. number of days to complete census).

Run of data

- Time period the data set covers (e.g. months, years, months per year).
- Frequency of data recording (daily/monthly/annually).
- Management changes over the run of data.
- Methodological/observer changes over the run of data.
- When have any of these changes occurred?
- Access to raw data behind available summary reports.

Spatial Accuracy

- Locations recorded accurately (grid ref or GPS).
- Distance and angle from transect to animal(s)/dung recorded.
- Geographic range over which the data is collected

Variation/error

- Does the method allow errors (in counts etc) to be estimated?
- How does within count error compare with between count error?

Covariates

- Habitat type/vegetation characteristics (e.g. height, density, spp)
- Weather when the data was recorded (wind, rain, sun, cloud, temp)
- Topography (slope, aspect)
- Co-existing herbivores counts/densities

Variables (example set)

- Date/time
- Group size and numbers of: stags, hinds, yearling males, yearling females, calves.
- GPS or grid reference
- Distance & angle (bearing)
- Vegetation type
- Topography (slope/aspect)
- Weather (wind, cloud, rain, sun)
- Cull data (age structure, reproductive rates, body mass)

5. EVALUATION OF DATASETS

5.1. WEST AFFRIC COUNT DATA

Description: These data, supplied by the National Trust for Scotland, comprise monthly counts of deer seen from two standard routes running along (1) the southern and (2) the northern marches of the 3660 ha West Affric Estate. The routes were planned specifically to gather data on individual groups of deer on West Affric and neighbouring ground in order to ascertain whether deer were moving onto West Affric as a response to lower density there, following an increased level of culling. The intended method was to walk the route on successive days to minimise the chances of deer being counted twice within a given month, but that was not always achieved as some counts were one to two weeks apart. The counts were conducted regularly between June 2003 and April 2004 (except in March 2004), but thereafter only sporadically (and not always on both routes) up to June 2005. The locations and composition of groups were provided in an Access database.

Aim: To determine whether we could detect groups of animals moving across the march.

Analysis: We examined the factors affecting the size of individual groups by fitting the total number of deer seen in each group ($n = 463$) to a generalised linear mixed model (GLMM) with visit as a random effect and a Poisson error distribution. Potential explanatory variables comprised counting route, year, quarter (1 = January to March, etc.), month, sex composition (stags, hinds, mixed or unspecified), whether the group was on West Affric or not, time of day ($n = 246$) and the distance at which the group was observed ($n = 203$). We tested whether the distance at which groups were seen varied between route or season to check for potential bias in the methodology, and looked for seasonal variation in the ratio of total numbers of deer seen on West Affric to numbers on neighbouring ground, to identify possible seasonal movements across the march. We also loaded the data into a GIS (ArcMap v9) and tried various ways of depicting the data, e.g. within group-size ranges, by month, by date if over a minimum group size.

Results: Group sizes and total numbers of deer varied significantly between seasons. There was less variation in total monthly count within West Affric than on neighbouring ground, but that could be due to observer bias (concentrating more on searching West Affric and being more likely to miss a group beyond the march). Also, as NTS staff pointed out, due to the higher culling pressure on West Affric, deer tend to use more inaccessible corries near the march and are therefore more likely to be counted from the routes following the march than deer on neighbouring estates, which may use lower ground to a greater degree and therefore be missed completely in certain months. Within the estate up to April 2004 (the most consistently recorded period), the total count varied two-fold between 246 and 542 animals, yet counts alternated up and down in successive months (c.v. = 26%); over all counts made during that period, numbers ranged from 354 to 1170 (c.v. = 42%). Group size differed significantly with quarter (higher in quarter 3 than in 2 or 4), month (highest in July, lowest in April), composition (in descending order: unspecified, mixed, hinds, stags) and location (smaller on West Affric than on neighbouring ground). There was no effect of the route, year, time of day or distance between the observer and the deer, and there was no interaction between location and quarter, i.e. group size was consistently lower on west Affric but varied seasonally in a similar way to areas out with West Affric. The effects of location, quarter and composition were additive. There was no effect of route or quarter of the year on the distance at which groups were observed, nor was there any seasonal difference in the ratio of numbers seen on either side of the march in a given month, either for individual routes or for both routes combined.

Potential and limitations: Data analysis in relation to deer movement is problematic as we have no suitable null model of deer distribution against which to detect net movements (other than a large and permanent migration). Such a model would have to account for a number of factors, including demography (fecundity, culling and natural mortality), seasonal habitat use (including regular, local cross-boundary movements), herding behaviour and detectability by the counting method(s) employed. An alternative is to instigate a count protocol before a change in management takes place, in order to determine the baseline pattern of movements so that any deviation from this pattern is more readily detected. Visual interpretation of the data using a GIS may give certain insights, but these must be, to a certain extent, subjective and thus open to disagreement. Paradoxically, the more detailed the data, the more difficult such methods become. Aggregation of the data in some way may be tried to overcome this, but is more likely to follow some anthropogenic view of the data rather than one based on the actual behaviour of the deer. One possible approach could be to aggregate the data in a zonal manner as used at Creag Meagaidh (see 2 below). This would involve dividing the West Affric count area into four zones: zone 1 = route 1, outside W. Affric, zone 2=route 1 inside W. Affric, zone 3 = route 2, outside W. Affric, zone 4 = route 2 inside W. Affric. We could then test in a rigorous statistical way whether the peak numbers inside W. Affric lag the peak numbers observed beyond the march. This approach would require multiple years of data. Currently there is only one year of suitable data. The effect of heavy culling on deer ranging behaviour in West Affric is not well documented, but anecdotal evidence suggests that the WA deer are using the higher more inaccessible corries that are close to the Northern March. This effect of culling on deer behaviour opens the possibility that deer at high densities in these northern corries may actually act as a buffer, limiting ingress by deer from neighbouring estates? If this was the case then this may cause a delay in any migration into the estate from higher density neighbours, with implications for the length of time that monitoring counts will be needed before movements are detected. Although the NTS data collection is well-structured, we have identified a few areas where inconsistencies and ambiguities are not highlighted in the database. These have been communicated to NTS staff so that potential future problems and false conclusions can be avoided, particularly when there are changes in future staffing.

5.2 CREAG MEAGAIDH COUNT DATA

Description: These data supplied by Scottish Natural Heritage comprised monthly counts between April 1992 and June 2005 of all deer seen in each of seven zones of the 3940 ha Creag Meagaidh Estate. The counts were conducted to monitor deer numbers on the estate following a sustained culling policy from 1986 to 1992 and thereafter a lower maintenance cull. The methods have been described by Putman et al. (2005) and the changes in total numbers over time analysed. They showed that, despite heavy and sustained culling pressure, the reserve still supports a significant population of deer. Although numbers declined until the mid 1990s, the population has increased and is now approximately at the levels it was prior to the heavy culling program. In addition there is marked seasonal variation. The age structure of the population has changed, with significant increases in the number of young stags. Together, this is interpreted as indicating that the increase in numbers is partially caused by a transient population of immigrant stags. Some background information on deer range use was supplied by the reserve staff: The reserve is thought to be characterised by two distinct populations: one to the North (Zones 6, & 7) and one to the South (Zones 1, 2, 3 4 & 5). This is based on the observation that animals are seldom observed passing between these two zone areas and the belief that zones 6 and 7 are inhabited by a herd of deer which commute solely from Glenshero and the northern area of Brae Roy on a mainly nocturnal pattern:. This is also thought to explain the low counts on zone 7 as counts are undertaken during daylight hours and the majority of the deer utilizing this part of the NNR may have already left before the count commences. Zone 6 tends to hold more deer during the day especially during the rut. This could be a reflection on the fact that extraction is a major problem from zone 6 and the animals feel 'safer' especially at the top end of the Coire.

Aditional information comes from animals clearly marked with collars in the late 80's and early 90's. The catcher was located near Aberarder and deer from zones 6 and mainly 7 were the most likely to have been caught. These collared deer were frequently observed on the NNR and occasionally on neighbouring ground – especially Glenshero. No marked deer were ever seen within the NNR apart from zones 6 and 7 and marked deer were observed to be using both zones i.e. there appeared to be a shared home range between zones 6 and 7 and the adjacent ground belonging to the neighbouring estates. No marked deer are still surviving.

The data were supplied in the form of Excel spreadsheets, each representing a data entry form for a single month. Data was re-entered into a single spreadsheet to allow analysis.

Aim: To test the prediction that since deer are moving in to Creag Meagaidh from neighbouring ground on a seasonal basis, we should see peak numbers on interior zones lagging peak numbers on peripheral zones. Specifically, zones 2 and 3 (combined because their counts were relatively small) should lag behind zone 1; likewise, zone 6 should lag behind zone 7 (see Putman et al., 2005 for description of zones).

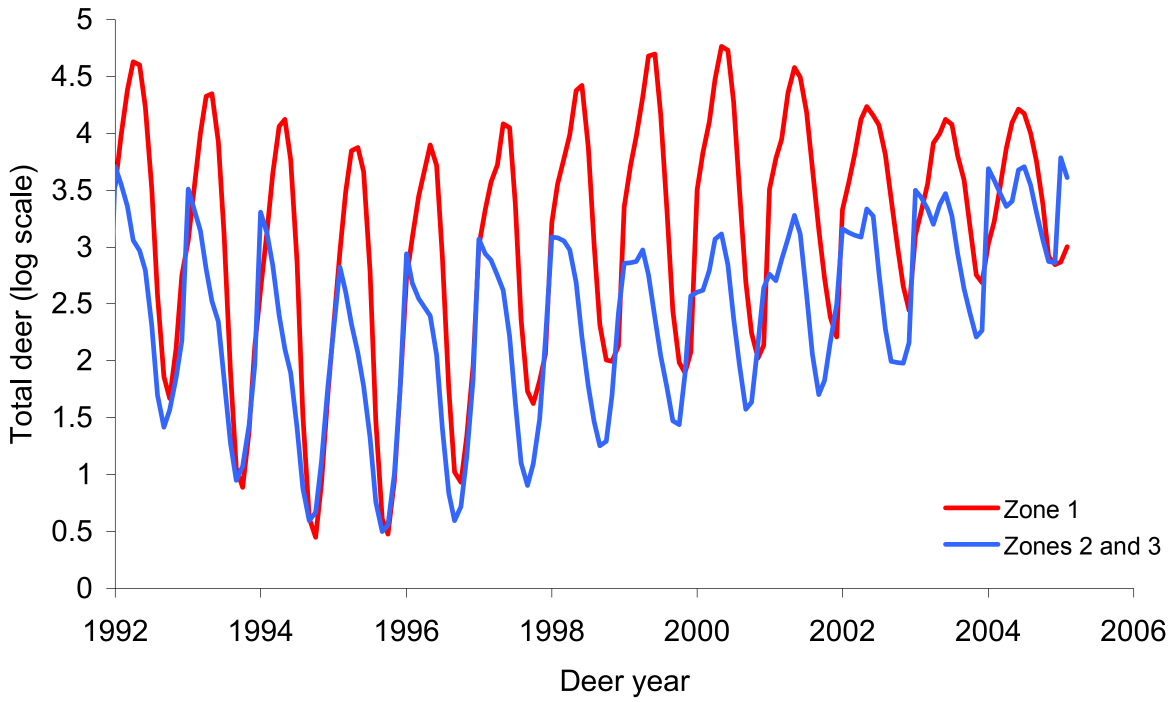

Figure 1. Predicted deer abundance in zones 1 and zones 2&3 combined. The data demonstrate the seasonal variation within year in counts. Values were generated from a generalised additive model with a 9th order polynomial. There is no strong evidence that the peak in zones 2&3 lags the peak in Zone 1.

Analysis: The approach we adopted was to attempt to identify for each zone the month within each year with the highest count of deer (total, stags, hinds, hinds + calves), and then examine the lags as identified above. However, we encountered two particular problems: (1) there was a lot of noise in the zonal count data from month to month – hence 'odd' peaks could occur (especially in the less used zones 2+3 and 7); and (2) the calendar year does not reflect deer movements. Problem (1) was addressed by smoothing the monthly counts within each zone by fitting a spline function (proc gam, SAS Inst, Cary, USA). We overcame problem (2) by defining a deer-year commencing in May (as no peaks ever occurred in May, and it is reasonably consistent with deer biology, i.e. the start of good weather and of the calving season).

Results: Peak numbers increased over time (i.e. they were higher in recent years than during the period when the heavy deer cull was active). As expected, there were strong seasonal peaks in all zones in autumn / early winter and troughs in spring / summer. The numbers were highest in zones 1 and 6 and lowest in zones 2+3 and 7. The seasonal pattern in the total deer numbers was similar for both hinds and stags. These high numbers in peripheral zones reflect immigration from outside, as they are unlikely to be due to movement from the interior to the periphery because of the relatively small numbers in the interior zones. However, there are no data for deer numbers in adjacent 'zones' on neighbouring estates to test this. Visual inspection of the smoothed zonal counts indicated no evidence for movement of deer as suggested in the hypothesis, i.e. the peak in zone 2+3 did not generally lag behind the peak in zone 1 (Fig 1) and the peak in zone 6 did not lag behind zone 7. However, there was some evidence that peak hind numbers in zones 6 and 7 lagged behind the peak in zone 2+3 suggesting that there could be some movement of deer within the estate although observations by reserve staff would refute this hypothesis (see 'Description' above) . Reserve staff also report that in the early to mid 90's there was also a trend for the deer using zones 1,2,3,4 & 5 to winter to the south of the NNR on the Tulloch Estate and then drift back onto the NNR from March onwards. This avoided the main part of the hind stalking season and numbers observed on Tulloch suggest that this was happening. Movements between Zones 6 & 7 and Glenshero and between zones 1-5 and Tulloch could be tested by marking animals in these populations and carrying out monthly censuses across these areas. The samples sizes and logistics involved are discussed in section 5.7

Deer movements at Creag Meagaidh are interpreted by reserve staff as an adaptation to a high culling regime so that deer visit the reserve at night but over winter in an area out-with the reserve during the main hind stalking season. This is thought to have influenced local deer movements and created a situation whereby the deer utilizing the area of the NNR share a home range with the neighbouring estates and are now described as a fairly transient population.

Potential and limitations: Additional count data collected in a comparable way from zones outside the estate would be invaluable to determine how those deer making large-scale seasonal movements into Creag Meagaidh are using neighbouring ground during the intervening periods. Our approach, in which the seasonal and annual patterns are displayed using smoothing splines to reduce noise, could be useful in providing a subjective analysis of temporal trends in deer numbers in a format suitable for facilitating discussions within a workshop or deer management group. The above analysis could be refined by correcting count data for numbers culled in each month.

5.3. RUM NORTH BLOCK CENSUS DATA

Description: The data provided by the Rum Red Deer Project records groups of animals observed from a fixed-route foot census of the North Block of Rum. All individuals are identified from ear tags and/or collars and sex and age-class is noted. Census frequency varies, but is 54 per year on average. The census data runs from 1973 to present.

Aims: (a) To determine the degree to which an animal consistently associates with the same individuals and (b) To determine whether the group composition associated with an

Year	Rut	Summer	Winter
1974	15	21	26
1975	15	21	27
1976	15	7	25
1977	10	19	27
1978	16	16	25
1979	15	16	27
1980	15	16	25
1981	16	15	21
1982	10	16	21
1983	10	15	21
1984	10	15	20
1985	10	11	5
1986	10	15	21
1987	5	15	20
1988	5	15	8
1989	5	16	23
1990	2	15	16
1991	5	15	12
1992		5	19
1993	5	15	19
1994	5	15	20
1995	5	15	28
1996	6	14	20
1997		11	15
1998	6	15	14
1999	5	15	20
2000	5	10	14
2001	6	14	26
2002	7	14	18

Table 1. Number of censuses per year per season. A census is defined as a day for which at least 50 deer records exist

individual remains the same after a long distance movement.

Analysis: The detailed data for group composition, comprising known animals from the Rum Red Deer Project, afforded the opportunity to examine how radio-tracking or GPS data might be interpreted in terms of movements of the animals other than those fitted with tracking devices. In effect, we conducted a virtual radio-tracking study with the advantage of a high degree of omniscience. For tracking, we selected, at random, up to 50 animals of each sex / data quality (1 = high quality [hereafter described as 'core'], 2 = lower quality because they were less often sighted [hereafter described as 'fringe']) combination. Eligible animals were restricted to those which lived to at least 6 years (or were still alive at the end of the census period and were aged over 2) and for which there were at least 100 sightings. These restrictions limited us to only 14 fringe hinds and 49 fringe stags and 50 of each sex from the core study area, giving 163 focal animals in total. We distinguished the increase phase (up to deer year 1982) from the subsequent stable phase in terms of hind numbers, following Albon et al. (2000), and we defined the 'deer year' as starting in May, consistent with Albon et al. (1992). On the basis of preliminary analyses conducted at the level of individual months, we aggregated months into three seasons: 'summer' from April to July, 'rut' from August to October and 'winter' from November to March. The number of censuses in each time period are outlined in Table 1.

Second and subsequent sightings of a focal animal on a given day were dropped, to avoid any possible influence of the observer on animal movements within the day. Analyses were limited to movements occurring over 10 days or less. This gave an approximately normal distribution of days and excluded a long tail, comprising both gaps in the census regime and sightings of deer following periods of absence from the study area. Analysis was difficult due to the high degree of temporal variation in group size; with focal animals associated with many other animals during the course of their life-time, but with most of these associations observed on only one or perhaps a few occasions. The solution we adopted was to identify the focal animal's 'best pals' within each deer year, i.e. the other animals with which it was most frequently associated (up to 10 per year were identified, subject to a minimum of 5 associations within the same group within the deer year). We calculated the similarity between successive groups in which the focal animal was located on the basis of the 'best pals' present within each group using the Jaccard similarity coefficient (the ratio of pals present on both occasions to pals present on either occasion; this ranges from zero, for no common pals at all, to one for identical groups). Note that the coefficient could not be calculated if there were no best pals in the current or previous group. Note also that, although the coefficient is bounded between zero and one, taking arcsine square-root transformation did not improve the fit of model residuals to a normal distribution, as no value could fall in the ranges $0 < J < 0.1$ or $0.9 < J < 1$ owing to the limit of ten best pals; to simplify interpretation of the fitted parameters, data were not transformed.

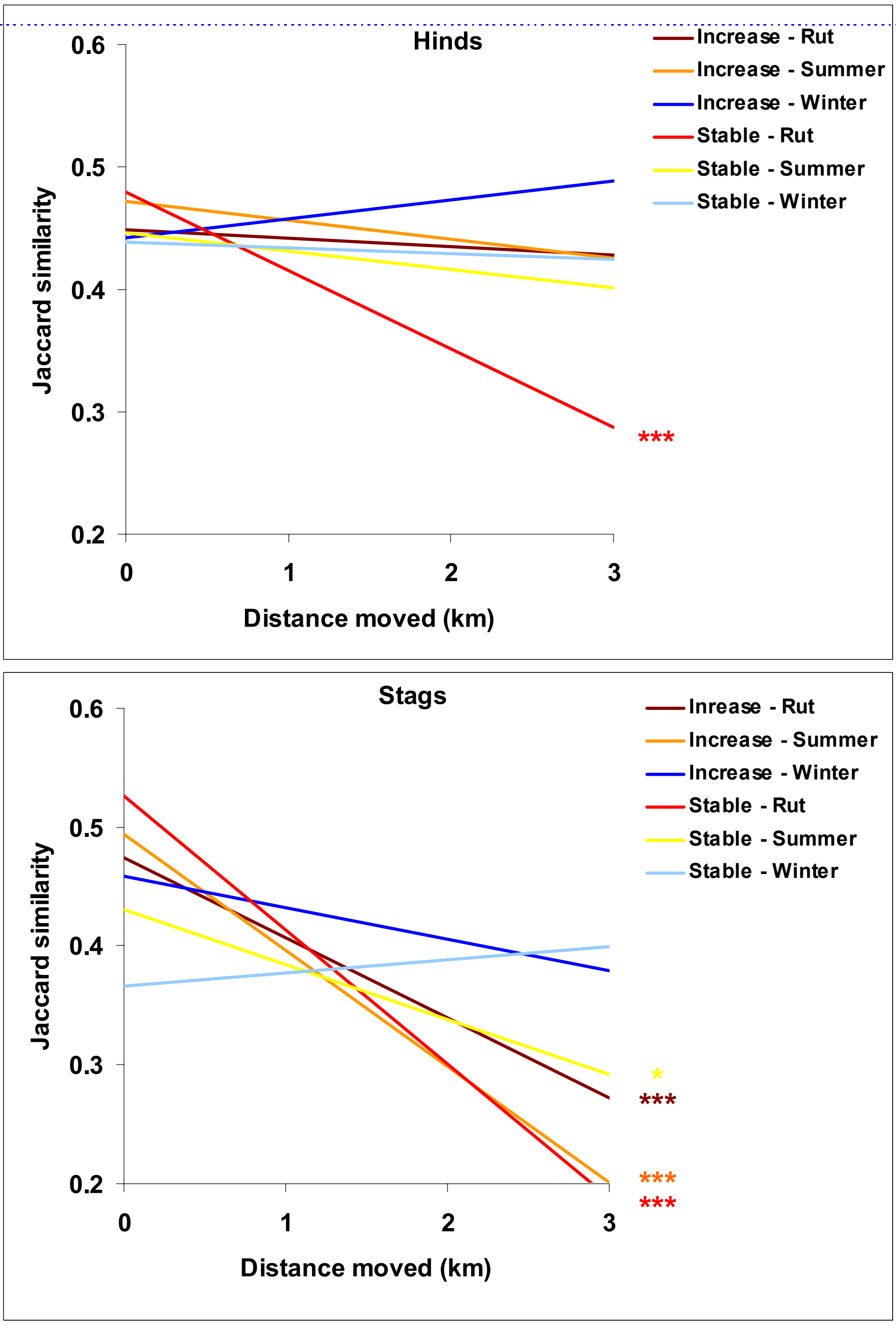

Figure 2. The relationship between the similarity of the associates of an individual animal between observations (as measured by the Jaccard index) and the distance it has moved for (a) hinds and (b) stags. Stars indicate that the slope of the line is significantly different from zero

Results: Group sizes for both sexes increased through the summer then declined rapidly to reach their minimum (at around 6 to 8) during the rut, before increasing slowly throughout the winter (consistent with Clutton-Brock et al., 1982). Group similarity was not correlated to group size for either sex. Hinds had the highest group similarity in June, but sample sizes within June were much smaller than for other months and limited to the first four years of the study. (There is separate data for daily calving censuses during June, which we have not used). Hind group similarity declined to its lowest level in October, followed by an increase through winter and spring. Stags had the highest similarity in August, declining to the lowest values in mid-winter. There was a highly significant interaction between sex, data quality, population phase and season on group similarity ($F_{24,730} = 116$, $P < 0.001$). Group similarities for core hinds and core stags were fairly stable throughout the year (between approx. 0.4 and 0.5), whereas those for fringe stags were generally low but increased considerably during the rut. Those for fringe hinds dipped rapidly from September to October and thereafter recovered gradually back to their high winter levels (approx. 0.6). There was no difference between years in group similarity. Having accounted for the 'static' effects of sex, data quality, phase and season, there was also a highly significant interaction between sex, data quality, phase, season and the distance moved since the previous location ($F_{24,inf} = 5.1$, $P < 0.001$). All significant distance effects were negative, indicating that similarity decreased with the distance moved (illustrated for core hinds and stags in each of the demographic phases in Figure 2a & b). For core hinds, the only significant relationship was during the rut, once the population had stabilised. In contrast for stags, similarity decreased significantly with distance moved during summer and during the rut, regardless of the phase of the population. Thus, we can conclude that, particularly for stags out with the winter period, the further a tagged animal has moved, the less likely are its regular associates to have moved with it.

Potential and limitations: This dataset has demonstrated that, particularly for stags during the summer and the rut, the further an individual moves, the less often it is observed with the animal it was last seen with. Movements of one individual stag are thus not representative of movements of the group. However, for hinds, the group similarity index did not decline with distance except during the rut, indicating that group composition is more fluid at this time. The data only represents movement of up to 3 km, which makes it more difficult to predict the group fidelity changes over the longer distances relevant to this project. The group sizes identified from this dataset are partly subjective, as they are based on the observer's interpretation of which deer were associating together at a particular moment. An improvement could be to try some other form of group similarity measure, e.g. based on identifying regular associates by hyperbolic mean separation distance during the year, rather than on group membership (see Albon et al., 1992). The similarity coefficient, as used, does not allow for gradual group fragmentation and coalescence over time. It might be improved by adding a second term (but down-weighted by time), based on the second order lag (i.e. on associates from two censuses previous to the current one). The analyses showed differences between core and fringe animals. Is this because fringe animals really behaved differently (e.g. because of the proximity of their regular ranges to lower density areas, and possible subjection to culling pressure out with the study area), or is it an artefact of their having been recorded less frequently? This could be checked out by sampling the "core" animals' sightings in a way that mirrored the "fringe" animals. The seasonal changes in association may be confounded with rutting behaviour. We did explicitly force "best pals" to be of the same sex as the focal animal, but most "best pals" were likely to be of the same sex, as association was determined over the course of a full year, rather than on a seasonal basis.

5.4. DEER COMMISSION FOR SCOTLAND COUNT DATA

Description: The data supplied by the Deer Commission for Scotland in GIS shape file format; one per year. These comprise census counts of Deer Management Group (DMG) areas (and in some cases, parts thereof) made in 1983 and 1987 and from 1989 to 2004. Counts of individual areas were periodic, and not all areas had repeat counts. ,.

Aims: To test for significant differences in the number of deer within counting blocks over time and for significant changes in the number of red deer in adjacent counting blocks, which may be indicative of large-scale redistribution of deer populations.

Analysis: These data needed a considerable degree of pre-processing, owing largely to inconsistent use of field names between years (and even the same name used for two different fields within individual shape files) and inconsistent count area (DMG) names and estate names between years. Data were transferred into an Access database, where they were combined together into a single table and the inconsistencies in area names rectified with reference to the spatial distribution of data, to ensure that a common name was assigned only when the spatial extent was similar.

Results: Nineteen count areas were regarded as having sufficiently spatially consistent counts in at least two years for population changes to be calculated, ranging over periods from one to twelve years. On the assumption of exponential population growth or decrease, no area had an annual total population (total of stags, hinds and calves) change of more than 7%, other than (a) a decrease of 39% in North Ross-shire between 2002 (DCS helicopter count) and 2003 (DMG foot count assisted by DCS), (b) a decrease of 22% p.a. in Strathtay between 1999 and 2001 (a relatively small area, possibly liable to regular fluctuations) and (c) an increase of 28% p.a. in North-west Sutherland between 2002 and 2004 (due to an increase of around 1000 hinds, but again a relatively small area, so perhaps not a true sub-population). The only cases where there was an increase and a decrease in neighbouring count areas, which could be suggestive of possible movements between DMG areas were (a) an increase of 1700 in South Perthshire from 1994 to 2000 against a decrease of 770 in Glenartney from 1993 to 2000 and (b) an increase of 250 in Morvern from 1994 to 2001 against a decrease of 200 in Ardnamurchan from 1997 to 2003, but the latter seems unlikely as the two areas are largely separated by Loch Sunart.

Potential and limitations: These data may yield more useful information on movements at the level of individual estates, but there was insufficient time available during this study to rationalise estate names in the database. More robust interpretation of this count data could be determined with the inclusion of cull returns at the same geographical scale. Differences may be entirely due to variation in management of static populations.

5.5. MAR LODGE COUNT AND CULL DATA

Description: Count and cull data from the National Trust for Scotland's Mar Lodge Estate were provided by Richard Luxmoore (1990-2002) and Shaila Rao (2002-2005). The data is in the form of annual counts from 5 areas on the estate. Cull data corresponding to these count areas is also available. A previous analysis has suggested that heavy culling pressure (24%) has failed to reduce deer numbers. The interpretation of this result is that either deer have moved in from neighbouring estates (although there is no evidence from the counts on neighbouring ground) or that earlier counts significantly underestimated the true extent of the deer population. However, foot counts do indicate that numbers of deer on the estate have been reducing, despite the actual numbers being underestimated. From 2003 onwards, differential culls have been taking place within the estate. In the northern area, culls are targeted at achieving 5 deer/km^2, compared to targets of 16 deer/km^2 in the southern area where traditional hunting activities are still carried out.

Aim: To test the prediction that counts in the northern area are not declining as fast as expected from the numbers culled because of an influx from the higher density southern population.

Analysis: Leslie matrix cohort analysis could be used to determine population size in each 'zone' corrected for numbers culled and compared to counts.

Results: Initial analyses have been reported elsewhere (Luxmoore 2003).

Potential and Limitations: Data from 1990 to 2002 could be regarded as baseline data to test for changes in deer densities resulting from the changes in target density objectives that have been in place since 2002. Such an analysis would benefit from a cohort-type approach, but this would require the aged animal cull data which we do not have access to.

5.6. MAR LODGE, INVERCAULD AND CAIRNGORM GPS DATA

Description: *(1) Mar Lodge*. The data supplied by the Macaulay Institute comprise locations of individual red deer stags (n=16) fitted with GPS collars at Mar Lodge over two periods, from April 1998 to February 1999 (n = 9) and from April 1999 to February 2000 (n = 7). Only 8 of the 16 stags were followed for at least 9 months, the remainder being followed for shorter periods due to collar failure, animals being out of range for downloading data or being shot. Fixes were taken at 4-hourly intervals during the first year and at 2-hourly intervals during the second year. Fixes were taken hourly on Sundays and Wednesdays in order to investigate effects of disturbance and on certain days fixes were taken at 15 minute intervals. There were periods of up to a few days when fixes were missed because the stag was in a location where insufficient satellite signals could be obtained. The data were provided in an Access database. Previous analysis had divided the data into five periods (May-June, July-August, September-October, November-January, February) which we retained for our analyses. *(2) Invercauld*. A similar dataset from Invercauld Estate comprised GPS fixes for 9 stags in 2003-2004 and 6 hinds in 2004. *(3) Cairngorm Reindeer*. A similar dataset comprised GPS fixes on 16 reindeer at Cairngorm between 1st June and 21st July 2004, taken at 10 minute intervals on Tuesdays and Wednesdays, and otherwise at 4 hour intervals.

Aim: To determine if range shift rather than seasonal habitat use can be detected in GPS collared individuals.Analysis: For each fix, we calculated the distance moved and the time since the previous fix and, from these, the average speed between fixes. We set binary fields to indicate whether the animal had moved more than 1km, 2km or 5km since the previous fix and a fix sequence number for each animal. These data were loaded into ArcGIS. An efficient method for viewing the data in ArcMap was to create a separate layer file for an individual deer and then colour the locations by month on a graduated scale (or, for longer runs of data, one could use year-season combinations). This took a few minutes manually per animal; possibly it could be automated for many animals. The probability of an individual movement being above a threshold distance was analysed by fitting a GLMM with deer as a random effect and a binomial error term. At the temporal scale of individual movements, those over 2km and 5km were too rare and under-dispersed for analysis. To overcome this, we used the last fix on each day to calculate daily net distances moved, and omitted any period greater than 48 hours. We conducted a similar analysis on the Cairngorm reindeer data with the exception that a 500m daily movement threshold was used rather than a 5km one.

Results: *Mar Lodge.* Visual inspection readily distinguished the non-returning movements made by stags A41 and A62 (they were both shot during October), the returning movements made by A42 and A51 and the more static patterns, e.g. D62. Individual movements of over 1km were more likely to have occurred: (a) if the recording period was over 12 hours; (b) in

Glen Dee and Glen Lui than in Luibeg (but subsequent visual inspection of the data indicates that the herds were by no means spatially distinct); and (c) by period in descending order April, Jul/Aug, Sep/Oct, May/Jun, Feb, Nov/Jan (Figure 3a), and there was no difference between the two years of the study. Omitting recording periods of more than two hours reduced the probability of moving over 1km by roughly a factor of 2, but did not alter the relative differences between periods (Figure 3b). Daily movements over 2km were most likely in Jul/Aug and Sep/Oct, and least likely in Nov/Jan (Figure 3c). There was a slight degree of under-dispersion for daily movements, but much less marked than for individual movements. Movements over 5km were still too under-dispersed and too rare for the GLMM to converge. Comparison of the individual and daily movements suggests that stags at Mar Lodge regularly made movements of over 1km within a few hours during the spring months, but these were generally within a relatively small "home" range, and did not tend to combine into daily net movements of 2km or more, whereas during the summer months leading up to the rut and during the rut itself, around a quarter of daily net movements were over 2km.

Invercauld. The data show that hinds do not range over a wide area and that distances moved between fixes is small. The data for stags show a similar pattern to that found at Mar Lodge.

Cairngorm. None of the reindeer made any substantial changes in their ranging behaviour during the monitoring period. Fewer than 5% of individual movements recorded were more than 500m, largely because of the high fix frequency employed. Daily movements of more than 1km were significantly more likely on Sundays and Mondays than during the rest of the week.

Potential and limitations: Writing analytical code to produce the information obtained by visual inspection of the spatial data would be complicated by irregular time periods (especially due to missing data) and the need to relate a number of successive movements to each other in order to distinguish long-distance movements from the 'non-directional' wanderings seen within the "home" range. GPS data are ideal for capturing long-distance unidirectional movements, as well as analysing more detailed behaviour patterns and habitat use. However, there remains the fundamental problem of scaling-up from the movement of individual animals equipped with GPS collars to the movement of entire populations of deer. Current prices of even the least expensive "store-on-board" GPS collars inevitably result in small sample sizes in research projects and are generally outwith the monitoring budgets of deer managers.

5.7 DEER COMMISSION FOR SCOTLAND CALF TAGGING DATA

Description: Calves were tagged shortly after birth in four sites over periods ranging from three to eight consecutive years, and the date and location recorded; subsequently, the locations and dates of shooting (and in a very few cases, of other mortality) were reported back to the DCS (Daniels and McClean, 2003). The data were provided in the form of Excel spreadsheets, one per site/year combination.

Aim: To utilise the re-sighting of individuals tagged as calves to estimate deer movement.

Analysis: The effects of site, year, sex and the interaction of sex with site on the probability of recovery were tested by fitting a generalised linear model with binomial error term. A similar model was used for the probability that a recovered animal had moved more than 5 km from its natal location.

Results: There were highly significant effects of site ($X^2_3 = 132$, $P < 0.001$), sex ($X^2_1 = 58$, $P < 0.001$) and their interaction term ($X^2_3 = 19.6$, $P < 0.001$) on the probability of recovery. Hinds were more likely to be recovered than stags at all sites except Strathconnon-Strathfarrar (where the sample size was substantially smaller). There were highly significant effects of site ($X^2_3 = 21.3$, $P < 0.001$) and sex ($X^2_1 = 31.7$, $P < 0.001$) on the probability of a recovered animal having moved more than 5 km, but there was no interaction between site and sex. Having allowed for site differences, 32% of stags moved more than 5km, but only 14% of hinds.

Potential and limitations: This individual level data does not provide information about population level movements. However, the data does indicate that distances between tagging and re-sighting vary with location of tagging, suggesting that the degree to which deer move is likely to vary across Scotland. This will be a function of a number of factors, one of which may be local deer density. However, we have not been able to analyse the data in relation to this, within the time constraints of the project.

5.8 ANALYSIS OF RUM ROUND ISLAND CENSUS DATA

Aim: To assess the suitability of this data set and census method to reveal movements between management blocks. In particular to test whether, since 1992 (post reduction cull), stags are migrating into Block 1 from other blocks (especially neighbouring Block 2). We also aim to identify when the stag count rises in Block 2 (excluding recruitment) and if there is a contemporary decrease elsewhere. A description of the reduction cull programme can be found in Coulson et al. (2004)

Methods: Data comprising locations of individual groups of deer (of the same sex/age) were supplied covering the period 1981 to 1999, and loaded into an Access database. Many grid references were corrupted by omission of the final digit (i.e. northing was given to 1000m precision instead of 100m); these were given a northing of the mid-point of the 1km square. An iterative procedure was used to identify records which were obvious spatial errors, and these were omitted from all analyses (unlikely to be demographically significant, as total counts omitted summed to 728 out of 150,000, i.e. less than 0.5%). Data on the route(s) walked on a given day and the census number were not supplied, and these were determined by visual inspection of the data using ArcMap. A total of five individual routes (counts) were assumed to be incomplete or otherwise in error, and the data rejected.

The census for a given block was deemed to be complete if all the routes covering the block had been walked during the particular census round. Counts were totalled for completed blocks at the level of year / census / block / class (sex) / age, together with the first and last dates contributing to the block totals, and these data were transferred to SAS for analysis. A census was deemed to be complete for the whole island if all five blocks had been counted, and the duration of the census (in days) was determined from the earliest first and the latest last dates of the five block censuses.

A linear mixed model was fitted to total island counts to test whether the total census (excluding calves) varied between seasons (spring / summer / autumn as defined in Clutton-Brock *et al.*, 2002) or with the length of time it took to complete the full census. Year was included as a random effect.

Results: <u>Preliminary inspection of the data</u> indicates that stag numbers have increased in blocks where culling pressure is less and that hind numbers in Block 1 have increased as the stag numbers have dropped. In the total count graph (Fig 1), Block 3 numbers appear stable after the cull but this seems to be because reduced hinds are compensated for by increased stags. In Block 1 numbers have increased post 1991 but this is because although stag numbers tend to decline, hind numbers have increased, probably due to recruitment (Coulson et al., 2004). Where hinds were culled heavily hind numbers remained low suggesting that numbers of hinds weren't replaced by immigration. This fits with the general understanding that hinds do not tend to make large movements and re-settle elsewhere. The total population in Block 3 may be higher than expected because stag numbers increase although the extent to which this is due to immigration from neighbouring areas is not well understood and is the subject of the analysis below. Where stags are culled (e.g. Block 1), it was difficult to keep numbers down. This is thought to be due to young stags moving in from surrounding areas (Clutton-Brock et al., 2002). The results below are aimed at detecting a drop in stag numbers mainly in block 2 but possibly in blocks 3 and 4 (Block 5 has too few deer to be informative) in order to support the interpretation that stag numbers have increased in Block 3 and not declined as expected in Block 1 due to immigration.

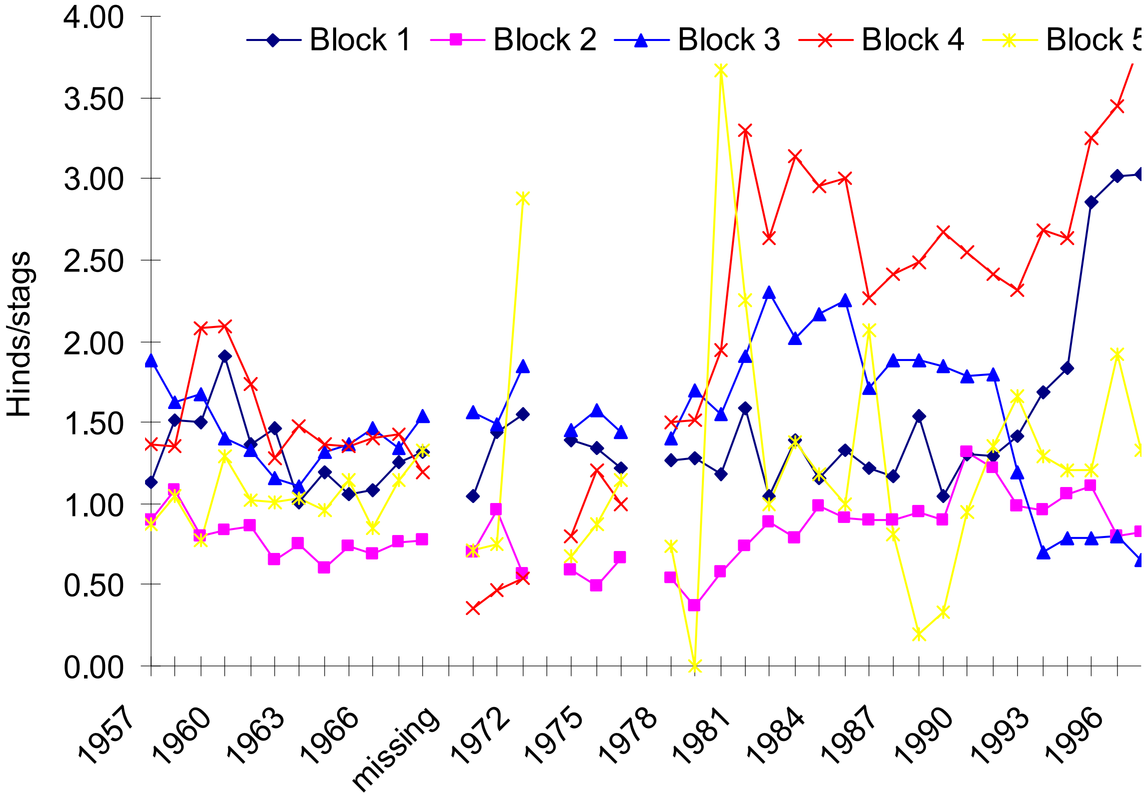

Figure 1. Total counts for each block displayed as a ratio of hinds to stags.

<u>Seasonal patterns in abundance.</u> The total island census varied roughly twofold from 1991 onwards (521 to 1116). There was a highly significant difference between seasons ($F_{2,115}$ = 29.8, P < 0.001), presumably reflecting the recruitment of the previous year's calves as yearlings in summer and the subsequent population reduction through culling. However, this seasonal effect reduced the within-year variance component by only 33%, implying that two-thirds of the variation within a year was not related to seasonal demography (although some of this could be due to within-season changes, particularly during the autumn cull). There was no relationship between census duration and total count in spring or summer, but an indication that the total census was inversely related to duration in autumn (by about 7 animals / census day; t_{126} = 1.96, P = 0.053).

Detecting the increase in stags in Block 3 and the decline in Block 1 above the noise in the data. A linear regression of stag numbers in block 3 from 1991 onwards against census date was highly significant ($F_{1,91} = 7.6$, $P < 0.01$, adj. $r^2 = 0.067$) and estimated an increase of 3.67 stags per year in the block. However, a better fit to the data was obtained by fitting an additional quadratic census date term ($F_{2,90} = 7.6$, $P < 0.001$, adj. $r^2 = 0.126$), which indicated an increase in numbers (most rapid at the start of the experimental cull) up to 1996 and thereafter the beginning of a decline. In Block 1, from 1991 onwards, there was a significant decrease in the stag count ($F_{1,91} = 12.0$, $P < 0.001$, adj. $r^2 = 0.107$), although it amounted to a loss of only 2.1 stags per year.

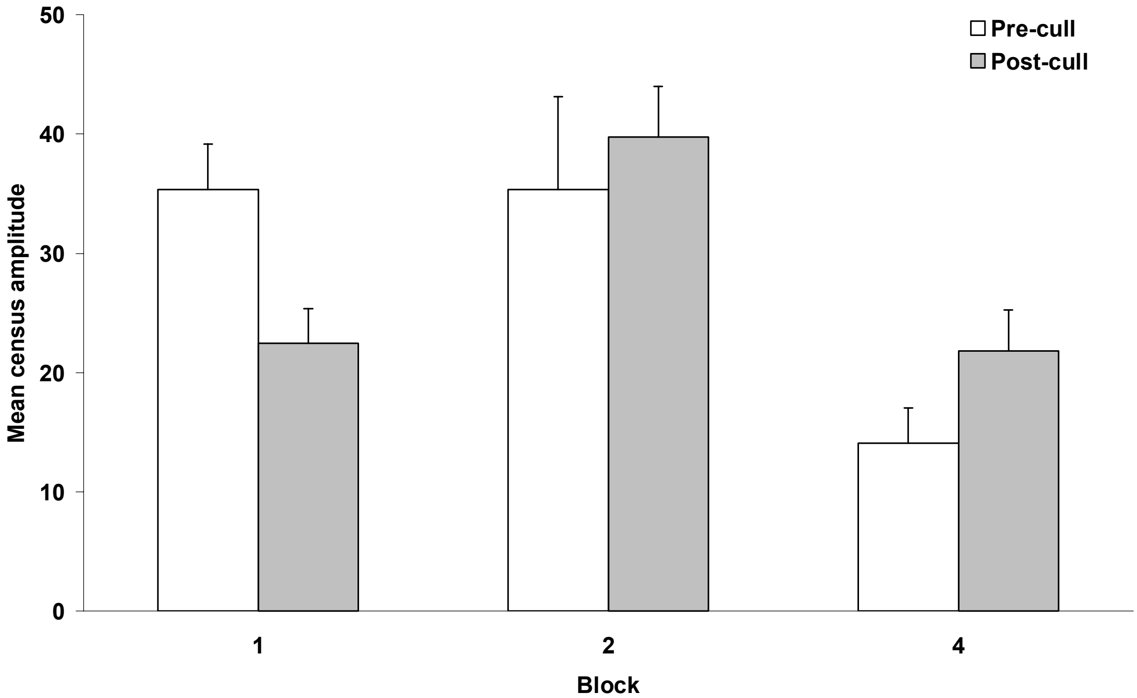

Figure 2.Tthe amplitude (difference between highest and lowest counts within a season). Open bars indicate the amplitude in the three seasons prior to the 1991-1992 cull and shaded bars indicate the amplitude in years subsequent to the cull.

Detecting a difference in the pre and post cull amplitude and variability of the counts (data from Blocks 1, 2 & 4). This analysis was conditional on a block having been counted at least three times within any season within any year to qualify for this analysis. *Amplitude* is the difference between the highest and lowest count within the season. There was a significant interaction between block and period (pre-1991 or post-1990) on the amplitude of the stag count ($F_{2,85} = 7.6$, $P < 0.001$; Fig 2). There was a significant decrease in amplitude in Block 1 (Tukey HSD test: $t_{68} = 3.1$, $P < 0.05$) but no change in either Block 2 or Block 4. Although there was also a highly significant seasonal effect ($F_{2,91} = 13.2$, $P < 0.001$), the amplitude in summer being significantly higher than in spring and autumn, there was no interaction of season with either period or block.

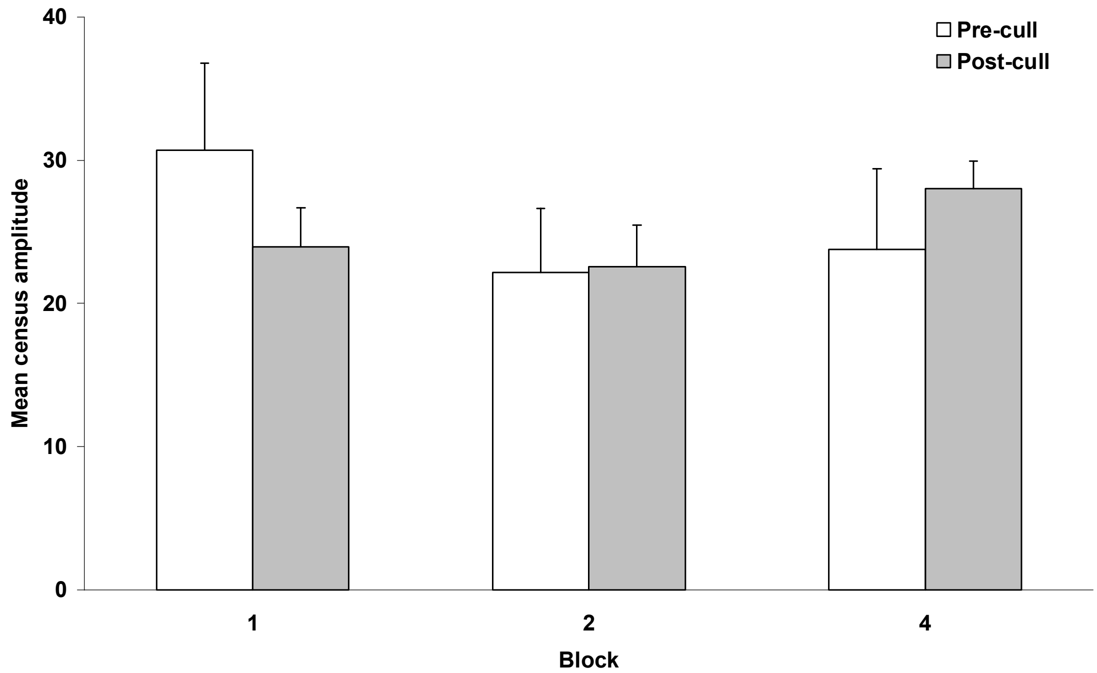

Figure 3. The coefficient of variation (CV) (difference between highest and lowest counts within a season). Open bars indicate the amplitude in the three seasons prior to the 1991-1992 cull and shaded bars indicate the amplitude in years subsequent to the cull.

Coefficient of variation. A similar, but less marked pattern was shown by the seasonal coefficient of variation ($F_{2,80} = 3.7$, $P < 0.05$; Fig. 3).

The change in amplitude of the stag count in block 1 would appear to be the result of the increased stag cull in that block rather than to any response to the hind cull in Block 3. There was no evidence from this analysis of a response by stags in either Block 2 or Block 4 which might have caused the increase in stags in the neighbouring Block 3.

Alternative approach. We used a subset of the data based on identifying which census or group of censuses give the highest counts within a year. If this is the same for each block then we can just use these data rather than all of the data. This approach is similar to the analysis in Coulson et al. (2004) but aims to determine which block is losing the bulk of the deer). The data can be smoothed to give a seasonal pattern in abundance in each block and look at how the peaks and troughs match up between blocks but this may not be informative because this assumes there is an annual cycle in abundance and we have no evidence for that. The expectation is that if stags move out (post reduction cull) then the seasonal peak in the population (relative to the baseline or trough population size) of that block will be lower than during years when young stags were not moving out (pre-reduction cull). The analysis based on this approach indicated that there is no obvious clear pattern for either stags or hinds on either a block/season or a block/census basis.

Conclusions

The count data are very noisy at the individual census level. Thus, although they can be used to detect long-term trends within blocks (Coulson et al., 2004; Clutton-Brock et al., 2002), they are not suitable for detecting short-term movements between blocks, either temporary or permanent. Although we were not able to detect from which block stags moved from to account for increases in stag numbers in Block 3, It is highly likely that where hinds are heavily culled stags will migrate into these areas although the extent to which these movements are permanent, seasonal or diurnal is not well understood (See analysis of Creagh Megaidh census data).

5.9. CALF TAGGING MODELLING STUDY

Rationale: The hypothesis of interest is that, if red deer density is reduced on one area (hereafter we will use the example of an estate within a DMG), deer will move in from surrounding areas where the density remains substantially higher. This is known as the vacuum effect. There are few examples where this has been demonstrated. The key evidence required if this is to be demonstrated comprises: (a) that the expected decline in numbers due to culling on the focal (sink) estate is not taking place, (b) that numbers on neighbouring (source) estates have correspondingly declined more rapidly than expected and (c) that individuals now resident on the sink estate were previously resident on one or more of its neighbours. It is proposed elsewhere in this report that issues (a) and (b) be addressed by conducting co-ordinated zonal counts on the sink and source estates. Here we consider under what conditions calf-tagging could be used to determine from which source estate(s) the immigrant animals have moved, by marking individuals on the source areas and detecting them in the sink area either during subsequent culls (using unobtrusive tags) or by recording them during zonal counts (using large, visible tags). We approach this by developing a computer simulation model to predict the probability of detecting, on the sink estate, marked animals from the source estates in numbers significantly greater than we would expect if there had been no reduction cull on the sink estate.

Simulation model: The individual-based simulation model was coded in SAS v. 9.1, and was based on three estates A, B and C, of which estate B constituted the sink area where the population was optionally subjected to a reduction cull. Under the default (control) scenario of a 15% maintenance cull on all estates, the estates started with populations of 1000, 1000 and 500 deer respectively. However, the area of C was half the size of A and B, in order to compare immigration from a smaller and a larger source estate, and thus the three estates had equal initial density (10 deer/km^2). For the purposes of this exercise, we are not concerned with the practicalities of marking, and so we assumed that marking had been carried out in previous years. We also assumed an equal sex ratio on all estates and an equal ratio of young and old animals. However, as the simulation was stochastic, the actual ratios of stags to hinds and of young to old varied slightly around the mean ratios. We did not include calves in the simulation, as it was assumed they would adopt the behaviour of their mothers. Although, in reality, all animals have the potential to move, in this exercise only young stags (regarded as 1-5 years old) were allowed to move from one estate to another. All animals were equally likely to be counted or culled.

The first stage of each simulation was setting up the initial populations, which were fixed on estates A and C. On estate B, the starting population was set at 1000 (regarded as the no-reduction control), 800, 600 or 400. The starting population was, in effect, the spring population, i.e. after either a standard maintenance cull or an increased reduction cull had taken place. Thus the three reduction culls on estate B represent 20%, 40% and 60% reductions over and above a standard maintenance cull. A specified proportion of young stags were given a tag identifying their natal estate. The proportion was the same on all estates, and was set at 10, 20, 30, 40 or 50%.

The second stage comprised allowing young stags to move independently away from their natal estate onto a neighbouring estate. The probability of movement was determined by a logistic function of the magnitude of the difference in density between the two estates. The intercept and slope parameters controlling the curve were set so that when there was no difference in densities the probability of movement was 5% (regarded as a reasonable 'background' movement rate). The probability of movement increased as the natal density increased relative to the neighbouring density up to a maximum probability of movement of 20%, at a difference of 10 deer/km^2 (the maximum difference possible in our system, if all animals on estate B were removed); if the natal density was lower than the neighbouring density (for animals potentially moving from the sink to a source) the probability declined towards zero (Fig. 4).

Following the redistribution of young stags, the final stage was to recover a proportion of the population on each estate and identify and count all tagged young stags recovered. Sighting during counts or removing a proportion of the population by culling constitute examples of the recovery process, albeit with substantially higher recovery rates from sighting. The culling option was fixed at a 15% maintenance cull on estates A and C. On estate B, the cull was either a 15% maintenance cull or an increased cull of 20, 30 or 40%, representing not only a further reduction cull of the population on estate B, but also an increased likelihood of detecting any immigrants present. The re-sighting recovery rates ranged from 70% to 100%.

In summary, we varied three inputs to the model: initial population on the sink estate B (control and three levels of reduction), proportion of young stags marked on each estate (five levels) and subsequent recovery rate on the sink estate (four cull levels and four re-sighting rates). Thus there were 160 possible combinations of inputs, each of which was replicated 500 times.

Data analysis: The critical factors of interest are as follows: (1) If we conduct a single 'trial' reduction of the population on the sink estate, how sure can we be that the number of tagged immigrant young stags we subsequently recover is more than the number we would have expected to recover had we not reduced the sink population? (2) How does our degree of certainty vary depending on the severity of the reduction cull, the proportion of stags we have marked and the recovery rate? (3) How does our degree of certainty vary according to the size of the potential source population (i.e. a comparison between immigrants from estates A and C)?

Thus we are not concerned with differences in the mean response over many trials, but on the power we have to detect more tagged immigrants that expected under the null hypothesis of no more immigration than the normal background level (which we set at 5% on average). That power is given by the proportion of stochastic trials in which we detect more than the background level of immigration. However, the background level of immigration is also variable, depending on the chance movement of individuals under conditions of equal density. For the purposes of this analysis, we used the 95th percentile of the background number of immigrants recovered as the expected number for a given combination of inputs, and determined the number of reduction trials in which it was exceeded. The predicted detection powers were validated by comparison with a similar population-level model coded in Genstat, which made random draws from binomial probability distributions rather than explicitly simulating the fate of each individual deer.

Results: For illustration, we present two comparisons of the distribution of the number of tagged stags culled, following a reduction cull, with the corresponding distribution after no reduction (Fig. 5). Under a scenario (a) with few young stags tagged on estate A and a standard post-movement maintenance cull on estate B, our expected number of culled tagged stags is one (the 95th percentile of the control distribution). Therefore we need to cull at least two tagged stags to be sure we are detecting a greater degree of immigration, and, following a 20% reduction cull, that rarely happens (only 16 times out of 500), and hence the power to detect a vacuum effect movement is very low. In contrast (b), if 40% of young stags were tagged and the post-movement cull on estate B was set at 40%, then our expected number of culled tagged stags is substantially higher, at five. Following a 60% reduction cull on estate B, we exceed that much more often (172 out of 500), and the power is much greater.

Although there are general trends of increasing power as the severity of the reduction cull increases, the recovery rate increases and the proportion of tagged young stags increases across the full range of inputs modelled (Table 1), there appear to be certain anomalies. For example, on the top line of part (a) for source estate A, the power increases from 3.2% to 9.6% as the tagging rate of young stags is increased from 10% to 20%, but then drops to only 3.0% as the tagging rate is increased further to 30%. This is counter-intuitive, as we would expect to have greater detection power as we increase our tagging effort. The decrease in power results from the fact that deer can only move as whole animals. Under 10% or 20% tagging, the upper 95% confidence limit for the number of tagged immigrant stags recovered under the null hypothesis is one, and, as we double our tagging effort, we increase our ability to detect more than one immigrant by a factor of three. However, if we tag 30% of young stags on estate A, then the upper 95% confidence limit for the number of marked animals recovered under the null hypothesis increases to two, and it becomes less likely to exceed this figure under the alternative hypothesis, despite there being half as many more tagged stags actually moving in on average.

Irrespective of these anomalies, it is clear that the power to detect a greater number of immigrant stags than expected remained low unless three conditions were met, namely the reduction cull was severe (60% in our case), a high proportion of potential immigrants was tagged and a high recovery rate was achieved on the sink estate. Even then, if recovery was by culling, the power to detect immigrants from the larger estate A generally lay in the range 25% to 50%, i.e. we were only likely to detect sufficient tagged immigrants in the first post-immigration cull to reject the null hypothesis with 95% confidence between one time in four and one time in two. For a limited reduction cull and low to moderate proportion of stags tagged, recovery by sighting was only marginally more powerful than recovery by culling, although relatively high power was attained by sighting recovery if the three critical conditions were met. The power to detect increased immigration from the smaller estate C was generally considerably lower than from estate A.

Discussion: In practice, an exercise such as that modelled here would require a major calf-catching effort. Depending on the numbers of animals on the estates chosen, it might be necessary to tag between about 50 (10% of calves) and 200 (40% of calves) animals per year across the three estates. Based on experience in Rum, 200 animals could take a team of 6 people as long as 10 weeks to catch. However, it is obviously not a particular problem to detect immigration by tagging calves on neighbouring estates, other than in terms of the logistics and costs involved. Clearly if a culled animal bears a tag indicating it was born elsewhere, it is either an itinerant or a permanent immigrant. The difficulty lies in determining with a reasonable degree of certainty whether the total number of tagged animals sighted or culled indicates anything more than a normal level of movement between populations on adjacent estates. There is no point in putting a large amount of resources into tagging calves, unless it is clear that significant movements can be detected. That is the reason for this modelling exercise

The statistical difficulty inherent in the type of count data we are dealing with is exacerbated by the paucity of information on what constitutes a 'normal' degree of movement between populations assumed to be at equilibrium with each other. In our simulation, we estimated the expected statistical distributions of the number of immigrant young stags from 500 simulations under the assumed equilibrium situation for different combinations of input values. Choosing the 95th percentile of each distribution gave us reference points which, if exceeded under non-equilibrium situations created by increased culling on an estate, would provide evidence of a vacuum effect. The statistical powers, estimated by exceedence rates of reference points from 500 simulations under non-equilibrium situations, in fact overestimate powers because the reference, equilibrium, situation must in reality be estimated rather than considered known. At best there might be some (say three years) base-line data from which to estimate the expected number of tagged immigrants under the null hypothesis, although movement in other directions (e.g. A to C, B to A, etc., not analysed here) could also be used to estimate background movement rates.

Although, at first sight, the results of this exercise appear somewhat discouraging, there are a number of issues to consider which might make the technique a more attractive proposition. For clarity, we allowed only young stags to move. Although they are the most likely migrants, evidence from Creag Meagaidh indicates that hinds may also move under certain conditions. The detection of only a small number of immigrant tagged hinds on the sink estate could be strong evidence of a vacuum effect movement, particularly if it could be shown that hind movements are very rare under equilibrium conditions.

The movement probability curve we used for young stags could be a considerable under-estimate of the extent of movement we might expect when a substantial disparity in density is induced. However, our simulation had the merit of applying exactly the same 'movement rule' regardless of whether a reduction cull had been conducted, which we might reasonably expect to be the case in reality. It would be prudent, if this modelling exercise were to be taken further, to conduct a sensitivity analysis of the parameters determining the movement function, and, if appropriate, to alter them.

Again, for clarity, we limited the detection of tagged immigrants to only a single recovery event following a single opportunity to move, which, in turn, followed a reduction cull applied as an instantaneous event. In reality, the reduction cull is likely to take place over a number of years, as will any vacuum effect movements and subsequent counts/culls on the sink estate. Thus there would be multiple opportunities to detect tagged immigrants and, moreover, to infer information from changes in the number of tagged animals recovered over time.

We varied only three inputs to the system. On the basis of the comparison between estates A and C, we may presume that if we had included a source estate with a larger population than on estate A, we would have had greater power to detect an increased level of immigration. We have limited analysis here to the recovery of tagged animals only. In reality, information from tagging would be more useful if considered in conjunction with regular zonal counts made on the sink and source estates. Provided counts were sufficiently accurate, they would provide information as to whether there had been any immigration, and the confidence level applied to tagging recoveries could be relaxed somewhat, thereby increasing the power to determine from which neighbouring estate(s) immigrants had come.

In conclusion, we have demonstrated that a relative simple model can be used to estimate how many red deer calves would have to be tagged on neighbouring estates in order to detect, with a specified level of confidence, a vacuum effect movement onto an estate where the density has been substantially reduced. The scope of the model has been necessarily limited under the terms of the present project, and it would be advisable to extend the model to operate over a period of several years before definite, detailed recommendations could be made. However, the model has served a useful purpose in showing that the proportion of animals tagged and the proportion recovered both need to be large if the technique is to be used to provide evidence of the occurrence of an increased level of immigration with a high degree of confidence.

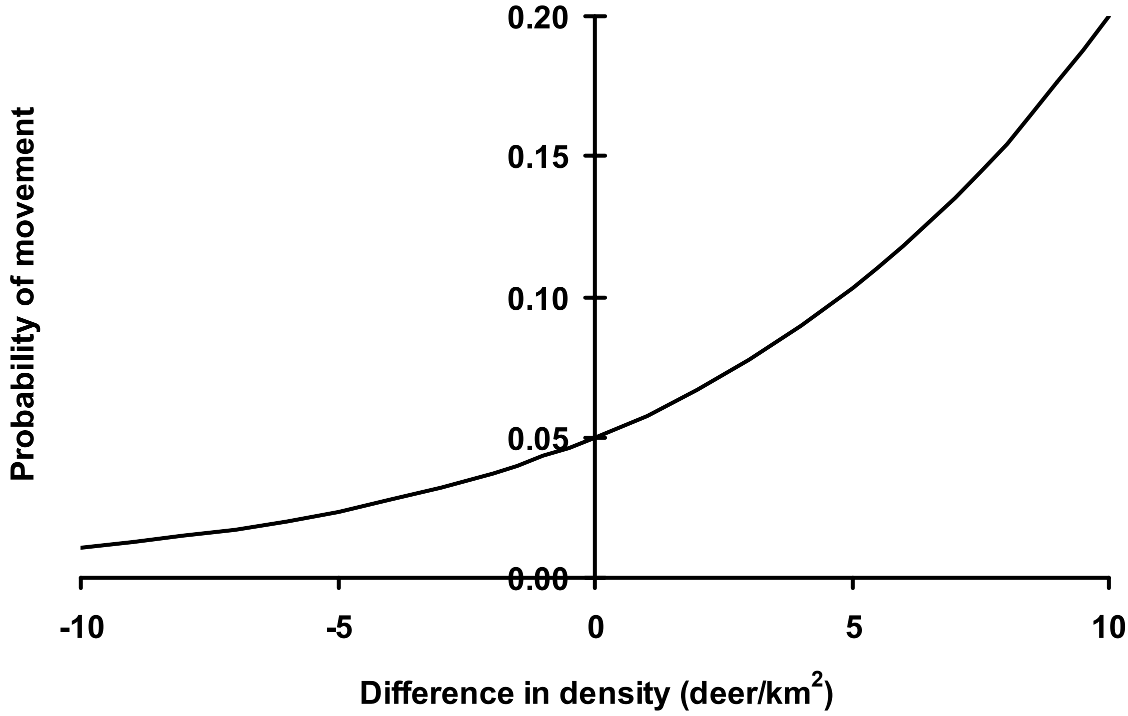

Figure 4. Modelled probability of a young stag moving from its natal estate to a neighbouring estate as a function of the difference in deer density between the two estates.

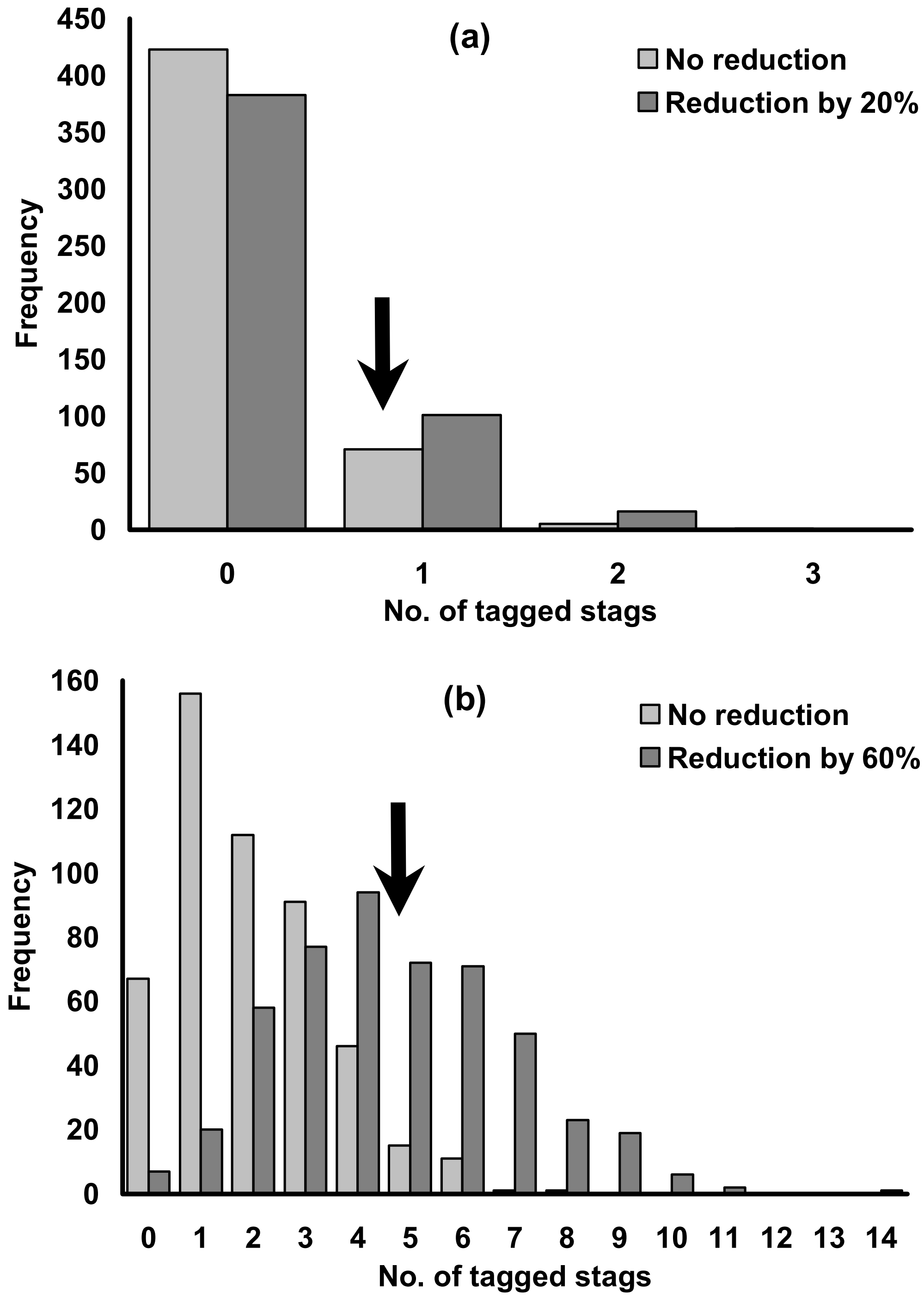

Figure 5. Comparison of the frequency distribution of the numbers of tagged immigrant young stags from source estate A culled on sink estate B: (a) with 10% of young stags tagged, either no reduction cull or a 20% reduction cull on estate B, and a subsequent standard 15% cull on estate B; and (b) with 40% of young stags tagged, either no reduction cull or a 60% reduction cull on estate B, and a subsequent 40% cull on estate B. The arrow indicates the location of the 95th percentile of the control (no reduction cull) distribution.

Table 1. Estimated power (as a proportion of replicate simulations) to detect a greater number of immigrant young stags on sink estate B than expected by chance from two neighbouring source estates (A having a population of 1000 deer and C having a population of 500 deer). Factors varied were: initial population size on estate B (following three levels of reduction cull); subsequent recovery rates on estate B; and percentages of tagged young stags on A and C. Numbers in parentheses under each power indicate the 95% point of the distribution of the number of recovered tagged stags under the null hypothesis of no vacuum effect movement.

(a) Recovery rates covering the range potentially achievable by culling animals fitted with unobtrusive tags

Initial Estate B population	**Recov-ery rate (%)**	**Estate A Young stags tagged (%)**					**Estate C Young stags tagged (%)**				
		10	**20**	**30**	**40**	**50**	**10**	**20**	**30**	**40**	**50**
800	**15**	0.032	0.096	0.030	0.072	0.032	0.010	0.028	0.048	0.008	0.022
		(1)	*(1)*	*(2)*	*(2)*	*(3)*	*(1)*	*(1)*	*(1)*	*(2)*	*(2)*
	20	0.060	0.028	0.072	0.038	0.080	0.010	0.054	0.006	0.020	0.044
		(1)	*(2)*	*(2)*	*(3)*	*(3)*	*(1)*	*(1)*	*(2)*	*(2)*	*(2)*
	30	0.016	0.086	0.078	0.046	0.092	0.022	0.004	0.022	0.052	0.034
		(2)	*(2)*	*(3)*	*(4)*	*(4)*	*(1)*	*(2)*	*(2)*	*(2)*	*(3)*
	40	0.036	0.052	0.054	0.054	0.116	0.032	0.022	0.072	0.042	0.070
		(2)	*(3)*	*(4)*	*(5)*	*(5)*	*(1)*	*(2)*	*(2)*	*(3)*	*(3)*
600	**15**	0.046	0.128	0.052	0.120	0.058	0.012	0.040	0.060	0.018	0.036
		(1)	*(1)*	*(2)*	*(2)*	*(3)*	*(1)*	*(1)*	*(1)*	*(2)*	*(2)*
	20	0.076	0.052	0.142	0.090	0.184	0.024	0.070	0.024	0.052	0.076
		(1)	*(2)*	*(2)*	*(3)*	*(3)*	*(1)*	*(1)*	*(2)*	*(2)*	*(2)*
	30	0.026	0.108	0.112	0.116	0.214	0.052	0.032	0.076	0.152	0.080
		(2)	*(2)*	*(3)*	*(4)*	*(4)*	*(1)*	*(2)*	*(2)*	*(2)*	*(3)*
	40	0.048	0.094	0.124	0.138	0.266	0.088	0.068	0.156	0.114	0.176
		(2)	*(3)*	*(4)*	*(5)*	*(5)*	*(1)*	*(2)*	*(2)*	*(3)*	*(3)*
400	**15**	0.058	0.202	0.114	0.220	0.142	0.024	0.082	0.164	0.048	0.098
		(1)	*(1)*	*(2)*	*(2)*	*(3)*	*(1)*	*(1)*	*(1)*	*(2)*	*(2)*
	20	0.106	0.106	0.246	0.210	0.334	0.038	0.120	0.040	0.098	0.184
		(1)	*(2)*	*(2)*	*(3)*	*(3)*	*(1)*	*(1)*	*(2)*	*(2)*	*(2)*
	30	0.042	0.250	0.268	0.268	0.432	0.076	0.068	0.140	0.254	0.186
		(2)	*(2)*	*(3)*	*(4)*	*(4)*	*(1)*	*(2)*	*(2)*	*(2)*	*(3)*
	40	0.114	0.212	0.278	0.344	0.532	0.140	0.118	0.264	0.216	0.344
		(2)	*(3)*	*(4)*	*(5)*	*(5)*	*(1)*	*(2)*	*(2)*	*(3)*	*(3)*

Table 1 (continued).

(b) Recovery rates covering the range potentially achievable by sighting during zonal counts animals fitted with large visible tags

Initial Estate B population	Recov-ery rate (%)	Estate A Young stags tagged (%)					Estate C Young stags tagged (%)				
		10	20	30	40	50	10	20	30	40	50
800	**70**	0.030	0.104	0.132	0.096	0.126	0.010	0.032	0.098	0.090	0.056
		(3)	*(4)*	*(5)*	*(7)*	*(8)*	*(2)*	*(3)*	*(3)*	*(4)*	*(5)*
	80	0.046	0.072	0.106	0.172	0.126	0.024	0.050	0.044	0.136	0.102
		(3)	*(5)*	*(6)*	*(7)*	*(9)*	*(2)*	*(3)*	*(4)*	*(4)*	*(5)*
	90	0.064	0.098	0.092	0.166	0.136	0.034	0.068	0.074	0.072	0.066
		(3)	*(5)*	*(7)*	*(8)*	*(10)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	100	0.090	0.138	0.142	0.150	0.142	0.050	0.096	0.112	0.118	0.116
		(3)	*(5)*	*(7)*	*(9)*	*(11)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
600	**70**	0.050	0.182	0.274	0.248	0.356	0.042	0.062	0.196	0.174	0.166
		(3)	*(4)*	*(5)*	*(7)*	*(8)*	*(2)*	*(3)*	*(3)*	*(4)*	*(5)*
	80	0.094	0.140	0.268	0.390	0.366	0.058	0.094	0.124	0.260	0.260
		(3)	*(5)*	*(6)*	*(7)*	*(9)*	*(2)*	*(3)*	*(4)*	*(4)*	*(5)*
	90	0.130	0.188	0.214	0.374	0.374	0.088	0.132	0.186	0.192	0.214
		(3)	*(5)*	*(7)*	*(8)*	*(10)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	100	0.178	0.284	0.336	0.380	0.402	0.112	0.180	0.228	0.248	0.274
		(3)	*(5)*	*(7)*	*(9)*	*(11)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
400	**70**	0.134	0.396	0.552	0.554	0.654	0.090	0.162	0.394	0.400	0.408
		(3)	*(4)*	*(5)*	*(7)*	*(8)*	*(2)*	*(3)*	*(3)*	*(4)*	*(5)*
	80	0.210	0.324	0.526	0.714	0.706	0.130	0.226	0.308	0.506	0.528
		(3)	*(5)*	*(6)*	*(7)*	*(9)*	*(2)*	*(3)*	*(4)*	*(4)*	*(5)*
	90	0.288	0.432	0.526	0.718	0.732	0.158	0.264	0.370	0.408	0.492
		(3)	*(5)*	*(7)*	*(8)*	*(10)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	100	0.350	0.542	0.658	0.728	0.784	0.202	0.340	0.450	0.524	0.582
		(3)	*(5)*	*(7)*	*(9)*	*(11)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*

6. CONCLUSIONS

Potential for identifying large-scale movements: This analysis and evaluation of data sets where red deer numbers and location have been recorded has provided some insights into the relative merits of the different protocols. If deer movements are to be monitored in the future than the following protocol may be the most likely to detect this:

- Deer should be counted in zones like those delineated in the Creag Meagaidh data set. Counts need to take place on zones on either side of boundaries at the same time and using the same protocols.
- It may be useful to mark animals (although GPS is not necessary) in the area from where animals are likely to migrate (source area) so that they may be detected in the sink area.

GPS technology can give very accurate and frequent locations for individuals and is useful for understanding habitat use. However, because of the insights relating to deer movement in Scotland that we have gained from our analyses of the available data sets, we conclude that GPS collars are of limited use unless a large proportion of the population can be fitted with them.

Data management: Red deer are wide-ranging animals and live in inhospitable terrain. Observing deer in a consistent and reliable way can be a labour-intensive task. In order to gain the best knowledge of their movements at landscape scales, it is important to glean information from whatever data resources are available and thus the management of those data resources is of great importance in the long-term to our knowledge of deer behaviour. We strongly recommend that, despite the financial constraints, data management be given an increased priority, both within and between (in the form of interchange of metadata) the various interested stakeholders. Given the expense that has been gone into the collection of the datasets we have analysed, it is imperative that their usefulness not be compromised by deficiencies in data management. Data management shortcomings have made analysis of the data more difficult and time consuming and potentially may have led to invalid conclusions being drawn, had inconsistencies and anomalies not been detected. We would stress, though, in the strongest possible terms, that these comments are not in the slightest way intended as criticisms of the individuals or organisation concerned, all of whom have been most helpful to us, and are duly acknowledged below. Rather, they reflect the fact that all organisations involved in research into, and management of, deer are operating under restricted budgets and under such constraints, data management cannot be made one of the highest priorities. However, good data management, including the provision of high quality metadata, requires substantial amounts of time, and therefore of financial resources. Some specific areas of concern regarding the data analysed for this project include:

- The format in which the data were made available. In some cases this necessitated a high degree of reformatting (complete data re-entry in one case) before they could be analysed.
- Frequently, there were little or no field-level metadata.
- Field methods need to be fully and carefully documented to ensure that data collected by substitute observers are consistent with those collected by the usual observers.

7. ACKNOWLEDGEMENTS

We are grateful to the following organisations and individuals who assisted with this analysis: NTS – James Fenton, Simon Frank, Shaila Rao, Richard Luxmoore; SNH – Richard Kilpatrick, Peter Duncan; Rum – Josephine Pemberton, Ian Stevenson; DCS – Mike Daniels; Macaulay Institute – Russell Hooper and Andrew Dalziel.

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ANNEX 2

REVIEW OF TECHNOLOGIES AND THEIR POTENTIAL FOR MONITORING RED DEER MOVEMENT IN SCOTLAND

Contents

1. INTRODUCTION

Methods for monitoring animal movements can be divided into three broad categories:

1. Traditional 'low tech' methods, such as counting of animals or dung deposits.
2. Methods employing rapidly developing 'high tech' technologies, such as satellite tracking collars.
3. What could be described as 'novel' methods, taking ideas from other fields of endeavour, such as warfare and forensic science. Examples of these are the use of remote sensing, seismic detectors and DNA 'finger-printing'.

The traditional low tech methods generally use low cost equipment, such as plastic ear tags or collars, or no equipment at all, but are expensive in terms of labour. They generally provide spatially imprecise and sometimes inaccurate data, but can provide information about the movements of large numbers of animals. Individual animals can be identified when ear tags or collars are used, but mostly they are not.

High tech methods currently use very expensive equipment, although labour costs are relatively low. They can provide data which is very precise and accurate, both spatially and temporally, but due to the high costs of the equipment they can realistically only provide information about the movements of small numbers of animals. These methods allow the movements of individual animals to be followed in great detail.

The so-called novel techniques are generally fairly imprecise, both spatially and temporally and generally do not distinguish between individuals. Some of these methods may be quite effective in showing population trends, but on the whole they are not able to provide information about actual movements of specific animals.

For this report, the various methods for monitoring animal movements have been evaluated for use with wild deer, using the set of criteria agreed at the Project Initiation Meeting on 15 June 2005 (see below). The concluding section includes a summary table, giving an indication of the strengths and weaknesses of each of the methods according to the main criteria.

2. CRITERIA FOR EVALUATING METHODOLOGIES FOR USE IN EVALUATING DEER MOVEMENT.

Spatial

- Accuracy in spatial location information (*e.g.* error associated with GPS fixes)
- Influence of topography, vegetation and other features on data quality
- Maximum distance over which method can monitor deer movements
- Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

Temporal

- Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)
- Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

Cost

- Collecting data, including materials and manpower and capturing animals where required.
- Analysing and interpreting data

Feasibility of monitoring sufficient animals

- Optimal number of deer to be monitored will be a function of herd size.
- Difficulties associated with capture and handling of wild animals, where required
- Difficulties associated with recapture of animals, where required
- Acceptability on ethical and welfare grounds

Timescale of data retrieval and processing

- Time delays built into the system
- Time required to collect, retrieve, analyse and interpret data.

Technical limitations

- Ability of technology to cope with Scottish weather.
- Reliability of technology/ failure rate.

Other

- Acceptability to landowners and land managers.
- Acceptability to other stakeholders such as hill walkers and conservation managers
- Ease with which the methods could be employed by non-scientists.

3. REVIEW OF METHODS

3.1. DIRECT COUNTS

There are a number of methods for directly counting animals, which include drive counts (Mitchell & McCowan 1981), static census (Mayle et al. 1999), vantage point counts (Ratcliffe 1987), aerial counts (White et al 1989), spotlight counts (Kie & Boroski 1995), thermal imaging counts (Red Deer Commission 1993) and mark-resighting (Clutton-Brock et al. 1982). The most widely applied of these methods in Scotland are open hill counts, which is effectively a form of vantage point counting. All the methods noted above have been tested on deer species in Scotland and have been previously reviewed by Mayle et al. (1999).

From the point of view of this review, the most useful methods are likely to be the open hill counts and mark-resighting, which could be used in conjunction with animals marked with satellite collars or other visible individual identification. This method is widely used in bird studies where resightings or recapture of ringed individuals provides information on small and large-scale bird movements. For example, this type of data has been used to investigate the effects of culling on winter site fidelity of cormorants (*Phalacrocorax carbo sinensis*) in Europe (Frederiksen et al. 2002).

Other parts of this review deal specifically with the use of thermal imagery and infrared technologies. However, for completeness all methods are discussed here, but where one method is clearly better at fulfilling individual criteria, this is noted in the text.

Technical Evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Because counts are done in known areas, map coordinates can be used to collect data on individual observations providing reasonable accuracy in location. But counts are influenced by seasonal changes in climate and deer behaviour. Precision cannot usually be determined, and is influenced by observer bias in misclassifying age and sex of individual animals, which is inherent in all direct counting methods.

In aerial counting, group size and vegetation cover are the primary factors affecting sightability, and correction factors are applied for each observed group of animals

(Samuel et al. 1987). In the United States, several wildlife agencies use aerial surveys for surveying elk (*Cervus elaphus*) populations and incorporate a visibility bias correction (Rabe et al. 2002) to adjust counts made from helicopters.

The use of digital photography in helicopter counts improved the ability to record all the deer in a group, especially for groups with more than 105 individuals, when compared to visual counts (Daniels, 2006). However, no comparison of classifying animals by sex or age was undertaken. In this example computer software was used to count animals on digital images but this may not be necessary if group sizes are not large. For example counts based on photographs of seabird colonies can be in excess of several thousand, but computer software was found to be slower than doing counts of projected images (Harris pers comm; Wanless, Murray & Harris 2005). Another advantage is that digital images can be re-counted and the totals checked if necessary.

Casual observations on marked animals would require both spatial and temporal data. Errors could occur if animals are colour marked, as colour blindness does affect a proportion of the potential observing population, whether estate staff or general public.

Influence of topography, vegetation and other features on data quality

All direct count and observational methods are influenced by topography, with the possible exception of aerial counts. Woodland also affects the accuracy of direct counts, and methods such as drive counts have been used with some success, but require a large number of people (Mitchell & McCowan 1981; Mayle et al. 1999). If counted frequently, the disturbance involved is likely to affect deer behaviour. Aerial counting is affected by vegetation cover with short vegetation, such as moorland, which is easier to search than woodland and dense forest (Samuel et al. 1987).

Maximum distance over which method can monitor deer movements

Counts are site-specific, and unlikely to provide information on movements of individual animals, but they do give estimates of changes in deer abundance. The exception to this is the mark-resight method, where it could be possible to sight individually marked animals over most, if not all, of Scotland, assuming that those people working in the countryside or members of the public would report sightings.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

These methods cannot be used to identify the start and end of individual movements of deer from one location to another but give information on the abundance of deer within delineated areas. If neighbouring areas had marked deer, then regular counting could determine when such animals were present at a location and for how long they remained there.

<u>**Temporal**</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Direct counts are done in real time and provide information only for the specific day of the count. Sightings of marked animals, whether from estate staff or the general public, would require information on location and date and time of the observation and a mechanism whereby sightings could be reported.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

Frequent counting would give data on changes in deer abundance, which, over time, could be used to infer change in the number or sex of animals in a particular area.

<u>**Cost**</u>

Collecting data, including materials and manpower and capturing animals where required.

Materials

Binoculars / telescope	£200-£1000
2 way radio	£150+
Digital camera	£200-£600

Manpower costs

The following costs are from three different study areas and are based on a minimum of three counts. In the case of the two aerial count methods (helicopter and infra-red) the full cost of hiring a helicopter is included in the mean prices given.

Study Site	***Mean time***	***Mean total cost***	***Mean cost per km^2***
Helicopter counts			
Syre	6 hours	£1105	£18

Croggan/Laggan	10 hours	£2072	£50
Rum	15 hours	£4826	£45
Ground counts			
Croggan/Laggan	60 hours	£2412	£58
Syre	84 hours	£2700	£43
Rum	178 hours	£3150	£29
Infrared counts			
Syre	3.5 hours	£2865	£45
Croggan/Laggan	6 hours	£3715	£90

(Source: Daniels, 2006)

Drive counts, although suitable for wooded areas, require from 60 to 120 people (Mayle et al. 1999). Based on the figure used by Daniels (2006) at £150 per person per day, drive counts could cost from £9000 to £18000, unless volunteers are available.

Similarly, static census counts require a lot of manpower, from 30-40 people (Mayle et al. 1999), and costs per day for this kind of count would be in the region of £4500 to £6000. Again, the use of volunteers would reduce costs.

Analysing and interpreting data

The cost of this is likely to be small in comparison to the costs of collecting data, as generally either deer density or total numbers are calculated. To estimate densities requires knowledge of the area counted, but usually this will already be well known or can be calculated from a map. Analysing digital images from aerial counting would be more time consuming than direct counts, but would improve accuracy in the numbers counted if not in the success of determining the sex and age of individual animals.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

The aim of most of these methods is to count all animals, within a previously defined area, on the same day.

Difficulties associated with capture and handling of wild animals, where required

With the exception of the mark-resighting method, direct counting does not involve the capture or handling of deer. Mark-resighting would generally require the capture of deer in order to add some individually recognisable identification. Researchers on the island of Rum were able to individually recognise a large proportion of animals without the aid of artificial markings (Clutton-brock et al. 1982). This was as a result of having time to become familiar with individual deer through visual observation and photography, and being able to share that knowledge with co-workers. Also the study animals became habituated to human presence allowing close proximity for identification. It is likely then that any large-scale attempt to identify individual deer would have to rely on some form of artificial marking.

Difficulties associated with recapture of animals, where required

No actual recapture of animals is required and, in the case of the mark-resighting method, 'recapture' of animals is visual.

Acceptability on ethical and welfare grounds

Generally, direct counting methods are acceptable on both ethical and welfare grounds. Possible exceptions to this would be drive counts where animals could be stressed. Aerial counts also run the risk of causing stress to animals.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

Data are collected on the day of counting, but in very large areas counts may take several days to process. The current frequency of most counts is too low to be used to judge movements between populations and would have to be increased and coordinated across several estates.

Time required to collect, retrieve, analyse and interpret data

Data can be collected relatively quickly, usually in a matter of days, depending on the size of area to be counted. Counts are usually made to estimate either densities of animals or total numbers and analysis is therefore straightforward and quick.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather

All direct counts are influenced by weather and delays in counting will add to the costs. Thermal imaging and infrared methods are dealt with elsewhere in this review, but are affected by severe weather conditions and, if used in aerial counting, would clearly have cost implications.

Reliability of technology/ failure rate

Direct counting/observation are low technology options, simply requiring good optical equipment such as telescopes and binoculars.

Other

Acceptability to landowners and land managers

Counts are widely undertaken in Scotland but aerial counts might be less acceptable to some individuals. An increased frequency in counting would require more time spent by staff in this activity and more expense.

Acceptability to other stakeholders

An increase in the frequency of counts could impact on hill walkers, if restriction on their movements was required for the purposes of counting. Low-flying aerial counts might also be less acceptable in some areas.

Ease with which the methods could be employed by non-scientists

Estates have used their staff for open hill counts and other types of ground counts. Aerial counts have been done on Mar Lodge and Letterewe estates, but they tend to be done mainly by staff from government agencies.

3.2. PELLET GROUP COUNTS

Estimating the abundance of mammals by counting faecal depositions has been undertaken for a wide variety of herbivorous and carnivorous species, including kangaroo, elephant, red fox, otter, as well as a variety of deer and other ungulate species.

Faecal pellet group counts are widely used for estimating deer abundance and there have been several methodological reviews undertaken (Neff 1968; Putman 1984; Buckland 1992; Doney 1998; Mayle et al. 1999; Campbell et al. 2004; Smart et al. 2004). There are two alternative methods. One method counts faecal accumulation between two points in time and the other counts the standing crop of pellet groups at a single point in time. These methods are known as faecal accumulation rate (FAR) and faecal standing crop (FSC) techniques.

In terms of monitoring movements at the landscape level, this is a low technology approach. Pellet group counts have been used widely in Scotland, especially in afforested areas (Campbell et al. 2004). It is possible to distinguish between individual deer species

(Welch et al. 1990), but it less useful when differentiating between the sexes within species, as factors other than body size can influence pellet size (Mitchell & McCowan 1982). Pellet group counts require either prior knowledge of, or an estimate of, defecation and decomposition rates (Mitchell & McCowan 1980; Mayle et al. 1999).

Technical Evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

The methods are often used to give estimates of deer density within a unit area and only provide spatial information at that level. There is a large coefficient of variation in pellet count data compared to other methods of estimating deer density (Daniels, 2006)??

Influence of topography, vegetation and other features on data quality

The technique requires an assumption, which may not be valid, that defecation will occur randomly over space and time. However, given that most areas are heterogeneous, because of differences in vegetation or topography, non-random use of a population's range is more likely to occur. To partially overcome this, pellet group counts require a stratified sampling approach to take account of different vegetation or woodland types.

Some vegetation types can be difficult to search and there is potential for missing groups. This is probably more serious if using the accumulation method, as there is a danger that missed groups may be counted at a later visit when searching is easier (Welch et al. 1990). The method also relies on knowledge of pellet decay rates, and these can vary significantly with weather and with habitat type.

Maximum distance over which method can monitor deer movements

In theory changes in deer abundance on neighbouring estates could be monitored simultaneously, though the technique has generally been used in forested areas, where direct counting of animals is difficult (Mayle et al. 1999; Campbell et al. 2004).

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

The method cannot be used to identify individual movements of deer from one location to another, but gives information on the abundance of deer within delineated areas.

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Pellet group counts are unsuitable for giving information on individual animals and therefore unable to show when an animal was present at a particular location, or for how long. The FAR method has been used to describe seasonal changes in forest habitat use (Welch et al. 1990;) so it is possible to collect data at this temporal scale. It is likely to be unreliable for shorter periods as the method is influenced by nil returns and requires time for pellet groups to accumulate (Campbell et al. 2004; Smart et al 2004).

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

It is not possible with this technique to follow individual animals. However long-term monitoring of population changes may be possible, though the method is thought to be poor at reliably detecting small changes in populations (Smart et al 2004). This study suggests, from simulation modelling, that it would take a 4 to 10 year time period to detect a 10% per annum increase or decrease in a population, depending on the method employed.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

There is little cost as regard equipment, though permanent markers are required for the FAR method. A GPS could give greater accuracy in locating or relocating plots but these units are relatively cheap (£100). In terms of manpower required the FSC technique is the cheapest method, requiring just one visit to plots. Mayle et al. (1999) suggest that two people working together could visit and check two or three 8-plot transects in a day (assuming 7 m x 7 m plots).

In a comparison of four different methods, Daniels (2006) estimated the mean labour costs per km^2 on three different study sites. Making infra-red counts from helicopters was the most expensive method at the two-study site at which it was undertaken. However, costs of the other three methods were quite variable, although on average helicopter counting was cheaper. At one of the three sites FAR dung counts were more expensive (£48 per km^2) than either ground or helicopter counts, but the costs were intermediate at the other two sites. The range of costs for dung counting at the three sites was £20 to £58 per km^2.

Analysing and interpreting data

Formulae for calculating deer densities from pellet group counts are easily available

(Mayle et al. 1999). There are standardised estimates for defecation and decomposition rates available, although local estimates are preferable (see note on previous page regarding variation with weather and habitat type).

<u>**Feasibility of monitoring sufficient animals**</u>

Optimal number of deer to be monitored will be a function of herd size.

This technique measures changes in local deer population densities. The two methods, FAR and FSC, appear to be more reliable at estimating higher deer densities (>10 km^{-2}).

Difficulties associated with capture and handling of wild animals, where required

This is an indirect method used for assessing changes in population density and is acceptable on both ethical and welfare grounds, as it does not require the capture or handling of any animals.

Difficulties associated with recapture of animals, where required

No animals require capture or recapture with this method.

Acceptability on ethical and welfare grounds

From the point view of animal welfare there are no obvious issues, however there are human health and safety issues with handling faecal material, if using the FAR plot clearance method.

<u>**Timescale of data retrieval and processing**</u>

Time delays built into the system

There is a time delay inherent in using the FAR method, which is generally recommended to be two to three months (Mayle et al 1999). This is to reduce the number of nil scores and is dependent on decomposition rates as well as numbers of deer present.

Time required to collect, retrieve, analyse and interpret data

Campbell et al. (2004) averaged out the time required to undertake FSC and FAR study counts in 10 commercial forests in Scotland, taking account of the time taken to design the study, including data entry and analysis, time spent travelling and time spent setting up plots and sampling time required. They report an average of 80 minutes (range 64-91 minutes) per plot using the FSC method and 140 minutes (range 114-167 minutes) per plot using the FAR method. The areas sampled ranged from 1482 ha (50 plots) to 9669 ha (100 plots). This suggests that on average the FAR method in the smallest study area took 16 person-days whereas the larger study was completed in 32 person-days.

Technical limitations

Ability of technology to cope with Scottish weather

Although there is no technology as such, the method is influenced by the weather, which affects decomposition rates of pellet groups (Neff 1968). If using the accumulation method it is therefore important to get local estimates of decomposition rates (Welch et al. 1990; Mayle et al. 1999). Many pellet group counts are undertaken over winter and spring when the Scottish weather could influence deer movements, or could delay counts.

Reliability of technology/ failure rate

Because there is no technology as such, there is nothing intrinsically to go wrong in regard to reliability or ability to cope with Scottish conditions. However, the precision of these methods appears to improve with increasing survey effort and deer population density, and accuracy also improves with increased deer population density (Smart et al. 2004). The methods require knowledge of defecation rates and decomposition. Pellet groups can be missed, which can easily occur in tall dense vegetation and can affect counts during summer months (Welch et al. 1990). In areas where other large herbivores share the ground, problems may arise with potential misidentification of pellet groups.

Other

Acceptability to landowners and land managers

If using the FAR method, permanent plots or transects would need to be set up. Using either method, counts could be done by local staff rather than by outsiders who would require permissions etc.

Acceptability to other stakeholders such as hill walkers

The FSC method requires no permanent marking of animals or plots and should be acceptable to stakeholders in that respect. The FAR method requires permanent plot markers but these could be relatively inconspicuous and location could be aided by using GPS technology.

Ease with which the methods could be employed by non-scientists

The method is relatively simple and requires some training and clear definitions. In Scotland pellet group counts have already been undertaken as a management tool. Counts have been made by forest rangers as well as by a private company. The method has also been employed by the Royal Society for the Protection of Birds at Abernethy forest to monitor deer densities in relation to tree regeneration.

3.3. BASIC COLOUR MARKING (e.g. PAINTBALL)

Paintball is a team game where a player uses a marker 'gun' to fire pellets containing water-soluble paint to mark an opponent. Oil-alkyde paint has been developed to mark caribou and elk (Mahoney, 1998; Skalski, 2005). Individuals or herds could be marked with a characteristic colour and then the public and other hill users could be asked to send in records. It would also be wise to use trained observers to attempt to locate marked animals at regular intervals, using the public records to supplement this more reliable data.

For paintball marking, a permanent colour marker could be used in the paintball pellets and the paintball marker gun could be used to apply this to the animals, utilising the skills of the stalkers (Cashmore, pers. comm.). Individual herds and/or estates could have separate colours and/or mark positions.

Technical Evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

These methods would need to rely on sightings being recorded by a range of observers, not all being project employees, so it is likely there would be some observer error involved. This error would be difficult to quantify.

Influence of topography, vegetation and other features on data quality

Some error (misreading/wrong colour etc) could occur due to the distance of the observer from an animal and marks could be obscured by vegetation.

Maximum distance over which method can monitor deer movements

If all colours are unique to an animal or to a herd/estate, then movements over any distance could be monitored.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

If an animal was individually identifiable then it could be tracked anywhere, as long as was observed. However there are unlikely to be very accurate timings for the start and end, only the ability to say that an animal had moved from one point to other, via some other points.

<u>Temporal</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Observers should be able to give an accurate time at which a deer was observed.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

This would depend on the durability of the marking used.,Paintball colouring would have to be tested before use, to identify the best colour and material (eg Picric dye, hair dye/bleach? paint?). However, the maximum period would be set by seasonal coat changes, being November to May/June for animals in winter and May/June to November for animals in summer coat.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

Paintballing would mean no captures were necessary. Marker guns cost approx £450 plus the cost of the pellets required, so a few guns could be bought to hand out to marksmen. If possible, it might be helpful to renew the marks over time, providing there was enough colour left to identify the animals.

Analysing and interpreting data

Would depend on sighting recoveries, could do basic point-to-point track analysis.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

It should be possible to monitor a lot of animals, if they could be marked, and the more animals that could be marked the better, as this would give a better chance of sightings.

Difficulties associated with capture and handling of wild animals, where required

NA

Difficulties associated with recapture of animals, where required

NA, but might need to remark animals over time.

Acceptability on ethical and welfare grounds

Any marker dye used for paintballing would need to be tested, to check that it was not harmful to the skin or other tissues, but stalking in order to apply the marker would be unlikely to disturb the animals.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

Will be delayed by the time to mark enough animals and to record sufficient sightings, but should provide a regular input of data in the long term.

Time required to collect, retrieve, analyse and interpret data.

This will be largely determined by the time taken to collect and collate the data. Analysis should be straight forward once the data is collected.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather.

Will be dependent on the weather for the ease of observing marked deer, but many gamekeepers will be out in most weathers. Potential permanent marker dyes would need to be tested for durability in different weather conditions.

Reliability of technology/ failure rate.

Reliable in itself, but may be prone to difficulties as a method for marking deer (e.g. moulting, effects of weather on paint durability, rubbing against trees, etc).

<u>Other</u>

Acceptability to landowners and land managers.

There might be aesthetic problems to do with marking wild animals with permanent colours, but hopefully these can be overcome.

Acceptability to other stakeholders

As above, hopefully any aesthetic problems of marking wild animals with permanent colours can be overcome with an appropriate explanation of the reasons for doing it.

Ease with which the methods could be employed by non-scientists.

Should be very easy to use for non-scientists, as it just requires the ability to shoot straight, and access to the equipment should not be a problem. The method relies on non-scientists for recoveries/sightings.

3.4. TAGGING and FREEZE-BRANDING

Tagging and freeze-branding would allow calves, which are relatively easy to handle, to be marked semi-permanently or permanently. Both procedures require capture and therefore a Home Office Licence. Ear tagging is a standard animal husbandry technique, but, like freeze branding, will involve a certain amount of stress in the case of wild animals, due to the requirement for the animal to be caught and restrained. Ear tags are fitted using a specialized hole-punch, which inserts the tag in one simple action. If tags are administered by an experienced person, the process is very quick. Freeze-branding marks are painlessly and easily applied by using liquid nitrogen to freeze the branding iron and only the hair follicle is damaged, making the hair grow in white, as opposed to hot iron branding which damages the skin (Farmkey, 2005; Whittier, 2005). Different brand marks could be applied for different herds and/or by different estates. Similarly, different coloured tags could be applied for different herds and/or by different estates.

Technical Evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

These methods would need to rely on sightings being recorded by a range of observers, not all being project employees, so it is likely there would be some observer error involved. This error would be difficult to quantify.

Influence of topography, vegetation and other features on data quality

Some error (misreading/wrong colour of tag etc) could occur due to the distance of the observer from an animal and marks could be obscured by vegetation.

Maximum distance over which method can monitor deer movements

If all tags or brand marks are unique to an animal or to a herd/estate, then movements over any distance could be monitored.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

If an animal was individually identifiable then it could be tracked anywhere, as long as was observed. However there are unlikely to be very accurate timings for the start and end, only the ability to say that an animal had moved from one point to other, via some other points.

Temporal

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Observers should be able to give an accurate time at which a deer was observed.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

This would depend on the durability in the case of tags. Branding should be permanent.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

Tagging and branding require capture, but calves could be caught relatively easily. For freeze-branding, irons would need to be made and dry ice and suitable carrying vessels would need to be purchased.

Analysing and interpreting data

Would depend on sighting recoveries, could do basic point-to-point track analysis.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

It should be possible to monitor a lot of animals, if they could be tagged or freeze-marked, and the more animals that could be marked the better, as this would give a better chance of sightings.

Difficulties associated with capture and handling of wild animals, where required

Tagging and branding require capture, but the method could be limited to calves.

Difficulties associated with recapture of animals, where required

Animals might need to be recaptured to replace tags, but branding should last for life.

Acceptability on ethical and welfare grounds

Tagging is a standard husbandry procedure, but capture of wild animals requires a Home Office Licence under A(SP)A 1986. Freeze branding is used routinely on domestic cattle and horses, however it would require a Home Office Licence if carried out on wild animals for scientific purposes.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

Will be delayed by the time to tag or mark enough animals and to record sufficient sightings, but should provide a regular input of data in the long term.

Time required to collect, retrieve, analyse and interpret data.

This will be largely determined by the time taken to collect and collate the data. Analysis should be straight forward once the data is collected.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather.

Will be dependent on the weather only for the ease of observing tagged or marked deer. Many gamekeepers will be out in most weathers.

Reliability of technology/ failure rate.

A small proportion of tags are likely to be lost in any system, but may be more vulnerable on wild deer, due to rubbing on trees for example. Freeze-branding is very reliable.

<u>Other</u>

Acceptability to landowners and land managers.

There might be aesthetic problems and perceived welfare problems, in relation to tagging and branding wild animals, but hopefully these can be overcome.

Acceptability to other stakeholders

As above, hopefully any aesthetic and perceived welfare problems of tagging and branding wild animals can be overcome with an appropriate explanation of the reasons for doing it.

Ease with which the methods could be employed by non-scientists.

Should be equally easy to use for non-scientists and scientists.

3.5. RADIO-TRACKING

This method has been widely used for studying insect, fish, mammal and bird movements in many different habitats. There are several reviews of the technology, the use of the methodology and the analysis of data (Kenward 1987, 2001; White & Garrot 1990; Priede & Swift 1992).

Radio tracking has been used on deer species to study many factors including home range estimation (Georgii 1980, 1983; Hinge 1986) migration and dispersal (Kilgo et al. 1996) habitat use (Catt & Staines 1987; Langbein 1997) and the effects of human disturbance (Jeppesen 1987a, 1987b). In relation to the capture and handling of wild deer there is excellent guidance provided by Rudge (1983). This is a Nature Conservancy Council publication that draws on the knowledge of a wide variety of expert opinion on all aspects of handing and capturing deer.

Technical Evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Animal locations are usually obtained using triangulation of bearings from known fixed points and there is often an error associated with this (Saltz 1994). Ideally, three bearings are required to detect erroneous bearings and potentially erroneous location estimates (White & Garrot 1990). In one Scottish study, the mean error of bearings in test fixes was 5.8º and mean locational error was 113 m (Catt & Staines 1987). However, accuracy was correlated with working distance from the transmitter and the mean quoted is for a distance of 1100 m. Much greater accuracy was achieved when the distance between the transmitter and receiver was less than 400 m. A 100 m error in location at the landscape scale is likely to be accurate enough for locating animals and showing large-scale movements. An alternative approach is to home in on the radio signal, thereby getting a visual contact with the marked animal (Kenward 2001).

Influence of topography, vegetation and other features on data quality

Radio waves are subject to reflection, refraction, diffraction, interference and polarisation (Kenward 1987). They are affected by topography and reflected or ‘bounced’ signals are common in rugged terrain. However, it is possible to evaluate this in field-testing and, by analysing the data in a Geographic Information System (GIS), locate the optimal locations for taking bearings (White & Garrot 1990). However, the precision will not be as good as for an area with no reflected signals. Ground vegetation can also affect signal intensity due to absorption and trees can be a source of reflection for radio waves.

Maximum distance over which method can monitor deer movements

There is probably no limit to the distance over which animals can be followed but this does depend on being able to get physically close enough to the transmitter to receive a signal. It is possible to track animals on foot or from specially adapted vehicles (Catt & Staines 1987). It is also possible to track from the air, and both helicopters and fixed-wing aircraft have been fitted with radio receiving equipment and used in wildlife studies in this country (Kenward 1987).

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to

As the method relies on the use of map coordinates as data points, it is possible to show large movements of individual animals.

<u>Temporal</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

This method gives real-time location of individuals.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

For any electronic device, the lifetime of batteries is likely to be the major limitation on how long a transmitter can operate. There are different types of battery, with the best lithium cells having a storage life of 10 years compared to about 14 years for silver-oxide cells, though the latter are not built in large sizes and it is more usual for the former to be used in tags of more than 4 g weight (Kenward 2001). An advantage of radio tracking is that animals can be located at different time frequencies, ranging from minutes to weeks or months and, if a microcontroller is fitted to the unit, the batteries can be switched on and off to increase battery life. However, this option may not be desirable if animals are moving far from their last known location.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

The receiving equipment

– up to 50 tags US$560

– up to 100 tags US$800 plus

Radio tags £170 + vat each

Receiving antennas Yagi £60

Receiving distance 4-6 km

Battery life 5-6 years

Analysing and interpreting data

A geographic information system (GIS) would be a useful tool from the point of view of analysing data. Graphic presentation requires that three-dimensional data (*x y* and *t*) be collapsed into two dimensions, although animation can be use to present the time dimension. However, it is just as straightforward to plot coordinates onto a map and follow movements through time.

<u>**Feasibility of monitoring sufficient animals**</u>

Optimal number of deer to be monitored will be a function of herd size.

The most likely limiting factor will be the number of animals that can be captured. There will also be a limit to the number of radio frequency channels that can be used.

Difficulties associated with capture and handling of wild animals, where required

This method requires live capture, whether by darting or capture in nets or other methods, and handling of deer. Darting will require a Home Office Licence under A(SP)A 1986. Darting is easiest when animals are habituated to the close proximity of people, for example at sites where animals are given winter feed. Experience shows that other animals do not react to the rifle being fired but do so once the drug starts taking affect, when the darted animal starts to show unusual behaviour. Once the darted animal has been collared and recovered, other deer soon return to the feeding site, so allowing several animals to be darted in a session. Generally winter-feeding attracts stags more than hinds and there is therefore potential for a sex bias in this type of darting exercise. As tranquiliser rifles are only effective up to 50 m, experience shows that the use of such weapons does not come naturally to professional stalkers, who are used to high precision weapons and shooting from a greater distance. Therefore training and familiarity with the darting system is essential for safe working practice. This also includes the choice of drug. Some drugs have a quick knock down time, such as ‘large animal immobilon’ but are dangerous to handle and require a loaded syringe of the human antidote in case of accidents. Others are safe for humans but take longer to knock down animals, running the risk of losing the animal if it runs off, and putting it at risk if not found quickly.

Deer in forests, have been captured live by driving animals into nets (Catt & Staines 1987; Hinge 1986), however this requires a lot of manpower as several kilometres of netting are usually needed to enclose a big enough undisturbed area. Such deer drives need to be well planned and coordinated and those involved need to be well briefed. There are several issues with netting, which include animal stress whilst being driven, either by beaters or trained dogs, and during capture, as well as human safety (Rudge 1983).

An alternative method is to use self-attaching expandable collars. These are effectively snares, but weakened so that once the collar is on and the animal meets resistance, the cord attached to the toggle, that locks the collar, breaks. These are probably best used along deer trails in wooded areas, and have been successfully employed in at least one study in Scotland (Hinge 1986). Once set out, collars need to be checked regularly, but can remain in place indefinitely, as modern transmitters have microcontrollers that can be used to stop and start transmissions when required, which saves battery use (Kenward 2001).

Difficulties associated with recapture of animals, where required

The method does not necessarily require the recapture of animals, as collars could be left on for life if expandable or fitted properly, or a device can be used that allows the radio and collar to drop off and to be recovered if necessary. However, all the problems of capture will hold true for recapture.

Acceptability on ethical and welfare grounds

There are clear guidelines for the capture and handling of wild deer (Jones 1984).

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

Data collection is in real time so there are no time delays. However, this is dependent on prior knowledge of animal location and if an animal has moved several kilometres then time is required to relocate. For example, in a radio tracking study at Glenbranter Forest in Argyll young stags dispersed 15 km on average (Catt & Staines 1987). Initially it took several man-days to relocate animals that had moved from their original range, but the area was used regularly for military exercises and it was possible to use a military helicopter to search for and relocate "missing" animals from the air, reducing the time spent searching to less than an hour (pers obs). If several neighbouring estates were collaborating, the location of animals would be easier.

Time required to collect, retrieve, analyse and interpret data

Radio transmitters need to be tested to determine errors in locating the transmitter. The frequency of locating animals could vary widely from daily, weekly to monthly. At times when animals are more mobile, for example during the rut or early summer when hinds may force their previous young to leave, more frequent locating of individuals may be necessary than at other times of years, when animals range less. Individual locations, or sequences of locations, can be displayed on a map or on a GIS almost instantly.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather

Radio signals are not influenced by the weather and receiving equipment is generally robust. Extreme weather, such as heavy snowfall, can make tracking difficult but, if necessary, radio tracking can be carried out using cross-country skis and a hand-held receiver and aerial.

Reliability of technology/ failure rate.

The technology has been around for some time and transmitters are generally reliable. For greater accuracy it may be necessary to be within 400 m of animals, but errors involved in location are not too large even at 1800 m from the transmitter. One possible reliability problem is 'frequency shift'

<u>Other</u>

Acceptability to landowners and land managers

Agreement would be necessary for the live capture and marking of animals, but radio-tracking could be done by local stalkers or forest rangers on an ad hoc basis.

Acceptability to other stakeholders

It is unusual for the general public to see marked animals and for some there would clearly be a novelty value, although for others it might not be acceptable.

Ease with which the methods could be employed by non-scientists

Radio tracking equipment is widely available to non-scientists and is used in ferreting, for example.

3.6. GLOBAL POSITIONING SYSTEM (GPS) TRACKING

The commercial development of Global Positioning System (GPS) technology for tracking animals started as long ago as 1991, but GPS telemetry is still a rapidly developing research tool (Hulbert, 2001; Fielitz, 2003). GPS receivers currently use signals from an array of 24 satellites, operated by the US military, to obtain fixes by triangulation. In 2008, a new European satellite navigation system (Galileo) will be launched, providing a highly accurate, guaranteed global positioning service under civilian control, which will be fully compatible with GPS.

GPS receivers are built into collars, which are fitted to animals for a designated period of time. Live capture is necessary for fitting the collars initially. Data can be stored in the collar or transmitted to earth via a satellite link. Data stored in the collar is downloaded onto a computer, either remotely via a UHF radio link, at regular intervals via the GSM mobile telephone network, or directly from the collar after removal from the animal. The more sophisticated units allow two-way communication, for the purposes of rescheduling of fixes or data download while the collars are out in the field. Collars are retrieved by live capture, or using an automatic release mechanism, which can be operated by a pre-set timer or remotely by a radio signal.

The first prototype GPS collars were tested on wild caribou (*Rangifer tarandus*) in Canada in 1993 (Rodgers, 2001) and the first research application was in habitat-utilisation studies with moose, also in Canada (Rodgers et al, 1995,1996,1997). Since then, GPS collars have been widely used for studies of habitat utilisation with large herbivores such as moose (Dettki et al, 2003, Dussault et al, 2004, 2005), red deer (Rumble et al, 2001; Adrados et al, 2003), reindeer/caribou (Kumpala et al, 2001; Rohner & Szkorupa, 1999) and goats (Poole & Heard, 2003). GPS collars have also been used for studies of grazing behaviour with cattle (Agouridis et al, 2004; Bailey, 2005; Schlecht et al, 2004) and sheep (Hulbert, 1998), and movement and distribution patterns with deer (Morales et al, 2004, Nelson, 2005), elephants (Blake et al, 2001; Cushman et al, 2005; Verlinden, 1998), gazelle (Miura et al, 2004) and wild dogs (Mills & Gorman, 1997).

Another application of GPS tracking has been to look at the effects of disturbance on wild animals, for example disturbance to deer from industrial development (Campbell et al, 2004), human recreation (Sibbald et al, 2001) and predation by wolves (Zimmerman et al, 2001; Fortin et al, 2005). GPS collars have been used to estimate cougar predation rates, by surveying prey remains in areas where location clusters were recorded (Anderson & Lindzey, 2003) and have been also been successfully tested on wild boar

(Baubey et al, 2004), grizzly bears (Gau et al, 2004), lynx (Palomares et al, 2000) and giant anteaters (Medri & Mourao, 2005).

As the technology has improved, a wider range of applications has been made possible. With the increasing miniaturisation of GPS units and batteries, satellite technology has become suitable for tracking birds and has been used to monitor the flight paths of homing pigeons (von Hünerbein, 2001) and migrating cranes (Minton et al, 2003), and as a consequence of the development of GSM facilities for rapid download of data, GPS has recently been used to monitor the training and performance of sports horses (Hebenbrock et al, 2005).

The great strength of GPS telemetry as a tool for studying animal movement is that large amounts of detailed and accurate positional data can be collected with relatively small labour costs, but the technology is very expensive and, in most studies, data can only be collected for a small number of individuals. In the future, it is almost certain that GPS collars will be become smaller and lighter, will have increasingly large data storage capacity and much better facilities for data retrieval (Hulbert, 2001; Fielitz, 2003). However, it is harder to predict whether costs will go down far enough to make them suitable for large-scale wildlife studies.

Technical Evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

A trade-off has to be made between accuracy and power constraints. Collar manufacturers tend not to give details about the accuracy of their products on their websites, since it can vary. Basically, higher accuracy requires longer fix times, particularly if fixes are infrequent and the GPS unit needs to update the ephemeris data. Blue Sky Telemetry claim that they can adjust the accuracy of their collars to suit the customer, with accuracy to the nearest 3 m if required. The accuracy of one Lotek model (GPS3000) was measured recently, in a static test with several collars on their default settings, as 67% of fixes within 5 m and 88% within 10 m of the mean value. This is probably typical of the type of collar generally available for use on large mammals such as deer.

A recent development is the availability of lightweight, ultra low-power GPS tags, designed to use minimal power by collecting essential satellite information but delaying all data processing until the data is downloaded to a PC. All ephemeris data is collected independently by a base station, allowing fix times as short as 60 milliseconds, but the manufacturers still claim accuracy of around 20 m.

Influence of topography, vegetation and other features on data quality

Data quality depends on the collar being able to get a clear view of satellites. This could be reduced in areas of high latitude and as animals move along north-facing slopes. However, Lotek collars used on red deer and reindeer in the Cairngorms in 2003 and 2004 had 97% or more of the fixes successful, at fix intervals ranging from 10 minutes to 4 hours. In addition, 87% of fixes had a Dilution of Precision (DOP) value of less than 10, which is a widely accepted criterion for accuracy. Performance can be reduced in dense vegetation and on steep slopes (Gamo et al, 1999), and fix success has been shown to drop to 60% when collars are located within stands containing a large proportion of tall coniferous trees (Janeau et al. 2001)

Maximum distance over which method can monitor deer movements

There is no constraint on the distance over which GPS units can be tracked by the satellites. The only potential constraints would be related to requirements to download data remotely or to apply differential correction. The Argos system, in which fix data is transmitted to earth via the satellites and the latest GSM collars, which send data via the cellular phone network, avoid restrictions on distance limitations for retrieval of data. However, in order to use differential correction, access to data from suitable base stations is required. It is necessary for the base station to be within 500 km of the animals to guarantee that the collars and base station will "see" the same satellites, although to maximise accuracy it is recommended that it should be within about 100 km. However, there are now several sources of base station data freely available on the internet and data from all over Britain is available from the Natural Environment Research Council British Isles GPS archive Facility (BIGF) (www.bigf.ac.uk) for scientific study.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

This will depend on the fix schedule, which would need to be appropriate for the time-scale of the movements. For efficient collar performance, it is recommended that fixes are taken at least 6-hourly, with 4-hourly considered safer. This would give a good idea of the timing of landscape-scale movements which take place over several days. However, to correctly identify the start and end of a movement that was completed in a matter of hours would require far more frequent fixes. GPS collars are capable of taking fixes frequently enough to identify the start and end of any movements considered to be "landscape-scale". However, the time scale for such movements is what determines how appropriate GPS tracking would be for measuring them, and a trade-off might have to be made between the degree of temporal precision required and the length of the tracking period. Nowadays most GPS collar manufacturers promise several thousand fixes before batteries have to be changed and fix intervals can be from 4 hours down to around 4 seconds. The new lightweight low-power GPS tags are claimed to be capable of taking fixes every 5 minutes for up to a year, equivalent to over 100,000 fixes.

<u>Temporal</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

GPS provides very accurate temporal information, as the times of the fixes are determined by satellite clocks.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

This will depend on battery life and there appears to be a practical limit of around a year for the current generation of collars/batteries. Lower fix rates will extend the temporal range, but battery life is still limited by power requirements for maintenance. One manufacturer (Wildlife Track Inc.) claim that their batteries will last up to 7 years, with one fix per day, but this is rather at odds with the other manufacturers and with the fact that fix efficiency can drop dramatically at such low frequencies. However, since the new, ultra low-power lightweight GPS tags do not need to update ephemeris data or carry out any data processing on board, they could potentially track individuals over much longer periods of time. With the best 7g battery available at present, the manufacturers estimate that one of their tags could theoretically track an animal for well over 10 years.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

<u>GPS collars for deer</u> ***(based on information from 3 mainstream manufacturers)***

Equipment	***Approximate Cost***

(NB: costs vary with optional extras and manufacturer)

Store-on-board collar	£1000-£2300 per collar
Collar with remote download	£1250-£2300 per collar
Handheld command unit (for remote download)	£400-£2375
GSM collar	£1650-£3350 per collar
GSM ground station (to receive data)	£330-600
Drop-off mechanism	£150
Collar batteries	£50-£150 per collar
Fitting collars to animals	
Scheduling, setting up and initialising (1 week)	£1500-£1750 per 15 collars
Delivering collars to capture site	
Darting	£470 per day
Darting equipment (drugs and darts)	£30 per animal
Collecting collars to retrieve data	
Collection of collars from capture site	variable
Recovery after automatic drop-off	unpredictable
Analysing and interpreting data	
Downloading and differential correction (2 weeks)	£3000-£3500 per 15 collars
Entry into GIS, production of initial maps (1 week)	£1500-£1750 per 15 collars
<u>Ultra low-power GPS tags</u>	
GPS tag	£1800 per tag
Download unit	£2000
Data processing	£100-150 per data set (costs vary with environment – e.g. data collected in dense vegetation is more difficult and expensive to process)

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

There are limitations to monitoring large numbers of animals, due to cost, but the optimal number will depend on the behaviour of the animals. The relationship between herd size and the number to be monitored depends on whether herds stay together or not. Groups of hinds are more likely to stay together than stags, but it is unlikely that enough animals could be monitored in any herd to be confident of knowing what is happening to the whole herd (see review of data analysis methods, elsewhere in this report).

Difficulties associated with capture and handling of wild animals, where required

Options for capture are darting, driving the animals into enclosures or using baited walk-in traps (used by scientists at INRA, Toulouse, for deer in the Cevennes; pers.comm.). Darting is only cost-effective when employed at feeding sites, or in enclosures. Darting could be done by specially trained stalkers, rather than professional darters, but this would still take a considerable amount of time unless done in conjunction with other stalking activities. NB. Darting for scientific study requires a Home Office Licence, and attendance at a training course.

Enclosures and traps both require initial investment in building equipment, plus either specialised handling facilities or darting to enable the fitting of collars. Driving animals into enclosures also requires the cooperation of landowners and stalkers and a considerable investment of time.

There is no alternative to live capture in order to fit GPS collars or tags to deer, but the animals may only need to be handled for a few minutes, just long enough to fasten the neck band (or ear tag) and ensure the fit is comfortable. There is no disturbance to the animals during the tracking procedure.

(see also Section **4. Radio tracking**)

Difficulties associated with recapture of animals, where required

Recapture presents the same problems as initial capture. Automatic drop-off mechanisms are now available, which should remove the need for recapture, but these have their own problems. Two options are available, timed drop-off mechanisms (programmed by manufacturer) or radio-controlled drop-off mechanisms. Since all collars have a VHF radio beacon, they can be located by conventional radio-tracking methods, but timed drop-offs could involve several man-hours searching for the collars. With radio-controlled mechanisms, however, there is still a risk of collars landing in inaccessible places and in order to guarantee retrieval, time would need to be spent tracking the deer and making sure the animal was in suitable terrain before operating the drop-off mechanism. However, the collar could take a short while to shake free before it fell, reducing the predictability of its landing site. Lightweight tracking tags could also be used in conjunction with a radio-controlled drop-off mechanism, by using a collar arrangement, although it might be advisable to incorporate a VHF beacon in the system, which is not currently included with the tag.

Acceptability on ethical and welfare grounds

There are some ethical/welfare issues with live capture of deer and the presence of a collar on a wild animal's neck, although discomfort from the collars is minimised with the design and weight of the current generation of collars. Although the heaviest of the collars are still within the proportion of live weight that is considered acceptable for animals to carry, there can be problems with collars on grazing animals with long, slender necks. If the collar can move on the animal's neck, the box can bang against the jaw, causing discomfort and possibly injury. However, collars that weigh around 500g do not appear to cause any discomfort. The basic unit weight for the ultra low-power tracking tags is around 25 g and could possibly be built into an ear tag, but could certainly be fitted to a lightweight collar, perhaps even an expandable collar suitable for very young calves.

There is always some risk of stress, discomfort and possible injury or even death from live handling procedures following capture in a fenced enclosure or trap. There are also risks from the darting process, if the dart hits the wrong part of the body or at the wrong speed, or if the animal is immobilised in unsuitable terrain (eg. river or steep ground). However, the risks are probably lower from darting than from other live handling methods.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

With store-on-board collars or ultra low-power tags, the data is not available until the end of the study period, however remote download allows data to be recovered at convenient intervals and GSM collars allow almost instant access to the data. With GSM collars data is sent from the collar to a cell phone modem and hence to a PC. Data can be sent either at regular time intervals or on demand in the case of two-way communication. Some of the latest GSM collars link directly to a cell phone or the internet, so that researchers can contact the collar directly and retrieve the data, as well as reschedule the collar if required. However these functions are obviously restricted to areas with mobile phone coverage. Data can also be sent to earth via a satellite (as in the Argos system), although satellites are not available 24 hours-a-day and data can only be sent or received when a satellite is overhead. It would not be appropriate to develop remote download or GSM versions of the low-power tags, unless the fix rate was very low, since vast amounts of data have to be collected for post-processing of fixes. However, the manufacturers have mentioned the possibility of developing a tag that could broadcast data for 1 or 2 fixes per day. However, a fairly powerful receiver would be required and the system might only work if a receiver (or receivers) were placed at strategic locations where the animals were likely to be within range.

Time required to collect, retrieve, analyse and interpret data

The time required to schedule, test and initialise collars, could be up to a week for 10-15 collars. No time needs to be spent collecting the data once the collars are on. Retrieving the collars can take time, if animals are to be captured/darted or if the collars are to be located in the field after automatic drop-off. This could take days or weeks, or even months if the drop-off is timed rather than radio controlled. All collars will emit a radio signal for one or two years after the drop-off is activated, so that they can be located by conventional radio-tracking methods, but recovery can still not be guaranteed for all terrains.

The process of downloading data in the laboratory, preparation of spread sheets, entry into GIS and production of initial maps of fixes is likely to take about a week for 10-15 collars. Differential correction of the data could take another 1½–2 weeks. Differential correction also requires an investment of time in maintaining a base station, or downloading data from other base stations off the internet. This needs to be done at regular intervals since data is not made available for very long, due to the huge amounts of data involved. However, data also has to be downloaded and stored at regular intervals from a self-maintained base station, due to the very large file sizes.

Many manufacturers will carry out data processing, including differential correction, as a service. In the case of the ultra low-power tags, data processing cannot be done by the customer. The time taken to interpret the data depends on individual requirements. With basic GIS skills, fixes can be displayed on maps within a matter of hours.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather

There are not likely to be any problems with the normal range of weather conditions in Scotland. GPS collars are thoroughly weather-proof and perform well in cold temperatures. The only weather-related problems that have been identified so far have been with batteries failure resulting from particularly high temperatures.

Reliability of technology/ failure rate.

There is a fair amount of information about collar performance in the literature, but since the technology is being improved all the time, historical information may not be very helpful for this review. GPS collar manufacturers tend not to give details of the expected performance of their products, other than the theoretical number of fixes possible, since fix success can vary with the environment and be a little difficult to predict.

As an example of collar reliability, when Lotek collars were used in the Cairngorms by scientists at the Macaulay Institute, only 10% of collars (1 unit out of the 9 or 10 used each time) failed completely, though some stopped working due to battery depletion a few weeks earlier than expected (eg after 10 months rather than 12). The current batch of collars performed consistently well while they were in operation, with around 98% of fixes successful.

Other

Acceptability to landowners and land managers

Early GPS collars were bulky and heavy and perceived by some to be detrimental to the welfare of the animals, but most of the current generation of collars are likely to be acceptable to landowners and managers. No objections were raised to the Lotek collars used in the recent Macaulay Institute tracking study. The latest ultra low-power GPS tags weigh less than 30 g and could be fitted to conventional marking collars or possibly even an ear tag. However, the organisation of live capture for fitting and removing collars is perceived as a nuisance by some stalkers. Their objections appear to be the inconvenience of setting up special feeding sites and of arranging for the darter to get within close enough range (around 20-30 m) to ensure successful immobilisation. There is also an issue with the drugs used for immobilisation, which may present a health hazard and prevent animals from entering the human food chain in the future.

Acceptability to other stakeholders such as hill walkers

It seems unlikely that the current lightweight collars with deer-coloured belts will be unacceptable to hill walkers. There have not been, as yet, any reports of hill walkers or other stakeholders/members of the public even being aware of collars on deer during the recent tracking study carried out by the Macaulay.

Ease with which the methods could be employed by non-scientists

Most GPS collars are still not "plug 'n play", but they are moving towards that. Setting up collars and processing data requires some basic computer skills and knowledge of GIS techniques is a distinct advantage for producing maps of the animals' movements. However, traditional map coordinates can be fairly easily extracted from the collar output files. It is also the case that most of the manufacturers now produce special software for converting fix information to map form. Televilt will send collars already programmed to your specification and will also extract the data at the end of the process, so that the collars can be employed by non-scientists. In the case of the ultra low-power tags, tags are also pre-programmed by the manufacturer and all data processing carried out when the tags are removed. Many of the other manufacturers offer "unlimited customer support" and "complete solutions" to tracking problems. In what is currently a very competitive field, they are increasingly likely to provide whatever customer support is necessary to sell their products.

3.7. PASSIVE INTEGRATED TRANSPONDER (PIT) TAGS

PIT tags are normally employed as eartags, with a network of readers. They can be used widely in studies of animals that can be made to pass near to the readers, for example penguins (Ballard, 2001), fish (Skov, 2005) and mammals (Rodgers, 2002; Schooley, 1993). This methodology would involve capturing animals, fitting them with a small inactive transponder in an ear-tag, and then relying on a network of reader stations to locate the tags when activated by proximity. This method has been used on pronghorns in the United States, where the researchers boosted the reader distance to allow location of pronghorns passing through a gap in a fence (pers comm. M Owens, Biomark.) In order to use PIT tags on deer, it might be feasible to fit gates or scratching posts with readers.

Technical Evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

This method relies on animals being recorded by readers placed in specific areas, so will be accurate spatially

Influence of topography, vegetation and other features on data quality

There should be no detrimental influence, if reader positions are chosen well.

Maximum distance over which method can monitor deer movements

Any distance could be monitored, as long as the animals encounter the readers.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

These movements could theoretically be identified if particular readers recorded frequent enough encounters of the same animals.

<u>**Temporal**</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Readers can give an accurate time at which an animal passes by.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

The temporal range will be long term, for the lifetime of the tag, and is most likely to be limited by reader station lifetime.

<u>**Cost**</u>

Collecting data, including materials and manpower and capturing animals where required.

Tags are relatively inexpensive to buy and fit, especially if fitted to calves, but setting up reader/recording stations with power systems (solar/wind, and manpower to periodically visit these sites to collect data and service equipment) will be expensive.

Analysing and interpreting data

Would depend on reader recoveries, could do basic point-to-point track analysis.

<u>**Feasibility of monitoring sufficient animals**</u>

Optimal number of deer to be monitored will be a function of herd size.

It should be possible to monitor a lot of animals, if they can be fitted with tags. Larger numbers will give a better chance of detecting the tags at readers.

Difficulties associated with capture and handling of wild animals, where required

The easiest method would be to limit the method to tagging calves. Difficulties with capturing adults would be the same as for other methods.

Difficulties associated with recapture of animals, where required

NA.

Acceptability on ethical and welfare grounds

PIT tags should be acceptable, as they can be fitted to a small ear tag.

Timescale of data retrieval and processing

Time delays built into the system

Will be delayed by the time required to mark enough animals and to record sufficient sightings, but should keep on producing data in the long term.

Time required to collect, retrieve, analyse and interpret data.

Dependent on the time to collect and collate the data. Analysis will be quick once the data has been collected.

Technical limitations

Ability of technology to cope with Scottish weather.

Will be dependent on weather only for the power source for the reader stations.

Reliability of technology/ failure rate.

Reliable.

Other

Acceptability to landowners and land managers.

Small marker tag should be acceptable, reader stations will need to be sensitively designed and placed.

Acceptability to other stakeholders such as hill walkers

Small marker tag should be acceptable, reader stations will need to be sensitively designed and placed, to be acceptable on aesthetic grounds and to avoid vandalism.

Ease with which the methods could be employed by non-scientists.

Should be easy to be used by non-scientists, since it just requires access to the equipment.

3.8. NODE TAGS

This technology is currently a concept from Bernie McConnell (personal communication) at the Sea Mammal Research Unit at St Andrews University. Funding needs to be acquired to build the tags and test them in the field. These are tags that would swap data when they come into proximity (a set distance) with each other such that, over time, each animal carrying a tag would carry information on not only which other tag-carrying animals it has come into contact with, but also who those other animals had come into contact with, thereby storing a network of inter-individual interactions. This in itself would only provide information on a network of interactions over time, but this would be useful for determining social structure or the likelihood of the spread of disease, for example. However, if a small proportion of the tagged animals also wore a GPS collar, information could be acquired about the positions of most (if not all) of the tagged individuals over time, when they came into proximity with a GPS animal.

Technical Evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Should be as accurate as GPS, depending on the pre-determined distance set to trigger a "contact" to swap data.

Influence of topography, vegetation and other features on data quality

As for GPS.

Maximum distance over which method can monitor deer movements

As for GPS.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

As for GPS for node-tagged animals frequently in proximity to a GPS-collared animal, but the accuracy would decline for animals that are rarely in proximity to a GPS-collared animal.

<u>Temporal</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a

deer was at a location)

As for GPS.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

As for GPS.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

The node-tags themselves would be cheap, but a small number of expensive GPS collars would be needed to provide the spatial information. There would be an initial high requirement for manpower to capture large numbers of animals to attach the node tags.

Analysing and interpreting data

The data is automatically downloaded into the node tags. However, analysis and interpretation of data has not yet been tried and is likely to be complex, therefore needing skilled personnel.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

This is limited only by the number of animals that can be tagged; the more the better.

Difficulties associated with capture and handling of wild animals, where required

Node tags could be fitted to calves, but the few with GPS collars would need to be attached when large enough to carry the collar (see GPS section). As always, capture will require a Home Office Licence, and it is possible that the fitting of node tags may also need to be done under Licence.

Difficulties associated with recapture of animals, where required

Retrieval of the tags could be done when the animals are shot or, if the data is needed before that time, the animals would need to be re-captured, necessitating a large amount of effort. Note that not all node-tags would need to be retrieved, since the data is swapped when "contact" is made.

Acceptability on ethical and welfare grounds

This may depend on the size of the battery required: small ones could be incorporated into an ear tag, but large, long-life ones may need to be on a collar.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

Node tag data could be collected for analysis months or years after attachment, depending on what is required.

Time required to collect, retrieve, analyse and interpret data.

Capture of calves or adults for attaching the tags will be time-consuming. Retrieval of tags could be from shot or live-caught animals. Data analysis could be time-consuming due to its complexity.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather.

As for GPS.

Reliability of technology/ failure rate.

Unknown as these tags have not been developed or tried yet.

<u>Other</u>

Acceptability to landowners and land managers.

As GPS.

Acceptability to other stakeholders such as hill walkers

As GPS.

Ease with which the methods could be employed by non-scientists.

Non-scientists could fit and retrieve the tags, but analysis and interpretation of data will be complex and need an expert.

3.9. SONIC TRACKING AND ACOUSTIC LOCATION SYSTEMS

Acoustic location systems are used in cetacean survey and behaviour research (Clark, 2000; Hayes, 2000) as these animals spend most of their time underwater and are hence difficult to locate and track. Fairly inexpensive techniques have been devised that could be adapted to land-based surveys of vocal land animals, where triangulation could be use to locate a calling animal (Hayes, 2000; McGregor, 1997)

Work on identifying deer vocalisations has used digitised recordings of deer vocalisations to produce a spectral signature for each individual (Reby, 1998), so this technique could be used to identify individuals without capturing them. The only drawback may be that red deer are only vocal during the rut season, and generally only males are vocal.

This methodology would use a network of sound sensors (microphones) placed over an area, to locate and potentially identify animals. Stags should be identifiable by their calls, using analysis software. Animals could be located using triangulation of the sensors picking up their calls.

Technical Evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Accuracy of location depends on factors such as topography or area, and the distance of an animal from the recorder, so an ALS grid would need to be calibrated before use.

Influence of topography, vegetation and other features on data quality

Some terrain features can cause reverberation of sounds, also some vegetation, affecting the quality of recordings.

Maximum distance over which method can monitor deer movements

Would depend on range of microphones, and hence the size of the grid required.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

If an animal was identified, and carried on calling, then it could be tracked anywhere, as long as recorders were positioned there.

Temporal

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Should be able to give time that deer called accurately

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

As above, would depend on the range of the microphones and size of grid the researchers were able to use. The method would also be limited to stags during the rut, as red deer are generally silent outside of this period, except for infrequent contact calls between hinds and calves.

<u>**Cost**</u>

Collecting data, including materials and manpower and capturing animals where required.

No captures are necessary. Cost can depend on the number of microphones required, and the time required to set up and service the recording grid.

Analysing and interpreting data

Would analyse the calls in the laboratory. Requires special software to identify the spectrogram of the call for each animal.

<u>**Feasibility of monitoring sufficient animals**</u>

Optimal number of deer to be monitored will be a function of herd size.

It should be possible to monitor a lot of animals, if good recordings can be obtained. However, this methodology would be limited to stags, as they are the vocal sex, but their calls are limited to the rut, a time of year when their movements are large and erratic.

Difficulties associated with capture and handling of wild animals, where required

NA

Difficulties associated with recapture of animals, where required

NA

Acceptability on ethical and welfare grounds

Should be acceptable, as no capture is involved.

<u>**Timescale of data retrieval and processing**</u>

Time delays built into the system

Will be delayed by the time to retrieve recordings, and is also most likely to be limited to the rutting season.

Time required to collect, retrieve, analyse and interpret data.

Dependent on the ease of identifying individuals individual calls with the software, and the time in the laboratory to analyse the calls

<u>**Technical limitations**</u>

Ability of technology to cope with Scottish weather.

Will be dependent on weather for quality of recording, microphones will be affected by wind, and rain, and ambient noises

Reliability of technology/ failure rate.

Reliable.

<u>Other</u>

Acceptability to landowners and land managers.

There may be aesthetic problems from laying out a grid of microphones on the hill, and also the potential for privacy issues.

Acceptability to other stakeholders such as hill walkers

There may be aesthetic problems from laying out a grid of microphones on the hill, and also the potential for privacy issues.

Ease with which the methods could be employed by non-scientists.

Analysis requires knowledge and use of specialist packages, therefore it is not likely to be suitable for use by non-scientists.

3.10 THERMAL INFRARED IMAGERY (FLIR airborne)

Thermal imaging was first trialled for wildlife counts on deer in America in 1967 (Croon, 1968) and has since developed into a potentially useful technique. The technique was developed from military imaging equipment that can use the differences in infrared radiation between an object and its background to produce an image similar to that of a television camera. For wildlife counts an infrared camera is usually mounted on an aircraft (plane or helicopter). FLIR can now detect differences of 0.3˚C, and produce exact images of objects, so that some degree of species, age and/or sex identification can take place (Dunn, 2002; Koerth, 1997; Naugle, 1996; Wiggers, 1993).

Basically these forward-looking infrared thermal sensors (FLIR) detect heat emitted by animals, therefore surveys are best done at times when there is maximum temperature difference between ground and animals (ie at night or in winter). Designated transects are flown using the aircraft's onboard GPS. There is a monitor and recorder in the aircraft, thereby allowing observers to be on board and count animals as the transects are done, and also to go over tapes later on, back in the laboratory. Tree foliage can mask the thermal image of an animal, so this technique is of little use in heavily forested areas and where similar-sized species occur in the same area, since confusion could occur between images (Dunn, 2002; Naugle, 1996; Potvin, 2005).

Technical evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

The method should be accurate, as GPS is used by the pilot to navigate along transects. It should be possible to either link the images automatically to aircraft positions, or for the locations to be recorded by the observer on the aircraft in the field. Any inaccuracies would therefore come from the inherent inaccuracy of the GPS data, which should be fairly small.

Influence of topography, vegetation and other features on data quality

Forest vegetation has an extremely detrimental influence on data quality in two ways. Trees emit their own thermal signatures and therefore mask the signatures of the animals, also trees with foliage can physically hide the animals from the sensors. Flights are best made about 1000m above average terrain level, as the speed of the aircraft is less apparent than at lower levels, and thus height allows better images to be produced.

Maximum distance over which method can monitor deer movements

This will be limited only by cost of flights, as search transects can be designed to accommodate all sizes of area, however terrain and forests could also influence this.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

The method would not work for individual animals, and is only suitable for counts and monitoring general movements.

<u>Temporal</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

The method can only give a snapshot of deer positions in general, as no individual recognition is possible.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

NA

Cost

Collecting data, including materials and manpower and capturing animals where required.

Would be costly in hire of aircraft time and purchase/hire of FLIR camera; manpower would be a minimum of a pilot and an operator for the FLIR, but 2 operators would be best to help with queries and video operation etc. The time for the survey will be dependent on the size of the area chosen. In a study in the United States 10 years ago, the cost was estimated at $99/km^2. In a recent study, the cost was estimated at £45-90/km^2 (Daniels, 2006) .No capture of animals would be necessary

Analysing and interpreting data

It is time-consuming to watch and interpret videos in the lab, perhaps using two observers to double-check the data. Counts could be done in-flight, with tapes just used to check for missed animals. Videos could also be analysed using image-enhancing software.

Feasibility of monitoring sufficient animals

Optimal number of deer to be monitored will be a function of herd size.

NA

Difficulties associated with capture and handling of wild animals, where required

NA

Difficulties associated with recapture of animals, where required

NA

Acceptability on ethical and welfare grounds

Should be acceptable, as no capture, and can avoid flying low. Best results seem to be from 300+m above the ground. Helicopters (if used) make a lot of noise, which can disturb the animals.

Timescale of data retrieval and processing

Time delays built into the system

The observers should have some training flights to improve their observation skills with this equipment.

Time required to collect, retrieve, analyse and interpret data.

Time would be required to ensure weather suitability; time spent on flights would depend on size of area chosen to monitor; analysis and interpretation in the laboratory is likely to be time-consuming.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather.

Will be dependent on weather mostly for flying conditions. Data-collection is likely to be impossible in wet, misty or windy weather.

Reliability of technology/ failure rate.

Reasonably reliable, as manufacturers supply armed forces and CCTV companies.

<u>Other</u>

Acceptability to landowners and land managers.

Problems unlikely as long as observers liaise over flight times and avoid hunting days

Acceptability to other stakeholders such as hill walkers

The method is likely to be acceptable, as flights are only likely to take place on one day in any particular area.

Ease with which the methods could be employed by non-scientists.

Basic analysis of tapes would be easily achieved with a timelapse VCR, although access to FLIR and helicopters might be a limitation, and it would be better to use trained and experienced observers.

3.11. PASSIVE CONVENTIONAL AND INFRARED IMAGERY

These technologies are widely used for CCTV security systems all over the world. Some (QWIP) are being developed to use as warning systems of large animal movements close to roads (Kinley, 2003) . Of the others, video timelapse systems are widely used to monitor bird nesting behaviour, predation on nests, and other regular activities of vertebrates (Culter, 1999). Whilst activity sensor cameras (eg trail cams) are mainly used where activity is less frequent, or unpredictable, or where a situation can be arranged to bring animals in eg. at a bait station or rubbing post (Culter, 1999; Jacobson, 1997; Koerth, 1997; Swann, 2004).

The most effective of this selection of methodologies are those which use a bait station to attract animals to a position where they can then be photographed and identified. Such stations require a camera, sensor and power system, along with some bait to attract the animals. They can either be triggered by activity, through infrared or movement sensors (QWIP etc), or programmed to take photos at set times (timelapse). Both allow individuals to be identified. Sites need to be serviced for bait, tapes and power regularly and, depending on the area and number of systems available, moved about regularly.

Technical evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Will be as accurate as GPS/map data, as cameras are placed in known positions.

Influence of topography, vegetation and other features on data quality

The camera's field of view and its depth of field will influence data quality, but positions should be carefully selected to be in clearings or wide flat areas of moorland.

Maximum distance over which method can monitor deer movements

The limitations are the number of cameras available for use and the time required to service each camera site (check camera, top up bait if used, etc). The grid for camera positions can be developed to accommodate all sizes of area, within these limitations. Perhaps more limiting will be the methods available to identify individual deer, for example if ear-tags or numbered collars are used.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

If individual animals are marked, the method could potentially show these sort of movements. But it would be dependent on an animals being filmed again later on, which would depend on the number of cameras and their positions.

Temporal

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Would give accurate positions for the particular deer photographed.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

Would only be able to 'follow' individual animals if they were identifiable and photographed by more than one camera station. However, there is no reason why this method could not be used for many years, as long as the identification marks were still visible.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

It could be expensive to purchase enough cameras and consumables to set up a decent sized recording grid. Ready built systems can be purchased for around £2000-3000, or systems could be custom built from parts, although that would be costly in manpower time. It will also be costly in manpower to service the camera grid (to check cameras and top up bait) and reset the grid in different areas. If it was decided to mark animals to identify them, it would be costly in time and manpower for this also.

Analysing and interpreting data

It is time consuming to watch and interpret videos/photos in laboratory, perhaps using two observers to double-check the data.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

Some papers state that they observed most of the animals in an area visiting baited sites, but these used enclosures. It is unlikely to get such good success rates in the open moorland.

Difficulties associated with capture and handling of wild animals, where required

Difficulties associate with capture and handling are the same as for other methods.

Difficulties associated with recapture of animals, where required

NA

Acceptability on ethical and welfare grounds

Initial capture and marking, if required, would have problems both ethically and on welfare grounds (see other methods reviewed). After this the method should be acceptable, as there is minimal disturbance to the animals.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

It will take time to set up cameras in each grid area, and then to reset and redo grids in new areas. It could take many man-days to move cameras and set them up, depending on the number used and the grid sizes required.

Time required to collect, retrieve, analyse and interpret data.

The time for data retrieval will depend on the size of area chosen to monitor, but analysis and interpretation of images is carried out in the laboratory and this part of the process is very time-consuming.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather.

Good data-collection is unlikely in wet, misty or very windy weather

Reliability of technology/ failure rate.

Reasonably reliable, although timelapse VCRs can be temperamental and need more visits for battery/tape changes than still cameras.

<u>Other</u>

Acceptability to landowners and land managers.

Lots of cameras all over the moor may be considered intrusive.

Acceptability to other stakeholders such as hill walkers

Lots of cameras all over the moor may be considered intrusive.

Ease with which the methods could be employed by non-scientists.

Basic analysis of tapes can be easily achieved, although access to enough cameras is likely to limit use.

3.12a. REMOTE SENSING – AERIAL AND SATELLITE IMAGERY†

Aerial photography has been used for many years as a method of estimating numbers of humans and of a variety of wildlife species (Laliberte, 2003; Lamprey, 2004). However, manual counts from these photos are labour intensive and can be subject to considerable error (Laliberte, 2003). To counter this, methodologies that utilise computer image analysis programmes (such as ERDAS Imagine, ImageTool, Matlab) have been developed to do automatic counts of images taken either from aircraft or satellite(Laliberte, 2003; Trathan, 2004). Satellite images (IKONOS) of <1m pixel size can now be obtained. Black and white and colour photos taken using either a handheld camera or mounted mapping camera can be scanned by a desktop scanner and manipulated to allow use of computer counting methods.

†See also Section 3.11b. Satellite Imagery on page 102.

Technical evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Should be as accurate as satellite images tend to be geo-referenced, so can link to OS grid. Aerial photos can also be linked to the OS grid.

Influence of topography, vegetation and other features on data quality

Some vegetation can shield the signatures of animals, and also some terrain features. Careful selection during pre-processing and set-up will be required to train the computer programme.

Maximum distance over which method can monitor deer movements

Remote sensing cannot identify individuals, so it is only suitable for counts and general movements.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

As above

Temporal

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Satellite images would only give a snapshot of deer positions in general, as only one image is taken every few days. Aerial photography could be used more frequently, if cost and time were not constrained.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

NA.

Cost

Collecting data, including materials and manpower and capturing animals where

required.

It could be expensive to purchase or obtain high enough quality satellite images, depending on the size of the images needed (eg IKONOS black and white 5m are $3600 per 70 x 70km scene, IKONOS 1m is $7-$39/km^2); the price of helicopter counts are roughly £45/km^2 (Daniels, 2006) so helicopter flights to take aerial photos would be a similar cost. Purchase of the software depends on a number of things, (eg. CEH have a licence for Erdas, so it would only cost approx £40 to add another copy to their system, but other organisations may have different agreements). No captures would be necessary.

Analysing and interpreting data

It is time-consuming to initially train computers to interpret images using GIS in the laboratory, perhaps using two observers to double-check data, eg. for a manual count from the images too, but once this is done it should be quick to process the rest of the data.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

NA. Herd spacing could cause problems for the image analysis programme, if the animals are tightly clumped together.

Difficulties associated with capture and handling of wild animals, where required

NA

Difficulties associated with recapture of animals, where required

NA

Acceptability on ethical and welfare grounds

Should be acceptable, as no capture or disturbance to animals is involved.

<u>Timescale of data retrieval and processing</u>

Time delays built into the system

There will be a delay before the release of the satellite images, or the time to obtain the aerial photographs.

Time required to collect, retrieve, analyse and interpret data.

Satellite images may not always be of use, due to cloud cover. Good photos are easier to obtain, as it is possible to control when and where they are taken. Analysis and interpretation of any good images will be done in the lab, and will be initially time-consuming.

Technical limitations

Ability of technology to cope with Scottish weather.

The weather conditions can affect image quality

Reliability of technology/ failure rate.

Imaging technology is reliable and image analysis technology seems easy enough to train, and is available as freeware on the internet.

Other

Acceptability to landowners and land managers.

There are unlikely to be any problems.

Acceptability to other stakeholders such as hill walkers

There are unlikely to be any problems.

Ease with which the methods could be employed by non-scientists.

Image analysis requires knowledge and use of specialist GIS and image analysis packages, therefore the method is not suitable for non-scientists.

3.12b. SATELLITE IMAGERY UPDATE

(following Expert Stakeholder Workshop 8-9th March 2006).

1. Counting animals from space

The workshop recommended following up satellite imagery as a potential new technology for counting red deer, as a method to monitor deer movements at the landscape level. It was agreed to look into the costs of acquiring images and, that ideally a comparison of the same area should be made between a known DCS count with those from satellite images for the same date. We contacted Andy Thomson (Earth Observations section, CEH Monkswood) who has previously attempted counting sheep from satellite images. He suggested that to be able to count deer would probably require the image scale to be at 1:10000, currently the scale is about 1:20000. Andy was unsuccessful in counting sheep and estimated that photographs would need to be at a scale of 1:5000 for this purpose.

We also contacted Infoterra Ltd, at Rothampstead (Appendix 2), who are involved in both satellite imagery and aerial photography and have done much work with DEFRA. Our contact, Paul Murphy (Infoterra Ltd), also suggested that a resolution of 10-25cm per pixel would be required before we could accurately count deer.

The resolution required to count deer will therefore be less than 1m per pixel and finer than any of the current high resolution satellites - see below. It is therefore not yet possible to use satellite imagery to accurately count deer and further improvement in pixel resolution will be required before it could become feasible as a technique. There are currently only a small number of satellites that have a resolution of 1m or below (high resolution), currently the best of these is the American satellite "Quickbird" and prices quoted from Infoterra Ltd for a new acquisition image of an area of 10,000 ha is $22 per km2 or a total cost of $2200 for data and a processing cost of £350 for ortho-rectification, enhancement and mosaicing. The cost for an archive image is $17 per km2 or $1700 for the 100km2 image plus processing cost of £350.

The Natural Environment Research Council (NERC), the parent body of CEH, has several units dedicated to satellite imagery. Enquiries were made to the NERC Earth Observation Data Centre (NEODC) with regards the costs of them providing researchers with archive high-resolution images however, it would appear they have no high resolution images of upland areas of Scotland (see Appendix 1). The NERC satellite receiving station Dundee (DSRS) website was visited but the highest resolution images received are only 250m per pixel (See Appendix 3). The satellites from which this station receives images are generally for more specialist research, e.g. for monitoring polar ice caps.

In early 2007 the satellite Orbview-5 will be launched with the capability of 0.41m resolution per pixel and it could be worthwhile following this up, as it should represent the greatest detailed images from space available commercially. Due for launch in late 2006 is TerraSAR-X, which will provide X-band radar images at 1m resolution. This technology can collect data independent of cloud cover and equates to a large improvement in the resolution of satellite radar imaging (see Appendices 4 & 5).

2. Current high resolution satellites

2.1 Ikonos

Has a 1m resolution per pixel panchromatic (black & White) and 4m resolution in colour. It has an 11km swath (width). Below is an example of an image from this satellite from its website, this is an enhanced image and reduced in area. Sales are through GeoEye, the American parent company of the satellite, but Infoterra are able to provide images.

Ikonos image (Sydney)

2.2 Quickbird

Has a 61cm resolution per pixel (panchromatic) and 2.44 per pixel in colour and has a 16.5km swath. Images from this satellite represent the most detailed available at present (see below) but are not thought sufficient for counting red deer.

Sales from quickbird are through digitalglobe an American company but can get hold of images through Infoterra Ltd.

There are three types
BASIC sold by scene, accuracy ± 23m
STANDARD sold by km2, accuracy ± 23m
ORTHORECTIFIED sold by km2, accuracy ± 12.7m

View of statue of liberty
From Quickbird satellite
© Digitalglobe

Below is a Google Earth image (from Quickbird) of sheep in a field near Dyce airport, just north of Aberdeen. Given the ideal conditions of a sunny day, a flat field with little shadow and the contrast between green and white, it is possible to count individual animals, and to infer that smaller animals would be lambs. However, the detail is not good enough to be absolutely certain. Clearly, at this resolution more cryptically coloured animals, such as red deer, would pose much more of a problem to identify against semi-natural vegetation, such as heather, and it would be impossible to sex animals accurately. The pixellation on the edges of the image is due to the effects of "zooming in" on the image.

3. New high resolution satellites coming on line

3.1 Orbview5

Will have 41cm resolution per pixel (panchromatic) and 1.64m per pixel in multispectral mode and is due for launch in early 2007 images would be available through GeoEye in the U.S. but Infoterra (Rothampstead UK) can get hold of them for us if needed. The images from this satellite will supersede those already commercially available, in terms of resolution, and it may be worth further investigation.

3.2 TerraSAR-X

This satellite is due for launching in late 2006 and will provide 1m resolution over an area of 10km x 10km in X-band radar meaning it is not affected by cloud cover or illumination. While images from this satellite are unlikely to be useful from the point of view of counting deer it does represent an improvement in the resolution of radar images.

4. Contacts

Andy Thomson Earth Observation section CEH Monkswood.

Alison Hopkin GIS software support CEH Wallingford.

Paul Murphy Business Development Manager Infoterra Ltd. www.infoterra-global.com

NERC Earth Observation Data Centre www.neodc.rl.ac.uk

NERC Satellite Receiving Station Dundee www.sat.dundee.ac.uk/

NERC Remote Sensing Data Analysis Service www.npm.ac.uk/rsdas/

3.13. SEISMIC DETECTION (Geophones)

This technology has only recently started to be used in wildlife studies and has developed from its initial use by the American military in Vietnam to monitor troop and vehicle movements on the Ho Chi Minh trail (Ullrich 1996). The technology is now used as part of security systems, where the detector equipment is sensitive enough to differentiate human footfall from those of wild animals www.telonics.com.

Basically, a buried detector (geophone) detects seismic activity at the detector location and generates an electrical signal. A single seismic detector can be deployed to monitor a small area or trail. Multiple detectors can be combined in a string to monitor large open areas or perimeters. The output signal from a geophone is normally very low and needs to go through a preamplifier. Output can be recorded direct onto a laptop computer, using a sound card to digitise the signal, or recorded onto Digital Audio Tape (DAT) or onto a seismic recorder.

Seismic monitors have been used to detect localised movements in elephant populations (Seneviratne & Rossel 2001; Wood et al. 2005) and as part of a detection system for warning vehicle drivers on US Highway 30 about migrating mule deer (*Odocoileus hemionus*) (Gordon et al. 2001). Seneviratne & Rossel (2001) describe a system using a geophone as a detector of elephants approaching agricultural fields so that early warning could be given to farmers before their fields were raided. However, the system proved to be expensive.

More recently, the method has been tested as a possible census technique for large mammals. This study recorded footfalls of elephants and other large mammals around a waterhole in Namibia and the researchers were able to discriminate between species using the spectral content of their footfalls with 82% accuracy (Wood et al. 2005). However, the system was less effective in estimating group sizes. Only a single geophone was used and the authors suggest that an array of geophones would have improved their ability to estimate the number of elephants passing by.

In the study by Gordon et al. (2001) the geophone system was one of three technologies tested, the others were infrared sensors for detecting the body heat of animals and microwave radar sensors. The number of detections recorded by each of the three systems were counted electronically and real time comparisons were made by visual counting. Microwave radar was found unsuitable for deer detection and infrared scopes had problems with both over- and under-detection and more than 50% of detections were false hits, not caused by deer. The geophone recorded no false detections and was the most reliable of the three systems tested.

Technical evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Geophones are located at known sites and so spatial information is accurate to within the range of the detector. In the case of the study on elephants (Wood et al. 2005) signals could be detected about 100 m away.

Influence of topography, vegetation and other features on data quality

Detection range will depend on several variables such as type of terrain, sensitivity setting of processor, and number of animals present. The geophones are buried and are therefore not affected by vegetation.

Maximum distance over which method can monitor deer movements

A single seismic detector can be deployed to monitor a small area or trail. Multiple detectors can be combined in a string to monitor large open areas or perimeters. Wood et al. (2005) estimate an array of three geophones would cover between 0.06 and 0.09 km^2.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to

Temporal

The method does not distinguish individual animals and therefore cannot identify the start and end of movements but can record frequency and direction of movements along trails or across perimeters.

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a

deer was at a location)

The method can record the time when animals passed close to the geophone.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

Geophones can be left indefinitely, but require maintenance for changing batteries on amplification and recording equipment. However, they will be unable to follow individual animals and can only give an estimate of animals moving near to or passing the geophone.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required

The study of Wood et al (2005) used a 4.5 Hz vertical geophone
Prices for this type of geophone vary depending on specifications but are in the region of \$57 to \$85 (excluding import costs)
Sources www.giscogeo.com and www.webtronics.com
A quote for an analyser for up to four geophones was £1169
And an interface card – required for every 8 geophones £218
Geophone strings £50 per metre
Source www.geoquip.com
Other equipment – used by Wood et al (2005)
Laptop computer £1000
Preamplifier
Software Cool Edit pro (version 1.2)
Sound card (VX pocket version 2)
Sound cards come with many computers and it is possible to get free downloads of recording software. Further investigation would be necessary to ascertain if this would be sufficient to provide quality recordings.

Analysis and interpretation

Specialist skill in signal analysis is required to analyse and interpret data. Specialist analytical software (Matlab) was used by Wood et al. (2005) to create power spectrum plots of footfalls. However, these authors are currently developing software that could aid the collection and analysis of seismic signals by biologists (Jason Wood pers comm.).

Feasibility of monitoring sufficient animals

Optimal number of deer to be monitored will be a function of herd size.

The method cannot follow individuals and can only record local movements near to the geophone or array.

Difficulties associated with capture and handling of wild animals, where required

No capture is required.

Difficulties associated with recapture of animals, where required

Animals do not need to be recaptured.

Acceptability on ethical and welfare grounds

This is a non intrusive method and is acceptable on both ethical and welfare grounds.

Timescale of data retrieval and processing:

Time delays built into the system

The only time delay is in the frequency with which data is downloaded from the data loggers.

Time required to collect, retrieve, analyse and interpret data

Monthly downloading may be possible, but this is dependent on the number of geophones, the sampling rate, computer memory and power requirements (Wood et al. 2005).

Technical limitations:

Ability of technology to cope with Scottish weather

Geophones are buried underground and are not affected by the weather. Recording equipment would need to be stored in waterproof conditions and extreme cold might drain any batteries, though regular maintenance should prevent this.

Reliability of technology/ failure rate.

The technology is widely used in geological circles and seems to be well tried and tested for this use. The experience of the few wildlife biologists who have used this technology also suggests that it is fairly robust (Wood et al 2005; and Jason Wood pers. comm.)

Other:

Acceptability to landowners and land managers

This is a non-intrusive method with regards to animals but requires the permanent installation of equipment and access for downloading data, which could cause problems.

Acceptability to other stakeholders such as hill walkers

No animals require tagging but the housing for specialist equipment may be visible.

Ease with which the methods could be employed by non-scientists

It would be straightforward to train non-specialist staff to download data, but analysis and interpretation requires specialist skills.

3.14. DNA GENOTYPING

Individual identification of animals from DNA in field-collected faeces, feathers, hair or other tissue samples is becoming an increasingly important tool in wildlife population monitoring (e.g. Creel et al. 2003), building on a strong foundation of research in human forensics. Combined with capture-recapture theory, the potential exists for addressing a wide variety of questions, including that of individual landscape-scale movements (Lukacs & Burnham, 2005).

Molecular techniques are also useful because they not only provide an idea of the movement of individuals in the particular season or year that they were sampled, but can also give an idea of how animals disperse over generations. DNA samples can also facilitate the identification of possible hybrids and give a better historical perspective of gene flow.

Technical evaluation

Spatial

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

Unless live capture is used or the moment of defecation or deposition of hair is observed, the location of animals can only be as accurate as knowing where the animal was when the sample was deposited. Although it is possible to estimate the age of faecal pellets, for example, to within a few days, the precise time at which the animal was at the sample location cannot be known.

Influence of topography, vegetation and other features on data quality

Weather conditions may affect the condition of the sample and hence the accuracy of estimated time since sample deposition.

Maximum distance over which method can monitor deer movements

This depends on the scale of the study area, i.e. some long-distance dispersal movements might not be detectable if a sufficiently large area is not sampled.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

The method will not be able to identify the start and end of a particular movement, but will simply record the fact that an animal was in location A at time 1 and in location B at time 2. The temporal sequence of times 1 and 2 will often, though not always, be clear from times at which the samples were found, in conjunction with the physical condition of the sample. In theory, an individual or group of individuals could be tracked across a landscape if a pellet or hair trail was followed, but the success of such an exercise would depend on the temporal precision with which the time of deposition of the sample could be estimated. In reality, tracking animals using DNA is not a trivial problem and the chances of resampling the same individual in a large area are extremely low. To be successful could involve a vast amount of manpower.

There are programs that can calculate the probability of an individual originating from where it was sampled, which is called an assignment index. With a comprehensive sampling program and relatively large numbers of microsatellite markers you can assign animals to a particular population with a high level of confidence (for a review see Manel et al. 2005).

<u>Temporal</u>

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Unless live capture is used, the time when a deer was at a location could only be estimated to within a few days. Since the quality of the DNA in faecal samples is only good enough for successful genotyping for about a week, the time when a deer was at a site where faeces were found could be pinpointed with that degree of accuracy. It is possible that an expert might be able to identify faeces after a slightly longer period of time.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

Provided the faeces, hair or other tissue samples can be collected within a few days, there are no theoretical limitations on the length of time over which it is possible to follow an individual.

<u>Cost</u>

Collecting data, including materials and manpower and capturing animals where required.

Lab costs

Example for 250 samples :

DNA extraction kits - for tissue and samples (£430 for 250 extractions), for faeces (£123 for 50 extractions) - £1000

PCR reagents - £1000

Fluorescently labelled primers – if amplifying 20 loci - £1500

Sequencer runs -£3000 (if using hair/faeces)

Tubes + tips + plates £500

When using non-invasive techniques to obtain samples (i.e. hairs, faeces) the number of PCRs to be performed are x 7, as the amplification of loci is generally more problematic. However, amplification tests do not necessarily need to be performed using the fluorescently labelled markers (which are more expensive) but can be checked using normal primers and run in 4.5% agarose gels in order to save money.

<u>Feasibility of monitoring sufficient animals</u>

Optimal number of deer to be monitored will be a function of herd size.

With molecular markers it is feasible to follow more individuals than when using direct methods like capture-mark-recapture, or radio-collared individuals. The number of animals to be monitored will depend on the scale of the study area. As a general rule in population genetics, about 20 individuals per population have been sampled but recently it has been advised that larger numbers should be sampled, as the power of the tests increases with more samples. However, for large mammals, when samples are often difficult to obtain, the number of individuals sampled will vary. Another factor is that sometimes it is quite difficult to determine what makes a population until the genetic profiles have been studied. In theory, using non-invasive techniques, you should aim for a high number of samples, as some will inevitably be unsuitable due to low quantity or quality of the DNA. The ideal situation is to take and analyse as many samples as possible, to maximise the chances of estimating allele frequencies and accurately identifying animals from particular populations. Logistics and cost limitations are likely to make it very difficult to monitor a sufficient number of animals with this method.

Difficulties associated with capture and handling of wild animals, where required

Live capture for removal of hair or tissue samples will be associated with difficulties, as described elsewhere (see section on GPS tracking).

Difficulties associated with recapture of animals, where required

NA

Acceptability on ethical and welfare grounds

Live capture for removal of hair or tissue samples is likely to raise some welfare issues (see section on GPS tracking), however the collection of hair by indirect methods (eg. after rubbing on posts or trees) or other non-invasive samples (eg. faeces) should be perfectly acceptable.

<u>Technical limitations</u>

Ability of technology to cope with Scottish weather

The only constraints are likely to be the variable effects of weather conditions on the rate of faecal pellet deterioration.

Reliability of technology/ failure rate.

Genotyping from the analysis of DNA in non-invasive samples, such as faeces, is error-prone. However, a number of methods have been developed by which errors can be reduced (Taberlet et al. 1996,1999; Gagneux et al, 1997; Morin et al, 2001; Miller et al, 2002) and those that cannot be avoided through laboratory procedure can be quantified (Broquet and Petit, 2004). Really fresh faeces will produce fairly reliable results, but hair samples are much more reliable in general, since the quality of the DNA is better and lasts longer.

<u>Other</u>

Acceptability to landowners and land managers

Since this technology does not need to involve direct contact with the animals, the only objection that might be raised by landowners or land managers would be the issue of disturbance. The collection of faecal or hair samples from the ground or, in the case of hair, from tree trunks or rubbing posts, would inevitably involve people working in areas frequented by deer. Apart from the usual issues with difficulties involved with live capture, the direct removal of hair samples is unlikely to be a problem.

Acceptability to other stakeholders such as hill walkers

This is unlikely to be an issue.

Ease with which the methods could be employed by non-scientists

Laboratory methods for DNA analysis are relatively simple, since kits are now available, but training is required to interpret the results and deal with any problems that may arise. Experience in molecular biology, in particular microsatellite markers, is preferable. Somebody without experience in microsatellite markers, but familiar with PCR could also be employed, but would require extra training and substantial supervision. Statistical methods are also highly technical. This is not really a method that could be employed by non-scientists.

3.15. STABLE ISOTOPES

Stable isotopes are absorbed from an animal's food and/or environment into their bones, hair and other growing body parts (Dalerum, 2005; Thompson, 2005). Studies of migratory birds (Chamberlain, 1997) have shown that breeding areas can be determined for birds caught on their wintering grounds, using the stable isotope signatures found in their feathers. Fish can also be traced to their natal rivers using the stable isotope signature in their bones (Kennedy, 1997) Even fossils have been studied using these techniques (Hoppe, 1999).

The use of this method would depend on being able to determine a signature for identifiable areas (eg perhaps individual valleys) of specific naturally occurring stable isotopes, such as $\delta^{13}C$ $\delta^{15}N$ and $\delta^{87}Sr$. These would then be linked to isotope signatures in tissues collected from deer (hair or possibly antlers). However, if antlers were used they may only give information about the area where an animal was when it grew them. Also, it is not certain if areas will have identifiable signatures at a fine enough scale to be of use to track the type of deer movements that are of interest. This technique could be used to identify dispersal of young, as their initial signature would be from their natal area.

Technical evaluation

<u>Spatial</u>

Accuracy in spatial location information (*e.g.* error associated with GPS fixes)

If area signatures are specific (eg. between valleys) then should be good accuracy.

Influence of topography, vegetation and other features on data quality

There should be no detrimental influence, as vegetation will be the key to the isotopes entering the animals' bodies.

Maximum distance over which method can monitor deer movements

Any distance could be monitored.

Ability to correctly identify the start and end of a landscape-scale movement (*i.e.* where an animal moved from and to)

These movements would not be identified.

Temporal

Accuracy in temporal information (*i.e.* ability to accurately describe the time when a deer was at a location)

Precise times could not be obtained.

Temporal range (*i.e.* the maximum period over which it is possible to follow an individual)

It should be possible to follow individuals over a long period of time, probably many years?

Cost

Collecting data, including materials and manpower and capturing animals where required.

Depending on what sample required, capture would not be required if the antlers could be collected once shed. Costs might be simply those of setting up and regularly visiting hair traps or perhaps scratching posts, where hair could be collected. Samples could also be collected from culled animals.

Analysing and interpreting data

This would depend on the cost of processing the materials in the laboratory and carrying out the isotope analyses in a mass spectrometer.

Feasibility of monitoring sufficient animals:

Optimal number of deer to be monitored. This will be a function of herd size; large herds require fewer animals to be monitored.

It should be possible to monitor a large number of animals, if samples can be obtained.

Difficulties associated with capture and handling of wild animals, where required

NA.

Difficulties associated with recapture of animals, where required

NA.

Acceptability on ethical and welfare grounds

Acceptable, as samples are collected remotely.

Timescale of data retrieval and processing

Time delays built into the system

It takes time for the required amount of tissue to be laid down by the animal.

Time required to collect, retrieve, analyse and interpret data.

Time is required to sample vegetation in areas and analyse SI signatures, to build up reference library. The time required to find and collect shed antlers is difficult to predict. Hair samples would need to be collected frequently. Laboratory analysis will be slow, but data analysis should be quick as the data is fairly basic.

Technical limitations

Ability of technology to cope with Scottish weather.

NA.

Reliability of technology/ failure rate.

If a reliable and accurate signature library can be developed then should be reliable.

Other

Acceptability to landowners and land managers.

The only issue might be the potential disturbance caused by people collecting samples..

Acceptability to other stakeholders such as hill walkers

Should be acceptable.

Ease with which the methods could be employed by non-scientists.

Collection of samples can easily be done by non-scientists, but the laboratory analysis is specialised.

4. SUMMARY TABLE

Table showing performance of methods and technologies reviewed, in relation to some of the main criteria by which they can be assessed for their suitability for tracking red deer. (Please note that this table is inevitably a simplification, since the answers to some of the questions are not necessarily straight forward, and is intended only as a rough guide.)

Method	Precision?		No of animals tracked	Could identify individuals?	Is live capture involved?	Cost of equipment/ analysis	Suitable for non-scientists?	Quick data access?
	spatial	temporal						
Direct counts	Poor	Good	High	No (unless marked)	No	Low	Yes	Yes
Pellet counts	Good	Poor	High	No	No	Low	Yes	Yes
Colour marking	Good	Good	High	Yes	Possibly	Low	Yes	Yes
Radio tracking	Good	Good	Small	Yes	Yes	Medium	Yes	Yes No
GPS tracking	Good	Good	Small	Yes	Yes	High	No	(Yes if GSM)
PIT Tags	Good	Good	Medium	Yes	Yes	High	No	No
Node Tags	Good	Good	Medium	Yes	Yes	High?	No	No
Sonic tracking	Poor	Good	Medium	Yes	No	Medium	No	No
FLIR	Good	Good	Large	No	No	High	Yes	Yes
Conventional and Infrared imagery	Medium	Good	Large	No (unless marked)	No (unless marked)	High	Yes	No
Remote Sensing	Medium	Good	Large	No	No	High	No	No
Seismic detection	Medium	Good	Large	No	No	High	No	No
DNA genotyping	Poor	Poor	Small	Yes	No	Medium	No	No
Stable isotopes	Poor	Poor	Large	No	No	Medium	No	No

5. CONCLUSIONS

As indicated at the beginning of this report, the choice between the methods currently employed for tracking animals really comes down to a choice between 'low tech' and 'high tech' methods. The latter involve high precision, expensive technology which can monitor the movements of relatively small numbers of animals in great detail, whereas the former involve less precise and much cheaper counting methods, which are labour-intensive, but which have a better chance of providing an overall picture of what large numbers of animals are doing. Methods that allow the movements of individual animals to be followed, whether low or high tech, have the disadvantage that they require live-capture in order to mark the animals in some way, or to fit a tracking device. However, counting methods without individual marking do not necessarily reflect the movements of animals, since they can only provide information about the numbers of animals in a particular area at a particular time.

So-called 'alternative' methods range from remote sensing, which has the potential for monitoring the actual movements of large numbers of animals, to chemical identification methods, such as the analysis of animal tissues for DNA fingerprinting or the detection of stable isotopes, which are only likely to provide general indications of population movements. Remote sensing currently has some technical limitations, such as limitations to the basic ability to see animals clearly enough from space, as a result of uneven or densely covered terrain or poor weather conditions, but it is likely that these will be overcome in the future, as the technology develops. DNA genotyping could theoretically be used to monitor the large-scale movements of large numbers of animals, but involves fairly expensive laboratory analyses and would require very labour-intensive sampling programs in order to track enough individuals and to obtain the samples within the tight time-frame necessary for correct identification

The summary table (above) indicates how the various methods perform in relation to what we consider to be the most important of the evaluation criteria. The recommendations that follow from this review were drawn up following discussions with a group of experts and stakeholders and are contained within the report of the Workshop held in March 2006 (see Annex 3).

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7. APPENDICES

Appendix 1. Communication with NEODC

This is a message from NEODC Helpdesk about a new or open query from you, reference number 1286.
Please use 'reply' to respond to this message and write your reply ABOVE this message.
For more information visit http://www.neodc.rl.ac.uk/help/query.html

Entered on 26/04/2006 at 10:35:34 by Victoria Jay:
Dear David,

Thank you for your enquiry about Ikonos imagery - I am afraid we do not have any suitable Ikonos or Quickbird images in our archive. However, if you would like to purchase high-resolution imagery we could liase for you with companies as Infoterra, Nigel Press etc. As you have already been in contact with Infoterra you will probably already have an idea of costs.
If you simply require high resolution EO imagery of a specific site we do hold quite an extensive archive of multispectral imagery and aerial photography of the UK, though at first sight it doesn't look like we hold data for the Scottish Uplands. If this would be of interest let me know details of a specific area you require and I can check. (Or you can search our catalogue: http://www.neodc.rl.ac.uk/datasearch/newcat/index.php
(use the keywords ATM or CASI for the airborne imagery), or use the interactive map http://www.neodc.rl.ac.uk/cgi-bin/mapserv40?layer=demis&map=..%2Fhtml%2Fmaps%)
We can distribute the airborne multispectral (ATM and CASI) free of charge (so long as it is not used for commercial purporses and its use is properly referenced) and the aerial photography archive is in the process of being scanned - digital images will become available, also free of charge for research use, during this year.

regards,
Victoria

Entered on 25/04/2006 at 15:07:02 by dsco@ceh.ac.uk:
Sir/Madam

I am involved in a small research project for the Deer Commission for Scotland and the Scottish Executive looking into novel technologies for monitoring red deer movements at landscape levels. I have already been in contact with staff at both CEH Monkswood and Infoterra and am convinced that at the moment this is not practical, due to the need for greater resolution than currently available. However our study is looking at the potential for technologies to be useful and I am aware that at least one satellite is due to be launched next year that will give even greater resolution that what is already available (though perhaps still not enough for my purposes).
That aside, my enquiry to you is whether you have access to IKONOS or QUICKBIRD images or hold them in your database and how much such images might cost (approximately) for me as a researcher to use, for example an enhanced image of a 10km x 10km area of the Scottish uplands.

many thanks
David Scott CEH Banchory

Appendix 2. Communications with Infoterra Ltd.

Dear sir/madam

I work for the Centre for Ecology and Hydrology and am involved in a research project, funded by the Scottish Executive and the Deer Commission for Scotland (DCS), which is looking at potential new technologies that could be used for monitoring deer movements at landscape levels. As part of this study we have reviewed current and potentially new technologies as to their suitability and following a recent workshop several were selected for more detailed follow up - including the use of satellite imagery. We are therefore doing a small pilot study to see if this approach is feasible and to get an appreciation of the potential problems.

My approach to you is to get estimates of costs of such images as, depending on costs, we would need to get further funding from the Scottish Executive to acquire potentially useful images.

Ideally our aim would be to compare a known count of animals done by the DCS (helicopter counts) of an area of open hill land in Scotland with that from a satellite image (or matched pair for stereoscopic interpretation). At this moment in time I have not been provided with any specific areas or dates but counts are usually over an area of 10s of square kilometres.

I am unsure as to whether we would need colour or black and white images
I believe we would need very high-resolution images from Bluebird or Ikonos for example
I would appreciate some help in this matter especially with potential costs.

Many thanks

David Scott (01330 826317 direct dial)
CEH Banchory
Hill of Brathens, Banchory,
Aberdeenshire AB31 4BW
Email dsco@ceh.ac.uk

REPLY

Dear David

Thank you for your enquiry. Unfortunately the resolution of Ikonos and quickbird imagery would not be good enough to locate red deer. If you have any questions please feel free to contact me.

Best Regards
--Paul Murphy, Business Development Manager

Infoterra Ltd. http://www.infoterra-global.com
<http://www.infoterra-global.com/>

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-----Original Message-----
From: David Scott [mailto:dsco@ceh.ac.uk]
Sent: 24 April 2006 12:29
To: Paul Murphy
Subject: RE:Counting red deer from satellite images

Paul

Many thanks for your quick reply, which makes life easy for me as it is clearly not feasible to use satellite images for counting deer at the moment.

I do however have a question which pertains to future developments in high resolution satellite imagery (as in many ways this is what our study is about).

Q There is a satellite called Orbview5 due to be launched next year with a panchromatic resolution of 0.41m would this be sufficient to locate red deer? or if not, in theory what do you think the resolution would have to be to achieve this?

David

David Scott
CEH Banchory
Hill of Brathens, Banchory,
Aberdeenshire AB31 4BW
Email dsco@ceh.ac.uk

REPLY

David

If the deer are static or in groups it may be possible to detect using 40cm imagery (preferably 10 - 25cm imagery would be ideal). We would have to look at some test images to see if it would be feasible.
We could arrange this once the satellite has been launched and is fully operational. Please contact me if you have further questions.

Best Regards

Paul
--
Paul Murphy, Business Development Manager
Infoterra Ltd. http://www.infoterra-global.com
T. +44 (0)116 273 2339 F. +44 (0)116 273 2400 M. +44 (0)788 074 0275

David

Currently Quickbird image prices are as follows: \$17 per km^2 (archive) or \$22 per km^2 (new acquisition).
Our standard image processing price for the imagery (ortho-rectification, enhancement and mosaicing, output to DVD): £375 per $100km^2$.
Therefore if you were to acquire new imagery over a (10km x 10km) 100km2 area the price would be:

Data: \$2200 Processing: £375

I hope this helps. Infoterra also provide image interpretation and classification services. Infoterra can also provide consultancy on GIS and data management systems. Please contact me if you require further information.

Best Regards Paul

Appendix 3. Dundee Satellite Receiving Station

Station Information

Introduction

The NERC satellite receiving station at Dundee University has been systematically recording satellite images on a daily basis since 1978.

Satellite Image Archive

Data archiving started with the launch of the prototype 3rd generation NOAA satellite TIROS-N in October 1978. The station also recorded data from the CZCS on NIMBUS-7 between August 1979 and the end of the mission in December 1986. A replacement, SeaWiFS, is now being received and archived. Data from MODIS, carried on the EOS AM/PM series satellites, is being received and archived here, providing much-improved spatial and spectral resolution. Data are also received from METEOSAT S-VISSR and other geostationary satellites for daily use but are not routinely archived for more than a few days.

To find out which areas of the earth we cover please see our coverage document.

The archive is kept on tape and CD-ROM, with a photographic archive kept for quick browsing. We can supply either enhanced photographic images produced from the data, or we can supply the data itself over the internet or on tape, disk or CD-ROM.

Data from satellite passes is kept on disc for six days allowing customers to order interactively on the World Wide Web. Passes older than that can be restored from the archive upon request.

Quicklooks on the Web

Quicklooks (small images) are created for each satellite pass and kept in a separate archive. The whole quicklook archive is available on the web so that customers wanting high resolution data can search for appropriate passes, for example those with cloud-free areas.

Services We Can Provide

- Free quicklook images on the Web
- High resolution data ordered on the Web and sent by FTP
- High resolution data on tape or CD-ROM
- Photographic image products and full-colour posters
- A full archive in hard-copy form back to 1978 for browsing here in Dundee
- The ability for us to perform searches of the archive based on your own criteria, such as cloud-free areas.

High Resolution Images

The quicklook images that can be viewed freely on our web site are reduced-size versions of the full high-resolution images received from the satellites. The resolution of the AVHRR and SeaWiFS scanners can be as high as 1km per pixel, adequate for most purposes except detailed town plans and such like. Our sample images can give you an idea of the resolution of AVHRR images. The MODIS scanner is higher resolution in some channels, up to 250m per pixel. (If you require even greater detail than that then you should consider aerial photographs or SPOT and Landsat and similar satellites from other sources).

We can supply high resolution images as computer data or as hardcopy photographs. If you wish to buy photographs then please read the Photographic Images document as the remainder of this document concerns computer data only.

High resolution data is available in two forms:

- Raw data from the satellite or processed to level-1b, in file formats such as NOAA-1B or HDF etc.
- The image data extracted from the raw data into one channel per file (GIF, PGM, binary arrays etc)

and on different media:

- Network data by World Wide Web (WWW) or File Transfer Protocol (FTP)
- Magnetic tapes Exabyte or DLT
- CD-R or DVD-R

Options include:

- calibration of the data to level-1a (scanner calibration) or level-1b (albedo or thermal calibration)
- re-projection to a standard view using Mercator, Cylindrical Stereographic etc. projections

We make a charge for supplying high resolution data in order to cover the costs of storage and processing. High resolution data supplied on magnetic tape should be ordered in the same manner as for hard-copy products such as photographs by using the order form.

To supply high resolution data over the internet we first ask that you apply for access. You should already have registered for viewing quicklook images; we simply upgrade that account allowing you to place orders for high resolution data using a Web orderform. A log will be kept of the data ordered and you will be invoiced quarterly. To upgrade your account please read the High Resolution Access Documentation.

Customers with high resolution data access may order data from any pass received within the last six days using the Web orderform. If, after browsing our quicklook archive or pass database, you wish to order from older passes, we can arrange for the pass to be restored from our tape archive. Simply contact us in the usual way or by e-mail to sales@sat.dundee.ac.uk

We can cater for other requirements such as

- ordering data from a large number of passes, or
- repeating orders, such as a particular region from all future passes at a given time of day

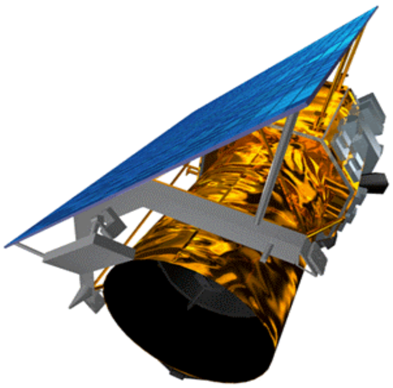
Appendix 4. Orbview-5 satellite

www.geoeye.com

Corporate

OrbView-5

Building on a Tradition of Innovation



ORBIMAGE will continue its tradition of innovation in mapping, monitoring and measuring the Earth's surface with the launch of OrbView-5, its next-generation satellite with the highest resolution and most advanced collection capabilities of any commercial imaging satellite ever developed.

Scheduled for launch in early 2007, OrbView-5 will offer unprecedented spatial resolution by simultaneously acquiring 0.41-meter panchromatic and 1.64-meter multispectral imagery. It can collect in excess of 800,000 square kilometers of imagery in a single day, downlink imagery in real-time to international ground station customers, and can store 1.2 terabytes of data on its solid-state recorders.

The detail and geospatial accuracy of OrbView-5 imagery will further expand the applications for satellite imagery in every commercial and government market sector.

OrbView-5 Specifications		
Imaging Mode	Panchromatic	Multispectral
Spatial Resolution	0.41 meter	1.64 meters
Imaging Channels	1 channel	4 channels
Spectral Range	450-900 nm	450-520 nm (blue)
		520-600 nm (green)
		625-695 nm (red)
		760-900 nm (near IR)
Swath Width	15.2 km	
Off-Nadir Imaging	Up to 60 degrees	
Dynamic Range	11 bits per pixel	
Mission Life	Expected > 7 years	
Image Area	User Defined	
Revisit Time	Less than 3 days	
Orbital Altitude	684 km	
Nodal Crossing	10:30 A.M.	
System Life	Minimum 5 years	

Appendix 5. TerraSAR-X satellite

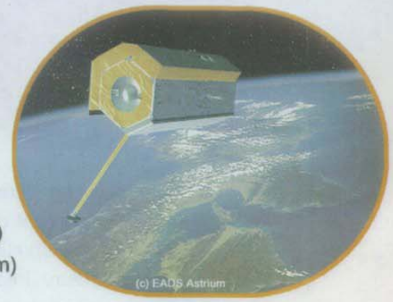
www.infoterra-global.com

infoterra
an astrium company

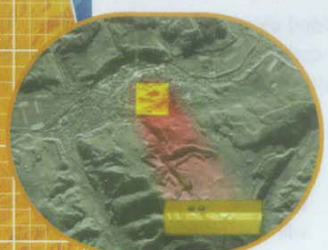
TerraSAR-X: System Capabilities

TerraSAR-X is the first commercially available X-band radar remote sensing satellite with a high productivity. It is capable of acquiring large area data as well as zooming in on selected focus areas. TerraSAR-X features a highly reliable observation capability, as the radar satellite collects data independent of cloud cover or illumination.

Technical Features



- Active phased array X-band SAR
- Resolution up to 1 meter
- Single, dual and quad polarization
- On board data storage (256 gigabyte)
- Sun-synchronous repeat orbit (514 km)
- Repetition rate: 11 days
- Due to its flexibility, TerraSAR-X can **cover any point on Earth within a maximum of three days**, 90% of the surface even within 2 days.



Operational Modes

TerraSAR-X will be capable of operating in three alternative modes:

- **Spotlight Mode** (left):
  1 m resolution for area of 5 to 10 by 10 km
- **Strip-Map Mode** (center):
  3 m resolution at 30 km swath width
- **ScanSAR Mode** (right):
  16 m resolution at 100 km swath width

For further Information, please contact Infoterra:
T. +49 (0) 7545 8 9969 F. +49 (0) 7545 8 1337 andreas.kern@infoterra-global.com

Products

Infoterra will offer a selection of high-quality Terra-SAR-X-based data products that can be chosen according to the clients' specific needs and requirements:

Basic Image Products

Depending on the clients' specifications and the desired application, the basic image products can be generated with any combination of the following image characteristics:
The products can be acquired in one of three main **Image Modes**:

- Spotlight (up to 1 m resolution, 10 km x 5 or 10 km);
- StripMap (up to 3 m resolution, 30 km x up to 1.500 km);
- ScanSAR (up to 16 m resolution, 100 km x up to 1.500 km).

In addition, the **Polarisation Modes** allow a variety of polarimetric combinations in HH/VV, HH/HV, or VV/HV, and the client may choose from several different **Geometric Projections**.

Enhanced Image Products

Orthorectified Image ORI^{SAR}
The enhanced ellipsoid corrected (EEC) SAR data, corresponding to DLR DEM standards, provides an excellent quality suitable for the vast majority of possible applications. On demand, high-precision digital elevation models can serve as an improved input to the orthorectification process of the ORI^{SAR} images, resulting in a higher geometric accuracy. Optionally, a **Radiometric Normalisation RaN^{SAR}**, compensating the dependency on local incidence angle of different objects on ground, is available.

Mosaic MC^{SAR}
Neighbouring orthorectified images are combined into one, the intersection line being specifically selected in order to avoid the visibility of cutting edges. All scenes are radiometrically balanced, which results in a seamless mosaic.

Oriented Image OI^{SAR}
Oriented Images are subsets of a mosaic, which are characterized by sheet orientations and layout according to relevant mapping standards or customer defined extensions.

TerraSAR-X Basic Products range from 16 m resolution large-scale radar images to 1m resolution images.

ANNEX 3:

DEVELOPING METHODOLOGIES TO MONITOR DEER MOVEMENT AT A LANDSCAPE SCALE

STAKEHOLDER WORKSHOP

8-9 MARCH 2006, DOUNESIDE HOUSE, TARLAND

1. ATTENDEES

Stakeholders:

Mike Daniels (MD) – Deer Commission for Scotland
Josephine Pemberton (JP) – Deer Commission for Scotland/University of Edinburgh
Jenny Bryce (JB) – Scottish Natural Heritage
Willie Lamont (WL) – Forest Enterprise
Richard Luxmoore (RL) – National Trust for Scotland
Shaila Rao (SR) – National Trust for Scotland

Staff:

Simon Thirgood (ST) - Macaulay Institute
Justin Irvine (JI) - Macaulay Institute
Angela Sibbald (AS) - Macaulay Institute
Lucy Gilbert (LG) - Macaulay Institute
Dave Scott (DS) – Centre for Ecology and Hydrology
Steve Palmer (SP) – Centre for Ecology and Hydrology
Fiona Leckie (FL) – Centre for Ecology and Hydrology

2. AGENDA

Wednesday 8th March:

1300 Lunch
1400 Introduction and Aims (Simon Thirgood)
1430 Presentation of Analysis of Existing Datasets (Justin Irvine)
1530 Afternoon tea

1600 Presentation of Review of Current and Future Technologies (Angela Sibbald)
1700 Summing up of Day 1 (Simon Thirgood)
2000 Dinner

Thursday 9th March
0830 Breakfast
0930 Introduction to Break-out Groups (Simon Thirgood)
0945 Break-out Groups
1100 Morning Coffee
1130 Rapporteurs Reports
1200 Final Discussion and Summing up (Simon Thirgood)
1300 Lunch
1400 Depart

3. INTRODUCTION AND AIMS (ST)

The background to the SEERAD Flexible Fund Project was outlined and a summary of this is given in the Introduction to this quarterly report.

The aims of the Stakeholder Workshop were:

(1) To present and discuss Objective 1 (A systematic and quantitative evaluation of existing data, literature and methods for monitoring red deer movement).

(2) To present and discuss Objective 2 (A review of technologies and their potential for monitoring animal movements).

(3) Through discussion in Break-out Groups to: (a) identify key questions in relation to deer movement in Scotland; (b) prioritise further analysis of existing datasets; and (c) prioritise further assessment of techniques and technologies. (Objective 3)

Discussion:

JP raised the question of the time scale of the movements that we are interested in e.g. diurnal, seasonal or permanent. ST suggested that each was potentially important and would require different approaches.

RL asked whether the question of deer movement was from the point of view of relevance to management or for purely academic study. ST replied that management relevance was the key driver.

MD wondered whether other academics could have been invited to this workshop such as researchers at the Sea Mammal Research Unit. LG replied that SMRU had been consulted and their ideas for novel technology would be reported.

4. ANALYSIS OF EXISTING DATA SETS (JI)

NB. The following is a summary of the presentation given at the workshop and the resulting discussions. A more detailed assessment of the existing data sets is given in Annex 1.

4.1. West Affric

The data set comprised monthly counts conducted in 2003-2005. Group size, composition and location were recorded both inside and outside the estate along two routes that followed the estate boundary. The location of the observer was also recorded. The data was analysed to test the hypothesis that groups of deer were moving in to the estate on a seasonal basis. This was carried out by investigating if the ratio of deer numbers inside the estate to the total numbers observed from any point changed from month to month in a systematic way. This approach is promising and could provide some estimates of seasonal movement patterns. Deer movement across the estate boundary was not detected in this example partly because consistent data were only available for 12 months and were compromised by different counting protocols between observers. Deer were observed to be at higher densities in the northern corries of West Affric. It has been suggested by local managers that these may be acting as a buffer that impedes ingress by deer from neighbouring estates.

Discussion:

ST suggested that the lack of an obvious vacuum effect in this data may be due to the problem of time scale with the analysis limited to one year. SP stated that this study highlighted the need for more counts on neighbouring estates however this would have necessitated more resources especially to conduct counts on consecutive days RL replied that even with more resources for counts the weather is limiting at West Affric with not enough good weather windows on consecutive days each month. SP indicated that if deer are not counted on consecutive days on either side of the march the probability of double-counting increases.

4.2. Creag Meagaidh

Deer have been counted monthly in the 8 zones of Creag Meagaidh NNR from 1992-2005. The data was analysed to test the prediction that, since deer are moving in to Creag Meagaidh from neighbouring estates on a seasonal basis, we should see peak numbers on interior zones lagging peak numbers on peripheral zones. Due to noise in the zonal counts, we investigated patterns in numbers using a smoothing spline. Peak numbers were higher in recent years than during the period when the heavy deer cull was active. There were strong seasonal peaks in all zones in autumn / winter and troughs in spring / summer. The counting protocol adopted at Creag Meagaidh would allow deer movements between count zones within the estate to be detected but because there are no comparable count data from neighbouring estates, it was not possible to detect movement across estate boundaries. Count data collected in a comparable way from zones outside the estate would be invaluable to determine how deer making seasonal movements into Creag Meagaidh are using neighbouring ground during the intervening periods. Local knowledge about deer movements and data quality are important.

Discussion:

ST asked whether deer could be moving from the West into the Interior zones and then continuing to the east of the Estate? SP replied that this was unlikely to explain the patterns observed because the opposite may also occur with deer moving in from the East. JP commented that rather than the middle zones (zones 2 and 3) lagging behind the western edge zone (zone 1), it looks as though the opposite may be true.

RL suggested that daily lags should be expected (not monthly lags, as investigated in the analysis), since deer go in and out of the estate daily. Again, this highlights the issue of time scale in the analysis of movements. LG commented that the outer zone has consistently higher peaks than the inner zones and asked that if all zones originally had similar deer densities (pre-cull) could this be evidence that there is a net influx of deer from outside into the outer zone? If this were true, then analysing the difference in peak heights between outer and inner zones over the years might be informative; if peak heights of inner zones become more similar to those of the outer zone over the years, this may indicate net influxes to the interior of the estate.

LG suggested that one fundamental problem with these data are that we don't have any pre-cull information. We need this to determine whether the current patterns of deer movements have changed as a result of the cull. RL stated that the usefulness of the data depends on whether or not we need to know where the deer come from. At Creag

Meagaidh, managers only need to know deer numbers within the estate in order to continue culling and do not need to know where deer move in from. ST suggested that it would matter where deer come from if there is a problem with neighbouring estates losing revenue from stalking due to a source-sink effect.

4.3. GPS tracking data

This analysis is based on data from individual stags fitted with GPS collars at Mar Lodge for two ten-month periods in 1998-99 and 1999-2000. Visual inspection of the GPS data readily distinguished the non-returning movements of individuals but would require considerable investment to automate the approach for analysing the movements of large numbers of individuals. We analysed the data to determine if range shift rather than seasonal habitat use can be detected in GPS collared stags. We calculated the probability of individual movements over 1km (habitat use) and daily net movement over 2 km (range shift). By comparing these two measures it was apparent that more individual movements over 1km occurred in April and Jul/Aug than at other times of the year. However, daily movements over 2km were most likely Jul/Aug and Sep/Oct. Therefore, stags are more likely to make move away from their normal range in summer and autumn than at other times of the year. Similar data from GPS collared hinds at Invercauld showed that hinds do not range over a wide area and that distances moved between fixes is small. The data for stags show a similar pattern to that found at Mar Lodge. GPS tracking can be used to distinguish between real range shifts and movements for normal habitat use and can identify seasonal variation in the extent of daily movement. However, the problem remains of scaling up from individual movement to population movement.

Discussion:

SR pointed out that GPS are too expensive to be useful as an ongoing management tool for estates and they are useful only for scientific research.

ST made the point that there is a generic problem that, even at the population level, deer movements may be specific to the local landscape and might not be easily applicable between different estates/areas.

4.4. DCS count data

The data comprised census counts of Deer Management Group (DMG) areas (or parts thereof) made in 1983, 1987 and from 1989 to 2004. Counts of individual areas were periodic and not all areas had repeat counts. We analysed the data to test for significant differences within counting blocks in the number of deer over time and for significant changes in the number of deer between adjacent counting blocks which may be indicative of large scale redistribution of deer populations. Nineteen count areas were regarded as having sufficiently spatially consistent counts in at least two years for population changes to be calculated, ranging over periods from one to twelve years. There was no strong evidence for population growth within areas or movement between areas except in a small number of cases where counting methodologies varied between counts and the size of the count area was small and therefore subject to high variability. These data may yield more useful information on movements at the level of individual estates. More robust interpretation of these data could be determined with the inclusion of cull returns at the same geographical scale.

Discussion:

RL suggested that in order to use the count data for estimating long-term range shifts it was necessary to take cull data into account. This would take more time to analyse especially because much of the time in the previous analysis was spent checking and correcting the datasets.

4.5. DCS calf tagging data

Calves were tagged shortly after birth in four sites over periods ranging from three to eight consecutive years and the subsequent location and date of shooting or other mortality were reported back to DCS. We analysed the data to calculate the probability that an animal had moved more than 5km between marking and re-sighting. The fate of the bulk of marked animals was unknown; therefore caution is required because tag recovery rate was around 25% and 61% of these were for hinds. Hinds were more likely to be recovered than stags at all sites. 32% of stags moved more than 5km, but only 14% of hinds. The age at re-sighting was related to distance moved. Stags over 12 months old moved a greater distance and were more likely to have moved >5km than stag calves, hind calves or adult hinds. These individual level data do not provide information about population level movements. However, the data indicate that distances between tagging and re-sighting vary with location and that the degree to which deer move is likely to vary across Scotland. This will be a function of a number of factors, one of which may be local deer density. However, we have not been able to analyse the data in relation to this. Future tagging schemes need to ensure that animals are marked in areas where management and ecological data are available. In addition, there is a need to assess what proportion of the population needs to be marked if the data are going to be representative of population level movements.

Discussion:

AS stated that there was an intrinsic bias in the data from stags and hinds because stags are shot during the rut at the time that they range furthest so obviously the data from culls would show a difference between hinds and stags in the distance moved between tagging and being shot. SP comments that if we use just the hind data, and hinds are shown to move far between tagging and shooting, this might show a true range shift. Stag data would be less useful because stags range during the rut and then return to their home range. In addition, such data cannot show their range use during their life times. LG suggested that the stag data are useful because, in some cases, it is the birth-to-death movement that is of interest, especially if an estate's revenue is from stag shooting but their stags disappear to an adjacent estate during the rut. ST pointed out that if biodiversity impacts are of interest, then the calf tagging data are not useful, because we need information on range use and habitat use in continuous time. Therefore, again it was shown that the usefulness of the data depends on the stakeholder's interest and the specific question being asked.

4.6. Rum North Block data

The Rum North Block has been censused on average 53 times a year from 1973 to present. Groups of animals are observed from a fixed route. All individuals are identified from tags/collars and sex and age-class is noted. We analysed these data to determine: (a) the degree to which an animal consistently associates with the same individuals; and (b) whether the group composition associated with an individual remains the same after a long distance movement. The approach was to select 50 focus animals from each sex at random from both the core of the study area and from the fringe areas. We then determined the 10 individuals that were most regularly seen with each of the focus animals in each year. Using the Jaccard similarity index, we calculated how similar the group composition was between two consecutive sightings of the focus animals. We then investigated how the similarity index varied in relation to the distance that the focus animal had moved since it was last sighted.

The results showed that the movement of one individual stag was not representative of the group because the further a stag moved, the less likely its regular associates were to have moved with it. In contrast the group similarity index for hinds did not decline with distance except during the rut indicating that group composition is more fluid at this time. The data only represent movement of up to 3 km which makes predicting the group fidelity changes over longer distances relevant to this project more difficult. The analyses also showed differences between core and fringe animals. Is this because fringe animals really behaved differently (e.g. because of the proximity of their regular ranges to lower density areas, and possible subjection to culling pressure out with study area), or is it an artefact of their having been recorded less frequently? This could be investigated by sampling the "core" animal sightings in a way that mirrored the "fringe" animals. This dataset could also be used to investigate the proportion of a population that needs to be marked in order to detect population level movements.

Discussion:

JP suggested that movements of deer within the Rum population might not be representative of movements of deer on the mainland, and urged caution in the generalisation of these results to other settings.

4.7. Mar Lodge count and cull data

Data take the form of annual counts and cull data from 5 areas on the estate from 1990-2005. Previous analysis suggests that heavy culling pressure (24%) has failed to reduce deer numbers. The interpretation is that either deer have moved in from neighbouring estates (no evidence from the counts on neighbouring ground) or that earlier counts significantly underestimated the true extent of the deer population. However, foot counts indicate that numbers on the estate are reduced despite the absolute values being underestimated. From 2003 onwards differential culls have been taking place within the estate: In the Northern area, culls are targeted at achieving 5 deer/km^2 compared to targets of 16 /km^2 in the southern area where traditional hunting activities are still an objective. An analysis of these data could test the prediction that counts in the Northern area are not declining as fast as expected from the numbers culled because of an influx from the higher density southern population. For this purpose, data from 1990 to 2002 could be regarded as baseline data to test for changes in deer densities subsequent to the change in target density objectives that has been in place since 2002. Analysis would benefit from cohort type analysis which would require the aged animals cull data which we do not have.

Discussion:

RL added that the North areas of Mar Lodge estate have few hinds and that it is important not to confuse seasonal movements with the vacuum effect. He again suggested that an increase in the number of hinds, as opposed to stags, might suggest a real range shift because hinds generally range less widely than stags. RL also suggested that information on calving rates would be needed to tease apart the effect of immigration and the effect of increased fecundity as a density dependent response to culling.

4.8. Conclusions and Recommendations

Zone counts such as conducted at Craig Meagaidh can be very revealing. However, the data need to be collected over a long time period, including baseline data before any management change, to be useful in monitoring long term deer movements over large areas. It is also important to have reliable counting methods involving enough observers and calibration between individual observers. In addition, it would be ideal to supplement the count data with demographic data on culling/mortality rates and calving rates.

Calf tagging studies provide an estimate of the minimum distance moved between tagging and death. This method provides little information on habitat and range use. However, the use of a larger tag, readable at a distance, could allow re-sighting throughout the animal's lifetime.

GPS collars give detailed data on individual movements including range and habitat use. However, there is a problem in upscaling from individuals to populations.

Detailed census data such as available for the Rum North Block provide an opportunity to look at the associations between individuals, and this can help us determine how representative individual movement patterns are. However, we do not know to what extent the Rum deer are representative of mainland deer populations.

General points repeatedly raised were (1) the importance of time scale when considering deer movements, e.g. whether the interest is in diurnal or seasonal movements, or permanent range-shifts/dispersal into new areas; and (2) the relevance of the data or methodologies depends on whether we are interested in understanding deer movements from an academic stand-point, or for making locally relevant guidelines for management purposes.

Based on the analyses summarised here, the following protocol was suggested for monitoring deer movements from a management perspective:

(a) Neighbouring estates should be divided into zones with observers counting on their neighbour's ground together. Training on counting protocols is essential to ensure data are comparable within and between counts.

(b) Baseline counts across the whole area of interest should take place prior to a change in density on the potential sink area. Multiple years of count data are required to overcome the stochastic nature of the data and to detect the long term patterns.

(c) Directionality could be investigated through ear-tagging animals on the suspected source areas to determine if they start appearing in the sink area. If funds allow this could be supplemented by GPS tagging individuals for more detailed movement data.

(d) Data management should be given an increased priority, both within and between the various interested stakeholders.

5. REVIEW OF CURRENT AND FUTURE TECHNOLOGIES (AS)

NB. The following is a summary of the presentation given at the workshop and the resulting discussions. A more detailed assessment of the technologies is given in Annex 2.

5.1 Introduction

A number of different methods have been used for tracking the movements of deer. Direct animal counts and faecal counts have been used to estimate deer numbers on the ground at particular times, while ear-tagging has been used to assess lifetime dispersal of individuals. VHF and GPS collars have been used for the purpose of learning more about deer ecology and habitat preferences. The full range of methods suitable for assessing deer movement can be considered to fall into three categories: (1) 'low tech' methods, which use low cost equipment and provide limited information about large numbers of animals; (2) 'high tech' methods, which use more expensive equipment and tend to provide high-quality detailed information about small numbers of animals; and (3) 'novel' methods, which take ideas from other fields such as the military and forensic science and have a variety of applications.

The criteria against which methods and technologies need to be assessed for their potential for monitoring landscape scale movements of deer include: (1) spatial and temporal resolution; (2) cost; (3) the numbers of animals that can be monitored; (4) the time involved in collecting and analysing data; (5) technical limitations; and (6) acceptability to stakeholders in terms of ethics and practicality. One conclusion from this review is that, at present, rather than there being a completely new technology which could be used to solve the problems of monitoring movements of deer in Scotland, traditional ‘low tech’ approaches and advances in current ‘high tech’ methods and reduction in their costs are more likely to provide the answers.

5.2. Low Tech Approaches

Traditional low tech methods include direct counting, either from the ground, when observers walk a predefined route or man a vantage point, or from the air. Ground counts are labour intensive, imprecise and can disturb the animals, whereas helicopter counts are proving to be more efficient and compare quite favourably in terms of cost. Ear-tagging of calves can be used to measure dispersal if tags are re-sighted, but this generally does not occur until the animals are shot and therefore provides only limited information about deer movements. Another traditional low tech method is pellet group counting, which gives an estimate of deer density based on the density of faecal pellets in an area. However, the method assumes that defecation rates are regular over time and requires an accurate estimate of pellet decay which can vary greatly with weather conditions and with the type of vegetation eaten.

5.3. High Tech Approaches

Current high tech methods include tracking of individuals using VHF or GPS collars. Both depend on live capture in order to fit collars and both use triangulation to obtain locations for the animals. VHF tracking uses traditional radio receivers with human operators who need to keep within range of the collared animals in order to pick up the signals. Manual VHF tracking is extremely labour intensive. A more sophisticated approach is to use automated recording systems with VHF transmitter but this done obviate the need to remain within range of the collars. GPS collars take fixes with the aid of orbiting satellites and can either store the data onboard the collar for later retrieval or transmit to a fixed receiver thus removing the need for operators. GPS collars are currently very expensive (~£1000 to £3000 depending on capabilities) thus limiting their use to small numbers of animals, but prices should fall in over the next decade. GPS technology is developing rapidly with units being produced which weigh as little as 20g and are capable of taking and storing thousands of fixes. Their usefulness is currently limited by battery technology and costs but it is highly likely that there will eventually be an affordable ear tag that can transmit information about an animal's movements throughout its lifetime.

5.4. Novel Approaches

Rather than following individual animals, some other high tech approaches use fixed detectors which are activated when animals pass by. These include PIT (passive integrated transponder) tags, acoustic location systems, heat-sensitive infra-red cameras and seismic detectors, the latter falling into the 'novel' category since they were developed by the military for detecting troop movements, although they have recently been used to monitor the presence of wildlife species, notably elephants. PIT tags are also novel in this context, in that they are routinely used for identification purposes, eg. for opening gates into milking stalls for dairy cows, but have not been used widely for tracking movements. All these systems have potential, but are more suitable for answering questions about movements at specific locations, such as road crossings or feeding sites, than landscape scale movements, since these could require vast numbers of detectors to cover a large enough area. Another potential method for tracking individual animals uses the concept of node tags, which would record all contacts with other tags and thereby produce information on the movements of animals in a contact network, providing some individuals within the network were able to take GPS fixes.

Some of the novel methods simply provide ways of improving our ability to count animals. At the low tech end of things, direct counting could be aided by an adaptation of the paint balling technique. A suitable semi-permanent dye, applied with a paint ball gun, could be used to determine directionality of movement by colour-coding deer from different areas or estates. Paint balling would serve the same purpose as ear tags, but could be applied without having to handle the animals and should be more clearly visible from a distance. Thermal infra-red cameras mounted on aircraft can be used for counting, by detecting small differences in infra-red radiation between the animals and their background, as can conventional aerial photography, although both techniques are limited by picture quality and hence topography and weather conditions. Cost can also be a limiting factor, but unmanned aircraft are now being developed which can fly predetermined routes and carry cameras, making the use of aerial photography on a routine basis more feasible. Remote sensing, using cameras attached to satellites, has now been developed to such an extent that it is possible to identify troops on the ground and to determine the sex of some wildlife species from space. Although some satellite images are freely available on the internet, high quality images are still expensive. Image analysis software is also freely available, but currently requires some knowledge of GIS methods to operate. However, it is anticipated that all this will change, and within a decade it may be possible to log onto the internet and count the deer on your own estate, whenever you choose. The main limitation, as with aerial photography, may be the Scottish weather.

Two other novel methods for tracking animals have been borrowed from forensic science, namely DNA finger printing and stable isotopes. DNA finger printing can assign individuals to populations, based on shared microsatellite markers, and hence indicate long-term movements between populations. Analyses are carried out on faeces, hair or tissue samples and the technique could theoretically be used to track animals in the short term if the same animals could be re-sampled. Stable isotopes can link individual animals to particular areas, based on the fact that isotopes present in the soil and vegetation are incorporated into the growing body parts of animals, such as hair, antlers and bones. The usefulness of the technique will depend on the relative timescale of the tissue growth and the uniqueness of isotope signatures in particular areas.

5.5. Conclusions

The choice of the most suitable technology for tracking movements of deer at the landscape scale will ultimately depend on the particular questions being asked. These questions include the numbers of animals involved, whether or not it is necessary to obtain information on the directionality of the movements and the timescale of the movements. There currently appear to be no “silver bullets” in the terms of novel technologies that can be applied cheaply and simply by practical deer managers. Our review of technologies suggest that simple counting and marking methods may be most useful for deer managers, supplemented in some cases by detailed information from GPS collars. Remote sensing may offer the potential to count animals in the future but it wider application will depend on cost and availability of images.

Discussion:

JP suggested that instead of paintballing deer from the ground, it may be logistically easier to mark deer with paint from helicopters. There was much discussion about the problems of capturing deer to attach devices such as VHF or GPS collars, PIT tags and Node tags. ST made the point that whilst it was logistically feasible to dart deer from helicopters to attach collars this was not currently politically acceptable in Scotland. DS briefly described the use of self-attaching collars. This has been used successfully in commercial forestry plantations in Glenbranter, Argyll. The collar is attached to a noose hanging from a tree and effectively operates as a snare. This approach would have very limited value in an open hill context.

There was an extensive discussion of the future possibilities of remote sensing to count animals and monitor population scale movement. ST stated that remote sensing was currently used to count barren-ground caribou in Canada. Images are currently very expensive and may not be available for times and areas that are required. It was agreed that this technology was promising and require further investigation.

RL pointed out that none of the methods reviewed could be described as “traditional knowledge” and much was to be gained by simply asking stalkers what they know of deer movement patterns. MD replied that if we are interested in deer population responses to perturbation such as the vacuum effect, local knowledge would not be able to predict what the deer would do under these novel circumstances. SP asserted that whatever approach was used for monitoring deer movement, we need more knowledge of the movement and behaviour of deer in a stable situation, i.e. before any perturbation takes place.

6. BREAK-OUT GROUPS

6.1. Introduction

Break-out groups were formed to discuss the following issues:

(1) What are the key questions in relation to deer movement in Scotland?
(2) What are the priorities for further analysis of the existing data sets?
(3) What are the priorities for further investigation of the technologies?

NB. Whilst the groups were asked to consider data analysis and technology separately in practise one group provided a single list of priorities for discussion.

6.2. Report from Group 1

Justin Irvine (Facilitator), Richard Luxmoore (Rapporteur), Willie Lamont, Mike Daniels, Lucy Gilbert, Dave Scott

Key questions:

(1) Does the vacuum effect result when deer on one estate are culled?
(2) Is it possible to maintain differential deer densities between estates?
(3) Whose deer are affected by a big cull? E.g. Is there a source-to-sink, i.e. bulk movement from one area into another?; Are individual animals (e.g. prize stags) lost to a neighbour?; Do other people's deer move in to eat your trees?
(4) What is normal deer movement when the population is stable, and how does this change with perturbation?

There was much discussion about the vacuum effect and (from RL) that, even if deer from one estate do move into a neighbouring estate to fill a vacuum, does that matter if the neighbour does not notice a difference in deer numbers? RL argued that it is not important to know where the deer come from during the vacuum effect; it is only important that the estate conducting the cull knows how many deer it has and thence to cull them or not. However, WL explained that, in practice, most estates seem very interested in where their deer come from and where they go to, and that many DMG meetings turn to this very discussion. This is also essential in terms of collaborative deer management, such as in Strathspey. There was also some discussion about the differences in movement patterns of hinds and stags. Since stags are known to make large movements during the rut but then to return to home ground, is it movements of hinds that we need to be more interested in? A range shift in hinds should reflect a range shift of the local deer population.

Research priorities:

(1) Creag Meagaidh – it would be valuable to look at the count data on adjacent estates, to look at the demography (calving and culling information) on adjacent estates, and to ask the adjacent estates if they have observed a difference in deer numbers or revenue since SNH conducted the cull.
(2) Cost-benefit analysis of novel methods of census and movement analysis, in

particular, satellite images and stable isotopes.

(3) A quick test of the feasibility of paint-balling, e.g. the range of the gun and the length of time the paint remains visible on a deer. This could easily be done at a deer farm such as the Macaulay's Glensaugh.

(4) Add cull data to the DCS count data, and feed the new information into the case studies (described by JI on Day 1).

(5) Demography and density dependence: what is the response in terms of fecundity/calving rates to large scale culls? This information is important because we need to be able to separate out these density-dependent effects on fecundity from the vacuum effect.

6.3. Report from Group 2

Steve Palmer (Facilitator), Josephine Pemberton (Rapporteur), Jenny Bryce, Angela Sibbald, Fiona Leckie

Key questions:

(1) What is the unperturbed ranging behaviour (diurnal and seasonal)?

(2) What is the response to perturbation (diurnal, seasonal and permanent)?

(3) How do individuals compare with populations? Directionality (from a to b) is explicit in this.

(4) What are the impacts of the above on various land uses – natural heritage, forestry/agriculture and sporting revenue?

(5) Development of research and monitoring for (a) researchers and (b) managers.

Data analysis priorities:

(1) Whilst further analysis of the data sets already presented might be of interest it was not felt that this was a priority within the current project.

(2) It was suggested that it would be worth exploring the Rum Round Island data at least to describe it if there were no resources available for analysis.

Technology assessment priorities:

(1) Remote sensing should be explored. First source images and compare to

historic counts of the same area on the same date. Check the availability of usable images for Scotland.

(2) Stable Isotopes. Explore the background isotopic signatures available and at what spatial resolution they are available.

(3) Paint-balling. Duration of paint marking on deer should be tested.

(4) Calf-tagging. If large, visible tags were used, the spatial locations of an individual could be recorded at various times over its lifetime. A desk study should be able to model how many large tags would be necessary to provide useful information, as well as the time, man-power and budget.

6.4. Research priorities for remainder of FF project

The priorities for the remainder of the SEERAD FF Deer Movement Project were discussed and agreed as:

Data analysis priorities:

(1) Rum Round Island Study. Assess suitability for analysis of deer movement. Note that the data is already in hand.

(2) Creag Meagaidh. Add cull data from SNH and compare with count and cull data on adjacent estates.

(3) Creag Meagaidh. Calf-tagging feasibility study. Use Craig Meagaidh data to model the percentage of calves that would need to be marked with large visible tags to provide useful information on deer movement. Incorporate time and financial budgets to conduct such as study. This was carried out as the calf-tagging modelling study (Section 5.7 in Annex 1).

Technology assessment priorities:

(1) Remote sensing feasibility study. How much do images cost? What is the availability of usable images for Scotland? Obtain an image(s) and compare with a known count, matched for date and location. This was carried out and reported as the Satellite Imagery Update (Section 3.11b in Annex 2).

(2) Paint-balling feasibility study. At Glensaugh deer farm, test the range of a paint-ball gun, and for how long the paint remains visible on a deer. This was not carried out, since the method was considered to be unfeasible due to the difficulty of obtaining permission to shoot paint balls at wild deer under the A(SP)A 1986.

6.5. Recommendations for future monitoring of deer during large culls:

There was an extended discussion of the optimal deer monitoring programme to be adopted during large management culls. It was agreed that this should adopt a low technology approach that could be implemented by the Deer Management Group without external scientific support. The following points were agreed as essential.

(1) Pre-perturbation information was required.

(2) Data should be collected on target estate and surrounding estates.

(3) Collect density data from zonal counts.

(4) Collect recruitment data (eg. calving rates)

(5) Collect condition data (eg. larder weights).