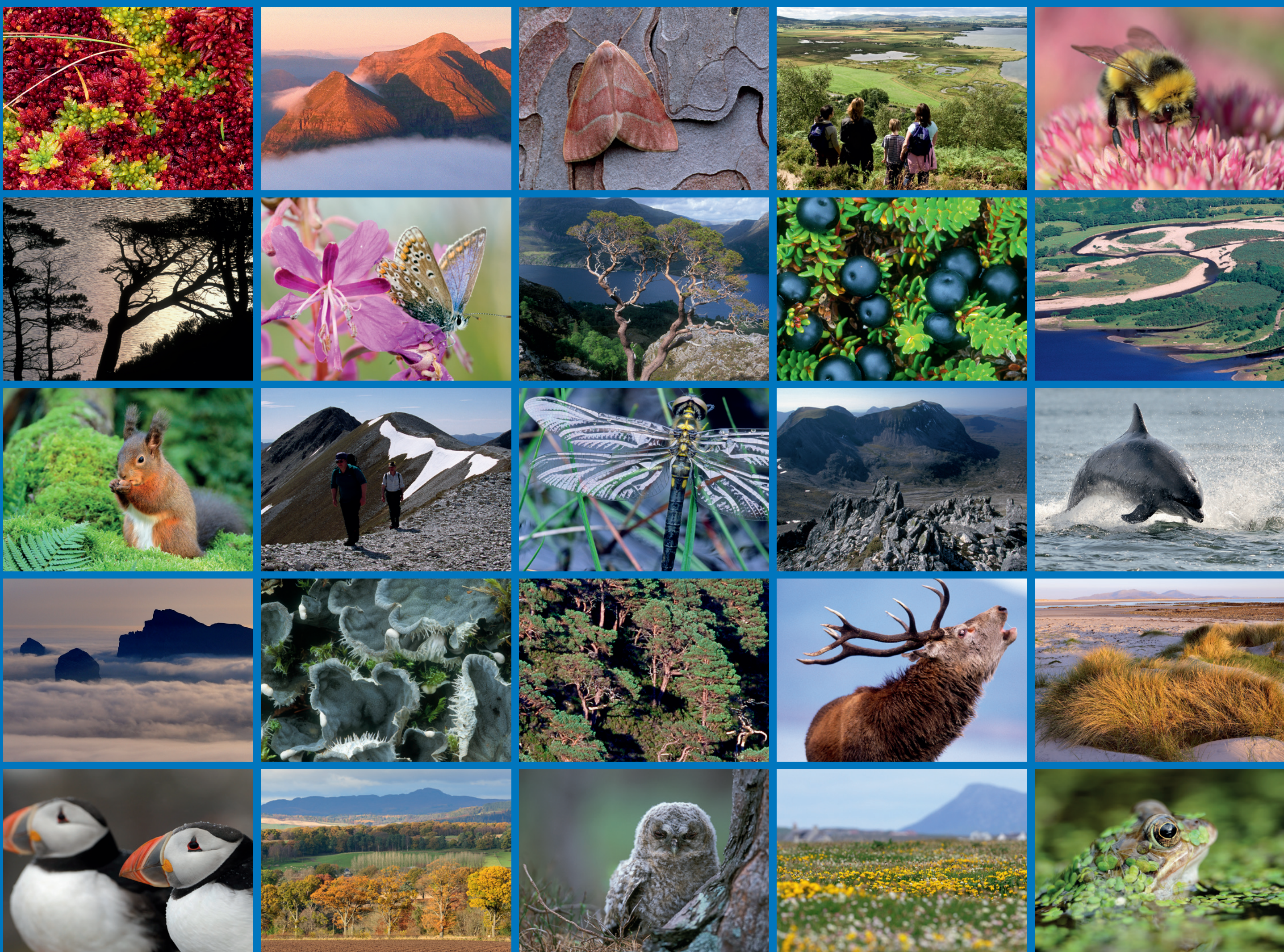
Scottish Natural Heritage
Commissioned Report No. 948

Trends in woodland deer abundance across Scotland: 2001-2016



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COMMISSIONED REPORT

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Trends in woodland deer abundance across Scotland: 2001-2016

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COMMISSIONED REPORT

Summary

Trends in woodland deer abundance across Scotland: 2001-2016

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Keywords

Wild deer; Scotland; woodland; population modelling; historic trends; abundance; density.

Background

Prior to the recent review of deer management by SNH, it became evident that contemporary estimates of wild deer abundance at a national scale were not available.

SNH contacted Forest Enterprise Scotland (FES), which manages the National Forest Estate (NFE), to enquire if their national monitoring data could be compiled and analysed to provide a summary of spatial and temporal trends in woodland deer densities across the NFE. The findings could then be included in the SNH review report for Ministers.

Deer population models were built for 32 forests representing a cross section of conditions across Scotland within the NFE, and covering 38% of the land area under management. Trends in deer abundance over the period June 2001 to June 2016 in each forest were predicted from the models, which used historic deer cull records, estimates of historic deer recruitment rates and estimates of abundance obtained from routine monitoring of the NFE using deer dung counts.

The estimates of deer abundance for June 2016 from the 32 forests modelled were used in an extrapolation exercise which produced an estimate of the total number of deer considered to be currently present within the NFE as a whole.

Using national cull records provided by SNH an estimate of the number of deer present in private woodlands was also produced, albeit using a much less complex methodology, so that a broad contemporary estimate of overall woodland deer abundance for Scotland could also be obtained. The main findings of this review were incorporated in the SNH review of deer management presented to Ministers.

Main findings

- The results of the population modelling exercise indicate that deer population density at the national scale on the NFE has declined markedly since June 2001, albeit this general trend masks a wide range of site-specific trends (decreasing, stable and increasing population density at the local scale).

- An overall decline in deer numbers of between 20% and 30% has evidently occurred between June 2001 and June 2016, but with the majority of the change occurring in the past five years.
- The modelling indicates the abundance of wild deer on the NFE in June 2001 may have been ~ 109,000 or 16.5 deer per km^2. On the basis of culls taken, and prevailing recruitment rates over a 15 year period, that number is believed to have fallen by June 2016 to ~ 82,000 or 12.5 per km^2. This represents a decline of 24% or ~ 26,500 deer over a 15 year period.
- When the overall trend is broken down into regions, it appears that deer densities over the 15 year period have declined markedly more in the South and in the North than in the Central operations areas of the NFE. Moreover, roe/sika/fallow deer densities appear to have declined markedly more than red deer densities nationally across the NFE.
- A complex variety of interacting factors appears to be responsible for the temporal and spatial trends observed in each region, and between deer species groups. These include: recent differences in culling intensity between regions; inherent differences in the proportions of each deer species present (and resulting differences in overall recruitment, as each species recruits at different rates); differences in the type of deer controllers used (employed versus contract); differences in weather patterns; and variation in the degree of external influences apparent (e.g. red deer densities in woodland are in part controlled by factors such as migration from open range populations, which is the likely reason why they have not declined as quickly as roe/sika/fallow over the same period).
- The modelling exercise for the NFE as a whole indicates that the current likely size of the population in June 2016 is 40,000-45,000 roe/sika/fallow deer and 40,000-45,000 red deer (total of 80,000-90,000 deer).
- The most recent annual culls on the NFE have averaged ~ 30,000 – 32,000 animals. If this level of culling continues across the NFE as a whole it is likely that population densities, on average, will continue to decline. That said, there is also good evidence to show that densities are currently rising locally in a proportion of monitored forests, notably so in terms of red deer populations. Allocation of additional culling effort to these places would be required if a consistently low density population of deer is to be achieved, as is the aim of FES nationally so that all their key crop and habitat management targets can be met.
- There is good evidence to show that recruitment rates are rising in many places on the NFE as a result of declining deer densities and, perhaps, due to continuing changes in forest structure. Therefore, culling levels will need to take this into account in future alongside consideration of other key practical factors including the implications of tree species changes due to disease (implications for carrying capacity), declining budgets for forest operations generally and the continuing movement of deer from private land onto the NFE locally (e.g. over the 15 year period since June 2001 it is estimated that ~ 16,000 male red deer and ~ 5,000 male sika deer shot on the NFE migrated into NFE forests from neighbouring private land).
- The situation in private woodlands is much less well understood, even with the various elements of analysis undertaken for this report. The various analyses show that deer culling intensities are lower than on the NFE and recruitment rates are also lower (normally a sign that deer are at higher density, given the geographic distribution of sites and the habitat in private woodlands overall are both broadly similar to that of the NFE). Much more data gathering and analysis is required if the effectiveness of deer management in these areas is to be quantified. In the interim, the results of this study indicate it is safest to assume that deer densities on average are currently somewhat higher in private woodlands than on the NFE, and that populations in general are more likely to be stable on average than declining (as opposed to declining markedly overall as on the NFE).

- The last section of this report makes a range of recommendations on possible ways to improve our understanding of spatial and temporal trends in wild deer abundance in woodland habitats at the national scale in the future.

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Draft by / date	Checked / date	Final by / date	Checked / date
MM 15/06/16	DC 20/06/16	SQ 05/08/16	DC 10/08/16

Standard caveats

- SCL have exercised reasonable skill, care and diligence in the preparation of this document, in accordance with the standards of a qualified and competent person experienced in carrying out work of a similar scope and complexity to the agreed services and current at the time when the services were performed.
- SCL have performed the agreed services generally in accordance with our proposal document or otherwise according to the clients specification, but have in places added to and varied the scope where it appeared to us necessary and reasonable to do so.
- SCL have taken all reasonable precautions to avoid damage to property belonging to the client and any third party.
- SCL worked with sub-contractors to perform part of the services and we exercised all reasonable care to ensure that they were appropriately skilled and experienced in relation to the work that they were instructed to carry out.
- The services and the service products delivered to date cannot necessarily reveal all adverse or other material conditions at the site that could otherwise be identified either through a different formulation of the services or through more detailed work being carried out by SCL.

Specific caveats

- The report in places uses data sets created by other organisations and we cannot be held responsible for their accuracy.
- The timeline for this project was very short, and as a result the full range of analysis we would have liked to undertake was not possible. The Interpretation section of this report lists the related issues and describes potential resolutions.

Acknowledgements

This report was prepared by Strath Caulaidh Ltd with contributions from the following external organisations:

- Ian Fergusson of Forest Enterprise Scotland (FES) for supplying cull records
- Donald Fraser of Scottish Natural Heritage (SNH) for supplying cull records
- Bruce Sewell of FES and Chris Nevin of SNH for jointly locating the funding for the study

1. INTRODUCTION

1.1 Study background

The Scottish Government (SG) recently undertook a review of deer management. When evidence was taken by the Rural Affairs, Climate Change and Environment Committee overseeing the review, it became evident that contemporary estimates of wild deer abundance at a national scale were not available.

Scottish Natural Heritage (SNH) is currently preparing a report on progress in deer management for Scottish Ministers. Part of that report includes information on deer populations and their trends. One relevant source of information is woodland deer density records for the National Forest Estate (NFE).

SNH contacted Forest Enterprise Scotland (FES), which manages the NFE, to ask whether the data could be compiled and analysed to provide a summary of spatial and temporal trends in deer densities nationally in NFE woodlands. The findings could then be fed into the report for the Scottish Ministers as part of the ongoing review of deer management in Scotland.

Strath Caulaidh Ltd (SCL) has gathered all of the woodland deer density data available from NFE land, on contract, since the late 1990's. FES and SNH jointly asked whether SCL, given its long historic involvement in the subject, would be able to help scope out and undertake the proposed study.

1.2 Aims of this study

The final scope of work SCL agreed with SNH and FES was as follows:

- Compile deer density survey data held for the NFE and summarise it. The time available for the project[1] prevented all records from being compiled and analysed for this report, hence it was agreed SCL would provide data for a representative cross-section of the NFE (SCL proposed ideally ~ 50% of the land mass managed).

- Obtain the full national cull records for the NFE for the past 15 years from FES, and analyse to produce statistics (recruitment rates and size of culls taken) for use in deer population models as well as for presentation purposes.

- Input the selected density data sets, and statistics derived from the cull records, into long-term deer population models spanning an agreed period (15 years, from 2001-2016). Use the models to forecast how many deer are likely to be present in each surveyed area in summer 2016. Model output will also be summarised to provide an overview of population trends over the past 15 years, in light of the size of culls taken relative to the rate of recruitment apparent, at the regional and national scales.

- Prepare a short written report, containing chart and map-based output as required, that will describe:

    - The methods used.
    - The key findings of the study (surveyed deer densities, culls taken, prevailing recruitment rates and resulting population trends over a 15 year period).
    - An explanation of the observed trends.
    - Any key recommendations arising.

[1] Two weeks were available to undertake this work, because of the overall deadline in place for the report to be produced.

2. THE NATIONAL FOREST ESTATE

2.1 Overview

Forest Enterprise Scotland (FES) manages the National Forest Estate (NFE) in Scotland. The NFE comprises ~ 658,000ha of land spread across the Scottish mainland and islands (Map 1). The exact size of the landholding varies from year to year due to disposals and acquisitions. The individual properties range in size from less than 100ha to over 10,000ha. The most extensive contiguous landholdings are in Galloway, Argyll-shire and Sutherland.

A large proportion of the NFE comprises commercial forest from which timber products are derived for national and international consumption. Some forests were established as early as the 1920's for this purpose, but most were established from the 1960's onwards; a small number of new forests continue to be created each year.

The harvesting and re-stocking of these forests for timber production is a major part of the work undertaken by FES managers. However, many landholdings within the NFE also contain semi-natural woodland remnants along with planted broadleaf woodland. The most recent acquisitions tend to be for new native woodland establishment projects. Native woodland restoration is another major focus for FES managers.

The NFE also contains a significant proportion of open range habitat, comprising a wide range of site types. Small areas of ride, streamside and glades are commonly found within all forests; a smaller number of landholdings comprise major mountain ranges which have more substantial tracts of heathland, grassland and bog present. Parts of the NFE comprise sites designated for nature conservation (a third major focus for FES managers), including a wide range of Sites of Special Scientific Interest (SSSI's), Special Protection Areas (SPA's) and Special Areas of Conservation (SAC's).

Four main species of wild deer are present on the NFE: roe (*Capreolus capreolus*), sika (*Cervus nippon*), fallow (*Dama dama*) and red deer (*Cervus elaphus*). Their grazing, browsing and trampling impacts on trees and ground vegetation can lead to problems in achieving management objectives across all site types if deer densities are inappropriately high. FES managers currently use a combination of two approaches to reduce deer impacts to an acceptable level: (i) control of deer by culling and (ii) protection using fencing.

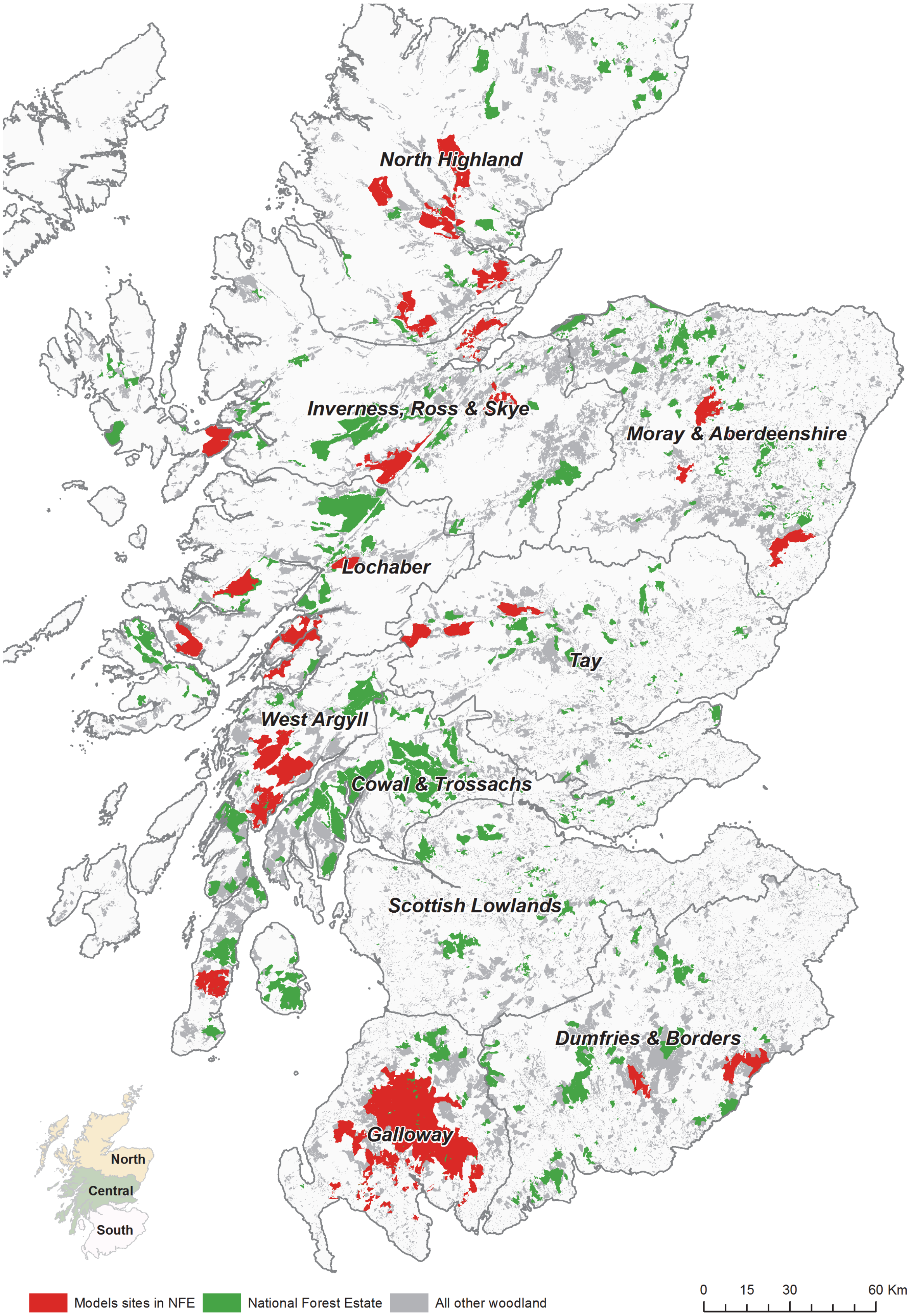
Culling tends to be undertaken across the entire landholding, the aim being to provide a broadly favourable environment for FES staff to re-stock trees, harvest timber and otherwise manage the environment to achieve conservation objectives.

Fencing tends to be used for forest perimeters, most commonly in the red deer range, to prevent wild deer from neighbouring land entering the NFE. In some situations fencing is also used to protect individual planting sites.

FES employs 45 in-house staff to control wild deer ('Wildlife Rangers' or WR) along with around 100 culling contractors working for FES and around 300 recreational stalkers who have Permissions to cull deer on the Estate. The individuals involved in culling are managed by Wildlife Ranger Managers (WRM's) and in turn Deer Management Officers (DMO's). The DMO's are overseen nationally by the Forest Management Officer (FMO).

The deer management operation on the NFE has gross costs of ~ £7 million per annum and net costs of ~ £5 million after £2 million revenues from leases, permit stalking and venison are accounted for. The argument in favour of a net cost in the deer department being sustainable is that otherwise the environment would rapidly become unfavourable for crop establishment (for example in 2015, 18.9% of Year 1 leading shoots on commercial crops were damaged by deer/sheep across the NFE),[2] for harvesting of quality timber and for achieving conservation and landscape objectives - production costs and environmental damage would thus rise, and revenues would decline, as a result in other departments. Also, forest planners would have much less choice over tree species selection and this could have serious implications given the rise in prevalence of tree disease of common crop species at present.

[2] Deer and sheep browsing impacts are difficult to distinguish between unequivocally in field conditions which is why the term ‘deer/sheep’ is employed.



Map 1. Woodland cover in Scotland within each NFE Forest District: private woodland (grey), NFE woodland modelled for this study (red) and NFE woodland not modelled (green).

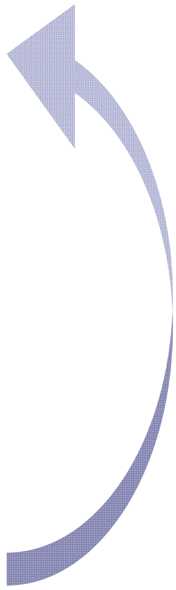
2.2 Monitoring approach

There is a well-developed framework in place to guide woodland deer management on the NFE, which can be encapsulated as follows:

- ✓ What impact are deer having?
    - o Re-stocking impacts on the NFE?
    - o Harvesting impacts on the NFE?
    - o Environmental impacts on the NFE and surrounds?
    - o Impacts on the human population (e.g. traffic collisions)?

- ✓ Are the desired management objectives & targets being met?
    - o YES: continue with the current culling program…
    - o NO: increase the deer cull /use extra fencing as required…

- ✓ To inform decisions on how many deer to cull, establish:
    - o Where do the deer spend their time?
    - o What density are they currently at?
    - o How fast is the population growing?
    - o Is there inward migration of deer?
    - o How long is needed to reduce the density to target?[3]
    - o Is the new cull level effective and efficient?



A range of monitoring has been developed since the late 1990's to try and help provide the Deer Management (DM) team with the information they need to operate this system.

2.2.1 Impacts

A major focus for the DM team is to monitor the impact of deer on the NFE. At present the main way this is achieved consistently at a national scale is through the annual Nearest Neighbour (NN) survey – these surveys have been undertaken across the entire NFE for the past 8 years, although they were also undertaken in individual districts before this date.

- ✓ The NN survey involves an annual assessment of all re-stock and woodland creation sites which are 1 year old. Between 250 and 450 sites are assessed each year depending on the pattern of harvesting and re-stocking apparent in previous years.

- ✓ 20 plots are spread on a grid across each, and the level of deer impact on young planted trees of each species group present is recorded. The data are presented in annual reports for each Forest District (FD) and show the trends across time in browsing impacts observed, benchmarked against national trends and targets set (the

[3] The NFE deer management team aims, in an ideal world, to hold all deer populations at an average density of ~ 5 per km2 to enable 'the majority of targets to be met in the majority of places for the majority of the time'. In reality, conifer crop protection objectives can often be met with densities closer to 10 per km2 depending on the circumstances. For native woodland restoration or standard broadleaf planting without deer fences, however, the density may need to be markedly lower than even 5 per km2. Adoption of general density targets enables robust resource allocation decisions to be made locally, regionally and nationally without recourse to gathering large volumes of site specific impact data across the wide range of issues under consideration (browsing impact on new conifer transplants, impacts on regenerating broadleaves, impacts from bark stripping on mature trees, impacts on ground vegetation, impacts on human population, impacts on neighbouring land managers etc). Research undertaken on the NFE has helped to show in most cases working to these density targets is an effective means of managing towards desired outcomes. It should be noted though that in many areas deer densities are above target. There are many reasons for this, some of which reflect deliberate decisions (e.g. lack of sufficient resources) and some of which cannot easily be controlled (e.g. deer migrating in from neighbours).

main target is for less than 10% of conifer leaders to be browsed in each Forest District). These reports are made available to the Forest Management (FM) teams.

- ✓ The 'background conditions' for each FD are also analysed annually, the reason being that the level of impact recorded on each site is not entirely within the control of the deer manager. In essence, deer use of each site is partly influenced by factors such as its size, its shape and the range of tree species planted – these decisions are made by the Planning, Harvesting and FM teams not the DM team. The overall level of impact at the FD scale is also partly influenced by the number and location of coupes surveyed; deer species and densities vary markedly between and within forests, and the locations/pattern of re-stocking varies each year, hence impacts vary partly for reasons of coupe location alone particularly in FD's where the number of coupes sampled each year is very small. In essence, all the deer manager can do in helping to manage impact on new trees is try to ensure that the deer density between forests is consistently low and that culling can, where possible, smooth out local variations in density within forests. The main factor acting to prevent this is that large parts of most forests cannot be easily culled due to access problems (lack of open ground for effective deer culling / no tracks to extract deer on / not cost-effective to shoot the area compared to other places, when resources are restricted etc).

Other types of impact are monitored by the DM team but this tends to be driven by local demand from FES staff:

- ✓ Open range impact surveys have been undertaken on a high proportion of the key landholdings in the North, often in tandem with dung counts (see later section). These are reported along with dung count results to the DM team, who will forward to the Environment Team as required.

- ✓ The browsing impacts on key semi-natural broadleaf woodlands are sometimes assessed for specific projects. These have site-specific reports which the DM team share with the Environment Team.

- ✓ Bark stripping impacts have, in the past, been assessed in some areas in tandem with dung counts although in recent years this has not been done as managers were focused on other issues. These data are not reported at present but continue to be gathered as part of the national survey program in place for deer density.

2.2.2 Culls taken

The DM team records the details of the cull taken in each area. The information gathered includes the species, age and sex of deer along with the location it was shot at.

The data are input into a national database (the Wildlife Management System); this system will soon be available in a spatial format (GIS). The data have been gathered for decades although the database only has data accessible back to the early 2000's.

The data are used by the DMO's as required for management monitoring (e.g. population modelling, legal returns, collaborative working, cull setting and staff performance appraisals) and are often also used to help with Freedom of Information requests etc.

The data are also used by SCL when they analyse deer density survey results (see below) because part of the process requires a population model to be built, and cull records are used for model parameterisation.

2.2.3 Deer density

A program of deer density estimation has been ongoing for almost 20 years across the NFE. The method employed is faecal pellet group count ('dung counting') because most of the forest cover on the NFE is too dense to allow direct counts to be undertaken. Also, because using a mixture of methods (direct counts on the NFE open range areas and dung counts in the NFE woodlands) does not work in free ranging populations hence dung counts are judged to be the most robust 'common currency' to use in these situations.

Forests in the program are sampled with a system of transects (generally 75m length; 50 – 150 transects per forest depending on forest size and other factors). Normally, dung on each transect is marked on a visit in the winter and then transects are re-visited in the spring when the faecal accumulation rate (FAR) is measured.

This 'pellet group density' data can be converted into an estimate of deer abundance, and in turn deer density, using knowledge of the deer defecation rate. Forestry Commission Bulletin 128, prepared by SCL and Forestry Commission, provides a detailed description of the methodology used in the analysis.

The method is considered to be fairly robust by most users, given the long experience of their deployment on the NFE, but various difficulties in interpretation can be experienced including that:

- ✓ Dung groups are highly spatially aggregated in forests – deer use certain parts of the forest preferentially depending on deer species type and associated behaviour and ecology - hence the pellet group densities measured can be relatively imprecise particularly when sample sizes for survey are small (restricted budgets) or where deer are at low density (more spatial aggregation of dung as deer density declines).

- ✓ Deer can freely move in and out of a lot of the NFE forests, as fences are porous or absent, meaning that the dung counted does not all relate to resident deer but can come from 'break-in' deer. The movement arises mainly from red deer moving in from adjacent open range, but can also arise from roe deer using adjacent woodlands or from colonising sika deer. Conversely some dung from resident deer can be 'missed' because it is deposited out with the NFE boundaries, in fields and neighbouring forests where the NFE deer may go to feed at night but which are rarely incorporated into surveys due to logistical and financial difficulties in arranging for collaborative work to take place.
- ✓ The rate of defecation of deer is not well studied, and the parameters used in models to convert dung into deer abundance are therefore not as well tested as they ideally should be. Experience, along with some recent research work by SCL in Galloway, suggests generally that the values used are too high, implying that deer densities are currently, and with all else equal, being somewhat underestimated on average.

- ✓ The views of local deer controllers are taken into account by managers also when deciding whether a survey report is 'accurate', and in turn when deciding which level of cull to set; their view will often differ from the result of the survey, leading to disagreement over the validity of the survey results.[4]

[4] A large proportion of wild deer shot on the NFE are culled from the forest road network, because this is the easiest way to access the forest. Also, because a large proportion of the annual cull is taken at night, at which time culling can only safely be undertaken form the roads. However, this means a high % of the cull is taken from a very small % of the forest area, and hence culling staff do not necessarily spend so much time in the wider forest. It is considered that culling staff tend to base their judgements on the number of deer they see from the roadside, rather than from a systematic appraisal of deer in the forest as a whole hence the mismatch in views.

The most powerful way to apply the dung count method is undoubtedly when a forest is surveyed in two different years, with known culls being taken in between times. A population model can then be built and forecasted forward to calculate how many deer should be left in the forest based on the estimated starting population, using known culls and using estimated annual recruitment. Model predictions which agree with the second survey help to confirm that the starting population estimate was broadly accurate; models which do not agree were either based on an inaccurate survey, or more often, typically confirm that deer occupancy has declined much more slowly than the model suggests it should have – these are normally examples of ‘inwards movement’ of deer caused by a vacuum being created in the NFE (lower rates of culling outside the NFE is normally shown to be the main cause when tested).

The current program of deer density assessment has been ongoing for 18 years and ~ 85% of the NFE has now been surveyed once, with many areas now surveyed at least twice.

3. METHODS

3.1 Study Site Selection

The national dung count data set formed the basis of this report. However, the actual selection of monitoring sites for this study was influenced by a number of factors. Firstly, there was a very short timescale available to produce the report (2 weeks) which necessarily curtailed ambitions to model all available data. Also, other factors had to be considered:

- The ideal sites to employ in this type of study had at least two assessments undertaken, several years apart from each other and with one of the studies having been undertaken relatively recently (ideally within the last 4-5 years). These study sites were given priority in the analysis but only cover a proportion of the land being managed.
- Some sites had been frequently monitored but are very small in the context of the overall NFE landholding. Given the need to estimate population trends at a national scale for this report it was decided to de-prioritise these sites as each analysis required a fixed amount of time – larger sites in general account for a larger proportion of the NFE deer population being managed.[5]
- Some sites had been monitored twice or more, but were known from monitoring to experience very high levels of inwards migration from neighbouring landholdings. These areas are far more complex to model, hence given the time constraint it was decided to omit them.
- Some data sets from the NFE covered large areas of land, but the surveys are now very old (> 15 years old) and these baseline studies have never been repeated due to the areas being judged 'lower priority' by managers in a regional or national context. The data were omitted, given the large degree of uncertainty over population models run forward for 15 years from the baseline point.
- A small number of sites were assessed with a slightly different method (known as Faecal Standing Crop or FSC; only uses one visit to site and then estimates average pellet group age, rather than employing a known accumulation period – see Bulletin 128), or otherwise had only one recent survey undertaken with no baseline data. These were included in the study where they covered large sections of the NFE, as they would contribute markedly to the overall population trend being modelled.[6]

Overall, a total of 32 sites were included in the study.[7] These covered a total of ~ 248,000 (or ~ 38%) of current NFE land holding which is ~ 658,000ha. A list of the study sites is included within Annex 1 of this report – see sub-headings naming each forest.

[5] It is also the case that the landholdings remaining un-sampled across Scotland (~ 15%) tend to comprise lots of small parcels of land. These are very expensive to assess, as the method involves the use of minimum sample size of plots irrespective of survey area (50 transects, to achieve the *minimum* necessary level of precision). For that reason, the data presented herein suffer from a known bias towards larger landholdings.

[6] Some of these were included for strategic reasons, as otherwise certain Forest Districts would have been severely underrepresented in the analysis (even with this approach some were). Some FD's undertake large amounts of dung counting, whereas others tend not to. This potential bias had to be taken into account when selecting sites for the study. It remains the case that some FD's are underrepresented as historically – for example in the Scottish Borders area - they have not undertaken much counting due to national priorities lying elsewhere (for example, where large nature conservation sites take precedence in the Highland Region).

[7] More can be modelled but there was insufficient time to undertake more work because of the project deadline.

3.2 Models of deer population dynamics

The survey data for each study site was obtained from the most recent survey reports, each of which includes analysis of original baseline survey and any monitoring surveys undertaken since. The deer abundance estimates from these reports were input into a population model which compared the survey results to long term predicted trends in the population obtained by the process outlined below.

The abundance survey data employed had already been corrected for births, such that the data reflected the point of 'maximum population density' in summer as opposed to the minimum population in spring after culling had ceased.[8] The only additional correction applied for this study was on monitoring sites where red deer abundance in the older reports had been estimated using an average over-winter defecation rate of 20 groups per day; the red deer rate has been revised in recent studies to put it in line with the rates that have always been used for roe/sika/fallow deer (16.5 groups per day).[9]

A population model was built for each study site, with a common starting point (June 2001 i.e. post calving) and a common end point (June 2016 i.e. post calving). The survey data from reports were inserted into the model at the relevant times, to act as guides for predicting the most likely population trend over the 15-year period.

Two versions of the model were created for each site, where applicable:

- Model for red deer (the dung of this species can be distinguished in the field from other species due to its size, with relative ease).[10]
- Model for roe/sika/fallow deer (separating out these species is difficult and hence error-prone in field conditions so all three species were modelled together as one group. This is not an ideal approach, as each species has a different recruitment rate due to their biology. That said, the numbers of sika and especially fallow present in many areas are considered to be relatively small, based on cull returns, in comparison with roe – Table 1 – hence in many cases the bias will be limited. Moreover, in the models the recruitment rate employed was weighted by the % of each of the three deer species shot annually to minimise the extent of any residual bias).

[8] This is the population density measured by dung count surveys, which are almost always completed in early spring before calving takes place in late spring.

[9] This change arose from a large body of evidence gathered over 20 years of work. It is often found from long term studies that deer numbers are under-estimated using the current system, in particular red deer and sika deer. Moreover, a recent trial in the Galloway Forest Park found that red deer over-winter were defecating at a much lower rate than previous research in the 1980's had shown. A decision was made, given the evidence, to bring the red deer rate in line with roe/sika/fallow deer until such times as further work can be undertaken. As a result, the old results reported are now considered to be under-estimates and hence were scaled up accordingly for this study.

[10] FC Bulletin 128 describes the process, which employs various field-based techniques coupled to post-hoc analysis using modelled national data. http://www.forestry.gov.uk/fr/infd-6xgf8f

Table 1. Deer species present and percentage culled within each forest district.

DMO Area	District	Roe deer	Sika deer	Fallow deer	Red deer	% Roe	% Sika	% Fallow	% Red
North	Inverness, Ross & Skye	Yes	Yes	Yes	Yes	30%	20%	<1%	49%
	Moray & Aberdeenshire	Yes	Yes	No	Yes	91%	<1%	0%	9%
	North Highland	Yes	Yes	Yes	Yes	34%	36%	0%	30%
Central	Cowal & Trossachs	Yes	Yes	Yes	Yes	25%	<1%	0%	75%
	Lochaber	Yes	Yes	No	Yes	21%	5%	0%	74%
	Tay	Yes	Yes	Yes	Yes	43%	<1%	8%	49%
	West Argyll	Yes	Yes	Yes	Yes	28%	21%	0%	51%
South	Dumfries & Borders	Yes	Yes	Yes	Yes	89%	7%	4%	0%
	Galloway	Yes	Yes	Yes	Yes	70%	<1%	5%	26%
	Scottish Lowlands	Yes	Yes	No	Yes	93%	1%	0%	6%

The known level and composition of annual cull for each of the 15 years was added into each model for each species group.

The rate of recruitment used for each population was estimated in the first instance using a standard 'long- term average' for the forest, based on the % of juveniles culled[11] 'at the foot' of females each winter.[12] However, it is evident from national cull records that the rate of recruitment on NFE land does clearly vary between years – contributory factors include variations in the weather, as well as the density of deer present (this varies according to the intensity of cull taken annually, and the consequent trend in population density year-to-year). National data sets were analysed to quantify the overall annual trend for red deer recruitment and for roe/sika/fallow deer as separate groups. The long-term national average for each species group was calculated and then the difference between this and the local rate for each of the 15 years in the model was calculated (e.g. 5% lower than the long-term average, 11% higher etc). These differences were used to adjust the long-term average recruitment rates in each model, for each species group, to make them more accurate on an annual basis and thus help increase overall model accuracy.[13]

Some NFE forests show a skew in the cull records towards male calves in comparison with female calves. There are a number of reasons for this, the main one being that the

[11] This estimate takes account of any calf mortality occurring in early summer when juveniles are first born. Otherwise, the total number of calves born at the start of the year is estimated and then an adjustment is made for natural mortality in the first year.

[12] There is a known bias in the ageing of juvenile deer, arising because of the way deer are processed in the larder. In essence, juvenile male deer are shot in April and May each year but tend sometimes to be recorded as 'yearlings' rather than 'juveniles'. The result is a slight underestimate of the % juveniles culled 'at foot' and in turn causes a slight underestimate of the recruitment rate used in models. However, the error is variable between areas hence was not accounted for herein.

[13] It is not generally advisable to undertake this calculation for each forest on its own because numbers of deer culled are relatively small, and statistics calculated from these data are likely to be unreliable in comparison with regional and national scale patterns observed (these are assumed to be far more robust even though some regional and local bias will then creep in).

populations are heavily culled and in such cases male red deer calves tend to be more often produced, and survive better, in comparison with places where environmental stress on the mothers is high during gestation and lactation (e.g. open range populations, woodland populations at high density). In some areas, the skew is towards female calves in the long-term records. Models took account of this by initially setting the annual sex ratio at birth in relation to the long term proportions of male: female calves shot in each study area. Limits were set on this such that no more than 55% and no less than 45% male or female calves could be present.

Allowances were also made for natural adult mortality, poaching and road traffic collisions. Experience of the NFE sites over a 20 year period of work suggests that the combined level of all these ‘other forms’ of mortality is low overall (i.e. almost all adult deer die from being officially culled). Evidence includes the fact that it is very rare to find skeletons of wild deer in these forests, during dung counts, other than occasional calves. Moreover, most forests have few or no public roads passing through them at all, and most forests are heavily patrolled by stalkers and busy with contractors meaning illegal culling is assumed to be very limited *relative* to the size of populations present. The level in all models was set at a standard combined rate of 1% losses per annum, which will in some places overestimate and in some underestimate the ‘non-cull’ losses.

In order to help identify the best fit of survey and cull data, the model employed was sex-age explicit. Models had 3 streams of data running in tandem: males > 1 year old, females > 1 year old and calves < 1 year old. An assumption was made at the start of each model that the adult sex ratio was 1: 1. The trend in abundance of each sex-age group over time was then assessed separately. In most cases models for females and calves fitted well whereas male models sometimes did not achieve a satisfactory fit – this is because of an underlying problem of male deer being mobile in many of the study sites. Indeed, it is well documented that in many NFE properties an excess of red deer stags (and sometimes the males of other species, particularly sika deer) are culled each year. In the past 15 years, almost 16,000 more adult red stags and 5,000 more adult sika stags have been culled on the NFE compared to adult females of the same species. In part this arises due to a differential level of culling effort (the length of time males are culled for is longer, taking into account ‘authorisations’ to shoot ‘out of season’) in some forests. However, the main reason this arises is thought to be because of movement of deer into NFE forests. This happens often in winter during severe weather, when red deer stag body condition is very poor and they come to seek shelter and better grazing but are then shot. In the case of sika stags a common cause is where they are actively colonising new ground as part of their ongoing range expansion in Scotland. In the case of roe deer movement typically arises due to territorial behaviour and the resulting inwards migration from neighbouring properties holding deer at much higher density, which is particularly important in lowland forests.[14] In this study, ‘excess’ male deer[15] in the cull records were removed before modelling long-term population trends, as they were assumed to be ‘non-resident’ hence would otherwise have skewed the long-term model results markedly.

Once the models were parameterised appropriately, the ‘start population’ was estimated by a process of iteration, as in almost all cases baseline survey data were gathered post-2001. The process employed was to increase the start population size gradually, by a fixed amount each time, until such times as the predicted trend passed through as many (or all) of the

[14] Young roe deer (in particular male deer but also female deer), will move from woodland areas of high density to low density in the spring when their mothers push them out of their territories to reduce resource competition.

[15] The excess was defined as the total adult males minus the total adult females culled. In effect, the number of resident male deer shot each year was assumed to be equal to the number of adult females shot.

monitoring data points. Where possible the model was fitted, by varying start population size, to pass between the 'mean density' and upper 95% confidence limit of each density estimate,[16] but where this did not occur the model was preferentially fitted through at least one density estimate in the same way (the most recent estimate if possible). In some cases this process of re-fitting also failed to result in the predicted trajectory passing through any of the re-survey points. In these cases, the model was first checked to ensure the adult sex ratio predicted was close to 1: 1 (we would not expect significant skews in the long term within enclosed populations) – adjustments were made to the birth sex ratio where needed to achieve parity in the adult sex ratio over the duration of the model. An additional step, where required, was to vary recruitment rates through a process of systematic increase[17] (or decrease in a few cases)[18] until the model achieved a best fit with the data to hand.[19] This often resulted in models which only fitted part of the abundance monitoring data, but was judged on balance to provide the best fit overall. Annex 1 contains all the model output, which shows how survey data fitted long-term model predictions. There are a number of reasons[20] why some of the abundance data did not always appear to provide a close fit, with key reasons being that:

- Sampling error on estimates is sometimes marked due to necessity, because of the small sample sizes that often have to be employed for budgetary reasons.
- Sampling error can be marked for populations at low density, because dung is highly spatially aggregated in such places. This often affects red deer population estimates where the deer can be present in small numbers due to occasional winter presence only.
- Bias is known to be present in some estimates, particularly older estimates, due to the involvement of Wildlife Rangers in some of the surveys – audits of their plots showed there to be underestimates of dung in some cases.
- Some surveys had to be completed in a narrow time window, for operational or weather-related reasons, which reduced the time plots have to accumulate dung – a short duration survey results in lower precision.

To illustrate model sensitivity, once the model had been fitted to satisfaction as described above, two additional model runs were undertaken and the results plotted on the same chart for comparison; in one run, the selected start abundance was reduced by 1% and in the other the selected start abundance was increased by 1%.

3.3 Compilation & extrapolation of model outputs

The data from the 32 forests (32 roe/sika/fallow models & 29 red deer models; total of 61 individual models) were compiled into a single database and this was used to create a range of outputs for presentation. This included trends at individual forest scale and on per species group basis. The data were then aggregated to illustrate trends at the DMO scale and the national scale. FD scale data were also produced, but are only of value where there was judged to have been sufficient coverage of surveys included in the modelling exercise. The FD's considered, on this basis, to have inadequate coverage from which to determine trends at the district scale are listed in the table below.

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[16] This was because in many cases long-term studies show that the methods being used for survey of deer abundance tend still, with all else equal, to under-estimate deer numbers.
[17] The approach to ageing deer in the larder is known to cause an under-estimate of the calves shot, as previously mentioned.
[18] Stalkers have to select which animal to cull in a group, and in some places this is thought to bias the proportions of deer culled relative to their occurrence in the wider population.
[19] There is a range of common reasons why long term models of this type will not always fit the survey data available. These are described in the Interpretation section of the report.
[20] See Annex 2 for a list of other possible reasons.

Table 2. Summary of models used in the analysis.

DMO Area	District	Area (ha)	% Land included in models	No. forests modelled	No. of models: roe/sika/fallow	No. of models: red	Comments
North	Inverness, Ross & Skye	82,642	30%	4	5	4	
	Moray & Aberdeenshire	59,025	26%	4	4	4	
	North Highland	72,854	50%	6	6	6	
Central	Cowal & Trossachs	59,218	7%	1	1	1	Poor coverage – only 1 forest modelled
	Lochaber	56,723	26%	3	4	4	
	Tay	37,592	27%	3	3	3	
	West Argyll	96,103	44%	5	5	5	Includes Barcaldine which covers West Argyll and Lochaber FD
South	Dumfries & Borders	57,754	16%	2	2	0	Poor coverage – only 2 forests modelled
	Galloway	115,868	79%	3	2	2	Large forest units – very well covered
	Scottish Lowlands	20,108	0%	0	0	0	Poor coverage – zero forests modelled
ALL	Total	657,889	38%	2	32	29	Good general coverage, but with local spatial bias apparent (Map 1)

As the combined model output only covered ~ 38% of the NFE landholding an estimate of abundance across the entire landholding was ideally needed. The available model outputs were used, along with a Geographic Information System, to produce an extrapolated estimate of deer abundance and trends across the entire NFE over the past 15 years. This process is inherently error-prone,[21] but it was still judged worthwhile to attempt because the central aim of the wider SNH project is to produce national estimates of deer abundance as well as an indication of recent historic trends leading to 2016.

A basic GIS model of the NFE was built to quantify the physical nature of the land inside the 32 study sites (~ 38% of land area) in comparison with the remaining land comprising ~ 62% of the NFE. It included the following elements:

- Forest area (ha) and open range area (ha)
- Altitude (number of hectares within 100m bands)
- Soils (broad classes – e.g. brown earths, peats, podsols etc)

The GIS model was used to derive statistics on the % of land in each of the categories listed above, within (i) the combined study area covered by our 33 study sites and (ii) the wider area not included in our models.

[21] Particularly due to the severe shortage of time available to undertake this work – a total of only 2 weeks from the date of commissioning to draft stage.

A similar process was undertaken on the national cull data set, whereby a variety of statistics were generated and compared within (i) the combined study area covered by models and (ii) the wider area not included in models. The statistics compared were:

- Proportions of each deer species culled
- Densities (per km^2) of each deer species culled
- Rates of recruitment within each species group

The resulting GIS model and cull-based data were assessed to evaluate how similar the land included and excluded from our models was. The process of extrapolation was determined following an assessment of the level of similarity between the 'modelled' and 'not modelled' areas. The process followed is described in the relevant results section.[22]

3.4 Factors influencing abundance trends on the NFE

National cull data for the NFE were analysed and assessed at the block, FD, DMO and national scales. The aim was to understand by how much culls varied each year, relative to the levels of recruitment expected from predicted abundance levels. The findings were presented alongside output from each study site model, to facilitate comparison (see Annex 2).

The national data set on crop impacts was also examined and trends in impacts at FD, DMO and national level were compared with those obtained from deer density modelling. This data set is, in some senses, considered to be a rough proxy for deer densities at large spatial scales such as in Galloway and North Highland (the exceptions to this are the small FD's like Tay and Lochaber which have lots of small spread out forest blocks and very limited re-stocking programs).[23] The aim was to compare impact trends against abundance trends and see whether any general relationship was apparent. Of course, it is also true that the national impact results influence, to an extent, allocation of culling effort each year - this was another reason for presenting this data (i.e. the deer culling levels from ~ 2010 onwards were undoubtedly influenced by a sequence of relatively poor crop impact survey results in preceding years).

Another analysis undertaken employed the Sub-Compartment Data Base (SCDB). This model confirms the spatial extent and ages of all forest crops and native woodland as well as open range habitats in Scotland within the NFE. A simple model was created in Excel to assess retrospectively the general changes in overall forest structure and composition that have occurred since 2001 (i.e. since the start of our modelling period) on the NFE at National scale. The aim was to establish what level of underlying change might have occurred in the carrying capacity of the NFE forests – this could conceivably help explain, to an extent, trends in deer abundance over the period.

Another analysis examined the changes in the way in which the national cull has been taken over 15 years in different areas and overall. Known changes in management approach over the past 15 years have occurred, with a general move towards contract stalkers being used in preference to government-employed stalkers as they have retired or moved to other posts. Also, over the same time, there has been some variation in the extent of stalking leases offered on the NFE - in middle of the model period NFE managers experimented with an

[22] A more robust but more complex based on regional differences could be employed, but there was not time. In addition, there are other dung count data sets that could be modelled, to increase survey coverage, but again no time was available to do this.
[23] A very small number of coupes assessed each year, when coupled to their inevitably wide ranging physical characteristics and locations, tends to result in wildly varying average impact levels being recorded annually.

approach based on renting out land for stalking to try and re-coup some of the costs of deer management, whereas before that and more recently this has been used less often. Again, changes in management approach may help in part explain the trends in abundance predicted by models.

Finally, an assessment was undertaken to examine the nature of the weather over the past 15 winters, plus related factors affecting cull practicality. The winters of 2009-10, 2010-11 and 2012-13 were very severe, with snow cover lying for very long periods especially in the east of Scotland. This severely impeded the ability of stalkers to access some sites, and resulted in cull targets not always being met. A similar situation existed during the foot and mouth outbreak of 2000-1, which meant that access to many areas was restricted for a long period. The reduced cull this season (not shown in our records) meant that many populations were severely under-culled, which in turn had consequences for subsequent years (as covered by the start of our modelled period in 2001).

3.5 Abundance trends in private woodlands

For interest, nationally-available private sector woodland data were also examined. The private sector does not in general undertake systematic deer abundance survey work nor in general does it undertake formal impact assessments as on the NFE. That said, they do provide cull records to SNH. Cull data were analysed and compared to the returns from the NFE over a similar period, to check for similarities and differences in the pattern of culling and the pattern of recruitment – both of these variables can provide an indication of deer density and trends over time, if compared with other information available. The aim of this analysis was to ascertain whether a sensible ‘ballpark’ estimate of deer abundance in private sector woodlands might be obtained using easily available data.

3.6 Comparison with open range populations

Cull data for open range areas were provided by SNH, at the same time as the private woodland data. These data were analysed alongside those from the woodlands, to help illustrate the fundamental difference between populations using these two types of habitat, namely the inherent differences in recruitment rate relating to environmental differences. The aim was to help illustrate how much harder it is to manage woodland populations, and also to highlight other important related factors (e.g. inwards movement of open range deer to woodlands in winter).

4. FINDINGS

4.1 Modelled abundance: part of the NFE

The outputs from individual population models for each species group are presented in Annex 1[24] along with the cull data employed in each. Maps 2-4 illustrate the results spatially. The outputs from models were also compiled and used to create an overview of the results at three spatial scales: national ('ALL'), by DMO area and by FD (Figures 1-4). The results suggest that the abundance of wild deer, on the 38% of the NFE modelled, in June 2001 may have been ~ 35,000 or 14 per km^2 (Figure 1 & 3). On the basis of culls taken, and prevailing recruitment rates over the period, that number may have fallen by June 2016 to ~ 26,000 or 10 per km^2. This represents a decline of ~28% or ~ 9,500 deer over a 15 year period.

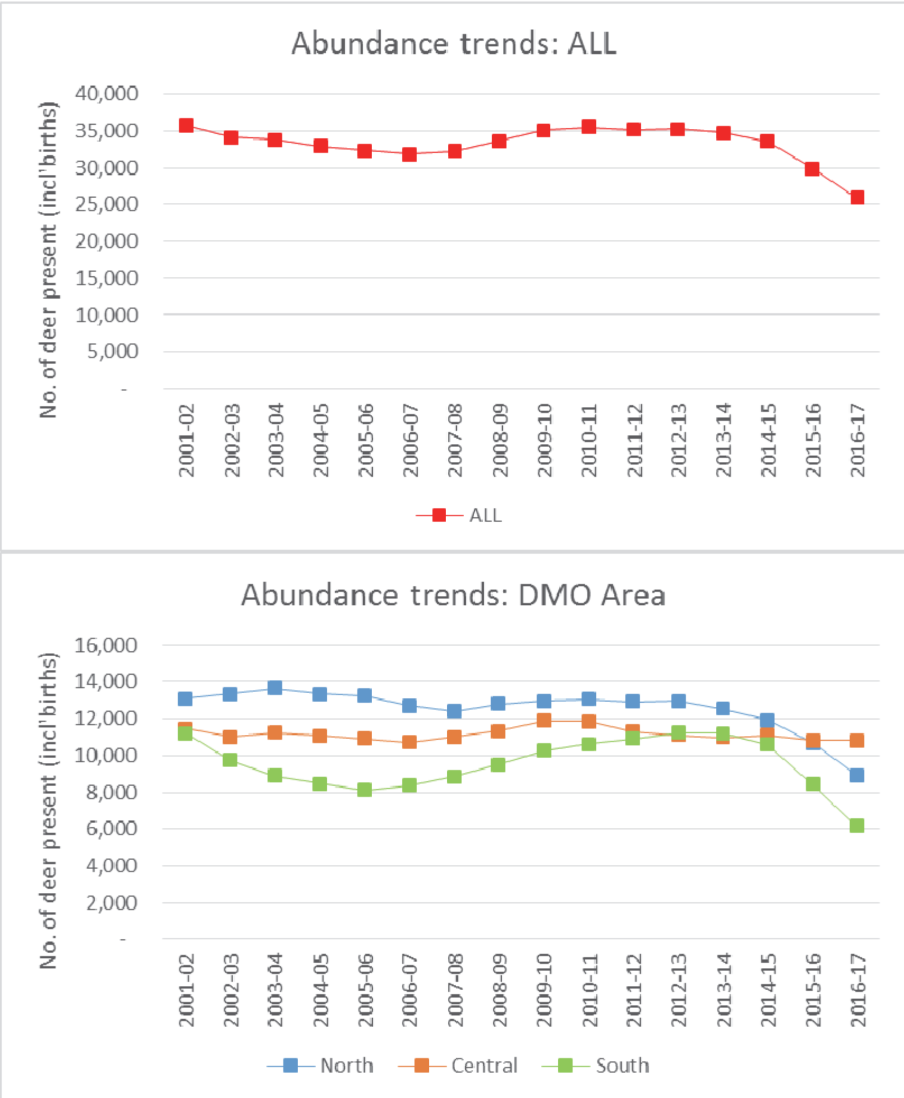


Figure 1. Aggregate deer abundance estimates from the 32 modelled NFE forests: National & DMO trends. The models cover 38% of NFE land.

[24] Each forest is presented on a separate page. There are 4 charts: (i) modelled prediction of abundance for roe/sika/fallow deer, (ii) chart showing roe/sika/fallow deer culls taken compared to predicted calves born, (iii) modelled prediction of abundance for red deer and (iv) chart showing red deer culls taken compared to predicted calves born.

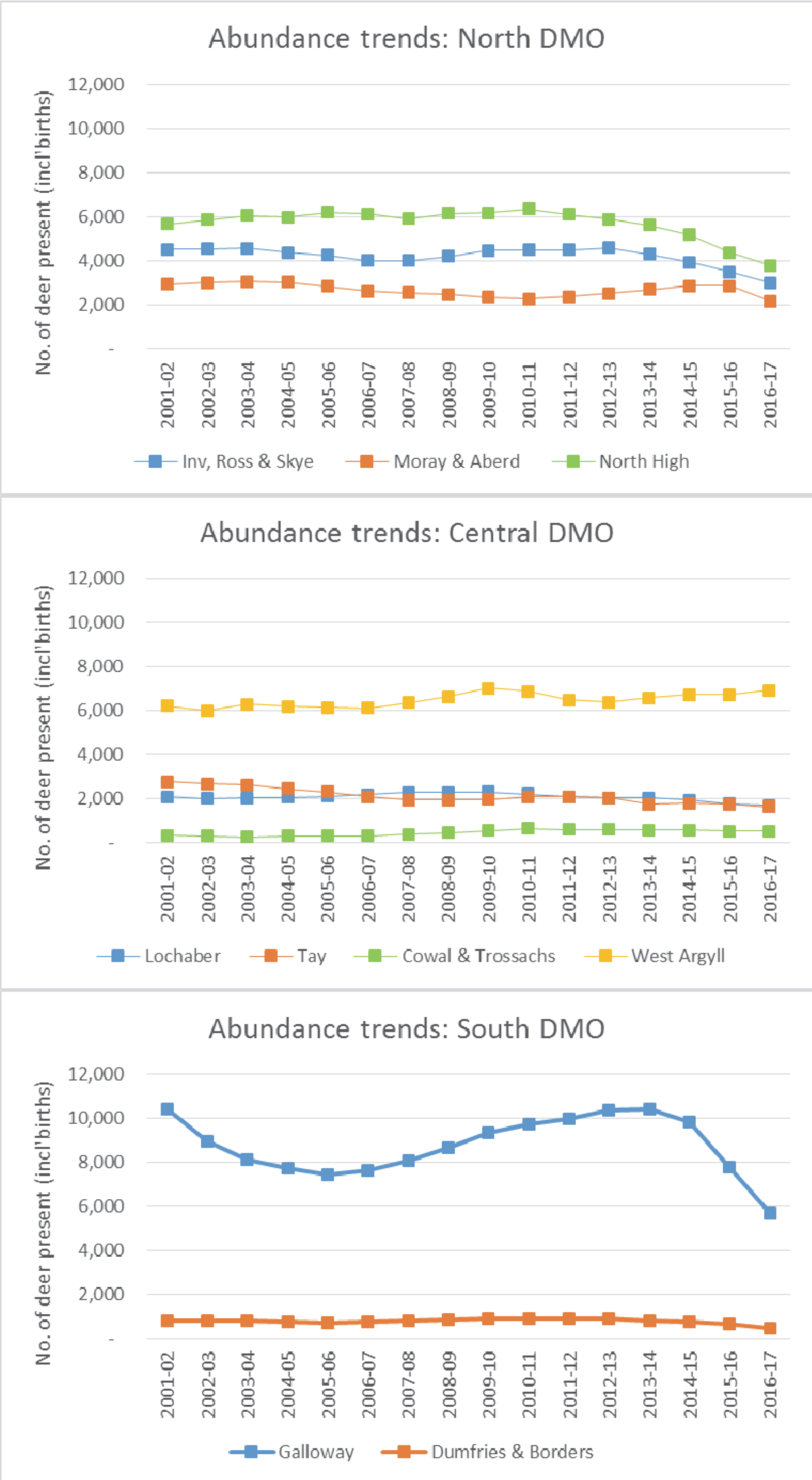


Figure 2. Aggregate deer abundance estimates from the 33 modelled NFE forests: Forest District trends. The models cover 38% of NFE land.

Figure 3. Aggregate deer density estimates from the 33 modelled NFE forests: National & DMO trends. The models cover 38% of NFE land.

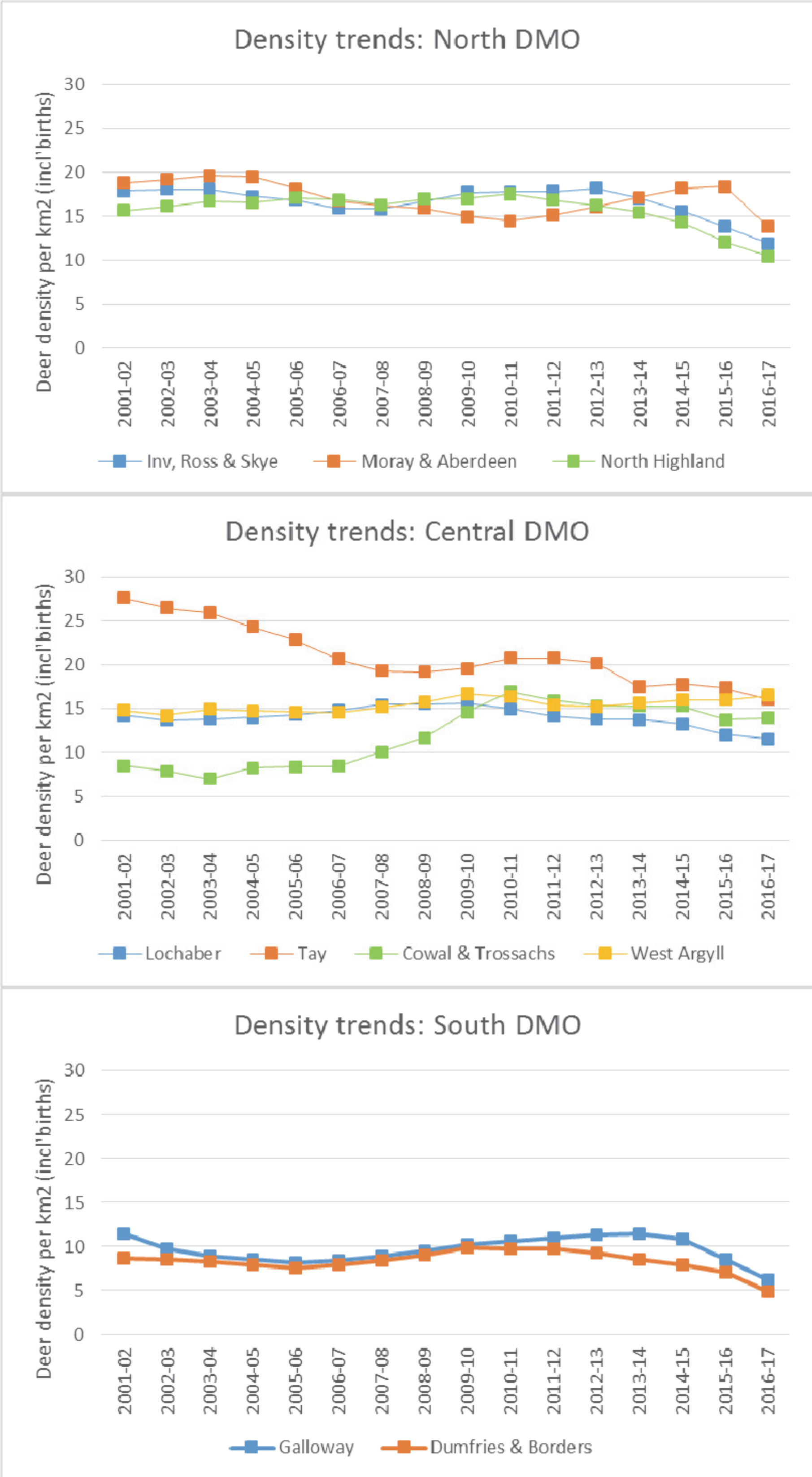
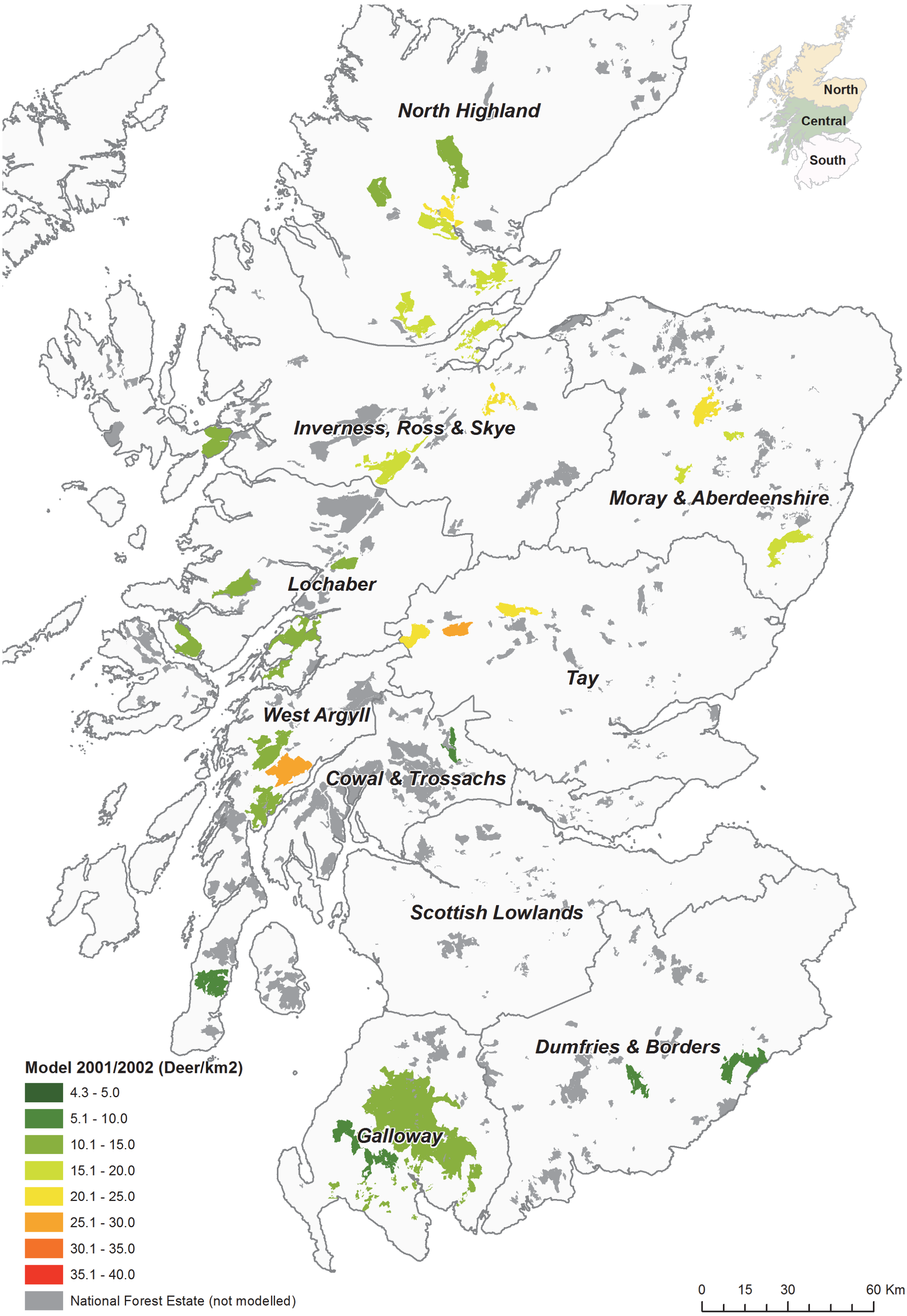
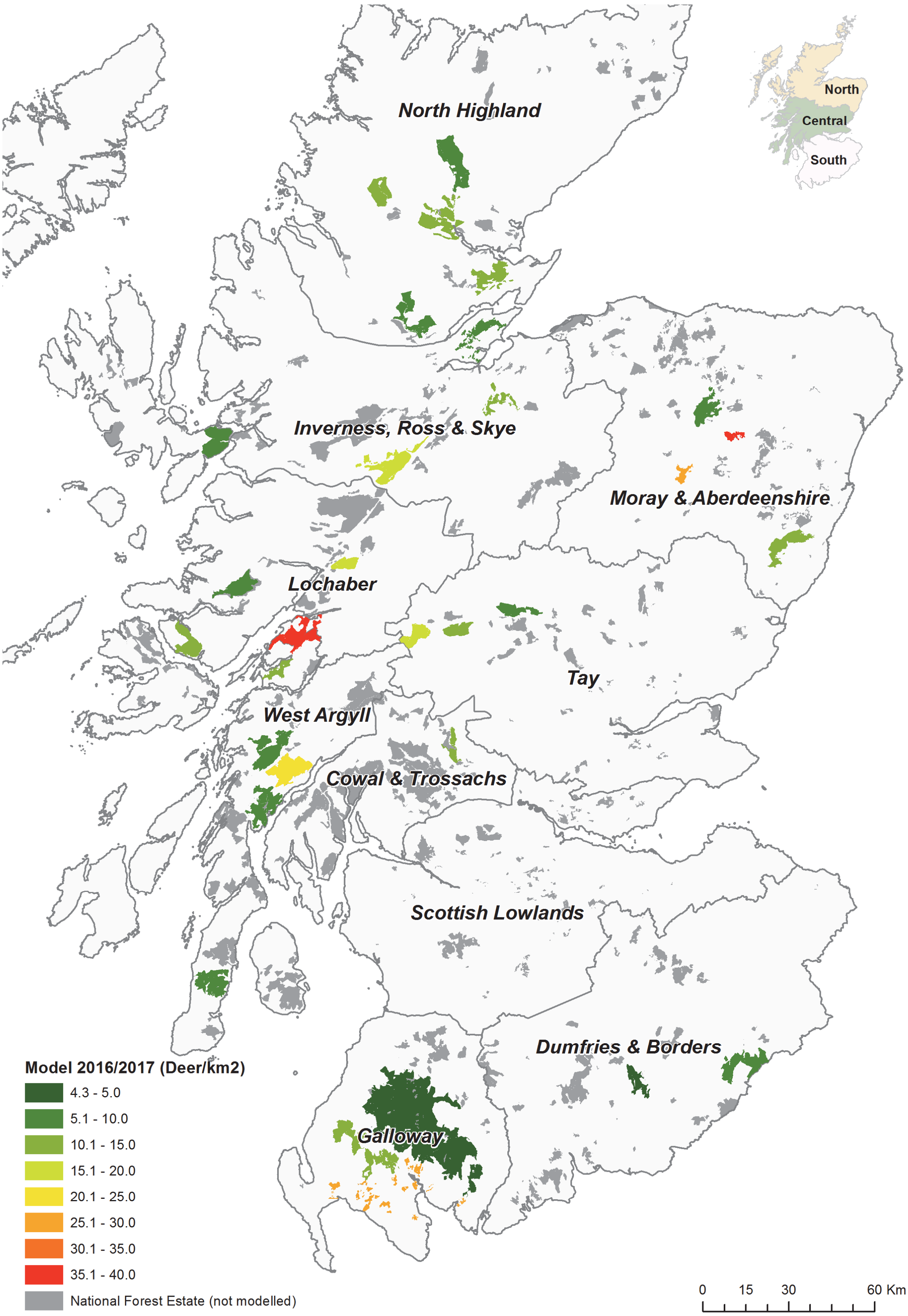


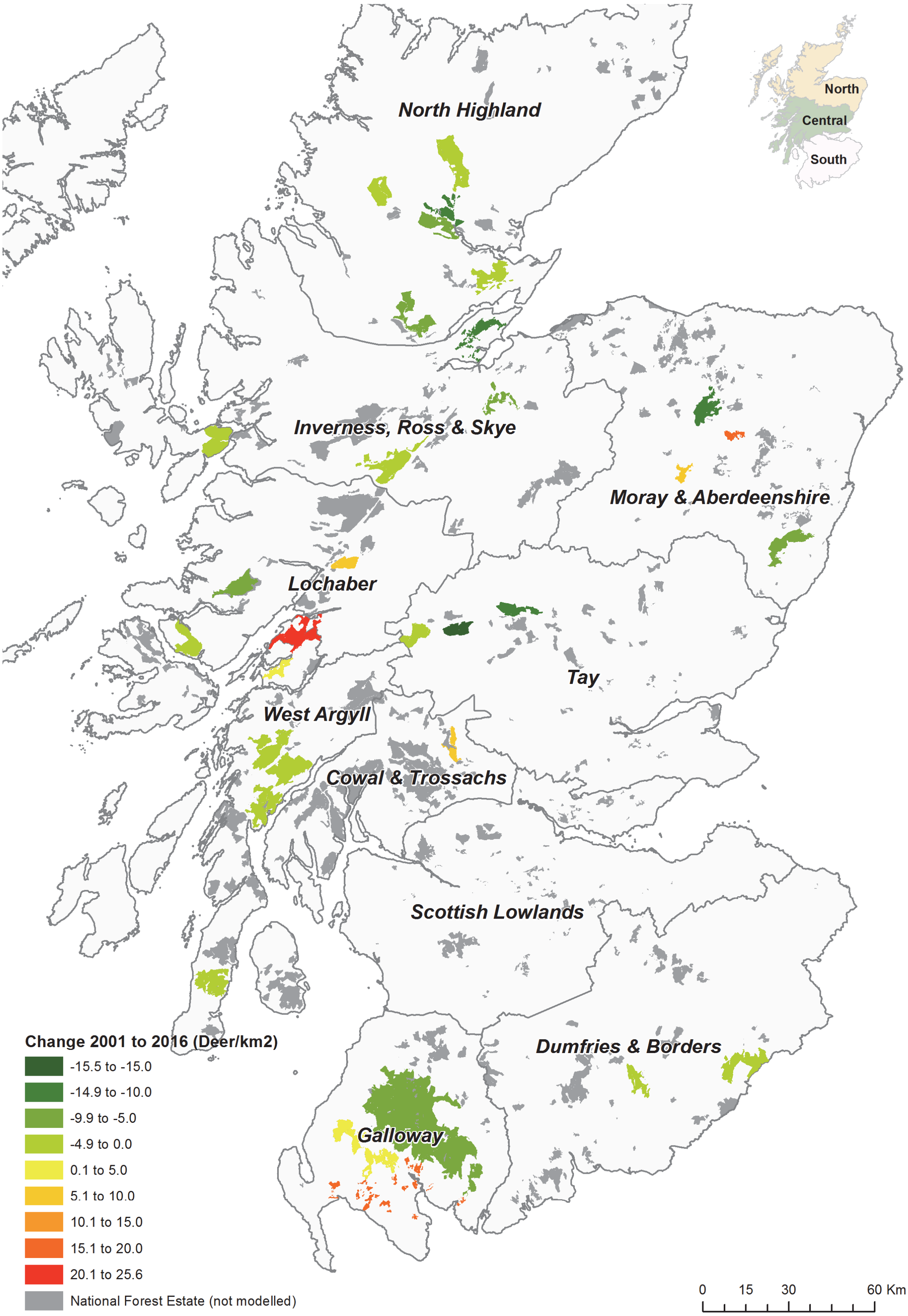
Figure 4. Aggregate deer density estimates from the 33 modelled NFE forests: Forest District trends. The models cover 38% of NFE land.



Map 2a. Deer density per km2 in each study area, as predicted by models, in June 2001.



Map 2b. Deer density per km2 in each study area, as predicted by models, in June 2016.



Map 2c. Change in deer density per km2 in each study area, as predicted by models, between June 2001 and June 2016. Green = reduced population density over the modelling period, and orange/red = increased population density over the period.

4.2 Predicted abundance: the entire NFE

The 32 modelled forests cover a total of ~ 38% of NFE land. The land not covered by models, a total of 62% is, in general, very similar in character to the land covered by models (Figure 5). The % of woodlands versus open range, the % of land within various altitude bands and the % of land within various key soil classes is all comparable.

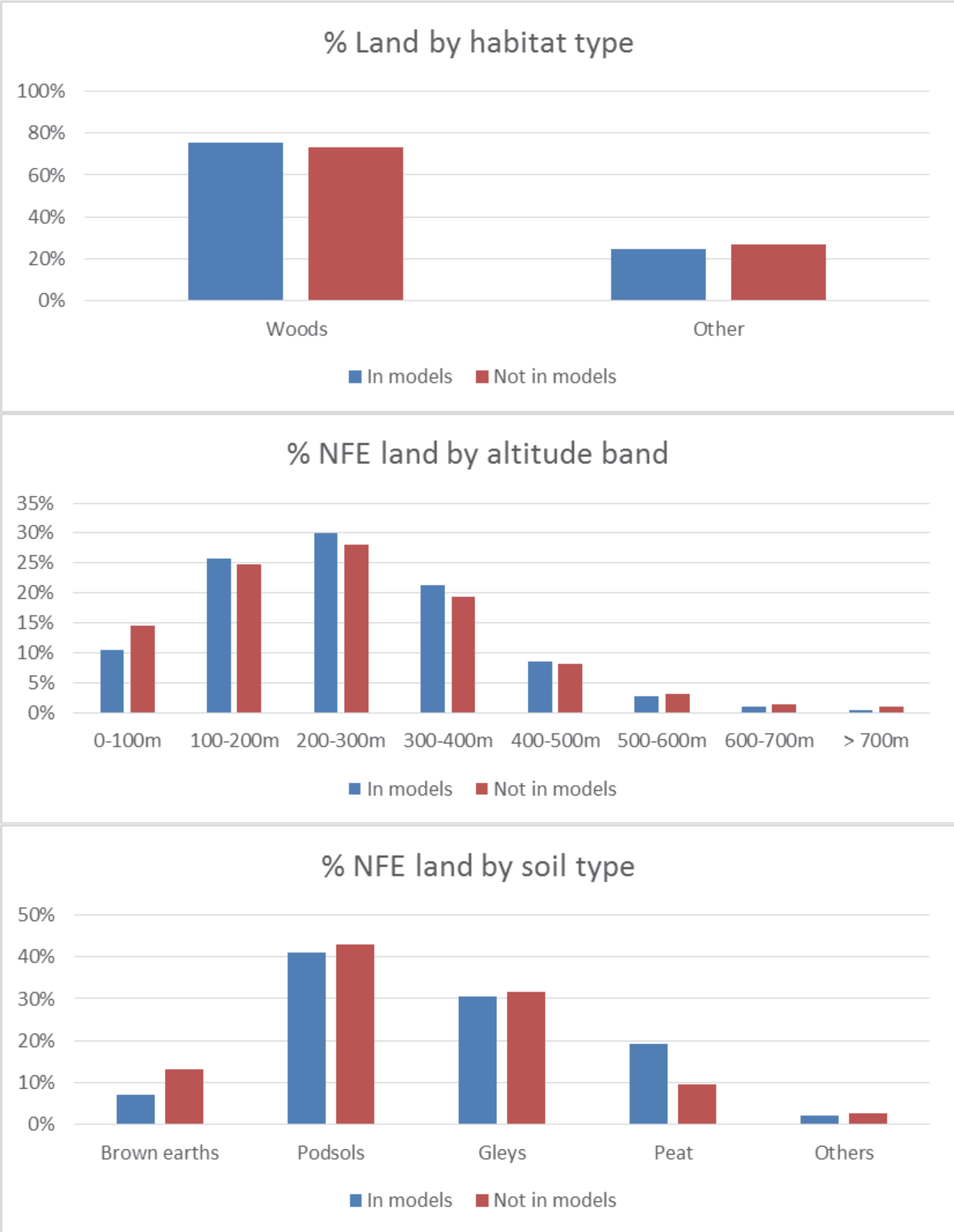


Figure 5. Comparison of key physical characteristics of NFE land (i) covered by population models (blue) and (ii) not covered (dark red).

Given the broad similarity in the two parts of the landholding, and the availability of detailed cull records for both parts, an attempt to estimate the numbers of deer present across the entire NFE using the outputs from the land modelled was considered worthwhile.[25]

Extrapolation of the modelled outputs to the non-modelled land involved firstly confirming the average density of deer per km^2 in each Forest District from model outputs. This was done for the two main species groups separately. Then the average cull per km^2 in modelled areas for each species group in each Forest District, over the preceding 3-year period, was calculated. The ratio of population density to cull density was calculated (e.g. 3: 1, 5: 1 etc).

The ratios from the modelled areas were then used to estimate, in broad terms, the likely size of population in the remaining land within each Forest District. The 3-year average cull per km^2 for the un-modelled areas was multiplied by the ratio for the relevant species group and Forest District, to provide an estimate of total density present. This density was then multiplied by the un-modelled land area (ha) present within each Forest District. The results were added together to produce an estimate of total roe/sika/fallow and total red deer for the un-modelled land in each Forest District. These data were added to the modelled figures to produce a broad estimate of total likely population size within the NFE.

The results of the simple extrapolation exercise, which must be treated with considerable caution, suggest that the abundance of wild deer on the NFE in June 2001 may have been ~ 109,000 or 16.5 per km^2 (Figure 6). On the basis of culls taken, and prevailing recruitment rates over the period, that number may have fallen by June 2016 to ~ 82,000 or 12.5 per km^2. This represents a decline of 24% or ~ 26,500 deer over a 15 year period.

The model suggests the abundance of roe/sika/fallow[26] on the NFE in June 2001 was approximately 63,026 or 9.6 per km^2, which declined over the 15 year period to 42,186 or 6.4 per km^2, a reduction of ~ 20,800 or 33%. For red deer the abundance in 2001 was approximately 45,790 or 7.0 per km^2 which declined to 40,075 or 6.1 per km^2 over the 15 year period, a reduction of 5,700 or 12%.

Given the uncertainties involved in the modelling process, and the fact that the deer defecation rates used in the abundance estimation process are thought to underestimate the numbers present, the national population estimates presented above should be considered minimum figures.

[25] There are more sophisticated ways of producing these estimates, but time was not available to undertake the necessary work.

[26] In the results section, roe/sika/fallow has been shortened to roe/sika as so few forests have Fallow present.

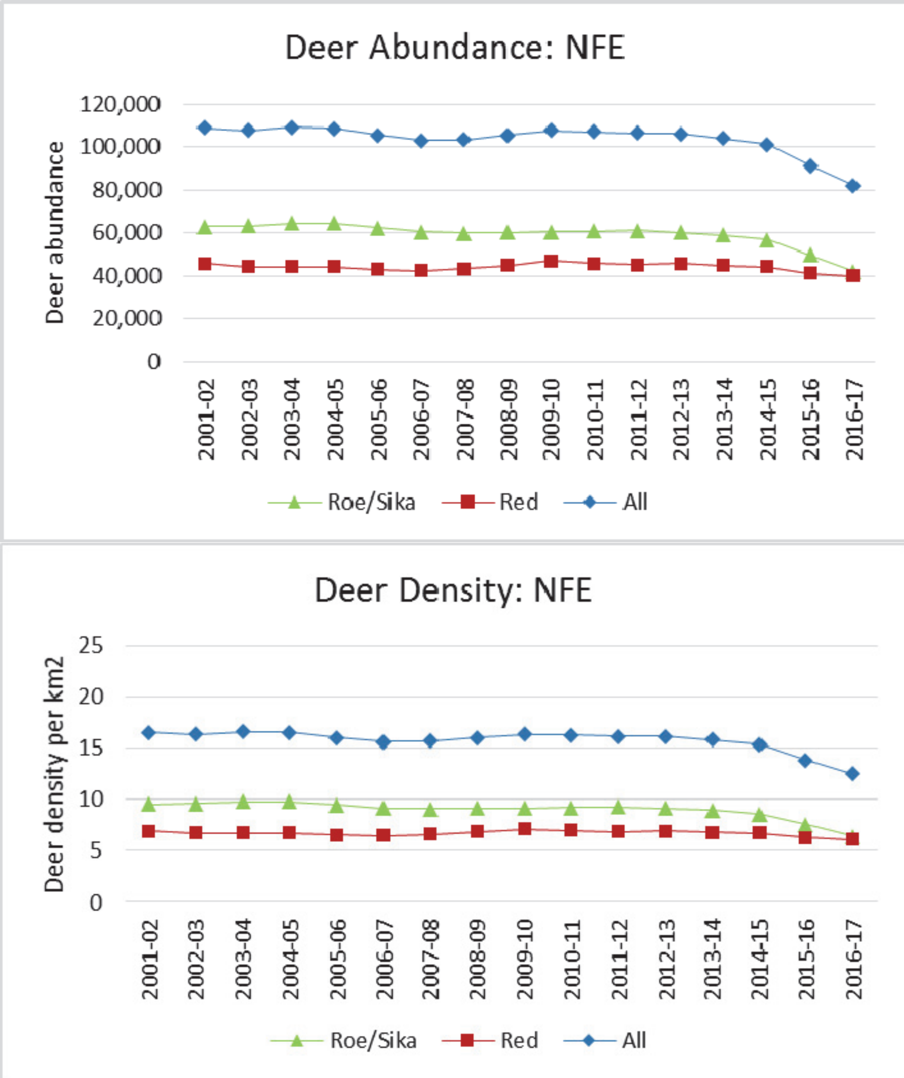


Figure 6. Extrapolated deer abundance estimates for all NFE land: National trends.

The extrapolated model for the entire NFE can be broken down by DMO area (Figures 7 & 8). The results suggest:

- A 29% drop occurred in deer numbers in the North, from 39,600 to 28,100 (18.5 per km^2 to 13.1 per km^2), over the period 2001-2016. Roe/sika/fallow exhibited a 40% decline from 27,100 to 16,200 deer with red having a smaller 5% decline dropping from 12,600 to 11,900 over the 15 years.
- A 17% drop in Central, from 47,700 to 39,700 (19.1 per km^2 to 15.9 per km^2), occurred. Roe/sika/fallow exhibited a 24% decline from 18,100 to 13,700 deer with red having a smaller 12% decline dropping from 29,600 to 25,900 over the 15 years.
- A 33% drop in South, from 21,500 to 14,500 (11.1 per km^2 to 7.5 per km^2) occurred. Roe/sika/fallow exhibited a 32% decline from 17,900 to 12,200 deer with red having a larger 38% decline dropping from 3,600 to 2,200 over the 15 years.

Figure 8 confirms the predicted current deer density, split by species group and based on the extrapolated model outputs, for June 2016.

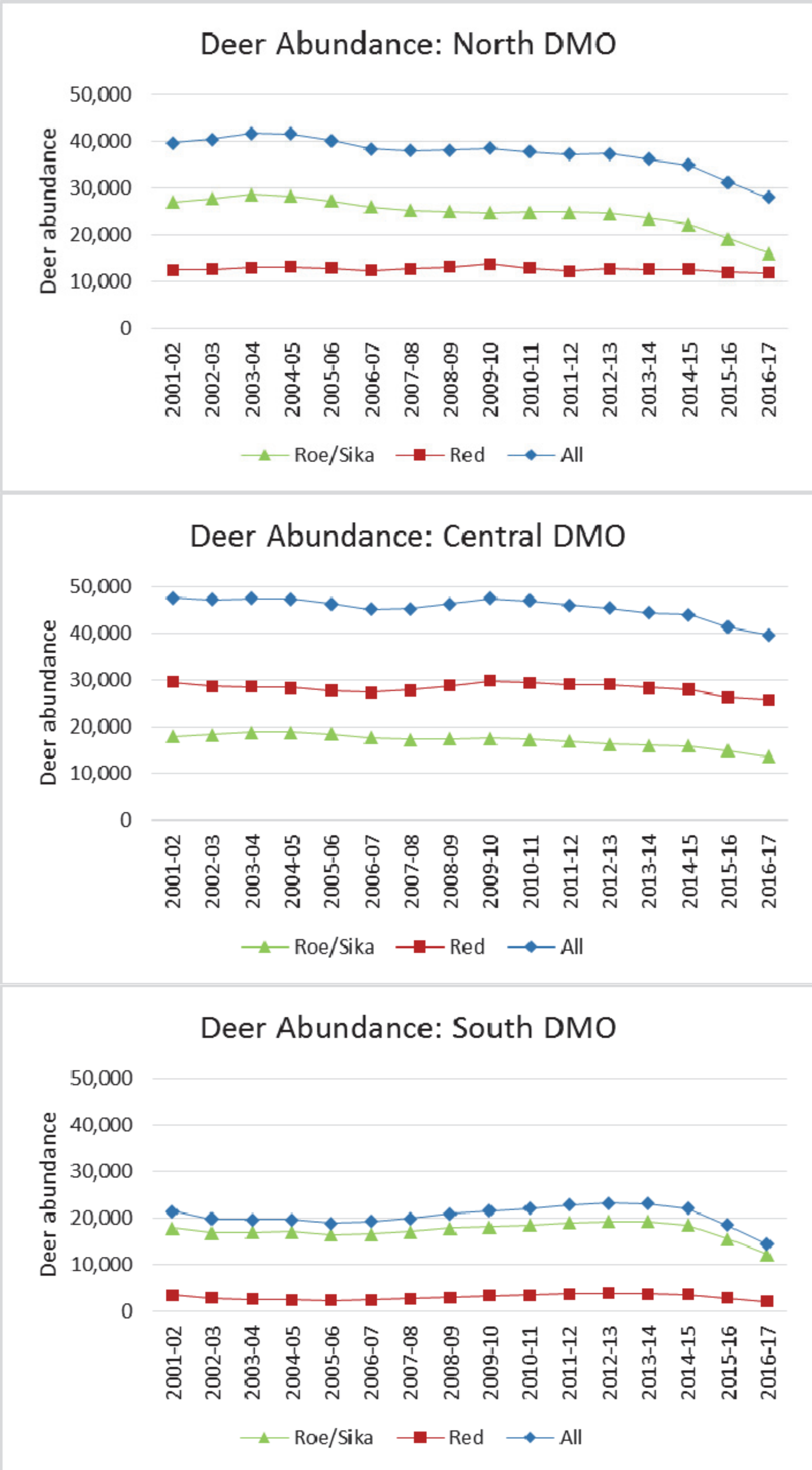


Figure 7. Extrapolated deer abundance estimate for all NFE land: species groups within each DMO area.

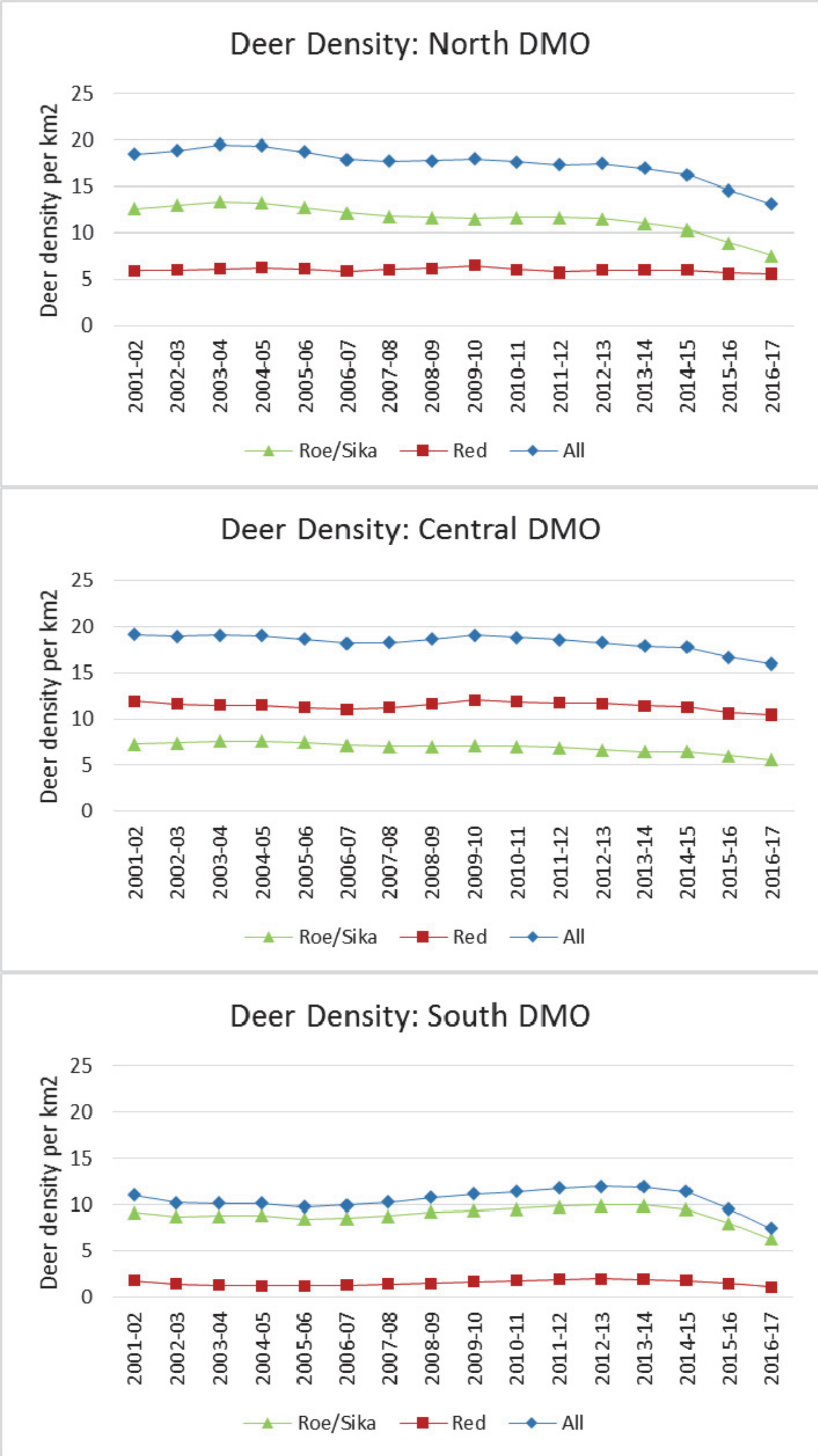


Figure 8. Extrapolated deer density estimates for all NFE land: species groups within each DMO area.

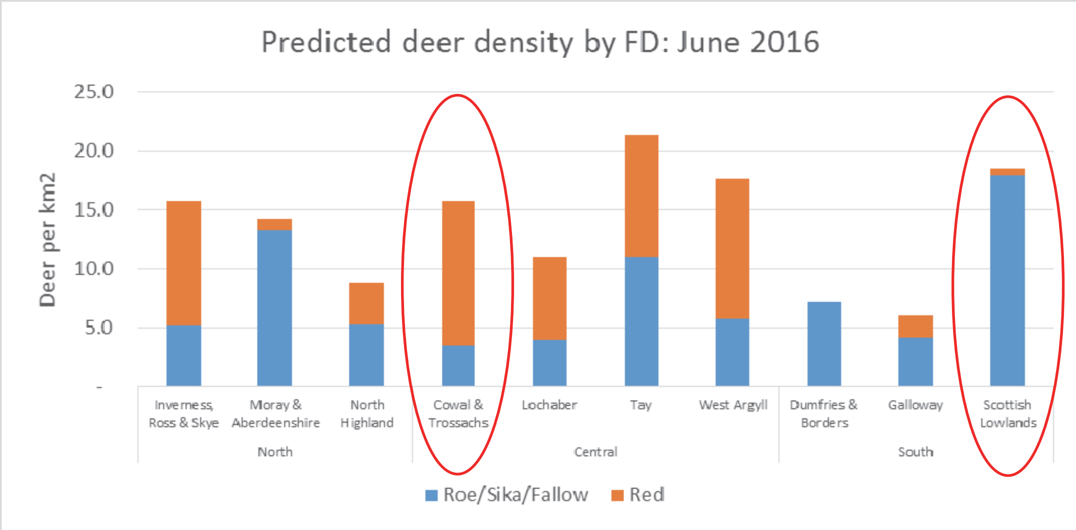


Figure 9. Predicted deer density in each Forest District based on the extrapolated population model outputs. Two Forest Districts (circled in red) are considered to have unreliable estimates because they were not properly covered by the modelling exercise undertaken for this report.

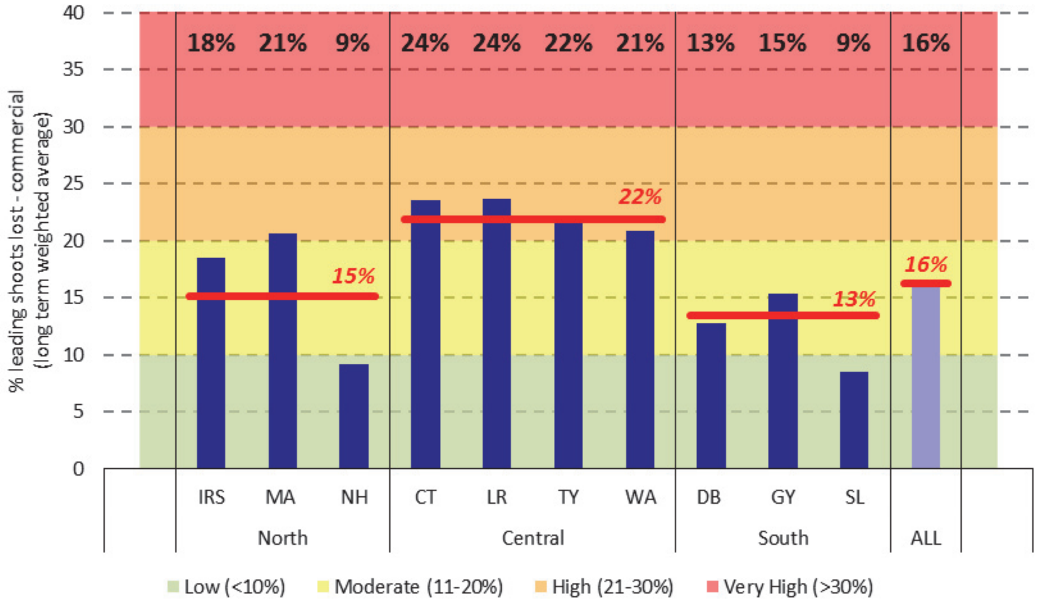
The reliability of the output from the extrapolated model exercise can of course be debated. But other sources of information are available to corroborate the findings. The most potentially useful data come from the national crop impact survey, on young planted conifer trees, which has been undertaken annually since 2009 at the national scale (Figure 10a & 10b).

The charts in Figure 10a and 10b show the 'rolling 3-year average' impact levels in each Forest District and wider management region. These results are, in effect, a weighted average across all sites sampled in a 3 year period within each district. The reason for using these smoothed averages is that the number, location and size of sites planted each year, along with the proportions of species planted, can be very variable within Forest Districts. As a consequence the annual results are often highly variable, which makes trend identification difficult. This is particularly the case for the districts with small re-stocking programs e.g. Cowal & Trossachs, Lochaber, Tay and Scottish Lowlands. The charts also include long term (8-year) average data for reference.

Two Forest Districts have achieved consistently low impact results over the period national assessments have been undertaken. These are North Highland and Scottish Lowlands. The other two Forest Districts with relatively low levels of impact are Dumfries & Borders and Galloway. The Forest Districts which tend to have the highest levels of impact are: Inverness, Ross & Skye, Moray & Aberdeenshire, Cowal & Trossachs, Lochaber and Tay. It is evident from a comparison of Figure 9 and Figures 10a/10b that the browsing impact data for young commercial crops on the NFE broadly corroborate the findings of the deer density extrapolation exercise, in that North Highland along with the South DMO areas tends to have the lowest impact results. A clear exception is Scottish Lowlands, where the predicted density appears far too high relative to the impacts experienced. On the other hand the other two districts within the North DMO area, along with most in the Central DMO area[27], tend to have the highest impact levels and also the highest predicted current densities. That said, a key fact to take into consideration is that use of rolling averages produces a lag

[27] Some of these Forest Districts have been experimenting with use of deer fences to exclude deer from their re-stocking sites – this is not common in the other areas, nor was it common place in Central until 5 years ago. This has affected the ability to compare data on a 'like-for-like' basis.

effect - the present deer density in many FD's has recently dropped significantly whereas the 'rolling' impact results will not show this for another 1-2 years.



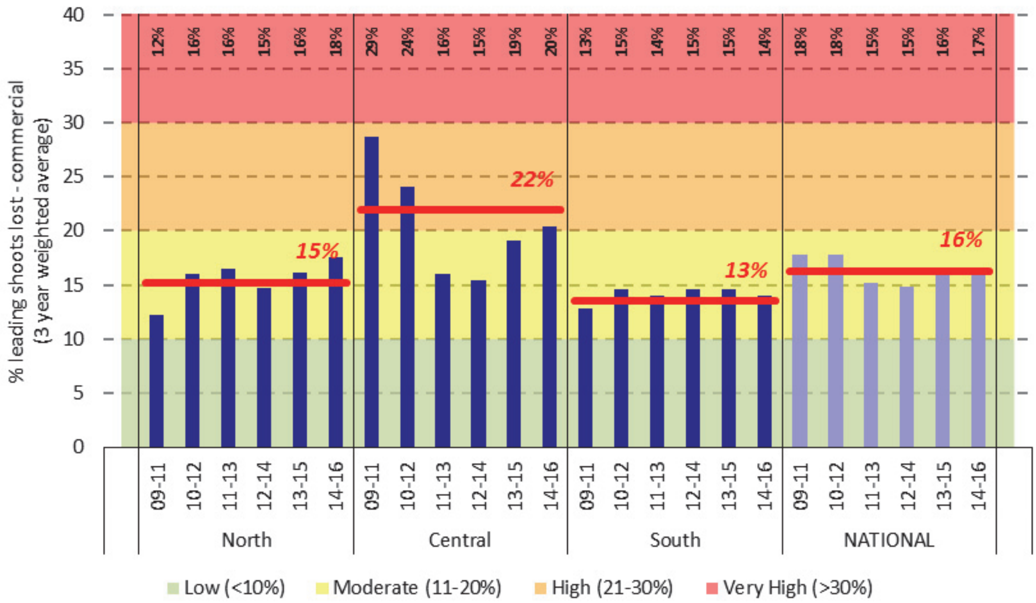


Figure 10a. Trends in national impacts levels on young re-stocked conifer transplants across the three management zones of the NFE (North, Central and South) and the ten Forest Districts (FD) within them. The upper chart shows the weighted average impact levels for the entire 8-year period that national impact monitoring on young crops has been run at the national scale across the NFE (blue bars = FD results; red lines = DMO regional results). The lower chart shows 3-year rolling averages, which reflect the trend over time in impact level at regional scale (these averages are used to help smooth out annual variations in impact level which can be sizeable in some places). Note the national data set only started in 2009, whereas the population modelling period in this report begins in 2001. IRS = Inverness, Ross & Skye; MA = Moray & Aberdeenshire; NH = North Highland; CT = Cowal & Trossachs; LR = Lochaber; TY = Tay; WA = West Argyll; DB = Dumfries & Borders; GY = Galloway; SL = Scottish Lowlands. For management purposes, impact results are classified: Low = average of 10% leading shoots browsed or less; Moderate = average of 11-20%; High = average of 21-30% and Very High = average of > 30%.

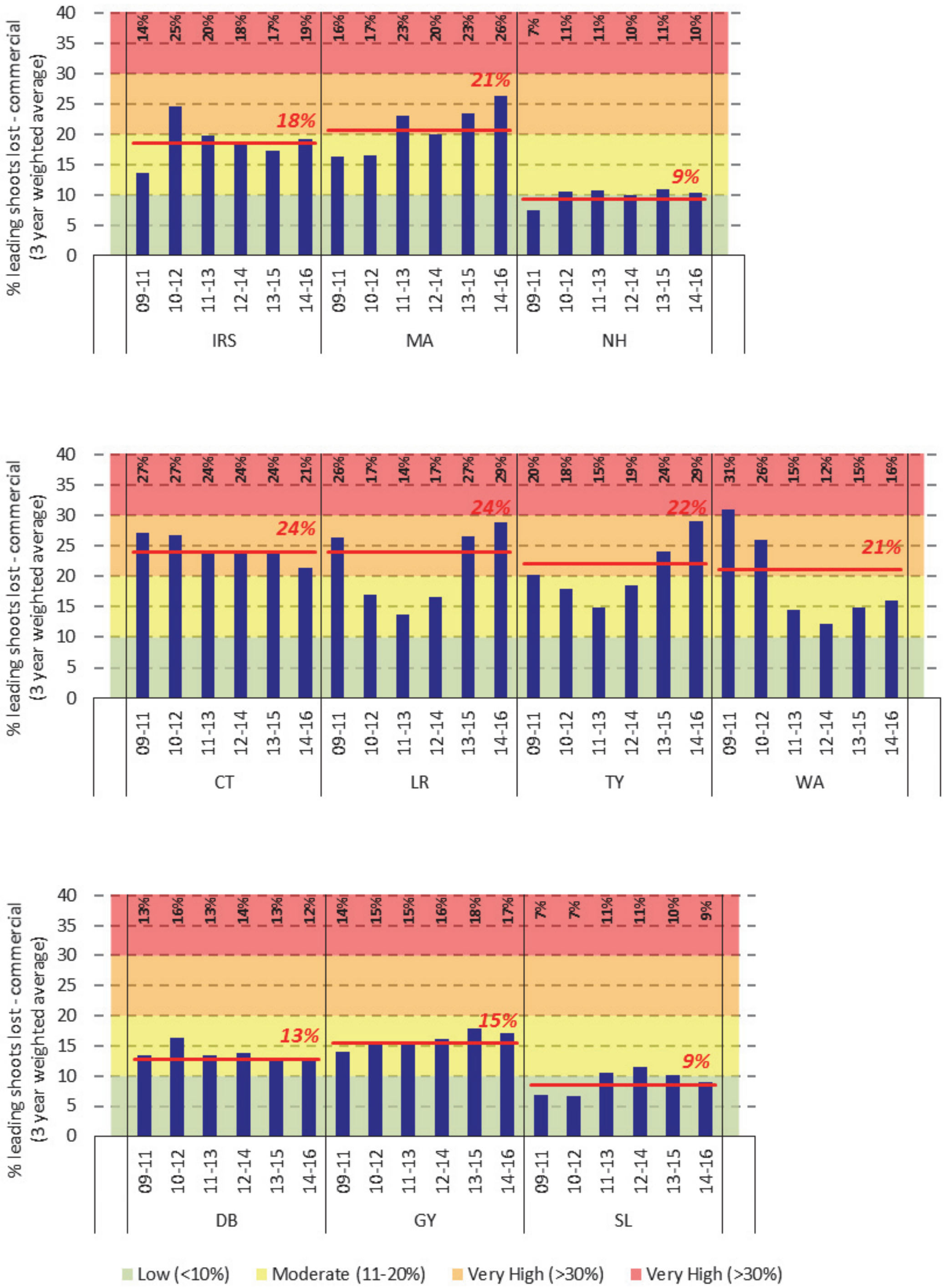


Figure 10b. Trends in national impacts levels on young re-stocked conifer transplants across the three deer management zones of the NFE (North = upper chart, Central = middle chart and South = lower chart) and the ten Forest Districts within them. The blue bars on the charts show 3-year rolling averages, which reflect the trend over time in impact level at regional scale (these averages are used to help smooth out annual variations in impact level which can be sizeable in some places). The red lines are the long-term 8-year averages for each DMO region. Note the national data set only started in 2009, whereas the population modelling period in this report begins in 2001. IRS = Inverness, Ross & Skye; MA = Moray & Aberdeenshire; NH = North Highland; CT = Cowal & Trossachs; LR = Lochaber; TY = Tay; WA = West Argyll; DB = Dumfries & Borders; GY = Galloway; SL = Scottish Lowlands. Note: see the Figure 10a caption for an explanation of the legend.

4.3 Factors influencing trends on the NFE

4.3.1 Patterns of culling

The size of cull taken is the most important determinant of population trends on NFE land. Over the past 15 years, the overall trend in culls taken has varied markedly. In the first half of the period, culls remained stable or declined gently towards 2007-08 (Figure 11). In the second half, culls rose in successive years to reach a peak of ~ 32,000 in 2014-15. The largest decline in culls in the early years was in the South, whereas all three operations areas saw marked increases in culls from 2008-09 onwards.

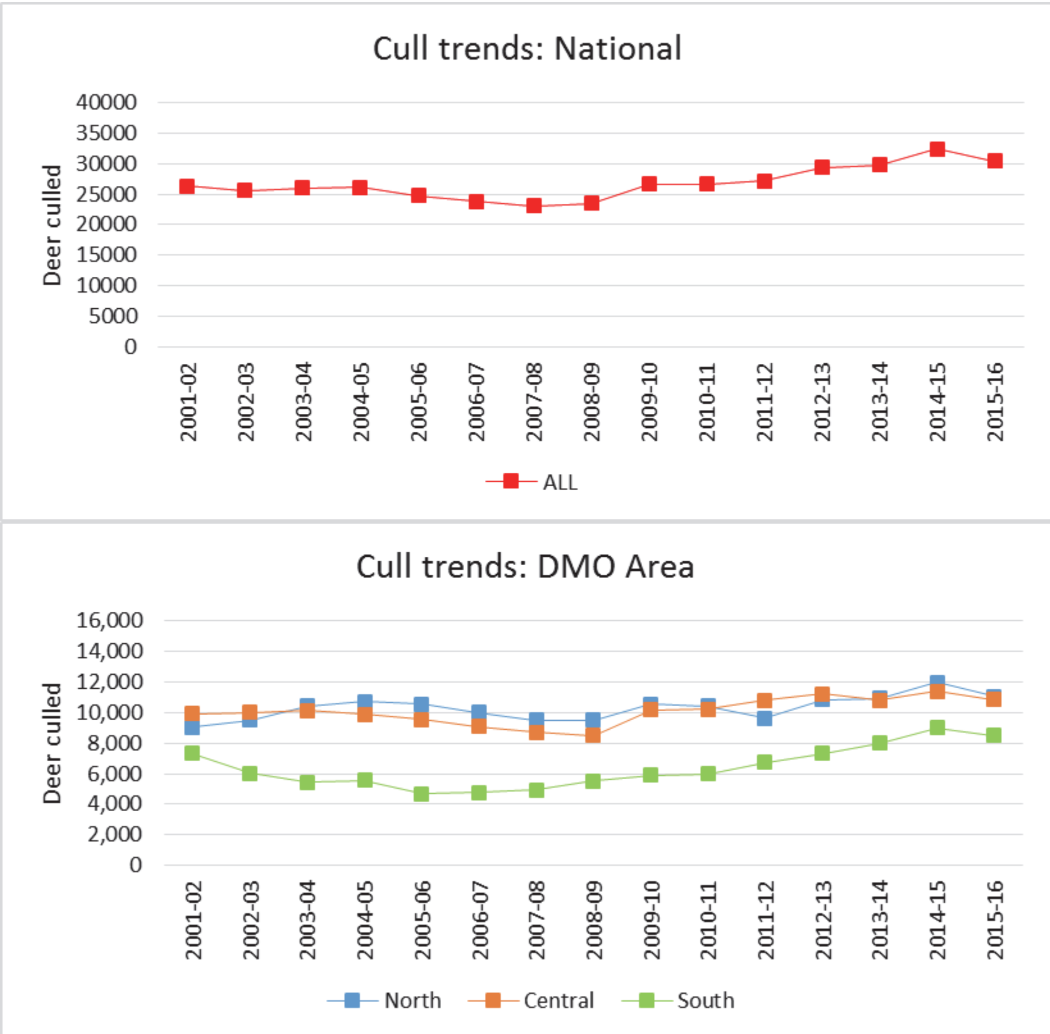


Figure 11. Total number of deer culled across the NFE: National and DMO trends.

The intensity of cull taken varies between geographic areas. The overall cull level rose from ~ 4 per km^2 to ~ 5 per km^2 nationally over the 15 year modelling period (Figure 12). However, within the regions larger levels of variation were apparent. The highest cull per km^2 was taken in the North, closely followed by Central, and the lowest was in the South. To a considerable degree though, this reflects differences in the underlying deer density.

In essence, most forests in the South only had small numbers of roe deer present when they were created from rough grazing land (these areas were generally devoid of any native tree cover, as sheep grazing was very commonplace). Small pockets of sika deer have since spread (from Peebles) and a resident red deer population has always been present on the

Merrick Range in Galloway (now also expanding slightly). Densities of deer have in most places never been high on average in the South, compared to the Central and North areas, although local areas in the South have had extremely high densities on a par with anywhere else. Two other key differences are that: (i) there are almost no open range deer populations NFE managers in the South need to contend with and (ii) the size of the Galloway Forest Park is unique in Scottish terms as it is entirely under NFE managers control from a deer management perspective. In the Central and North, the majority of properties have 2 or 3 resident deer species, have high densities of open range deer on their peripheries, limited or old deer fencing in many places and hence have inherently higher levels of deer present from the outset. Management of the North and Central populations is markedly more complex as a consequence, and also more expensive because of the need for perimeter fencing on many sites.

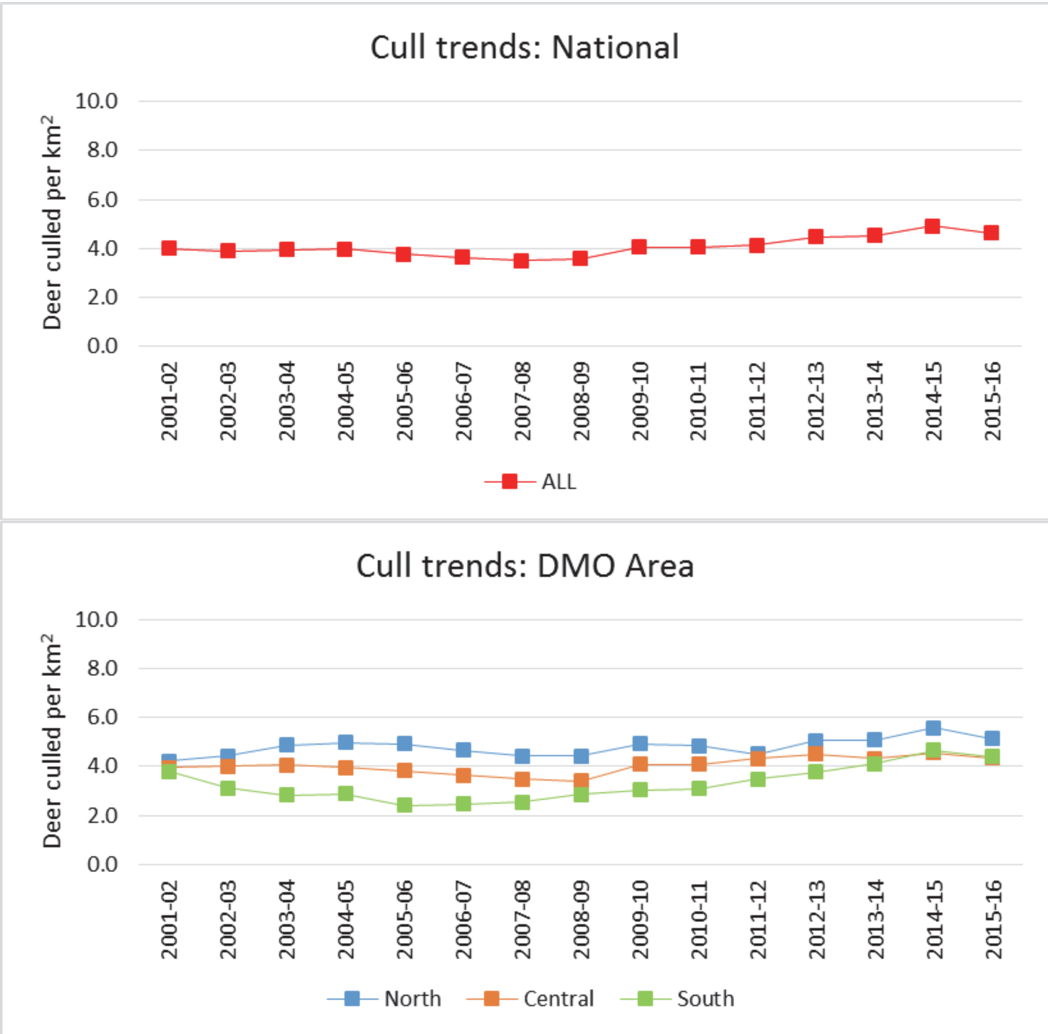


Figure 12. Mean density per km2 of deer culled across the NFE: National and DMO trends.

4.3.2 Culling method

A significant factor contributing to the variation in culls across the modelling period relates to changes in the way NFE managers have chosen to take the culls (Figure 13). At the outset of the period, the majority of the cull was taken by employed Wildlife Rangers. In the middle of the period there was a brief resurgence in the leasing of land to shooting tenants, the aim being to bring cash into the business to offset the high costs of deer management for crop protection. Over the 15 year period, districts also used varying amounts of contractor help to deliver the required culls. Use of contractors was least common in the South until recently, and equally common in the Central and North areas in the early part of the modelling period; in recent times a large increase in contractor use has occurred in North whilst in Central and South a markedly lower but still significant increase has occurred. The districts with the highest % of contractor culls are currently North Highland at ~ 91% of deer shot and Scottish Lowlands (83%). Most other FD's use ~ 50% contract help, with some FD's (e.g. West Argyll 22% and Cowal & Trossachs 31%) using lower amounts.

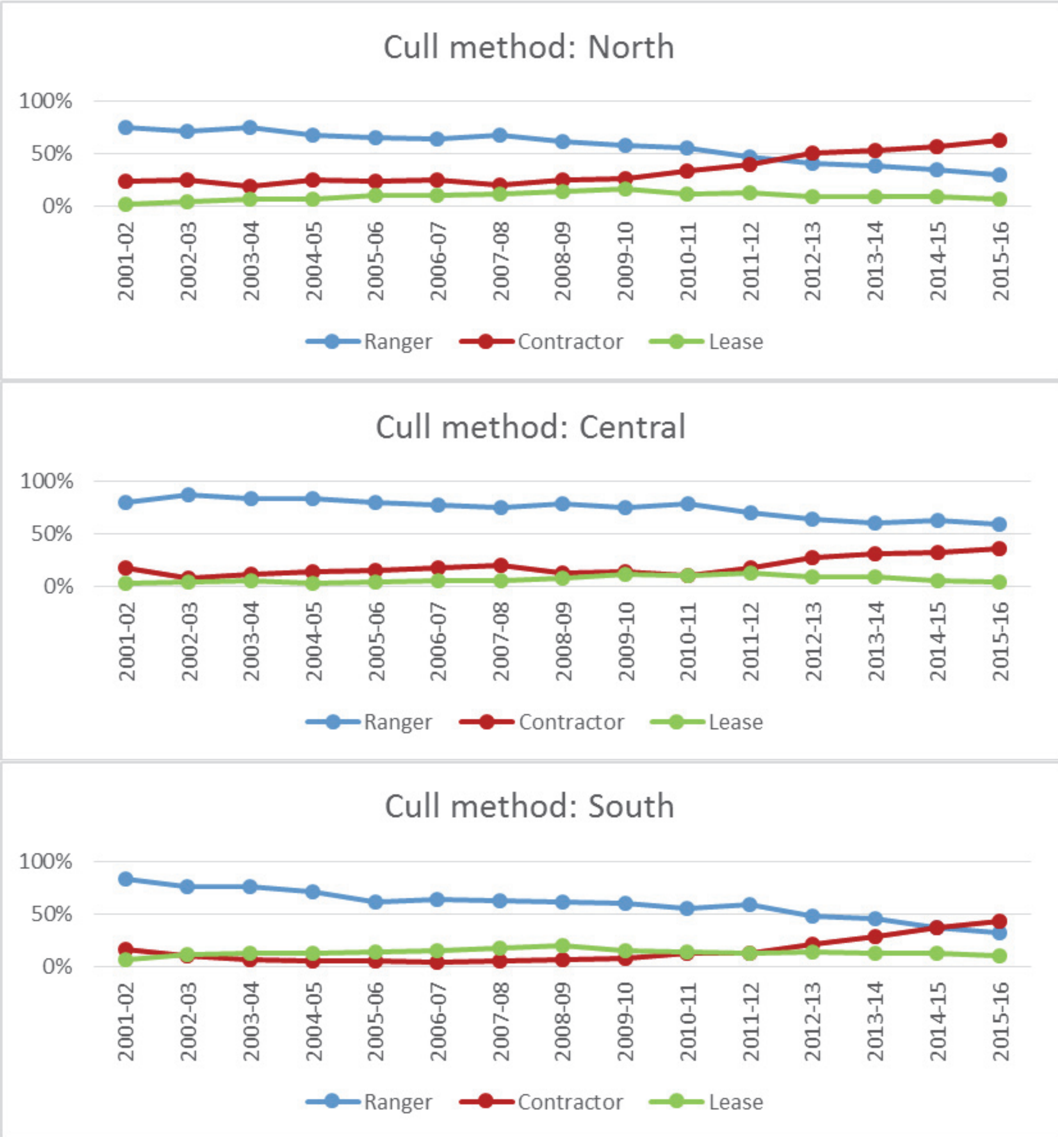


Figure 13. Methods used to cull deer across the NFE: DMO trends.

4.3.3 Patterns of recruitment

The rate of recruitment into populations from births determines, to a significant degree, the level of culling effort needed to reduce local population density to a specified target. The level of recruitment at national scale in the NFE varies annually (Figure 14), partly in relation to weather but also in relation to deer density. Poor weather in early summer can kill calves around the time of birth, and in very wet spring weather after a long winter can also kill young deer. The level of recruitment also varies regionally, for similar reasons (Figure 15). Each species recruits at a different rate also, because of their differing body size / biology.

In order to keep populations stable, a cull similar in size to the level of recruitment is needed. In the North, the mean % calves shot at foot across all species over 15 years was 65% compared with 53% in Central and 87% in South. This means that in the North DMO area around 24% of the population needs to be shot annually just to keep it stable. In Central the figure is ~ 21%. However, in the South it is ~ 30% – a significantly larger task.

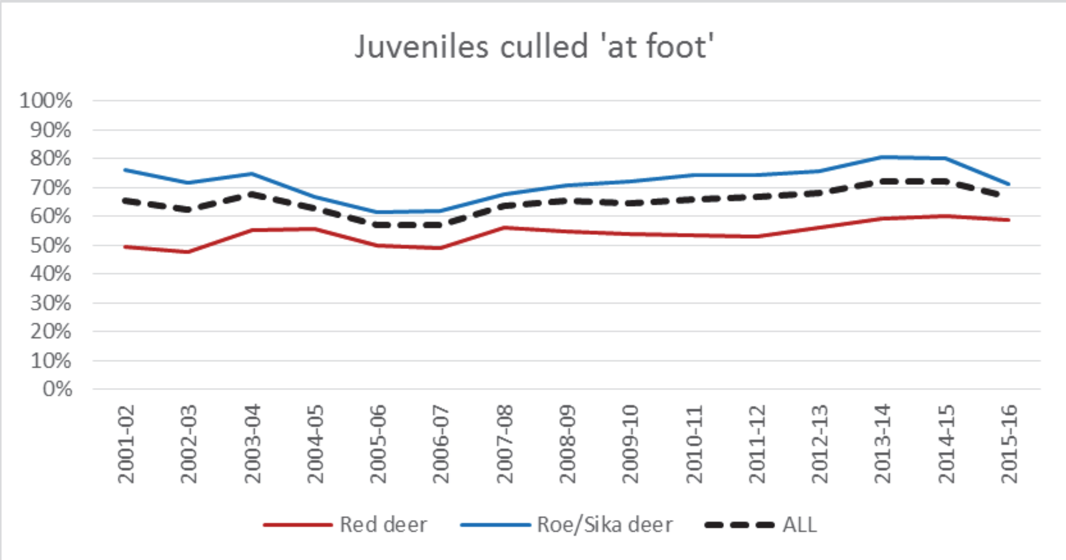


Figure 14. Variation in the annual level of recruitment in the two main species groups being culled: National results.

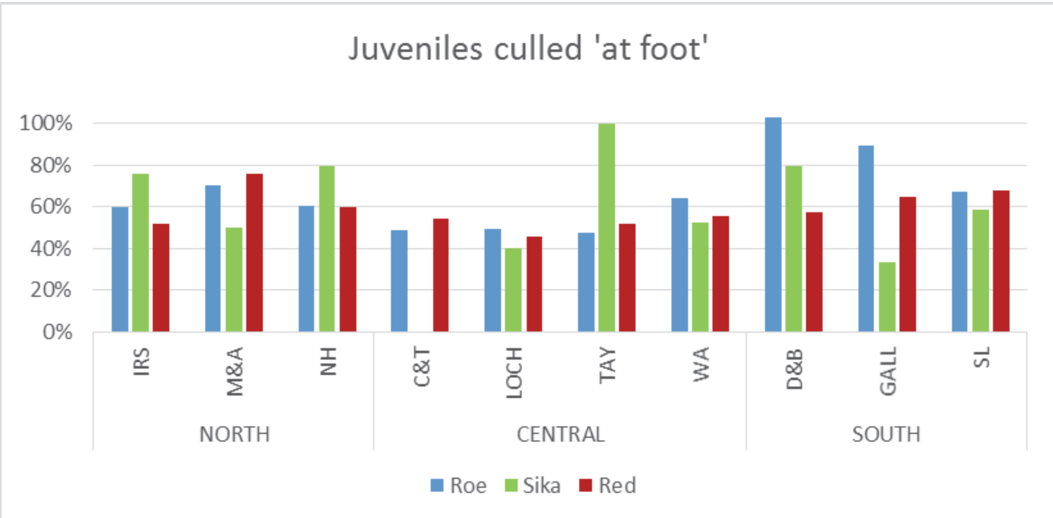


Figure 15. Variation in the long-term level of recruitment between species groups and Forest Districts.

Another factor influencing the number of deer needing shot to reach a specified density target is the rate of influx of deer from neighbouring land. It is difficult to obtain accurate national measures of this, but at a local scale long term monitoring has shown that in some places well over 50% of the annual cull comes from deer which have moved into the NFE from adjacent land (see Annex 1 cull charts – hollow blue bars show male deer thought to have moved into the NFE from adjacent land). One long-term data set which is available comes from an analysis of the NFE cull records, which show a significant imbalance in some Forest Districts in the number of male deer shot. Whilst this can, in the short term, simply reflect a skew in culling effort, in the long-term it is widely recognised to reflect movement of male deer from neighbouring land.

Figure 16 confirms that there are highly marked skews in the national cull towards male red and sika deer, along with slight biases towards male roe also. The skew is consistent for almost all districts in relation to sika deer, which are known to be actively spreading across Scotland (males tend to disperse first). The skew in the male red deer cull is very marked in the North, along with parts of Central (the skew is marked in D&B but they shoot a very small number of red deer annually). The inwards flow of male deer makes achieving density targets markedly harder, as the focus of the stalker can be drawn towards culling the more obvious 'break-in' deer and away from culling the more cryptic resident deer.

In the past 15 years, almost 16,000 more adult red stags and 5,000 more adult sika stags have been culled on the NFE compared to adult females of the same species.

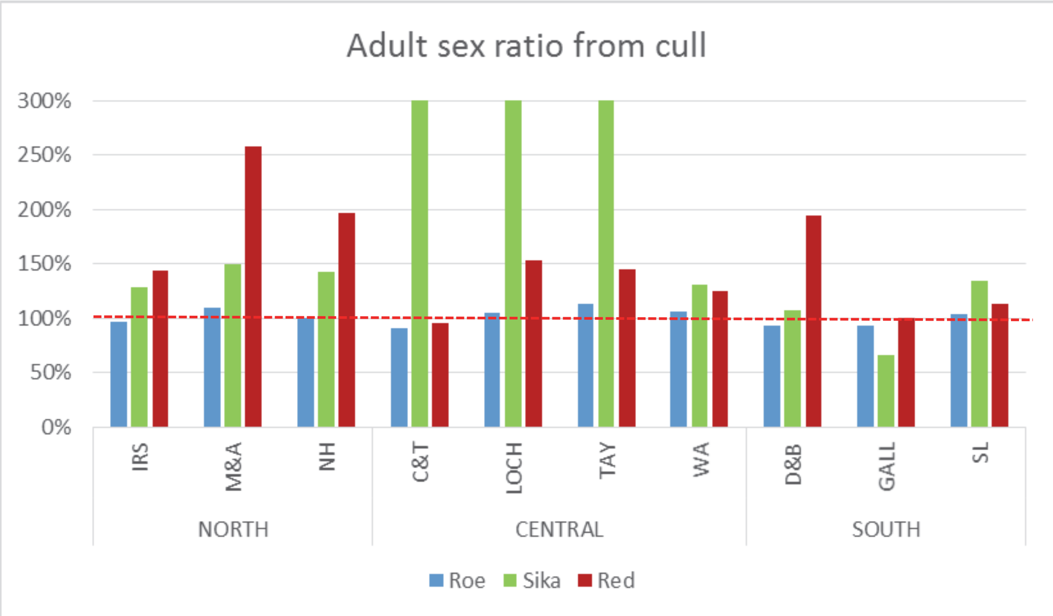


Figure 16. The ratio of adult male: adult female deer shot over a 15-year period in each Forest District. The dashed red line shows a balanced 1:1 sex ratio in the cull.

4.3.4 Underlying changes in forest structure

A key driver of deer 'carrying capacity' in NFE forests is the proportions of habitat types present. When forests were first planted they comprised open range land with young trees, and thus provided high levels of grazing but no shelter. Over the 'first rotation' of ~ 40-50 years, the forests grew up and then closed canopy, killing off much of the ground vegetation. At this stage, they reached the low point in their ability to carry deer albeit they provided good shelter. In the late 1980's and early 1990's, many NFE forests began to be re-structured whereby stands were felled and then re-stocked. This activity quickly gathered momentum, then, in the past 15-20 years, has continued at a relatively steady pace. There have been slow changes in the proportions of some habitats present (Figure 17) but in general these do not appear to have been significant enough to explain much of the trend in deer abundance over the last 15 years produced by the modelling exercise. The most obvious change has been in the area of broadleaves present, which has risen from ~ 40,000 to ~ 50,000ha over the modelling period. However, this has been offset by a reducing extent of young conifers being planted. There have also been local changes in the amount of open ground in the forests, left unplanted after felling, but at a national scale they do not amount to a large change in the database. In the long-term, conversion of forests towards broadleaf (and increased small areas of open ground locally) will increase their carrying capacity, and also make the environment more stable for deer in the short term depending on how extensive they become. It is also true that the NFE forests, given the way they are now designed, provide an ideal habitat for wild deer to thrive in.

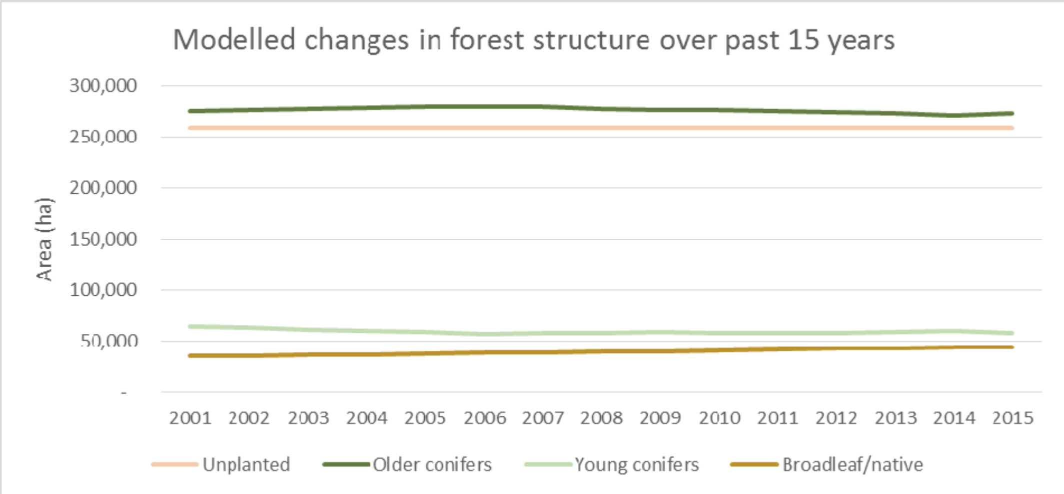


Figure 17. Predicted variation in the area (ha) of key habitat types on the NFE during the modelling period. Young conifers are all crops < 16 years old, with the balance being defined as older conifers.

4.3.5 Winter weather and site access

The pattern of national culls taken on the NFE can be affected by weather. In winter 2009-10 a very prolonged period of snow lie occurred especially in the east of the country. This acted to prevent stalkers from accessing the woodlands for long periods, as it was unsafe to use road vehicles. In that year many NFE staff reported failing to meet their cull targets. A similar but less severe spell of weather occurred again in 2010-11 and in 2012-13 but stalkers were then better equipped (e.g. with tracked quad bikes).

The foot-and-mouth outbreak of 2000 also caused severe difficulties with forest access, as deer culling was halted for a long period to help with disease control. This cull season is not included within the modelled period for this study, but national culls were undoubtedly much lower in the season 2000-01 than they otherwise would have been – this would have contributed to populations locally remaining stable or rising in subsequent years when they might otherwise have fallen or remained stable.

4.3.6 Other factors

A range of other factors have also contributed to the patterns of culling, and hence trends in abundance, observed over the past 15 years across the NFE:

- Changes in deer behaviour arise as culling intensities increase. Deer become more cryptic, and in particular more nocturnal, in response to heavy pressure being applied. They tend to use deep cover more, open ground less, and be far more vigilant. This makes culling increasingly difficult, as densities decline along with encounter rates. A related recruitment factor is that recruitment rates, on average, rise as densities decline as is evident in the data presented earlier.
- The changing forest structure over time has produced a much smaller proportion of well-thinned mature tree crop, and in turn a much more varied type of cover with

multiple age classes and many small pockets of open ground hidden from view. This makes it less likely deer will travel to open ground to feed, and in turn makes it harder for the stalker to find and cull deer. Another problem is that forest tracks have become overgrown with tree regeneration - this makes culling from the road harder.

- Patterns of public access have changed markedly in the last 15 years, with cycling and particularly dog walking now highly prevalent even in the early hours of the morning or late at night when a lot of culling needs to be undertaken.
- Sika deer have undoubtedly been expanding their range over the past 15 years. Densities of this species tend to rise once the first wave of male colonisation has passed through, as to start with these deer can be difficult to detect. Once established, they recruit at a high rate, more similar to roe deer than to red deer. The increasing proportion of sika deer in NFE forests plays a part in the increasing difficulty of securing low density populations in all areas.
- Changes in the available funds for deer control over the past 15 years also play their part. This is related to variations in timber price, as well as more recently to reductions in central government funding plus reduced renewables income. Overall, budgets continue to be reduced and this in turn has made it harder to achieve the necessary cull with a diminishing resource.
- National priorities also play a part in determining culling patterns. Some areas of the NFE are considered more important to focus on than others, in terms of deer control, meaning that other areas are left with a lower level of resource to cull. Good examples are districts such as Inverness, Ross & Skye which has large areas managed mainly for nature conservation including their huge forest and open range landholdings in Speyside and in Glen Affric. Stalkers tend to be asked to deliver culls in these areas as a priority, meaning some other forests will be visited less.
- The employed stalkers working for FES have a wide range of other work duties and demands made of them, meaning that they are rarely able to put all their time into culling deer. As these demands have varied, and invariably increased over time as administration becomes a larger part of their workload, so the time available for culling has declined in many cases.
- Some FD's operate a different system of silviculture in their forests (Low Impact Silvicultural Systems) – this is based on natural regeneration systems, and deer can often be held at higher density in these places (i.e. a deliberate decision can be made to cull less) because they browse natural regeneration less than planted trees.
- Varying levels of buy-in to the monitoring program also play their part – some Forest Districts tend to use the national monitoring information much more than others, in particular the deer density results. This has probably contributed to variations in the observed trend in deer densities between Forest Districts over time.

4.4 Predicted abundance: private woodland

There is little monitoring of deer density or formal systematic monitoring of impacts within private sector woodland. However, forest owners do return their cull records to SNH annually. The national woodland cull (private and NFE combined) has been rising over the past 10 years, at a time when the open range cull has remained stable or fallen (Figure 18). The rate of rise has been similar in both private woodland and the NFE, but the intensity of cull (i.e. cull per km^2) has been markedly lower in the private woodlands.

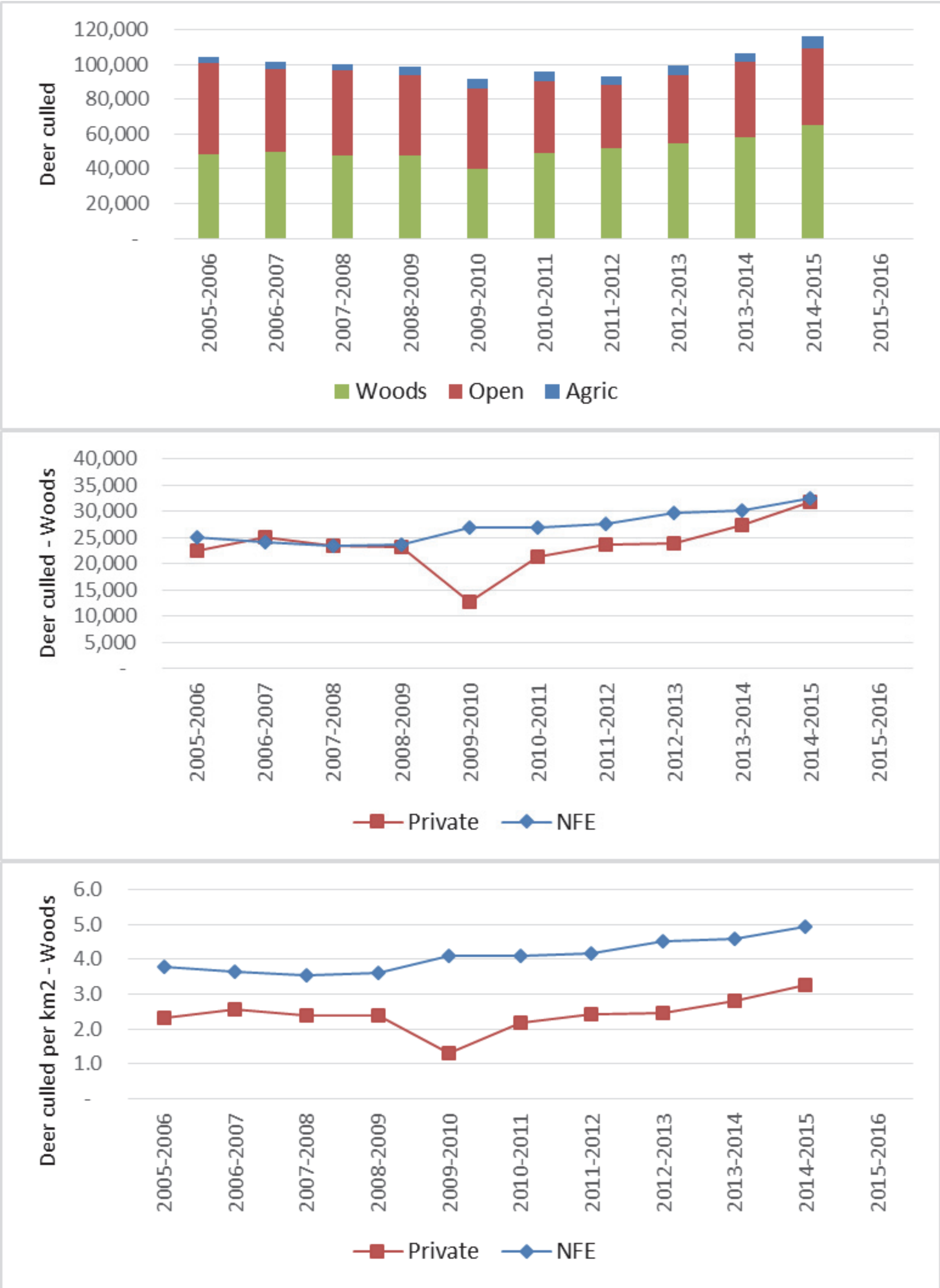


Figure 18. Patterns of national deer culling over the past 11 seasons.[28]

It is also apparent that the composition of the deer cull is different, on average, in the private woodlands compared with the NFE (Figure 19). Slightly larger numbers of roe deer were shot in private woodlands, in comparison with the NFE, whereas levels of red deer culled were smaller. Sika deer culls were comparable.

[28] Data for 2001-05 was supplied but judged unreliable (not complete – resides in another database). Data for the 2015-16 cull season has not yet been fully submitted to SNH hence was omitted also. It is also apparent that the data for the cull season 2009/10 is only part complete (see obvious drop) but the reason for this is unknown.

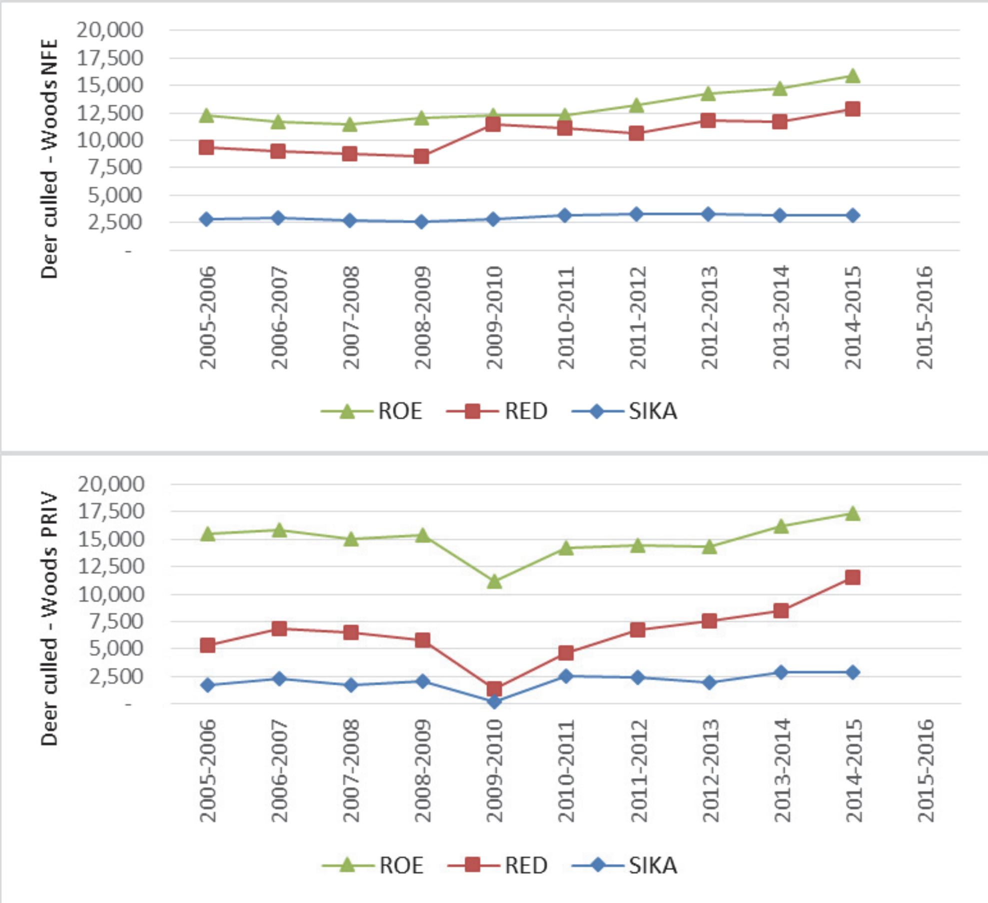


Figure 19. The number of deer of each species shot on the NFE and in private woodlands.

The rate of recruitment of deer into the private sector woodland populations appears lower than for the NFE based on cull returns provided (Figure 20 & 21). The rate for private sector woodland appears intermediate between the NFE and the open range sector. NFE woodland populations on average are recruiting at twice the rate of open range populations.

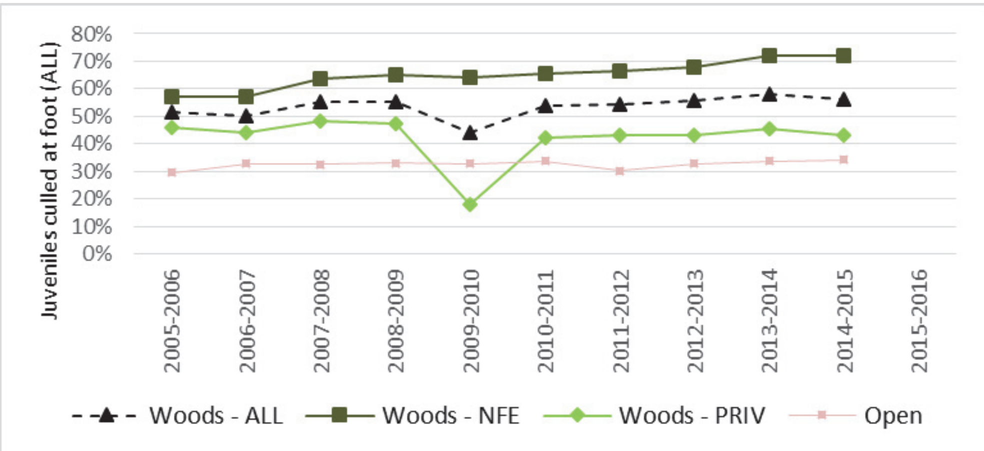


Figure 20. The % of juveniles culled at foot on the NFE and in private woodlands. Open range levels shown for comparison.

The records indicate that average roe deer recruitment rates are much higher on the NFE than in private woodlands. The difference for sika deer is less marked, and for red deer is smaller again in absolute terms. Nevertheless, there is a consistent difference between NFE and private returns for all three species and all years records are available for.

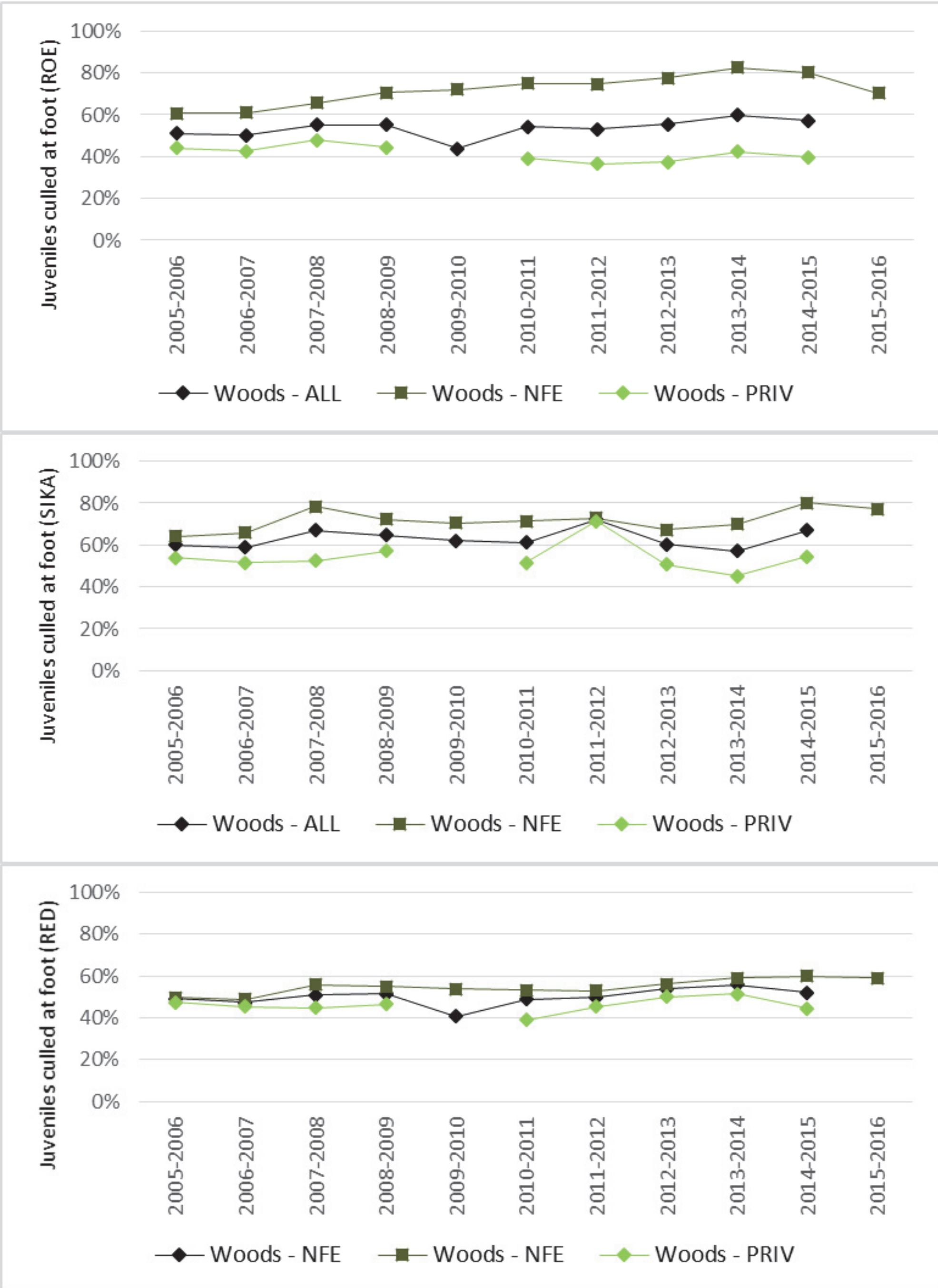


Figure 21. The % of juveniles culled at foot on the NFE and in private woodlands broken down by species group.

Given the brief of this project, it was thought appropriate to give some consideration to the possible size of the deer population in the private sector woodlands. A range of information is available to help make an informed judgement.

The National Forest Inventory (NFI) confirms that private sector woodland (~ 945,000ha) is much more extensive than the NFE (~ 485,000ha). That said, the NFE has a large amount of open range land (~ 170,000ha) which the private woodland records do not have. Figure

22 confirms that the private woodland area recorded in the NFI comprises almost entirely woodland cover.

However, the nature of the woodland cover, within wooded parts of the NFE and private sector areas, is broadly comparable (Figure 22). The key differences include that private woodlands have a higher % of broadleaf present and a lower % of mature conifers.

The nature of the cover within the private woodlands indicates that it should be at least as good for deer as the NFE in terms of carrying capacity, but probably if anything slightly better on average.

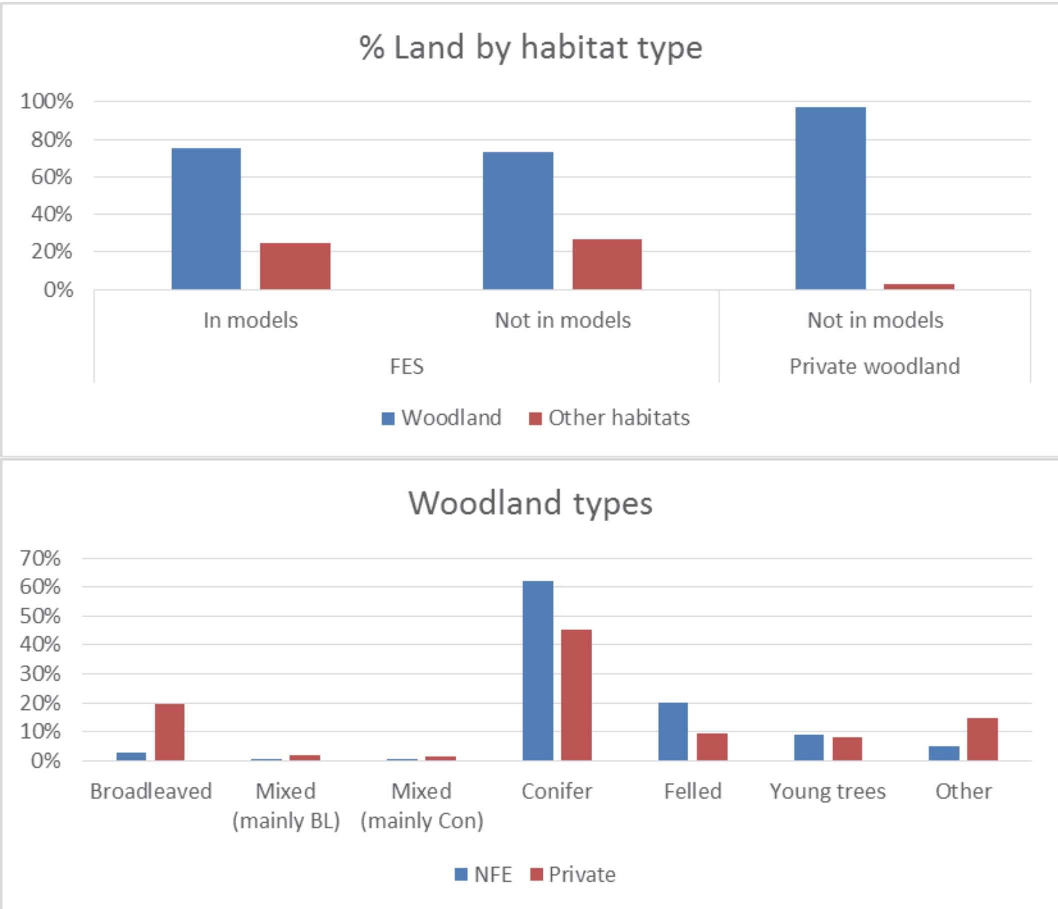


Figure 22. The % of land types within the NFE (modelled and un-modelled sections) along with the equivalent for the private woodland within the NFI records.

The cull records for the private woodland show overall that ~ 45 juveniles are shot for every 100 adult females – if we assume the adult population has a 1:1 sex ratio then we might assume with all else equal that ~ 18% of the population comprises juveniles overall.

On this basis, if the cull being taken keeps the population stable then it is likely that the total population present is ~ 5-6 times larger than the cull itself. This simple rule of thumb has been used for many years by NFE managers to obtain a rough indication of the number of deer they might be managing.

Applying this approach to the private sector cull records, we can multiply the cull per km^2 of each deer species in 2014-15 by a factor of ~ 5, assuming the population is stable. If we are to assume the population is declining, then a factor of 3-4 might be more appropriate. If we are to assume the population is rising, a factor of 6-8 should be used.

Table 3. Summary of the simple 'rule of multiples' when estimating number of deer in a population based on the cull taken.

Estimate Type	Roe	Sika	Red	ALL	% cull taken
x3	52,143	8,508	34,626	95,277	33%
x4	**69,524**	**11,344**	**46,168**	**127,036**	**25%**
x5	**86,905**	**14,180**	**57,710**	**158,795**	**20%**
x6	104,286	17,016	69,252	190,554	17%
x7	121,667	19,852	80,794	222,313	14%
x8	139,048	22,688	92,336	254,072	13%

There is some useful evidence available to help inform the judgement on which ratio to adopt. The fact that recruitment rates appear to be consistently lower than on the NFE from the national cull record suggest that deer densities might be somewhat higher on average in the private woodlands. It is also the case that the habitat is probably at least as good, based on data contained within the NFI.

Working on the rule of multiples outlined in the table above, it is probably safest to assume the private population is ~ 4-5 times larger than the cull presently being taken. This assumes that densities are probably higher than on the NFE but that they may now be declining *on average* with the increased culls taken in recent years. Of course, this is a complete generalisation – in reality, as with the NFE, there will be areas where densities are declining steeply or are already very low, and places where densities are very high already or rising steeply.

On balance of evidence, it is thought likely the private sector woodland deer population therefore lies in the range 130,000-160,000 deer. This is likely to break down as ~ 50-60% roe deer, 5-15% sika deer and 30-40% red deer based on the pattern of culling evident in records returned to SNH. In reality, it is probably the case that sika and red deer are being culled very heavily in relation to roe deer given the difference in recruitment and culling rate patterns observed with NFE records. On this basis, it might be best to assume the roe deer population is larger and the red deer population smaller than is shown in the table.

4.5 Predicted abundance: all woodlands

If we combine both sets of evidence together, from the NFE and private woodlands, it would appear sensible to assume that the woodland deer population in Scotland is currently in the region of 210,000-250,000 animals. The proposed breakdown is outlined in the table below.

Table 4. Estimates of the number of deer in Scottish woodlands.

Estimate Type	Roe / sika / fallow	Red	ALL	Comments
NFE woodlands	40,000 to 45,000	40,000 to 45,000	80,000 to 90,000	Based on 40% land mass estimated from population models and 60% from extrapolation of these models
Private woodlands	85,000 to 100,000	45,000 to 60,000	130,000 to 160,000	Based on scaling up of national cull levels, using recruitment rate data contained within the cull records and other available indicators of population performance and trajectory
ALL Woodlands	125,000 to 145,000	85,000 to 105,000	**210,000** to **250,000**	Combined estimates based on modelling exercises plus extrapolation

Given the evidence available, we assume the deer population on the NFE is currently in strong decline overall. The population in the private woodlands is assumed to be stable or perhaps declining slowly overall, based on the limited evidence available at this time. Overall, the woodland deer population in Scotland is assumed to be gradually declining in size.

Of course, this proposed 'overall trend' in deer abundance masks a massive degree of local variation in population trends – in reality woodland populations exist at a wide range of densities (5 to 60+ per km^2) across Scotland, are highly dynamic and constantly changing in terms of species density, species composition and recruitment rate as a result of culls taken, culling tactics, prevailing weather and ongoing changes in forest structure locally.

The wide variation in deer density at the local scale is what drives the levels of deer impact observed in forests, agriculture and semi-natural habitats. Site managers need to undertake local scale monitoring of deer density and deer impacts in order to deliver effective management on the ground, rather than receive or be judged on national or regional scale information. That said, larger scale synthesis of information is required by the government and other large private or third sector to drive strategic decisions and policy. This larger scale data can be derived, as in this report, with relative ease from local scale data if monitoring coverage is sufficiently widespread and regular.

5. CONCLUSIONS

The results of the modelling exercise indicate that deer population density at the national scale on the NFE has declined markedly, albeit this general trend masks a wide range of site-specific trends.

An overall decline in deer numbers of between 20 and 30% has probably occurred between June 2001 and June 2016, but with the majority of the change occurring in the past 5 years. More change has occurred in the South and North than in the Central operations area over the modelling period. Also, roe/sika/fallow deer densities appear to have declined markedly more than red deer densities overall. Red deer densities in woodland are in part controlled by external factors, mainly migration from open range populations, which is the likely reason why they have not declined as quickly as the other species.

If the current overall level of culling continues it is likely that population densities on average will continue to decline, but there is evidence also to show that densities are rising in a considerable proportion of monitored forests, notably so in terms of red deer populations locally. That said, overall levels of impact would be expected, with all else equal, to decline if the trends predicted by the population models are generally borne out on the ground.

However, there is good evidence to show that recruitment rates are rising in many places on the NFE as a result of declining deer densities as well as continuing changes in forest structure coupled perhaps to changes in weather patterns. Therefore, culling levels will need to take this into account in future alongside consideration of other key practical factors including the implications of tree species changes due to disease, the continuing movement of deer (in particular red deer) from private land onto the NFE locally and declining budgets for forest operations generally.

The situation in private woodlands is much less well understood, even with the various elements of analysis undertaken for this report. Much more data gathering and analysis is required if the effectiveness of deer management in these areas is to be quantified. In the interim it would be safest to assume that deer densities are on average somewhat higher in private woodlands than on the NFE, and that populations in general are more likely to be stable than falling as they are across much of the NFE presently.

6. RECOMMENDATIONS

- The annual cull of deer on the NFE should be maintained at a level of 30,000 – 35,000 deer for the next 3-5 years at least, in order to achieve the management objectives set.
- Culling effort must be maintained in forests with low deer densities but additional targeted effort is needed in areas where deer abundance is locally high, to ensure densities are 'homogenised' across the NFE – this is the best way, along with a parallel policy of adopting generic density targets, to secure a consistent outcome in terms of achieving long-term low levels of impacts across all areas of departmental responsibility.
- Monitoring of deer densities should continue, and ideally increase in extent and frequency, to ensure adequate survey coverage of the NFE land on a regular basis. This is the best way to help managers ensure that population dynamics are properly understood, and hence have confidence that local cull targets are being appropriately set. This ensures the most rapid reduction in density which, in turn, leads to a situation where a smaller number of deer need to be culled going forward to maintain stable populations – this will reduce costs in the longer-term.
- Monitoring should ideally be extended out to include neighbouring land, in particular private woodlands and neighbouring open range areas, so that NFE managers have a better chance of understanding the true level of inwards movement they might need to take into account when setting culls. The available evidence shows that deer from these areas are, in many places, migrating into NFE forests and adding to the underlying burden of work.
- It would be of immense value if NFE managers could set up collaborative agreements to cull deer across boundaries, and even help neighbours cull their deer, if it achieves a better overall outcome within the NFE and an equal or more cost effective outcome in terms of net expenditure. At present, at least ~ 5% of the national cull taken on NFE land (a minimum of 20,000 deer over 15 years) comprises male deer which are believed to have moved in from neighbouring land anyway. Culling females from surrounding areas would ultimately help reduce the flow of males.
- The modelling in this report could be usefully extended to cover larger parts of the NFE, and analysis techniques refined with more time available, to improve the quality of the outputs presented herein. At present, only 38% of the landholding has been covered and yet ~ 85% of the NFE has data available to build models with.
- The modelling could be further extended to include neighbouring open range areas using the same techniques, if equivalent SNH data sets were made available. These analyses, along with the NFE analyses, could then be updated annually to help inform strategic decision-making at government and local level. At present, much of the data available is collated to some extent but is otherwise then rarely looked at.

ANNEX 1: POPULATION MODEL OUTPUT AND CULL RECORDS

This Annex contains chart-based output from each of the population models built as part of this study.

Each chart title confirms which deer species are actually present in the forest being modelled. Only some forests have sika deer present and almost none have Fallow deer present. Roe and red deer are present in almost all forests.

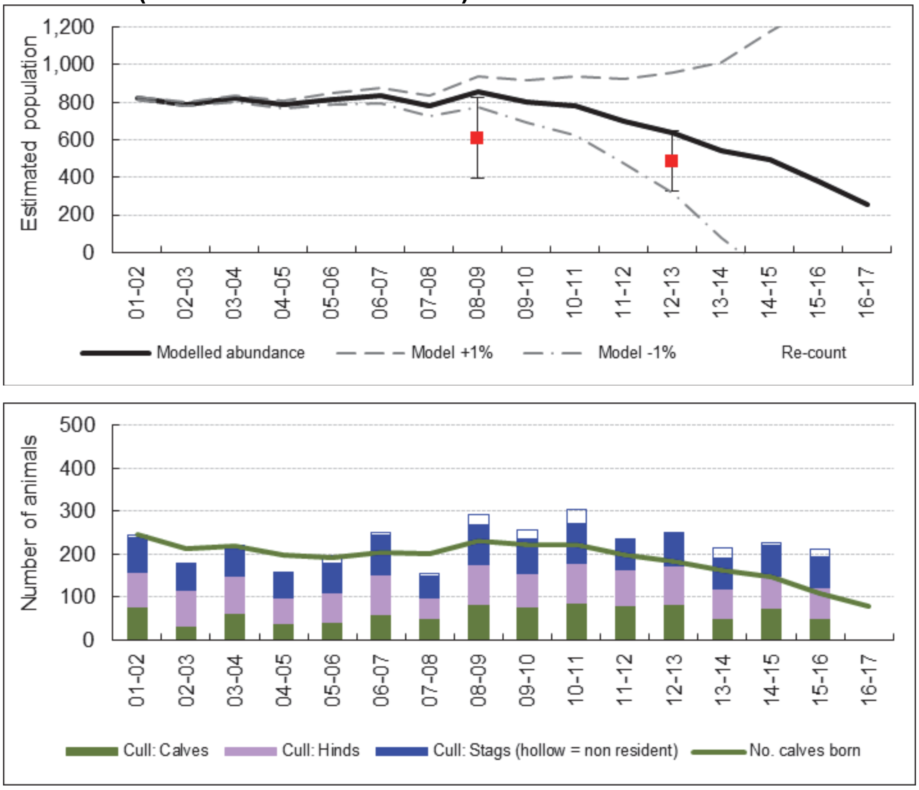
Readers should note the variable scales used on the y-axes of the charts presented - the numbers of deer present in each forest vary widely because of interactions between deer density and land area, hence use of a single scale was avoided despite it being preferred to enable easy comparisons between forests.

In general, readers will note agreement between long-terms models and deer density survey data is best in study areas which have larger numbers of deer present; where small numbers are present deer densities tend to be inherently very low (e.g. 1 per km^2) and in these circumstances obtaining accurate population estimates is far less easy given the budgets typically assigned to this type of work (in general, surveys with a low sampling intensity produce results of lower precision but in many areas they do not hold sufficient management priority to justify extra expenditure).

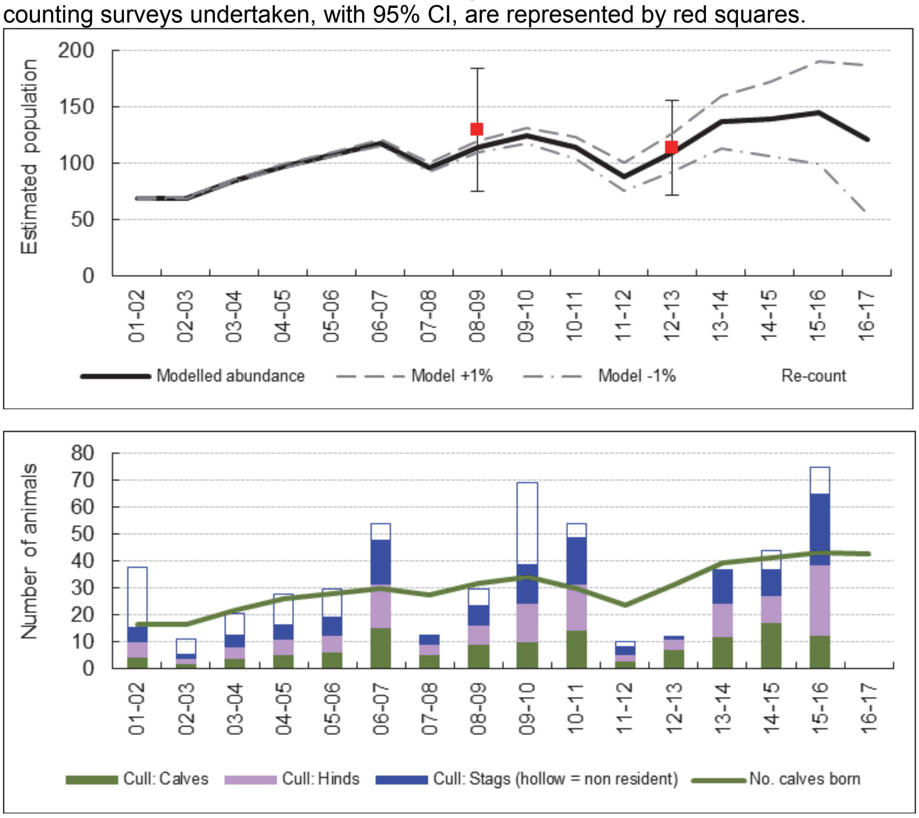
Other reasons for difficulties in balancing models relate to uncertainty over the recruitment rate (sometimes, the rate calculated from the cull seems unusually low for the type of habitat and deer density present – but this is not always easy to corroborate or validate in a desk-based study). Also, in some places there is some uncertainty over the sex ratio of the population at birth or as adults – these can play a very significant role in determining population trajectories over timescales of 15 years. Finally, some forests experience a significant degree in inwards movement and in places this is increasing year-to-year (e.g. in Moray & Aberdeenshire forests) despite the fact that red deer culls are continually rising in some of these areas. This can also complicate the models, making it hard to make baseline and monitoring surveys both tie in with model predictions.

Note: The type of population model and modelling process we used does not lend itself to easily deriving variance estimates for each deer abundance prediction, without resorting to a form of bootstrapping or similar. The short timescale for this project precluded such a process being used. Instead, we brought together all available evidence and used it to hand fit models as best we could to the range of data and parameters available. The best we could do in the time available was to include the dashed lines on each model chart showing the sensitivity of each model to a 1% change in input population size.

ACHANY (NORTH HIGHLAND FD)

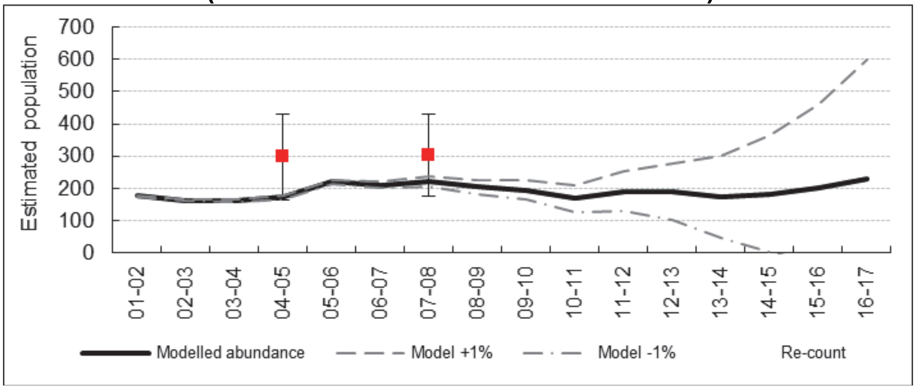


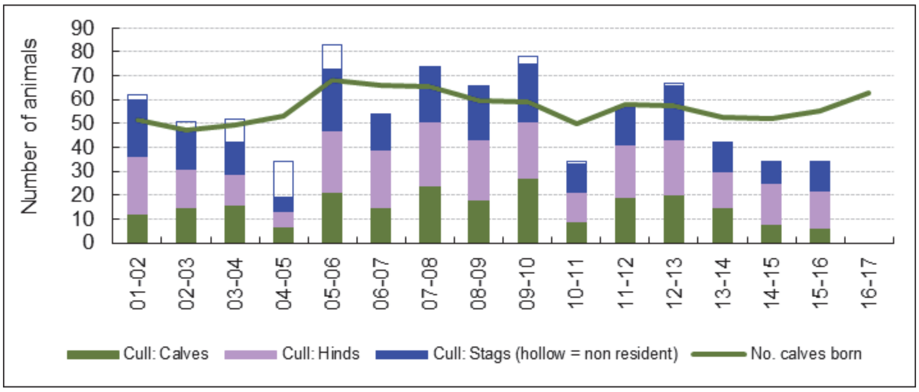
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.



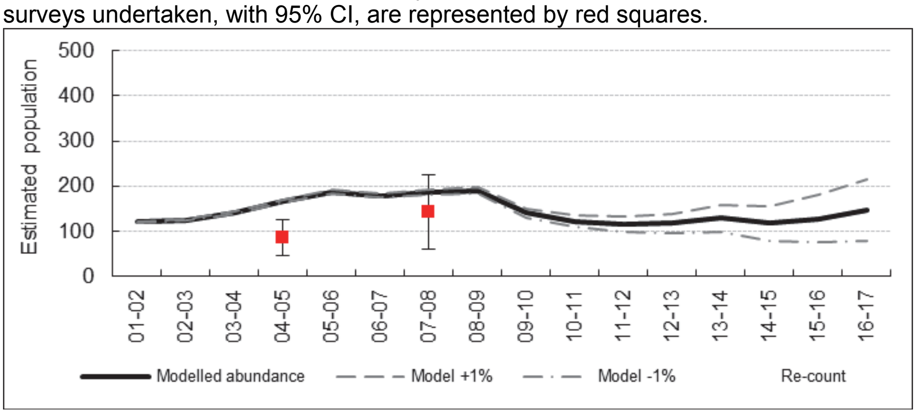
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

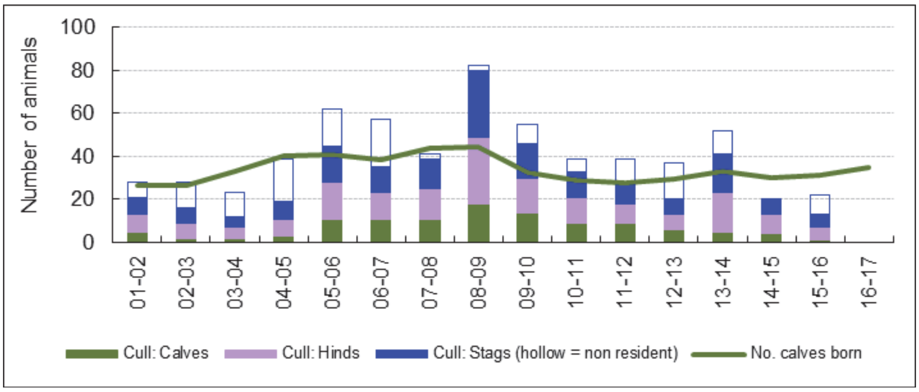
BARCALDINE (WEST ARGYLL & LOCHABER FD'S)





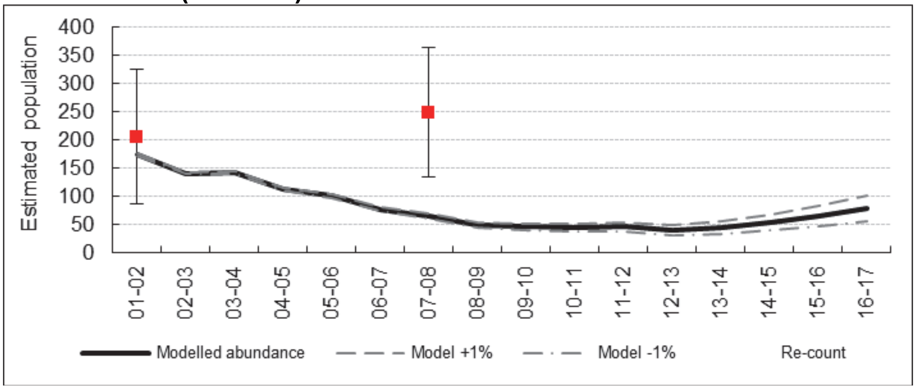
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

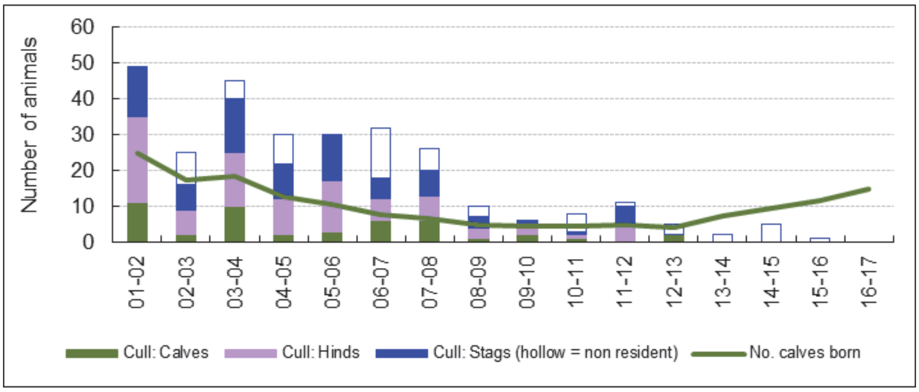




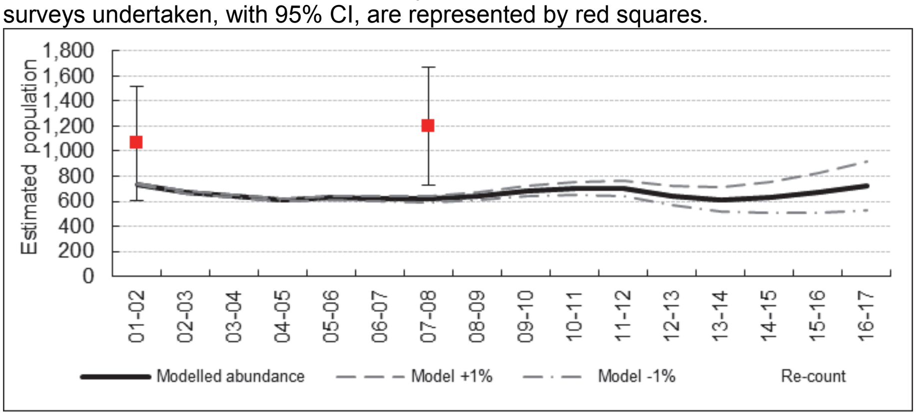
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

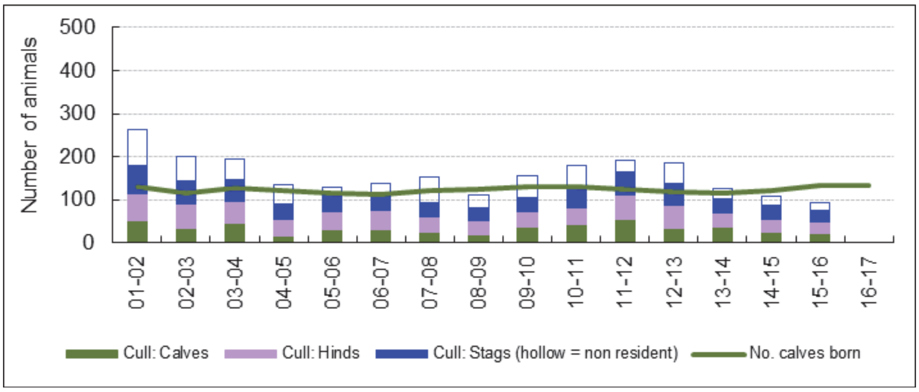
BARRACKS (TAY FD)





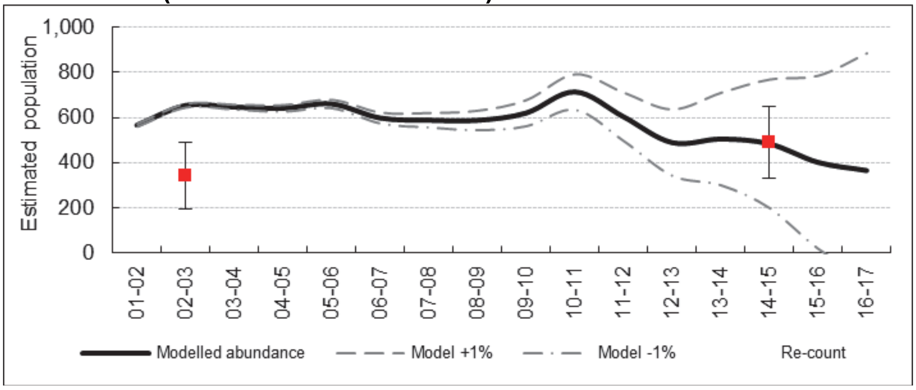
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

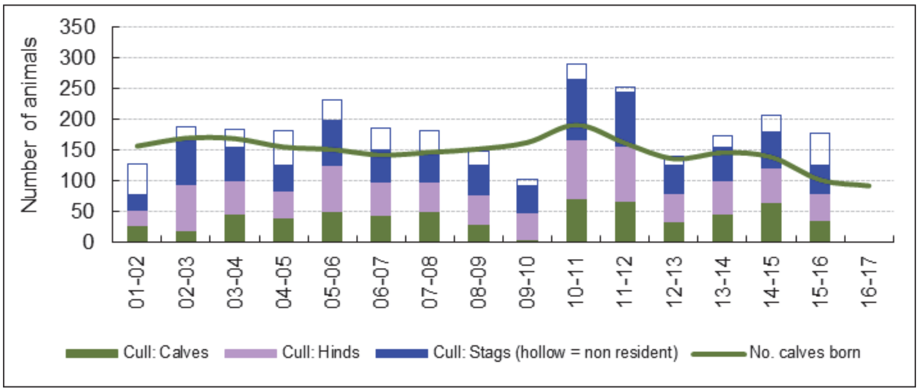




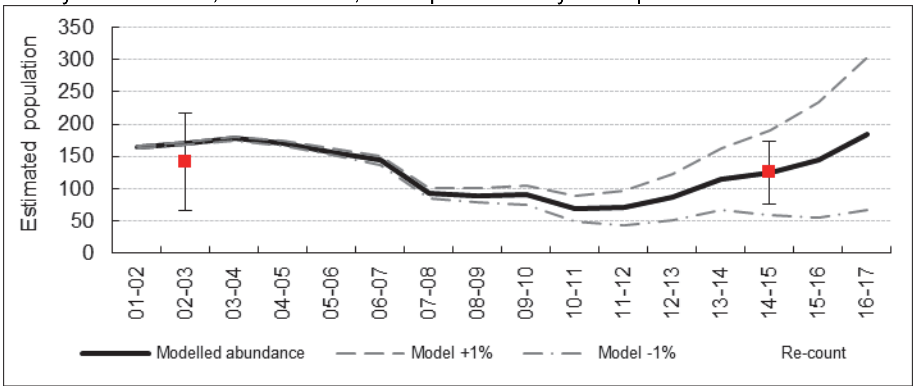
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

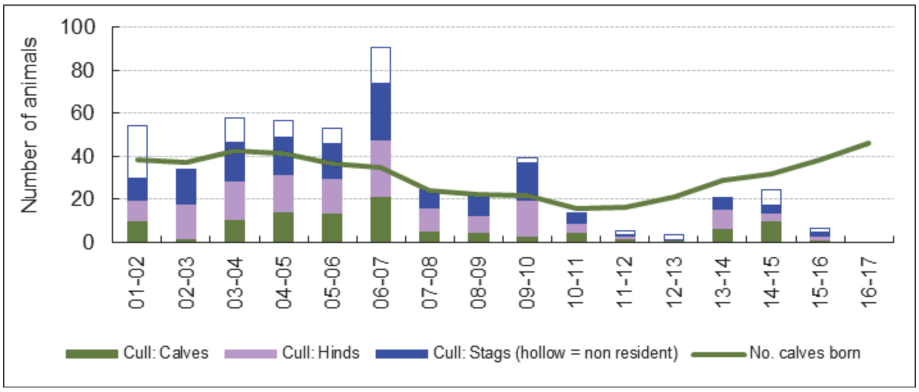
BENMORE (NORTH HIGHLAND FD)





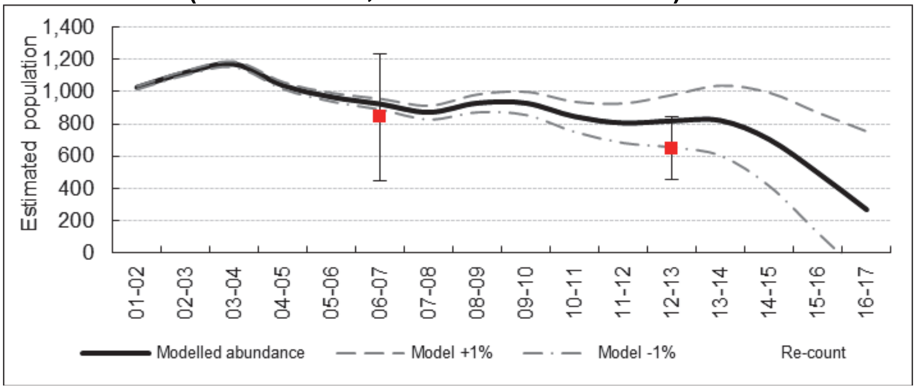
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

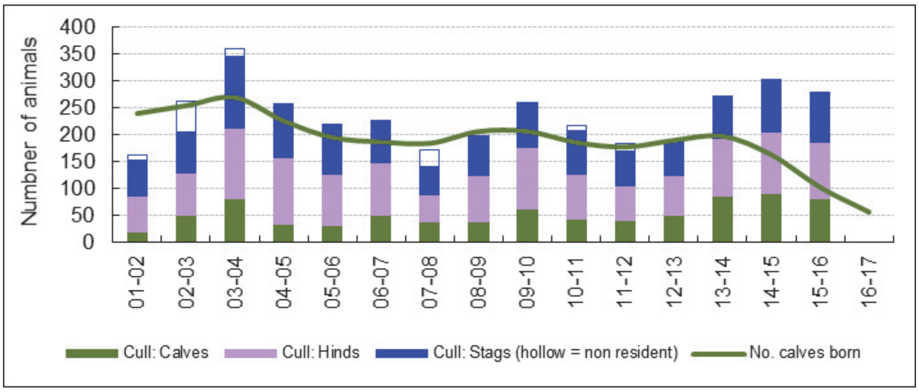




Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

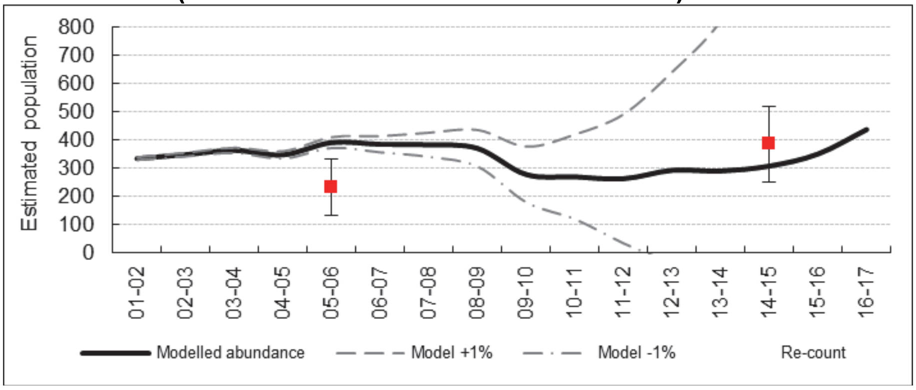
BLACK ISLE (INVERNESS, ROSS AND SKYE FD)

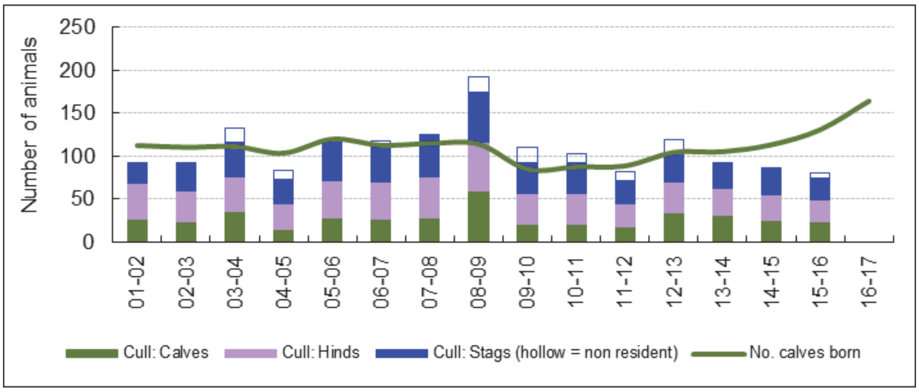




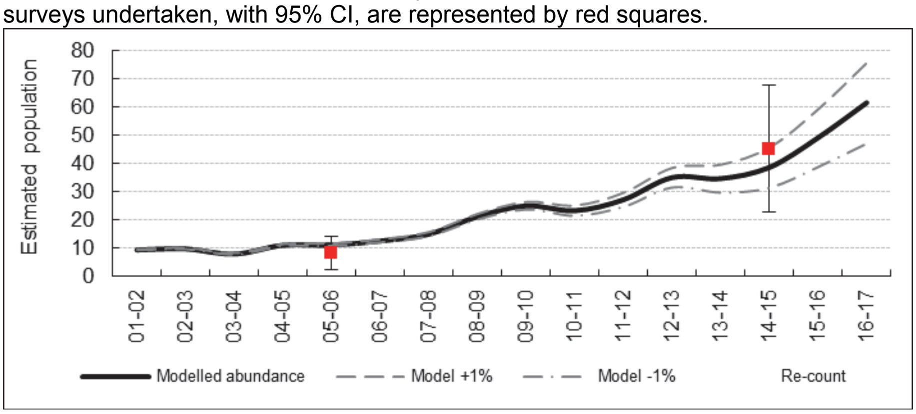
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

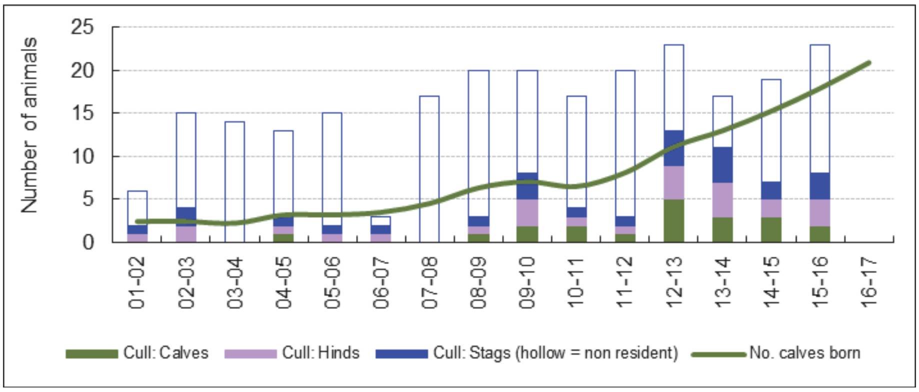
BUNZEACH (MORAY AND ABERDEENSHIRE FD)





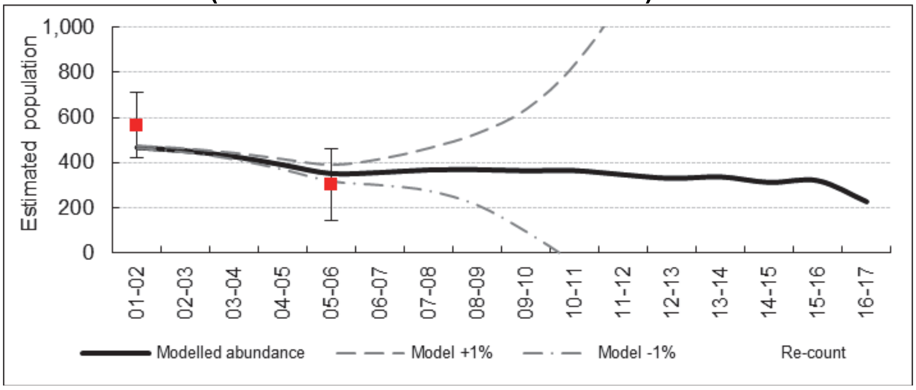
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

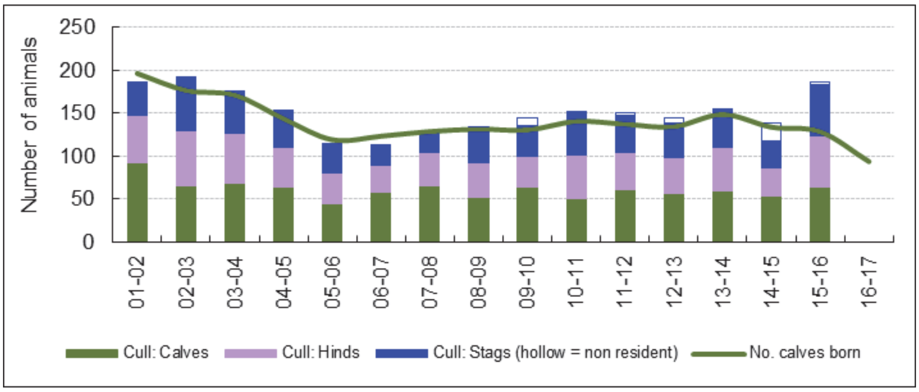




Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

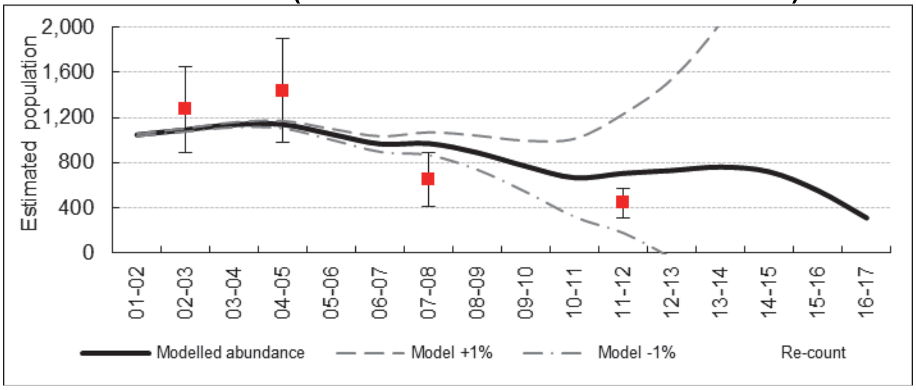
CASTLE O'ER (DUMFRIES AND BORDERS FD)

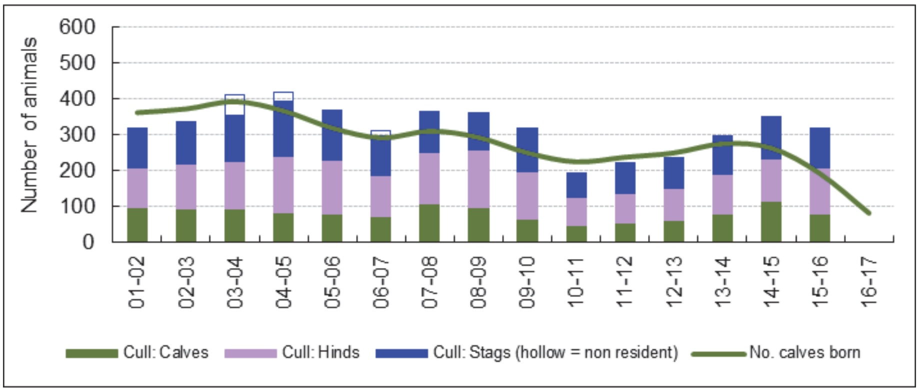




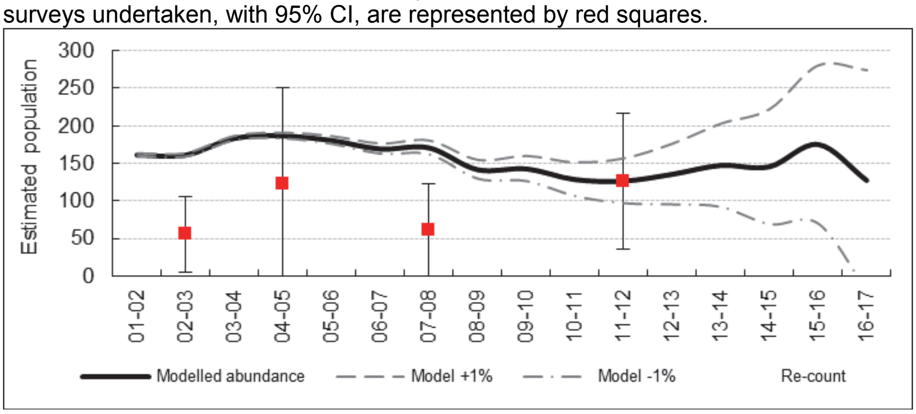
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

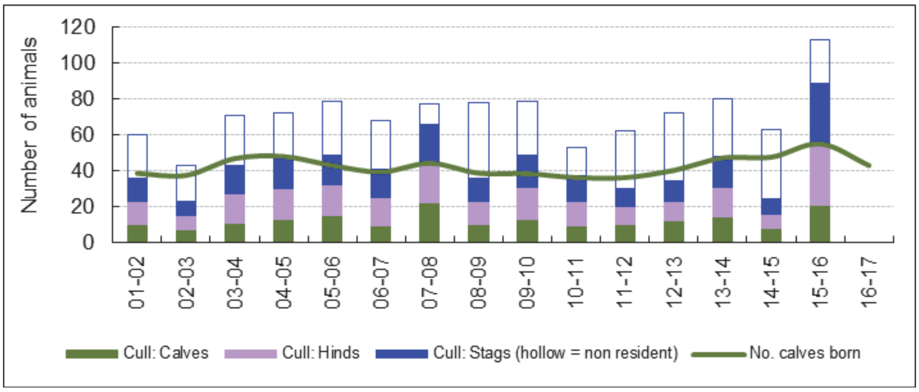
CLASHINDARROCH (MORAY AND ABERDEENSHIRE FD)





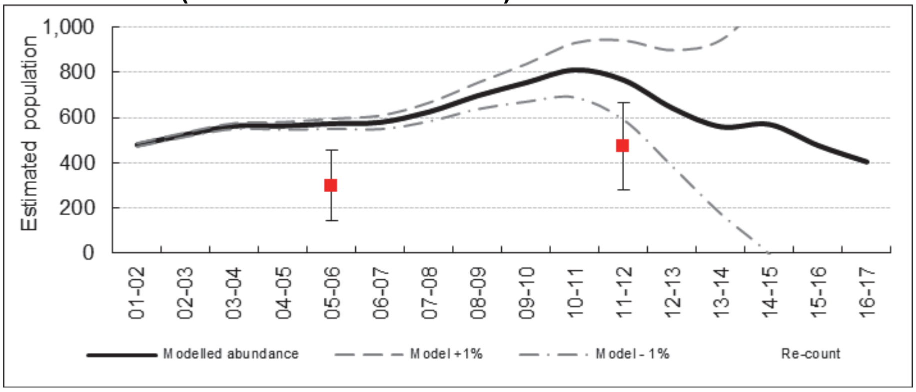
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

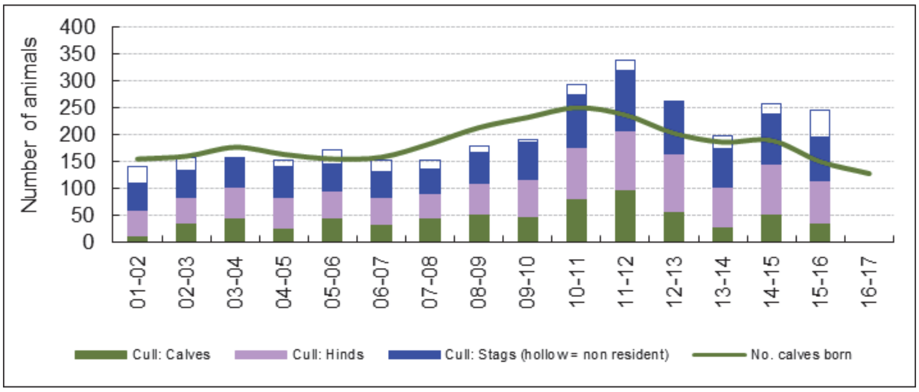




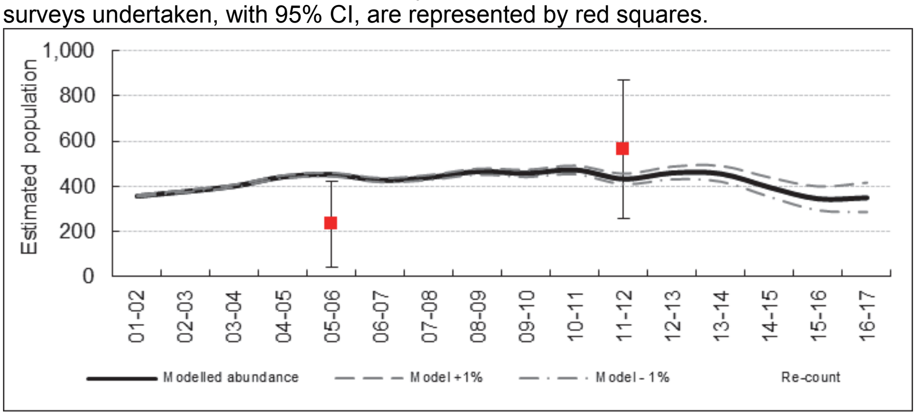
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

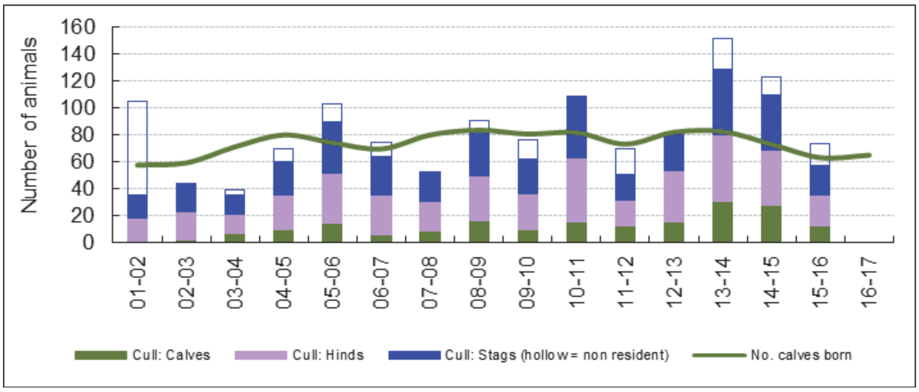
DALCHORK (NORTH HIGHLAND FD)





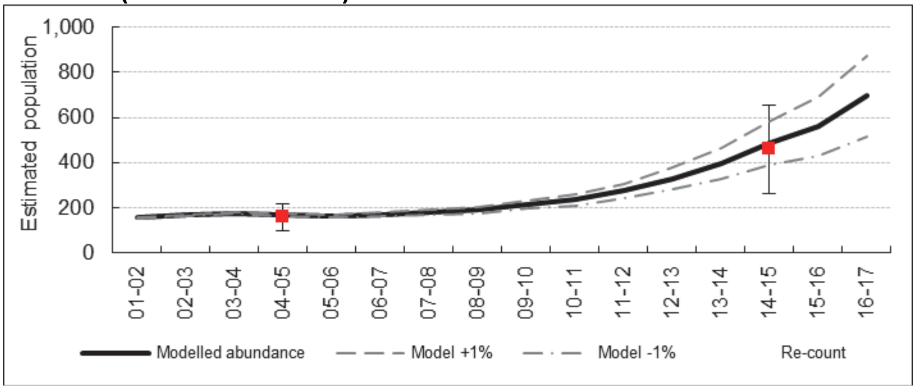
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

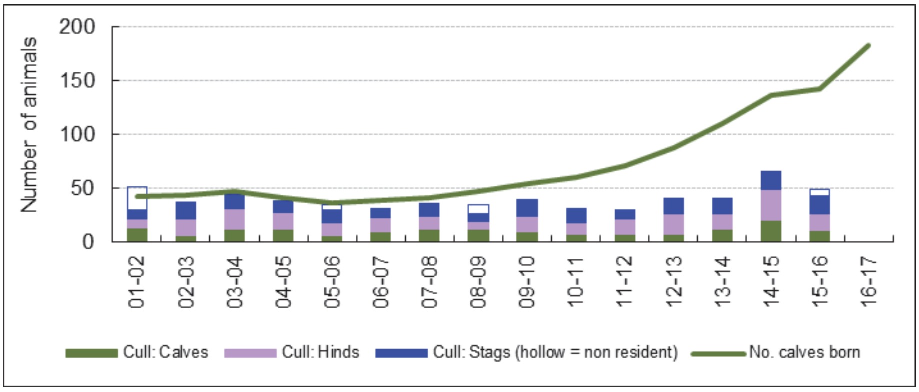




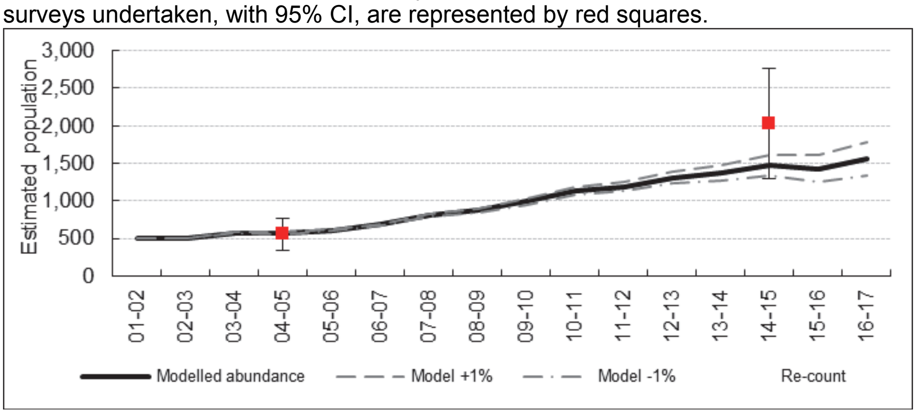
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

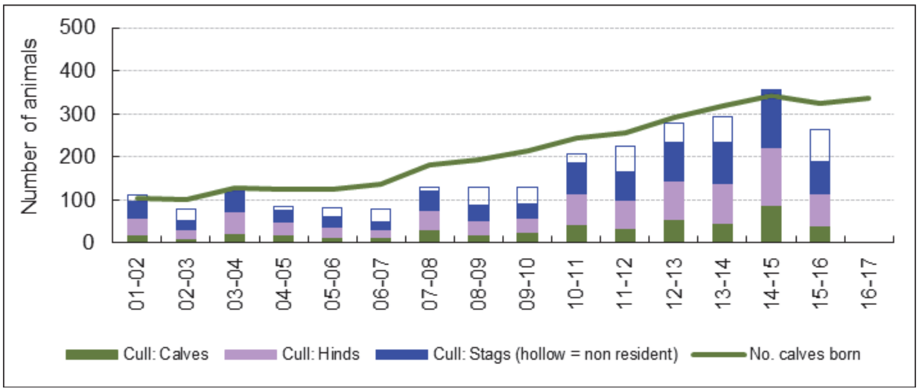
DUROR (LOCHABER FD)





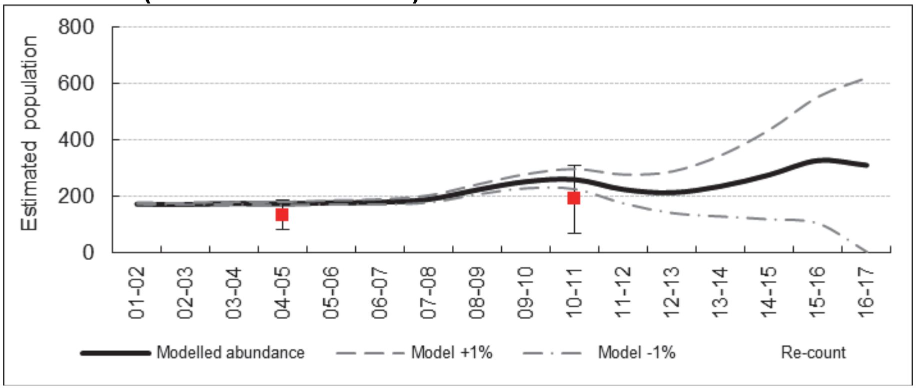
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

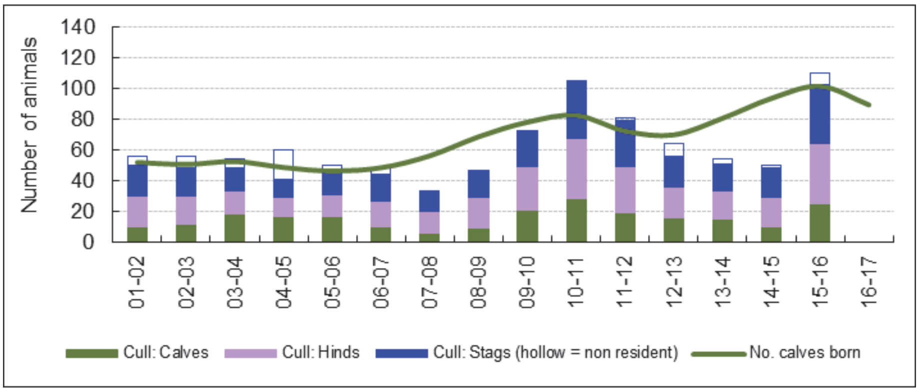




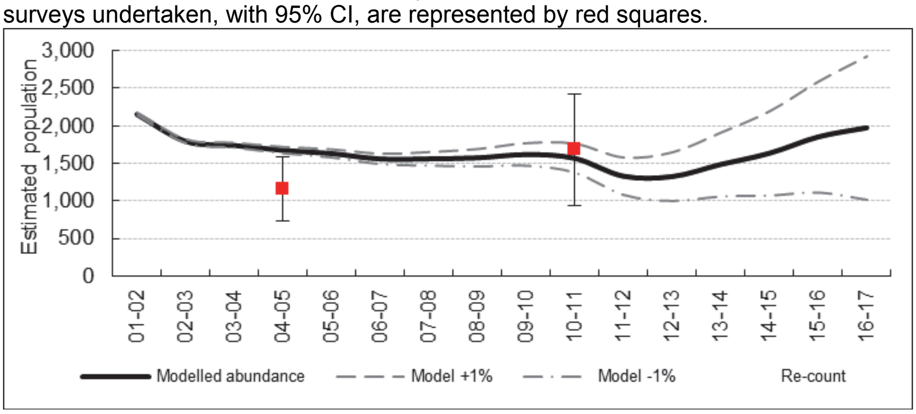
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

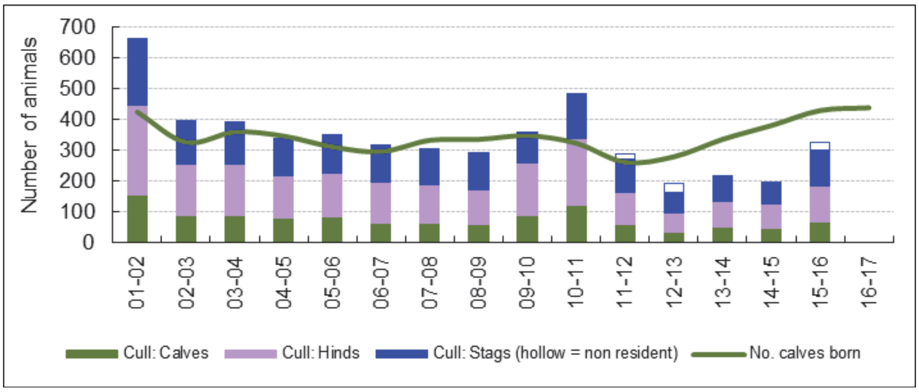
EREDINE (WEST ARGYLL FD)





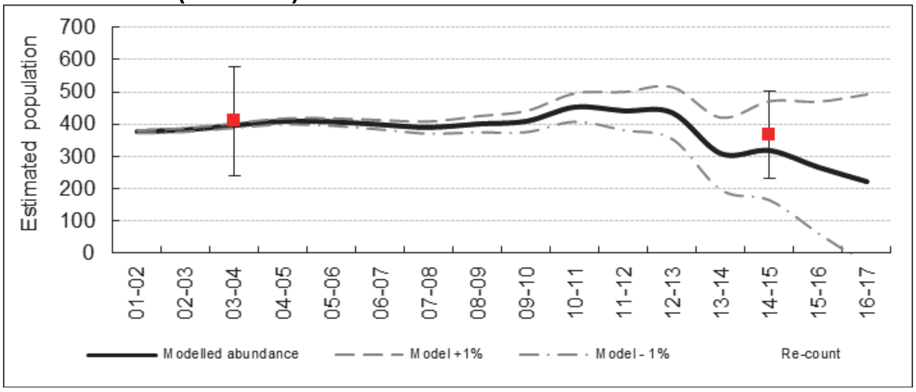
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

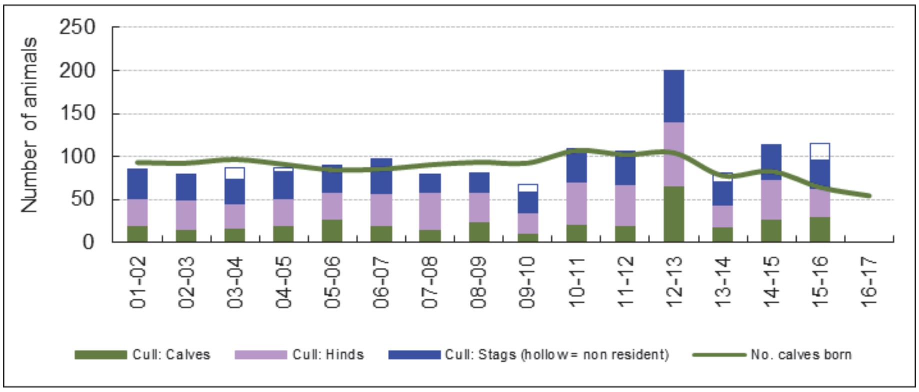




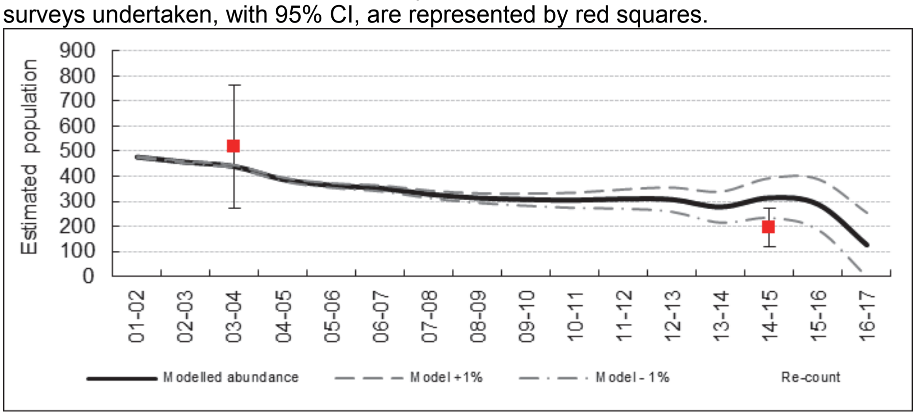
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

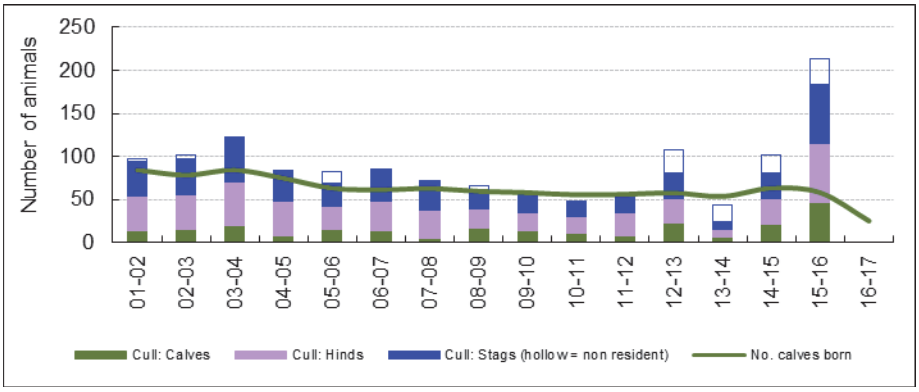
ERROCHTY (TAY FD)





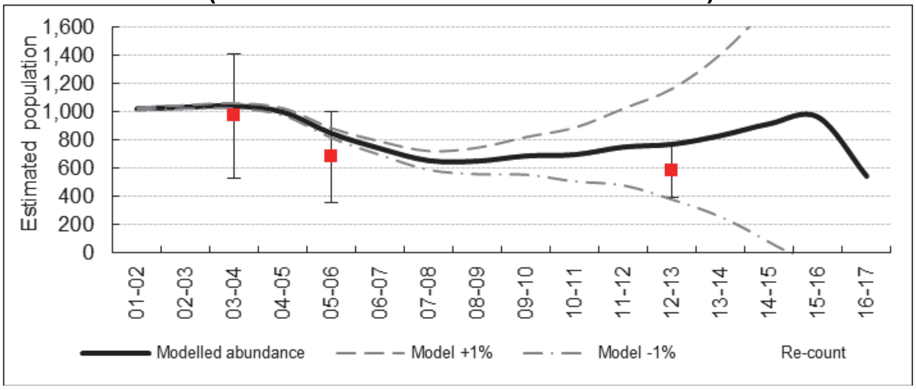
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

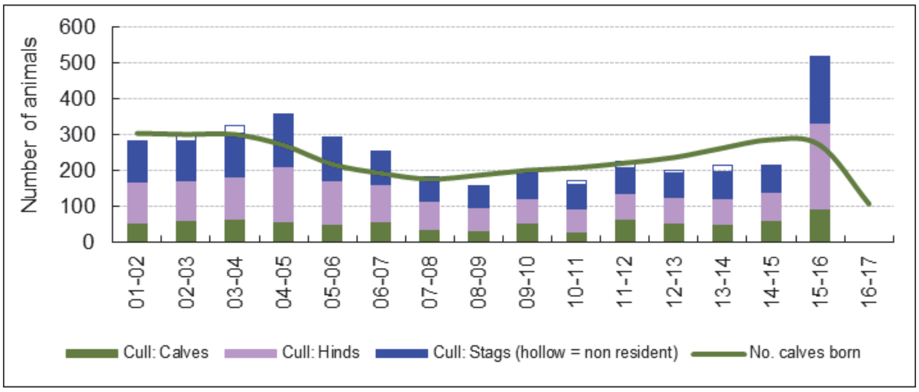




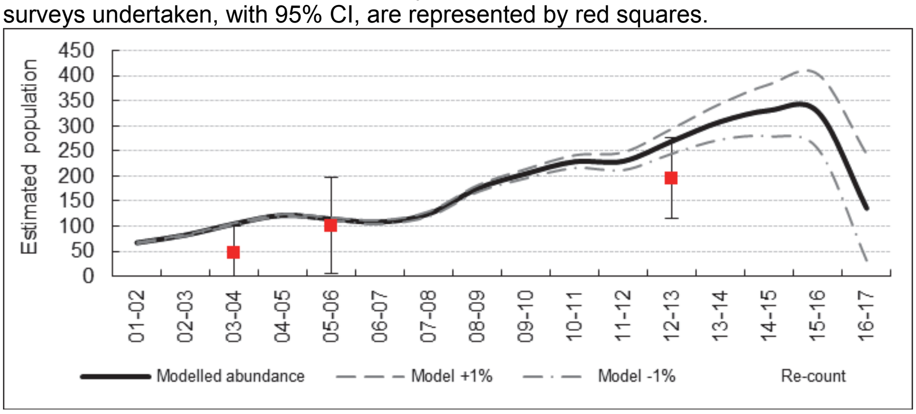
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

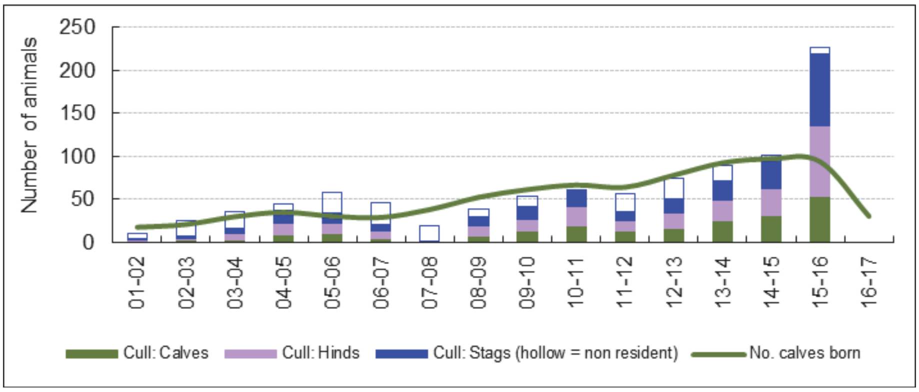
FETTERESSO (MORAY AND ABERDEENSHIRE FD)





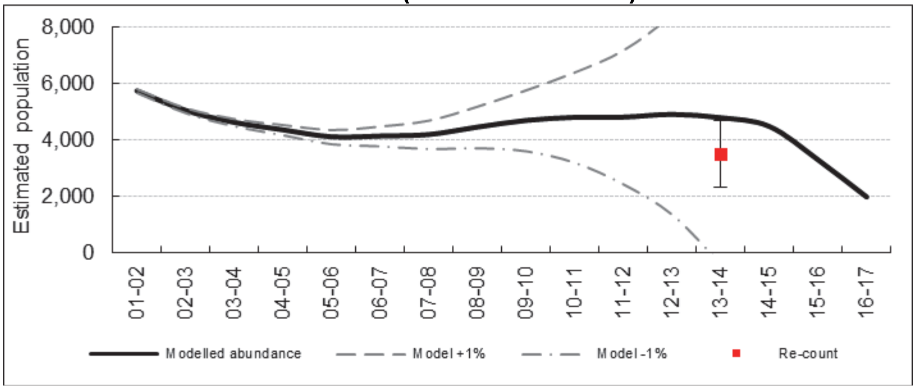
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

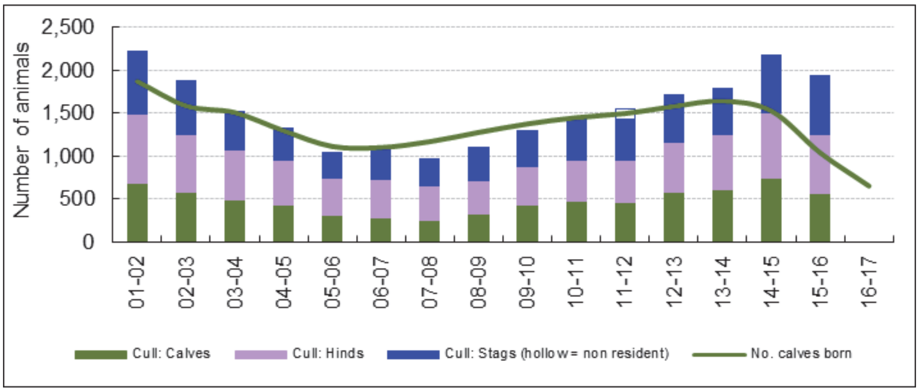




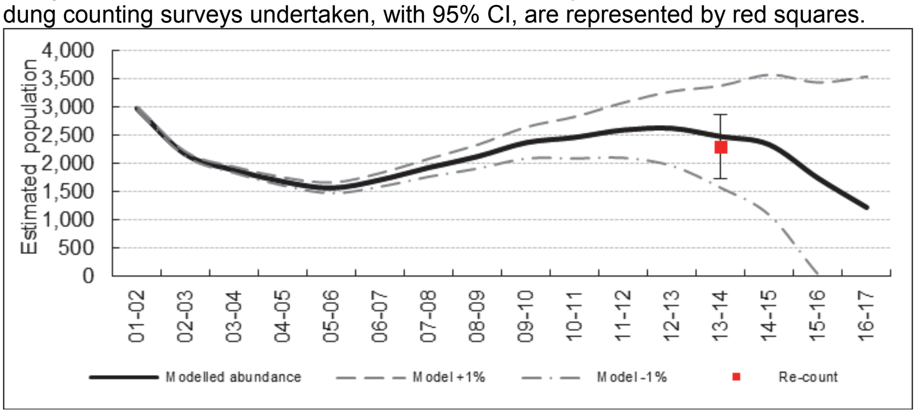
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

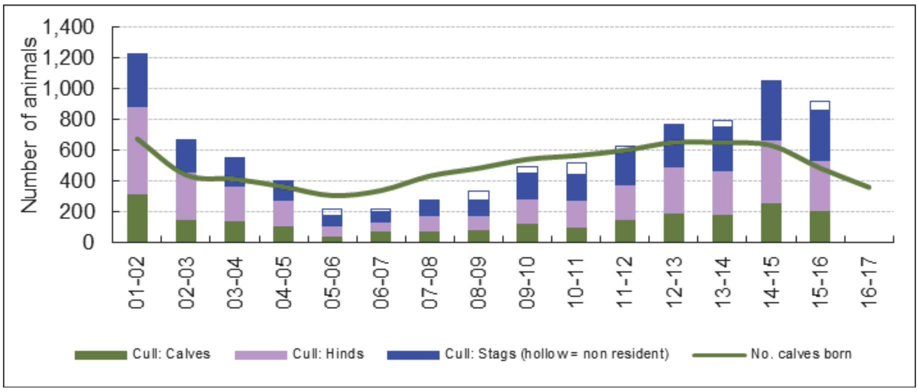
GALLOWAY FOREST PARK (GALLOWAY FD)





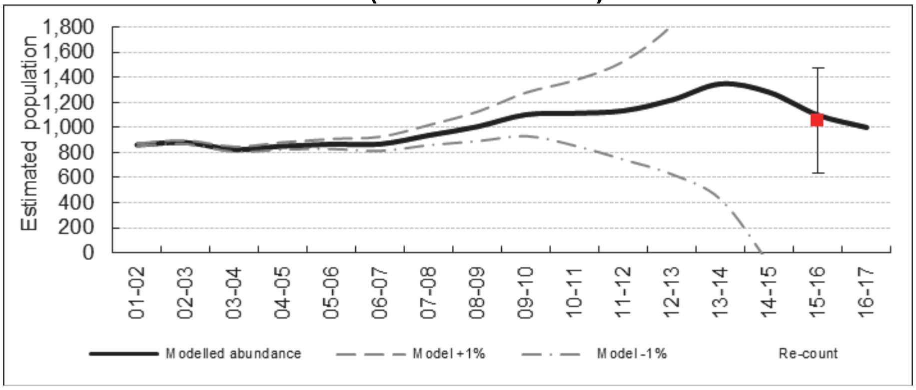
Roe/sika/fallow deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

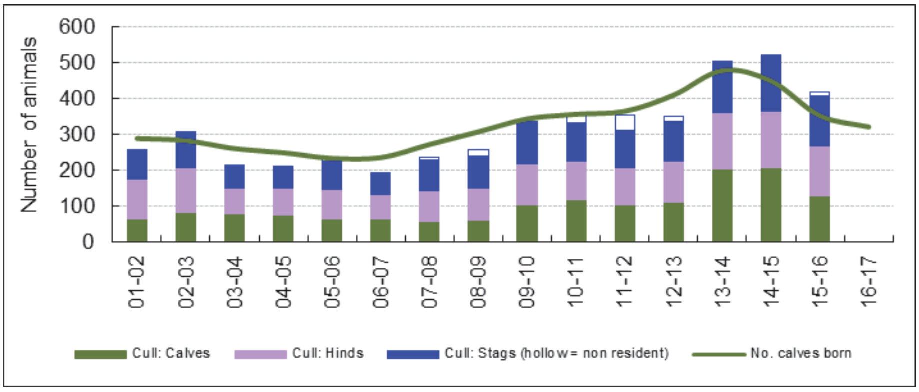




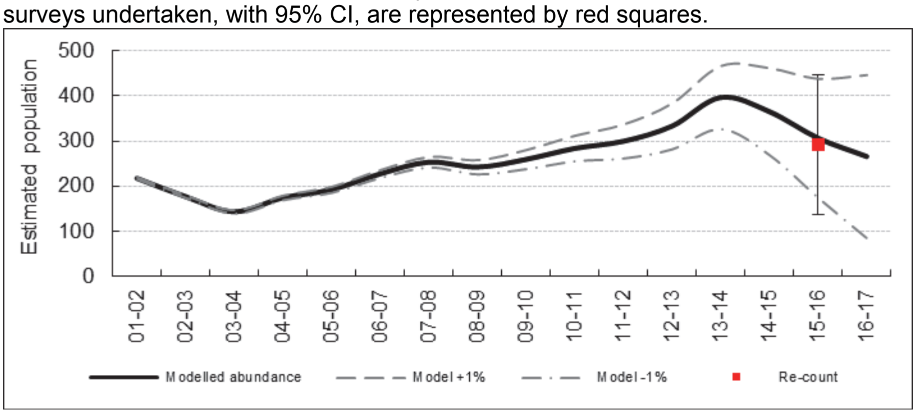
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

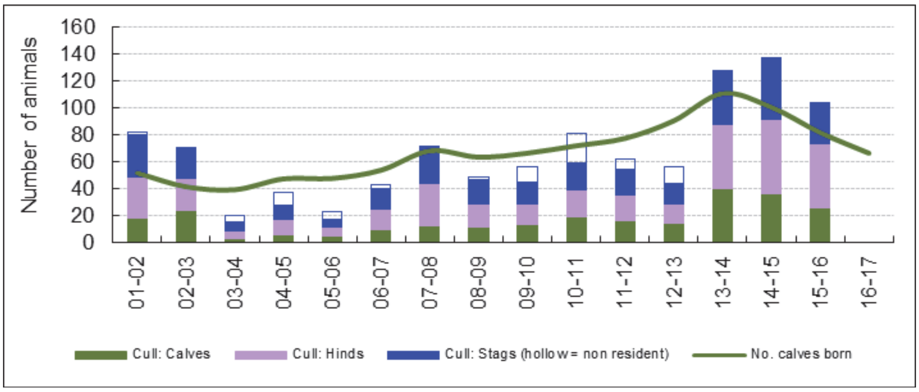
GALLOWAY WEST: MAIN (GALLOWAY FD)





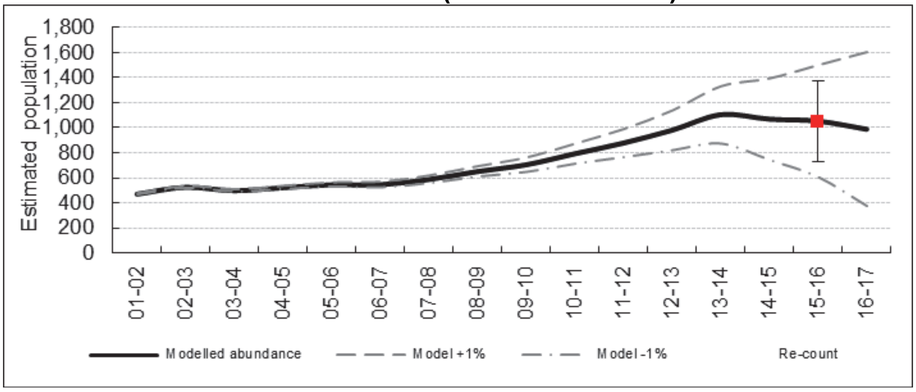
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

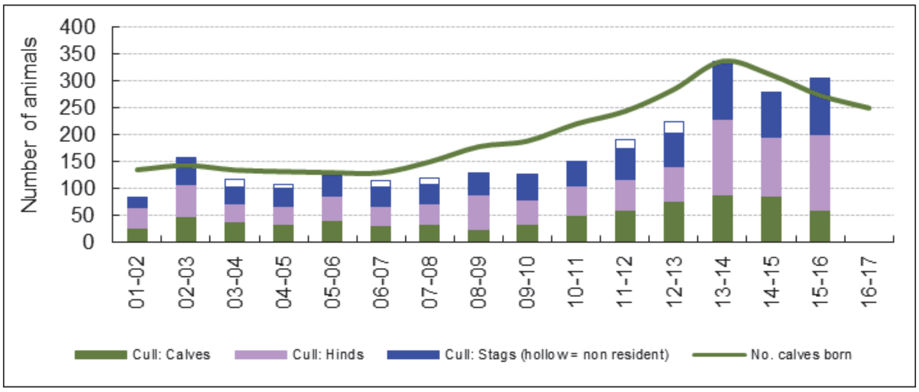




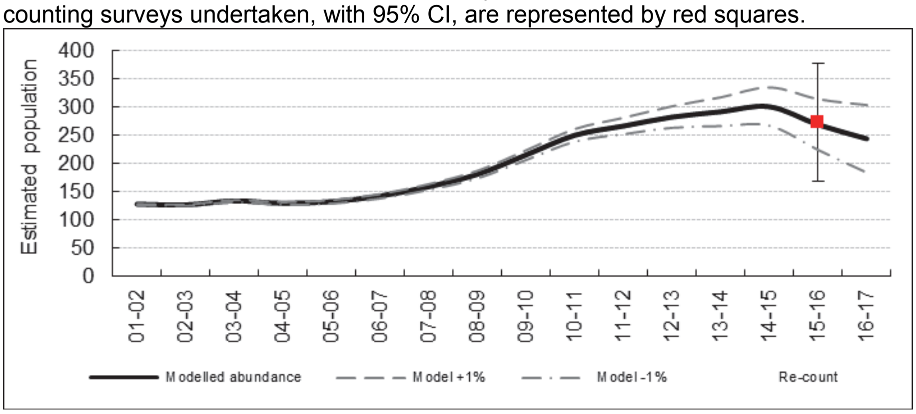
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

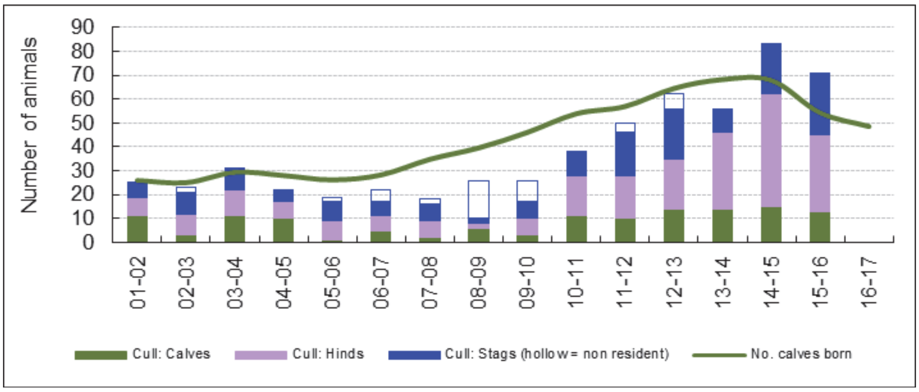
GALLOWAY WEST: OUTLIERS (GALLOWAY FD)





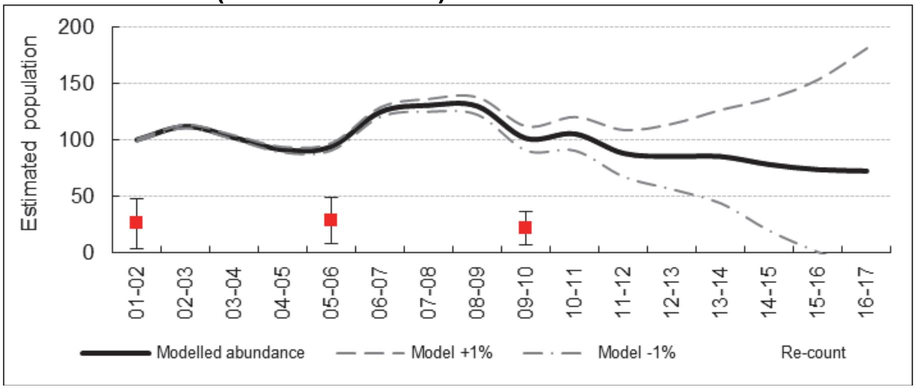
Roe/fallow deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

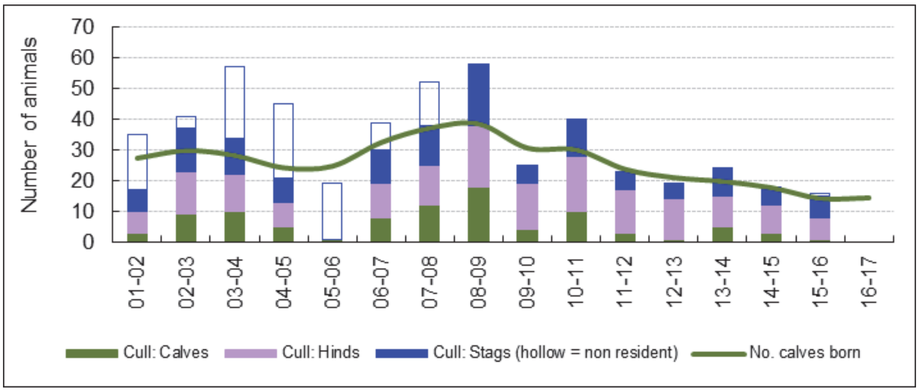




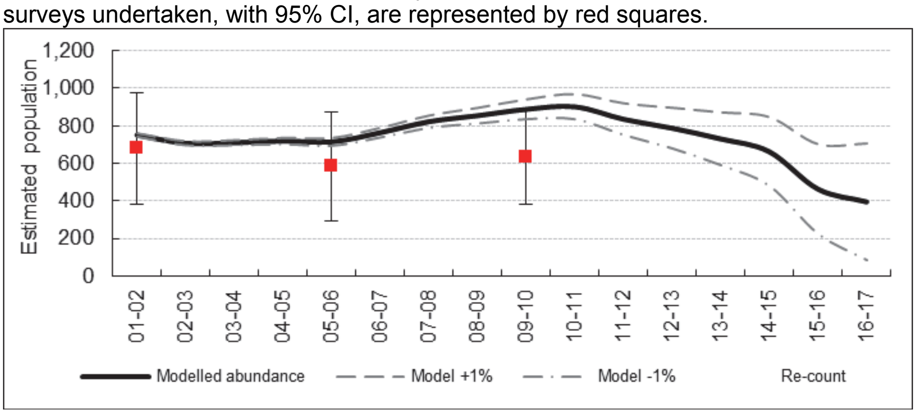
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

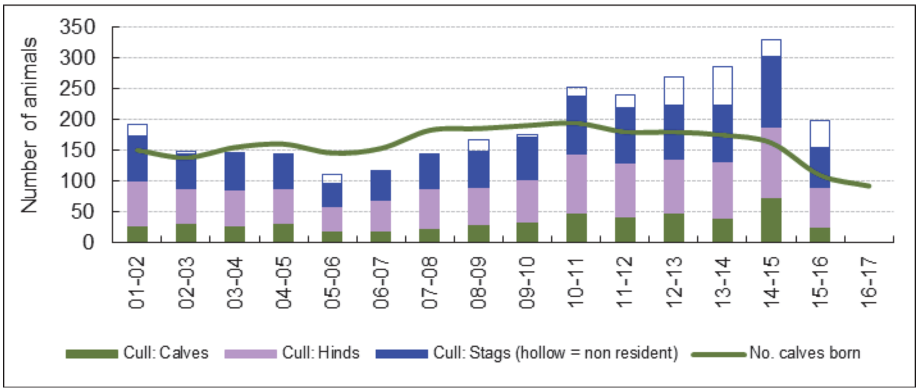
GLEN HURICH (LOCHABER FD)





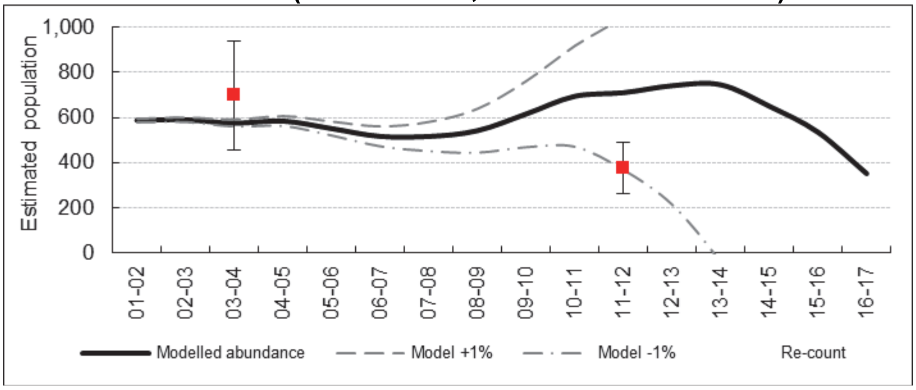
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

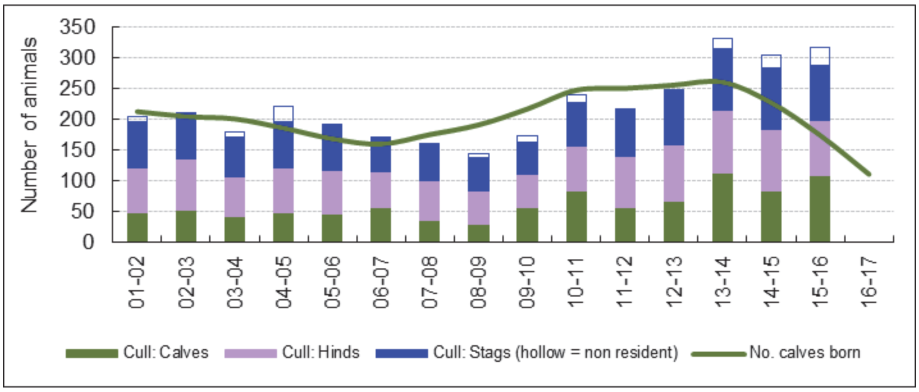




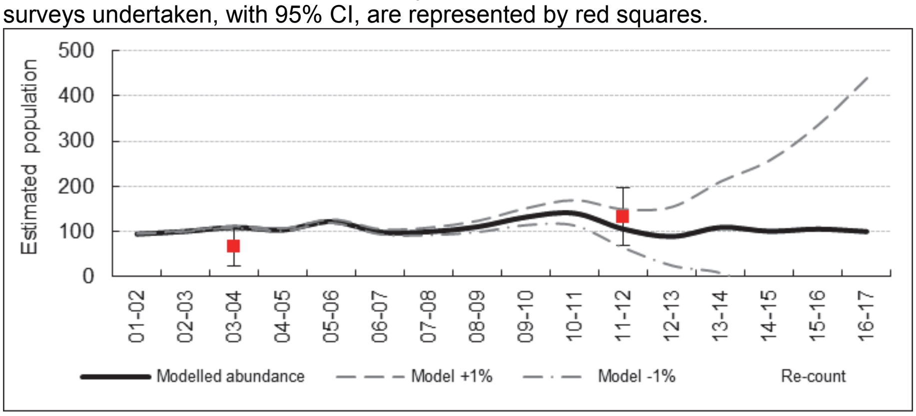
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

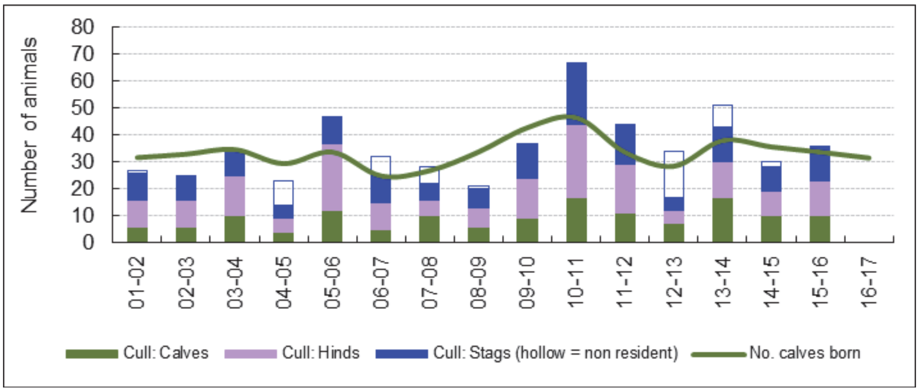
INVERNESS SOUTH (INVERNESS, ROSS AND SKYE FD)





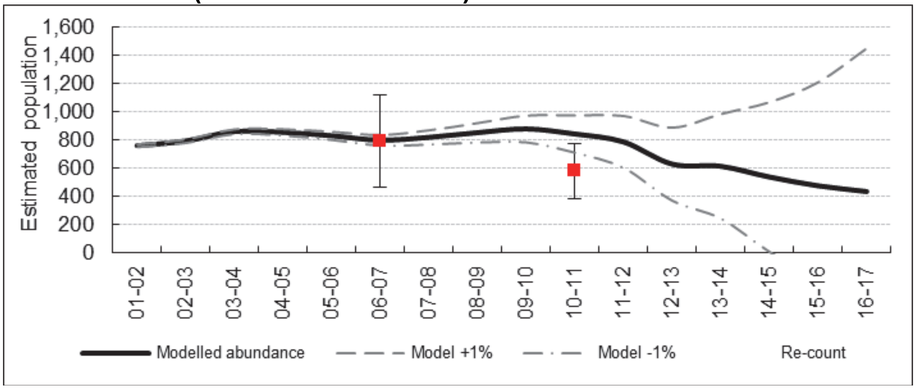
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

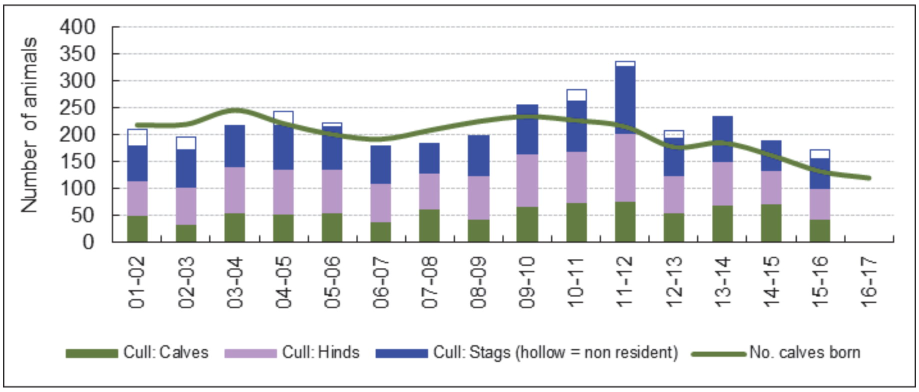




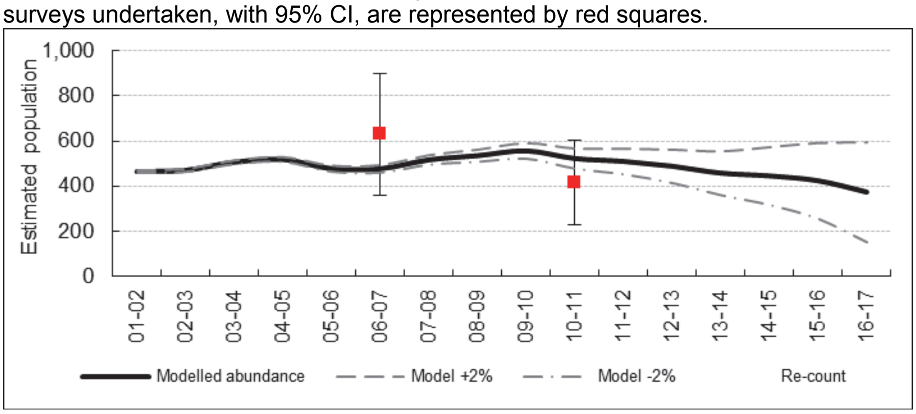
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

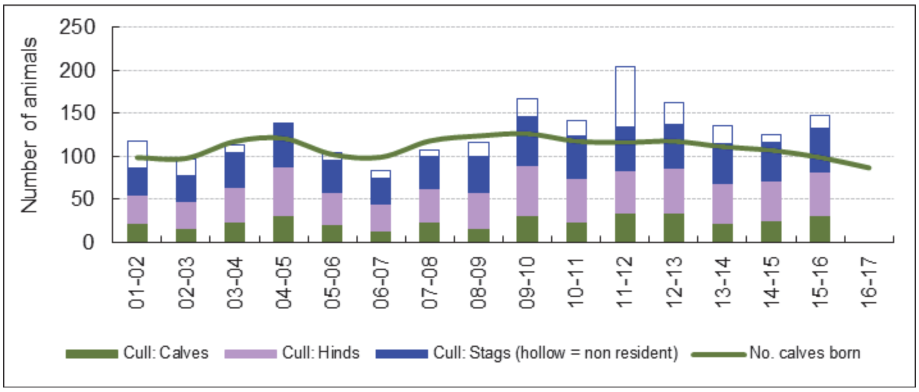
KILMICHAEL (WEST ARGYLL FD)





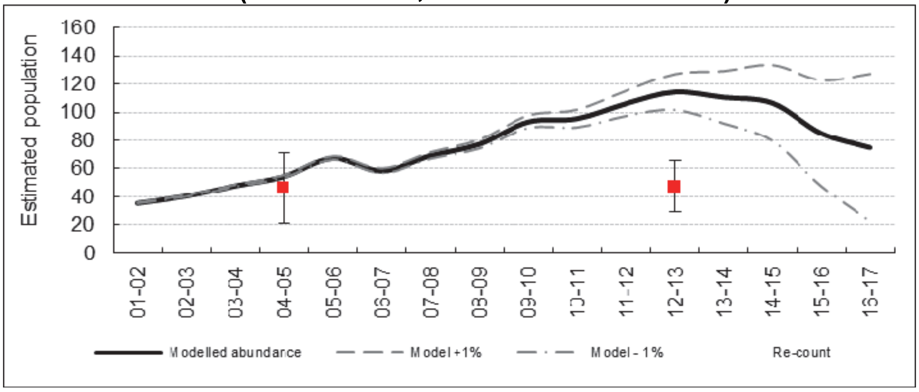
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

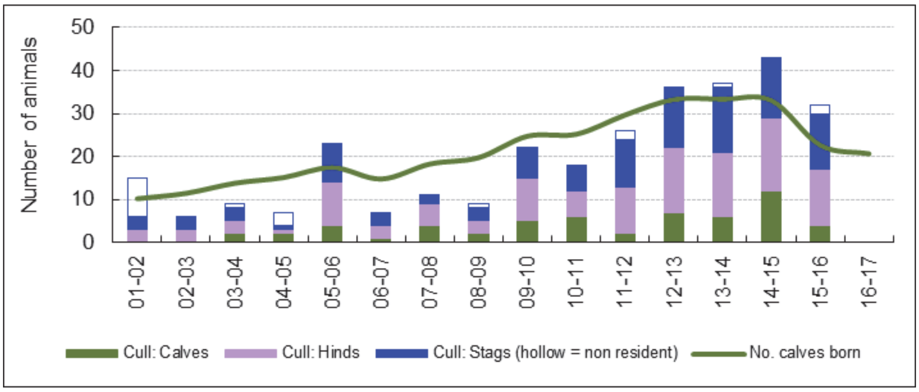




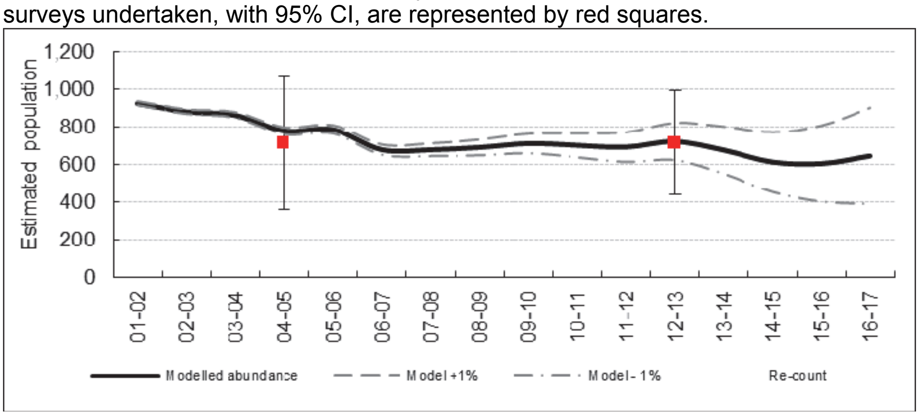
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

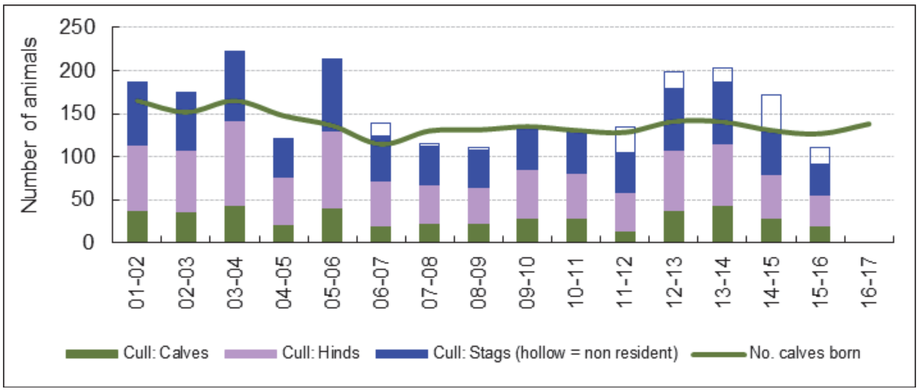
KINLOCH HILLS (INVERNESS, ROSS AND SKYE FD)





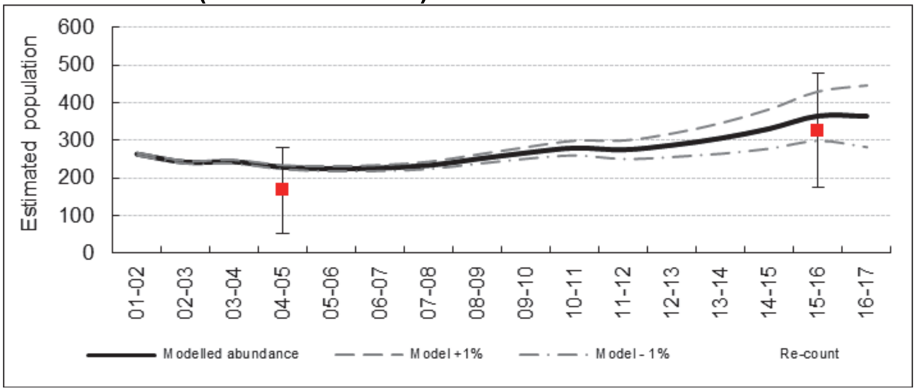
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

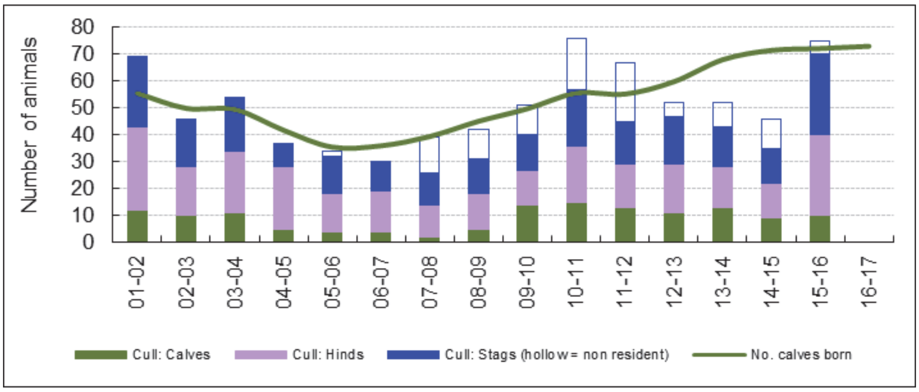




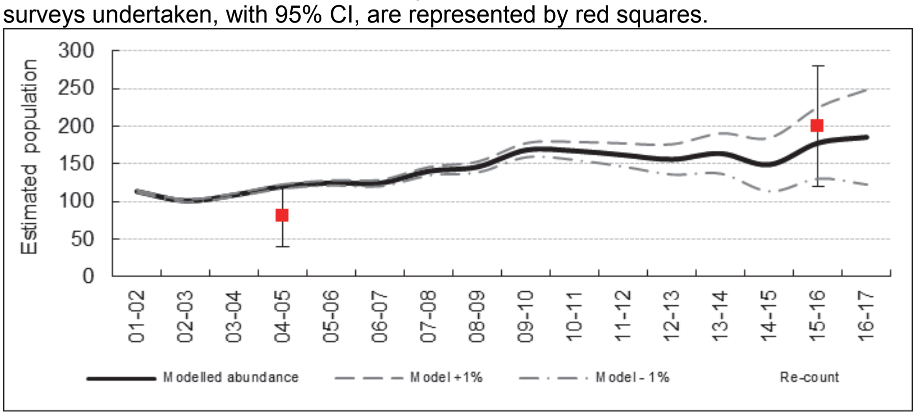
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

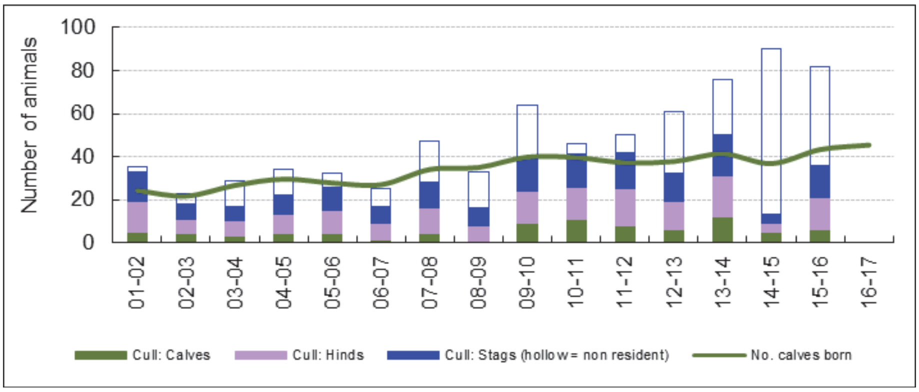
LEANACHAN (LOCHABER FD)





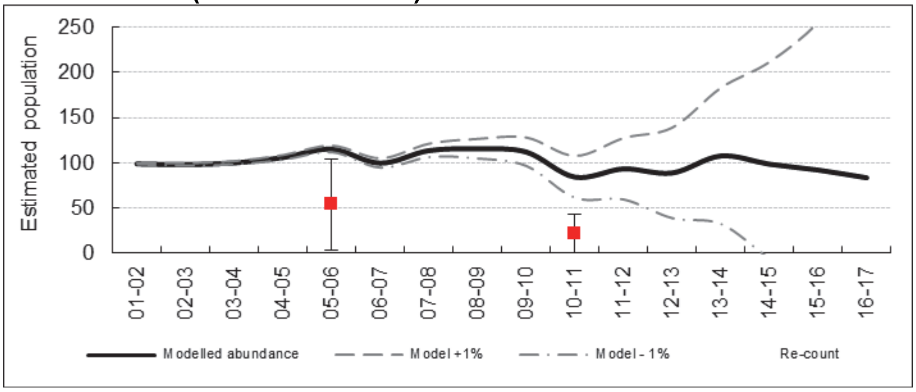
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

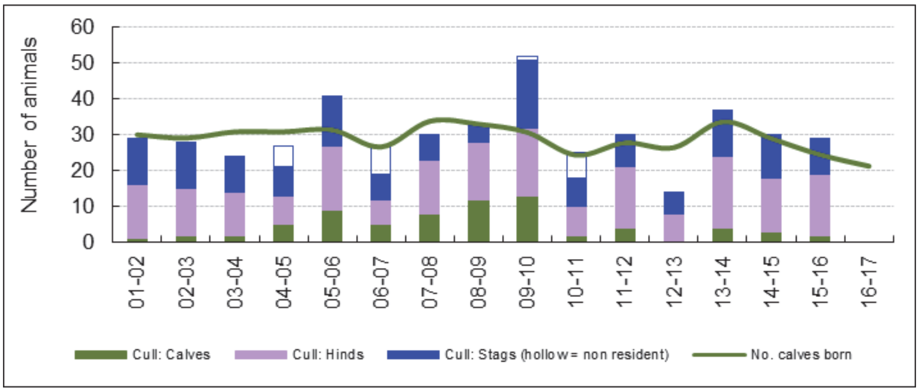




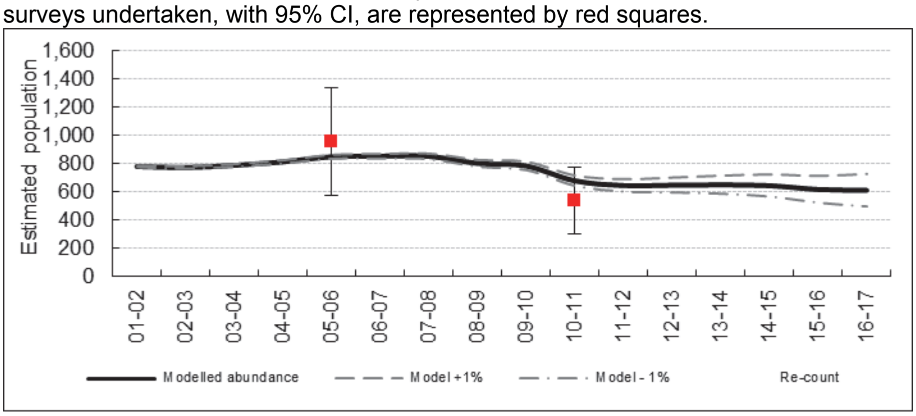
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

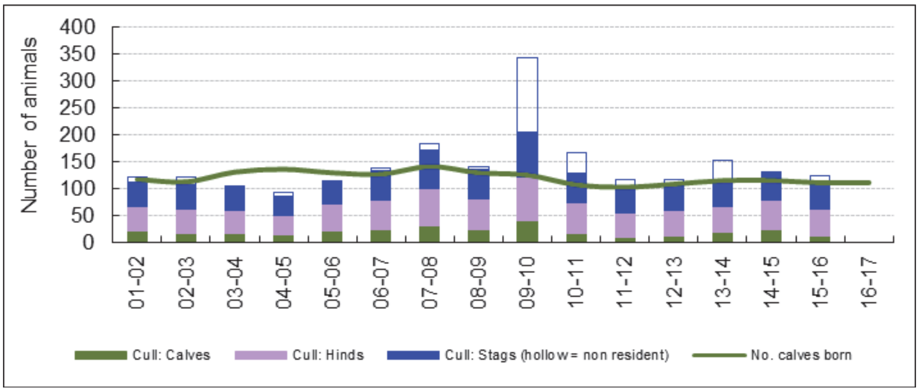
LOCH ALINE (LOCHABER FD)





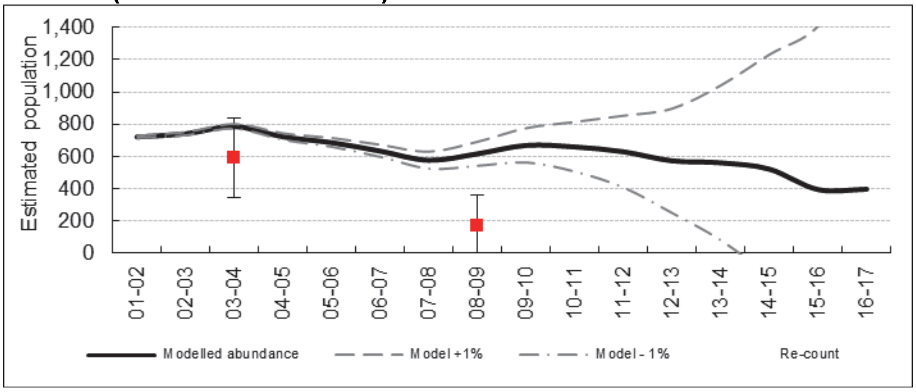
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

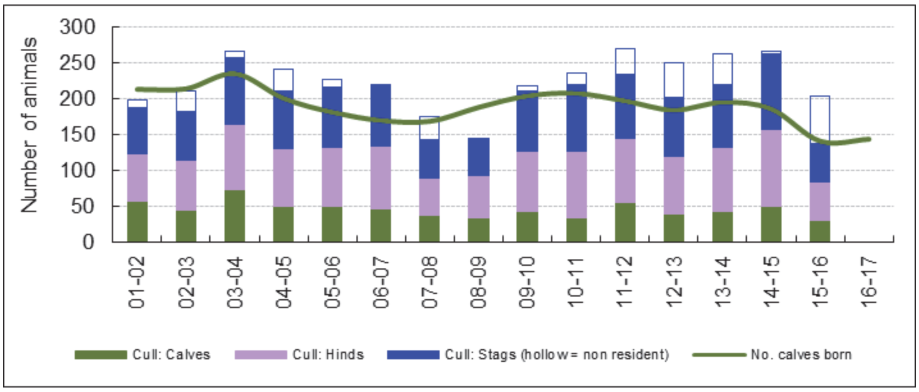




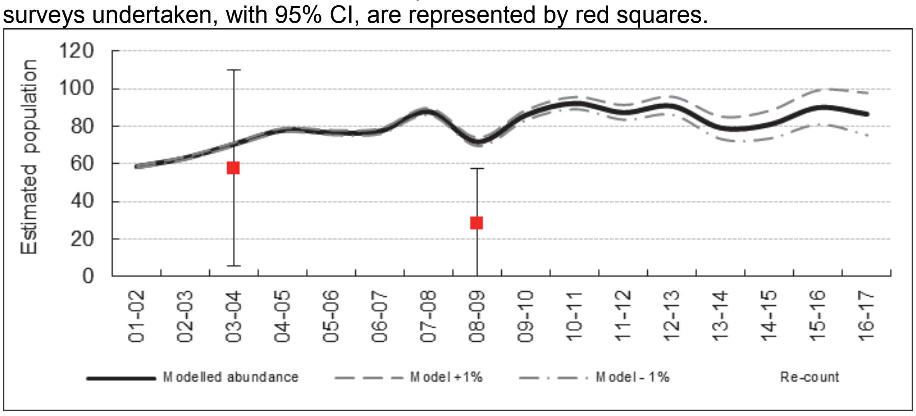
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

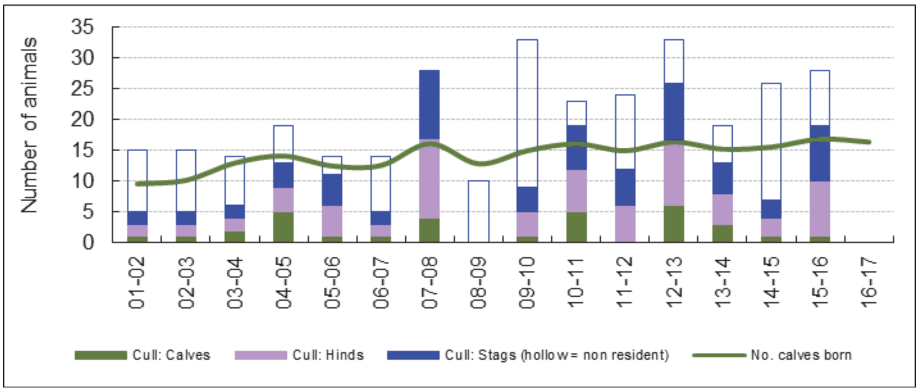
LUSSA (WEST ARGYLL FD)





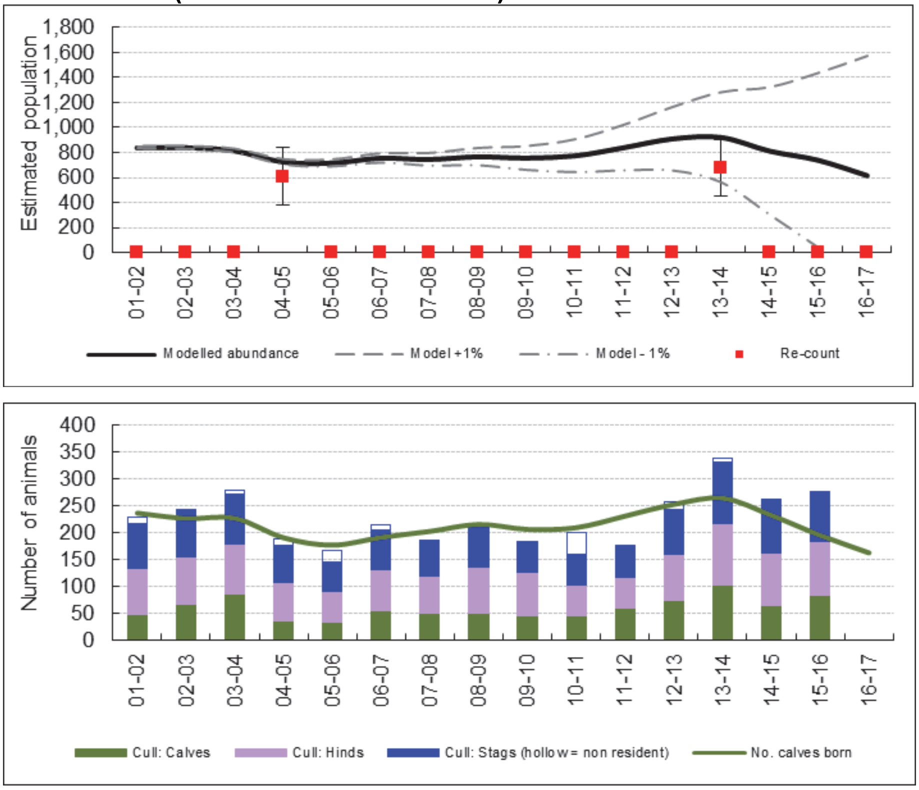
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.



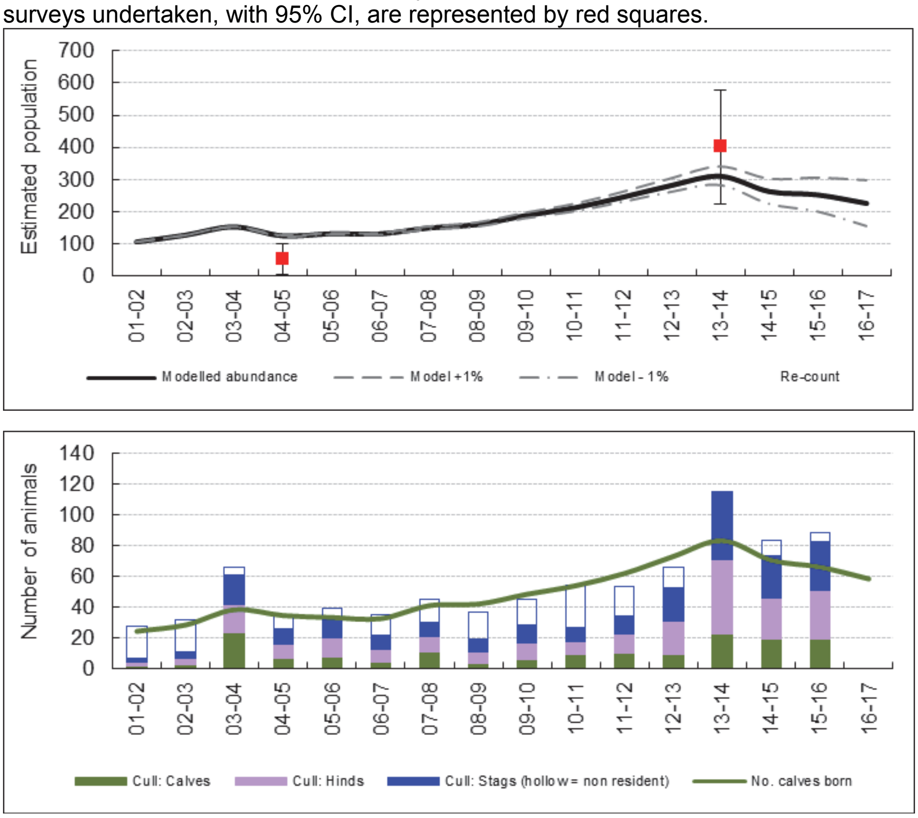


Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

MORANGIE (NORTH HIGHLAND FD)

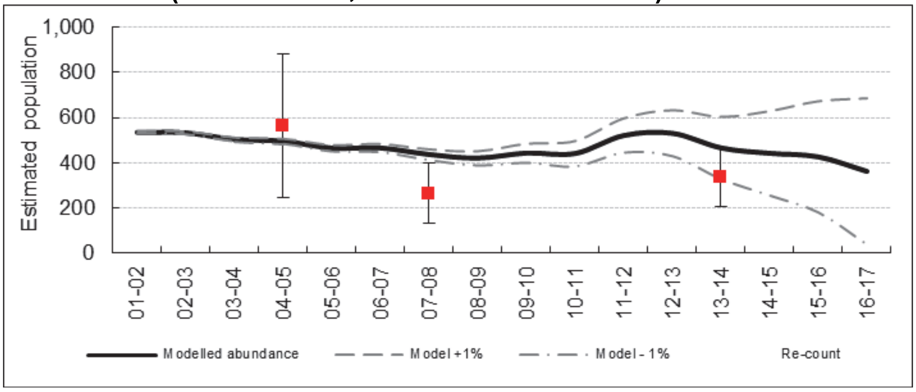


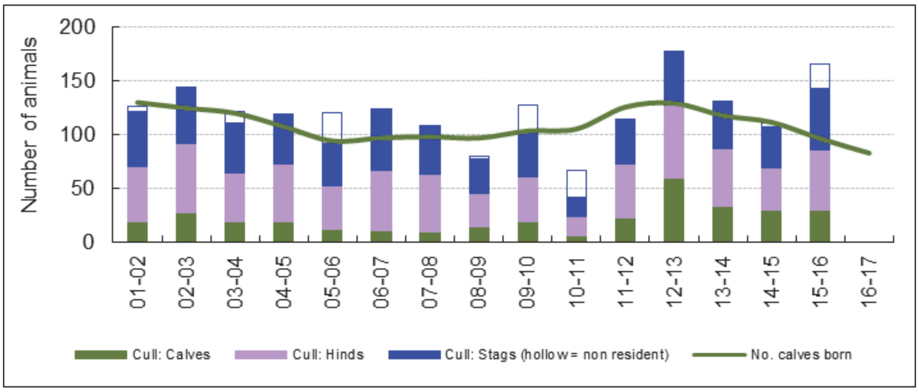
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.



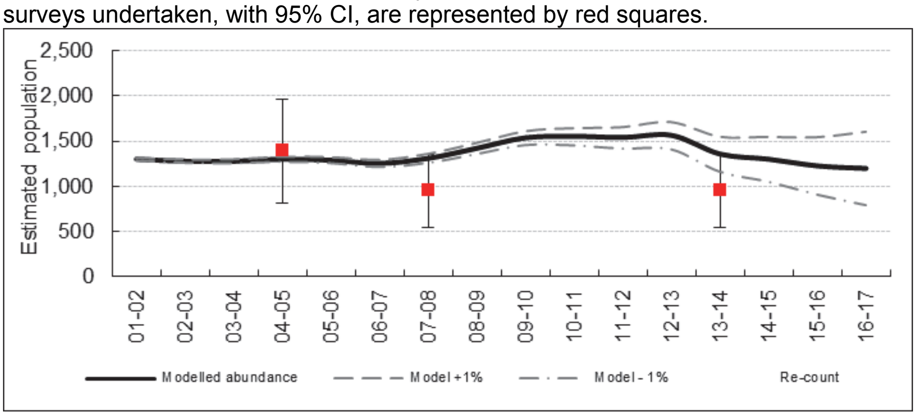
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

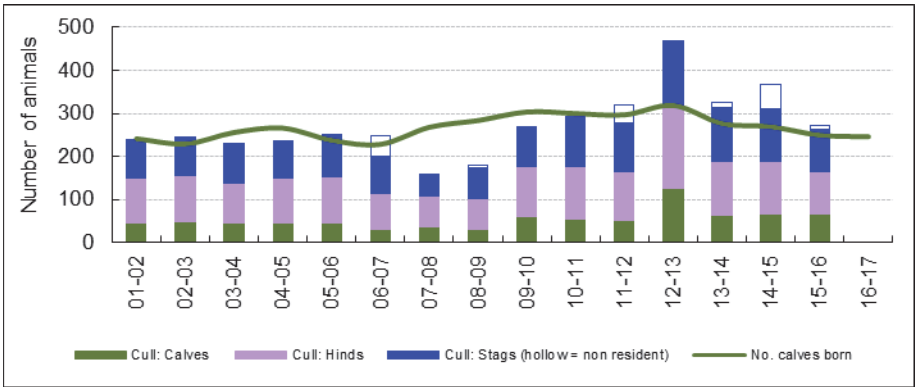
MORISTON (INVERNESS, ROSS AND SKYE FD)





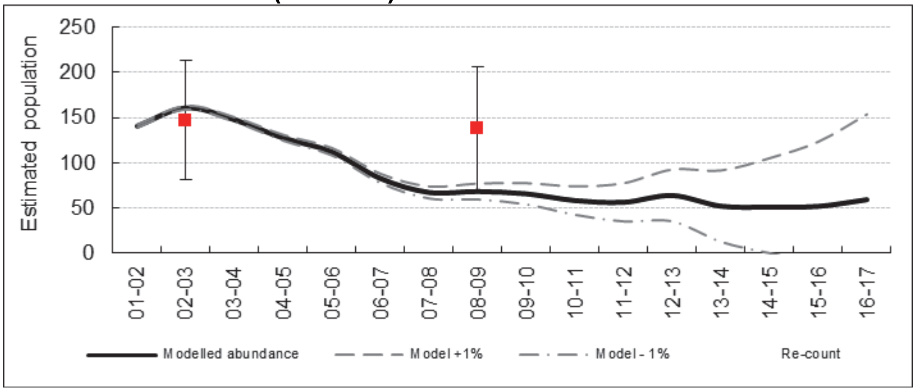
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

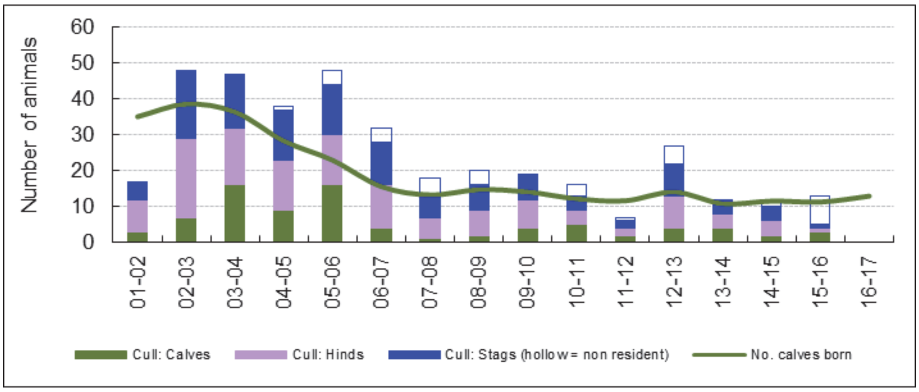




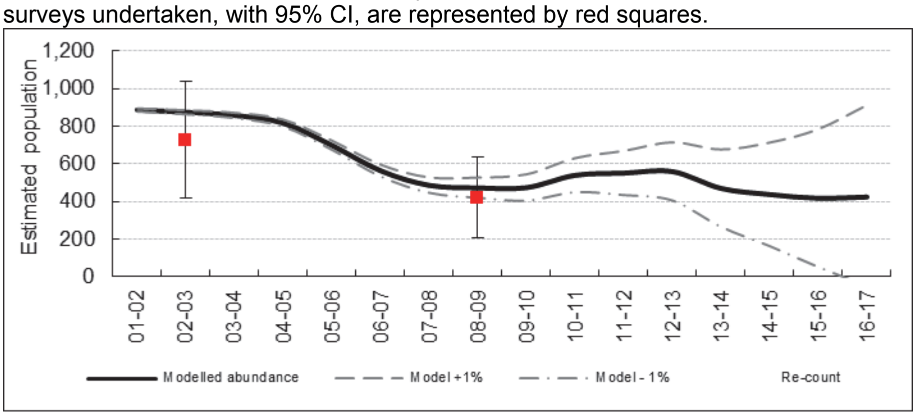
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

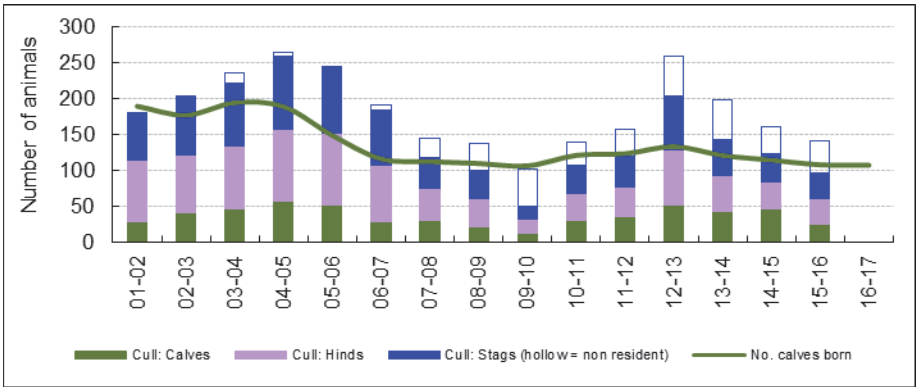
SOUTH RANNOCH (TAY FD)





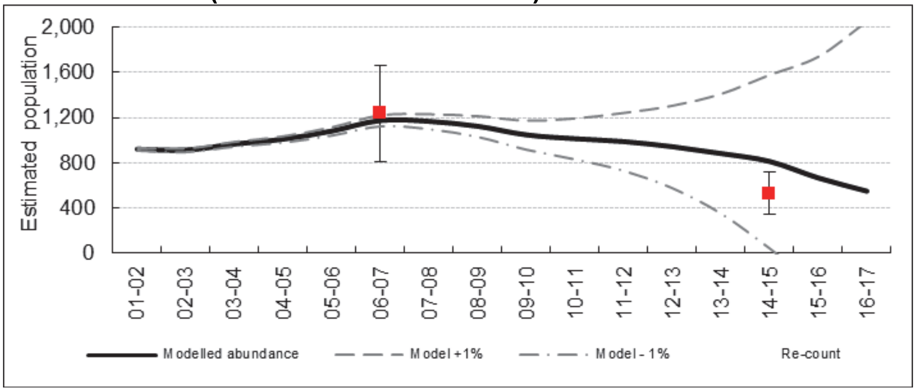
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

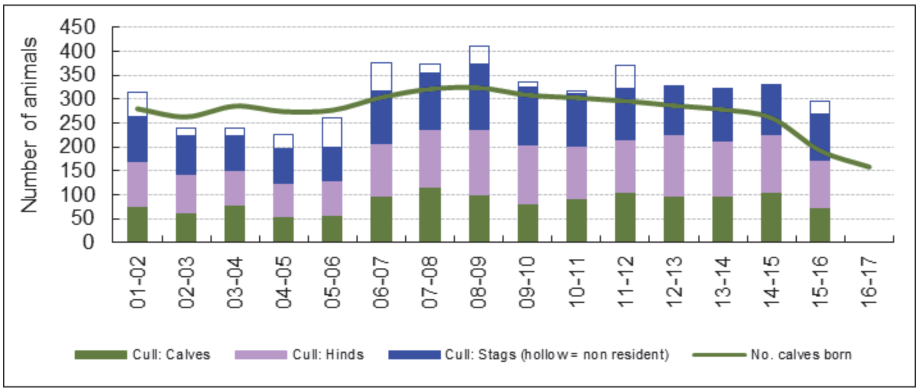




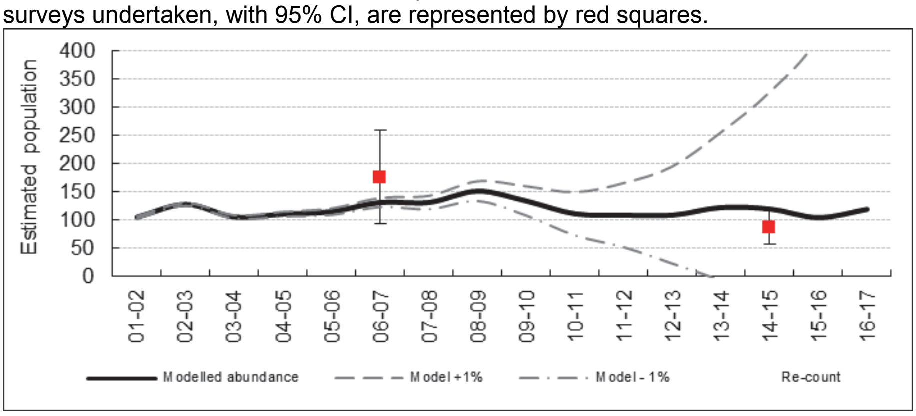
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

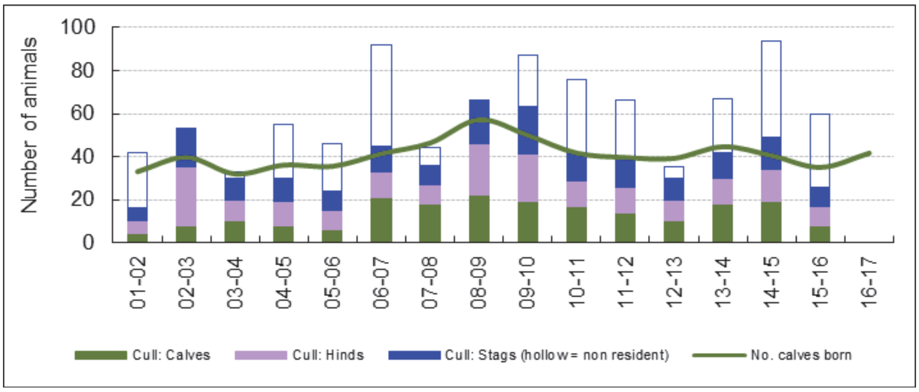
STRATHKYLE (NORTH HIGHLAND FD)





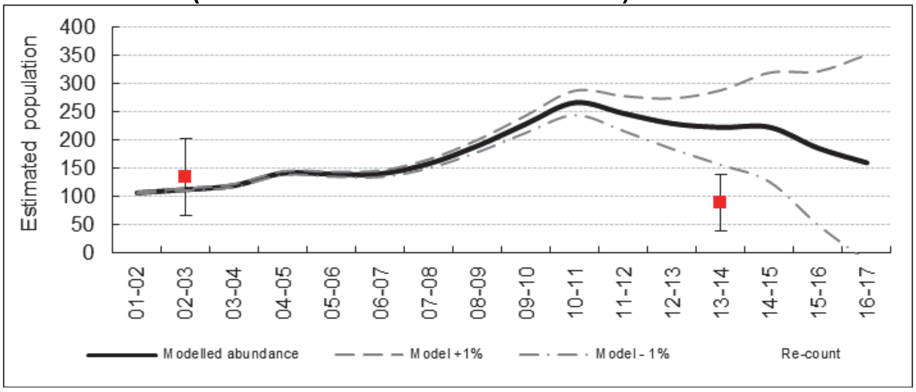
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

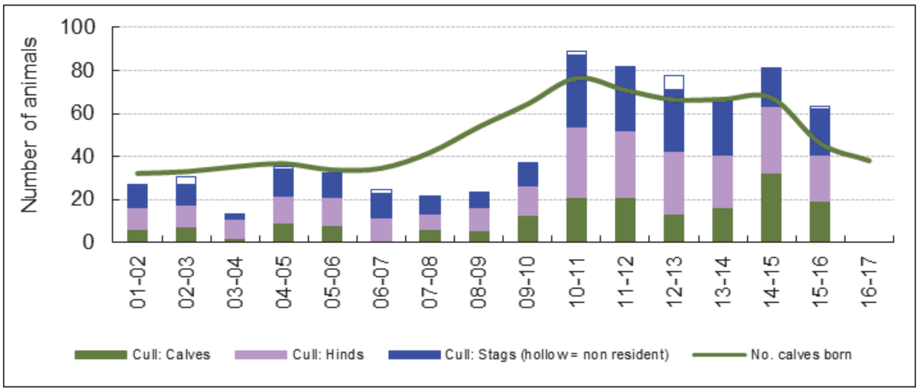




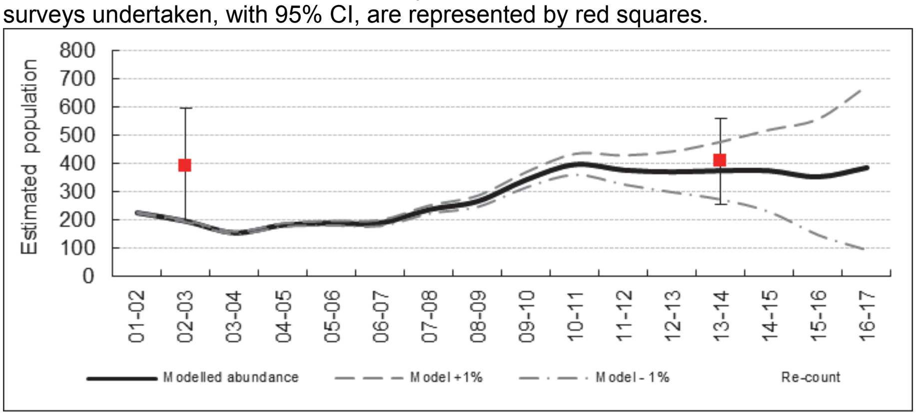
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

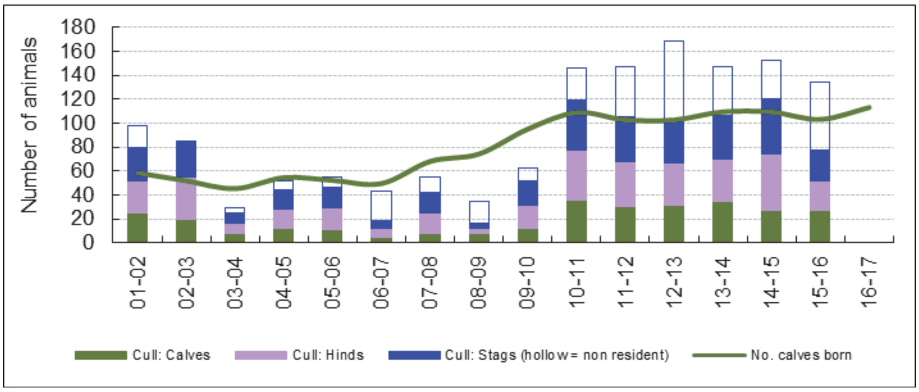
STRATHYRE (COWAL AND TROSSACHS FD)





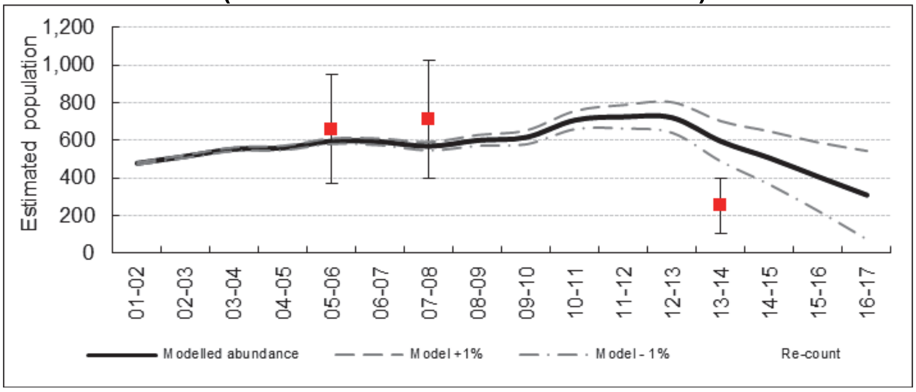
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

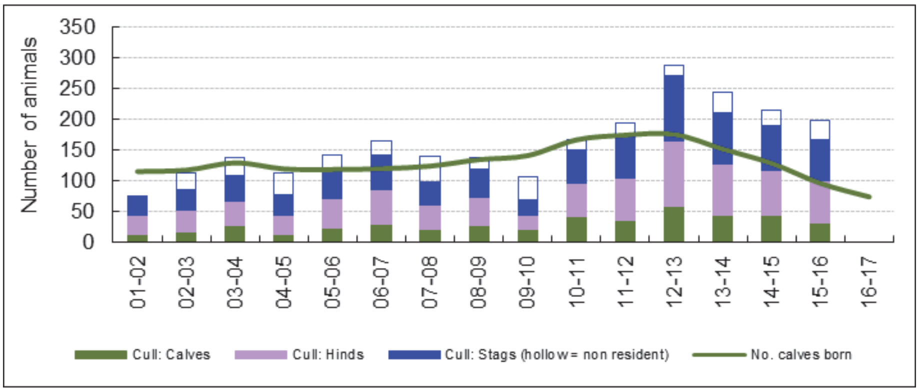




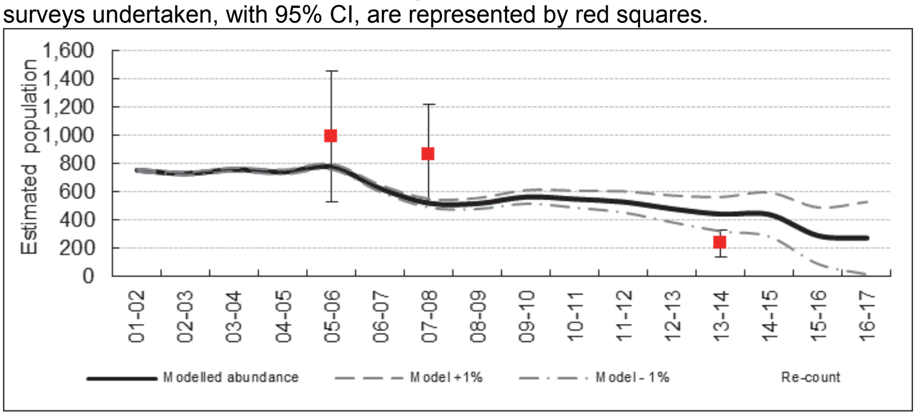
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

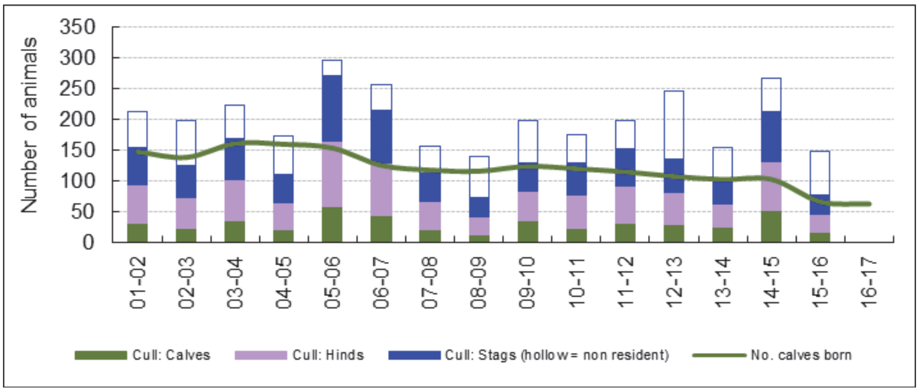
TORRACHILTY (INVERNESS ROSS AND SKYE FD)





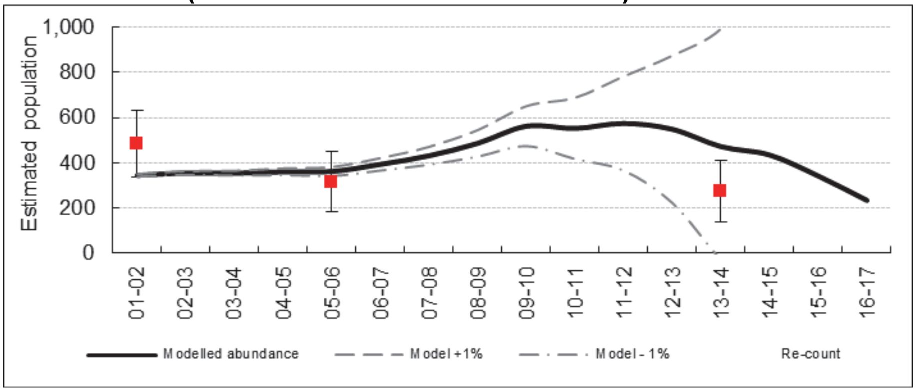
Roe/sika deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

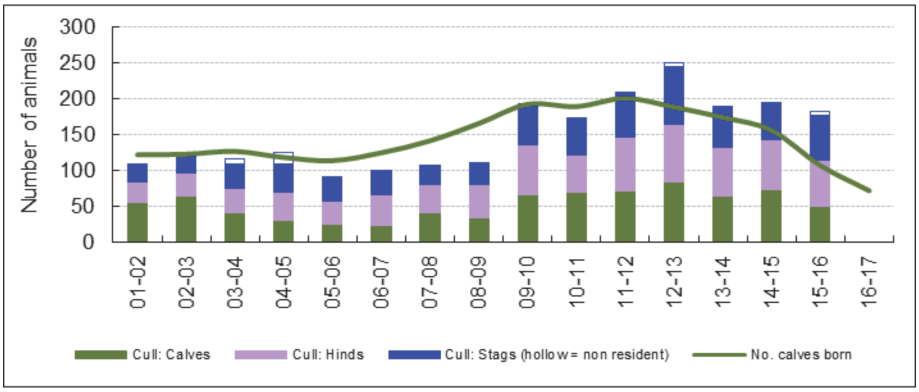




Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

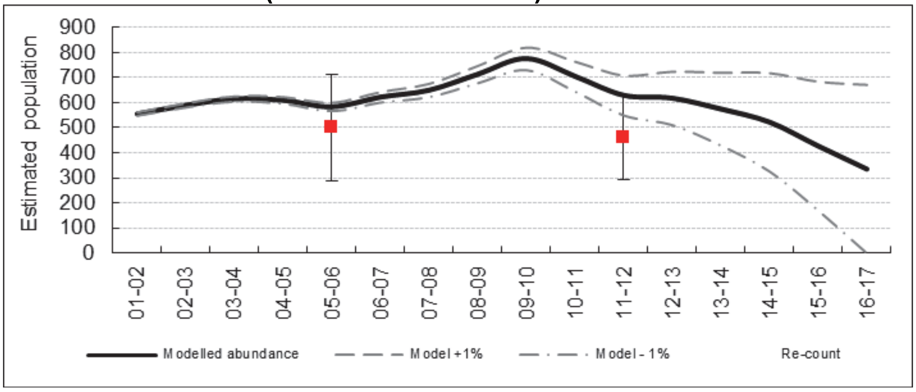
WAUCHOPE (DUMFRIES AND BORDERS FD)

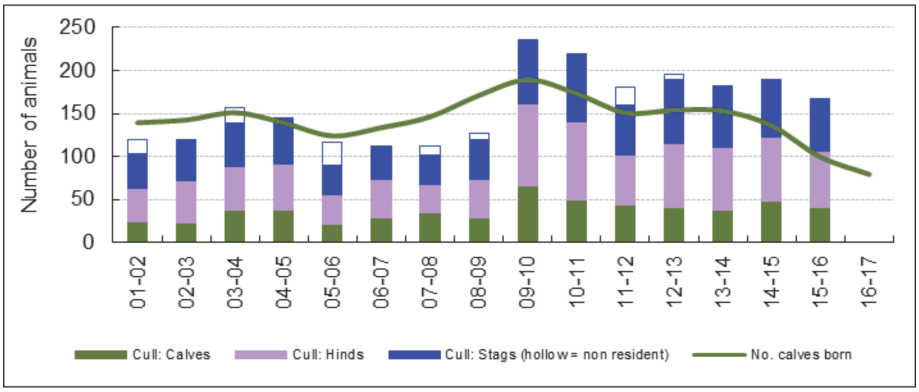




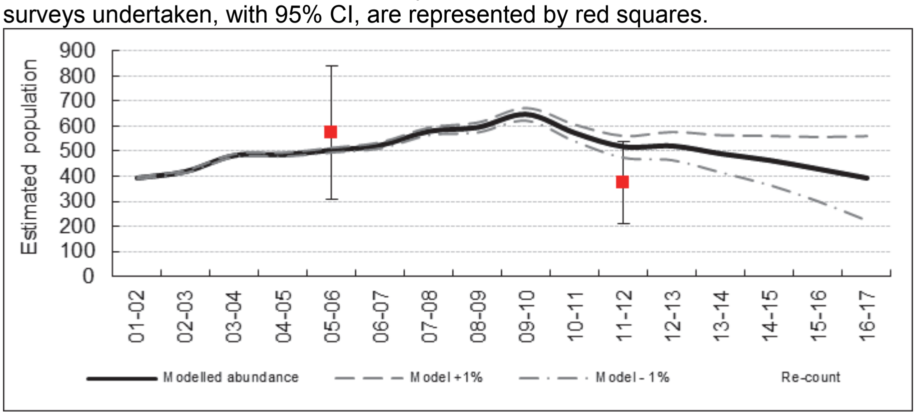
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

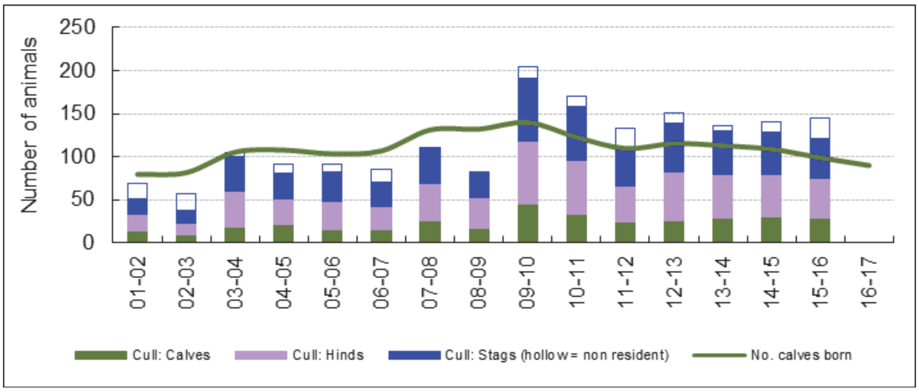
WEST LOCH AWE (WEST ARGYLL FD)





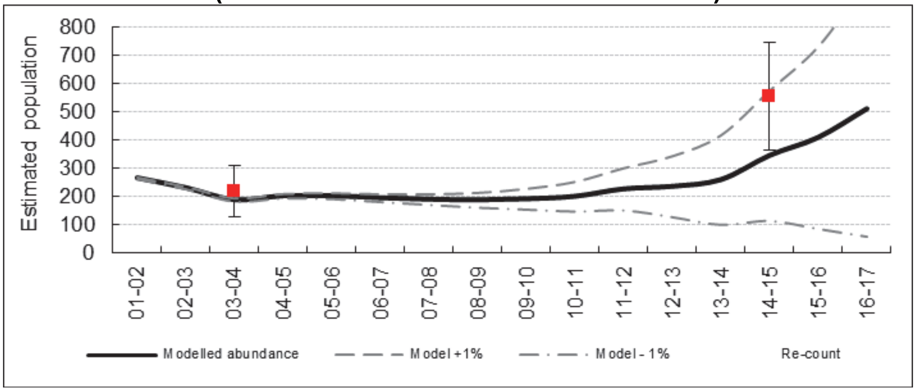
Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

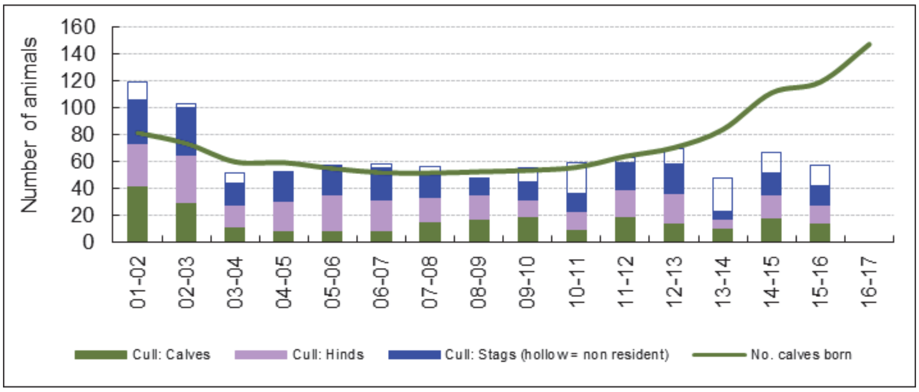




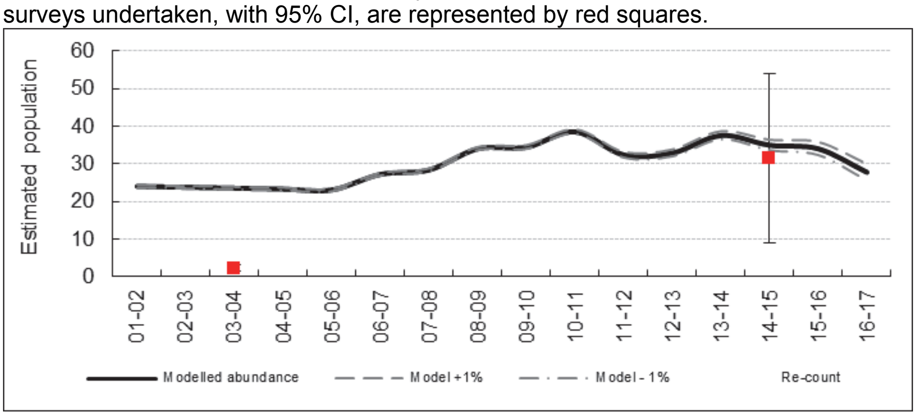
Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

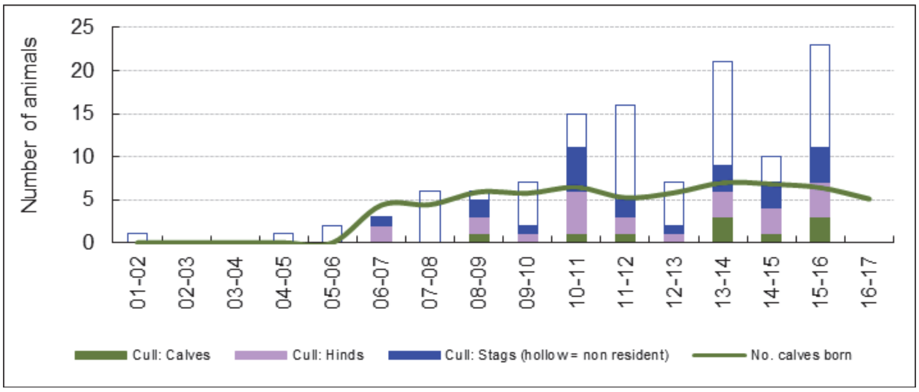
WHITEHAUGH (MORAY AND ABERDEENSHIRE FD)





Roe deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.





Red deer: predicted trend in abundance over 15 years (upper) and annual cull taken, alongside the predicted number of calves born each year (lower). Deer population estimates based on dung counting surveys undertaken, with 95% CI, are represented by red squares.

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