Effect of reducing red deer *Cervus elaphus* density on browsing impact and growth of Scots pine *Pinus sylvestris* seedlings in semi-natural woodland in the Cairngorms, UK

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SUMMARY

Fencing is the most commonly used management intervention to prevent damage to young woodland regeneration from deer. However, damage can also be prevented through reducing red deer numbers and alleviating browsing pressure. We investigated the effect of reducing red deer *Cervus elaphus* density on browsing impact and growth of Scots pine *Pinus sylvestris* seedlings at Mar Lodge Estate, Cairngorms, UK. Red deer numbers were reduced significantly between 1995 and 2016, and there was a concomitant significant reduction in deer pellet densities and browsing incidents. Positive growth of seedlings was small in the years soon after the deer reduction programme began, and was still being suppressed by browsing in 2007. However subsequently, seedling growth has increased as red deer numbers have been maintained below 3.5/km^2. Red deer reduction appears to have been effective in reducing browsing impacts on Scots pine seedlings, allowing successful growth and establishment of regeneration.

BACKGROUND

Red deer numbers increased by 60% in Scotland between 1961 and 2000, reaching a peak in 2000-2001 (Scottish Natural Heritage 2016). The estimate of red deer numbers in woodland habitats in 2016 was 85,000 to 105,000 (Scottish Natural Heritage 2016). It is widely recognised that red deer can have a significant impact on woodland habitats through browsing trees and tree seedlings, as well as bark rubbing and stripping (Gill 1992, Hester & Miller 1995, Miller & Cummins 1998, Staines *et al*. 1995). The Native Woodland Survey of Scotland recorded 33% of native woodlands as having high or very high impacts from herbivores, mainly deer (Forestry Commission Scotland 2014). In many pine woodlands in Scotland, deer have prevented regeneration by consuming small seedlings and suppressing growth of established seedlings by browsing (Miller *et al* 1998, Palmer & Truscott 2003, Staines *et al*. 1995).

Fences are commonly used to exclude deer from woodlands, preventing damage and allowing successful establishment of regeneration (Scott *et al*. 2000, Gong *et al* 1991). However deer are a natural part of woodland ecosystems, and fences can have negative impacts on both the landscape and other species such as endangered woodland grouse (Catt *et al.* 1994). Successful seedling establishment and regeneration growth may be achieved without fencing through reducing deer density by culling or disturbance, thus decreasing browsing pressure. This strategy has been successfully employed by a small number of estates in the Scottish uplands (Holloway 1967, Beaumont *et al.* 1995, Staines *et al.* 1995, Putman 2003). Evidence from Scotland suggests that densities must be below approximately five red deer/km^2 to allow successful establishment and unchecked growth of pine regeneration (Holloway 1967, Beaumont *et al.* 1995, Staines *et al.* 1995, Putman 2003). Scots pine is less preferred than most broadleaved species and hence it may regenerate successfully at higher deer densities than broadleaved species (Gill 1992).

In this study we assess the effects of reducing red deer density on the browsing impact and growth of seedlings over 15 years at the National Trust for Scotland's Mar Lodge Estate in the central Cairngorm mountains in Scotland (Figure 1). The estate supports 840 ha of semi-natural woodland dominated by remnant Caledonian pinewood, with some upland birch woodland. The Caledonian pinewood is a priority feature within the Cairngorms Special Area of Conservation which covers multiple land ownerships and is currently in unfavourable declining condition. Outside fenced exclosures there has been no pinewood regeneration on Mar Lodge Estate in the last 200 years, primarily been due to browsing by high densities of red deer (Steven & Carlisle 1959, Watson 1983). In 1995 the estate was acquired by the National Trust for Scotland, with a main objective being to restore and expand the Caledonian pinewood through reducing numbers of red deer and roe deer *Capreolus capreolus*. Since 1995 deer reduction has been targeted in a 12,487 ha 'regeneration zone', containing 840 ha of semi-natural woodland at its core, as well as surrounding moorland and high montane ground (Figure 1). Deer count data have been available since 1990, and in 2001 the National Trust for Scotland began a programme of tree seedling monitoring and deer pellet counting to inform deer management. There has been no sheep or cattle grazing in the regeneration zone since before the monitoring began. Mountain hares *Lepus timidus* were present and were not culled on Mar Lodge Estate during the study period.

ACTION

Deer reduction: Both red and roe deer density were reduced within the regeneration zone through culling, although roe deer were at a lower density than red deer throughout the study. Culling occurred both in and out of season and during both the day and night with the relevant authorisations in place. In 1995 an initial target population of 350 red deer was set for the regeneration zone and with no specific target population for roe deer. As tree seedling monitoring indicated continued high levels of browsing, the target number for red deer was revised downwards over the years, until in 2009 a "zero tolerance"

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ISSN 1758-2067

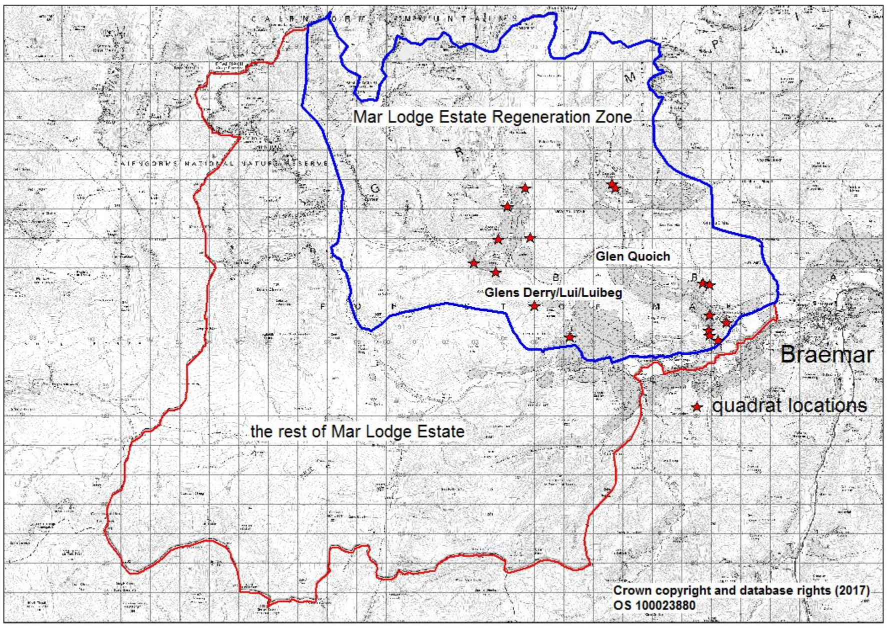

Figure 1. Map of Mar Lodge Estate indicating the Regeneration zone, quadrat locations, Glen Quoich and Glens Derry/Lui/Luibeg and the rest of Mar Lodge Estate.

approach to both red and roe deer was adopted for the regeneration zone. Prior to 2009, limited culling of roe deer occurred as stalking of roe deer by paying guests was still ongoing. By 2009 it was recognised that roe deer could also be contributing to the browsing impact and hence they were included in the "zero tolerance" approach.

Deer monitoring: Red deer count data for the 12,487 ha regeneration zone were available from 1990–2016. Over that time there were small differences in the count area and in count method. Counts carried out between 1990 and 1994 included an additional 1677 ha which was not counted after 1994. From 1990-2001, the annual winter red deer count was done from the ground; since 2002 the same area has been surveyed by helicopter. Count data were converted to a density (number of red deer/km^2) for the regeneration zone area. Roe deer were not subject to annual counts due to the difficulty in counting this species in woodland habitats.

Seedling growth and browsing impact: In 2002, seventeen 10 m x 10 m quadrats were established around the pinewood area where regeneration was present (Figure 1). Twenty seedlings within each quadrat were individually marked. In 14 quadrats the number of seedlings present exceeded 20, and in the remaining three quadrats all seedlings present were marked. A total of 319 seedlings, mainly pine (259) but occasional birch (20), larch (20) and aspen (20), were marked for monitoring. Each year in July/August the height of each marked seedling (distance in cm from solid ground to the top of the seedling without straightening the seedling) was recorded, along with whether or not its leading shoot had been browsed in the current year. As susceptibility to browsing differs between tree species, data is only reported for pine seedlings.

In addition, the total number of all pine seedlings within each quadrat was counted annually between 2002 and 2016 and the percentage that had been browsed in the previous 12 months was recorded. A standing count of individual hare pellets and deer pellet groups (minimum six pellets) of any age was also conducted annually within each quadrat.

To measure the growth of unbrowsed pine seedlings, 50 seedlings from each of two fenced deer exclosures within the regeneration zone were marked in 2006. These samples were selected to reflect the size distribution of the marked seedlings within the regeneration quadrats. The height of each unbrowsed seedling was measured in 2006 and 2007 to determine annual average growth.

For data analysis, tree growth data from the two main glens (Glen Quoich and Glens Derry/Lui/Luibeg) within the regeneration zone were treated separately. For day to day management purposes it is useful to consider them separately, as Glen Quoich borders a neighbouring estate and is thus open to deer movements from outwith Mar Lodge Estate, whereas Glens Derry/Lui/Luibeg are integral within Mar Lodge Estate.

CONSEQUENCES

Deer culling: The number of red deer culled annually from 1990 to 2016 varied between 143 and 561 (Figure 2). The regeneration zone is not a closed population as there was free

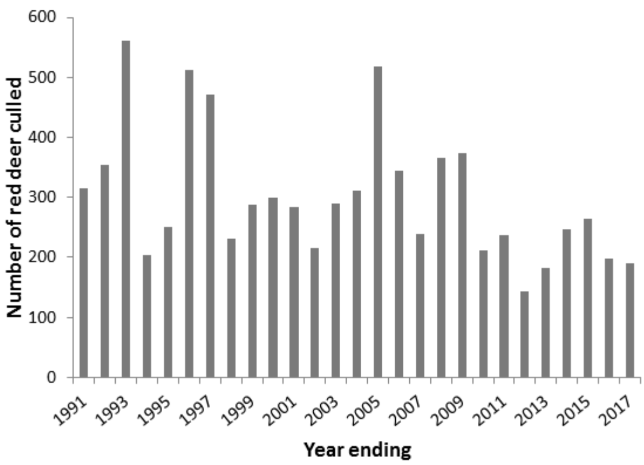

Figure 2. Number of red deer culled annually from the regeneration zone between 1990 and 2016.

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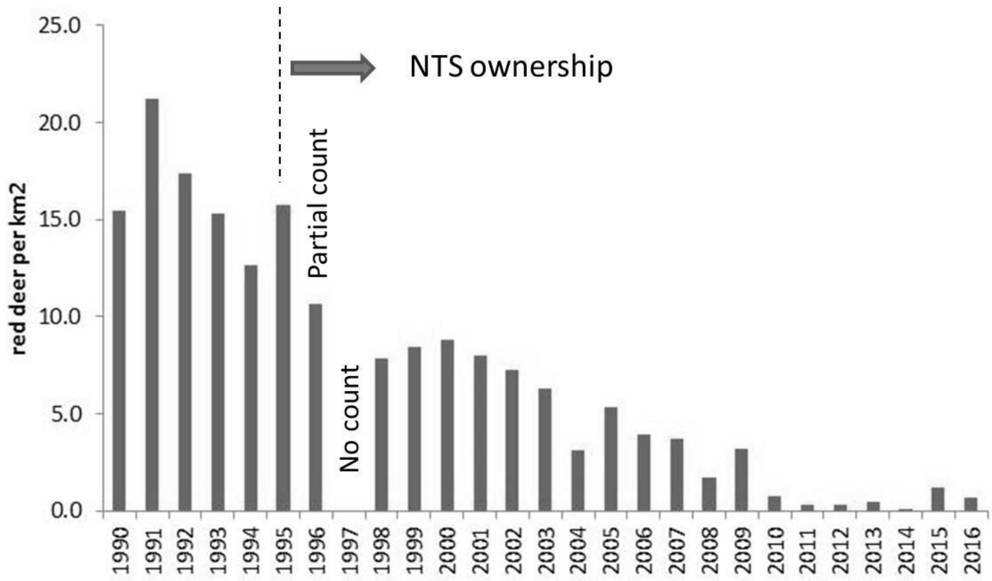

Figure 3. Red deer density in winter in the regeneration zone in 1990-2016 recorded by ground counts (pre-2001) and helicopter counts (post-2001). A deer reduction programme started in 1995, when the National Trust for Scotland (NTS) took ownership.

movement of red and roe deer across most of its boundary. Therefore the number of deer removed does not correlate with measures of browsing or seedling growth, but rather is an indication of culling effort

Deer population: Between 1990 and 1995, before the deer reduction programme began, red deer density in the regeneration zone fluctuated between 12.6 and 21.2 deer/km^2 (Figure 3). Since 2001, red deer density in the regeneration zone has been reduced from approximately 8.0 to 0.7 deer/km^2. This result is supported by a decline in the number of deer pellets within the regeneration quadrats between 2002 and 2016 (Figure 4).

Browsing impact: The percentage of marked seedlings that had had their leading shoot browsed, and also the incidents of total browsing (leader and browsing of other shoots) across all the seedlings in the quadrats has decreased since 2002 (Figures 5 and 6). It was not possible to separate red and roe deer browsing on tree seedlings and it is likely that a small proportion was attributable to roe deer. In the last three years, hare browsing has been separated from deer browsing where possible, but the level of hare browsing was negligible relative to deer.

Seedling height: From 2002 to 2016 seedling growth rate within the regeneration quadrats was initially slow, but has increased since 2008 (Figure 7). The mean growth increment of unbrowsed seedlings in deer exclosures between 2006 and 2007 was 3.5 cm (S.E. 0.6 cm), compared to a mean growth increment of sample seedlings in the regeneration quadrats in the same year of 1.9 cm (S.E. 0.4 cm) in Glen Derry/Lui/Luibeg and 0.8 cm (S.E. 0.5 cm) in Glen Quoich. This indicated that deer browsing was still reducing the growth rate of seedlings in 2006 - 2007, despite the already decreased red deer population (Figures 3 and 4).

DISCUSSION

The effect of fencing as a protective mechanism for the establishment and growth of regenerating seedlings in Scotland is well documented (Scott *et al*. 2000, Gong *et al* 1991). However, the effect of using deer reduction as a tool to reduce browsing impact and improve the growth of pine regeneration in Scotland is little reported (Holloway 1967, Beaumont *et al.* 1995). The deer population reduction employed by the National Trust for Scotland across the regeneration zone of Mar Lodge Estate has correlated with reduced browsing levels,

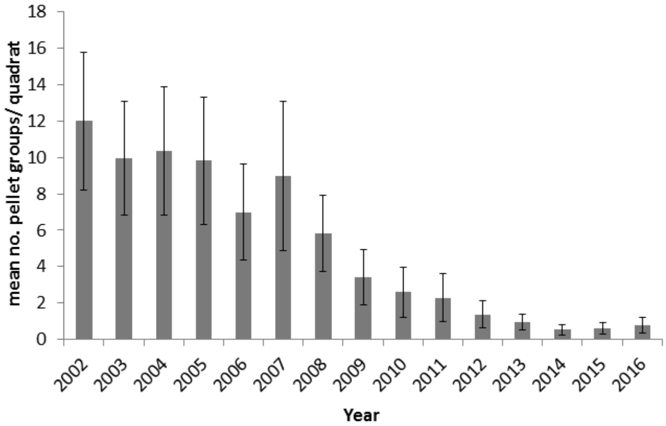

Figure 4. Mean number of deer pellet groups per 10 x 10 m quadrat (± S.E.) in the regeneration zone between 2002 and 2016. Deer reduction started in 1995.

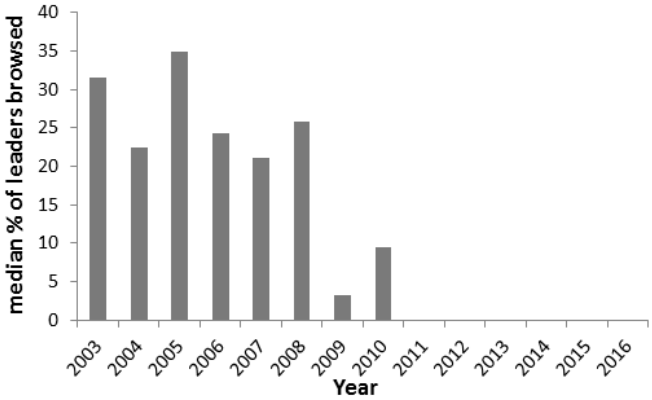

Figure 5. The median percentage of marked seedlings in the regeneration zone with their leading shoots browsed in each year (mean n = 176).

ISSN 1758-2067

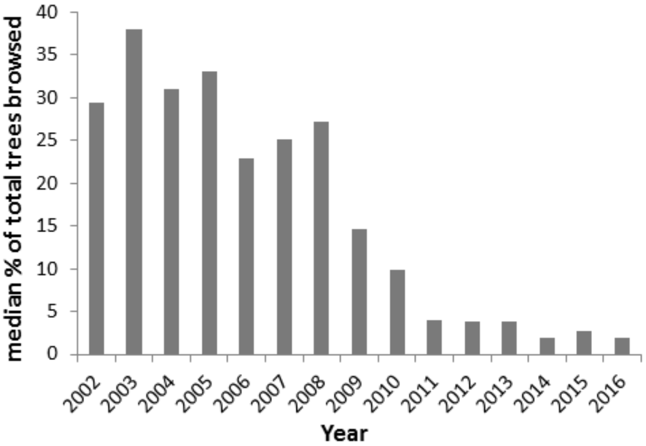

Figure 6. The median percentage of all seedlings in quadrats in the regeneration zone that had been browsed in the current year (Mean n = 1803).

allowing increased growth of pine seedlings (Figures 6, 7 and 8).

This change has taken place gradually over 15 years, but the data suggest that 2008-2009 may have been the key point when browsing levels dropped below 20% and growth of tree seedlings began to increase. The deer density in the 2008 winter count was 1.7 deer/km^2 having fallen from 3.9 and 3.7 deer/km^2 in 2006 and 2007 when data suggested seedling growth was still being checked by browsing. The deer density has not risen above 3.5 deer / km^2 since 2008 (Figure 3), and this appears to have allowed natural regeneration to occur (Figures 5, 6, 7 and 8). Growth of seedlings may be possible at a higher deer density but is likely to be suppressed, and regeneration slower.

Previous estimates of the maximum red deer density that allows natural pinewood regeneration is between 3 and 5 deer/km^2 (Holloway 1967, Beaumont *et al.* 1995, Staines *et al.* 1995). This study concurs with these estimates and minor differences are likely to be the result of variability in factors such as alternative and seasonal food availability, topography, altitude and weather which influence snow lie and shelter. Broadleaved species were excluded from this analysis as too few were sampled, but the deer density required to achieve unchecked growth of more preferred broadleaved species is likely to be lower.

In this study, red deer density was calculated over a large area (12,487 ha), with impacts assessed on a much smaller area of woodland (840 ha). This was done because red deer range across a much larger area throughout the year, but in winter and early spring, when the weather is harsh and most seedling damage occurs, the deer used a much smaller area (the core woodland). Had red deer density been calculated across this smaller area then it would have appeared that seedling browsing was reduced at a much higher deer density.

The density calculation is dependent on deer count estimates (Figure 3). It is worth noting that the red deer count data only gives a one day 'snapshot' of numbers and distribution, and does not provide information on seasonal changes in distribution. However, the pellet count data mirrored the deer count data and provided a direct indication of deer utilisation of the core woodland (Figure 4).

Roe deer were present in the regeneration zone at lower densities than red deer throughout this study. There is no empirical data on their density nor their contribution to the browsing impact. It is likely they have contributed in part to the browsing of pine seedlings over the years, but unlikely that they have been the dominant browser. It is however important to note that roe deer are ubiquitous throughout upland Scotland within woodlands but also on hill ground, and it is necessary to consider this species alongside red deer when considering a deer reduction approach to encouraging tree regeneration.

There is currently a debate in Scotland as to how to manage deer, and the optimum population size and density in relation to impacts on the public interest, including native woodland regeneration (SNH 2016). This study provides support for the effectiveness of deer population reduction as one aspect of achieving native pine woodland regeneration.

ACKNOWLEDGEMENTS

The author is grateful to the National Trust for Scotland staff that have been involved in the management intervention and monitoring documented in this paper. Thanks also to Andrew Painting and Mike Daniels who provided valuable comments on the manuscript.

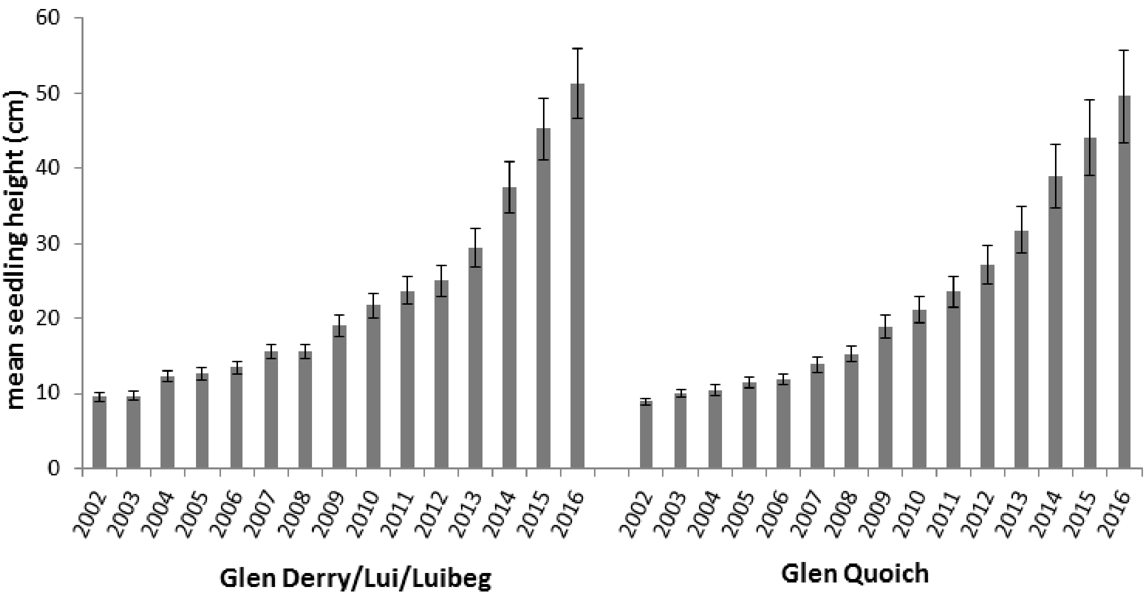

Figure 7. Mean height (± S.E.) of seedlings, marked in 2002, within regeneration quadrats in two different glens between 2002 and 2016 (mean n across years for both glens = 131)

ISSN 1758-2067

Figure 8. Photos illustrating the tree seedling growth within two quadrats between 2005 (left) and 2016 (right).

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ISSN 1758-2067