The creation of structural diversity and deadwood habitat by ring-barking in a Scots pine *Pinus sylvestris* plantation in the Cairngorms, UK

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SUMMARY

Fifteen-hundred Scots pine trees were ring-barked (as individuals, groups of five or 15) on Mar Lodge Estate, Scotland in order to create structural diversity and deadwood habitat in two plantations. A sample of 220 was monitored annually and compared with a control sample of 10 non ring-barked trees, to quantify structural changes as well as use by saproxylic invertebrates and woodpeckers. Eight years after ring-barking 26.1% (±6.13% S.E.) of the trees had snapped off and 2.4% (±1.37%) had fallen over completely; 48.0% (±12.5%) had lost 60-90% of their branches and 34.9% (±24.2%) had lost more than 50% of their bark. Additionally 98.5% (±0.92%) of the trees showed signs of wood boring invertebrates and 74.5% (±11.6%) were used by woodpeckers. Six species of beetle, four of which were saproxylic, and a single species of saproxylic fly were identified from fallen deadwood from the ring-barked trees. The control trees remained largely structurally unchanged and none were colonised by saproxylic invertebrates or woodpeckers. There were significant differences in structural change and use by woodpeckers between the two plantations but none in the occurrence of saproxylic invertebrates. Group size had no significant effect on colonisation, except for woodpeckers which used small groups of trees significantly more than larger groups. Ring-barking can provide an effective management tool to create structural diversity and deadwood habitat within a short period of time. However it is necessary to regularly repeat ring-barking in groups of different size in order to maximise structural variation and ensure niche diversity of such a dynamic substrate.

BACKGROUND

The importance of deadwood to woodland biodiversity is well-documented. Elton (1966) estimated that 20% of British fauna depends on dead or dying wood. The degree of biological diversity supported by deadwood is revealed by the extensive research into saproxylic invertebrates (e.g. Rotheray *et al*. 2001), fungi (e.g. Lonsdale *et al*. 2008), bryophytes (e.g. Odor *et al*. 2006) and lignicolous lichens (e.g. Coppins & Coppins 2006). However, due to the historic removal of dead trees, deadwood is often scarce in contemporary woodland and it is becoming increasingly important for managers to actively create deadwood.

In Scotland a national policy of promoting monoculture plantations following World War II has resulted in a considerable acreage of plantation woodland where there is now a desire to create woodland of conservation value through restructuring. Woodland of plantation origin has been recognised as particularly devoid of deadwood, with volumes of deadwood 17-34 times greater in pine-dominated old growth than in plantations under 40 years old (Fridman & Walheim 2000, Siitonen 2001, Jonsson *et al*. 2005, Svensson *et al*. 2013). Consequently, many managers are seeking to emulate natural processes that create structural elements present in native woodland (Willström & Eriksson 2000). Despite a wealth of research regarding the presence and creation of deadwood in production-based silviculture (e.g. Nascimbene *et al*. 2008, Caruso *et al*. 2010), there has been little regarding the benefits of deadwood creation where the end goal is semi-natural woodland of high conservation value.

Ring-barking is a technique commonly used by managers as a conservation measure to increase the structural diversity of woodland and increase the volume of deadwood where these components are deficient. Despite widespread use, the effectiveness of ring-barking for this purpose has not been documented. The aim of this study was to determine the conservation value of artificially creating deadwood by ring-barking. This was achieved by quantifying the extent to which ring-barking creates structural diversity in a woodland of plantation origin and by monitoring colonisation by saproxylic invertebrates and use by woodpeckers.

ACTION

Site description: Mar Lodge Estate, which makes up 7% of the Cairngorms National Park in the Highlands of Scotland, is an important conservation landscape nationally and internationally. This has led to European conservation designations over 80% of the estate. Upon purchasing the estate in 1995, the National Trust for Scotland inherited 12 plantation blocks originating from the 1970s. The majority of non-native species have been removed and Scots pine *Pinus sylvestris* is now the dominant species in all the plantations. The management objective was to increase the biodiversity and landscape value of the plantations. Ring-barking was identified as an appropriate and sensitive method of restructuring and creating deadwood in such a highly designated site. Two plantation blocks were studied here, situated in Glen Quoich in close proximity (<50 m) to native pine woods. Compartment 2 (centre point NO 0790 9300) covers 82.5 ha and Dubh Ghleann (centre point NO 0750 9585) 42.2 ha.

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Table 1. Details of monitored trees

Plantation	Group size	Number of groups	Number of trees
Dubh Ghleann	1	20	20
Dubh Ghleann	5	10	50
Dubh Ghleann	15	10	150
Dubh Ghleann	1 (Control)	10	10
Compartment 2	1	20	20
Compartment 2	5	10	50
Compartment 2	15	10	150
Compartment 2	1 (Control)	10	10

Fifteen-hundred Scots pine trees were ring-barked using hand axes in 2005 (Figure 5). These were split evenly between Compartment 2 and Dubh Ghleann. Two plantations were included to increase sample size, for replication and for management practicalities. Trees were ring-barked at varying heights, from close to the ground to above head height. Ring-barking was carried out on individual trees, groups of five or groups of 15 trees, in order to maximise structural diversity and investigate differences in colonisation between groups of different size. A sample of these was monitored annually between 2006 and 2013 (with the exception of 2010 for Dubh Ghleann) and a sample of 10 live trees per plantation was also monitored as a control group (Table 1).

Annual monitoring was carried out to assess the rates of decay, colonisation by saproxylic invertebrates and woodpecker use. Ordinal information was recorded for each study tree (Table 2). Decay assessments were made by visual estimation, and the presence/absence of saproxylic invertebrates and woodpeckers by checking each tree for holes of appropriate size. Additionally, beetle and fly species were identified to species level on a sub-sample consisting of 36% of the monitored trees and surrounding fallen deadwood by a contracted specialist in October 2013. An assessment of the volume of deadwood available to invertebrates contributed by the ring-barked trees relative to control trees was also made.

Time commitment and cost of the project were minimal. Ring-barking was carried out over five days by volunteers, the only cost incurred being hand-axes. Monitoring took two to three days per annum and was carried out by National Trust for Scotland staff, so no extra cost was incurred. The invertebrate survey was commissioned at a cost of £450. The cost would be greatly increased if volunteers were not available to undertake the ring-barking.

Statistical analysis: To establish the fit between the exponential curves of decay and time since ring-barking the coefficient of determination (r^2) was calculated. Analysis was carried out to determine any difference in the rates of decay or colonisation by saproxylic species between the plantations or between groups of different sizes, hypothesising that there was no difference. This was achieved using a chi-squared test to test whether the frequency of trees in each condition category, and on which saproxylic species occurred, varied between plantations or groups of different sizes. Yates' correction for continuity was utilised where there was only one degree of freedom.

CONSEQUENCES

Ring-barking improved structural diversity, with both tree condition and side branch loss progressing in an exponential manner (Figures 1 and 2). There was a strong positive correlation between the time since ring-barking and the exponential curve of the proportion of trees that had snapped off ($r^2 = 0.95$) and between the time since ring-barking and the exponential curve of trees with 1-30% branches lost ($r^2 = 0.96$).

Tree decay did not proceed in an exponential manner, but three years after ring-barking there was a dramatic rise in the proportion of trees in category three (some bark loss, > 50% bark remaining, wood hard), which remained the decay category most frequently recorded for the remainder of the study (Figure 3). Eight years after ring-barking 26.1% (±6.1% S.E.) of trees had snapped off, 2.4% (±1.37%) of trees had fallen over, 48.0% (±12.5%) had lost 60-90% of their

Table 2. Details of monitoring categories

Assessment	Monitoring category	Value
Tree condition	Whole tree intact	1
	Tree snapped off	2
	Tree fallen over	3
Side branches	Side branches present	1
	1-30% side branches lost	2
	30-60% side branches lost	3
	60-90% side branches lost	4
	All side branches lost	5
Tree decay	Needles still green, tree healthy	1
	Needles brown, bark intact, tree died recently	2
	Some bark loss, >50% bark remaining, wood hard	3
	<50% bark remaining, wood hard	4
	<10% bark left, wood slightly soft	5
Saproxylic species presence	Fungi (observed on tree)	1
	Lichen (excluding species present on live trees)	1
	Invertebrates (burrowing holes)	1
	Birds (woodpecker holes)	1

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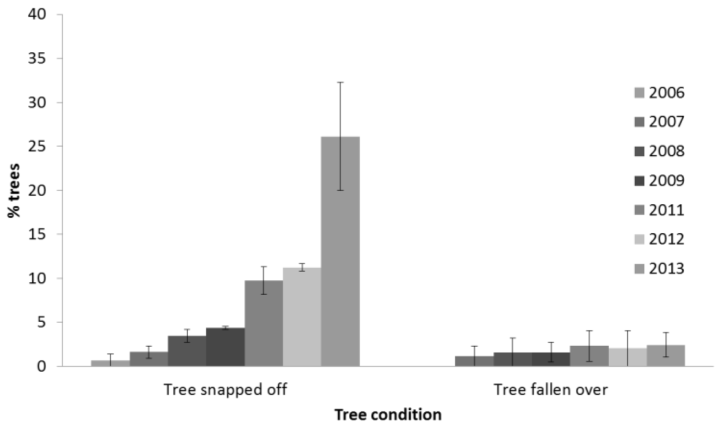

Figure 1. Percentage of trees that snapped off or fell over between 2006-2013 across two plantations. Bars show standard errors of the mean. Data for 2010 not available.

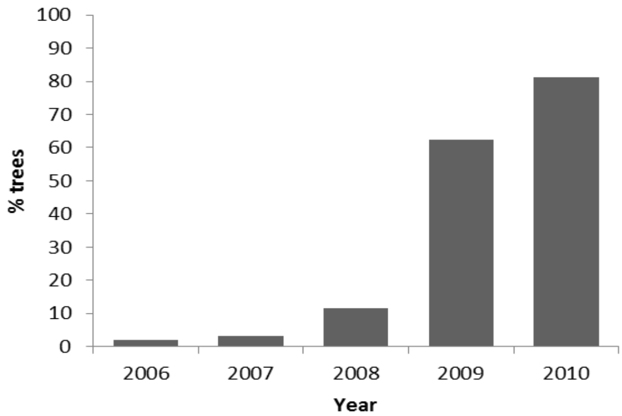

Figure 2. Proportion of trees with 1-30% side branches lost in 2006–2010 in Compartment 2, where data was available for 2010.

branches and 34.9% (±24.2%) had lost more than 50% of their bark. After eight years 100% of the control trees remained intact and 100% were still healthy with green needles. The only change was in side branch loss, where 70% of the control trees had 100% of their side branches present and 30% had lost 1-30% of their side branches.

By the eighth year following ring-barking 98.5% (±0.92) of the trees were colonised by wood boring invertebrates and 74.5% (±11.6) were utilised by woodpeckers (Figure 4). Woodpecker and invertebrate holes were not recorded in any of the control trees.

The specialist study found evidence of tunnelling by bark (Scolytidae) and long-horn (Cerambycidae) beetles in all the standing ring-barked trees and 68.7% of the fallen deadwood. Eighty-four per cent of the fallen deadwood pieces from trees in groups of 15 showed evidence of beetle tunnelling compared to 65% and 57% of those from groups of five and individual trees respectively. This could be explained by the volume of deadwood produced by each group, which was 2648 cm³/tree for the groups of 15 compared to 589.6 cm³/tree and 500 cm³/tree for groups of five and individuals respectively. There was also a larger variation in the volume and diameter of deadwood from trees in groups of 15. Six species of beetle, four of which were saproxylic, and a single species of saproxylic fly were identified from fallen deadwood (Table 3). No deadwood was produced by the sub-sample of control trees and evidence of beetles was not found on control trees.

Statistical analysis revealed that eight years after ring-barking, trees in Compartment 2 had snapped off significantly more frequently than those in Dubh Ghleann (χ^2_2 = 10.5, p < 0.01), whereas tree decay (χ^2_4 = 210.2, p < 0.001) and branch loss (χ^2_4 = 55.4, p < 0.05) were significantly higher in Dubh Ghleann.

There was no statistically significant difference in the occurrence of saproxylic invertebrates (χ^2_1 = 2.5, p > 0.05) between the two plantations eight years after ring-barking, whereas woodpeckers utilised significantly more trees in Dubh Ghleann than Compartment 2 (χ^2_1 = 28.7, p < 0.001). There was no statistically significant difference in colonisation by saproxylic invertebrates of ring-barked trees between groups of different sizes in Dubh Ghleann (χ^2_2 = 0.29, p > 0.05) or

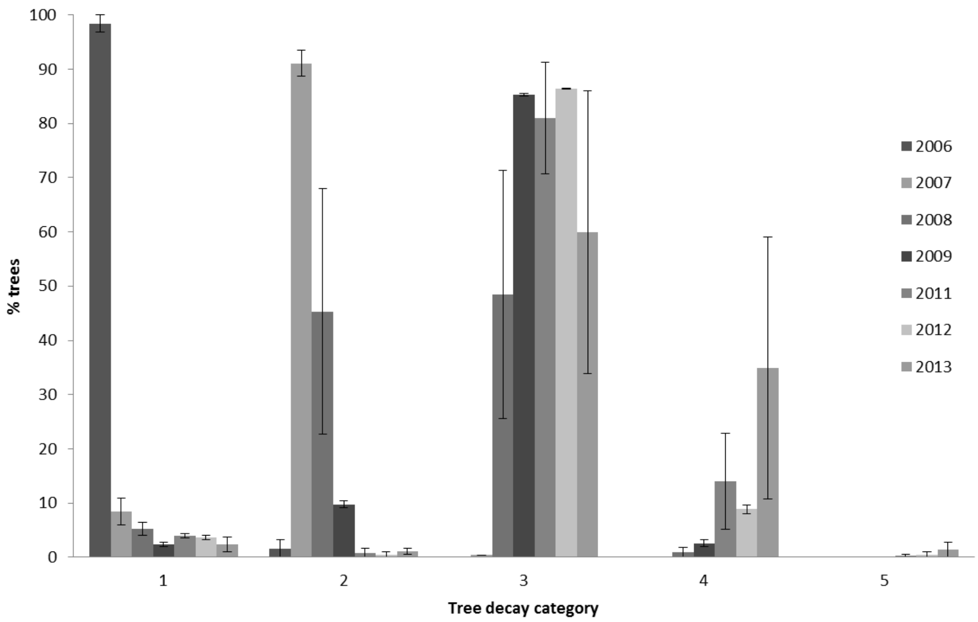

Figure 3. Percentage of trees at different stages of decay between 2006-2013 across two plantations. See Table 2 for details of categories. Bars show standard errors of the mean. Data not available for 2010.

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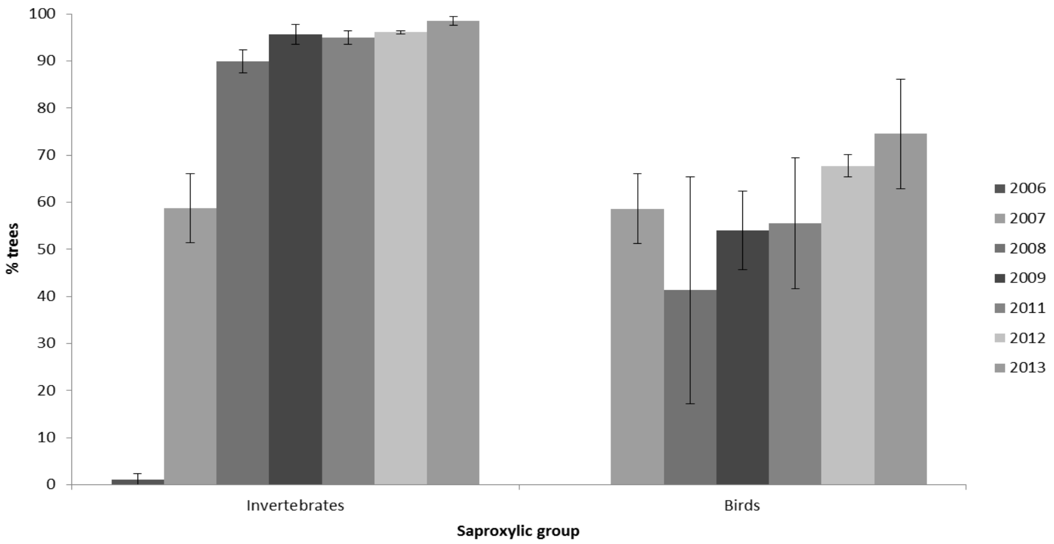

Figure 4. Percentage of ring-barked trees colonised by two groups of saproxylic species between 2006–2013. Bars show standard errors of the mean. No data available for 2010.

Compartment 2 (χ^2_2 = 0.18, p > 0.05). Woodpeckers in Compartment 2 utilised groups of smaller size significantly more than larger groups (individuals > groups of five > groups of 15) (χ^2_2 = 28.7, p < 0.05) but there was no statistically significant difference in Dubh Ghleann (χ^2_2 = 0.33, p > 0.05).

There was a statistically significant difference in the occurrence of beetles in deadwood produced by ring-barked trees from groups of different size, with more evidence of beetles than expected recorded from trees in groups of 15 (χ^2_2 = 8.9, p < 0.05).

DISCUSSION

The exponential progression of the deterioration in tree condition and branch loss indicates that structural diversity can be rapidly created within woodland of plantation origin by ring-barking. Trees snapped off leading to gaps in the uniform plantation canopy, whilst snapped off tree tops and branches contributed coarse woody debris to the woodland floor. In addition trees which had fallen over contributed a deadwood habitat of higher moisture content more suitable for saproxylic fly species. Ring-barked trees suffered more than 50% bark loss in many cases, and all lost some bark during the eight year study, although the wood on ring-barked trees remained hard within this time. This resulted in a habitat suitable for beetles which can utilise a hard woody substrate and created exposed standing deadwood which is otherwise largely absent from such woodland.

Ring-barking created a variety of niches suitable for colonisation by saproxylic invertebrates, and coloniser invertebrate species became ubiquitous within a short period of time. The invertebrate assessment indicated that although occupancy was high species, richness was low, particularly for flies. This was due to the limited prevalence of soft decay, as saproxylic fly species are almost always associated with deadwood in soft and wet conditions (Rotheray *et al*. 2001). All the saproxylic invertebrate species were located on deadwood from trees in groups of 15, which is likely to have resulted from a larger volume and variety of fallen deadwood produced by groups of this size. This could indicate that ring-barking in larger groups provides a larger and more varied resource of fallen deadwood or simply that fallen deadwood is produced more rapidly considering that the trees were of the same age and therefore a similar volume was available to break off from each tree. Consequently, creating deadwood in both small and large groups will maximise the diversity of fallen deadwood over time, and therefore the habitat available for deadwood invertebrates. In addition, woodpecker use varied with group size, suggesting that diversifying deadwood creation will also positively impact upon woodpeckers. Higher woodpecker use in Dubh Ghleann was a surprising outcome. It is hypothesised that this was due to the larger size of Compartment 2, which diluted the proportion of ring-barked trees; this suggests that the number of trees to be ring-barked should be informed by plantation area.

This study shows that ring-barking is an effective tool for managers to create structural diversity and deadwood habitat within woodlands of plantation origin. If volunteers are available to carry out the ring-barking financial input is minimal. There may be safety concerns regarding trees snapping off or falling over, particularly in woodland used by the public, which need to be fully considered in decision making. The composition of the ring-barked trees changed rapidly over the eight-year study supporting conclusions elsewhere that deadwood is a highly dynamic substrate (e.g. Jönsson *et al*. 2008, Caruso *et al*. 2010). It is therefore recommended that managers ring-bark in regular temporal cohorts in order to create structural and niche diversity, as well as maintaining the continuity of substrate availability.

Table 3. Invertebrate species recorded on fallen deadwood produced by ring-barked trees

Species	Saproxylic
COLEOPTERA	
Oulema melanopus	No
Ocalea rivularis	No
Quedius plagiatus	Yes
Leptusa pulchella	Yes
Dropephyllla koltzei	Yes
Agathidium rotundatum	Yes
DIPTERA	
Clusoides caledonicus	Yes

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Figure 5. A group of ring-barked trees that have died (left) and volunteers ring-barking trees (right)

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