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A lack of large-diameter logs and snags characterises dead wood patterns in Irish forests

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ABSTRACT

Dead wood is an important component of forest ecosystems and volumes vary depending on forest age, management intensity and productivity. This is the first large-scale study to quantify dead wood in Irish forests and to compare them to forests in other locations. We measured the volume and size distribution of logs, the density and size distribution of snags and the volume of dead wood contained in stumps in Oak (*Quercus* spp.) and Ash (*Fraxinus excelsior*) forests and in Sitka spruce (*Picea sitchensis*) plantations throughout Ireland. We also assigned each log, snag and stump to one of three decay classes (intact, part-rotted and well-rotted). We found no significant difference in log volume between any of the forest types. The majority (>90%) of logs were less than 20 cm in diameter, and large logs (>40 cm diameter) were scarce. We found a relatively high density of snags in all forest types but, as in the case of logs, over 90% of snags were <20 cm DBH and large snags (>40 cm DBH) were rare. The volume of dead wood contained in stumps was significantly higher in plantations than in Oak or Ash forests as a result of thinning and harvesting. Most logs and snags were moderately decayed but, in plantations, most stumps were intact. Log volume and the size of logs and snags were considerably lower than in old-growth forests in other regions. These patterns may reflect historical use of Irish forests for coppice and timber production. Management for biodiversity should aim to accelerate dead wood accumulation to increase the frequency of large-diameter logs and snags. Although management seeking to replicate the dead wood volumes of old-growth forests is ideal, it may be unrealistic in the short term.

1. Introduction

Dead wood is an integral component of forest ecosystems and its quantification is important to inform management decisions. Dead wood influences soil chemistry (Kappes et al., 2007) and processes such as nutrient cycling (Hafner and Groffman, 2005), germination (Kennedy and Quinn, 2001) and seedling survival (Mori and Mizumachi, 2005). Dead wood is also closely associated with the life-histories of a variety of flora and fauna, including fungi (Nordén et al., 2004b), bryophytes (Ódor et al., 2006), invertebrates (Kappes, 2006; Topp et al., 2006) and birds (Smith, 2007).

Dead wood takes one of two forms: fine dead wood (brash), and coarse woody debris (CWD). The latter comprises fallen trunks or branches (logs), intact dead branches, standing dead trees (snags) and stumps. Species, or groups of species, may associate closely with a specific type of dead wood (Jonsell and Weslien, 2003; Hjältén et al., 2007) at different levels of decay (Jonsell et al., 1998). When managing forests for biodiversity, it is therefore important to maximise the volume and diversity of dead wood in forest stands so as to ensure optimum habitat heterogeneity for species that utilise this resource (Lindhe et al., 2005; Hottola and Siitonen, 2008). Many saproxylic species that depend on dead wood are rare (Jonsell et al., 1998; Lindhe and Lindelöw, 2004; Djupström et al., 2008). Management affecting this resource may thus have a disproportionately large impact on the conservation value of forests, although empirical evidence is currently lacking in this regard (Davies et al., 2008).

Approximately 6000 years ago Ireland had extensive native forest cover. This declined from the Bronze Age, due primarily to the actions of Ireland's dense human population (Mitchell, 1995), and forests accounted for approximately 2% of land area by 1650 (Rackham, 1995). Pollen data indicate that the decline in forest area accelerated in the last 300 years, when Ireland's population grew to its maximum, and that almost all native woodland cover was cleared resulting in the present-day level of 1% of land cover (Cole and Mitchell, 2003). Remaining patches of native forest are typically small and highly fragmented, and Ireland has no areas of

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primeval forest or large tracts of continuous forest cover comparable to those found in Northern and Eastern Europe. All of Ireland's remaining native forests have been subject to management at some point. Non-native coniferous plantations were first introduced in the 1700s (O'Carroll, 1984) but European Union grant schemes in the 1980s contributed to a rapid expansion of the area under commercial forests, and today approximately 10% of Irelands land area is forested, 90% with coniferous plantations. The most commonly occurring tree, comprising ~60% of Ireland's forest estate, is non-native Sitka spruce (*Picea sitchensis*) (Forest Service, 2007).

Data on dead wood volumes and type are important to forest managers seeking to maximise biodiversity. Estimates of dead wood volumes are available from many different countries, but until now there has been no estimate of the quantity of dead wood in native Irish forests. In this paper we compare the volume, size distribution and decay status of dead wood contained in logs and stumps and the density, DBH distribution and decay level of snags in the two most prevalent native forest types in Ireland: those dominated by Oak (*Quercus* spp.) and those with a high proportion of Ash (*Fraxinus excelsior*) in the canopy. We also estimate dead wood metrics in coniferous plantations, to allow direct comparison of dead wood levels between native forests and non-native plantations due to the prevalence of plantations in Ireland and elsewhere, and a corresponding need to evaluate their potential utility to biodiversity. Existing data for Irish plantations (Forest Service, 2007) was collected using a different survey methodology from that adopted by the majority of published studies. We then place these figures in a European and global context, paying special attention to studies that have quantified dead wood levels in old-growth or 'pristine' forests (these offer a reference point against which Irish native forests can be compared) and studies that assess managed forests. We finish by making recommendations for future management of native and plantation forests based on the results of this study.

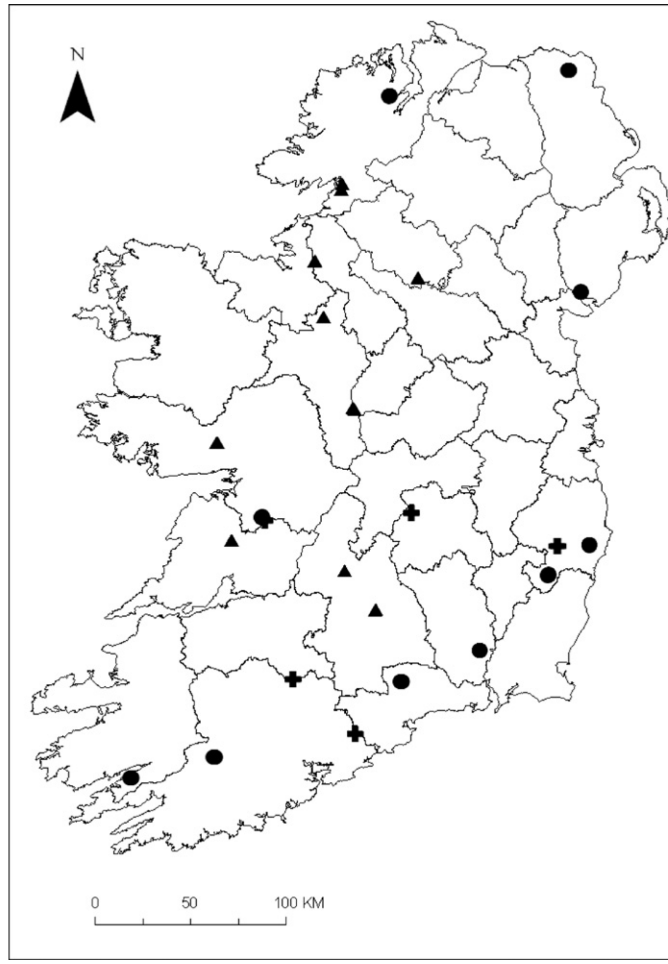

Fig. 1. Distribution of dead wood study sites: (●) Oak; (▲) Ash; (✚) Sitka spruce plantation.

2. Methods

2.1. Study site selection and management history

We conducted dead wood surveys in 20 native forests. 10 were dominated by Oak and 10 had a large proportion of Ash in the canopy alongside Oak. These forests correspond to the WN1 and WN2 classifications of Irish habitats (Fossitt, 2000). We also surveyed five commercially mature (40–50 years old) Sitka spruce plantation forests (Fig. 1). The size of the native forests ranged between 8.3 and 119 ha, with an average forest size of 36 ha. It was not possible to calculate a meaningful size for the plantation forests as the studied stands were usually embedded in a larger area of uneven aged plantation forests. Where possible, native forests were selected for study based on their presence on maps dating from the 1840s (the earliest available for Ireland). In the case of forests in Northern Ireland, forests were selected that were listed as ancient (continuously wooded since 1600), long-established (appearing on maps dating from 1840s maps) or possibly ancient in a survey of native forest patches (The Woodland Trust, 2007). This was to ensure that forest age was not a confounding factor when attempting to explain differences in dead wood volumes. However, two forests that were surveyed were not on the 1840s maps and are thus somewhat younger. These were selected due to a lack of suitable alternative sites in the Irish landscape. As dead wood patterns in these forests did not differ from the older forests, they are included in the data presented.

Information on management of individual forest patches is scarce, but a survey of native woodlands in the Republic of Ireland (Perrin et al., 2008) found man-made structures (walls, ditches, banks, ruined buildings or ridges) in 15 of the native forests in this study (the other 5 forests did not appear in their study) which suggests widespread historical exploitation of forest resources. Six of the native forests in this study are owned by the National Parks and Wildlife Service (NPWS) and are designated as Special Areas of Conservation, which prohibits the removal or felling of any timber. However, all designations are recent (within 10–30 years). At least four forests are known to have been managed for coppice, with one cut over as recently as 1920 (Rackham, 2006). A study of woodlands in Northern Ireland (The Woodland Trust, 2007) identified two of the forests in this study as 'possibly ancient woodland', and one as 'long-established' woodland. Ideally, we would have liked to control for management but, given the scarcity of woodland in Ireland and the widespread history of human exploitation of woodlands, this was not possible. However, we restricted our site selection to those forests that showed no signs of recent management.

2.2. Dead wood transects and log volume calculation

We used ArcGIS v9.2 to randomly place 10 transect start points in each of the 25 forest patches: 10 Oak, 10 Ash and 5 Sitka spruce plantations. The design was unbalanced as this study was part of a larger study to investigate the biodiversity of native and plantation forests and time was limiting. To compensate for the unbalanced survey design, we selected five Oak and five Ash forests at random and calculated the dead wood data from these sites. We repeated this process five times and took the mean value from the five random samples. We then compared these data to the calculations using all sites and all transects to ascertain whether the different number of sites surveyed affected the dead wood estimations.

Table 1
Summary of dead wood metrics for Oak, Ash and plantation forests after having been corrected for unequal survey effort.

Dead wood metric								
Log volume (m^3 ha^{-1} ± SE)			Snag density (No. ha^{-1} ± SE)			Stump volume (m^3 ha^{-1} ± SE)		
Oak	Ash	Plantation	Oak	Ash	Plantation	Oak	Ash	Plantation
20.68	27.06 (1.32)	13.55 (1.90)	92.21 (3.28)	86.84 (7.79)	72.26 (30.23)	6.07 ± 2.71	7.90 (3.52)	25.40 (5.16)

Prior to visiting the site, we assigned one of eight compass bearings (N, NE, E, SE, S, SW, W, NW), denoting transect orientation, to each start point. This was to ensure that there was no observer bias either towards or away from large logs or snags (Ringvall and Ståhl, 1999). We located start points in the field with the aid of a Garmin GPS. Each transect was 30 m long and measured out with a tape measure which then formed the transect centre line. Most Irish forest patches are small and, in many of the smallest patches, transects longer than 30 m would have exited the forest. For the sake of consistency, we therefore fixed transect lengths at 30 m transect length in all forests. We then conducted as many transects as patch size and terrain allowed in each site, up to a maximum of 10, to ensure that each forest was sampled as thoroughly as possible. Following data collection, transect lengths were corrected for slope to ensure that dead wood calculations were as accurate as possible. To check that the variable transect numbers did not bias results, we selected seven transects at random from each study site and used the raw data from those transects to calculate the dead wood estimates. We then compared these results to those calculated using all transects.

We used line-intersect sampling (see Kirby et al., 1998, for a detailed description of the methodology) to calculate the volume of logs in all of the forest patches. We recorded all logs greater than or equal to 5 cm in diameter at the point of intersection with the transect line and placed each log into one of five size classes: 5–10 cm, 11–20 cm, 21–30 cm, 31–40 cm and >40 cm. These intersections were then converted to volume of fallen wood (m^3 ha^{-1}) per transect using the mean diameter of measured logs in each size class. The mean of the volumes calculated from each transect was then taken as the site volume. We used 5 cm as a minimum log diameter as we felt that using a larger minimum diameter would have underestimated log volumes. However, to ensure comparability with as many published studies as possible, we also calculated log volumes using a minimum diameter of both 7 cm and 10 cm. We also assigned each log to one of three decomposition classes: (1) intact (still solid with bark attached); (2) part-rotted (bark absent and beginning to decompose) and (3) well-rotted (crumbly).

2.3. Standing dead wood and stumps

We classed snags as standing dead wood greater than 2 m in height. We recorded only those snags with a diameter at breast height (DBH) of greater than 5 cm that were within 2 m either side of the transect line. Snags were placed in the same three rot categories as used for logs. Because the area surveyed was known (for a flat 30 m transect, 60 m^2 was surveyed each side of the transect line, resulting in a total of 120 m^2) we were able to calculate the density of snags. We did not attempt to calculate snag volume as the precise height of snags was not measured. We also recorded all stumps (standing dead wood less than 2 m in height) located within 2 m each side of the transect line. These were treated as frustums (truncated cones) and were measured both at the base and the top, allowing calculation of the dead wood volume using the formula:

$$V = \frac{\pi h}{3} * (b^2 + bd + d^2)$$

where h is the height of the frustum, b the basal diameter and d the top diameter. The dead wood volume ha^{-1} contained in stumps was subsequently obtained by calculating the number total of stumps ha^{-1} at each site and multiplying this figure by the total dead wood volume in measured stumps.

2.4. Data analysis

Data were checked for homogeneity and normality using SPSS (SPSS Inc., 2006). We used ANOVA and a Tukey HSD post hoc test to compare the mean volume of dead wood contained in stumps and snag density between the three site types. The log volume data did not meet the assumptions of parametric tests and therefore a Kruskal–Wallis test with a Dunne's post hoc was used. Graphs of log volumes and snag densities revealed one Ash site in each with an outlying value that could not be addressed by transformations. Analysis was run with and without these sites and it was found that their inclusion did not alter the outcome of the results. We therefore present results for all data points. A log volume outlier also existed in plantation forests and was removed from analysis. This site contained large areas of wind-throw and therefore did not represent a typically managed plantation.

3. Results

We calculated the dead wood metrics for all the forests, and again for the data corrected for differences in survey effort. The corrections did not have a large effect on the dead wood metrics and so, from this point on, we analyse only those metrics that were corrected for survey effort so that data are directly comparable between site types (Table 1).

3.1. Logs

The mean volume of logs in Oak forests was 20.68 ± 1.87 m^3 ha^{-1} (range: 15.01–25.94 m^3 ha^{-1}; median = 21.19 m^3 ha^{-1}). The mean log volume in Ash forests was 27.06 ± 1.32 m^3 ha^{-1} (range: 24.49–30.67 m^3 ha^{-1}; median = 25.39 m^3 ha^{-1}) and the mean log volume in plantations was 13.55 ± 1.90 m^3 ha^{-1} (range: 8.74–18.97 m^3 ha^{-1}; median = 13.24). We found a significant difference in log volume between the three forest types (Kruskal–Wallis $H = 11.64$; $P < 0.01$). Dunn's post hoc indicated no significant difference between the log volumes of Oak and Ash forests ($Q = 1.58$, $P > 0.05$) or between Oak and plantation forests ($Q = 1.49$, $P > 0.05$), but Ash forests had significantly higher log volumes than plantations ($Q = 2.99$, $P < 0.01$).

In all forests, over 90% of all recorded logs were less than 20 cm in diameter. In plantations, no logs over 40 cm in diameter were recorded while in each of Oak and Ash forests, logs of this size were rare (Table 2). Most recorded logs in all size classes were part-rotted, except in the largest category where half of recorded logs were well-rotted (Fig. 2).

Re-calculating log volumes using a minimum diameter of 7 cm and 10 cm at the point of intersection did not result in a large decrease in the log volumes in Oak forests (7 cm: mean = 20.12 ± 1.98 m^3 ha^{-1}; 10 cm: mean = 18.51 ± 1.95 m^3 ha^{-1}).

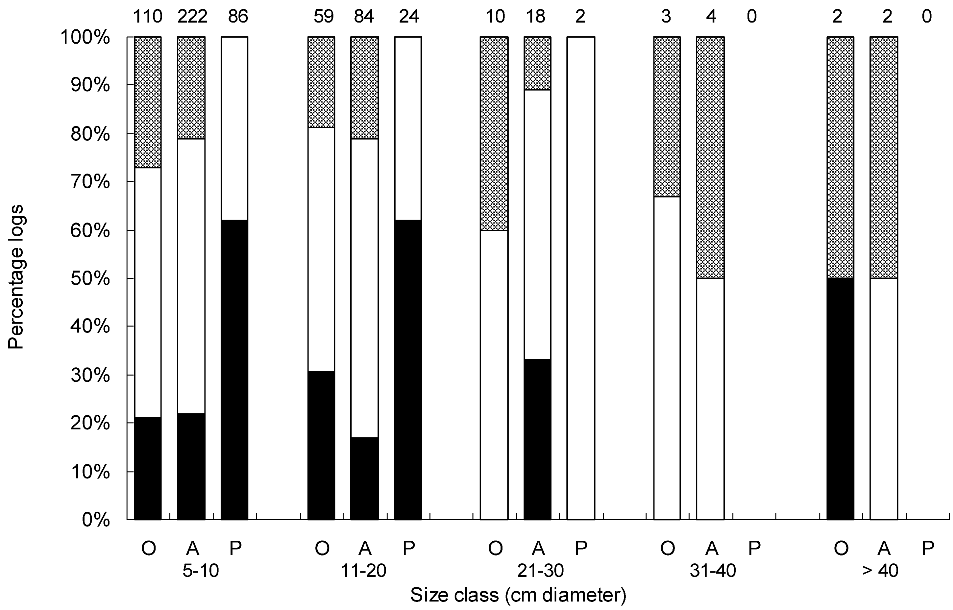

Fig. 2. Percentage of recorded logs in each size class in each rot category (intact = black section; part-rotted = open section; well-rotted = shaded section). O, Oak; A, Ash and P, plantation. Actual numbers (corrected for survey effort) are shown above the bars.

Log volumes in Ash forests were not reduced substantially after the 7 cm cut-off (mean = 26.91 ± 1.38 m^3 ha^{-1}), but were reduced by approximately 25% after considering only logs ≥ 10 cm diameter (mean = 20.97 ± 1.41 m^3 ha^{-1}). Similarly, in plantations, log volume was not significantly reduced after analysing logs ≥7 cm diameter (mean = 11.85 ± 2.45 m^3 ha^{-1}), but was reduced by around 40% after analysing only logs ≥10 cm diameter (mean = 8.19 ± 3.15 m^3 ha^{-1}) (Fig. 3).

3.2. Snags and stumps

We recorded only two snags greater than 30 cm DBH (both in Oak forests) and only one of these (0.5%) was greater than 40 cm DBH. However this snag was removed after correcting for survey effort (Table 2). In Oak forests, mean snag density was 92.21 ± 3.28 ha^{-1} (range: 81.34–100.39 ha^{-1}; median = 90.86 ha^{-1}), and in Ash forests, mean snag density was 86.84 ha^{-1} ± 7.79 (range: 61.03–107.27 ha^{-1}; median = 89.52 ha^{-1}). Snag density in plantations was 72.26 ± 30.24 snags ha^{-1} (range: 11.90–170.73 snags ha^{-1}; median = 59.52). There was no significant difference between the density of snags in the three forest types (Kruskal–Wallis $H = 0.74$; $P > 0.05$).

Snag size distribution over all forests closely resembled that of logs with over 90% of all recorded snags under 20 cm DBH. As in the case of logs, most snags were categorised as part-rotted. All 30 snags recorded in plantations were under 20 cm DBH and none were classed as well-rotted (Fig. 4).

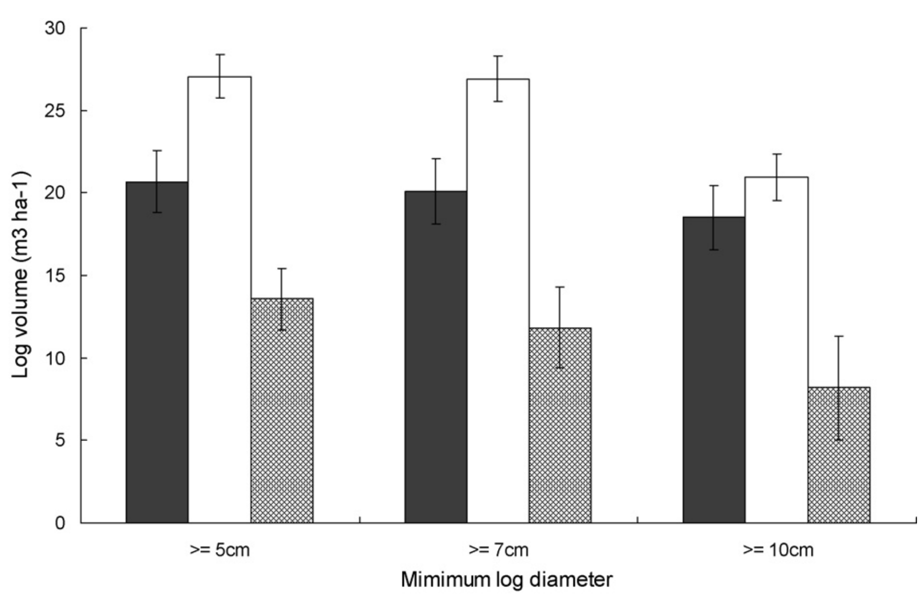

Fig. 3. Mean log volume (m^3 ha^{-1} ± SE) in Oak (grey bars), Ash (open bars) and plantation (shaded bars) forests when calculated using minimum log diameters of 5 cm, 7 cm and 10 cm.

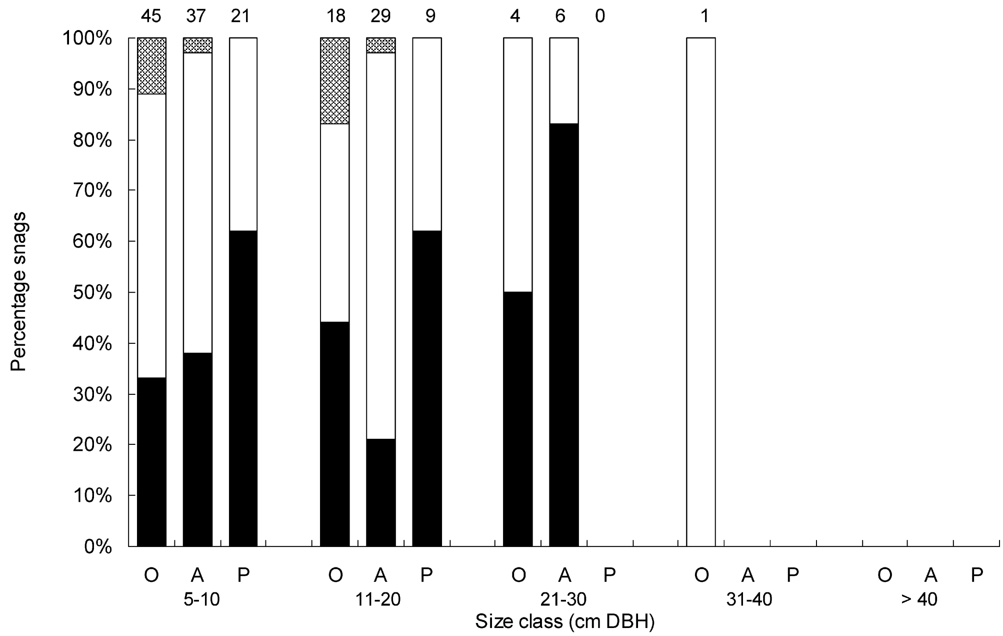

Fig. 4. Percentage of recorded snags in each size class in each rot category (intact = black section; part-rotted = open section; well-rotted = shaded section). O, Oak; A, Ash and P, plantation. Actual numbers are shown above the bars. After correcting for survey effort, there were no snags >40 cm recorded.

Table 2
Size distribution of recorded logs and snags in Oak, Ash and plantation forests after correcting for survey effort. Size of logs is expressed as cm diameter while snags are cm DBH.

Size class	Forest type					
	Oak		Ash		Plantation	
	% Logs	% Snags	% Logs	% Snags	% Logs	% Snags
5–10	57	61	66	46	69	70
11–20	35	32	26	45	21	30
21–30	6	6	6	9	9	0
31–40	1	1	1	0	1	0
>40	1	0	< 1	0	0	0

Mean stump volume in plantations was $25.40 \pm 5.16\,m^3\,ha^{-1}$ (range: $14.32–42.61\,m^3\,ha^{-1}$), in Oak forests mean stump volume was $6.07 \pm 2.71\,m^3$ (range: $4.33–8.01\,m^3\,ha^{-1}$) and in Ash forests, the mean stump volume was $7.90 \pm 3.52\,m^3\,ha^{-1}$ (range: $4.66–11.34\,m^3\,ha^{-1}$). There was a significant difference in volume of dead wood contained in stumps in the three forest types ($F_{2,14} = 12.00$, $P < 0.01$). The stump volume in plantations was significantly higher than that in Oak ($q = 6.32$, $P < 0.01$) or Ash ($q = 5.72$, $P < 0.01$) forests. There was no significant difference in the stump volumes of Oak and Ash forests. The distribution of stumps between the different rot classes in Oak and Ash forests was similar, with most classed as part-rotted. Most stumps in plantation forests were classed as intact (Fig. 5).

4. Discussion

4.1. Native Irish forests in context

The size distribution of logs in Irish native forests resembles that of young-growth and managed forests elsewhere in Europe (Table 3), with only two large logs (>40 cm diameter) recorded in the entire study. Logs in old-growth forests typically span a wide range of decay states, and have a more even size distribution than those found in this study (Jonsson, 2000). Developing old-growth conditions incorporating high CWD volumes, large logs and large snags will take a long time in Irish forests in the absence of intervention (Siitonen et al., 2000; Vandekerkhove et al., 2009). Large living trees are a prerequisite for large logs and snags, and these are scarce in Irish forests (Coote et al., unpublished data). In terms of CWD volume, Irish forests also fall well below the normal range for old-growth forests. This is partly a consequence of the low numbers of large-diameter dead logs which contain large volumes of dead wood, but may also be a consequence of Ireland's mild, damp climate which likely results in rapid decomposition of dead wood.

The high density of small snags that we recorded may be the result of stem mortality due to competition. Old-growth forests are characterised by having a lower density of snags than found in this study, but with a larger DBH (Nilsson et al., 2002). One study recorded 60% of snags to be over 30 cm DBH (Jonsson, 2000), while the prevalence of such snags in Irish forests is just 1%.

We found that the mean volume of dead wood contained in stumps in native forests was 20–30% of that contained in logs, which is partially a consequence of the low numbers of large-diameter logs. The absence of large-diameter fallen logs and the high numbers of stumps and small DBH snags may be a reflection of

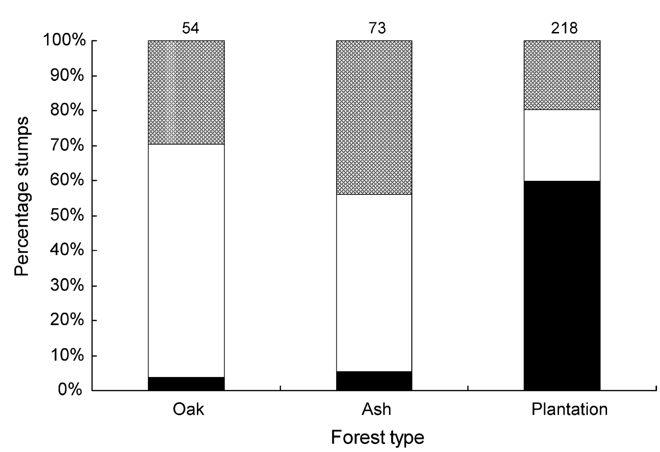

Fig. 5. Percentage of recorded stumps in each forest type in each rot category (intact = black section; part-rotted = open section; well-rotted = shaded section) in native and plantation forests. Actual numbers are shown above the bars.

Table 3
Studies quantifying dead wood levels in various forest types and geographical locations. CWD volumes are expressed as m^3 ha^{-1}, size of large logs is expressed as cm diameter and size of snags as cm DBH. Unless otherwise stated, all studies recorded CWD ≥5 cm diameter.

Reference	Location	Forest type	CWD volume	Large logs	Snag density	Large snags
Green and Peterken (1997)	Great Britain	Old-growth	15–113	0–60% CWD		
		Young-growth	11–26	0–20% CWD		
		Managed	4–12	>40 cm: 0		
		Common	15	>40 cm: 0		
		Plantation	3–20	>40 cm: 0		
Hodge and Peterken (1998)	Great Britain	Plantation	4–20			
Kirby et al. (1998)	Great Britain	Unmanaged	0.3–139		<50 ha^{-1}	
Lindenmayer et al. (1999)	Australia	Regeneration	342			
		Regrowth	309			
		Mature	393			
		Old-growth	375			
McGee et al. (1999)	USA	Old-growth	137	>50 cm 17% CWD	60 ha^{-1}	>50 cm 30%
		Partially cut	60	>50 cm 8% CWD	43 ha^{-1}	>50 cm 0
		Even aged	59	>50 cm 3% CWD	96 ha^{-1} (all <10 cm)	>50 cm <1%
Fridman and Walheim (2000)	Sweden	Managed	4.5 (>10 cm diam.)			
Greif and Archibold (2000)	Canada	Timber productive			55–440 ha^{-1}	>21 cm 5%. DBH increased as stands aged
Jonsson (2000)	Sweden	Old-growth	17–65			60% >30 cm DBH
Runkle (2000)	USA	Old-growth			15–18 ha^{-1}	
Siitonen et al. (2000)	Finland	Old-growth	110			Large (30–40 cm) snags 25–30 times more common than in other forest types
		Over-mature (managed)	17			
		Mature (managed)	11			
Siitonen (2001)	Fennoscandia	Old-growth (northern)	50–80 (spruce) 70 (pine)			
		Old-growth (middle and southern)	90–120 (spruce) 60–120 (pine)			
		Managed	2–10			
Bobiec (2002)	Poland	Developing	97–241			
		Old-growth	84–157			
Mountford (2002)	France	'Near natural'	160			
Nilsson et al. (2002)	Europe (3 countries)	Old-growth		>40 cm 10–30 ha^{-1} >70 cm 1–2 ha^{-1}	<20 cm 5–93 ha^{-1}	>40 cm 0–28 ha^{-1} >50 cm 0–14 ha^{-1} >70 cm 0–8 ha^{-1}
Humphrey et al. (2003)	UK	Plantation	23			
Marage and Lemperiere (2005)	France	Ancient (managed)			7.5–27.5 cm: 21 ha^{-1} 28–42.5 cm: 5 ha^{-1} 43–62.5 cm: 3.6 ha^{-1}	
		Ancient (unmanaged)			7.5–27.5 cm: 17 ha^{-1} 28–42.5 cm: 12 ha^{-1} 43–62.5 cm: 8 ha^{-1} >62.5 cm: 10 ha^{-1}	
Debeljak (2006)	Slovenia	Old-growth	248–626			
		Managed	41–67			
Forest Service (2007)	Ireland	Plantation	11.2 (≥7 cm diam.)			
Pfeil et al. (2007)	USA	Old-growth	Mean 85			
Atici et al. (2008)	Turkey	Managed	10 (>10 cm diam.)			
This study	Ireland	Plantation	9–19	Absent	8–140 ha^{-1}	Absent
		Native	5–59	>30 cm, <1% recorded logs	0–175 ha^{-1}	>30 cm, 1% recorded snags

historical forest management which has resulted in a size distribution of dead wood more closely resembling young forests. Stumps do not appear to be the result of timber harvesting as they are not only generally small in diameter, but are frequently birch (*Betula* spp.) which is a pioneer tree and not widely used in Ireland for timber (O'Connor, 2006). Therefore it seems likely that most stumps are a result of natural succession and stem competition.

4.2. Dead wood in plantations

Managed forests typically contain less CWD than unmanaged forests (Kirby et al., 1998; Siitonen et al., 2000; Bobiec, 2002). We found that log volume in managed plantations decreased considerably when we used a larger (≥10 cm) minimum log diameter, which indicates that dead wood in plantations is largely composed of small diameter timber. Our log volumes, when calculated using a minimum log diameter of 7 cm, are similar to those calculated in an earlier survey of Irish plantations which found CWD volumes of between 5 and 11 $m^3\ ha^{-1}$ (Forest Service, 2007).

Current Irish forestry guidelines (Forest Service, 2000) state that some dead wood should be left *in situ* after thinning and harvesting, and that foresters should aim to ensure the presence of 2 $m^3\ ha^{-1}$ of CWD (snags or logs) following thinning, and 5 $m^3\ ha^{-1}$ following final harvesting. Thinning is routinely carried out in plantations in the Republic of Ireland (where all plantation forests were located) to promote the growth of remaining trees, and some of the smaller diameter thinnings may be left through biodiversity considerations. Such timber accounted for a large proportion of logs in some plantations. According to our results, many Irish plantations may exceed the dead wood volume guidelines, but the guidelines are low and more ambitious targets would be desirable.

One plantation study site was not included in the analysis because it contained a large number of wind-thrown trees. This plantation contained log volumes higher than most native forests (~50 $m^3\ ha^{-1}$), illustrating the potential for increasing dead wood volumes in plantations by leaving wind-thrown trees *in situ*. High volumes of CWD in plantations in Great Britain have also been attributed to wind-throw and self-thinning (Humphrey et al., 2003). However, such log volumes are not typical of plantations in Ireland, and mature downed trees are commonly processed and extracted for timber, not left on site as dead wood.

Plantations in this study contained a larger volume of dead wood in stumps than in logs. The higher stump volume in our study was probably due to the fact that all forests were in their second rotation and some stumps still persist from when the sites were last harvested. The large number of intact stumps recorded suggests that recent thinning further increased stump density. Our findings suggest that stumps are an important source of dead wood in plantations and that the value of this resource for some saproxylic species may increase as sites enter later rotations and stumps enter more advanced stages of decay.

4.3. Influence of past management

In Ireland, as in Great Britain, primeval forests do not exist. The survival of many forest patches throughout times of intense human pressure on land, such as during the Irish famine that began in 1845, was due to the utility of these forests for coppice and timber production (Rackham, 1995). Coppice was taken from the understorey, and timber from large Oak 'standards' which grew through several coppice cycles. Four of our forests are known to have undergone past management (one was planted in the 1700s, probably for wood production) but it is likely that others also underwent some form of management. Therefore, even in the unlikely event that an area in Ireland has been under continuous forest cover for hundreds of years, the present-day forest may not possess old-growth features such as large-diameter trees due to historical exploitation (Rackham, 1995). This is illustrated by one of our study sites which is thought to have been last felled for timber and coppice ca. 1920 (Rackham, 1995), although pollen data indicates that the area may have been forested for 3000 years (Budd, 1998). The low frequency of large-diameter logs in Irish forests may therefore be attributable to the historical removal of such timber from managed forests before it could be deposited as dead wood. The fact that most forests used for timber production would have had Oak standards may explain the slightly higher dead wood volumes found forests with a high proportion of Ash, as this species was not as highly valued for timber.

4.4. Future management recommendations

Because many existing forest patches in Ireland are now managed for conservation and recreation purposes, an opportunity exists to increase dead wood levels for the benefit of biodiversity. One of our study sites is subject to a management plan which involves resuming coppicing in the forest. This site was one of the few in which large-diameter dead wood was encountered, and because the large Oak standards present are not included in the management plan, they may continue to deposit large-diameter dead wood following branch death or storm damage.

Dead wood levels in Irish forests are low even compared to those in Great Britain which has also experienced extensive forest clearance (Rackham, 2006). According to the dead wood categories proposed by Kirby et al. (1998) for use in British forests, most Irish native forests and plantations would be classed as low or medium in terms of CWD levels, snag density and snag size. However, these proposed categories do not take account of the requirements of dead wood flora and fauna and are based on current variation in dead wood levels.

Despite a lack of published research on saproxylic flora and fauna in Ireland, at least 600 species of invertebrates are known to utilise dead wood and many are rare or localised in the country, particularly some Staphylinidae species (Alexander, 2002). Historical forest clearance and loss of CWD and mature trees; a decrease in pine in the landscape; changes to forest disturbance regimes and climate change may all have contributed to the extinction of several species of forest beetle in Ireland, including some that are presently relatively common in Britain (Whitehouse, 2006). Saproxylic beetles are often poor dispersers (Grove, 2002), and recolonisation by many of these species is likely to take a long time as source populations are distant, though the original post-glacial colonisation of Ireland by such species suggests that it is not impossible (Whitehouse, 2006). In any case, a diverse range of dead wood habitats are utilised by current saproxylic fauna (Alexander, 2002) and so management should aim to ensure a mix of dead wood types and to ensure that some dead wood is sun-exposed (Lindhe et al., 2005).

Due to the lack of knowledge of the saproxylic flora and fauna of either native or plantation forests, it is difficult to suggest meaningful dead wood targets. However, large logs host many species of saproxylic fungi (Lindhe et al., 2004) due to the variety of microhabitats and slow decomposition rates they exhibit (Grove, 2002). Increasing the prevalence of such logs should therefore be one of the primary targets for management of dead wood in Irish forests. Snags are also important nesting and foraging sites for woodpeckers (Smith, 1997), and the lack of large-diameter snags in Irish forests may have implications for the recolonisation of Ireland by the great spotted woodpecker (*Dendrocopos major*), which is known to have bred successfully in several locations in Ireland in 2009 (Coombes, 2009). Felling unwanted non-native tree species and importing large logs grown elsewhere are two methods to increase large-diameter dead wood in forests over a short space of time

(Speight, 1989). In the absence of timber extraction, this would be augmented over time by natural processes which would ensure the deposition of dead wood in a variety of decay states (Similä et al., 2003).

Plantation forests currently meet the forestry guidelines in terms of recommended dead wood volumes. However, most of this dead wood is in the form of small diameter timber, and large logs and snags are even scarcer in plantations than in native forests. Forestry guidelines state that some over-mature trees should be retained following harvesting (Forest Service, 2000), but such trees remain rare in plantations. Stricter adherence to these recommendations would help to ensure the long-term development of large-diameter dead wood. These trees should be as large as possible to increase the potential for deposition of large-diameter CWD (Similä et al., 2003). Ideally, some large-diameter logs should also be left post harvesting to complement the large amounts of brash typically left following clearfelling.

5. Conclusions

There is a striking paucity of large-diameter logs and snags in Irish forests. Because of their importance to dead wood flora and fauna, managers should consider accelerating the accumulation of these features, although more work is required in Ireland to determine the richness and degree of specialisation of the saproxylic flora and fauna. The volume of logs in Irish plantations is between 40 and 50% that in native forests and both forest types contain considerably lower log volumes than old-growth forests in other parts of the world. Low log volumes and small snags in Irish native forests are likely due to a history of extensive deforestation and exploitation of forests for wood resources. As a result, replicating old-growth dead wood conditions in Irish native forests may be unrealistic in the short term.

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