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Research article

Effect of woodstack structure on invertebrate abundance and diversity

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Reduced quantities of dead wood in managed forests have resulted in a reduction in the abundance and diversity of saproxylic invertebrates to the extent that many are now considered red list species. To mitigate against this loss, one conservation measure is the provision of dead wood, in the form of piles of chopped logs, i.e. 'woodstacks'. The heterogeneity and volume of dead wood habitat is considered to be an important component of habitat suitability. However, the value of different woodstack types to invertebrate conservation has rarely been quantified and there is little consensus on how to best to survey the invertebrate fauna of woodstacks. This study used both sticky traps and pitfall traps to sample the invertebrate fauna of three types of sycamore woodstack. Woodstacks were made from 10 logs, 20 logs and 10 scorched logs plus a control woodstack made of unplasticised polyvinyl chloride (uPVC) plastic piping and observed over a 4-week period. A total of 1446 invertebrates from 16 orders, including 127 Coleoptera, were caught during the sampling period. A generalized linear model was used to analyse invertebrate abundance between woodstack and between trap types, and diversity was determined using Shannon diversity indices and analysed using a two-way Analysis of Variance (ANOVA). The woodstack type had no effect on the abundance of invertebrates. However, Shannon diversity was highest on the scorched woodstacks, with little difference between the 10 and 20 log stacks and the control uPVC woodstacks. However, closer inspection of orders revealed the uPVC woodstacks to have the lowest abundance and diversity of Coleoptera. This study suggests that constructing woodstacks can provide suitable habitat for a variety of invertebrates. However, these invertebrates may have simply used the structures for shelter and the true value with saproxylic invertebrates could not be measured in this 4-week study. To fully appreciate the conservation value of woodstacks will require longer term studies that examine how and when saproxylic invertebrates use dead and decaying wood.

Keywords: dead wood, woodstack, biodiversity, sticky trap, pitfall trap, invertebrates

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Introduction

A supply of dead wood in forest ecosystems, such as the preservation of veteran trees and the construction of woodstacks is recommended in conservation management strategies (e.g. Kirby, 2001). Woodstacks are frequently constructed from the cuttings of felled trees and other forestry management practices (e.g. Hedin *et al.*, 2008) and have the potential to provide habitat for entire communities of species associated with dead wood. Saproxylic invertebrates are a major component of such communities, being dependent on dead wood as a food source directly or indirectly (Speight, 1989). This dependency makes saproxylic species sensitive to the availability and distribution of dead wood.

As part of silviculture, old and dead trees are often removed from woodland to allow space for tree planting and to prevent pest infestation (Winter, 1993). The resulting reduction in dead wood habitat has had a negative effect on saproxylic insects (e.g. Berg *et al.*, 1994; European Environment Agency, 2010a). For example, in Sweden, 80% of the IUCN red-listed woodland insects are saproxylic (Berg *et al.*, 1994) and currently 14% of all saproxylic beetles in Europe are threatened (European Environment Agency, 2010a).

The importance of dead wood in promoting arthropod biodiversity been recognized in the last 20 years, after the European Council recommended the protection of saproxylic invertebrates and their habitats (Speight, 1989). Currently, The Ministerial Conference on the Protection of Forest in Europe incorporates the presence of dead wood as one of nine sustainability indicators. The European Environment Agency suggests that having dead wood in a habitat is a long-term indicator of biodiversity (Kristensen, 2003). The addition of dead wood is thus seen as a highly significant factor in reducing the rate of decline in biodiversity. For example, previous studies have highlighted the correlation between the volume of dead wood and the richness of invertebrate species (Økland *et al.*, 1996; Martikainen *et al.*, 2000). However, simply increasing the volume of dead wood within managed woodland may not necessarily improve invertebrate diversity (Simila, Kouki and Martikainen, 2002).

In unmanaged woodland, the diversity of dead wood is usually high (Spies and Franklin, 1988), creating a diverse range of microhabitats. For example, factors such as decay stage and size of wood are equally important as the total volume in affecting invertebrate diversity (Siitonen, 2001) and given many pyrophilous invertebrates are saproxylic (Wikars, 1992), the presence of burnt wood can also affect invertebrate diversity (Wikars, 2002). In addition, synthetic logs have been shown to support unique communities of invertebrates (Fager, 1968) highlighting the possibility that artificial logs may constitute a unique microhabitat suitable for invertebrates.

Previous methods used to extract invertebrates from dead wood include Tullgren-funnels (Jonsell, Nittérus and Stighäll, 2004) and less destructive sampling methods such as flight-interception traps (Simila, Kouki and Martikainen, 2002; Hjalten *et al.*, 2007) and emergence traps (Yee, Yuan and Mohammed, 2001). However, removing wood or using emergence traps can fundamentally alter the composition and structure of the woodstack (Yee, Yuan and Mohammed, 2001; Jonsell, Nittérus and Stighäll, 2004) and flight-interception traps may fail to trap some saproxylic beetle species (Ranius and Jansson, 2002). Pitfall traps have been widely used for sampling ground-living invertebrates (Baars, 1979) but have also seen application in tree hollows to sample saproxylic species (Ranius, 2001), where they can trap species that are rarely collected by other methods, such as window trapping (Ranius and Jansson, 2002). In addition, glue traps have previously been used for field monitoring of Coleoptera such as Nitidulidae (Williams *et al.*, 1993) and the saproxylic emerald ash borer, *Agrilus planipennis* (Francese *et al.*, 2008) and have been effectively utilized to sample invertebrate abundance and diversity in hedgerows (Nicholls, Parrella and Altieri, 2001).

Given the extent of woodstack use in forestry and the paucity of scientific studies on the value of woodstacks in promoting invertebrate abundance and diversity, this study aimed to first, develop techniques for surveying the invertebrate community associated with woodstacks and secondly to assess the value of different types of woodstack on arthropod abundance and diversity, with a particular focus on the Coleoptera.

Materials and Methods

Study site

North wood is a managed broadleaved, deciduous woodland of ~1 acre, found within the grounds of Riseholme Park, Lincoln, UK (53°16′11″N, 0°31′53″W). The woodland predominantly comprises beech trees (*Fagus sylvatica*), with a patchy canopy allowing understorey growth of various plants such as *Hedera helix* (common ivy), *Mercurialis perennis* (dog's mercury), *Sambucus* (elder) and *Urtica* spp. (nettle).

Sampling design

Four types of woodstacks were constructed to assess the value of woodstacks for invertebrate diversity. Sycamore logs (*Acer pseudoplatanus*) roughly 70 cm long with diameters of 9–19 cm were used to create tiered pyramid-shaped woodstacks composed of either 10 logs per woodstack ($n = 5$), 20 logs per woodstack ($n = 5$) or 10 scorched logs per woodstack ($n = 5$). Sycamore was chosen due to the availability of relatively uniform logs, from recently felled trees. Logs were scorched by placing into a fire and turning every 2 min for a total of 10 min. As a control, 10 uPVC black plastic, 68-mm pipes (manufactured by Marley Eternit, Burton on Trent, England), were cut into 70 cm long sections and tied together to create five plastic 'woodstacks'. Woodstacks were placed every 20 m, in a square checkerboard configuration within North wood, with 4 woodstacks per 'row' and 5 per 'column'. Each row contained one woodstack of each treatment type, the order of which was different for each row, ensuring an even distribution of treatments through North wood.

Woodstacks were left for 10 weeks from the date of first placement on 28 June 2010 to allow colonization by invertebrates, before sampling commenced on 6 September 2010. Sampling of all woodstacks took place every 7 days until 4 October 2010, resulting in four weeks of consecutive sampling. Following Martikainen and Kouki (2003), the invertebrate communities of woodstacks were sampled using a combination of pitfall traps and sticky traps. A 35 mm diameter hole was drilled (75 mm deep) into the central log of each woodstack, ~20 cm from the end. A plastic pot (mouth diameter 35 mm, 70 mm depth) was lowered into the hole so that the lip of the pot was below the surface of the log. The pot was filled with 40 ml of 50% antifreeze (ethylene glycol) creating a pitfall trap, and the log was returned to the centre of the woodstack. A sticky trap was also set on the same log as the pitfall trap. The sticky trap was 120 by 60 mm and held within a wire mesh cage (10 mm^2 mesh) to prevent small mammal bycatch (Mitchell, 1963).

Analysis of traps

When removed from the woodstack, sticky traps were covered with cellophane wrap to maintain the integrity of the sample before analysis. Identifying invertebrates to the taxonomic level of order has been shown to provide an effective measure of diversity in agricultural environments (Biaggini *et al.*, 2007), thus all invertebrates were identified to the taxonomic level of order, following Tilling (1987). In addition, the Coleoptera were identified to the family level following Unwin (1984).

Statistical analysis

Four treatments (×5 replicates) each sampled on 4 occasions with 2 sampling methods (pitfall and sticky traps) resulted in a total of 160 samples. A generalized linear model (with a negative binomial error) was used to analyse the abundance of invertebrates on the woodstacks (Crawley, 2002). Invertebrate diversity was estimated using the Shannon diversity index (Magurran, 2004). However, the calculated Shannon diversity indicies were not normally distributed (Kolmogorov–Smirnov, $Z = 1.67$, $P < 0.008$; $Z = 6.30$ $P < 0.0001$) thus the values were transformed by adding 0.5 to each value then using the square root transformation (Fowler, Cohen and Jarvis, 1998). The transformed values were then analysed using a two-way ANOVA to test the effects of the trap type and the woodstack type on diversity. Post hoc testing was carried out using a Tukey test and *t*-test. All statistics were performed with PSAW (ver. 17. www.spss.com).

Results

Invertebrate abundance and diversity in relation to woodstack type

A total of 1446 invertebrates from 16 orders were caught during the sampling period. Collembola were the most abundant order, followed by Coleoptera, Acarina and Opiliones, respectively (Fig. 1). Lepidoptera, Dermaptera, Oligochaeta and Trichoptera were equally rare, being represented by one individual only. The majority of orders showed no difference in abundance between woodstacks. However, a generalized linear model revealed there was a significant effect of the woodstack type on the abundance of Opiliones, with the majority being found in plastic woodstacks ($F_{3,148} = 14.559$, $P < 0.0001$) and the most Collembola being found in burnt woodstacks and the woodstacks constructed from 10 logs ($F_{3,148} = 2.954$, $P = 0.035$).

A generalized linear model revealed no effect of the woodstack type on the overall invertebrate abundance ($F_{3,148} = 2.122$, $P = 0.10$) nor the interaction between the woodstack and trap types ($F_{3,148} = 0.574$, $P = 0.63$). However, the trap type did significantly affect the abundance of invertebrates caught ($F_{1,148} = 5.159$, $P = 0.025$), with more invertebrates caught in the sticky traps (Fig. 2A).

A two-way ANOVA revealed an effect of woodstack type on the calculated Shannon diversity indicies ($F_{3,155} = 3.250$, $P = 0.024$), whilst the trap type ($F_{1,155} = 0.109$ $P = 0.74$) and the interaction between the trap type and the woodstack type ($F_{3,155} = 0.379$, $P = 0.77$) had no effect on Shannon diversity. Invertebrate diversity was greatest in the scorched woodstacks (Fig. 2B).

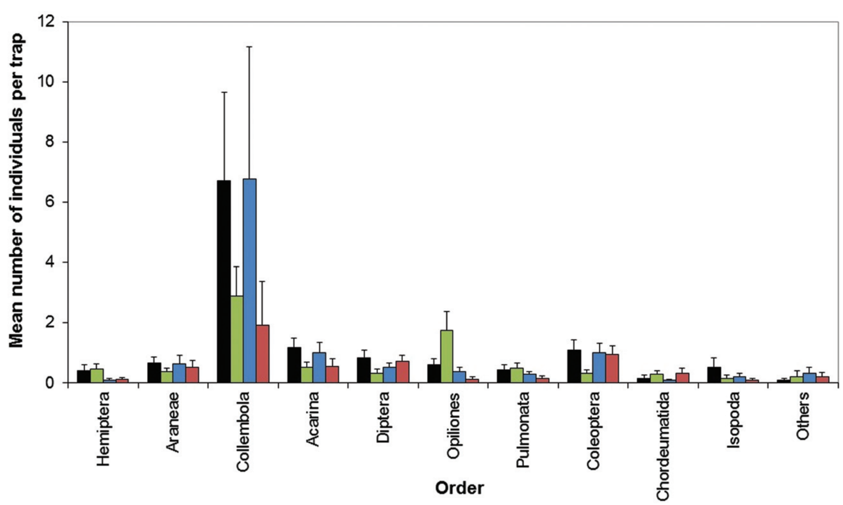

Figure 1. The mean (±SE) number of individuals per arthropod order caught per trap in each woodstack type. Black bars, scorched; green bars, uPVC; blue bars, 10 logs; red bars, 20 logs. Others combine data for Geophilomorpha, Hymenoptera, Lepidoptera, Dermaptera, Oligochaeta and Trichoptera, which were rare.

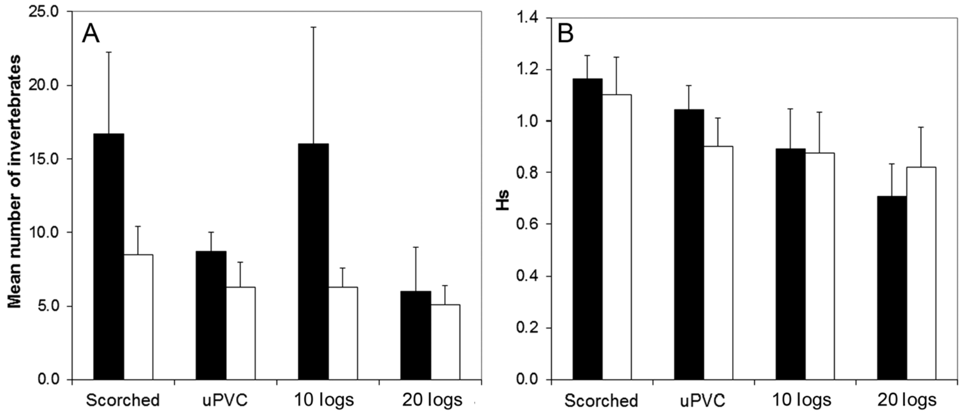

Figure 2. (**A**) The mean (±SE) number of invertebrates caught per trap in each woodstack type. (**B**) The mean (±SE) Shannon diversity index (Hs) of invertebrates per trap in each woodstack. Black bars, sticky trap; white bars, pitfall trap.

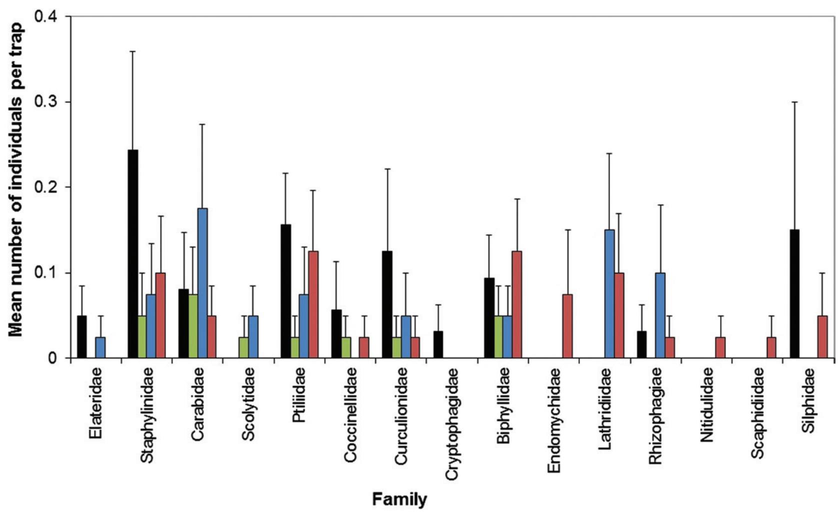

Figure 3. The mean (±SE) number of Coleoptera per family, per trap in each woodstack type. Black bars, scorched; green bars, uPVC; blue bars, 10 log; red bars, 20 logs.

Coleoptera abundance and diversity

A total of 127 adult Coleoptera were caught during the sampling period, totalling 15 families. Staphylinidae, Carabidae and Ptiliidae were the commonest families, whilst Crytophagidae, Nitidulidae and Scaphidiidae were rare (Fig. 3). A generalized linear model showed there was a significant effect of the trap type on the number of Carabidae caught, with pitfall traps being the most effective ($F_{1,148} = 6.068$, $P = 0.015$), whereas sticky traps were most effective for Latridiidae ($F_{1,148} = 36.531$, $P = 0.0001$).

A generalized linear model revealed a significant effect of the woodstack type on Coleopteran abundance ($F_{3,148} = 4.907$, $P = 0.003$), with the plastic woodstacks containing almost four times fewer Coleoptera than burnt woodstacks or the woodstacks made from 10 logs (Fig. 4A). There was no effect of the trap type ($F_{1,148} = 1.972$, $P = 0.162$) nor the interaction between the trap and the woodstack types ($F_{3,148} = 0.995$, $P = 0.39$) on Coleopteran abundance.

After transformation, a two-way ANOVA revealed the woodstack type ($F_{3,155} = 3.099$ $P = 0.029$), and the trap type ($F_{1,155} = 11.661$, $P = 0.001$) to significantly affect Coleopteran diversity, whilst the interaction between the trap type and the woodstack type did not affect Coleopteran diversity ($F_{3,155} = 2.511$, $P = 0.061$). Post hoc testing using a Tukey test revealed that Shannon diversity indicies for the large woodstacks was considerably larger than those of the plastic woodstacks ($P = 0.029$) and a *t*-test revealed significantly greater diversity in pitfall traps compared with sticky traps ($t = 3.192$ df $= 154$, $P = 0.002$) (Fig. 4B).

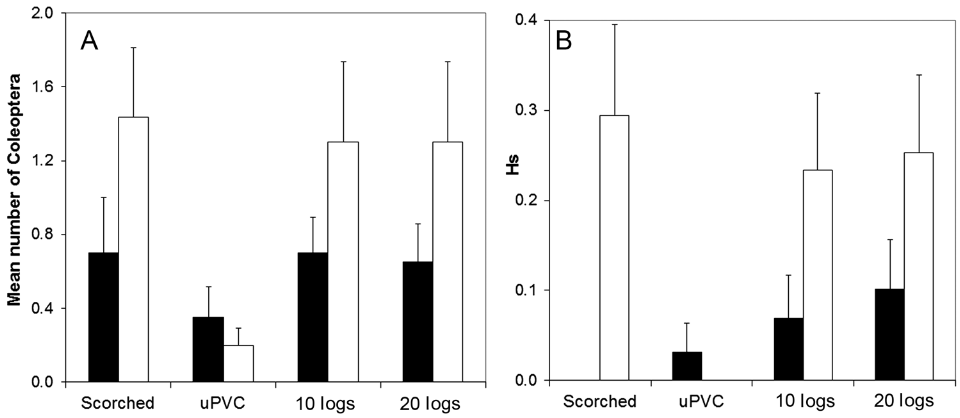

Figure 4. (**A**) The mean (±SE) number of Coleoptera caught per trap in each woodstack type. (**B**) The mean (±SE) Shannon diversity index (Hs) of Coleoptera per trap in each woodstack type. Black bars, sticky trap; white bars, pitfall trap.

Discussion

The total invertebrate abundance was unaffected by the woodstack type, although the abundance of certain taxonomic groups did differ between the woodstack types, with more Opiliones and fewer Coleoptera present on the plastic woodstacks and more Collembola sampled on the scorched woodstacks. Invertebrate biodiversity at the level of order was affected by the woodstack type, with the scorched woodstacks being associated with the greatest level of invertebrate diversity. When analysed at the level of family (Coleoptera only), the plastic woodstacks had the lowest biodiversity. The trap type also affected abundance and diversity; overall, sticky traps caught more invertebrates than the pitfall traps, although this was not the case when Coleoptera were considered separately.

Despite identifying Coleoptera to the taxonomic level of family, considerable ecological diversification within some families, such as Curculionidae is apparent (Oberprieler, Marvaldi and Anderson, 2007), such that it was not possible within the confines of this study to identify those species that are saproxylic. However, where specialist taxonomic knowledge is limited Biaggini *et al.* (2007) and Deeming, Bennett and Morrant (2010) have shown the identification of invertebrates to higher taxonomic levels to be sufficient to detect general trends in biodiversity.

There was no difference in the abundance or diversity of invertebrate orders between 10 log, scorched and uPVC woodstacks. This shows that plastic 'woodstacks' are valuable habitats in their own right, supporting a diverse range of orders, and that invertebrates will utilize structures for hunting or shelter regardless of the material used (e.g. Turner, Ebert and Given, 1969; Gulickx, Beecroft and Green, 2007). Therefore, recommendations for creating shelters for hibernating insects advocating the use of both natural and artificial materials, such as plastic straws (RSPB, 2011), are not unreasonable. Some hemipteran families are considered to be generalist predators (Dolling, 1991), as are Opiliones (Nentwig, 1986) and uPVC woodstacks supported the highest densities of Opiliones and the joint highest density of Hemiptera, possibly because hollow plastic pipes have a greater surface area compared with solid wood, allowing for greater movement. However, plastic pipes may support entire ecosystems. Bacterial biofilms may form on plastic pipes (Flemming, 1998) and bacteria can support higher trophic levels, such as invertebrates, in some ecosystems (Hall and Meyer, 1998). This does not necessarily mean that plastic pipes are a valuable alternative to woody material in conservation strategies, because the broad-scale estimates of diversity and abundance in this instance are unlikely to represent the value of this resource to saproxylic organisms. For example, Anulewicz *et al.* (2008) found the saproxylic emerald ash borer (*Agrilus planipennis*) to avoid plastic pipes in favour of ash (*Fraxinus*) logs.

The current study found Shannon diversity indicies to be lowest on the woodstacks made of 20 logs, which also had significantly fewer Collembola in comparison with 10-log woodstacks. This possibly bucks the general trend of increased invertebrate abundance and biodiversity with increasing levels of dead wood (Martikainen *et al.*, 2000). However, Collembola are known to exist in large densities under favorable conditions (Hopkin, 2007), thus one or two randomly distributed Collembola hot spots could have produced the variation seen in the present study. In addition, the finding may be an artefact of sampling effort to wood volume ratio; the larger woodstack represents a larger habitat space, yet sampling effort was equal across all treatments. Furthermore, the wood used in this study was relatively fresh, with little sign of visible decay. As decay progresses, invertebrate diversity increases (Jonsell, Weslien and Ehnström, 1998).

There was no difference in invertebrate abundance and diversity nor coleopteran abundance and diversity between the scorched woodstacks and the 10-log woodstacks. This result differs from that of Wikars (2002) who found that burned spruce logs supported fewer Coleoptera compared with unburned logs. However, Wikars (2002) surveyed over 2 years, showing a possible effect of succession not tested in the current study. Generally, bark beetles (Scolytidae) are rarer in burned trees (Ehnström, Langström and Hellqvist, 1995) and in the current study there was a complete absence of Scolytidae from scorched woodstacks. Bark beetles are considered keystone species in saproxylic communities (Weslien, 1992) and thus their presence is likely to affect community composition. However, scorched logs can attract certain Dipterans and Coleopterans that are not found on other types of logs (Wikars, 2002; Johansson, 2006), leading to unique assemblages (Johansson, 2006).

Characteristics of woodland that can affect saproxylic species such as shading or exposure (Johansson, 2006; Franc *et al.*, 2007) were not assessed in this study, although woodstacks were distributed evenly, such that variation in microclimate is unlikely to have been solely responsible for the statistically significant results reported in this study. The type of wood used (Paviour-Smith and Elbourn, 1993) and decay stage (e.g. Jonsell, Weslien and Ehnström, 1998) are also known to influence the assemblages and diversity of species in woody debris. Indeed, many saproxylic species are tree genus specific, for example, in Sweden, around 1/3 of saproxylic species sampled were unique to one tree genus (Jonsell, Weslien and Ehnström, 1998). Thus, the use of sycamore [introduced to Britain ca. 1250 (Southwood, 1961)] in the current study may present a restricted picture of the value of woodstacks to invertebrate biodiversity, and the use of native species such as oak may have resulted in a different set of conclusions. In addition, many saproxylic species are restricted to a small number of localized sites, notably ancient woodland (Nordén and Appelqvist, 2001), which means that dead wood in relatively new woodland may be colonized by more generalist invertebrates of lower conservation concern. However, given the paucity of data on the value of woodstacks to invertebrate conservation, and specifically saproxylic invertebrate conservation, studies comparing the value of woodstacks constructed from different species of tree and in different aged woodland are required to help inform conservation managers.

Conservation implications

The results of this study show that constructing woodstacks in broadleaved woodland is effective in providing habitats for many invertebrates. Despite the effort required to burn logs, this method appears not to generate greater improvements to biodiversity compared with other types of woodstack, most likely because forest fires in British broad-leaved deciduous woodland are rare (Peterken, 1993) or possibly because burnt wood *per se* does not provide the high heterogeneity caused by a forest fire (Wikars, 2002; Johansson, 2006). Thus, controlled burning may provide a more effective conservation strategy than the provision of burnt wood (Wikars, 2002).

The minimum amount of dead wood required in managed woodland is yet to be quantified (European Environemnt Agency, 2010b) and the volume of dead wood at the landscape scale appears to be more important than at the local scale for saproxylic organisms (Ranius, 2006). The supply of dead wood in natural woodland is somewhat stochastic (Jonsson, Kruys and Ranius, 2005), resulting in a dynamic process of extinction, dispersal and colonization of invertebrate populations (Ranius, 2006). Therefore, the connectivity of suitable habitat is an important factor in successful colonization (Schiegg, 2000). For example, plots of clumped dead wood (such as woodstacks) were found to support fewer species than plots with connected pieces of wood (Schiegg, 2000), although these relationships only existed on scales of >150 m. This suggests that the continual supply of dead wood (Siitonen, 2001), evenly distributed throughout the woodland is essential for the conservation of saproxylic invertebrates.

The amount and quality of dead wood present in woodland is a dynamic quantity, due to continued death and decay, but tends to accumulate over time (McComb and Lindenmayer, 1999). This means newly planted woodland contains small amounts of dead wood (Kirby and Drake, 1993). Some management recommendations suggest the mutilation of young trees (e.g. Speight, 1989) with chainsaws (Carey and Sanderson, 1981), inoculation with fungi (Silverborg, 1959) or even explosives (Bull, Partridge and Williams, 1981) to create dead wood habitats. However, the creation of woodstacks in newly planted woodland is an easier and cheaper option, which is likely to be a more favourable option to land owners.

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Author biography

Richard Sands studied BSc Conservation Biology at the University of Lincoln. He graduated with a First Class Honours Degree in 2011 and was awarded the Oxford University Press achievement in Biosciences. Richard is particularly interested in the ecology and applied conservation of arthropods. Richard is currently researching for an MPhil degree at the University of Manchester. Ultimately, Richard would like to complete a PhD and pursue an academic career.

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