Understanding of our knowledge gaps, which include a detailed study conducted during the spring of 2014. It highlights some of the factors influencing the Bourne Gutter valley.

The geological factors influencing the Bourne flow thus also require further investigation. There is an intriguing landform at the head of the Bourne Gutter near Banks Rise as the valley axis switches from a NE/SW orientation to a NW/SE direction, leading into Hockeridge Bottom. There was no evidence in 2014 of stream flow from the Hockeridge Bottom Rise (SP983055), which is now under arable cultivation, as opposed to the pasture downstream of Banks Rise (SP989051). It is possible that local water extraction has been responsible for the failure of the Hockeridge Bottom Rise. There are no records of springs or flow in the valley to the SW of downstream of Banks Rise (SP989051). It is possible that local water extraction has been responsible for the failure of the Hockeridge Bottom Rise. There are no records of springs or flow in the valley to the SW of Banks Rise, which is a classic asymmetrical Chiltern dry valley, with a steeper north-facing slope and more gentle south-facing slope.

The aim of this article has been to provide an observational snapshot of flow in the Bourne Gutter during the spring of 2014. It highlights some of our knowledge gaps, which include a detailed understanding of the geology and its impact on the hydrology. Superimposed on this is the status of the aquifer prior to periods of heavy rainfall, when the heavy rainfall occurs, and the impact of abstraction. I anticipate the hydrology of the Bourne Gutter valley will receive a lot more attention if, as widely predicted, we experience a wetter climate in future but greater demand on our finite water resources.

Acknowledgments

I wish to thank in particular the support and assistance provided by John Catt both in the field and commenting on this script. I also thank Tony Scott, ECN Site Manager at Rothamsted Research, for providing the rainfall data, and the Geography Department at UCL for the loan of the stream flow meter.

References


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A soil quality comparison from agriculture to afforestation in Heartwood Forest

Ashley Lydiat and Chantal V. Helm

Introduction

The benefits of afforestation as mitigation for climate change and the promotion of biologically diverse wildlife communities are becoming increasingly recognised as having global importance (Berthrong et al., 2009; Malhi et al., 2002; Woodland Trust, 2011; Zanchi et al., 2007). As human urban populations and their demands on land and resources continue to grow, finding land suitable for afforestation is likely to become more difficult. Jorgensen and Fath (1998) noted that, despite an overall global rise in agricultural land (Benayas et al., 2007), between 1961 and 2002, the UK had the tenth highest continuous abandonment of agricultural land in the world. If this trend were to continue, it would leave a large amount of open land that may be useful for the implementation of afforestation projects. Inherently, however, agricultural methods have numerous, often negative impacts on soil quality (Kibblewhite et al., 2008). As a consequence, the resultant reduction in soil quality, or the soil(s)’ capacity to function (Karlen et al., 1997), could be seen as a potential driver for the rises seen in agricultural abandonment. It may be therefore that agricultural land abandoned for these reasons may not be suitable for afforestation (Flinn & Marks, 2007).

On completion, the Woodland Trust’s Heartwood Forest project in Hertfordshire will be the largest new deciduous woodland in England. Some areas have only ceased use as agricultural land in the last couple of years. When fully mature, Heartwood Forest would be classified as a temperate deciduous forest, a habitat with vastly different soil quality requirements from the agricultural communities that were sustained on the land prior to the project’s commencement. Care should be taken to ensure that the soil attributes at Heartwood Forest reflect those found within other established forests of this type within England (Schoenholtz et al., 2008). Soil quality is a well-researched area of study and an abundance of information can be found on both woodland and agricultural soils. However, there is limited knowledge on how, what and when soil quality changes occur with a transition from agricultural land to woodland over time. As there is a high likelihood of further afforestation projects occurring on abandoned agricultural land in the UK in the future, it is crucial to achieve a robust understanding of what management techniques may need to be employed to ensure healthy woodland growth and on around altered and improved soils, if any.

This study provides analysis of parameters indicative of soil quality: pH (acidity/alkalinity), electrical conductivity (EC), soil organic matter (SOM) as well as earthworm surveys. The combination of these factors will help build an understanding of the soils found in three different habitats in Heartwood Forest, an area of unplanted agricultural land, recently planted woodland and ancient semi-natural woodland (ASNW). Comparisons will be drawn between these habitats to assess how soil quality has changed over time from being arable agricultural land, to how it may be when the woodland is fully established, whilst also providing a starting point for any continued monitoring of the site.

Site description

Heartwood Forest is a 347 ha area of ex-agricultural land, formerly known as Hill End Farm, purchased by the Woodland Trust in 2008; situated north of St Albans near Sandridge, within the Green Belt. The aim of the Heartwood Forest project is to create England’s largest new deciduous woodland, with 600,000 trees planted over a ten year period, which, once mature, will provide connections between the areas of existing woodland (ASNW), found on the site and the nearby Nounsman Common to the north-east of the site (Figure 2). The predominant tree species planted include Quercus robur (Pedunculate Oak), Fraxinus excelsior (Ash) and Carpinus betula (Hornbeam), with Acer campestre (Field Maple) and Betula pendula (Silver Birch) also featuring. Woody shrub species planted include Corylus avellana (Hazel), Illex aquifolium (Holly), Crataegus monogynia (Common Hawthorn) and Viburnum opulus (Gauler Rose) (Woodland Trust, 2012; Smith, 2012).

The previous agricultural aspect of the land displays field patterns suggesting a 300+ year history as grade 3 arable, with likely crops being cereals, oilseed rape, and...
beans and grass leys. The soils would have mostly been disturbed through ploughing and cultivation, with recent modifications by herbicide and pesticide use (Woodland Trust, 2009). Communications with the previous farm manager and subsequent desk study of the provided input/output data (1995-2012) from fields used as study sites showed extensive use of chemical additives to the soils whilst in production, including ammonium sulphate (21% N: 60% SO4) based fertilisers and a wide array of herbicides, fungicides, insecticides and molluscicides. Typical N input ranged from 180-220 kg/ha, with SO4 input ranging from 34.5-75 kg/ha depending on the field (K. Pearcy, 2013, pers. comm.: farm manager 1961-2012). The post-agricultural soils found on the Heartwood Forest site therefore provide a good comparable representation of the majority of agricultural soils across the UK.

In order to test soil quality changes between unplanted agricultural land and newly planted woodland over time, sample sites were selected that reflected habitats at progressive stages of afforestation (Figure 1). These were an unplanted area (U) that had been abandoned from agriculture in 2012 and left fallow but had not yet been planted with any trees (Plate 1) and a planted field (P) that had been planted with rooted whips (immature tree formed of a stem and small root system) two to three years before the samples were collected (Plate 2). Further samples were collected from a section of existing woodland (W) in order to compare what was found in habitats U and P to the possible eventual climax habitat of the site (Plate 3). In each habitat, five sample sites were used: the minimum amount per hectare as suggested by McRae (1988) (Figures 2, 3 & 4 and Table 1, GPS coordinates). It was necessary to select sample sites based on comparability with each other as well as ensuring that in each habitat only sample sites within the same geological profile (h5**: Upper Chalk) were selected (Figure 5).

**Sampling strategy and analysis**

From each sample site, five sub-samples were selected from a 20 x 20 m grid using a random number generator. Soil from the A-horizon was extracted using an auger to an amount of approximately 500 g soil (wet weight) as suggested by ICP-Forests (2010). The five sub-samples were mixed to form an homogenised composite sample. This was repeated for the five selected sample sites and for each habitat so that a total of 15 samples was collected. The samples were

### Table 1. Coordinates of the sample points, unplanted U, planted P and Woodland W.

<table>
<thead>
<tr>
<th>Unplanted</th>
<th>Planted</th>
<th>Woodland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample ID</td>
<td>Coordinates</td>
<td>Sample ID</td>
</tr>
<tr>
<td>U1</td>
<td>TL17213 11401</td>
<td>P1</td>
</tr>
<tr>
<td>U2</td>
<td>TL17273 11446</td>
<td>P2</td>
</tr>
<tr>
<td>U3</td>
<td>TL17375 11534</td>
<td>P3</td>
</tr>
<tr>
<td>U4</td>
<td>TL17317 11581</td>
<td>P4</td>
</tr>
<tr>
<td>U5</td>
<td>TL17289 11652</td>
<td>P5</td>
</tr>
</tbody>
</table>

**Figure 1.** Site map showing planting phases and dates for each section. Pale green areas are ancient woodlands – Pudler’s Wood, Well Wood, Pasmine Spring and Langley Wood, as well as the nearby Nomansland Common, with which Heartwood Forest will connect once fully developed (Source: Woodland Trust & Ordnance Survey).
tested for pH, and levels of electrical conductivity and soil organic matter, measured using the loss on ignition method.

**Earthworm survey strategy**

The earthworm survey was conducted during early spring (16 February–2 March, 2014), as time constraints meant that the temperature dropped below a suitable level for the earthworms to be active enough to survey at a similar time to the soil sampling. It was completed over two weeks under weather conditions and temperatures comparable to the times for the soil sampling. Using the same sample sites as those used for the soil sample extraction, the GPS coordinates were used to locate the central point of the 20 × 20 m quadrat. The procedure used for the survey followed those outlined in the OPAL soil and earthworm survey guide (OPAL, 2014). The soils in habitat W showed the most acidic mean pH value (Figure 6). An analysis of variance (ANOVA) displayed a significant difference between the habitats (F_{2,12} = 29.784, p < 0.001). Tukey’s HSD Post-hoc Test showed a significant difference between habitats P – W and U – W. (Tukey’s HSD, p < 0.05).

**Results**

**pH**

The soils in habitat W showed the most acidic mean pH value (Figure 6). An analysis of variance (ANOVA) displayed a significant difference between the habitats (F_{2,12} = 29.784, p < 0.001). Tukey’s HSD Post-hoc Test showed a significant difference between habitats P – W and U – W. (Tukey’s HSD, p < 0.05).

**Electrical conductivity**

The lowest mean EC level was observed in habitat U and habitat W the highest (Figure 7). An ANOVA calculated no significant difference between any of the three habitats (F_{2,12} = 0.774, p = 0.483). The data set with the biggest range between minimum and maximum values was that of habitat W.

**Soil organic matter**

The highest organic matter levels were measured in habitat W (Figure 8). An ANOVA test calculated a significant difference between the habitats (F_{2,12} = 9.817, p < 0.003). Tukey’s HSD Post-hoc test showed that there was a significant difference between habitats U – W (p < 0.05). No significant difference was found in comparisons between the other habitats.

**Discussion**

Perhaps unsurprisingly, habitat U displayed very little in the way of ground flora or grasses present at the time of study (Plate 1), especially in comparison with habitat P, which showed an observable abundance of the time of the surveys. The highest total abundance of earthworms was found in habitat P, with 91 immature and 10 adult earthworms found over five surveys. The highest abundance of adult earthworms, however, was found in habitat U, where 28 adults were found, with only 21 immature. No earthworms of either immature or adult stage were found in habitat W (Table 2).

**Table 2. Adult and immature earthworm abundance observed in the three habitats. Habitat U and P showed significant differences in earthworm frequency compared with habitat W for both immature and adult earthworms, (Kruskal-Wallis, p < 0.05).**

<table>
<thead>
<tr>
<th>Earthworm species</th>
<th>Overall abundance (per 0.02 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Woodland (W) Planted (P) Unplanted (U)</td>
</tr>
<tr>
<td>Aporrectodea caliginosa</td>
<td>0 7 8</td>
</tr>
<tr>
<td>Allolobophora chlorotica</td>
<td>0 2 10</td>
</tr>
<tr>
<td>Allolobophora chlorotica (green form)</td>
<td>0 0 1</td>
</tr>
<tr>
<td>Eisenia fetida</td>
<td>0 1 0</td>
</tr>
<tr>
<td>Lumbricus terrestris</td>
<td>0 0 2</td>
</tr>
<tr>
<td>Octolasion cyanenum</td>
<td>0 0 4</td>
</tr>
<tr>
<td>Aporrectodea rosea</td>
<td>0 0 3</td>
</tr>
<tr>
<td>Total immatures</td>
<td>0 91 21</td>
</tr>
<tr>
<td>Total adults</td>
<td>0 10 28</td>
</tr>
<tr>
<td>Total worms</td>
<td>0 101 49</td>
</tr>
<tr>
<td>Total species</td>
<td>0 3 6</td>
</tr>
</tbody>
</table>

**Figure 5. Underlying geology of the Heartwood forest site with site boundary shown in red (Source: adapted from Ordnance Survey, 1978).**

**Figure 6. Mean pH levels of the three habitats, with error bars showing standard deviation. Significant differences were found between habitats P – W and U – W. (Tukey’s HSD, p < 0.05).**

**Figure 7. Mean electrical conductivity (EC) levels of the three habitats. Error bars show standard deviation.**

**Figure 8. Mean percentage levels of soil organic matter (SOM) found in each habitat with error bars showing standard deviation. Significant differences were found between habitats U and W (Tukey’s HSD, p < 0.05).**

Of the two dozen species of earthworm found in Britain, seven were identified at Heartwood Forest at the time of the surveys. Of the two dozen species of earthworm found in Britain, seven were identified at Heartwood Forest at the time of the surveys. Of the two dozen species of earthworm found in Britain, seven were identified at Heartwood Forest at the time of the surveys. Of the two dozen species of earthworm found in Britain, seven were identified at Heartwood Forest at the time of the surveys.
grasses and other forbs (herbaceous plants) (Plate 2). Dead plant matter was noted to be present, which was likely to be of agricultural origin, since the field was in production at least until 2012. Communications with the previous owner of the site (Red Farm) revealed that, for the production year 2011/12, the crop grown on this habitat site was Solstice wheat. He had no involvement in the management of the field used for this habitat study by this time, however, and so could not say for certain, but assumed that 220 kg N/ha were applied to the field along with 62.5 kg 21% N. 60% SO4/ha (ammonium sulphate based fertiliser product) and a similar pesticide application strategy to the rest of the site (K. Pearcy, 2013, pers. comm.). Agricultural input and output data were not known for the following year.

Electrical conductivity (EC)

Electrical conductivity gives an understanding of the nutrient transport and availability of a soil by measuring the amount of soluble salts, whereas the higher the electricity reading the lower the concentration of salts. It is generally understood to be the most important water quality parameter with regard to irrigation, as it can affect the pH balance of the soil, the ability of plants to absorb water and nutrients, whilst high alkalinity (associated with high salt content) can cause organic matter dispersal and therefore has a direct effect on the texture and overall quality of the soil. Tolerance levels to soil salinity vary greatly between plant species and tolerance tends to increase with maturity. Whilst small amounts of soluble salts are important to the health of a soil and nutrient uptake of plants, in situations of poor drainage and at this concentration the concentrations can accumulate to toxic levels, with concentrations above 4-8 dS/m (400,000-800,000 µS/cm) proving too high for many plants and 0-2 dS/m (0-200,000 µS/cm) being favourable for most plants. Soils with higher clay content have an increased ability to retain water and therefore are more susceptible to detrimental concentrations of salts (Gerard, 2000; Keren, 2000; Miller & Gardiner, 1998).

All three habitats on the Heartwood Forest site yielded EC levels below the thresholds known to be unfavourable for healthy plant growth and within the low range found by McRae, K. (2006) and had similar mean EC levels found in habitat W (73.4 µS/cm). This could be attributed to the slightly higher clay content of the soils found here. The underlying calcareous geology in this respect does not seem to have had a noticeable effect on the overall alkalinity and EC of the habitats. As all EC levels are well below what would be considered unfavourable to plant growth and the maturity of the woodland (400+ years old) it is unlikely this would pose any direct problem to the woodland or to the newly planted areas as they develop. Further, with the gradual increase in EC seen from the agricultural soils to be expected on the old woodland in only a few years, it is possible that the EC of habitats U and P will achieve a similar level to that of habitat W within only a few more years of growth. It may be that levels end up surpassing those found in habitat W. However, this would need to be confirmed with further monitoring.

Soil organic matter (SOM)

Levels of organic matter play a role in virtually all soil functions. It is the main store of carbon (the main constituent element of all flora and fauna around 45%) and therefore has a direct effect on the texture and overall quality of the soil. In terms of pH, the accumulation of organic matter will lead to higher levels of acidity (Bloom, 2000), increased nutrient content (such as N, P and K) and cycling (Binkley & Fisher, 2013 Kibbleswhite et al., 2008; McLauchlan et al., 2006). It can indicate lower concentrations of soluble salts (Gerard, 2000) and greater abundances of earthworms (Kibbleswhite et al., 2008; Sims & Gerard, 1999). Evidently, therefore the organic matter content of a soil is a critical indicator of its overall health. Boatman et al. (2007) note that inorganic fertilisers typically used on agricultural soils reduce the amount of organic matter present. Furthermore, when harvested from arable agricultural land inherently removes a large amount of organic material that in non-agricultural habitats would usually be left to decompose back in to the soil, continuing the nutrient cycle. For this reason, woodland soils, especially ASNW, have a high SOM content (Forestry Commission, 2011). It was expected, therefore, that habitats U and P would yield the lowest SOM values (U showing the lowest), with habitat W having the highest observable SOM content. This was borne out with the results; with habitat U showing the lowest mean SOM (5.67), habitat P showing the highest (7.12) and habitat W showing the most (8.96). The only significant difference found was between habitats U and W, which gives an indication of the short amount of time it takes to replenish SOM content. This result is supported by McLauchlan et al. (2006) findings, which suggest that in habitats converted from agriculture to grassland, SOM and associated nutrients, mainly carbon, build up in decadal timescales, reaching a maximum within 55-75 years. Considering habitat P had been planted a mere two years prior to testing and was already showing SOM levels that were statistically insignificantly different from habitat W, it can be expected, assuming habitat P had a SOM content similar to habitat U before planting, that either this rate of increase will begin to slow until it is at a more comparable level to habitat W or that it will surpass levels found in habitat W. If only temporarily, until an equilibrium is reached. This can only be known if further habitat samples are taken on the site. The SOM of the samples for this research was determined using the ‘loss on ignition’ method, which involves burning off the carbon content of the soil sample at high temperatures and measuring the weight difference before and after ignition. It is noted by McRae (1988), however, that this method can produce erroneous results. This is due to weight being lost from the conversion of free CaCO3 in the soil to CaO. This can be corrected for if the amount of CaCO3 is known prior to testing. Further losses in weight can be due to dehydration of amorphous oxides of iron and aluminium (McRae, 1988). Due to the calcareous underlying geology and clay content of the samples sites used, future monitoring of the site should take this factor into account when determining SOM levels and a more robust method of analysis would be preferable.

Earthworms

Earthworms are frequently considered to be some of the most important of all soil fauna due to the amount of essential physical and chemical processes to which they actively contribute. Binkley and Fisher (2013) suggest the optimum soil pH for most earthworms to be between pH 6.8-7.3. However, earthworms originating from arable agricultural land inherently removes a large amount of organic material that in non-agricultural habitats would usually be left to decompose back in to the soil, continuing the nutrient cycle. For this reason, woodland soils, especially ASNW, have a high SOM content (Forestry Commission, 2011). It was expected, therefore, that habitats U and P would yield the lowest SOM values (U showing the lowest), with habitat W having the highest observable SOM content. This was borne out with the results; with habitat U showing the lowest mean SOM (5.67), habitat P showing the highest (7.12) and habitat W showing the most (8.96). The only significant difference found was between habitats U and W, which gives an indication of the short amount of time it takes to replenish SOM content. This result is supported by McLauchlan et al. (2006) findings, which suggest that in habitats converted from agriculture to grassland, SOM and associated nutrients, mainly carbon, build up in decadal timescales, reaching a maximum within 55-75 years. Considering habitat P had been planted a mere two years prior to testing and was already showing SOM levels that were statistically insignificantly different from habitat W, it can be expected, assuming habitat P had a SOM content similar to habitat U before planting, that either this rate of increase will begin to slow until it is at a more comparable level to habitat W or that it will surpass levels found in habitat W. If only temporarily, until an equilibrium is reached. This can only be known if further habitat samples are taken on the site. The SOM of the samples for this research was determined using the ‘loss on ignition’ method, which involves burning off the carbon content of the soil sample at high temperatures and measuring the weight difference before and after ignition. It is noted by McRae (1988), however, that this method can produce
In the current study, the abundance of earthworms was found to be higher in habitat $P$ than in habitat $U$, displayed a higher abundance of adults. Some species of earthworms can live as long as 120 years in favourable conditions, with A. chlorotica reaching maturity after 17-19 weeks (Sims & Gerard, 1999). This suggests that, although at the time of sampling habitat $P$ contained more identifiable adult specimens than habitat $U$, within a few months it is likely that habitat $P$ will overtake $U$, to yield a more robust assemblage of mature earthworms. Again, this would need to be assessed with further surveys. The previous study of earthworm assemblages in Heartwood Forest by Shah (2012) found Lumbricus terrestris to be the most abundant on site. The difference could be attributable to the time of year the study was conducted, Shah’s in autumn, this study’s in early spring. It may also be due to changes in soil quality since 2012. Further monitoring of the site may provide some more clarity on the discrepancies found between the two studies.

**Conclusion**

This study has provided a baseline assessment of a number of soil quality variables across three different habitats found at Heartwood Forest. The three habitats used in the study were selected to provide a basic understanding of how the land was prior to the study (unplanted post-agricultural land – habitat $U$), how the majority of the site is currently (recently planted woodland – habitat $P$) and the possible eventual climax habitat of the site (ASNW – habitat $W$). Prior to sample collection and analysis and earthworm surveys, desk study and personal communications with the previous land manager provided contextual knowledge on past land management practices on the site. This showed extensive agro-chemical and fertilizer applications typical of an arable farm of this type in the UK for at least the last 10 years.

Analyses of soil samples showed that, overall, soil quality appears to be developing and improving from post-agricultural land to woodland, with EC levels seen to show a closer relation between recently planted woodland and ASNW. Currently, however, the recently planted soils were still quite different from the ASNW soils. Soil pH was found to be marginally higher in habitat $P$ than $U$, but still significantly different from $W$. Whether this is a successional response to increased grass cover, higher abundance of earthworms, anomalous outliers in samples collected, or possibly several other factors cannot be said for certain without further monitoring. Earthworm abundance was higher in habitat $P$, showing that soil conditions for this habitat are presently more favourable than the unplanted ex-agricultural habitat. A possible link can be seen here with the higher levels of SOC, a factor likely to increase as the woodland develops over time.

**Acknowledgements**

We would like to thank The Woodland Trust and site manager Louise Neicho for permission to carry out the study at Heartwood and the HNHS WT Heartwood Monitoring Group for encouragement. All the photographs were taken by Ashley Lydiate.

**References**


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