Soil disturbance resulting from stump harvesting

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Soil Physical Disturbance resulting from Stump Harvesting

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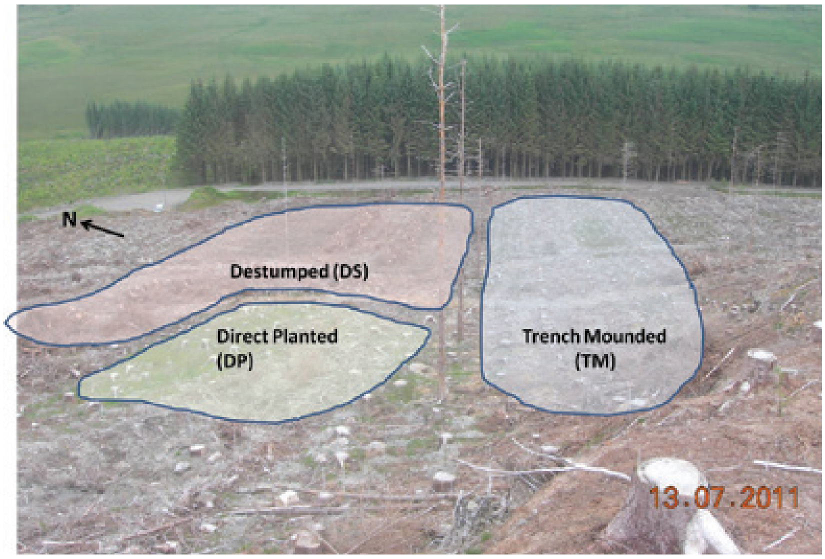


The site.

Summary

This paper describes a detailed study of stump harvesting in Lamloch Forest in north Dumfries and Galloway from 2010 to 2014. The study explored both the nature and extent of soil disturbance resulting from stump harvesting using a variety of standard and innovative techniques. Stump harvesting disturbance was compared with that of other forestry practices.

To complement the two-dimensional and subjective nature of visual assessment techniques, a radiometric approach was adopted, utilising residual Chernobyl ^{137}Cs fallout to determine the degree of soil mixing. To support bulk density measurements, micromorphological analyses of soil thin sections were carried out to investigate the impact of compressive force on pore space. Low-cost tracer devices were deployed in the soil around stumps prior to extraction to permit the monitoring of soil lateral movement during stump extraction.

The study showed that stump harvesting followed by restock, when carried out under current guidelines, disturbed around five times the volume of soil compared to that disturbed by trench mounding. Stump harvesting also resulted in a net reduction in soil bulk density. Suggestions for modification of stump harvesting operations are made to reduce soil disturbance, including avoiding raking over the site following stump harvesting which is estimated to add a further 10% to the volume of soil disturbed.

Introduction

The harvesting of tree stumps and major roots for use as bioenergy feedstocks has taken place in various parts of the world over the last few decades. Interest in this commercial opportunity in the UK began in the 2000s and experimental and operational scale trials took place, mainly in Scotland, to explore the technology and its logistics (*e.g.* Saunders, 2008). In parallel, reviews of the possible environmental consequences of stump harvesting were commissioned (e.g. Walmsley and Godbold, 2010). These pointed to the likely increased effect on soil disturbance that stump harvesting could cause. They also identified the need for further 'field scale research…. to ensure that the desire to source local biomass is fully compatible with other efforts to maintain the functioning of forests ecosystems and the vital services that they provide us' (Walmsley and Godbold, 2010, p. 33).

The assessment of soil physical disturbance resulting from stump harvesting is the focus of this study. To address this question, an intensive integrated research campaign was carried out at an operational harvesting site in Scotland, which also allowed comparison of disturbance levels with other forestry operations (trench mounding and direct planting). The importance of evaluating the impact of stump harvesting on other aspects of the forest environment, for example carbon and nutrient dynamics, is readily acknowledged here. However, resources were inevitably limited and it was considered that an important first step in understanding overall impact was to establish the nature of soil disturbance itself. This has been little studied to date.

In the context of this study, a stump is defined as both the above-ground stump remaining after stem harvest, and the below-ground extractable root mass. For conifers, and using modern extraction technologies, these typically constitute around 25% of the biomass of the tree (Eriksson and Gustavsson, 2008). Extracting this resource from the soil requires considerable force and invariably involves some degree of soil disturbance (Moffat *et al.*, 2011), the latter defined by the UK Forestry Commission's Forests and Soil Guidelines (2011) as "any activity that mixes and moves soil material".

Materials and methods

Site and operational description

The experimental work was carried out at Lamloch Forest in north Dumfries and Galloway, (National Grid coordinates NX 51480 97920), within a privately owned plantation managed by Tilhill Forestry. The site had been ploughed and planted with Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in the mid-1970s, and was being actively harvested during the study. The research site is located in Compartment 51 on the east-northeast slope of Cullendoch Hill in an area of 0.71 hectares. Elevation rises from 250 to 280 m O.D. The average gradient across the site is 13.3°, with shallower gradients of around 8° in lower areas, rising to almost 20° in the upper reaches. The latter is just within the current UK guidelines for the permitted gradient for stump harvesting (Forestry Commission, 2009).The soil was categorised as predominantly an upland brown earth (Paterson and Mason, 1999; Kennedy, 2002), with a sandy silt loam texture and pH of 3.5.

Following stem harvesting three different treatment areas were established: 1) trench mounding, 2) stump harvesting, and 3) direct planting. Table 1 summarises the schedule of operational activity on site. Trench mounding (Forestry Commission, 2002) involved the excavation of spoil trenches down a line of uprooted stumps, and planting mounds were created using material excavated from the trenches (Morgan and Ireland, 2004). This was carried out in accordance with the contemporary UK guidelines (Forestry Commission, 2009). For stump harvesting, a Cat 21B excavator fitted with a Pallari KHN-60 destumping head was used (Figure 1). The jaws penetrate beneath the stump while gripping it with the shear "thumb". Vertical force is applied to lift the stump and roots from the ground, followed by shaking to release adhering soil. Larger stumps are split into a number of fragments by closing the thumb onto the jaws. The fragments are stacked by the excavator into adjacent stump windrows prior to transfer to the roadside by forwarder. The destumped area was then direct planted.

Figure 1. Destumping shear head.

An additional area was also direct planted without it having been stump harvested or mounded.

Figure 2 shows the operational sequence for destumping in schematic form, with the excavator initially advancing upslope. The stump and its fragments are vigorously shaken to dislodge adhering soil before being transferred to the stump windrow. The excavator advanced uphill, and subsequently reversed back along the same track lines, raking over the soil behind it in the process. Stump windrows were formed along either side of an existing extraction rack, following industry guidance (Forestry Commission, 2009).

Dates	Activities
July 2010 – Feb 2011	Stem harvesting and timber removal
April – May 2011	Ground preparation and drain construction
June 2011	Stump harvesting (research site only)
July 2011	Replanting completed

Table 1. Operational schedule for Compartment 51 forestry operations.

With stump harvesting carried out and restocking of the entire site completed in August 2011, the next phase, during autumn 2011, was to measure by various means the resultant disturbance in each of the three treatment zones.

Research methodology

Disturbance levels were measured in four ways: (a) visual ground disturbance survey, (b) soil bulk density measurement (supplemented by soil thin section analyses), (c) radiometric determination of the degree of soil mixing, and (d) soil movement tracking. Taken together, the outcomes from the methods provided a comprehensive comparison of the level of soil disturbance following stump harvesting, compared with other forestry operations, for the upland brown earth soil type studied.

(a) Visual Ground Disturbance Survey

Ground disturbance surveys sample the selected area at defined intervals, and allocate one of four disturbance classes (Table 2) to each sample point based mainly on the categorisation system of Bockheim *et al.* (1975), with subsidiary disturbance states allocated to brash-covered and stump-occupied sampling points. Such surveys were carried out both before and after the application of differential treatments, denoted as "Harvested" and "Restocked" surveys respectively. Transect sampling lines following McMahon's (1995) guidance were set up spanning the three treatment zones (Figure 3), these being Destumped (DS), Trench Mounded (TM), and Direct Planted (DP). Sampling points were set approximately one metre apart, in locations that equated to the pre-existing ridge and furrow apexes. A Chi-Square test was applied to test for significant differences between the Harvested and Restocked surveys.

(b) Soil Compaction

A total of 71 soil samples to determine bulk density were taken at various depths through the profile (max depth 50 cm) from soil inspection trenches located in each of the treatment zones. This permitted a comparison between treatment zones of soil compaction/ decompaction levels. Samples were extracted using steel coring rings (5 cm internal diameter by 5.1 cm height), following the method of Smith and Thomasson (1974). Differences in soil bulk density between TM and DS treatments were tested statistically using the t test.

Additional sampling using 20 metal cuboid 'Kubiena' tins of 7.5 x 5.5 x 4 cm size was carried out for subsequent

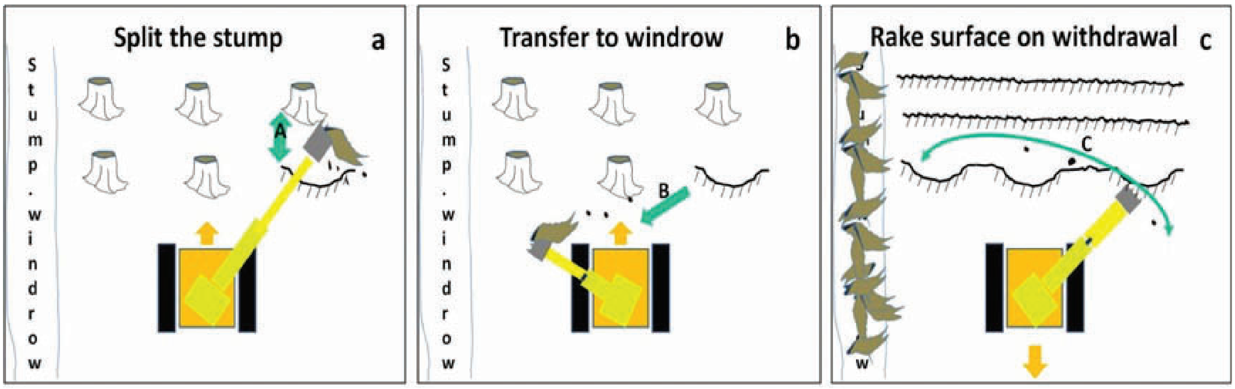


Figure 2. Destumping operational processes: splitting, transferring, raking.

preparation as soil thin sections, permitting micromorphological analysis of relative pore space and complementing the soil bulk density measurements. Sixteen samples were taken from soil inspection trench profiles in the DS, TM and DP treatment zones, additional samples were taken from the exposed face of a drain (Drain), the fill of a stump extraction hole that hadn't been raked over (Stump) and a pair of samples from the track of a stump excavator (TrkA) and immediately adjacent to it (TrkB).

Relative pore space was determined from thin sections using image analysis of composite images taken under plane polarised and cross polarised light. This allowed colour thresholding of the images to isolate the resin filled void space (Xu *et al*., 1994). Differences in percentage pore space between TM and DS and between Disturbed and Undisturbed samples were tested statistically using t tests.

(c) Soil Mixing

In-situ radiometric measurement was employed to provide an objective indication of soil mixing depth. The experimental site had been subjected to measureable levels of atmospheric radionuclide deposition, particularly following the Chernobyl incident in 1986 (Clark and Smith, 1988). Radionuclide ground deposition in a forested environment tends to be preferentially adsorbed onto surface litter debris (Milton *et al*., 2001; Kaste *et al*., 2007), with relatively little subsequent vertical migration in the acidic soil (Riesen *et al*., 1999; Milton *et al*., 2001). When undisturbed since deposition, as initially at the experimental site, such deposits can therefore be used as a marker of pre-existing surface material. Post-disturbance, when surface material may have become buried through mixing effects, a ground based detector may be used to measure the energy level of photons released from radionuclides bonded to this buried material. With detected photon energy levels being broadly inversely proportional to the quantity of intervening mass through which they have travelled since release, analysis of this energy spectrum can yield an indicator, known as Qcs, that varies inversely with the burial depth of the formerly surface material, and hence the depth of soil mixing following a particular disturbance (Tyler, 2004). The study utilised *in-situ*

Code	Ordinal value	Title	Description
DC0	0	undisturbed	Litter horizon undisturbed
DC1	1	forest floor disturbance	Disturbance of the forest floor, but no exposure of underlying mineral soil
DC2	2	shallow soil disturbance	a) forest floor removed and mineral soil exposed
			b) less than 5 cm mineral soil deposited on forest floor
DC3	3	deep soil disturbance	a) mixing of mineral soil evident
			b) more than 5 cm of mineral soil deposited on forest floor

Table 2. Criteria for classifying soil disturbance (modified from Bockheim et al., 1975).

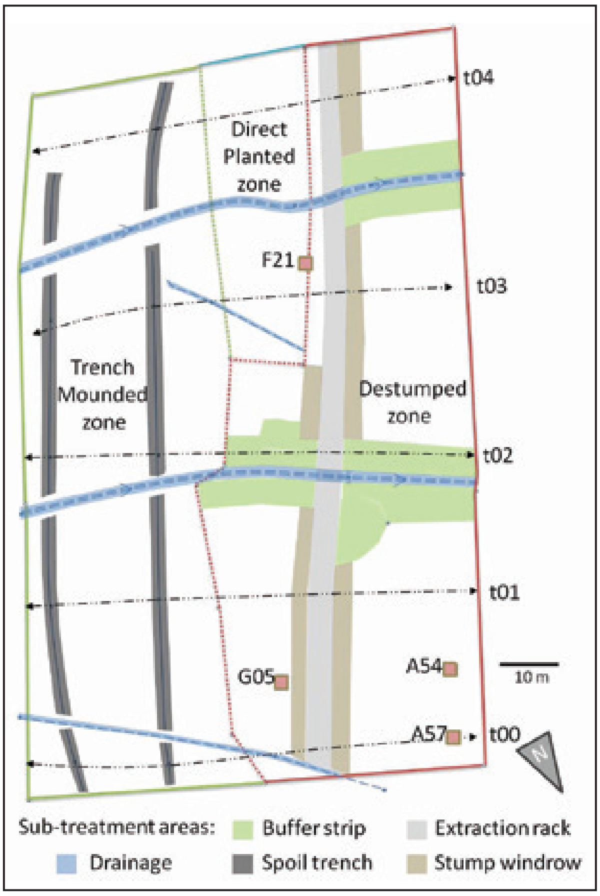


Figure 3. Research site layout following stump harvesting. The boundaries of the three treatment zones are indicated, along with the location of sub-treatment areas.

gamma-ray spectrometry to measure relative degrees of soil disturbance. *In-situ* radiometric readings were taken at each survey point, both before (Harvested survey) and after destumping (Restocked survey). Qcs values were calibrated using laboratory measurements of radionuclides in soil cores collected from the site. ANOVA and Tukey HSD were used to test for significant (95%) differences in Qcs values between disturbance classes (visual ground disturbance survey) and treatments (TM, DS and DP).

The application of this non-intrusive ^{137}Cs *in-situ* method to an operational forestry environment to determine soil mixing is believed to be without recorded precedent.

(d) Soil movement

Soil movement tracking was employed both to provide an indication of the lateral movement of soil disturbed by the extraction of a stump, and, by establishing the locus of non-displaced soil in the vicinity of an extracted stump, to determine the volume of soil that had been disturbed by the extraction. This was achieved by designing and manufacturing Soil Movement Tracking Devices (SMTD), each with a height of 25 mm and diameter of 18 mm (Figure 4). Each SMTD was individually identifiable, being of a broadly similar density to the soil at the site and embodying a gel coating which could coalesce with adjacent soil to improve co-movement, and having a metal core to facilitate post-disturbance detection.

Seventy-five SMTDs were placed using a relatively non-intrusive placement method around each of four selected stumps arranged in a five by five horizontal array with placement at three depths at each assay point. Following stump extraction, the location of both moving and non-moving SMTD placements were analysed to determine the two factors of interest noted above.

Results

(a) Visual Ground Disturbance Survey

Table 3 shows the spectrum of observed disturbance in each treatment zone, both before and after the treatments had been applied. Prior to the application of treatments, the level of disturbance in each zone was not significantly different to that in any other. Following treatments, a significant overall difference (increase) in the level of disturbance was detected. In the Restocked survey, each of the treatment zones has a disturbance level which is significantly different to that of the other zones. Restocking by the Direct Planting (DP) method resulted in no significant increase in disturbance.

The values of the composite measures 'percentage Mineral Soil Exposed' (MSE), first described by Bockheim *et al.* (1975), and 'mean DC value' in Table 3 give a clear indication of the relative degree of disturbance between treatment zones in the Restocked survey. Mean DC value is simply the mean of the Disturbance Class values for a given grouping, with a range between 0 and 3, a higher value being indicative of greater disturbance. Table 3 shows that in terms of the degree of disturbance, the order between treatment zones is DS > TM > DP.

Figure 4: SMTD prior to pre-placement in ground. Height: 25 mm, diameter: 18 mm.

The overall value of 41% mineral soil exposed following stem harvest, sits well with results from other comparable studies (Garrison and Rummell, 1951; Wooldridge, 1960; Dyrness, 1965; Bockheim *et al.*, 1975; Ryan *et al.*, 1992; Redfern, 1998; Block *et al.*, 2002; Ares *et al.*, 2005; Eisenbies *et al.*, 2005; Jusoff and Majid, 2012). The values obtained for MSE following both trench mounding preparation (58%) and destumping/restock (89%) are at the upper end of results quoted from other experiments. This may be explained in part by the exceptionally wet weather in south west Scotland during the summer of 2011 resulting in higher than normal disturbance levels (Moehring and Rawls, 1970).

(b) Soil compaction

Figure 5 shows the soil bulk density (Db) values from samples taken from each of the treatment zones and at varying depths. In addition, the four TM samples at zero depth and relatively high Db were collected from constructed planting mounds formed by trenched material. Average Db in the DS zone was 0.61 g cm^{-3} (33 samples), whilst in the TM zone it was 0.94 g cm^{-3} (30 samples), a significant difference. With a smaller number of samples (8), the mean Db value for the DP zone was intermediate between the other zones, and not significantly different from either. Overall therefore, the DS zone exhibited lower Db values following a particular disturbance (Tyler, 2004).

	Harvested survey				Restocked survey			
	All	**DS**	**TM**	**DP**	**All**	**DS**	**TM**	**DP**
Number of sample points:	338	151	154	33	346	156	159	31
DC0 (%)	$_{1}30$	$_{a,1}28$	$_{a,1}33$	$_{a,1}21$	$_{2}7$	$_{a,2}3$	$_{b,2}11$	$_{c,1}6$
DC1 (%)	$_{1}30$	$_{a,1}30$	$_{a,1}27$	$_{a,1}39$	$_{2}23$	$_{a,2}8$	$_{b,2}31$	$_{c,1}58$
DC2 (%)	$_{1}28$	$_{a,1}24$	$_{a,1}31$	$_{a,1}36$	$_{2}20$	$_{a,2}11$	$_{b,2}26$	$_{c,1}35$
DC3 (%)	$_{1}13$	$_{a,1}19$	$_{a,1}9$	$_{a,1}3$	$_{2}50$	$_{a,2}78$	$_{b,2}32$	$_{c,1}0$
MSE: (Mineral Soil Exposed, %)	$_{1}41$	$_{a}42$	$_{a}40$	$_{a}39$	$_{2}70$	$_{a}89$	$_{b}58$	$_{c}35$
mean DC value	1.2	1.3	1.2	1.2	2.1	2.6	1.8	1.3

Table 3. Proportions of sample points in each Disturbance Class and composite disturbance indices, by treatment zone. DC0 – DC3 disturbance levels described in Table 2. DS =Destumped, TM = Trench mounded, DP= Direct planted. Differing alphabetic subscripts indicate significant difference between treatments in single survey. Differing numeric subscripts indicate significant difference between surveys. MSE (Mineral Soil Exposed) = (DC2+DC3)/(DC_all).

Figure 5. Scatter graph of soil bulk density by depth and treatment area for samples from excavated trenches. Dashed ellipse highlights TM samples taken from the planting mound.

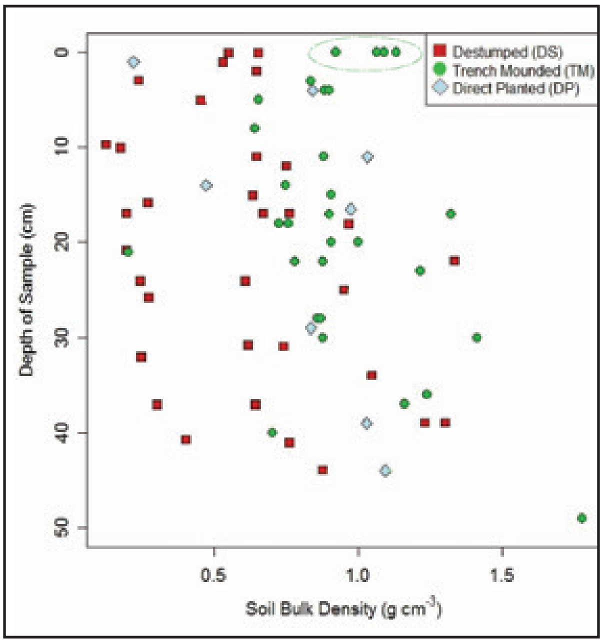


Figure 6. Mean pore space by depth of sample, treatment type and disturbance state for all thin section sample points. Mean pore space for undisturbed and disturbed soil is shown by dashed vertical lines and differing alpha subscripts indicate a significant difference at 95% confidence level.

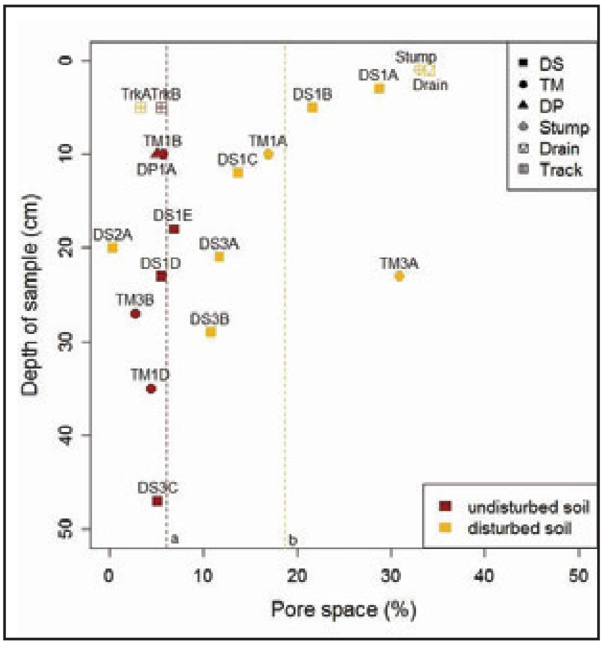


Figure 6 shows the pore space results for the thin section samples, indicating a significant difference in average pore space between non-disturbed (DP and most TM samples) and disturbed (DS and TM mound) samples, being greater in the latter. Whilst pore space for undisturbed samples remains largely uniform with depth, for disturbed samples pore space tends to decrease with depth. This may demonstrate the ease with which the open inter-aggregate structures produced by disturbance may become re-compacted in the presence of compressive force as experienced intrinsically at depth in the soil profile or extrinsically from subsequent wheeling.

These results indicate that disturbance resulting from stump harvesting has a loosening effect on soil in the absence of subsequent compressive force.

(c) Soil mixing

Figure 7 illustrates that the results from radiometric analysis paralleled the disturbance values obtained by the Visual Ground Disturbance Surveys. A lower Qcs value relates to a deeper burial of surface material and by inference a higher level of disturbance. Figure 7 shows that the radiometric results obtained correlated with the results of the visual Ground Disturbance with significantly different Qcs values recorded between each of the sequential Disturbance Classes. However, the degree of spread of radiometric outputs precluded the direct inference of Disturbance Class value solely by this means. Attenuation of ^{137}Cs gamma emissions is pronounced in saturated soil so Figure 8 shows the post-disturbance radiometric results by treatment area for upper transects where slopes of up to 20° prevented saturation. There was a significantly higher level of disturbance as recorded by Qcs in the DS zone than in the TM zone, paralleling the results carried out by visual assessment.

The radiometric results in Figure 8 for the DP zone are anomalous, in that they imply a reduction in disturbance levels following restocking. The most plausible explanation for this effect is that the vigorous grass cover which developed in this undisturbed area following tree harvesting, the first vegetation cover since Chernobyl, has drawn radionuclide material upwards, potentially into the grass itself (Broadley and Willey, 1997).

(d) Soil movement

The spatial distribution of SMTDs following stump

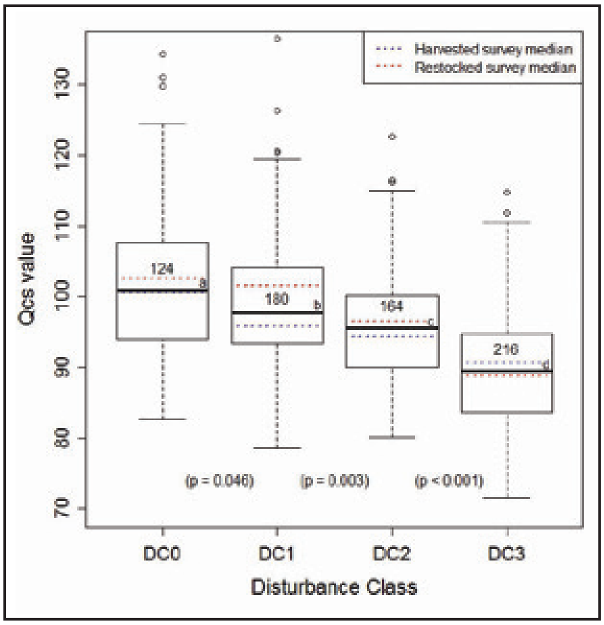
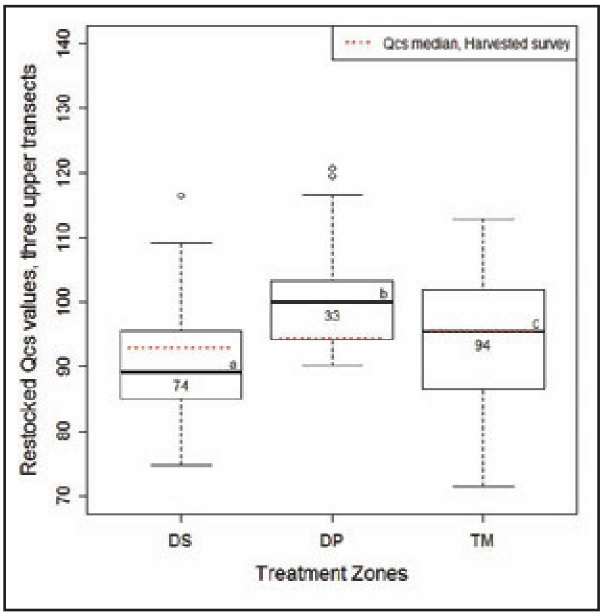


Figure 7. Box-and-Whisker plot showing median Qcs values, interquartile ranges (IQR) (boxes) and 1.5 x IQR (whiskers) grouped by Disturbance Class from both surveys. Numbers in each box indicate the sample size for that Disturbance Class. Dashed lines indicate the median Qcs value from the respective individual survey. Differing alphabetic subscripts indicate statistical difference at 95% confidence level between adjacent Qcs datasets, using Tukey HSD analysis. "p" values relate to the comparison between the relevant pair of adjacent groups.

Figure 8. Box-and-Whisker plot showing median Qcs values, interquartile ranges (IQR) (boxes) and 1.5 x IQR (whiskers) by treatment zones for upper three transects. Number of samples from each zone is as indicated. Datasets with different alphabetic subscripts are significantly different at 95% confidence level using ANOVA and Tukey HSD analysis (DS-TM: p=0.017. DS-DP: p<0.001. TM-DP: p=0.004). Qcs median from Harvested survey indicated.



extraction is shown for one of the monitored stumps in Figure 9. This shows that there are several differing types of soil trajectories detected by this method, relating to the operational processes described above in Figure 2. A count of the SMTDs recovered against each of these processes provides an indication of the relative distribution of soil disturbed during a stump extraction. Sixty one percent were recovered in the immediate stump vicinity, being deposited during lifting, splitting and shaking. Twenty nine percent were associated with the transferral to and storage of stump fragments in the windrow, whilst 11% were associated with the subsequent raking process.

Figure 10 shows a composite depiction of the disposition of SMTDs which were recovered in an undisturbed state from the three monitored stump sites (the fourth stump was not extracted due to the premature termination of destumping). Stumps were extracted from the centre of this array, with the orientation of the pre-existing plough ridge also indicated. The absence of non-disturbed SMTDs along the ridge is consistent with preferential tree root development in this direction (Coutts *et al.*, 1990) the extraction of which may have resulted in significant disturbance. That a high proportion of SMTDs remained undisturbed along the right-most face, in Figure 10, is probably because at all three sites there were no adjacent stumps to be extracted beyond this face, whilst all other faces were subject to interference disturbance from the extraction of adjacent stumps. Results from the right face therefore provided valuable data on both the radial extent and vertical shape of stump extraction disturbance zone.

Data from soil movement analysis were supplemented by the physical survey of an isolated stump extraction depression and compared with measurements from

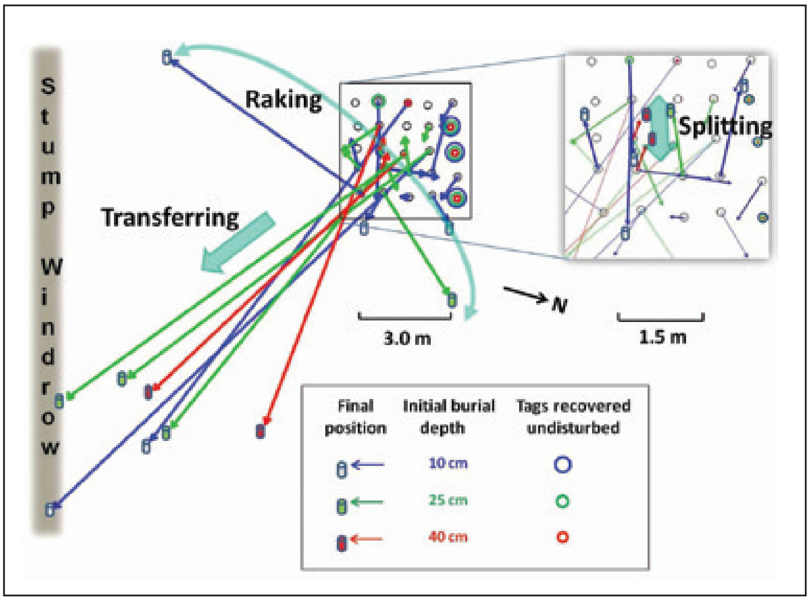


Figure 9. Schematic context diagram for stump site A54. SMTD placement matrix area is shown enlarged at upper right. Arrow identifiers relate to the destumping operational processes as identified in Figure 2, where "Transferring" relates to the movement of stump fragments to the windrow.

adjacent windthrown Sitka spruce sites. This yielded an average radius of disturbance from stump harvesting at this site of 1.6 m, with little occurring beyond 2.2 m. The volume of soil disturbed by a single stump extraction was estimated at 1.76 m^3 (2 S.E. = 0.30 m^3). The mean depth of disturbance in the destumped area derived from SMTD analysis was 23 cm, and by direct measurement across 172 sampling points from inspection pits and from soil cores was 23.6 cm, giving a weighted mean of 23.4 cm. The close correspondence of these two independently derived values lent credibility to the novel SMTD method.

Discussion

This study has used a variety of different but complementary techniques to establish the actual nature of soil disturbance at an operational scale tree stump harvesting site in Scotland. Table 4 shows the disturbance generated at a landscape level by stump harvesting compared to other forestry operations. The volume of soil disturbed by trench mounding was derived from the analysis of the volume of spoil trenches developed on site to provide the source material for mounding. It can be seen that this generates a volume well in excess of that required by the mounds, indicative of substantial spoil wastage in this process. Overall the study shows that stump harvesting followed by restock on this site, when carried

Figure 10. Recovered non-disturbed SMTD placements. The position of the pre-existing ridge line is indicated.

Produced using the on-line tool Lego Digital Designer 4.3.

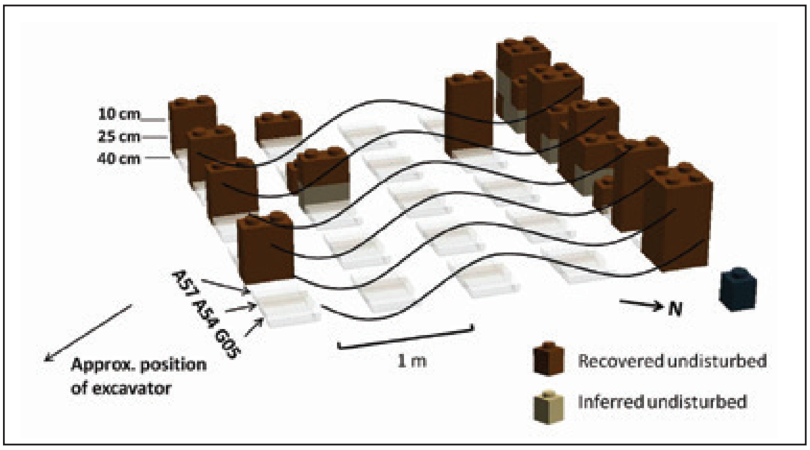


Table 4. Estimated volume of soil disturbance generated by various forestry operations. Per hectare totals are rounded to the nearest 10 m^3. Data for ploughing, from Worrell (1996), are included for comparison. Volume multiples are broad comparisons referenced to Trench Mounding disturbance.

	Unit volume (m^3)	**Per hectare (m^3 ha^{-1})**	**Range (m^3 ha^{-1})**	**Worrell (m^3 ha^{-1})**	**Volume multiple**
Planting Mound	0.025	70			
Trench Mounding		250	210 - 300	300 - 400	1
Ploughing		–		350 - 850	2-3
Stump Harvesting	1.76	1260	1150 - 1380		5
Raking (15 cm)		1050	1000 - 1400		4
S.H. and Raking		1400	1400 - 1560		6

out under current guidelines, disturbed around five times the volume of soil compared to that disturbed by trench mounding. However, there may have been more disturbance than normal due to the consistently wet weather preceding and during stump harvesting in 2011 (Moehring and Rawls, 1970). The effect of weather on destumping volume of disturbance adds a further complication to any operational assessment of the impact of stump harvesting on carbon and nutrient balance, as required by current Forestry Commission guidelines (2011).

The research indicates that stump extraction operations carried out under current UK guidelines and accepted management practice can result in an overall loosening rather than compaction of soil. Whilst the risk of subsequent compaction remains, this can be managed by ensuring the absence of any subsequent vehicular traffic. The association between stump harvesting and actual compaction is likely to have arisen in the literature because many early results came from field operations that had used bulldozers (Thies *et al.*, 1994).

Stump extraction was followed by the raking over of the surface using the excavator head. As well as being observed in the field, the soil movement arcs of this operation were detected by the final positions of some SMTDs (Figure 9). Analysis suggests that such raking increased the volume of disturbed soil by around 10%. This would not however alter the overall outcome of net loosening of soil. Forest managers may prefer the more uniform surface generated by raking in order to minimise trip hazard to tree planters and to afford the most direct planting lines (G. Chalk, personal communication). However, the absence of a requirement for raking in forest management documentation may make it difficult to support this operation in light of the Forests and Soil guideline No. 13 on minimising disturbance (Forestry Commission, 2011).

Unless stump extraction to the rear of the excavator is possible, some degree of excavator compression on recently disturbed soil is unavoidable. With forward-facing extraction, any pre-existent brash matting is disturbed and rendered ineffective. The more effective use of such brash is to reinforce adjacent forwarder stump extraction racks. It is suggested that the stump harvesting operator should minimise the footprint of excavator compressed soil, for example by retracing the ingress track pathways when exiting an area. Loosening of compacted soil in the track pathways behind the excavator whilst reversing out is in accordance with Forests and Soil guideline No. 12 (Forestry Commission, 2011) on compaction mitigation.

If raking is not carried out, stump harvesting operations will generate both stump extraction depressions and adjacent deposited soil berms (Davis and Wells, 1994; Courtin, 2010), a microrelief similar to pit and mound disturbance resulting from natural tree fall (Lyford and MacLean, 1966; Schaetzl *et al.*, 1989). The post-destumping soil berm and depression microrelief has many similarities to that gained by intentional operational mounding, particularly in terms of localised soil moisture gradients. Lyford and MacLean (1966) suggest that pit and mound environments are more beneficial for tree establishment than the more uniform microrelief generated by some cultivation, in this case by raking over. At the research site it was striking to note on the one hand the effort to generate a roughened restocking microrelief by trench mounding operations, whilst in the adjacent area an already roughened post-destumping microrelief was being smoothed by raking.

Conclusions

The Lamloch study has quantified the degree of soil disturbance following stump and root harvesting quite precisely, and allowed comparison with other forms of site preparation. Novel techniques for evaluating soil and site disturbance have been developed and tested. Focussed study on the stump harvesting technology and its consequent effects have allowed recommendations for future deployment which should reduce environmental impact.

Acknowledgements

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