Report of the rhododendron feasibility study

Prepared for the Beddgelert Rhododendron Management Group by the School of Agricultural and Forest Sciences, University of Wales, Bangor.

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EXECUTIVE SUMMARY

The feasibility study considered the quantities of rhododendron available, its potential use as mulch, biofuel, charcoal, foliage, as a source of phytochemicals and as a specialist wood for turnery. The toxicity of the smoke generated by normal clearance operations and in charcoal was tested. The study is able to provide preliminary results but there is a need for further replication in several of the tests. The main results are as follows:

Product tables
Indicative tables suitable for the estimation of total biomass, leaves, twigs, branches and wood have been prepared for open grown rhododendron based on average bush height. It proved harder to determine biomass/height relationships for shaded bushes (in woodland), if these are required further field sampling will be necessary. Results of the biomass sampling gives total rhododendron biomass of 170 tonnes per ha for open grown bushes more than 4 m tall. This compares favourably with the biomass resulting from forestry thinnings and logging residues.

Toxicity
Grayanotoxin (the toxin principle in rhododendron) which comes in a range of variants (GI and GIII) is a stable (resistant to temperatures of 300 ºC) non-volatile compound which is water and lipid soluble. It is a heart and neurotoxin which is not fatal to humans in normal doses. Evidence for traces of grayanotoxin were found in dry wood samples and insignificant traces were found in charcoal using gas chromatography. Ideally this work should be replicated and confirmed by alternative analytical means (mass spectrometry). However, the amounts found suggest that it is highly unlikely that any grayanotoxin will be found in charcoal so it can be considered as safe as any other charcoal for food preparation.

The grayanotoxins were not found in significant quantities in the smoke arising from burns of fresh green material or from wood, twigs etc.. Any traces found were at lower concentrations than any other material sampled by several orders of magnitude so concentrations are tiny and are not likely to cause ill health from casual exposure though the effects of long term exposure are not known. There is a need to fully examine the range of toxicants from smoke but these are unlikely to differ from other plant material.

It should be stressed that many woods are toxic and repeated exposure to any wood smoke is a health risk. Rhododendron probably does not constitute a significantly greater hazard than other woods all of which should be treated with respect.

Calorific values and use as a biomass fuel
The calorific value of rhododendron wood and leaves was shown to be comparable to Douglas fir which has the highest calorific value we found in the literature. This suggests that it should be well received by the biofuel market as whole plant chip which would save the considerable handling costs of sorting wood from leaves.

The biofuel market is growing but offers very low prices as a consequence of the general depression in timber prices and particularly small roundwood thinnings and arisings. Entry into this market is probably not economically feasible unless better prices are available or the costs of harvesting are considerably reduced through adoption of mechanised forestry techniques on suitable sites.

Charcoal
Although rhododendron charcoal was found not to contain significant amount of grayanotoxin and is of a superior grade and calorific value it is not able to compete in the current market structure and pricing. This is because of the quantities and quality required by larger scale commercial makers and the inability of smaller operators to compete with cheap imports. The only opportunity would be for the establishment of a local large-scale charcoal operation preferably specialising in undersupplied market segments such as that for activated charcoal. Such options were not investigated by the study.

Mulch properties and markets
A good mulch should be durable, however, chemical weed suppression properties as suggested for rhododendron would present a useful bonus. Both of these were tested for a range of rhododendron

derived mulches and compared with commercial alternatives. It was found that rhododendron leaves and pooled chip are at least as durable and effective at suppressing seed germination as conventional commercial mulches. Rhododendron is as least as good as standard commercial mulches and may offer a slight advantage in that it shows initial durability but then rots down relatively quickly to give soil conditioning.

Foliage trade

The export of rhododendron foliage from the UK to Amsterdam is large and could potentially absorb the whole production from Wales. Present levels of export by one trader is 200,000 stems per week and the demand is estimated as five times greater than supply. Prices offered for the stems does not include a payment to the landowner with most benefits being in the form of rural employment. Initial (and admittedly rather uninformed) estimates are that it may be possible to harvest up to 37,500 stems per ha from cut stumps, providing an income of £1,700 ha^{-1} every second year. Pickers can expect to earn £500-600 a week. Further work is needed to identify potential sites for rhododendron harvesting and the prospects for using this to stimulate rural employment and revenue for rhododendron clearance are suggested.

Phytochemicals

The rhododendron family contains many members which are used as herbal remedies in China, Korea and Germany. The active compounds in several species have been determined and they include potent anti-HIV compounds as well as heart stimulants and decongestants. Few studies have been done specifically on *R. ponticum* which may also contain useful pharmaceutical compounds.

Turnery

Trials with rhododendron for turning suggests that it is a superior wood being dense, diffuse porous and even grained. Although turning will not provide a market for much wood it may be possible to use it to create craft articles for sale.

Sudden oak death

A new disease caused by *Phytophthora ramorum* is killing oaks and other trees in California. It has been found on rhododendron in Europe and the possibility of it spreading to British oaks and other trees is an increasing concern. Under SI 1350 which came into force in May 2002 commercial movements of rhododendron as a Sudden oak death susceptible species are required to be fully documented and reported to the Plant Health Inspectorate. If *P. ramorum* is found in Wales, rhododendron movements are likely to be severely restricted. The risk to oaks posed by rhododendron in Welsh woodlands may however stimulate clearance programmes. Unfortunately, *P. ramorum* does not kill rhododendron.

Conclusions

There are several opportunities that have been identified for commercialisation of rhododendron clearance. The most promising of these are the commercial collection and export of rhododendron foliage. However, although this may be capable of providing an income to offset clearance costs it will not in itself kill the plant. Other areas worth further investigation are the use of rhododendron as a chipped biomass fuel though it seems likely that harvesting costs will need to be subsidised.

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Note on nomenclature

Throughout the report the term 'rhododendron' has been used to denote *Rhododendron ponticum* L. the species which is invasive through North Wales. Other *Rhododendron* species are referred to by their Latin names e.g. *R. maximum.* '*Rhododendron*' is used to denote the genus.

1. BACKGROUND

Rhododendron ponticum is an exotic species introduced into north Wales in the early 1800's, probably from Portugal. Since that time it has naturalised and spread through layering and seed dispersal, and in 1985 was estimated to have infested 38 km² of Snowdonia. The plant favours a mild climate (it is frost sensitive) with warm temperatures and humid conditions in early spring and acidic soils. Growth from seed is very slow and requires humid microsites such as bryophyte cushions, during this stage it is very vulnerable to browsing and competition. Once it is established at about eight years old it grows rapidly and begins to flower and set prolific amounts of seed. Clearance of rhododendron is difficult and costly. The plant coppices generously from stumps and requires repeated herbicide applications to kill it. A feature of clearance operations is the length of time it takes for more natural vegetation to establish itself. There is no vegetation under dense rhododendron and it does not support a large or interesting insect fauna, indeed young leaves are toxic to insect predators. Although it provides cover for birds and small animals it is also toxic to mammals and generally has an adverse impact on biodiversity. Control and eventual clearance of rhododendron is therefore high on the agenda of the SNP, CCW and others concerned with the ecology of Snowdonia.

The purpose of the study was to determine the feasibility of generating revenue from utilisation of rhododendron to offset the considerable costs of clearance in the Beddgelert area. Consequently this report focuses on potential uses of rhododendron rather than its ecology or control. However, during the course of the study a great many references on rhododendron where accumulated, although it has not been possible to review these in this document they are listed under subject categories in the bibliography as a resource to be used by others researching rhododendron, its uses and control. A great many people active in rhododendron control, ecology and control contributed to the report and we are grateful for their generous contributions to this report.

2. QUANTITIES AND PRODUCTION PRICES

2.1. Rhododendron product tables

When marketing any product it is important to know the quantities and quality of material available for sale. Moroney (1997) estimated rhododendron biomass on a 0.01 ha circular sample plot for a dense open-grown stand on the Craflwyn estate. He used the data to provide a conversion factor that could be used to amend the FC hazel yield table for rhododendron. He found his site contained a total biomass of 103 t ha^{-1} with 66 t ha^{-1} being suitable for use as charcoal. This equated to approximately 8% less biomass than predicted by the FC hazel yield table at a stool density of 1200 stems ha^{-1} at 25 years old. The main problem with this approach is that it relies on a single sample site and the results cannot be extrapolated to other sites with any certainty.

E°en (2000) estimated biomass for two sites in Turkey where rhododendron grows under a beech canopy. This study used a systematic sampling design based on 6 m radius plots on a 50 x 200 m grid giving 63 and 70 plots per site. Unfortunately this study concentrated on measurements of basal area, age structure and site characteristics and did not include biomass estimates.

On-going work at the University of Stirling (Atkinson *pers comm*) is developing biomass tables for individual plants of rhododendron concentrating on the pre-establishment stage. Unfortunately, these results will not be available until at least 2003.

Currently there are no accepted biomass tables for rhododendron in the UK.

2.1.1. *Methodology*

Since there are no yield tables for rhododendron in North Wales it was decided to undertake sampling of rhododendron in the Beddgelert area in order to generate biomass tables that could be used to estimate the live biomass per ha for a range of sites and densities of rhododendron. Since it seemed likely that the amount of shade would have an impact on the biomass potential of rhododendron, sampling was stratified to include shaded and unshaded sites.

The sampling took the form of a random sample of 2 x 2 m plots in six sites as listed in Table 2.1. The protocol used for the fieldwork is reported in Appendix 1 and illustrated in Plates 2-1 to 2-3. Briefly it comprised the weighting of material in four categories; leaves, twigs (< 2 cm d), branches (2-4.9 cm d) and stems (> 5 d) in the 2 x 2 m plot. All the material falling within the plot was sampled regardless of whether it was rooted in the plot. This is emerging as a conventional technique for sampling shrubs and was used by Alldredge *et al* (2001) to sample *Rhododendron maximum* in Idaho. A sample of each material was removed and oven dried to obtain the moisture content. Stems greater than 5 cm d were measured in order to determine their volume. The largest stem related to the material in the plot (could be outside the plot) was cut close to the ground and aged using ring counts.

Table 2-1 Sites sampled in product table fieldwork

Site code	Name	Description	Number of plots
CF	Craflwyn	Mix of shaded and open mature bushes	4
GP	Glynllifon	Mature bushes in shade on bank above a series of ponds	3
GF	Glynllifon	Mature open grown bushes in level fields	4
SS	Sygun	Approximately 20 year old re-growth	4
ST	Sygun	Tall, open growth (not re-growth)	4
CO	Coederyr	Tall growth under deep shade	2
Total			21

In all eight plots where sampled under a woodland cover (mostly broadleaves) and 13 in the open.

Plate 2-1 Laying out the 2 x 2 m sample plot

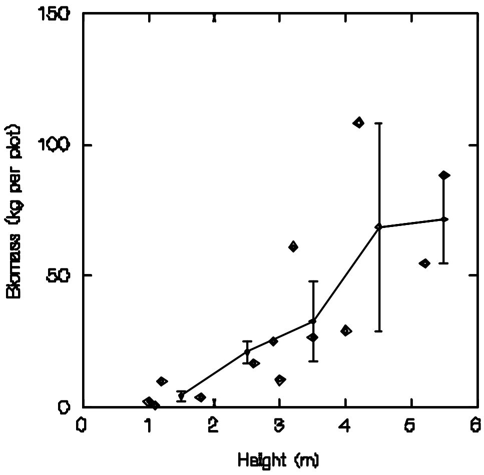
Plate 2-2 After removing all twig and branch material

Plate 2-3 Rhododendron within plot sorted for weighing

2.1.2. Results for open sites

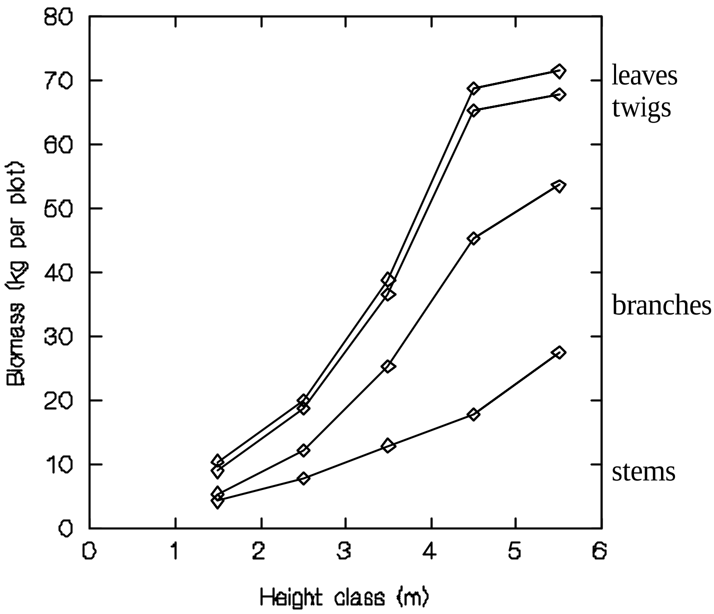
The open plots exhibited a reasonable relationship between height and biomass as illustrated in Figure 2-1. The line appears curved which is expected as it is generally the case that biomass and a measure of plant size exhibit a sigmoid or 'S' shaped relationships. There is insufficient data to determine the mathematical equation that describes the curve for rhodododendron as a basis for predicting the biomass. Since it is difficult in any case to measure the height of the canopy with any accuracy the mean biomass present in each of 1 m canopy height classes has been used as the best estimate of biomass with canopy height.

Figure 2-1 Rhododendron biomass against average canopy height on open sites



The rhododendron was sampled in four parts; leaves, twigs (< 2 cm diameter), branches (2-4.9 cm diameter) and stems (> 5 cm diameter), the mean biomass in each part by 1 m height classes is shown in Figure 2-2. The proportion of the biomass represented by leaves varies markedly with plant size being around 47% of the total mass in plants < 1 m tall and only 5% of the mass of plants > 5 m tall. Roughly it appears that leaf mass remains constant as the plant gets bigger. This is probably because once the plants grow sufficient leaves to capture the available light at a relatively small size there is little scope for increasing the number of leaves on the plant. Most of the increase in biomass is accounted for by woody material. The proportions of biomass in twigs, branches and stems is more or less constant though there are no stems > 5 cm diameter below 3 m height.

Figure 2-2 Biomass of rhododendron leaves, twigs, branches and stems on open sites



The data presented in Figure 2-2 are given in tabular form as tonnes per ha in Table 2-2 which can be used as an indicative biomass table for open grown rhododendron in northern Snowdonia. Table 2-3 gives the volume per ha for woody material greater than 2 cm diameter. Although biomass is reasonable compared to trees, volumes are very low as there are relatively few large woody stems in rhododendron stands.

Table 2-2 Live biomass table for open grown rhododendron in nothern Snowdonia

Height class (m)	Live biomass (tonnes per ha)				
	Leaves	Twigs < 2 cm d	Branches 2-4.9 cm d	Stems > 5 cm d	Total
1	2.362	1.877	0.784	-	5.023
± 95% CI	0.733	0.356	0.144	-	1.009
2	5.868	21.834	8.965	18.377	42.793
± 95% CI	0.166	1.548	1.790	-	4.784
3	6.245	31.013	26.409	28.703	81.421
± 95% CI	0.679	5.174	5.554	4.611	16.251
4	8.291	50.414	68.828	44.293	171.825
± 95% CI	0.938	7.132	13.953	13.191	35.214
5	9.015	35.711	64.899	68.929	178.555
± 95% CI	0.604	2.576	8.612	3.038	14.830

Table 2-3 Live volume of wood > 2 cm diameter for open sites

Height class (m)	Volume (m^3 per ha)		
	Branches 2-49 cm d	Stems > 5 cm d	Total
1			
± 95% CI			
2	31.451	35.136	66.587
± 95% CI	-	-	
3	38.172	42.341	80.513
± 95% CI	18.144	15.512	
4	113.176	72.700	185.876
± 95% CI	56.899	53.997	
5	127.711	137.242	264.953
± 95% CI	37.738	9.497	

The tables can be used to generate an estimate of biomass for a stand in the following way:

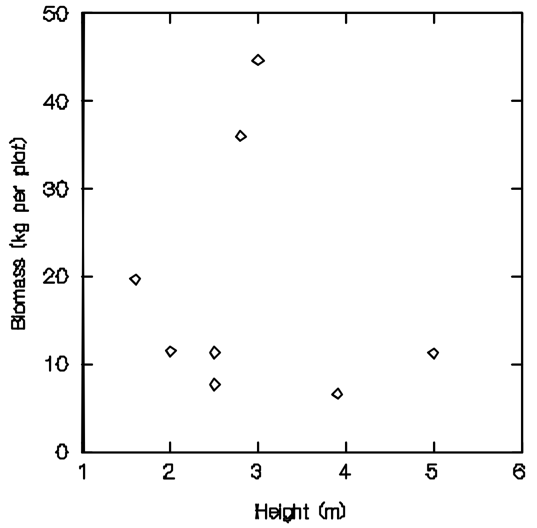
- Estimate the area of the stand in ha
- Estimate the average height of the canopy (half way through the main mass of leaves)
- Multiply the area in ha with the per ha figure given for the relevant height row in Table 2-2 or 2-3
- The 95% confidence interval for the estimate is the area in ha multiplied by the ± 95% CI figures in the tables multiplied by any estimate of error in the area.

2.1.3. Results for shaded sites

Only eight of the 21 plots fell within woodland. As Figure 2-3 shows these data do not exhibit a clear relationship between biomass and height. Consideration of the nature of the plots suggests that the scatter on Figure 2-3 is probably related to light intensity, i.e. to overstorey species and density. The two plots with low biomass at 4 and 5 m tall where both senescent (dieing) stands under dense overstories. In one case a multi-layered overstorey of birch, oak, holly and beech and the other under beech and western hemlock. It appears that closed western hemlock casts shade deep enough to kill rhododendron (as seen at Coederyr). It may be that beech can also kill rhododendron but this may not be possible as E°en (2000) reports rhododendron surviving under beech with a basal area of 20-22 m^2 ha^{-1} in Turkey. As plants are shaded they tend to etiolate (stretch) for light and consequently get taller and weaker making the relationship between height and biomass appear constant. The other shaded plots had overstoreys principally of oak and birch which are the dominant species in woodland sites in Nant Gwynant. Under these canopies we did not record any rhododendron taller than 3 m and these plots had comparable or slighly lower biomass to open sites. This may suggest that biomass in the shade reaches a maximum dependent on the density of shade and taller bushes may have reduced biomass as they start to die.

It has also been observed that rhododendron can exhibit a range of forms dependent on whether it is open or shaded (Moroney 1997). It may be that different biomass curves are needed for each growth form of rhododendron in the shade. Further work is needed if biomass tables for woodland rhododendron are required.

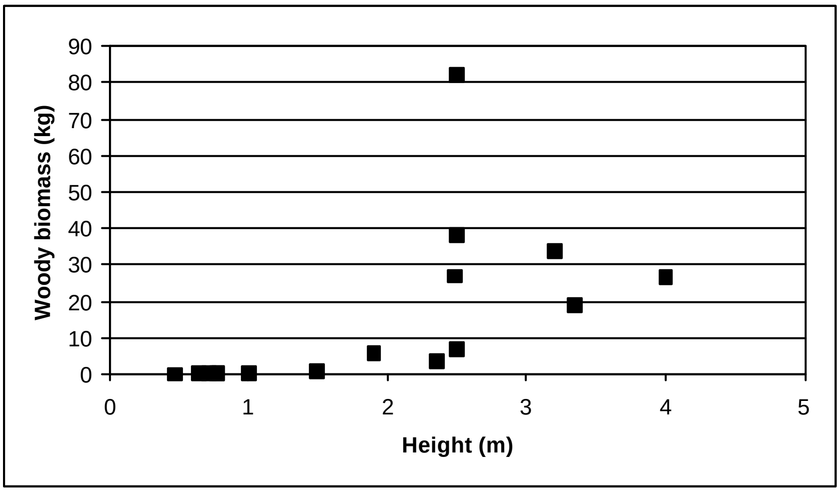
Figure 2-3 Biomass and height for shaded sites



2.1.4. Discussion

The use of a volumetric plot rather than whole bush sampling was used as it provides a more direct estimate of area-based biomass (per ha). It was also found to be logistically simpler than sampling huge, sprawling dense growth where it can be difficult to identify an individual bush and direct measurement of weights would be very laborious. The rhododendron project in Stirling (Atkinson *pers comm*) has employed a bush-based method for their sampling as they are primarily interested in the establishment phase and individual bush development. Premliniary results for the Stirling work is given in Figure 2-4 (Atkinson *pers comm*) and indicates that biomass increases rapidly with height beyond 2.5 m. Most of the bushes sampled by our project where taller than 2 m and it is hoped that there will be an opportunity to compare results in a more formal way during the Stirling project which has about another 2 years to run.

Figure 2-4 Woody biomass and height for individual bushes (Atkinson per comm)



The tables for the open grown rhododendron is acceptable for the gross estimation of biomass over large areas using average canopy height. However, basal diameter is a better predictor of biomass if more accurate estimates are required. More data and a sampling scheme for basal diameter (e.g. number of stems to be measured in an area of rhododendron) would be needed to exploit this relationship in more precise biomass tables.

It was not possible to construct biomass tables for shaded rhododendron from the few samples taken. If such tables are required then it would be advisable to stratify sampling according to overstorey species and density and sample at least 10 plots in each strata. Such tables would be useful for estimating the total biomass available if a site where to be clear felled for biomass (e.g. clearfelling as a prelude to re-stocking in conifer plantations).

2.1.5. Comparison of rhododendron yields with common forestry species

In order to compare rhododendron yields with those from conventional forestry species the yield class that could be expected for Nant Gwynant was estimated using the Ecological Site Classification (ESC) of the Forestry Commission and the Forest Management Tables (Hamilton 1971). The ESC estimates the yield class by species from the altitude, soil type and location of a site. The yields in Table 2-4 were estimated for the lower Nant Gwynant using an altitude of 70 m and a ‘loamy pdozol’ soil. The yield class was then used to obtain the yields for final crop fellings and thinnings for the maximum age given in the Forest Management Tables. The resultant figures are presented in Table 2-4 for volumes to 7 cm top diameter.

Table 2-4 Expected yields m^3ha^{-1} for selected forestry species in Nant Gwynant

Species	Ecological Site Classification yield class	Yield from thinnings m^3ha^{-1}	Yield from main crop m^3ha^{-1}
Douglas fir	10	20	380
European larch	6	3	264
Sitka spruce	17	26	656
Western hemlock	16	44	630
Beech	5	12	298
Oak	4	6	238
Silver birch	9	9	293

It is obvious comparing Table 2-3 with Table 2-4 that rhododendron yields (35 to 127 m^3ha^{-1}) are much more than thinnings but even for the densest stands (137 m^3ha^{-1}) is less than half the yield of the low yielding broadleaved forestry main crops.

2.2. Clearance costs

The project was asked to prepare a current estimate of the costs of clearing and extracting rhododendron in the Beddgelert area. Initial discussions indicated that costs can vary enormously depending on many factors ranging from the use of volunteer labour, extreme terrain, difficulties in estimating the amount of work involved etc. It was therefore decided that the best approach would be to try and understand some of the variation in costs by collecting relatively detailed information on actual contracts on a written questionnaire. The questionnaire itself can be found in Appendix 2. A total of 30 commissioning organisations and contractors were approached. In all 14 completed questionnaires were returned comprising 36 job descriptions.

It was hoped that we would have obtained sufficient questionnaire returns to analyse how costs vary with terrain, access and rhododendron cover, which would then have been used to generate a clearance cost GIS based model for Nant Gwynant. Unfortunately, the number of responses was too low so a simpler analysis was undertaken. Table 2-5 shows the range and mean cost of clearing rhododendron of differing densities.

Table 2-5 Cost per ha for clearing rhododendron

	Operation	Manual cut	Cut & Spray	Spray	Pick seedlings	Stem injection
	Bush height	> 2 m	1-2 m	< 1 m	< 0.5m	> 5 cm d
Bush cover on site	Scattered (< 20 %)	1800		18-75	15	13,000
	Moderate (20-49 %)	2500	566	120-500	400	
	Dense (> 50%)	2500-5500	1000-2600			

The figures indicate great variability in prices some of which might be explained by some of the jobs not having costed labour. In general the pattern is that the cost of cutting is higher for denser stands and that contracts for shorter bushes tends to be for spraying as well as cutting. Spraying costs vary with the density and can be very low for sites with scattered, small bushes. Hand picking seedlings is also a relatively cheap affair. Although the FC undertook its stem injection experiments in Hafod Boeth (behind Plas Tan-y-Bwlch) it seems that this is not generally used except in inaccessible areas. Consequently stem injection is usually combined with rope access which is why it is so expensive in the Beddgelert area.

The questionnaire and discussions with land managers around Beddgelert suggests that most clearance in the area is achieved through the use of handtools (9% of cutting jobs) or chainsaw (91%). Use of a chainsaw increases the rate of cutting over hand tools (but does not alter the time spent burning), so should reduce costs, but this is offset by the use of handtools by volunteer (free) labour. The only other technology used is stem injection with Glyphosate in areas where rope access is required. This is very expensive and a contract for killing rhododendron in the Aberglaslyn Pass cost £13,000 per ha. Mechanised clearance using a flail has only been done experimentally near Maentwrog and is not in common usage.

Costs per ha used by CCW in clearance project proposals ranges from £3,000 to £4,000 per ha in dense stands with spraying at £800 per ha. Oliver also reports that Tir Cymen give payments of £2,471 per ha for rhododendron clearance. The costs of spraying used by CCW seem high compared to the figures given in Table 2-5 but is presumably is intended to include two sprayings at £350 each.

2.2.1. Clearance costs at other localities

The Forestry Commission provides a table of indicative costs for vegetation management for guidance in preparation of Woodland Improvement Grants (http://www.forestry.gov.uk). These figures, at 2001 prices are given in Table 2-6.

Table 2-6 FC indicative costs for rhododendron clearance technologies (2001)

Technology	Rhododendron bush height (m)		
	< 2.5	2.5 – 3.5	> 3.5
Cut with RGL flail		500	1,200
Cut with Menzi flail	1,000	1,300	1,950
Manual cut, rake and burn using excavator	1,750	2,600	
Manual cut and burn		2,500	5,000
Uproot and burn using excavator			1,900
	1100 plants ha^{-1}	2250 plants ha^{-1}	
Spot spray	80	100	

Average costs for rhododendron clearance in the Ardtornish project (Robertson 1999) is given in Table 2-7. These are 'real' figures in that the actual cost for a series of measured 1 ha blocks of different densities was used to calculate the mean figures. Again the figures for manual clearance are comparable to those in Snowdonia.

Table 2-7 Rhododendron clearance costs at Ardtornish (1999)

Activity	Cost ha^{-1}
Hand cutting and clearing 100 % cover areas	2,400
Machine flail (RGL)	1,100
Glyphosphate spraying 100 % cover areas	232
Glyphosphate spraying 1% cover areas	4

It is evident that there are clearance technologies which are not being used in Snowdonia notably the use of mechanical technologies (RGL, Menzi flail and excavator). This is because many of the areas being cleared are of conservation interest or are steep, covered in rocks or otherwise unsuitable for heavy vehicles. A Menzi flail was used on a trail basis near Maentwrog around three years ago but has not been used elsewhere.

2.2.2. Average costs of manual rhododendron control

Descriptions of clearance operations suggest the following timetable of activities and their associated costs for clearing a dense stand > 2 m tall are given in Table 2-8.

Table 2-8 Timetable and costs for Rhododendron clearance operations

Year	Operation	% cover of rhododendron	Cost ha^{-1}
1	Manual cut & disposal	100	4000
2	Spray	13	300
4	Spray & Pick seedlings	10	600
5	Pick seedlings	negligible	400

This gives a total estimated cost of £ 5,300 for the first five years of rhododendron control. Unless there are no seed sources near the site (distance is site dependant) it is suggested that picking young plants is going to have to become a recurrent cost of £ 300-400 every three (Robertson 1999) to five (Oliver *pers comm*) years.

2.3. Harvesting costs

For the purposes of determining the costs of harvesting rhododendron we assume that it is only bushes greater than 2 m tall which contain significant quantities of woody biomass that is of interest. From the returned questionnaires it appears that there is little removal of rhododendron off the site, and on only three of the 36 sites was wood removed as firewood, with one each being used for chip and charcoal. In all cases the amount of material used was small and only for personal use. Since there are no real costs for harvesting rhododendron the questionnaire asked what the contractor would charge to extract the rhododendron from each site. This was attempted on six sites. The results indicate that extraction would on average increase costs by 175% (range 62% to 300%). This reflects the difficulties of handling the crooked, whippy stems of rhododendron on steep, rocky slopes, far from a road without the aid of machinery. It is presumed that most contractors were quoting for manual handling of the woody material which it is estimated would cost between £1,300 and £28,000 per ha. The majority of the costs are likely to be the handling of the rhododendron so costs will probably be the same regardless of which part of the plant is harvested.

The only way that costs could be significantly reduced would be to use forestry machines and techniques. One suggestion is to use a large caterpillar tractor (CAT D4) to winch rhododendron by the stumps onto a landing. This would have the advantage of removing the stump which would reduce re-growth and also collecting the material for chipping or cross-cutting and extraction. To date this has not been tried in Wales. However, a very similar idea using a winch was tried at Ardtornish (Robertson 1999). In this trial a winch (report doesn't say which type) was used with a choke around the base of the bush. A chainsaw operator worked around the back of the bush cutting stems/layered branches which came under tension so the brash could be dragged away onto a landing. It is noted that this is potentially extremely dangerous though it is also suggested that the idea has merit. Certainly using a heavier machine capable of ripping the stumps out would be safer but would only be possible on gentle slopes where potentially severe soil disturbance would not be a problem. It has also been suggested that on slopes it should be possible to use conventional forestry high lines systems to extract the rhododendron. In this case a tractor would be placed at the top and bottom of the slope with a continuous chain running between them. The cut rhododendron would be choked onto the running chain and thus transported to the bottom of the slope. Both of these technologies would probably only be cost-effective for large, dense woody material (though the whole plant could be removed) covering large areas. Costs of such systems would probably be in the same order as for normal forestry operations per ha as indicated in Table 2-9.

The figures in Table 2-9 were obtained from:

- The Forest Enterprise Wales Harvesting & Marketing Unit (WHAM), and are based on an average standing volume of 450 m^3 per ha for clearfell and 50 m^3 per ha removal for thinning
- a local contractor, based on costs per m^3 of chip to roadside
- The Forestry Commission Website Indicative Costs Tables, based on FE experience and WGS applications (not Wales specific):

Table 2-9 Forestry harvesting costs

Site type	Technology employed	Felling costs £ m^{-3}	Thinning costs £ m^{-3}
From WHAM:			
Easy	Harvester-forwarder combination	7.00	12.00
More Difficult	Tractor and winch	12.00	17.00
Most Difficult	Winch at roadside (access not possible)	18.00	23.00
From local contractor:			
Easy	Harvester-forwarder combination	3.50	
Average	Harvester-forwarder/tractor-winch	11.67	
Most difficult	Winch at roadside (access not possible)	29.17	
From FC Website:			
Thinning	Fell, sned, cross-cut and extract		20.00
Felling	Harvester felled/extraction to roadside (av. tree 0.6m^3 : density 525kg.m^3)	16.57	
	Felling/extraction of large hardwoods (av. tree 1.4m^3)	13.50	
Felling conifer to waste and clearing site	3-6m high, extract and chip (or burn). Based on 50m^3 standing volume per ha	24.00	

Taking the WHAM figures on a per ha basis and assuming that rhododendron clearance is going to take at least the same time and effort as harvesting trees together with the volumes given in Table 2-3 gives the comparative cost per cubic metre figures presented in Table 2-10.

Table 2-10 Comparative costs per cubic metre for rhododendron harvesting

Site type	Equipment employed	Rhododendron		Forestry	
		2-3 m tall 39 $m^3 ha^{-1}$	> 3 m tall 105 $m^3 ha^{-1}$	Thinnings 50 $m^3 ha^{-1}$	Fellings 450 $m^3 ha^{-1}$
Easy site	Harvestor-forwarder	80	30	12	7
Moderate site	Tractor and winch	138	51	17	12
Difficult site	Winch at roadside	207	77	23	18

The questionnaire results give an estimated cost for harvesting tall, dense rhododendron by hand in the region of £178 per cubic metre.

Of course the comparison would look better if the volume of forestry material available is lower than that used in the WHAM figures, indeed Table 2-3 suggests much lower figures for broadleaves in the Beddgelert area. However, forestry operations, especially thinnings are often not economic in north Wales so it seems unlikely that rhododendron harvesting would be profitable unless it were subsidised or rhododendron could attract a price premium.

2.3.1. Chipping costs

Since rhododendron is difficult to stack, uses which accept the material as chip would be preferable. Chipping on site has the advantage of reducing the bulk of the rhododendron and making it easier to handle. Unfortunately, rhododendron does not chip easily as it has long, crooked, whippy stems which tend to catch in the throat of smaller chippers. Larger chippers are difficult to get onto many sites. Average costs of chipping stacked material are around £350 per day (3 men plus machinery). In a worst case scenario (rhododendron on steep ground) it is estimated that it would be possible to handle 625 m^3 per day yielding 10-12 m^3 of chip at roadside. This does not compare well with an average forestry job which can yield 20/30 to 100 m^3 of chip a day.

Local prices for chip vary from £10 m^3 delivered to £20-30 a green tonne. Rhododendron would not be able to compete with these prices unless the clearance is subsidised or greatly reduced through the use of more mechanised forms of clearance perhaps through the use of highlines, skidders and the like.

3. PROPERTIES OF RHODODENDRON

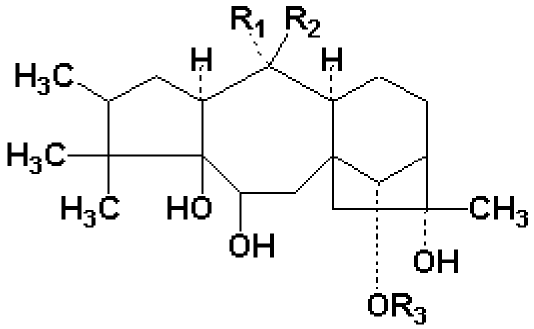
3.1. Toxicity study

Rhododendron is infamous for being toxic to animals through ingestion of the leaves and man through consumption of 'mad' honey. As far as the clearance and use of rhododendron is concerned there are two main issues; the toxicity of the smoke and residual toxicity in wood products and charcoal. We undertook studies to analyse each of these for grayanotoxin which was first isolated from rhododendron by Plugge and de Zaayer (1889). There may be other toxins such as Rhodojaponin but we did not analyse for these in this feasibility study.

3.1.1. Grayanotoxin

The main toxins in rhododendron is a group of compounds called grayanotoxins. These have also been called andromedotoxin, acetylandromedol and rhodotoxin. These comprise a number of closely related chemical structures. The principle toxic isomer in rhododendron is grayanotoxin III (GIII) although others grayanotoxin I (GI) and grayanotoxin II (GII) are present in lower amounts. GI is also toxic and GII is less toxic. A variety of other Rhododendrons, Azaleas and other members of the Ericaceae also contain these toxins (e.g. *Kalmia* spp.). There are however some 18 grayanotoxins reported and a variety of other, potentially toxic (to a lesser degree), compounds such as rhodojaponins. Grayanotoxin I, II and III are diterpenes which are polyhydroxylated cyclic hydrocarbons with the general structure shown in Figure 3-1.

Figure 3-1 General structure of grayanotoxin



GRAY	R_1	R_2	R_1R_2	R_3
GRAY1	OH	CH_3	-	H
GRAY2	-	-	$=CH_2$	H
GRAY3	OH	CH_3	-	Ac

Grayanotoxins are often isolated in methanol or chloroform but these solvents dissolve a range of compounds so that they require further purification before they can be crystallised out or subjected to detailed analysis. Crystalline needles of grayanotoxin melt at 228-229°C (Plugge and de Zaayer 1889).

There are reports that grayanotoxin is highly water soluble and lipid soluble.

The toxin is a neurotoxin interfering with the transmission of the action potential by blocking sodium channels in cell membranes. GI and GIII have the ideal shape for this whereas GII does not. This is borne out by the observation that 1.28 and 0.84 mg kg^{-1} of GI and GIII respectively injected under the skin of a mouse is fatal while 26.2 mg kg^{-1} are required for GII to be fatal. Estimates have been made to the effect that 100 to 225 g of leaves must be eaten to seriously poison a 55lb (25 kg) child.

The toxin is in its highest concentration in young shoots, leaves and in the bud scales and probably serves as an anti-herbivory agent (grazing ruminants and insects). Most reported cases of poisoning in animals are with goats and sheep where some fatalities occur. Few if any cases of direct ingestion of plant material by humans are reported, although it seems that honey which is made from predominantly rhododendron nectar has lead to human poisoning. In Turkey 16 cases of 'mad-honey' poisoning were reported between 1984 and 1986. Human poisoning is rarely fatal and complete recovery occurs in 24 hours. One study on the composition of the honey failed to find any of the grayanotoxins.

The reported effects of poisoning include dizziness, weakness, excessive perspiration, nausea, vomiting shortly after ingestion, difficulty in breathing and loss of balance. Convulsions have also been reported. Low blood pressure and brachcardia develop and heartbeat rhythm anomalies are reported, presumably by neurotoxicological effects. No data on the chronic effects of long term exposure were found.

In this study we have looked for the presence of GI and GIII in a variety of parts of the rhododendron plant and in charcoal derived from rhododendron wood, as described in following sections.

3.1.2. Charcoal

As noted by Moroney (1997) the temperature of the charcing process and the technology used will have an impact on the amount of volatiles driven off and the amounts of residual ash. It was decided to prepare charcoal using three alternative technologies during a charcoal making course held May 2002 by the Nanteos Group based near Aberystwth. Rhododendron wood was collected from stacks at Craflwyn that had been standing outdoors for about nine months and was therefore reasonably well seasoned. The three charcing technologies are detailed in Appendix 3 and summarised in Table 3-1 below. The soil clamp did not burn well and on this occasion did not produce useable charcoal. The toxicity analysis was therefore done on the charcoal produced by the single drum and retort processes. The charcoal was milled and the grayanotoxin removed using the process described in Appendix 4.

Table 3-1 Charcoal technologies used in study

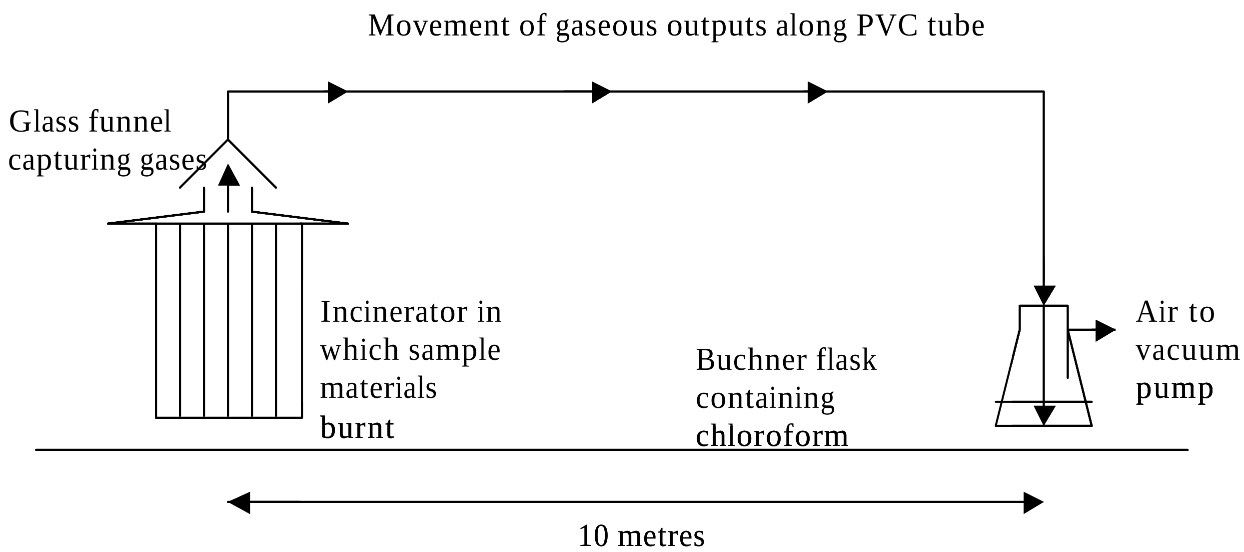
Type	Description	Max temperature	Burn duration	Conversion
Soil clamp	Earth covered bonfire	516	~75 hours	~20%
Single drum	Open burn in drum which is sealed once hot	620	3-6 hours	23%
Oil drum retort	Drum sealed and heated externally with gases fed back into the drum	620	1-3 hours	65%

3.1.3. Collection of open burnt smoke

In order to investigate the chemistry of open burnt smoke of rhododendron, it was first necessary to collect samples of the smoke. This was done by conducting a controlled burn of rhododendron material using a domestic incinerator and collecting the smoke generated.

A schematic diagram of the equipment we devised is given in Figure 3-2. The experiment was conducted at Henfaes, the SAFS farm near Abergwyngregyn. The incinerator used was a conventional model based on a dustbin available from garden centres for burning garden refuse. A fire was started in the bottom of the incinerator using dried rhododendron leaf and twig material. Once the fire was established the incinerator lid was put on with a glass funnel fitted over the chimney to collect the gases. The funnel was attached to a Buchner flask part filled with approximately 500 ml of chloroform by 10 m of 20 mm bore PVC tubing. This length of tubing was used to minimise the likelihood of the chloroform combusting. Chloroform was used as it is known that grayanotoxins are soluble on this solvent. A vacuum pump was attached to the outlet pipe, creating a vacuum in the flask and thus drawing the gases from the incinerator along the PVC tubing and causing them to bubble through the chloroform.

Figure 3-2 Schematic diagram of method used to collect smoke samples



Initially dry woody material was burnt, then air-dried (weathered) leaves, then green leaf material, and finally green regrowth material. The samples were burnt in this order with the material anticipated to contain the least grayanotoxins first and the material expected to contain the most grayanotoxin last. This reduced cross contamination between samples.

The smoke and gases were collected from each sample for a set period of time and minimum, maximum and average temperatures in the incinerator were also recorded when possible. The burn time and temperature readings for each material are given in Table 3-2. After the set time, the chloroform sample was decanted into a collection bottle, the Buchner flask was refilled with chloroform and the next sample was added to the incinerator.

Table 3-2 Temperatures of burns

Rhododendron Material	Burn time (minutes)	Minimum temperature (°C)	Average temperature (°C)	Maximum temperature (°C)
Dry Wood	30		530	671
Air-dried leaves	10		435	682
Green leaves	60	149	460	737
Regrowth	30	171	483	776

The samples were then refrigerated until they could be extracted and analysed using gas chromatography.

3.1.4. Chemical analysis

Rhododendron plant materials (wood, twigs, leaves, flowers and seed capsules) were collected, dried and milled as in Appendix 4. Once weighed, oven dry flours were Soxhlet (hot) extracted in methanol. The crude extract was then evaporated to dryness and weighted. The extract was then redissolved in chloroform and analysed by a variety of techniques (HPLC, GC, GC-MS[1]) for the presence of GI and GIII. Standards of GI and GIII were obtained from Aldrich/Sigma Chemicals to show the locations of the peaks and to allow quantification of amounts of GI and GIII in samples.

The HPLC method failed to find any grayanotoxins because the UV detector connected to it was not suitable for this purpose. A mass spectrometer detector is necessary for this method. GC initially failed to locate the grayanotoxins and the GC-MS revealed impurities in the standards which left some doubt as to the identity of the peaks. A final method, which proved highly successful involved derivatising the grayanotoxins (after Terai and Tanaka, 1993) and clearly defined peaks of the derivatives were visible using GC. The method used gave detection sensitivity down to 5 mg l^{-1}. Higher sensitivity (x100) could be acheived using a different technique (splitless injection) and is recommended for further studies.

3.1.5. Results

Gas chromatography results

The concentration of grayanotoxin in the various plant parts was calculated by manually measuring the heights of the appropriate peaks (Tables 3-3 and 3-4). Peaks on the GC trace are seperated by time, with the 'retention' time being unique for each compound in the test sample. The peaks in the rhododendron traces were matched as having the closest retention times to the standards of 18.6075 and 21.9918 mins for GIII and GI respectively. There was some deviation from the standard values amounting to +/- 4 seconds for GIII and +12 / -9 for GI so some interpretation of the results has been necessary.

[1] HPLC – High performance liquid chromatography, GC – gas chromatography, GC-MS – gas chromatography with mass spectrometry

Table 3-3 GI concentrations (mg g^{-1} dry wt) of various rhododendron plant parts

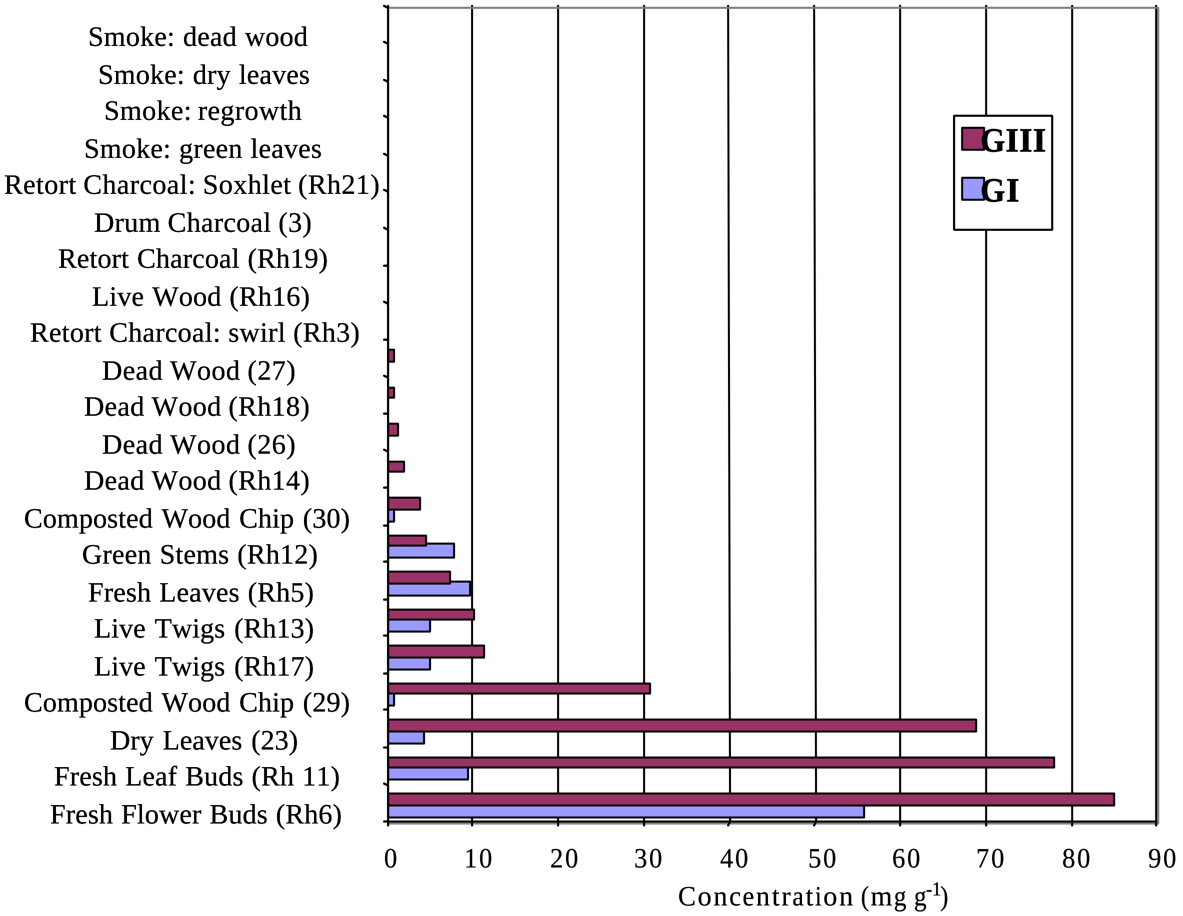
Sample	**GI conc.** mg.g^{-1}	**Peak retention time** (mins)
Standard		21.9918
Fresh Flower Buds (Rh6)	55.2617	21.8427
Fresh Leaves (Rh5)	9.4048	21.8378
Fresh Leaf Buds (Rh 11)	9.2507	22.1957
Green Stems (Rh12)	7.6030	22.1350
Live Twigs (Rh13)	4.9175	21.8662
Live Twigs (Rh17)	4.8909	21.8593
Dry Leaves (23)	3.9152	22.0055
Composted Wood Chip (29)	0.6322	22.0877
Composted Wood Chip (30)	0.5325	22.0405
Live Wood (Rh16)	0.3042	21.9560
Dead Wood (Rh14)	0.1341	21.9900
Retort Charcoal (Rh19)	0.0833	22.1212
Dead Wood (26)	0.0823	22.1011
Dead Wood (Rh18)	0.0762	21.9957
Retort Charcoal: Soxhlet (Rh21)	0.0439	22.0387
Drum Charcoal (3)	0.0371	22.0362
Dead Wood (27)	0.0286	22.0234
Retort Charcoal: swirl (Rh3)	0.0151	21.9918
Smoke: dead wood	0.0029	22.0370
Smoke: green leaves	0.0018	22.0622
Smoke: dry leaves	0.0009	22.0108
Smoke: regrowth	0.0003	22.0000

Table 3-4 GIII concentrations (mg g^{-1} dry wt) of various rhododendron plant parts

Sample	**GIII conc.** mg.g^{-1}	**Peak retention time** (mins.)
Standard		18.6075
Fresh Flower Buds (Rh6)	84.6182	18.6088
Fresh Leaf Buds (Rh 11)	77.7297	18.6290
Dry Leaves (23)	68.6445	18.6179
Fresh Leaves (Rh5)	33.7427	18.6027
Composted Wood Chip (29)	30.5816	18.6593
Live Twigs (Rh17)	11.1952	18.6220
Live Twigs (Rh13)	9.9411	18.6270
Green Stems (Rh12)	4.2145	18.5845
Composted Wood Chip (30)	3.5191	18.6299
Dead Wood (Rh14)	1.6436	18.5843
Dead Wood (26)	0.9913	18.6730
Dead Wood (Rh18)	0.5444	18.5698
Dead Wood (27)	0.3205	18.6106
Retort Charcoal: swirl (Rh3)	0.2727	18.6193
Live Wood (Rh16)	0.2516	18.5347
Retort Charcoal (Rh19)	0.1494	18.5780
Drum Charcoal (3)	0.1281	18.6558
Retort Charcoal: Soxhlet (Rh21)	0.0625	18.5955
Smoke: green leaves	0.0035	18.6527
Smoke: dry leaves	0.0011	18.6028
Smoke: regrowth	0.0015	18.5927
Smoke: dead wood	0.0005	18.6218

The amount of GIII found in the different plant parts was greater than the amount of GI found in all cases (Figure 3-3). It can be seen that there are very high quantities of GI and GIII in the fresh flower buds and significant amounts of both GI and GIII in the other actively growing parts of the plant (leaves, leaf buds and green stems). These are also the parts of the plant most susceptible to browsing, which supports the suggestion that grayanotoxins perform an anti-herbivory function.

Figure 3-3 Concentrations (mg g^{-1})of Grayanotoxins, GI and GIII found in different parts of rhododendron



While both GI and GIII were found in freshly cut and air-dried wood samples, their relative amounts could be considered insignificant when compared to the amounts found in fresh leaves. For GI the amounts are orders of magnitude lower (e.g. 0.03 – 0.13 mg g^{-1} of GI in wood, compared to 3.9 – 9.4 mg g^{-1} in leaf samples) as for GIII (dead wood 0.32 – 1.64 mg g^{-1}, compared to leaves, 33.7 – 68.6 mg g^{-1}).

In charcoal samples, traces of GI and GIII were found, but these amounts are again many orders of magnitude lower than the amounts in leaves (e.g. GI 0.015 – 0.083 mg g^{-1}; GIII 0.063 – 0.27 mg g^{-1}).

In smoke samples the traces found are so small as to be negligible and are close to the detection sensitivity of the equipment and could be considered as artefacts. The amounts measured range from 0.3 – 2.9 µg g^{-1} for GI and 0.5 – 3.5 µg g^{-1} for GIII. These represent thick smoke collected for up to 1 hour of burning rhododendron samples so that these represent only miniscule amounts.

It is, however, interesting to note the relatively high amounts of GI and GIII found in composted wood chip sample 29 (0.63 mg g^{-1} of GI; 30.6 mg g^{-1} of GIII). The GIII value is high but the peak is close to the edge of the range of retention times accepted as a positive GIII trace and so may be regarded as less reliable. If the results are reliable the GIII may have originated from included leaves. This result would suggest that while grayanotoxins are readily denatured by heat (thus making rhododendron safe for use as charcoal), but they are not rapidly broken down by decomposition. This may impose limitations on their use for mulches or animal bedding when they include high proportions of leaves.

At this point, we would like to clarify that while some quantitative conclusions have been drawn from this data, the analyses should be repeated more extensively as the small sample sizes require replication to be validated and other analytical methods should be included to confirm the identity of the peaks (e.g. GC-MS). We would therefore not recommend quoting the concentrations of grayanotoxin as absolute, but would rather suggest treating the data more qualitatively, and are happy that these results give an indication of *comparative* amounts of grayanotoxin present in the various rhododendron samples tested.

3.2. Sudden oak death

Sudden oak death is a disease which is presently affecting oaks and other woody plants in California (http://www.cnr.berkeley.edu/oaks). The disease is caused by *Phytophthora ramorum*. This is a species of fungi from a diverse group prone to hybridisation that causes many, often fatal diseases in plants. *P. ramorum* was first seen on Rhododendrons in Europe but it is not yet known where it originated (USA, Europe or elsewhere). In California sudden oak death is causing extensive dieback of Tanoak and is affecting a range of species, including species of the genera *Quercus*, *Rhododendron*, *Vaccinium*, *Aesculus*, *Lonicera*, *Acer* and *Pseudotsuga menziesii* which have representatives in Wales (oak, rhododendron, bilberry, horse chestnut, honeysuckle, sycamore and Douglas fir). In oaks the first symptom of fungus attack are the appearance of stem cankers that bleed a dark red sap. In rhododendron the symptoms are cankers that spread from twig tips to the base of the stem with blackened circular patches on the leaves. Rhododendron can be defoliated by *P. ramorum* attacks but grows back with apparently healthy leaves. It is not yet known if the fungus might still be in the plant and therefore infective.

P. ramorum has been identified in nursery material of rhododendron and Viburnum in the Netherlands, Germany and most recently in the UK. A survey by the Forestry Commission discovered *P. ramorum* on Viburnum in nurseries in West Sussex, Dorset, Lincolnshire and Lancashire earlier this year. All infected material was immediately destroyed. Early results of tests by the FC suggest that the UK oaks (*Q. petrea* and *Q. robur*) are not as susceptible as Californian species and that there are differences between European and Californian strains of *P. ramorum*. In response to the threat that *P. ramorum* potentially poses to UK woodlands a series of Statutory Instruments have been enacted to restrict movement of susceptible material in the UK. The Welsh Statutory Instrument 2002 No 1350 (W.130) The Plant Health (*Phytophthera ramorum*) (Wales) Order 2002 (http://www.hmso.gov) came into effect on the 14 May 2002. The order requires that anyone dispatching 'susceptible' material including all Rhododendron species for the purpose of trade or business should provide to a Plant Health Inspector full documentation of the quantities, species, recipient and mode of despatch within one day of despatch. Although this does not restrict the trade in rhododendron foliage if *P. ramorum* is discovered on wild rhododendron it is likely all movements will be prohibited.

Since rhododendron is known to be susceptible to Sudden oak death and it is commonly found in oak woods it is an obvious route for potential infection of native oak woods. This could possibly be used as a means of stimulating interest in rhododendron eradication.

3.3. Biomass for energy production

The use of rhododendron as a biomass fuel is an obvious high volume use of the material. However, as mentioned in Section 1.3.1 it is only going to be profitable to harvest if the whole plant can be chipped on site as it would take a lot of handling to separate the wood from green material. Anecdotal reports suggest that rhododendron makes a superior fuelwood with perhaps the highest calorific value of any UK woody plant. We wanted to test this and to determine the calorific values of green material which is noted as producing a very hot fire.

3.3.1. Calorific value

The calorific value of various parts of the rhododendron plant were determined using bomb calorimetry. The samples tested were: wood and leaves left to dry on site for six months or more and fresh wood and green leaves. Two types of charcoal (single drum and retort – see below) were also tested.

The calorific value of plant material increases as its the moisture content is lowered. Therefore, the wood samples, the air-dried leaves and one sample of the green leaves were milled and then oven-dried at 60°C to reduce their moisture content. A further sample of the green leaves and the green stems were milled, without oven-drying, to estimate the calorific value of burning green material. The charcoals were simply milled as their moisture content would have been minimised during the charcing process. A standard sample of Douglas fir wood (*Pseudotsuga menziesii)* was also oven-dried at 60°C and included in this experiment to provide a reference, as its calorific value is known.

A Gallenkamp Ballistic Bomb Calorimeter was used to determine the calorific value of the samples. Bomb calorimetry permits the complete combustion of a known weight of material in a high oxygen environment. The heat given off by this combustion is measured on a linear scale, allowing comparison of different materials. The bomb calorimeter was first calibrated using benzoic acid (whose calorific value is known) and then replicate sub-samples of each of the above materials were processed through it. The full results are given in Appendix 5 and summarised in Table 3-5 below. Table 3-6 gives the calorific values of various other fuel materials (taken from the literature) for comparison.

Table 3-5 Calorific value of various parts of rhododendron plant compared with Douglas fir

Material	Mean Calorific value kJ g^{-1}
Rhododendron plant parts:	
Air-dried wood	21.85
Freshly cut wood	24.79
Air-dried leaves	20.90
Green leaves	20.96
Green leaves (not oven-dried)	8.98
Green stems (not oven-dried)	9.88
charcoal: Single drum	28.14
charcoal: Retort	34.85
Douglas fir wood	24.39

As mentioned previously, it is expected that calorific value will increase as moisture content decreases. This is observed by the lower calorific value of the green leaves and stems that were not oven dried.

It is, however, interesting to note that the calorific value of oven-dried freshly cut rhododendron wood (24.79 kJ g^{-1}) is higher than that for wood (21.85 kJ g^{-1}) which has been air-dried in the field for at least 6 months. It suggests that a volatile may be present in the wood which burns well when the wood is freshly cut but degrades over time. It has been suggested that green rhododendron leaves burn very well due to their waxy coating and this would appear to be the case as even the green leaves have a higher calorific value than most hardwoods including ash (see Table 3-5).

The calorific value of rhododendron plant parts compare well with other species commonly found in UK forestry. Generally softwoods have a higher calorific value than hardwoods (see Table 3-5) as they contain more lignin, and lignin contributes to the energy value of the species. In our experiment the calorific value obtained for Douglas fir is rather high (24.39 kJ g^{-1}) compared to that given in the literature (21.05 39 kJ g^{-1}), and it is therefore possible that the other values obtained by our experiment are also above average. However, it is encouraging to note that the calorific value of freshly cut rhododendron wood is slightly greater than that for Douglas fir, which has one of the highest calorific values reported in the literature. It is not known at this stage why the calorific value of rhododendron is so high, but may be due to a high lignin content or the volatiles previously mentioned. Whatever the reason, these results suggest that further investigation is worthwhile as rhododendron may make a superior biofuel. The high values for the leaves also suggests that including the leaves and twigs in chipped biofuel would not seriously degrade its calorific value. Even taking the average values for wood and leaves, rhododendron has a higher calorific value than most other woods.

The calorific value of the two charcoals are much higher than that of the wood. This is because moisture and volatiles are driven out of the wood during the charcing process reducing it to dry carbon. The retort kiln operates more efficiently than the single-drum kiln during this process driving more moisture out of the wood. This makes a better quality charcoal, whose calorific value is higher than that of coal. The potential of Rhododendron charcoal is discussed further in Section 4.5.

Table 3-6 Calorific value for woods and other fuels (taken from literature)

Material	Calorific Value KJ g^{-1}	Source
Softwoods:		
Douglas fir	21.05	Tillman (1981)
Western hemlock	20.05	Tillman (1981)
White cedar	17.98	Tillman (1981)
Sitka Spruce	18.80	Reisinger *et al* (undated)
European Larch	17.58	Reisinger *et al* (undated)
Hardwoods:		
Ash	19.09	Tillman (1981)
Oak	18.85	Tillman (1981)
Poplar	19.09	Tillman (1981)
Birch	19.39	Tilman (1978)
Beech	19.67	Tilman (1978)
Other Fuels:		
Peat	27.23	Tillman (1981)
Coal (anthracite)	30.84	Tillman (1981)

3.4. Decomposition of rhododendron

For a mulch to be a useful material it needs to persist long enough once laid down. This part of the study looks at the rate of breakdown (biological decay) of various sources of rhododendron mulch (leaves, chips, wood and composted mulch, fine roots) and compares their breakdown with reference materials (cellulose filter paper, birch leaves, pine, birch and beech wood blocks). The test was performed in a soil burial bin using a "standard" horticultural soil, John Innes No.2 compost. This has been found to give good rates of decay of wood and constitutes an unsterile soil medium. The decay rate is generally fast in this system as essential factors, including aeration, moisture content and mineral content (particularly N) are provided. Decay studies normally take several months to complete so the experiment has been duplicated into a short (25 day) indicative decay experiment and a longer term study (100 day).

In addition the study provides some data on the durability of rhododendron wood, although the test performed was not to the recognised natural durability decay test of the CEN standards (BS EN). However, the test did follow the procedures laid out in ENV 807, which gives an appropriate combined test method for wood blocks and the other plant materials included. Also included in the test are samples of the fine roots of rhododendron. The persistence of fine roots may explain some of the behaviour of rhododendron in reducing growth of other species in cleared rhododendron sites.

Regularly shaped wood blocks were included in the test as surface area to volume ratios markedly affect the decay rates and thus wood block decay rates can be linked to chip decay rates.

3.4.1. Materials and methods

Fresh rhododendron material (Table 3-7) was collected from under conifers close to Glasinfryn and cold stored if not used within three days. Birch leaves were collected from local trees and were air dried prior to use. Reference wood blocks (Table 3-7) were taken from standard laboratory stock, i.e. of sapwood or outerwood, harvested and dried at modest temperatures without biocidal treatments.

Table 3-7 Details of the materials exposed to soil burial

Material tested	Identification code used	Sample quantities (g)	Replication*
Fresh, green Rhododendron leaves	RhL	0.53	2 x 6
Old weathered Rhododendron leaves collected from the litter layer	RhM	0.55	2 x 3
Birch leaves	BirL	0.48	2 x 6
Rhododendron fine roots	RhFR	0.31	2 x 3
Rhododendron pooled wood chips and leaves, i.e. above ground material	RhPC	3.95	2 x 3
Rhododendron wood chips	RhWC	4.47	2 x 3
Commercial mulch, composted	Comm M1	2.62	2 x 3
Commercial wood chip, not Rhododendron	Comm W1	3.57	2 x 3
Whatman No.1 Filter paper	FP	0.51	2 x 3
Rhododendron wood block	RhWB	0.75	2 x 6
Corsican pine sapwood	Cp	1.00	2 x 3
Beech outerwood	BeWB	0.90	2 x 3
Birch outerwood	BIR	0.82	2 x 3

*the “2” denotes that the experiment was run for 25 and for 100 days, i.e. the experiment was replicated

Mesh bags (100 mm square) were manufactured from 1 mm PVC mesh. 100 x 200 mm mesh strips were cut out, folded over and were heat sealed along two of their edges with a Liebherr bag sealer in a running fume cupboard. Mesh bags were then sequentially numbered with indelible felt pen. Bags were then dried in a forced air oven at 60°C overnight, cooled in a desiccator charged with dry silica gel and weighed.

Dry bags were then filled, heat sealed at their ends to close the bags and oven dried at 60°C for 18 h and weighed as above. The initial weights of material for the decay study were recorded as oven dry filled bag weight – oven dry empty bag weight.

Wood blocks were cut to a nominal size of 30 x 10 x 5 mm (L x R x T), numbered, oven dried and weighed as above but at 105°C. Initial oven dry block weights were recorded.

The blocks and bags were then buried in a large rectangular soil bin containing 100 litres of John Innes (JI) No. 2 compost. The bottom of the bins were drilled to allow excess water to drain out and granite chips were placed above this layer to allow good drainage and aeration. Some 50 litres of JI compost was placed above this and the bags and blocks were planted into this layer in a randomised block pattern. The blocks and bags were then buried in the compost by completely covering them with the remaining compost. The moisture content of JI compost was adjusted to give wood block moisture contents of 40-80 % after 2 weeks equilibration, expressed on a dry weight basis. The top of the soil bin was covered with a sheet of board to reduce moisture loss. The assembled soil bins were incubated at 28°C, 65% relative humidity.

An additional set of eight beech blocks (100 x 25 x 5 mm) were machined to monitor moisture content. After numbering, oven drying and weighing, these were planted vertically in the soil leaving the top 5 mm free from the soil surface. Their moisture content was checked at 14, 23 and 100 days by the oven dry method.

At 23 days one filter paper sample (bag 70) was removed and examined visually and by weight loss. It looked to be extensively decayed and weight loss was sufficient for the early set of samples to be examined. The initial test was therefore terminated after 25 days incubation. The second part of the test was terminated after 100 days. At this time the filter paper had completely degraded.

The sets of samples were removed, weighed, oven dried, weighed and then washed (to remove adherent soil particles), oven dried and reweighed. Results are expressed as percentage weight loss and percentage moisture content expressed on a dry weight basis. Moisture content data are included because insufficient water will prevent decay, whereas too much will reduce aeration and retard decay; the results demonstrate that suitable conditions have been used.

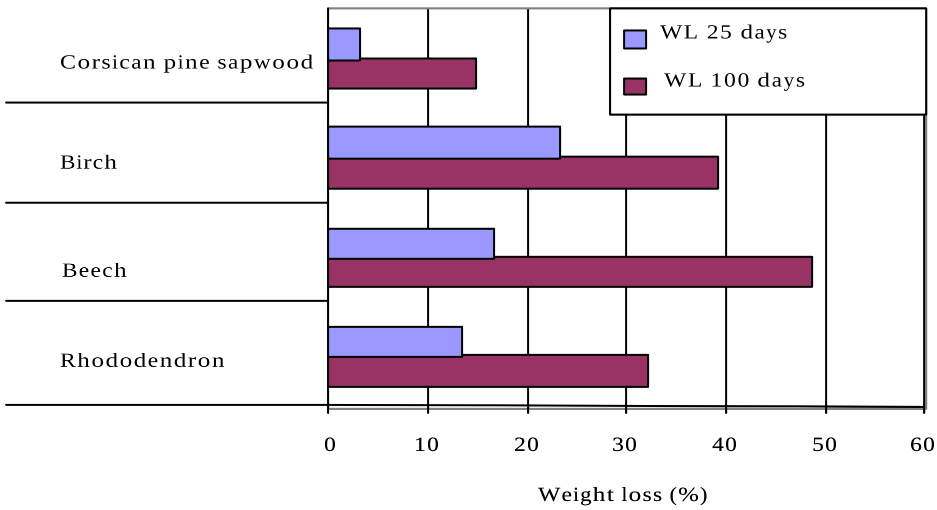
3.4.2. Results

The mean weight losses and moisture contents are shown in Table 3-8 and Figure 3-4 for wood blocks.

Table 3-8 Mean weight loss (%) and final moisture contents of wood blocks decayed for 25 and 100 days in soil burial.

	25 days exposure		100 days exposure	
Specimen identity	**Weight loss (%)**	**Moisture content (%)**	**Weight loss (%)**	**Moisture content (%)**
Rhododendron wood	13	71	32	106
Beech wood	17	61	49	117
Birch wood	19	62	39	103
Pine sapwood	3	35	15	48

Figure 3-4 Weight losses of wood blocks after 25 and 100 days soil burial



The results with the wood blocks (Table 3-8, Figure 3-4) showed rapid decay after only 25 days exposure: birch and beech blocks lost the most mass (19, 17% respectively), rhododendron 13% and pine the least (3.0%). After 100 days exposure there was greater decay with beech (49%) than the birch (39%). These high decay rates are expected and these species were included in the test for this reason. Rhododendron showed similar but slightly lower decay (13 and 32% at the two exposure periods) than the beech and birch.

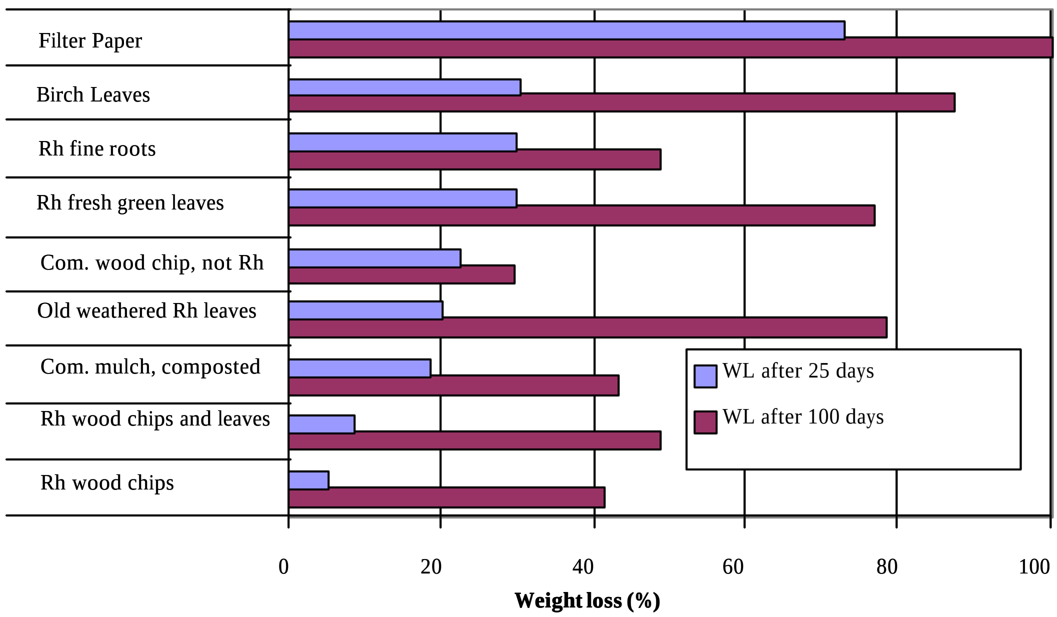
The results show a high rate of decay indicating optimal decay conditions in the soil burial test. The moisture contents are all above 25% and are within the optimal range. The lower decay rate of the pine (3 and 15% at 25 and 100 days respectively) is attributable to the higher content and type of lignin in pine. In a natural durability ranking none of these species would be regarded as durable for structural purposes but the woody material will persist for some years in the soil in a partially decayed form, consisting of degraded lignin.

The results for the litter bag experiements are given in Table 3-9 and Figure 3-5.

Table 3-9 Decay and final moisture content of leaves, fine roots, wood chips and partially decomposed mulch.

Specimen identity	25 day exposure			100 day exposure	
	Initial weight loss (%)	Moisture content (%)	Weight loss after wash (%)	Moisture content (%)	Weight loss after wash (%)
Fresh, green Rhododendron leaves	-13.6	139	29.6	109	76.7
Old weathered Rhododendron leaves collected from the litter layer	-6.9	100	20.1	122	78.1
Both sets birch leaves	-27.5	107	30.3	81	87.4
Rhododendron fine roots	-4.1	89	29.8	92	48.4
Rhododendron pooled wood chips and leaves, i.e. above ground material	2.2	57	8.4	61	48.6
Rhododendron wood chips	-1.1	51	5.1	99	41.4
Commercial mulch, composted	2.2	64	18.6	107	43.0
Commercial wood chip, not Rhododendron	11.0	58	22.5	109	29.6
Filter paper, both sets	-5.4	79	52.4	112	100

3- Weight losses of different plant parts after 25 and 100 days soil burial



-9, Figure 3 5) initially experienced some problems. With one set of samples, the composted commercial mulch, the material in the bags was break being put into the decay experiment so the weight loss results are suspect in that they may be too high. With the other samples the soil particles entered into the mesh of the bags during soil exposure and *gains* in we the initial analysis of weight loss the bags were washed briefly for 2 minutes in cold deionised water to remove adherent soil particles. In the event this is only likely to have caused mulch which already contained small soil particles.

The before washing results (initial weight loss, Table 3- results are not presented for the 100 day exposure and are ignored for the purposes of comparison. After washing, the highest weight losses were noted with the filter papers (52, 100% means 25 and 100 days). The fresh leaves of rhododendron, the dried birch leaves and the rhododendron fine roots also showed high decay (*ca.* 30%) to similar amounts after 25 days but after 100 days the fine roots showed much lower decay than the leaves. Old weathered leaves showed less decay after 25 days (20%) than the fresh counterparts (30%), but after 100 days both fresh and old leaves showed similar decay amounts, somewhat less than the birch. Initially the fresh leaves will decay rapidly due to the stimulating effect of free sugars; these will have been depleted in the old dry leaves. The differences between the birch and the rhododendron at 100 days indicates that there is some resistant material in the leaves, probably polyphenolic, or lignin-like. There is little indication however, that the toxins seen to be present in the leaves has any effect on the decay rates, in this test which is designed to stimulate microbial, not invertebrate, activity.

The composted rhododendron mulch and fresh commercial wood chips initially decayed at similar rates to the weathered leaves (*ca.* 20%), considerably more than the fresh pooled wood chip material (8%) or the fresh wood chips (5%). This initially indicated that the fresh rhododendron material may persist longer than other mulches but that this effect may decline with storage. After the 100 day decay period the weathered rhododendron leaves were much more decayed (78%) than the rhododendron wood chips (*ca.* 41 - 49%) but the non-rhododendron commercial wood chip mulch was less decayed (29.6%).

3.4.3. Discussion

If the decay method used is valid, i.e. due to the washing to remove grit, the results indicate fast rates of decay in the artificial decay environment used. Early indications (25 day) were that that the fresh rhododendron mulch had the potential advantage of a longer life as compared to other wood chip sources but the longer exposure (100 day) showed the reverse, i.e. greater decay in the rhododendron. Given that the rhododendron wood blocks showed an essentially low decay resistance the performance of the rhododendron mulch in terms of decay should be adequate and better than many other hardwoods (i.e. birch and beech). In comparison with softwood mulches they may not last as long but this may not entirely be an advantage: woody material will breakdown and act as a soil conditioner.

It is surprising that the rate of decay of the birch leaves was similar to those of rhododendron. Studies by Bocock (1964) indicated that rhododendron leaves were much more resistant than birch leaves and were similar in persistence to beech leaves. It is possible that the fine mesh used in the experiment excluded the microfauna to a significant degree and that the decay was mainly microbial. This may have cause a significant reduction in the decay of birch leaves as it is unlikely to have any chemicals which markedly affect the microfauna whereas compounds in rhododendron may reduce the activity of the microfauna when they are given access to rhododendron leaves.

Another important difference in this experiment is that the leaves are within the soil rather than on the surface as they would be in a mulch system. Under the conditions used in this experiment this will markedly increase their rate of decomposition by supplying a constant source of moisture and mineral nutrients.

It has been observed in the field that the decay rate of the rhododendron leaves on the soil surface appears slower in areas where there is pure rhododendron leaf litter under a rhododendron stand than where the leaf litter is mixed with other leaf species, e.g. oak. It is possible that the higher rates of decomposition in this case are because other leaf species support the microfauna sufficiently so that they can tolerate some rhododendron. In addition frass and rejectimenta may start to bury the rhododendron leaves into the litter layer where they may become wetter and decay will be enhanced. The size and waxy nature of the dead but intact rhododendron leaves in a pure rhododendron leaf litter may reduce leaf wetting and consequently decay.

The oven dry, dead roots did not show any special decay resistance but they are similar to the woody material.

The resistance of rhododendron wood to insect attack is not examined here. Anecdotal evidence suggests that little insect attack occurs and its incorporation into boards could lead to a more insect resistant board.

blished on several soil sites in combination with a spring timed mulch trial.

3.5.

Mulching has traditionally been used as a weed management technique both in agriculture and amenity marily by preventing sunlight reaching the soil surface and also as a physical barrier to plant growth. It has been suggested that rhododendron releases alleopathic compounds which nt in the mulch then it may confer a chemical weed suppression advantage to rhododendron mulch. Such effects have been observed -derived mulches. For example, Rice (1995) reports an investigation done by Putman and DeFrank effects of allelopathic crop residues on emergence and growth of annual weeds. This study used sorghum (maize) residues and found that weed populations were reduced by up to 98%,

found in species that have medicinal or anti- those that cause allelopathy (Nilsen *et al* *Rhododendron* family is well documented as being used ewing insects that attack species within the family (Nilsen 1999). The allelopathic properties of *R. maximum* were investigated by Nilsen *et al* study concluded that direct allelopathic influences cannot be considered an important factor associated with inhibition of seedling survival under , it was argued that the results did not rule out indirect allelopathic effects, for example, the r bacteria and invertebrates resulting in reduced soil nutrient availability. Lower nutrient availability is reported as being characteristic of forests where is present and may be an important factor in

evergreen layers is a common trait.

Boettcher (1991) found that earthworm density was significantly lower in mineral soils under both yellow *Liriodendron tulipifera*) and eastern hemlock ( ) when *R. maximum* understorey, compared with the population under the same two tree species when rhododendron was absent, supporting Nilsen's hypothesis.

Studies h subsequent plant growth. A study by Pickering and Shepherd (2000) carried out at the Royal Horticultural Society's gardens in Wisley, Surrey found that wood and bark ba subsequently planted and that wood chips, even though more acidic at the beginning of the experiment, led to a pH level significantly greater than the control at the end of the experiment. This was not true for k derived mulches indicating that wood chips would be make a superior mulch material in North Wales when compared to bark, as the soils here are predominantly acidic.

We set up a series of experiments with the aim of investigating whether rhododendron material exhibited -suppression properties than other mulches easily available in the Snowdonia area. If this

to its competitors. We were particularly keen to see if enhanced weed suppression properties meant that

confer a definite benefit. The Royal Horticultural Society recommend an application of 8 cm of mulch to

terms of direct use and transportation (Carter 1990).

Methods

The aim of the experimental work carried out was to explore whether, apart from acting as a physical

properties. The full protocol for this work is given in Appendix 6 and illustrated by Plate 3-

Plate 3-1 Layout of weed suppression experiment

Seven different mulches made from rhododendron, a locally available commercial wood chip, a synthetic mulch and a control with no mulch were tested to determine which were the most efficient at reducing weed appearance in a controlled environment. The mulches tested were:

1. Shredded rhododendron leaves. Section 3.1 indicates that levels of grayanotoxin are highest in green material and so we investigated whether higher levels of this toxin (or any other toxins present in the leaves) would affect germination.
2. Chipped rhododendron wood – average size 1.5 x 1.0 x 0.5 cm. While it is known that there are higher levels of grayanotoxins in the leaves, commercial mulches are more commonly sold as wood chip. Introduction of chipped rhododendron wood onto the mulch market would be easier than chip containing shredded leaves or shredded leaves on their own, as it would fit better with the perceptions and expectations of the mulch market.
3. Rhododendron root material was also included in this experiment as it has been suggested that the allelopathic effect observed in the rhododendron family is due to root exudates.
4. Whole rhododendron bushes were also chipped giving a mulch containing both woody stems and leaves, termed 'pooled chip' in this experiment. It is suggested that this would reduce processing costs on site if leaves do not have to be separated from stems, and may have added allelopathic effects due the inclusion of the leaves.
5. A locally produced non-rhododendron wood chip – average size 2 x 1.5 x 0.5 cm was included in the experiment to provide a comparison with how the commercially available market alternatives would perform.
6. A locally produced wood mulch, consisting of partially decomposed wood chip, was also included.
7. Finally, a synthetic mulch (hydrolite) was included, to provide an indication of how much weed suppression effects observed could be attributed to the physical effects of blocking out light and how much can be attributed to any phytochemicals in the mulch itself.

Trifolium repens (white clover) was selected as the 'weed' in this experiment, as this species is commonly found growing in North Wales. We used a local provenance from Aberystwyth, courtesy of Western Seeds, based in Pembrokeshire.

Within a controlled temperate greenhouse environment (20°C day, 18°C night, photoperiod 16 hours), trays were sown with 48 white clover seeds and then covered with 2 cm of each of the mulch treatments. minimise effects that could be attributed to physically blocking out light and therefore increase the likelihood of observing phytochemical effects. There were

tray were recorded every day for 14 days. The mean number of seeds germinating under each mulch treatment are tabulated below. The full outputs

3.5.2. *Results*

Table 3- rhododendron leaf mulch (mean per tray = 41.75) when compared to the control (mean per tray = 47.25). The commercial chip and mulch also perf 42.75 respectively), also significantly reducing the number of seeds germinating when compared to the control.

While the number of seeds germinating under commercial chip was slightly less than u rhododendron leaf, there was no significant difference between the number of seeds germinating under these two treatments, indicating that shredded rhododendron leaf performs as well as mulch materials

The mean number of seeds germinating per tray under rhododendron wood chip and pooled rhododendron chip was 46.00 and 43.50 respectively. Although neither of these treatments performed as the presence of leaves in the pooled rhododendron chip has reduced the number of seeds germinating when compared to the wood chip.

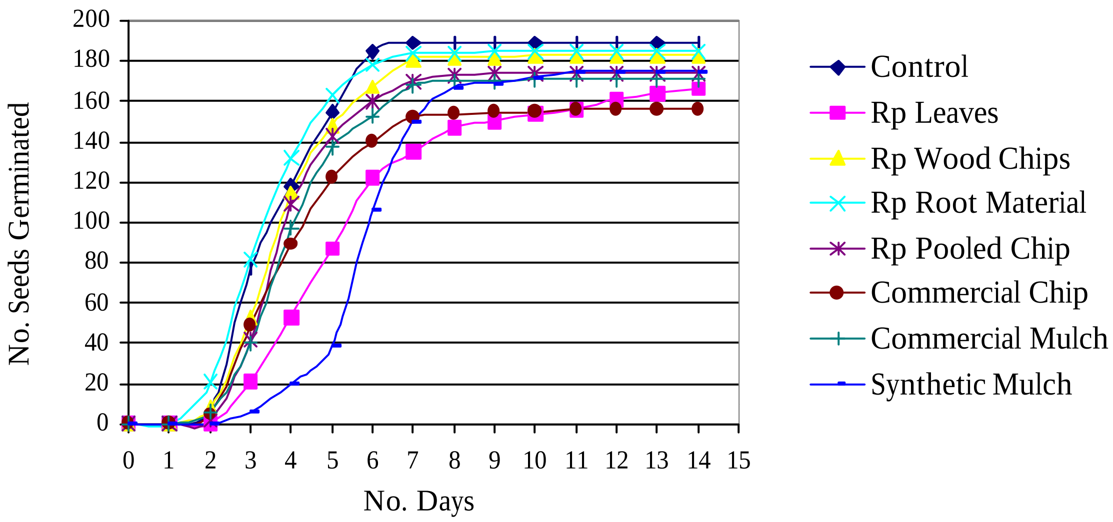
Table -10 different mulch treatments

Treatment	Mean number of seeds	germinating	deviation	Significantly different from
	47.25	98.44		-
Rhododendron shredded leaves		86.98	0.50	
Rhododendron wood chi	46.00	95.83		No
Rhododendron root material		96.35	1.26	
Rhododendron pooled chip	43.50		2.52	No
	39.00	81.25		Yes
Commercial wood mulch		89.06	2.22	
Synthetic mulch	43.72		1.26	No

The mean num barrier to light, without any chemical effects) was 43.75. Both the shredded leaves and the pooled chip (containing leaf material) suppressed seed germination more than significant in this test).

The length of time to 100% germination was also investigated. Plotting number of seeds germinating against time gives a germination curve for each of the treatments as illustrated in Figure 3 6.

Figure 3-6 Germination curves for white clover under the different mulch treatments



lowest in the commercial chip treatments (3.48%), closely followed by the pooled rhododendron chip and the shredded rhododendron leaf mulch (4.85 and 5.56% respectively). These differences were not statistically significant. However, the mean number of seeds germinating under the rhododendron shredded leaf, the rhododendron pooled chip and the commercial wood chip treatments were significantly lower than the number of seeds germinating under the synthetic mulch treatment (22.92%).

This again indicates that rhododendron mulches perform at least as well as mulch materials currently available in the local market and, while not statistically significant, their performance is improved if shredded leaf material is included in the mulch. This may be worthy of further study.

3.6. Phytochemistry

The *Rhododendron* family is a rich source of chemicals and form the basis of various traditional medicines (Table 3-12), particularly in China. Apart from the major components present as part of normal cellular metabolism and structural components (e.g. i.e. those which make up wood) there are a variety of other chemicals which can be extracted in various solvents, often referred to as extractives. These chemicals make up a small percentage of the total dry weight of the material although some of the more pharmacologically active compounds are only present in trace amounts (less than 0.001%).

Table 3-12 Medicinal uses of *Rhododendron* species

Species	Potential use	Country	Reference
R. adamsii	Flower tea -> stimulant	Mongolia	Anon.1991
R. albiflorum	Wood ash -> swellings Bark -> stomach remedy Buds -> colds and sore throats Chewed buds -> wound dressing Buds -> ulcerated stomach	Canada USA	Moerman undated
R. anthopogon	Leaves & twigs -> aromatic oil	Nepal	Rawal undated
R. dauricum	Traditionally: Dried leaves -> expectorant & acute/chronic bronchitis Clinical: Anti-inflamatory etc. Laboratory: Potent anti-HIV activity	Japan China	Kashiwada *et al* 2001 Cao *et al* 2001
R. ellipticum	Leaves -> hypertension	Taiwan	Ho & Lin 1995
R. ferrugineum	Traditionally: Medicine & tonic -> rheumatism	Germany	Chosson *et al* 1998
R. latoucheae	Traditionally: Flowers & leaves –> skin festers Roots -> paregoric and antidote Leaf tea -> chronic tracheitis	China	Fan *et al* 2001
R. molle	Flower	China	Liu *et al* 1990

The chemicals concerned fall in a variety of categories and their detection is often dependant on the method of extraction and analytical system used, so that any one paper listing the compounds present does not constitute an exhaustive list and a full characterisation is a laborious process. In this part of the study the literature relating to the compounds present in the genus *Rhododendron* has been examined.

The compounds of interest are often present as plant defence compounds against attack by fungi, insects and other herbivorous animals, for example, grayanotoxins in *Rhododendron* are in their highest concentrations in the bud scales and young shoots where sheep and other herbivores are most likely to graze.

The extractives from rhododendron species reported include a variety of biochemically active alkaloids, terpenes, phenolic acids, polyphenols, flavanoids and others (Table 3-13). Such isolates can form the basis for pharmaceutical products as well as herbal remedies although there is a body of non-scientific opinion that many herbal remedies work better as natural crude forms rather than isolated and purified products. The complexity of many of the compounds means they can be difficult or extremely costly to synthesise and so are extracted from the plants. This could provide a lucrative market for specific parts of the plant (e.g. leaves, twigs and flowers) where the phytochemicals are in higher concentrations.

The chemicals isolated from Rhododendron species listed in Table 3-14 have a range of actions from an expectorant (*R. latoucheae*, *R. dauricum*), anti-oxidants (a variety of compounds in a variety of species, e.g. *R. simsii*: 3,4-dihydroxybenzoic acid, methyl 3,4-dihydroxybenzoate) through heart stimulant (*R. adamsii*) to one with potent action against HIV (*R. dauricum*, daurichromenic acid). There have been a number of studies of the phytochemistry of *Rhododendron*, notably by Keller *et al* (1970a, b and c) in East Germany and also in America (US Agricultural Research Service) – see Table 3-14. There is also work that is ongoing by Molecular Nature Limited based in Aberystwyth (Nash p*ers comm*). Given that the most recent extensive studies have been done on *R. dauricum* have shown some potentially useful compounds the phytochemical compounds of *Rhododendron* should be looked at in more detail.

Table 3-13 Identified phytochemicals from *Rhododendron* species

Species	Phytochemical	Reference
R. dauricum	Chromene and chromane derivatives	Kashiwada *et al* 2001
	Farrerol	Cao *et al* 2001
	Quercetin	
	Phenolic acids	
R. ellipticum	Quercetins	Ho & Lin 1995
R. ferrugineum	Phloracetophenone glucodide	Chosson *et al* 1998a
	Dihydroflavonol glycosides	Chosson *et al* 1998b
	Flavonoids	
R. latoucheae	Iridoids	Fan *et al* 2001
R. molle	Diterpenoids	Liu *et al* 1990
R. ponticum	Sterines	Keller *et al* 1970c
	Triterpenes	
	Acetylandromedenol	Keller *et al* 1970b
	Ursolic acid	Keller *et al* 1970a
	Uvaol	
R. ponticum x catawbiense	Salidroside	Thieme *et al* 1969
R. simsii	Triterpenes	Takahashi *et al* 2000
	Flavanone glycoside	
	Matteucinol	
	Benzoic acid derivatives	

Table 3-14 Phytochemical compounds in *Rhododendron ponticum*

Chemical	Source	N plants containing compound	Rhody position in list	N of biological activities	Pesticide	Active against:					Medicinal	Pigment
						Cancer	HIV	Bacteria	Yeast	Fungi		
(+)-Catechin	Leaf						+				+	
(+)-Gallocatechin	Leaf										+	
Acetylandromedienol	Leaf											
Acetylandromedol	**Leaf**	**2**	**2**	**1**							**+**	
Alpha-amyrin	Plant			4		+					+	
Andromedolditerpenes	Leaf											
Arbutin	Plant	17	13	11	+			+	+	+		
Beta-sitosterol	Plant			37		+			+		+	
Caffeic acid	Plant	30		69	+	+		+		+	+	
Chlorogenic acid	Plant	30		62	+	+	+	+				
Delta-10(18)-acetylandromedol	Leaf											
Epicatechin	Leaf	26	17	29	+			+			+	
Friedelin	Plant	22	19	2							+	
Gossypetin	Plant	5	4	6	+			+				+
Malvidin-3,5-diglucoside	Plant											
Malvin	Plant	3	2	2							+	+
Myricetin	Plant	30	25	31	+				+		+	
Rhododendrin	Plant											
Simiarenol	Leaf											
Tannin	Leaf	30		32		+	+	+			+	
Ursolic-acid	Leaf	30		57		+	+	+			+	
Uvaol	Leaf	7	6	5		+					+	

Source: Dr Duke's Phytochemical and Ethnobotanical Databases, Agricultural Research Service, USDA

Notes:
Acetylandromedol is a former name for Grayanotoxin.
No numbers in the table signifies that only traces of the compound have been identified in *Rhododendron ponticum*

4. POTENTIAL USES

The study concluded by considering a range of potential uses for rhododendron in terms of its suitability for the use, markets and pricing.

4.1. Floristry

The shoots of rhododendron are used by florists as a backdrop to flower arrangements and for long-lasting wreaths. Marketable shoots must be straight, 60 cm long and composed of perfect, regular leaves. Standards are high and quality control is important. Several clearance projects have been able to sell rhododendron stems to the wholesale floristry market and it has been advocated as a means of contributing to the control of the plant which pays for itself (Robertson 1999). Unfortunately, the best quality stems are two years old and it seems that this is sufficient time for the stump to store sufficient resources to keep it alive indefinitely. Repeated cutting of younger material can kill the stump but experience suggests that the this needs to be flushing buds and it still takes several (seven) years to kill the stump. Therefore it appears that foliage harvesting will not kill the plants but would at least prevent them from flowering and may provide a small income that could be used to fund other clearance activities.

4.1.1. Markets

We spoke to four enterprises who collect and wholesale in foliage and have some interest in rhododendron to try and get an impression of the market.

Two of the enterprises deal directly with the local (UK) market. The larger of these sells 7 million rhododendron stems a year directly to the UK supermarkets. This is obtained from 36,000 acres over which he holds a contract with the FE and other landowners and provides employment for 36 people. However, he suggests that the UK market is completely saturated and the strong pound means that it is not possible to get good prices for sale to Amsterdam. This impression was corroborated by a north Wales based trader who said that the UK market for temperate foliage is declining as fashions change to favour tropical foliage imported from countries such as Costa Rica.

The two exporters we spoke to gave a quite different impression. Both suggested that the Amsterdam based demand was insatiable and they would be able to sell as much rhododendron as Wales could produce. Typical quantities currently being traded are 200,000 stems per week with demand for 5 to 6 times current supply. Both exporters are consequently keen to expand the area over which they collect and have a preference for establishing areas of land over which they can cut rhododendron on two-year re-growth cutting cycle. One trader says that the foliage cut from rhododendron under conifers is superior to that cut in the open. All shoots are harvested and later graded so management effectively prevents the plants from flowering.

The foliage trading companies are prepared to enter into licensing or contracting arrangements over areas of land but these are presently only token payments. For example the FE only charge £200 a year for a license to collect foliage over the whole of Argyll and Bute. This would not in itself provide an income but it may be possible to negotiate a higher rate if there is demand for the resource. Foliage cutting is seasonal (August to May) although increasing demand for budded shoots and flowers is extending the season. One contractor organises his own labour while the other uses freelance pickers. In one case the price per stem was extremely low at 0.35 p per stem though it is not clear if this is all the pickers get for their work. The other collector pays 90 p per bunch of 20 and since a picker can expect to pick 50-100 bunches of 20 stems in a day this translates into a daily income for picking of £45-100 per day and £500-600 a week. Large volumes are required for the export market and one trader said he needs to be able to move more than 2000 bunches a week to cover transport costs.

None of the traders mentioned the new regulations governing the commercial movement of rhododendron material (see Section 5). This is probably because they are very recent (May 2002) and are not yet in force on the ground. Phytosanitory precautions for movement of rhododendron are likely to increase if widespread *P. ramorum* infection is found in Europe. How this will affect the foliage trade is not yet apparent but it is conjectured that the foliage trade contributed to the spread of Sudden oak death in California.

4.1.2. Logistics in Beddgelert area

The information collected suggests that large scale foliage collection would not directly contribute to the clearance of rhododendron as the plants are not killed by cutting the preferred two-year old regrowth. However, it might be possible to set aside an area of heavy infestation for rhododendron shoot management with profits ploughed into clearance projects elsewhere. Both the interested contractors mentioned that they see the main advantage of the foliage trade being the provision of rural employment, indeed this is something that would be attractive to Objective 1 funding. However, although the traders are evidently making a profit little revenue is returned to the landowners (for example, the National Trust). Given it appears that there is demand for access to new rhododendron stands it may be worth considering negotiating a price and management 'rules' for rhododendron harvesting.

A quick sample of 0.1 ha of recently cleared mature rhododendron in Craflwyn confirmed the finding of Moroney (1997) that rhododendron densities in the open is around 1200 stumps per ha. A quick assessment was made of the number of vigorous stems likely to be harvestable after a years growth. Our counts suggest that there may be as many as 32 harvestable stems per stump giving a potential yield of perhaps 37,500 stems per ha. This would be represent a picking income of £1,700 per ha every two years.

4.2. Turning

In response to a request for ideas on things that could be done with rhododendron that we put out on the Welsh Timber Forum website, the Woodland Turnery in Pontypool offered to turn some rhododendron. This is their report:

1) Although slightly wet when I started to use it I found it very good and easy to cut to my requirements on the bandsaw.

2) I didn't get any nasty smells or irritations when I started to use it. Although I did work with it carefully.

3) It was brilliant to turn as it was a good consistency and pleasant to turn like Hornbeam but not quite so dense.

4) It is a very white wood once turned and holds it's colour well (some woods start out white but go greyish quickly once turned and exposed to the light).

5) When making bobbins, tends to wobble a bit on the neck of the bobbin 1/8th inch thickness (see samples to follow) some other woods do this too (example - Elm), others don't.

However, the Powis Estate reports that they offered rhododendron turning blanks for sale without much success. This may be because rhododendron is not well known for this purpose, rather than not very good, given that it is suggested it has superior qualities for turnery. Turnery is never likely to be a large user of rhododendron wood but could possibly be marketed at a premium, especially with a 'Save Snowdonia' label attached.

4.3. Commercial mulch

The work undertaken on the decomposition and weed suppressing properties of rhododendron wood chip suggests that it has some potential as a horticultural mulch.

4.3.1. Feasibility of selling rhododendron mulch in north Wales

The various considerations that must be addressed if the rhododendron resource in Snowdonia is to be used as a mulch are discussed below.

The most economical way to transport large volumes of rhododendron is as chipped material, due to the 7:1 decrease in volume on chipping. Chipping on site, or as near as possible to this would be recommended. Costs for mechanised clearing and chipping of rhododendron (on favourable sites) are given in Section 2.3 and range from £60-120 per m^3 at roadside. If the mulch buyer will not accept green material within the chip, then removal of leaves would add to this cost.

As discussed previously, it has been suggested that the market is currently flooded with arisings from forestry thinning operations, although there appears to be only one local entrepreneur who is selling arisings as chip and mulch for around £21 per m^3 (£40 per tonne) and selling around 300 m^3 of wood chips per year. From the figures derived in Section 2.3, this indicates that this contractor is selling the chip at cost price.

Prices paid for mulch increase if the seller enters the market aimed at small scale gardeners through retail outlets such as B&Q or the Holland Arms Garden Centre (two large retailers of garden products in the area). Here mulch typically sells for around £5.99 for an 80 litre bag (£448.50 per m^3). After deducting the costs (£60 per m^3) this affords a massive profit of around £400 per m^3.

Alternatives within the market include other forestry residue products such as bark and wood chips from other woody species. Discussions were held with Jenkinsons, the largest dealer in sawmill residue in the UK, based in Cumbria. They pay £20-£22 per tonne for small diameter hardwood and hardwood chip delivered to Cumbria, but have never been offered and would not accept rhododendron. They felt that it would be difficult to achieve economical throughputs feeding any chipper with rhododendron and that there are plenty of alternatives easier to handle and chip.

In terms of quality requirements, there are currently no British standards that control the sale of materials for mulch, unless it is to be sold specifically for play areas and then it must conform to BS/EN1177:1998 (which stipulates impact absorption and sharp edge standards). It may be advisable to test to BS4790:1987 (an ignition test for fire safety) if the mulch is to be used on an area of potential fire risk, such as in car parks or in fuel filling stations.

In addition to the mulch market, the BRMG may like to consider the animal bedding market. We have not had the time to fully investigate the potential of this market, but it has been recommended as it is thought to be growing. Straw is currently selling for £50 per tonne in North Wales and is very expensive to transport due to its low density. There is a £10 per tonne economic advantage to purchasing wood chip over purchasing straw, and this benefit must be increased once transport costs are also taken into account. The lack of toxicity in the wood reported in Section 3.1.5. coupled with a small trial of sheep on rhododendron bedding at the university farm, which reported no ill effects (Hale *pers comm*) imply that there should be no side effects on animal health from using rhododendron as animal bedding.

We have as yet been unable to identify individuals or organisations willing to purchase large volumes of rhododendron wood chip in North Wales for sale either as mulch or as animal bedding. We would therefore recommend that if the BRMG did want to pursue this option, revenue would be maximised if they could manage the enterprise themselves and if they could access the small scale horticulture market.

Before any large scale rhododendron clearance is undertaken, it is again recommended that a consultation period be undertaken with all stakeholders to discuss issues such as the possibilities of local employment, any predicted effects of increased haulage activity on road traffic, and the affects on the general public of rhododendron clearance (especially on-site chipping) both on health and safety and on the amenity value of the local area.

Although none of our studies demonstrated this to be a problem, we recognise that viable rhododendron seed may be present in chipped material. The risk posed by this possibility needs to be determined.

4.4. Biomass markets in the Beddgelert area

There are currently no combined heat and power plants within the economic catchment of Snowdonia for transporting biofuels (it is generally accepted that the economic threshold for haulage sets the maximum distance from fuel source to plant at no more than 50 miles (T Jenkins *pers comm*) There is, however, a company (Engi-Torren of Llangefni) offering heat supply contracts. This company sells heat that is produced by burning woodchips to customers who have customised boilers on their premises. The customers' consumption of hot water is metered and charged at 3 p per kW h^{-1}.

At present the size of the local biofuel market is small as the technology is still unfamiliar. Biofuel operators presently pay up to £10 per green tonne for roadside material which is comparable to other chip markets. The low market value can be attributed to the enormous competition from other cheap small roundwood sources. This is not favourable given the estimated 'best case scenario' costs in Section 2-3 for mechanised extraction to roadside for rhododendron being £30 per m^3 (£57 per tonne, as rhododendron has a density of 525kg per m^3).

The Centre for Alternative Technology in Machynlleth has been using rhododendron chip in their wood chip boiler. They suggest that rhododendron chip does "burn better than any other wood and certainly cheap wood chips". It was suggested this could be due to its low moisture content, as the wood dries out very rapidly if the leaves are retained. Small diameter wood was found to be easy to chip, but they agreed that the market is currently flooded with low grade forestry waste so only low prices would be fetched if rhododendron was sold in this market.

There are various other considerations that must be addressed if the rhododendron resource in Snowdonia is to be used as a biofuel (Note: these considerations also apply to removal of rhododendron in any great quantity for any purpose from the National Park).

Firstly there is the issue of seasonality of supply. Rhododendron clearance is not practiced during the nesting season due to conservation concerns, and so as a biofuel this discontinuity of supply must be able to be absorbed within the market.

In terms of economic feasibility, most biofuel buyers would prefer the material as roundwood, but without leaves. It seems unlikely that the prices paid would cover the cost of extraction and sorting and the leaves still have to be disposed of. The high calorific value of the leaves also suggests that sorting would be a waste of a potential fuel. Attempts should be made to verify and then publicise the quality of chipped whole rhododendron as a biofuel.

British BioGen (the trade association of the UK bioenergy industry) also recommend a consultation period before engaging on wood fuel supply initiatives, with all stakeholders. This process should be fairly straightforward for the BRMG representatives of most stakeholders sit on this group. During consultation it would be important to discuss issues such as the possibilities of local employment within any biofuel initiative, any predicted effects of increased haulage activity on road traffic, and the affects on the general public of rhododendron clearance (especially on-site chipping) both on health and safety and on the amenity value of the local area.

Generally, it is expected that the renewable energy market in the UK is likely to grow significantly due to government policy supporting energy from renewable resources (British BioGen *u.d.*). British Biogen suggest that funding may be available to support renewable energy projects using wood fuel and offer themselves as a contact point for details of potential funding. However, there appears to be intense competition within this market from arboricultural thinnings (some of which would alternatively have to be landfilled, therefore being subject to landfill tax and are subsequently available at no cost to those wishing to use them) which is driving down prices within the market. However, rhododendron biomass is such that it may be able to compete with thinnings and forestry wastes if the costs of clearance are subsidised.

4.5. Charcoal

The economics of charcoal production from the Craflwyn estate was provided by Moroney in 1997. The manufacture of the charcoal required for the toxicity study also provided an opportunity to collect ancillary information on the economics and logistics of small scale charcoal production.

Of the three methods, the double retort system appeared to be the cleaner, most efficient and quickest. Temperatures reached in the retort were higher and, because the gasses vented off were also burnt, it is likely that less potentially polluting smoke is produced. These gasses also helped to fuel the burn, so that the overall amounts of fuel used were reduced. More investment in equipment is needed, but the retort and metal stands could still be fairly easily moved between sites if necessary. The soil clamp method appeared to be the most time consuming, and least efficient, though no additional equipment is needed. If alternative, larger scale charcoaling equipment was not used, then one system might be to run several double retort kilns simultaneously.

Charcoal prices (£ per kg for 5kg bags)

Warrington shop	0.550
Tesco	0.596
B&Q	0.794
Safeways	0.798
Bob Shaw	1.500
GF Organics	2.020
Average:	1.043

Current prices for charcoal are very low due to depression from cheap imports, unfortunately often from countries with fuel crises of their own. In this climate it is all but impossible for small scale colliers to make a profit. Larger scale producers survive through economies of scale and also through large contracts to supply large retailers such as B&Q. Retailing through garages and informal outlets is not profitable unless the supplier already has a reason to pass by (Bioregional Charcoal *pers comm*). In the current climate the best option for rhododendron as charcoal would be to sell to a large scale manufacturers. These operations have large retort kilns which require 3.5 m^3 of wood per burn cycle and need sizes of between 7 and 15 cms diameter and 60 cm length. Bioregional Charcoal organises the B&Q contracts and says that size and quality grading for this market is strict and increasingly is wanting the wood to come from FSC certified woodlands. This poses a considerable barrier to rhododendron wood.

Perhaps the only option for rhododendron charcoal would be the establishment of an activated charcoal manufacturer locally. Activated charcoal is a very high value product which has a steady demand in the UK all of which is presently met from imports from France. Retort charcoal from rhododendron has a very high calorific value and might be suitable for activation.

5. CONCLUSIONS

The study has been a feasibility study and has necessarily looked at many issues. Some of these such as the detection of grayanotoxin turned out to be much more time consuming that anticipated. The results of the study are encouraging, in that we were able to get some results for every study component. However, several areas require more data to provide conclusive results.

Biomass tables for rhododendron were developed for open grown sites but more work is needed to develop similar tables for shaded plants. Overall biomass and volume yields of rhododendron are low on a per ha basis and the form of the plant makes it particularly difficult to harvest. Harvesting costs are higher than for conventional forestry operations and would need to be subsidised in some way to make rhododendron chip competitive.

The costs of rhododendron harvesting are high given that most activity involves hand clearance albeit often using volunteer labour. Simple estimates of the relative costs of harvesting rhododendron using conventional mechanised procedures suggests that costs per cubic metre for rhododendron would be four times higher than timber from conventional forestry. This is mostly because the volumes available from rhododendron are small while the logistical difficulties are high. It appears that bulk harvesting of rhododendron will un uneconomic unless subsidised or the harvested material can be sold at a substantial premium.

Chipped rhododendron was found to have similar decomposition and weed suppression properties to other wood chip and would make an acceptable mulch. Rhododendron wood has a high calorific value which matches that of Douglas fir which is the best of the forestry species. Indeed all rhododendron parts including the leaves have high calorific values and would justify the use of whole plant chip in biomass plant. If a premium where available for higher calorific value material this might help to offset the higher production costs of rhododendron.

Perhaps the most significant findings of the study is the absence of grayanotoxin III in rhododendron dead wood, smoke and charcoal tested. The results for grayanotoxin I is more confused and should probably be repeated but it was always found in the same samples at much lower concentrations than grayanotoxin III. This suggests that health risks posed by working or disposing of rhododendron are probably confined to live material which should be handled with care. Rhododendron wood and products are probably no more toxic than other hardwoods.

In this study it was only possible to undertake a literature review of the phytochemicals present in rhododendron which may have commercial applications. The literature review suggests that there are a range of compounds active against HIV and cancer present in other members of the rhododendron family. Screening of *R. ponticum* is underway in Wales but results are not yet available. Given the presence in rhododendron of diterpenes and other compounds of interest to the pharmaceutical industry it is worth following developments in this area.

The epidemic of Sudden oak death in America is causing concern and the possibility that it may spread to Europe and the finding earlier this year of three infected plants in English nurseries have prompted the issuing of precautionary phytosanitory regulations for rhododendron. This may impact on the development of commercial use of rhododendron particularly the export of foliage as especially as the foliage trade is implicated in the spread of Sudden oak death in California. On the positive side the risk posed by rhododendron under native oak may prompt more investment in clearance programmes.

There are many potential uses for rhododendron that look promising; but many are stymied by high harvesting costs and the relative isolation of Beddgelert from high volume markets. In the present economic and market climate perhaps the most promising venture would be the development of high volume foliage production for the export market. However, this would have to be strictly according to the Plant Health regulations to guard against possible infection with Sudden oak death. Other areas which require more development work would be the use of chipped rhododendron as a mulch and biofuel. For this some trials costings of mechanised extraction would be useful along with a more formal market and pricing analysis. Other uses such as phytochemical extraction and charcoal production look less promising and would require considerable investment and research.

BIBLIOGRAPHY

Sampling methods and yield determination

Alldredge M.W., Peek J.M. and Wall W.A. (2001) Shrub community development and annual productivity trends over a 100-year period on an industrial forest of Northern Idaho. Forest Ecology and Management 152: 259-273.

Forestry Commission (2001) Ecological Site Classification database (version 1.7, May 2001). Forestry Commission, Edinburgh.

Hamilton, G.J. (1971) *Forest Management Tables (Metric). Forestry Commission Booklet No. 34.* HMSO, London.

Moroney D.W. (1997) The suitability and economic potential of *Rhododendron ponticum* L. for charcoal production. Report to Snowdonia National Park. Unpublished.

Biofuels

British BioGen & Forestry Commission (forthcoming) Guide to Producing Wood Fuel.

British BioGen (1998) Describing Wood Fuel. British BioGen.

British BioGen (1998) Supplying Wood Fuel. British BioGen.

British Biogen. Wood fuel from forestry and arboriculture. http://www.britishbiogen.co.uk (downloaded 30 June 2002).

CPRE (1995) Renewable Energy in the UK – Financing Options for the Future.

ETSU (1996) Forest Industry Wood Fuel Supply. Border Biofuels, 1996. Available from ETSU. B.W1/00420/REP.

ETSU (1997) UK Industry Wood Fuel Resource Study – England, Wales and Scotland. ETSU B/W2/00548/15/REP.

ETSU (undated) Establishing Guidelines for Wood Fuel Standards. Project Summary. Ref ETSU B/W3/00161/REP.

ETSU (undated) Financing Renewable Energy Projects – A Guide for Developers. ETSU.

ETSU (undated) Wood Fuel Standards. B/W3/00161/REP.

EU (1998) Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan. European Commission, Brussels.

Matthews G. (1993) The carbon content of trees. Technical Paper 4. Forestry Commission.

Reisinger K., Haslinger C., Herger M., Hofbauer H. B I O B I B - A database for biofuels. Institute of Chemical Engineering, Fuel and Environmental Technology, University of Technology Vienna.

Renewable Energy Advisory Group (1994) New and Renewable Energy – Future Prospects in the UK. Department of Trade and Industry.

Tillman D.A. (1978) Wood as an energy resource. Academic Press, New York.

Tillman D.A., Rossi A.J. and Kitto W.D. (1981) Wood combustion: Principles, processes and economics. Academic Press, New York.

Phytochemistry and ethnobotany

Andrade P., Ferreres F., Gil M.I. And Tomas-Barberan F.A. (1997) Determination of phenolic compounds in honeys with different floral origin by capillary zone electrophoresis. Food Chemistry 60: 79-84.

Anon. (1991) Medicines from the rainforest. New Scientist 17 August 1991.

Bird C. and Sattuar O. (1991) Medicines from the rainforest. New Scientist 131 issue 1782 page 34.

Cao Y., Lou C., Fang Y. and Ye J. (2001) Determination of active ingredients of *Rhododendron dauricum* L. by capillary electrophoresis with electrochemical detection. Journal of Chromatography A 943: 153-157.

Chosson E., Chabould A., Chulia A.J. and Raynaud J. (1998a) A phloracetophenone glucoside from *Rhododendron ferrugineum*. Phytochemistry 47: 87-88.

Chosson E., Chabould A., Chulia A.J. and Raynaud J. (1998b) Dihydroflavonol glycosides from *Rhododendron ferrugineum*. Phytochemistry 49: 1431-1433.

Dean M.H. (1966) A survey of the uranium content of vegetation in Great Britain. Journal of Ecology 54: 589-595.

Fan C.Q., Zhao W.M., Ding B.Y. and Qin G.W. (2001) Constituents from the leaves of *Rhododendron latoucheae*. Fitoterapia 72: 449-452.

Ho L.K. and Lin W.N. (1995) Quercetin 5,4'-dimethyl ether from *Rhododendron ellipticum*. Phytochemistry 39: 463-464.

Holstege D.M., Puschner B. and Le T. (2001) Determination of Grayanotoxins in biological samples by LC-MS/MS. Journal of Agriculture and Food Chemistry 49: 1648-1651.

Kashiwada Y., Yamazaki K., Ikeshiro Y., Yamagishi T., Fujioka T., Mihashi K., Mizuki K., Cosentino L.M., Fowke K., Morris-Natsche S.L. and Lee K.H. (2001) Isolation of rhodaurichromanic acid B and the anti-HIV principles rhododaurichromanic acid A and rhododaurichromenic acid from *Rhododendron dauricum*. Tetrahedron 57: 1559-1563.

Keller S. auf dem, Pachaly P. and Zymalkowski F. (1970a) Ursolic acid and uvaol as contents of *Rhododendron ponticum*. Archiv der Pharmazie und Berichte der Deutschen Pharmazeutischen Gesellschaft 303: 243-248.

Keller S. auf dem, Pachaly P. and Zymalkowski F. (1970b) Delta 10(18)-acetylandromedenol, a new substance from *Rhododendron ponticum*. Archiv der Pharmazie und Berichte der Deutschen Pharmazeutischen Gesellschaft 303: 249-255.

Keller S. auf dem, Von Kurten S., Pachaly P. and Zymalkowski F. (1970c) Sterines and triterpenes from *Rhododendron ponticum*. Die Pharmazie 25: 621-625.

Li H., Ding M. and Wu Z. (2001) Analysis of flavonoid aglycons in Rhododendron of Sichuan Liangshan. Tsinghua Science and Technology 6: 160-184.

Liu Z.G., Pan X.F., Chen C.Y. and Chen J.S. (1990) Studies on the chemical constituents of *Rhododendron molle* G. Don. Acta Pharmaceutica Sinica 25: 830-833.

Moerman D. Native American ethnobotany database. Foods, drugs, dyes and fibers of Native North American Peoples. University of Michigan-Dearborn. Http://www.umd.umich.edu/cgi-bin/herb (downloaded 30/4/2002).

Plugge P.C. and de Zaayer H.G. (1889) Andromedotoxin. American Journal of Pharmacy 61(7) July 1889.

Rawal R.B. Commercialisation of aromatic and medicinal plants in Nepal. http://www.fao.org/docrep/x5336e/x5336e0j.htm (downloaded 24/4/2002).

Takahashi H., Hirata S., Minami H. and Fukuyama Y. (2001) Triterpene and flavanone glycoside from *Rhododendron simsii*. Phytochemistry 56: 875-879.

Terai T. and Tanaka S. (1993) Gas chromatographic determination of grayanotoxins. Chemistry Express 8 (6): 385-388.

Thieme H., Walewskw E. and Winkler H.J. (1969) Isolation of salidroside from leaves of *Rhododendron ponticum x catawbiense*. Die Pharmazie 24: 783.

US Agricultural Research Service (2002) Chemicals and their biological activities in: *Rhododendron ponticum* L. (Ericacae) -- Pontic Alpenrose. Dr. Duke's Phytochemical and Ethnobotanical Databases. http://www.ars-grin.gov/cgi-bin/duke/farmacy2.pl (downloaded 30/4/02). Chemistry

US Forest Service Value and use: *Rhododendron macrophyllum*. http://www.fs.fed.us/database/feis/plants/tree/rhomac/value_and_use.html. (downloaded 19/4/2002).

Control

Clipsham I.D. (1985) Effects of application method and adjuvants on Glyphosate and hexazinone phytotoxicity to *Rhododendron ponticum* L. Annals of Applied Biology 106: 98-99 Suppl. S Apr 1985.

Edwards C. (1995) Rhododendron control in native woodlands. Native woodlands discussion group newsletter.

Edwards C. (1999) Herbicide control of *Rhododendron ponticum* following mechanical clearance by hydraulic flail. Proceedings Crop Protection in Northern Britain 1999 (II) 145-150.

Edwards C. and Morgan J. (1994) Cut stump applications with imazapyr. Research Information Note 293. Forestry Commission.

Edwards C. and Morgan J.L. (1996) Control of *Rhododendron ponticum* by stump applications of herbicides following mechanical clearance. Proceedings Crop Protection in Northern Britain 1996 (II): 213-218.

Edwards C., Clay D.V. and Dixon F.L. (2000) Stem treatment to control *Rhododendron ponticum* under woodland canopies. Aspects of Applied Biology 58: 39-46.

Edwards C., Tracy D.R. and Morgan J.L. (1993) Rhododendron control with imazapyr. Forestry Commission Research Information Note 233.

Evans C.E. and Becker D. (1988) Rhododendron control on RSPB reserves. RSPB Conservation Review 2: 54-56.

Forestry Commission (1992) The Kaiser KDX mulcher. Technical Note 2/92.

Forestry Commission (1993) Menzi flail mounted on a tracked excavator. Technical Development Branch Report 23/93.

Forestry Commission (1996) Motor manual and mechanised rhododendron clearance. Technical Note 2/96.

Forestry Commission. Indicative Costs. http://www.forestry.gov.uk/website/oldsite.nsf/ByUnique/INFD-53CEUN (download 02/09/02)

Gritten R. (1987) The spread of *Rhododendron ponticum*. A national problem. Report o the discussion conference held in Snowdonia North Wales 26-27 March 1987.

Kowarik I. And Starfinger U. (2001) Biological invasions in Germany - A challenge to act? Contributions and results of a conference in Berlin October 4-7th, 2000. Federal Agency for Nature Conservation.

Kupiec J. (1985) An experiment into the control of *Rhododendron ponticum* L. BSc project, UWB.

Lawrie J. and Clay D.V. (1993) Responses of *Rhododendron ponticum* to imazapyr applied on different dates. Annals of Applied Biology 122:110-111 Suppl. S Apr 1993.

Lawrie J. and Clay V. (1993) Effects of herbicide mixtures and additives on *Rhododendron ponticum*. Weed Research 33(1): 25-34.

Manchester S.J. and Bullock J.M. (2000) The impacts of non-native species on UK biodiversity and the effectiveness of control. Journal of Applied Ecology 37: 845-864.

Robertson, A.F.G. (1999) Report of the Ardtornich Rhododendron eradication programme. Unpublished. 30 pp.

Simons P. (1998) The day of the rhododendron. New Scientist 7 July 1988.

Windsor and Maidenhead Conservation Volunteers. Rhododendron bashing. http://www.mncv.ecoworld.co.uk/tasks.html (downloaded 19/4/2002).

Ecology

Arunachalam A., Maithani K., Pandey H.N. and Tripathi R.S. (1998) Leaf litter decomposition and nutrient mineralisation patterns in regrowing stands of a humid subtropical forest after tree cutting. Forest Ecology and Management 109: 151-161.

Baker T.T. and van Lear D.H. (1998) Relations between density of rhododendron thickets and diversity of riparian forests. Forest Ecology and Management 109: 21-32.

Bocock K.L. (1964) Changes in the amounts of dry matter, nitrogen, carbon and energy in decomposing woodland leaf litter in relation to the activities of the soil fauna. Journal of Ecology 52(2): 273-284.

Boettcher S.E. (1991) Single-tree influence on earthworms in forest soils in eastern Kentucky. Soil Science Society of America Journal 55: 862-865.

Colak A.H., Cross J.R. and Rotherham I.D. (1998) *Rhododendron ponticum* in native and exotic environments, with particular reference to Turkey and the British Isles. Journal of Practical Ecology and Conservation 2(1): 34-40.

Cross J.R. (1975) Biological flora of the British Isles. *Rhododendron ponticum* L. Journal of Ecology 63: 345-364.

Cross J.R. (1981) The establishment of *Rhododendron ponticum* in the Killarney oakwoods, S.W. Ireland. Journal of Ecology 69: 807-824.

Cross J.R. (1982) The invasion and impact of *Rhododendron ponticum* in native Irish vegetation. Journal of Life Sciences Royal Dublin Society 3: 209-220.

Compton S.G. and Key R.S. (2000) Biological flora of the British Isles. *Coincya wrightii* (O.E. Schulz) Stace (*Rhynchosinapis wrightii* (O.E. Schulz) Dandy ex A.R. Clapham). Journal of Ecology 88: 535-547.

Coxon P., Hannon G. and Foss P. (1994) Climatic deterioration and the end of the Gortian interglacial in sediments from Derrynadivva and Burren Townland, near Castlebar, Country Mayo, Ireland. Journal of Quaternary Science 9: 33-46.

Duddridge J. and Read D.J. (1982) An ultrastructural analysis of the development of mycorrhizas in *Rhododendron ponticum*. Canadian Journal of Botany 60: 2345-2356.

E°en, D. (2000) Ecology and control of rhododendron (*Rhododendron ponticum* L.) in Turkish eastern beech (*Fagus orientalis* Lipsky) forests. PhD thesis, Virgina Polytechnic Institute and State University. Blacksburg, Virginia, USA.

Gritten R.H. (1995) *Rhododendron ponticum* and some other invasive plants in the Snowdonia National Park. Plant Invasions - General aspects and special problems. Pp 213-219. Pysek P., Rejmanek M. and Wade M. (eds).

Hockley T.G. (1989) Vegetation succession following the clearance of rhododendron in the Vale of Ffestiniog. MSc thesis, UWB.

Kameyama Y., Nakagoshi N. and Nehira K. (1999) Safe site for seedlings of *Rhododendron metternichii var. hondoense.* Plant Species Biology 14: 237-242.

Loucks E. (2000) Evaluation of allelopathy in Kudzu and Rhododendron. Undergraduate research project. Warren-Wilson College, Asheville NC, USA. http://www.warren-wilson.edu/~physics/NSS99_2000/abstracts-Spr-2000.ht (Downloaded 25/4/2002).

Mckiernan M. and Baker N.R. (1992) A method for the rapid monitoring of photosynthetic shade adaptation in leaves. Functional Ecology 6: 405-410.

Merrington O. (2002) Problems with replanting after clearing *Rhododendron* species. http://www.spri.cam.ac.uk/people/ojm21/rhodo.htm (downloaded 21/3/2002).

Mitchell R.J., Auld M.H.D., Hughes J.M. and Marrs R.H. (2000) Estimates of nutrient removal during heathland restoration on successional sites in Dorset, southern England. Biological Conservation 95: 233-246.

Mitchell R.J., Marrs R.H. and Auld M.H.D. (1998) A comparative study of the seedbanks of heathland and successional habitats in Dorset, Southern England. Journal of Ecology 86: 588-596.

Mitchell R.J., Marrs R.H., Le Duc M.G. and Auld M.H.D. (1999) A study of the restoration of heathland on successional sites: changes in vegetation and soil chemical properties. Journal of Applied Ecology 36: 770-783.

Mitchell D.T. and Read D.J. (1981) Utilization of inorganic and organic-phosphates by the mycorrhizal endophytes of *Vaccinium macrocarpon* and *Rhododendron ponticum*. Transactions of the British Mycological Society 76: 255-260.

Moos C.J. (1993) The use of geographic information systems in Rhododendron management. MSc thesis, UWB.

Moral R. del and Cates R.G. (1971) Allelopathic potential of the dominant vegetation of western Washington. Ecology 52: 1030-1037.

Nilsen E.T., Walker J.F., Miller O.K., Semones S.W., Lei T.T. and Clinton B.D. (1999) Inhibition of seedling survival under *Rhododendron maximum* (Ericaceae): could allelopathy be a cause? American Journal of Botany 86: 1597-1605.

Peterken G.F. (2001) Ecological effects of introduced tree species in Britain. Forest Ecology and Management 141: 31-42.

Pornon A., Escaravage N., Till-Bottraud I. And Doche B. (1997) Variation of reproductive traits in *Rhododendron ferrugineum* L. (Ericaceae) populations along a successional gradient. Plant Ecology 130: 1-11.

Roberts R.D., Marrs R.H., Skeffington R.A. and Bradshaw A.D. (1981) Ecosystem development on naturally colonized china clay wastes: I. Vegetation changes and overall accumulation of organic matter and nutrients. Journal of Ecology 69: 153-161.

Rotherham I.D. Factors facilitating invasion by *Rhododendron* ponticum. Unpublished manuscript.

Rotherham I.D. (1986) The introduction, spread and current distribution of *Rhododendron ponticum* in the Peak District and Sheffield area. Naturalist 111: 61-67.

Rotherham I.D. (1986) *Rhododendron ponticum* L. in the Sheffield area. The Sorby Record 24: 19-26.

Rotherham I.D. (2001) Rhododendron gone wild - conservation implications of *Rhododendron ponticum* in Britain. Biologist 48(1): 7-11.

Rotherham I.D. (2002) The ecology and history of *Rhododendron ponticum* as an invasive alien and neglected native with impacts on fauna and flora in Britain. Rhodo'02 Rhododendrons in horticulture and science, Edinburgh, 17-19 May 2002.

Rotherham I.D. and Read D.J. (1988) Aspects of the ecology of *Rhododendron ponticum* with reference to its competitive and invasive properties. Aspects of Applied Biology 16: 327-335.

Schofield K.A., Pringle C.M., Meyer J.L. and Sutherland A.B. (2001) The importance of crayfish in the breakdown of rhododendron leaf litter. Freshwater Biology 46: 1191-

Shaw M.W. (1984) *Rhododendron ponticum* - ecological reasons for the success of an alien species in Britain and features that may assist in its control. Weed control and vegetation management in forests and amenity areas. Aspects of Applied Biology 5.

Simons P. (1993) Why do rhododendrons turn into cigars? New Scientist 138 issue 1872 page 14.

Thomson A.G., Radford G.L., Norris D.A. and Good J.E.G. (1993) Factors affecting the distribution and spread of Rhododendron in North Wales. Journal of Environmental Management 39: 199-212.

Walker J.F., Miller O.K., Lei T., Semones S., Nilsen E. and Clinton B.D. (1999) Suppression of ectomycorrhizae on canopy tree seedlings in *Rhododendron maximum* L-(Ericaceae) thickets in the southern Appalachians. Mycorrhiza 9: 49-56.

Wu W.P., Sutton B.C. and Gange A.C. (1997) Notes on three fungicolous fungi: *Anastomyces microsporus* gen. et sp. nov. and *Infundibura adhaerens*. Mycological Research 101: 1318-1322.

Zhuravskaia A.N., Ivanova-Afanas'eva N.V. Nureeva G.V. and Kershengol'ts B.M. (2000) The effect of extracts from *Rhododendron aureum* Georgi and Artemisia yacutica drod. On wheat root meristem cells division. Tsitologiia 42: 903-906.

Mulch

Appleton B.L., Derr J.F. and Ross B.B. (1990) The effect of various landscape weed control measures on soil moisture and temperature, and tree root growth. Journal of Arboriculture 16: 264-268.

Brinton W.F. (2000) Compost quality standards and guidelines. Woods End Research Laboratory. Report to New York State Association of Recyclers.

Carter E.S. (1990) Weed control in amenity areas and other non-agricultural land. In: R.J. Hance and K. Holly (Eds) Weed Control Handbook: Principles. 8th Edition. Blackwell Scientific Publications. pp. 431-456.

Gliessman S.R. (1999) Field and laboratory investigations in agroecology. Lewis Publishers.

Pickering J.S. and Shepherd A. (2000) Evaluation of organic landscape mulches: composition and nutrient release characteristics. Arboricultural Journal 24: 175-187.

Rice E.L. (1995) Biological control of weeds and plant diseases: Advances in applied allelopathy. University of Oklahoma Press. Pp. 111-113.

Pathology

Inman A.J., Cook R.T.A. and Beales P.A. (2000) A contribution to the identity of Rhododendron powdery mildew in Europe. Journal of Phytopathology 148: 17-27

Judd S. and Rotherham I.D. (1992) The phytophagous insect fauna of *Rhododendron ponticum* L. in Britain. The Entomologist 111(3): 134-150.

Kenyon D.M., Dixon G.R. and Helfer S. (1995) Culture in-vitro of *Rhododendron* and *Erysiphe* sp. Plant Pathology 44: 350-354.

Kenyon D.M., Dixon G.R. and Helfer S. (1997) The repression and stimulation of growth of *Erysiphe* sp. On Rhododendron by fungicidal compounds. Plant Pathology 46: 425-431

Shimizu M., Furumai T., Igarashi Y., Onaka H., Nishimura T., Yoshida R. and Kunoh H. (2001) Association of induced disease resistance of rhododendron seedlings with inoculation of Streptomyces sp R-5 and treatment actinomycin D and amphotericin B to the tissue culture medium. Journal of Antibiotics 54: 501-505.

Taxonomy

Cutler D.F., Pudall P.J., Gasson P.E. and Gale M.O. (1987) Root identification manual of trees and shrubs. A guide to the anatomy of roots of trees and shrubs hardy in Britain and Northern Europe. Chapman and Hall.

Kron K.A. (1997) Phylogenetic relationships of Rhododendroideae (Ericaceae). American Journal of Botany 84(8): 973-980.

Milne, R.I. and Abbott R.J. (2000) Origin and evolution of invasive naturalized material of *Rhododendron ponticum* L. in the British Isles. Molecular Ecology 9: 541-556.

Milne R.I., Abbott R.J., Wolff K. and Chamberlain D.F. (1999) Hybridisation among sympatric species of Rhododendron (Ericaceae) in Turkey: Morphological and molecular evidence. American Journal of Botany 86(12): 1776-1785.

Toxicity

Ascioglu M., Cucer N. and Ekecik A. (1998) Effect of Grayanotoxin II on in vitro mitotic activity of human lymphocytes. Journal of International Medical Research 26: 140-143.

Center for Food Safety and Applied Nutrition. 1992 Information about rhodotoxin. In: Foodborne pathogenic microorganisms and natural toxins. Html://vm.cfsan.fds.gov/%nov/chap44.html (downloaded 19/4/2002)

Health and Safety Executive (2001) Toxic woods. Woodworking Sheet No 30. HSE information sheet.

Hennings. Rhododendron poisoning. http://www.user.fast.net/~shenning/rhodytox.html (downloaded 21/3/2002.

Humphreys D.J. and Stodulski J.B. (1986) Detection of andromedotoxins for the diagnosis of Rhododendron poisoning in animals. Journal of Applied Toxicology 6: 121-122.

Menai Organics Limited (1996) Report on analysis of Rhododendron charcoal.

Onat F., Yegen B.C., Lawrence R., Oktay A. and Oktay S. (1991) Site of action of grayanotoxins in mad honey in rats. Journal of Applied Toxicology 11: 199-201.

Onat F.Y., Yegen B.C., Lawrence R., Oktay A. and Oktay S. (1991) Mad honey poisoning in man and rat. Reviews on Environmental Health 9: 3-9.

Puschner B., Holstege D.M. and Lamberski N. (2001) Grayanotoxin poisoning in three goats. Journal of American Veterinary Medical Association 218: 527-528.

Sutlupinar N., Mat A. and Satganoglu Y. (1993) Poisoning by toxic honey in Turkey. Archives of Toxicology 67: 148-150.

APPENDIX 1: PROTOCOL FOR PRODUCT FIELD SAMPLING

University of Bangor - Rhododendron biomass study

Fieldsheet 1 – Site description

Site name: Date: Enumerator:

Approximate area of site: (ha)

General topography Slope (%)

Aspect

Altitude

Forestry Commission site type (see notes)

Bush type	
Seed sink / source	
Site suitability	
Phenology	
Site type	
Comments on use of classification on this site	

GPS co-ordinates of start point:

Transect length:

Number of bushes with stems>5cm rooted exactly on line

Transect bearing:

Plots at:

Sketch of site configuration – indicate start point

University of Bangor - Rhododendron biomass study

Fieldsheet 2 – Plot description

Date: Enumerator:

Site name: Plot number:

Tie-line from start point or last plot

Bearing: Distance:

Slope: Aspect

GPS co-ordinates Altitude

Height of lowest green rhododendron leaf (m)

Average height of rhododendron canopy (m)

Height of highest rhododendron leaf (m)

Overstorey species Canopy cover %:

Trees rooted in plot

Species	d (cm)

Comments / observations

Other vegetation in plot

Species	% cover

University of Bangor - Rhododendron biomass study

Fieldsheet 3 – Rhododendron measurements

Date: Enumerator:

Site name: Plot number

Wood > 5 cm diameter

#	Stem end diameter (cm)		Length (m)	Shape	Weight (kg)
	Large	Small			
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Branches<5 and>2cm diameter

Bag number	Weight (kg)	Bag weight (kg)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Twigs < 2 cm diameter

Bag number	Weight (kg)	Bag weight (kg)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Green leaves

Bag number	Weight (kg)	Bag weight (kg)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Samples for drying

#	Leaves wt (kg)	Bag/Tag wt (kg)	Twigs wt (kg)	Bag/Tag wt (kg)	Branches >2 and <5cm wt (kg)	Bag/Tag wt (kg)	Wood >5cm wt (kg)	Bag/Tag wt (kg)
1								
2								
3								
4								
5								
6								
7								

Rhododendron biomass tables – Protocol for field work

Sampling design

The sites to be used in the biomass study have been selected subjectively using criteria such as accessibility from Bangor, availability of on-site assistance, representiveness for rhododendron site types etc. In most cases the site is chosen to contain a patch of rhododendron of a specific bush/cover type. In order to achieve some objectivity in the design the plots in each patch will be randomly located. It is all but impossible to pre-plan plot locations because of the effort required to accurately map the patch and an inability to use GPS or tie-lines to locate selected points within dense growth. Therefore the plots will be located from a transect cut along a random bearing through the patch, beginning at a convenient access point. Plots will be located at random points along the transect (excluding those less than 5 m apart) and located 10m from it using a tie line cut perpendicular to the transect. Edge plots should be included but plots which fall completely outside the patch should be discarded and replaced with another. A judgement should be made whether a plot will fall outside a patch in very dense growth before cutting the tie line. Four plots should be located within the patch.

Plot enumeration

The plot should be a 2 m x 2 m square orientated to the same bearing as the transect, with the end point of the tie line at the bottom left hand corner. Ranging poles should be used to mark the corners of the plot using the diagonal to establish the square. Don't worry about slope corrections for the plot dimensions as these will be dealt with in the analysis. The diagonal of a 2x2 m plot should be 2.8 m. The maximum leaf height in the plot should be estimated using extended ranging poles if necessary. The average leaf height should also be estimated and lowest leaf height measured before the plot is disturbed. The GPS, slope and other general plot descriptions can be done after the plot is cleared.

Before cutting, the sides of the plot should be marked with saw marks or spray paint as high as can be reached (~3m). All rhododendron material intersecting the sides of the plot should be cut and thrown into or out of the plot as appropriate. All rhododendron rooted in the plot should be cut. The material in the plot should be cut and sorted into the following grades.

Wood > 5 cm d

Dead woody material should be included if not completely rotten and the fact recorded in the shape column of the fieldsheet. The stems should be measured - diameter at both ends and length. As many stems are oval in cross section, the maximum and minimum diameters should be measured with calipers. Each stem should be individually weighed. The shape of the stem length should be recorded using the following codes.

0 – straight or nearly straight
1 – one cut required to make two straight or nearly straight lengths
2 – two cuts required to make three straight or nearly straight lengths
TW – twisted – requiring more than two cuts to form straight lengths

Wood < 5 cm d and > 2 cm d

The stems should be gathered together into bags and weighed. Dead material should be included if not lying on the ground, for measurement the stems should be bundled together and a 'D' placed next to the bundle number.

Twigs < 2 cm d

Twigs stripped of leaves should be gathered into bags for weighing.

Leaves

Green leaves, flowers and seed capsules on the stems NOT on the ground should be put into bags and weighed.

Weights: A randomly selected 1 kg sample of each material should be packed into polythene bags, labelled with the date, site name and plot number and returned to Bangor for determination of dried weights.

Largest stem in plot: A clean cross section at least 1 cm thick should be taken from the largest stem found in the plot. This should be labelled in pen and/or pencil with the plot number and returned to Bangor for tree-ring aging.

Forestry Commission rhododendron site classification

Rhododendron bush type:
These categories are designed to match with particular clearance techniques. Type 1 are easy to clear using foliar herbicide sprays. Type 2 are too large for foliar herbicides because they are too tall, too wide or cannot be accessed from all sides. Type 3 are very large bushes with sufficient space underneath to get access to the main stems without cutting.

Bush	Height	Operand	Diameter	Operand	Access	Clearance technique
1	< 1.2 m	AND	< 2 m bush	AND	All sides	Foliar herbicide
2	> 1.2 m	OR	> 2 m bush	OR	Restricted	Cut and spray
3	> 3 m		Large stem		Under bushes	Stem injection

Seed sink/source:
Source - The site is a source of seed if it contains mature (=large) bushes which produce prolific flowers and seed. Check this by observing if the bush has flower buds, flowers or seed capsules at the end of most branches. Flowers are produced terminally.
Sink - The site is a sink for seed if it contains immature (=small) bushes which have been self-seeded into the site.

Site suitability for rhododendron growth:
Good – sites which are good for rhody growth and where colonisation is going to be rapid i.e. acidic soils, disturbed, open etc.
Poor – sites unsuitable for rhody growth i.e. very dry or wet, high pH, dense grass, exposed, dense overstorey etc..

Phenology:
Immature – no flower or seed production
Juvenile seed source – Few flowers because of site limitations e.g. shading etc.. Dispersal and potential establishment onto adjacent sites low.
Mature seed source – Many flowers/seed capsules on bushes. Dispersal and potential establishment onto adjacent sites very high.

Rhododendron site type:

Regeneration status	Site suitability	Phenology	Bush type	Site type	Priority
None			Bushes absent	Class 0	
Seed sink (self-seeded)	Poor		Type 1	Class I	7
	Good		Type 1	Class II	4
	Good		Type 2	Class III	6
Seed source (fertile plants)	Poor	Juvenile	Type 1	Class IV	3
	Good	Juvenile	Type 2	Class V	5
	Good	Mature	Type 2	Class VI	2
	Good	Mature	Type 3	Class VII	2
None			Stump regrowth	Class VIII	1

APPENDIX 2: CLEARANCE COSTS QUESTIONNAIRE

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a Choedwigaeth

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The costs of Rhododendron control

The University of Wales Bangor is undertaking a study of the feasibility of raising revenue from Rhododendron clearance. There are two main parts to the study: the determination of the costs of Rhododendron control and screening the market potential of products derived from Rhododendron.

We know that the costs of Rhododendron clearance are high and very variable and we would like to understand the reasons and conditions influencing them. Please help us by completing the questionnaire for your Rhododendron clearance contracts or activities over the past two years. We have tried not to ask questions which could be considered confidential but please ignore any questions you do not wish to answer. The information you give will be kept in strictest confidence and will only be used to provide a basis for a clearance cost model for Snowdonia for the purposes of delimiting areas from which different types of products could potentially be harvested. If successful this will be used to develop new rhododendron clearance projects.

If you have any suggestions or ideas on Rhododendron control and utilisation please let us know.

Many thanks for your co-operation.

Dr Jenny Wong
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The costs of Rhododendron control - Sheet 1

1. Which area do you work in ?

Northern Snowdonia		
Central Snowdonia		
Southern Snowdonia		
Gwynedd outside the National Park		
Powys		
Ceredigion		
Elsewhere in Wales (please indicate county)		
Outside Wales (please indicate county)		

2. How many people do you have available for Rhododendron clearance work?

Please indicate numbers

One-person operation	
Employees	
Sub-contractors	
Volunteers	

3. How many Rhododendron clearance contracts do you normally have in one year?

4. What equipment do you have at your disposal?

Hand tools		
Chainsaw		
4 x 4 used on site		
Tractor		
Trailer		
Mechanised flail		
Chemical sprayers		
Chipper		
Other (please specify)		

5. Are there any potential uses for Rhododendron that you think we should be considering in the feasibility study ?

The costs of Rhododendron control - Sheet 2

Please complete for your Rhododendron clearance activities over the past two years (make copies of sheet if more than 5)

Contract number	1	2	3	4	5
Size of area cleared (ha)					
Ground conditions (FC terrain classification number – see attached)					
Ground roughness (FC terrain classification number)					
Slope (FC terrain classification number)					
Site access Tarmac road / track / tractor / on foot only					
Distance to nearest tarmac road (m)					
Type of site Woodland / Non-woodland					
Cover of rhododendron on site Sparse (< 20%) / Moderate (20-50%) / High (> 50%)					
Height of rhododendron < 1 m / 1-2 m / > 2 m					
Type of clearance activity being undertaken Cut / post-cut spray / follow-up spray / picking re-growth					
What equipment did you use on this contract ? Hand tools / chainsaw / tractor / flail / other					
What was done with the rhododendron Left on site unburnt / burnt on site / removed / chipped					
Was any use made of the rhododendron Firewood / charcoal / other?					
Cost of operation					
Did contract include cost of chemicals					
Please estimate the feasibility and cost of removing rhododendron from this site					

Forestry Commission, Technical Development Branch, Technical Note 16/95

Terrain Classification

Class				
1	2	3	4	5
Ground Conditions				
Very good	Good	Average	Poor	Very poor
Dry sands and gravels	Firm mineral soils	Soft mineral or ironpan soils in drier areas	Peaty gleys in drier areas, soft mineral soils in wetter areas	Peaty gleys in wetter areas, deep peats
Ground Roughness				
Very even	Slightly even	Uneven	Rough	Very rough
Obstacles (boulders, furrows etc) small or widely spaced	Intermediate	Obstacles of 40 cm at 1.5-5 m spacing	Intermediate	Obstacles of 60 cm or more at 1.5-5 m spacing
Slope				
Level	Gentle	Moderate	Steep	Very steep
0-10% 0-6 degrees	10-20% 6-11 degrees	20-33% 11-18 degrees	33-50% 18-27 degrees	50%+ 27 degrees +

APPENDIX 3: CHARCOAL BURNING METHODS AND RESULTS

Nanteos group charcoal course 5-6 May 2002 (Bob Shaw)

1. Single drum: 1 vertical oil drum with 8 punched holes (2” diam) in base. Loaded horizontally in one direction to about 1 foot higher than rim, lid balanced on top. Stood on 3 small logs, small amount of shavings underneath drum and about 4 inches of shavings inside on bottom, underneath the wood. When logs burnt and settled enough, lid held on top, small airspace kept open with 1/16” shavings around rim. Temperature of burn regulated with soil around base of drum. When smoke turns from grey to clearer blue, then lid fixed down and made airtight and soil carefully banked up around base. Left to cool before emptying.

5/5/2 First burn, pure rhododendron. Approx 1.3 drums of wood, plus small amount of shavings as fuel. Charcoal at end: approx 1/3 of a drum.

Good charcoal (>1” diam):	6.1 kg	62%
Fines (<1”)	1.4 kg	14%
Brown ends	2.3 kg	23%

Time	Temp (Celsius)	Notes
10:50	16	Lit
10:57	150	
11:00	200	
11:03	285	
11:04	300	
11:07	320	
11:08	360	
11:09	380	
11:10	320	Steadying
11:11		Knocked lid down & lowered base
11:12	270	
11:15	208	Getting quieter
11:18	187	
11:20		Lid down
11:24	138	
11:28	119	
11:32	106	
11:36	104	
12:14	117	
12:23	129	
12:50	134	
13:22	154	
13:52	186	Charcoal settling?
15:00	226	
16:00	273	Smoke clearing (would normally shake drum)
16:20	198	
16:45	269	Close down – off stones at base, soil rammed around, remove chips from lid
16:48	242	Knock lid down & clamp closed so no leaks
17:15	78	
19:10	21	Opened up

2. Double retort

2 pairs of oil drums welded together into a long cylinder. 3” diameter galvanised down-pipe approx. 6” long welded underneath, swept back slightly from open end. Drums supported on frame of scaffolding poles and scrap metal, with large thick metal sheets over top and three sides to insulate. Separate large sheet of metal to put across front. Loaded tightly with wood length-wise from front and lid sealed tightly on. Fuelled with slab wood / dry scrap wood under the two long drums. After a while gasses are forced out of exhaust at pressure and ignite. Burn regulated by adding more or less fuel to maintain a constant high pressure jet of exhaust gasses. After gasses all burnt off, drum lid re-tightened and then left to cool.

5/5/2 First burn, pure Rhododendron. Pieces greater than 4” diameter were split to assist charcoaling.

Two oil drums of Rhododendron, quite full (but less than normal because not very straight), plus approx. 3-4 oil drums volume of fuel wood. Approx. 2/3 of the amount was remaining at end.

Mixed Species

Good charcoal (>1” diam):	19.5kg	76%
Fines (<1”)	3.0kg	12%
Brown ends	3.0kg	12%

Rhododendron

Good charcoal (>1” diam):	13.5kg	75%
Fines (<1”)	0.2kg	1%
Brown ends	4.2kg	23%

Time	Temp (Celsius)	Notes
12:25		Lit (no temp probe inside on 5/5/2)
13:45		Gas blowing from exhaust
13:50	750	Flame temp at back
15:00		Exhaust gas slowing down
15:30		Stopped blowing out exhaust gasses
19:30		Opened up

3. Soil Clamp

Short lengths (approx. 70cm) of wood stacked vertically to make a central triangular chimney. Cylinder approx. 2m diameter (smaller than normal) roofed with more wood laid horizontally. Birch brush (usually green vegetation) placed around the outside, followed by soil (without large stones) over the whole thing. Burning charcoal dropped into chimney with a few shavings to make a fire, then more brush and soil placed over the chimney. Grey smoke seeping out from top of clamp. Need to tend the clamp whilst “charcing”. Burns in a ring from the top downwards. When reaches bottom, is finished.

Started the burn (mixed woods, no Rhododendron) on Saturday, dismantled before completed on Sunday afternoon. If no collapses, can expect to get 1/3 to ½ of initial volume in charcoal, but need to tend constantly to prevent holes through soil forming.

Time	Temp1 (Celsius)	Temp2 (Celsius)	Notes
16:00	15		Lit on 5/5/2 sensor 2/3 way up
17:15	15		
17:20	30		Moved sensor
17:30	42		

19:10	80		
20:20	96		
04:30			Filled a few small holes, top beginning to collapse
06:00			Ewan found large collapses & repaired
09:30	189	232+	Temp1 @2/3; Temp2 @ top
09:40		250	
09:45	142		
09:55	200		
10:15	254	251	
10:30	303	252	
11:40	353	255	
16:00		390+	
16:25		516	
16:30			Closing down – dowsed all round with water
16:40		412	
18:25		150	Opened up

Sunday 6/5/2

1. Single Drum

Same as yesterday. But filled with mixed wood species (no Rhododendron) plus 6 baked bean cans of willow sticks.

Time	Temp (Celsius)	Notes
11:35		Lit
11:54	198	
12:05	296	
12:37	411	
12:55	500	
13:20	500	
14:25	496	
15:00	620	Removed stones and closed around base, still smoking grey blue
15:03	400	Closed down (prematurely – needed another 15 minutes)
15:45	136	
16:45	67	
17:00		Opened

Approx 1/3 of a drum of material left, of which approx 1/3 was brown ends (because closed down too early)

2. Double retort

Left hand retort contained mixed woods in back half, with Hazel in bottom half at front, Rhododendron in top half at front.

Right hand retort contained newly split Alder, not too dry, and quite large diameter.

Temperature probe near top of lid of left hand (Rhododendron) retort

Time	Temp (Celsius)	**Notes**
12:07		Lit
12:25	320	Increasing rapidly
12:29	405	Increasing rapidly

12:30		Some fumes coming out from exhaust, but not burning
13:00	580	Exhaust flaring
13:20	520	
13:25		Gasses slowing down
13:42		Re-lit the fire underneath (got too cool??)
13:43		Front plate back up
13:45	620	
13:49		Exhaust started blowing again
14:02		Exhaust jet slowing down
14:10		Jets slow
14:15	120*	Inside exhaust
14:20		Temp hole blocked up and front plate opened down
14:25		Left still blowing a little, Right stopped
18:10		Emptied both sides

Left hand retort with Rhododendron

Good charcoal (>1" diam): 13.5kg 48%
Fines (<1") 6.0kg 21%
Brown ends 8.5kg 30%

Results:

1. Single drum

Max temperature recorded: 380 and 620
Fuel used minimal (shavings)
Duration of burn 6 hours and 3.5 hours
Total duration 8 hours 20 mins and 5 hours 30 mins
Smoking time 6 hours and 3.5 hours
Volume of wood 1.3 oil drums
Total Volume of charcoal 0.3 oil drums
Weight of usable charcoal 7.5 kg
Weight of large charcoal 6.1 kg
Total labour required 4 - 7 hours
Pros: minimal equipment, very little fuel, very fast, drums last 25-30 burns
Cons: Large amount of wastage, smoky

2. Double Retort

Max temperature recorded: 620
Fuel used 2-3 oil drums
Duration of burn 3 hours and 1hour 45 mins
Total duration 7 hours and 6 hours
Smoking time 1 hour and ¾ hour
Volume of wood 2.0 oil drums
Total Volume of charcoal 1.3 oil drums
Weight of usable charcoal 21.5 kg and 19.5 kg (mixed spp.), 13.7 kg (pure Rhododendron)
Weight of large charcoal 19.5 kg and 13.5 kg (mixed spp.), 13.5 kg (pure Rhododendron)
Total labour required 2 – 3.5 hours
Pros: little wastage, moderate fuel, cleaner smoke, fast
Cons: more equipment with shorter life-span (<20 burns)

3. Soil Clamp

Max temperature recorded: 516
Fuel used minimal (charcoal & shavings)

Duration of burn	Interrupted – approx 72 hours??
Total duration	approx 75 hours??
Smoking time	approx 3 days
Volume of wood	3.0 oil drums
Total Volume of charcoal	1.0 oil drums
Weight of usable charcoal	22kg ? (similar to single drum*3)
Weight of large charcoal	18.3? (similar to single drum*3)
Total labour required	78 hours

Pros: no equipment, more ‘natural’

Cons: labour intensive, very smoky, more likelihood of failing, very slow

APPENDIX 4: PROTOCOLS USED TO EXTRACT AND IDENTIFY GRAYANOTOXIN

1. Extraction of samples to be used in gas chromatography

In preparing samples for gas chromatography the following method was used:

1. Samples are milled using a 0.5mm screen to bring them to a standard small particulate size.
2. Samples are extracted using a soxhlet method. This method is used as it means that the sample does not have to be heated directly which could cause denaturing of the chemical compounds (see concern expressed by Moroney, 1997). The solvent (methanol) is heated and then condensed in a glass column. The condensed solvent then drips through the sample, extracting the compounds required for subsequent testing. This is done for 4 hours.
3. Samples are then evaporated to dryness, without heating.

Six of the charcoal samples could not be extracted using the soxhlet method as the particulate matter was so fine it was blocking pores in the soxhlet thimbles. The following alternative method was employed for these samples, based on a method used by Holstege *et al.* (2001):

1. Methanol is added to the sample in a conical flask and shaken for 6 hours at room temperature
2. The solvent is filtered and then evaporated to dryness, without heating.

2. Determination of grayanotoxin I and III using gas chromatography

Grayanotoxins I and III were detected in samples of *Rhododendron* material by using gas chromatography. The method employed followed that developed by Terai and Tanaka (1993), and is summarised below.

1. Following extraction, as detailed in section 1 above, extracts were evaporated to dryness.
2. A mixture of 1.5ml of pyridine, 0.15ml of chlorotrimthylsilane and 0.3ml of 1,1,1,3,3,3-hexamethyldisilazane were added to the extracts
3. The samples were then heated at 75°C for 2.5 hours
4. After cooling, the samples were directly injected into the gas chromatography column set at the following conditions:
    a. Injector set at 300°C
    b. Detector set at 300°C
    c. The carrier gas used in helium (He)
    d. Column set at 200-300°C at 5°C/min^{-1} with a hold of 10 minutes
    e. Split injection set at 100:1
    f. Injection volume of 5µl

The standard grayanotoxin I retention time is 22.00 minutes and the standard grayanotoxin III retention time is 18.6 minutes.

The grayanotoxin III sample was supplied by Sigma Aldrich and the supplier notes that there are two small impurity peaks. These have been identified at 16.5 minutes and 17.2 minutes.

References

Holstege D.M., Puschner B. and Le T. (2001) Determination of Grayanotoxins in biological samples by LC-MS/MS. *Journal of Agriculture and Food Chemistry*, **49**: 1648-1651

Moroney D.W. (1997) The suitability and economic potential of *Rhododendron ponticum* L. for charcoal production.

Terai T. and Tanaka S. (1993) Gas chromatographic determination of grayanotoxins. *Chemistry Express*, **8** (6): 385-388.

APPENDIX 5: RESULTS OF BOMB CALORIMETRY

Readings for **0.7g** Benzoic Acid standard

Day 1	10.5	11	10.2	10.4	10.5	Mean =	**10.52**
Day 2	10.3	9.35	9.8	9.60	9.1	Mean =	**9.63**

Calorific value Benzoic Acid = **6.32 kcal g^{-1}**

Calculations

Day	Correction for constant heat gain (reading for cotton)	Calibration constant	Calorific value of sample
1	0.20	0.7*6.32 / 10.52-0.2 = 0.4286822	(deflection –0.2)*0.428682 / mass of sample
2	0.15	0.7*6.32 / 9.63-0.15 = 0.4666667	(deflection –0.15) *0.4666667 / mass of sample

Material	**Mass**	**Deflection**	**Calorific Value**	**Mean kcal g^{-1}**	**Mean KJ g^{-1}**	**Moisture Content**
Air-dried wood 1	0.50	6.35	5.27	5.22	21.85	2%
Air-dried wood 2	0.50	6.10	5.06			
Air-dried wood 3	0.50	6.40	5.32			
Air-dried leaves OD 1	0.50	6.20	5.14	4.99	20.90	4%
Air-dried leaves OD 2	0.50	5.85	4.84			
Air-dried leaves OD 3	0.50	6.00	4.97			
Green leaves OD 1	0.50	6.05	5.02	5.00	20.96	4%
Green leaves OD 2	0.50	6.00	4.97			
Green leaves OD 3	0.50	6.05	5.02			
Green leaves 1	0.50	2.70	2.14	2.14	8.98	15%
Green leaves 2	0.50	2.75	2.19			
Green leaves 3	0.50	2.65	2.10			
Green stems 1	0.50	3.00	2.40	2.36	9.88	21%
Green stems 2	0.50	3.05	2.44			
Green stems 3	0.50	2.80	2.23			
Drum charcoal 1	0.25	4.05	6.60	6.72	28.14	5%
Drum charcoal 2	0.25	4.10	6.69			
Drum charcoal 3	0.25	4.20	6.86			
Retort charcoal 1	0.25	5.00	8.23	8.32	34.85	5%
Retort charcoal 2	0.25	4.80	7.89			
Retort charcoal 3	0.25	5.70	9.43			
Retort charcoal 4	0.25	4.70	7.72			
Fresh wood 1	0.50	6.30	5.74	5.92	24.79	2%
Fresh wood 2	0.50	6.55	5.97			
Fresh wood 3	0.50	6.60	6.02			
Fresh wood 4	0.50	6.60	6.02			
Fresh wood 5	0.50	6.40	5.83			
Douglas fir 1	0.50	6.50	5.93	5.82	24.39	2%
Douglas fir 2	0.50	6.20	5.65			
Douglas fir 3	0.50	6.20	5.65			
Douglas fir 4	0.50	6.65	6.07			

APPENDIX 6: WEED SUPPRESSION PROPERTIES OF *RHODODENDRON PONTICUM*

Phase 1 Experiment

Objective:
To give an indication of whether *R. ponticum* has superior germination inhibition properties when compared to commercial mulch materials. To use a minimal amount of mulch to minimise physical effects.

Materials used:

- Experiments in Pen-Y-Fridd glasshouses, University of Wales, Bangor. Comparison of following mulch materials:

Plant part	Rhody	Commercial		Synthetic	Control
		Chip	Mulch	Mulch	
Leaf					
Wood					
Pooled chip					
Fine root					

- **The synthetic mulch was as close a physical analogue for chipped woody material as possible, i.e. ~ 1 cm in size and brown/black in colour.**
- Fine root material is included because this may have greater concentrations or different types of allelopathic compounds than other plant parts.
- White clover (*Trifolium repens*) was used as the test weed as it is a species commonly found in North Wales. A local provenance from Aberystwyth was used courtesy of Mr John Faulconbridge, Western Seeds, Pembrokeshire.

Protocol:

- All mulch materials graded by sieving thru a 2x2 cm sieve, except the fine root material.
- Seed trays filled with a 2cm depth of John Innes No. 1 Potting Compost.
- 48 white clover seeds sown evenly over the tray using a seed planter.
- Seed trays covered with a 2cm layer of test mulch. With the minimum amount of disturbance to the material, the fine roots were laid over the seed tray until covered.
- Each test mulch was replicated four times.
- The seed trays were positioned in the glass house according to a random layout.
- The seed trays were watered regularly from above to maximise effects of leaching.
- The number of seeds germinating every day was recorded for 14 days.

Random assignment of seed trays:

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32

Key:

- Control
- *Rhododendron* shredded leaves
- *Rhododendron* chipped woody stems
- *Rhododendron* root material
- *Rhododendron* chipped whole plant
- Commercial wood chip
- Commercial wood mulch
- Synthetic mulch

Outputs of Statistical Analysis for Phase 1 Experiment

```
Note: In all analysis and in worksheets:
1 = control, 2 = Rp Leaves, 3 = Rp Wood, 4 = RP Root, 5 = Rp
Pooled, 6 = Commercial Chip, 7 = Commercial Mulch, 8 =
Synthetic mulch.
```

One-way ANOVA: Germ WC versus Treatment

```
Analysis of Variance for Germ WC
Source      DF        SS        MS        F        P
Treatment    7    204.72     29.25    10.52    0.000
Error       24     66.75      2.78
Total       31    271.47
```

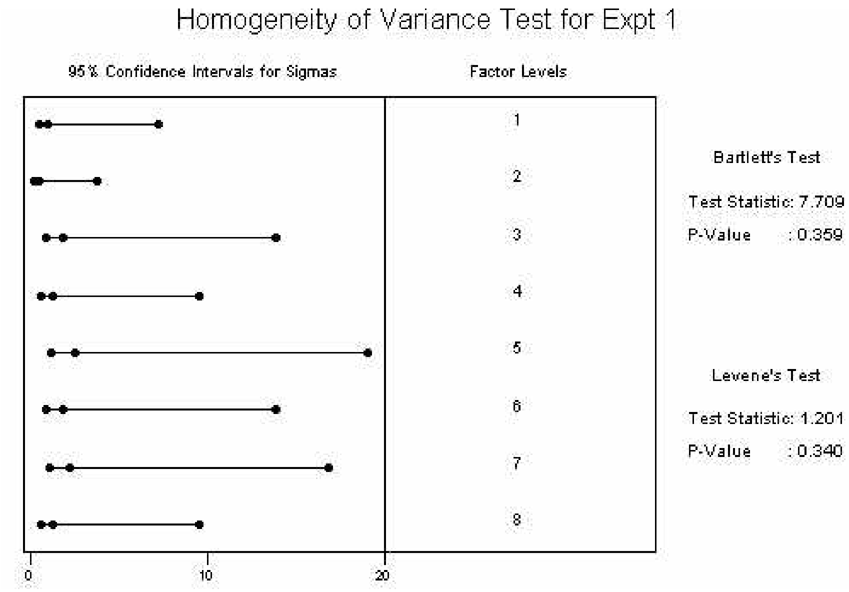
```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level  N      Mean     StDev     ----+---------+---------+--------
-+--
1      4    47.250     0.957                         (----*---
-)
2      4    41.750     0.500         (----*----)
3      4    46.000     1.826                     (---*----)
4      4    46.250     1.258                     (----*----)
5      4    43.500     2.517             (----*----)
6      4    39.000     1.826   (---*----)
7      4    42.750     2.217           (----*----)
8      4    43.750     1.258              (----*----)
                                 ----+---------+---------+--------
-+--
Pooled StDev = 1.668               38.5      42.0      45.5
49.0
```

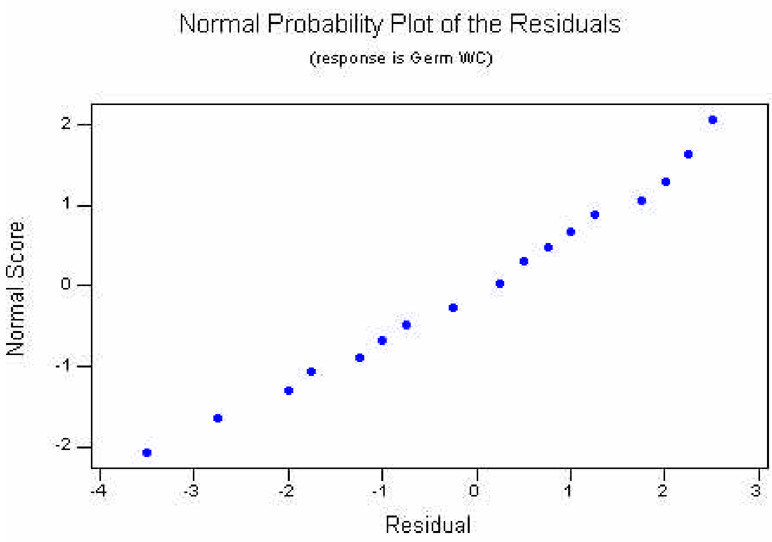
Tukey's pairwise comparisons

```
Family error rate = 0.0500
Individual error rate = 0.00294

Critical value = 4.68

Intervals for (column level mean) - (row level mean)

    1        2        3        4        5        6       7

2  1.598
   9.402

3 -2.652   -8.152
   5.152   -0.348

4 -2.902   -8.402   -4.152
   4.902   -0.598    3.652

5 -0.152   -5.652   -1.402   -1.152
   7.652    2.152    6.402    6.652

6  4.348   -1.152    3.098    3.348    0.598
  12.152    6.652   10.902   11.152    8.402

7  0.598   -4.902   -0.652   -0.402   -3.152   -7.652
   8.402    2.902    7.152    7.402    4.652    0.152

8 -0.402   -5.902   -1.652   -1.402   -4.152   -8.652   -4.902
   7.402    1.902    6.152    6.402    3.652   -0.848    2.902
```

Homogeneity of Variance and Normality of Residuals

The data met the necessary requirements both in terms of homogeneity of variance and normality of residuals. This validates their use and the results obtained from the above ANOVA.





Inhibition of seed germination by *Rhododendron ponticum* – Experiment 2

Objective: To find the LD50 depths for each of the test mulches, i.e. the depth of mulch that must be applied to prevent 50% of the seeds from germinating.

Materials used:
Experiments in Pen-Y-Fridd glasshouses, University of Wales, Bangor. Comparison of following mulch materials:

Plant part	Rhody	Commercial Chip	Synthetic Mulch	Control
Leaf				
Wood				
Pooled chip				

The synthetic mulch was as close a physical analogue for chipped woody material as possible, i.e. ~ 1 cm in size and brown/black in colour.
White clover (*Trifolium repens*) was used as the test weed as it is a species commonly found in North Wales. A local provenance from Aberystwyth was used courtesy of Mr John Faulconbridge, Western Seeds, Pembrokeshire.

Protocol:
All mulch materials graded by sieving thru a 2x2 cm sieve.
Seed trays filled with a 2cm depth of John Innes No. 1 Potting Compost.
48 white clover seeds sown evenly over the tray using a seed planter.
Seed trays covered with either a 4cm or 8cm layer of test mulch.
Each test mulch was replicated three times.
The seed trays were positioned in the glass house according to a random layout.
The seed trays were watered regularly from above to maximise effects of leaching.
The number of seeds germinating every day was recorded for 28 days.

Random assignment of seed trays:

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33			

Key: As for experiment 1

Outputs of Statistical Analysis for Phase 2 Experiment

Where 1 = control, 2 = Rp shredded leaves, 3 = Rp wood chip, 4 = Rp pooled chip, 5 = Commercial wood chip and 6 = Synthetic mulch

One-way ANOVA: Response versus Factor

```
Analysis of Variance for Response
Source      DF        SS        MS        F        P
Factor       5   4711.83    942.37   108.04    0.000
Error       12    104.67      8.72
Total       17   4816.50
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev --+---------+---------+---------+-
---
Control      3    47.000     1.000                                (-
*--)
Rp leaf      3     2.667     2.082  (--*-)
Rp wood      3     4.333     2.309   (--*-)
Rp pool      3     2.333     1.528  (--*-)
Wood chip    3     1.667     0.577  (-*--)
Synthetic    3    11.000     6.245        (-*--)
                                   --+---------+---------+---------+-
---
Pooled StDev =     2.953             0        15        30        45

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

             1          2          3          4          5

    2   36.234
        52.433

    3   34.567     -9.766
        50.766      6.433

    4   36.567     -7.766     -6.099
        52.766      8.433     10.099

    5   37.234     -7.099     -5.433     -7.433
        53.433      9.099     10.766      8.766

    6   27.901    -16.433    -14.766    -16.766     -7.433
        44.099     -0.234      1.433     -0.567     -1.234
```

Homogeneity of Variance and Normality of Residuals

The data met the necessary requirements both in terms of homogeneity of variance and normality of residuals. This validates their use and the results obtained from the above ANOVA.