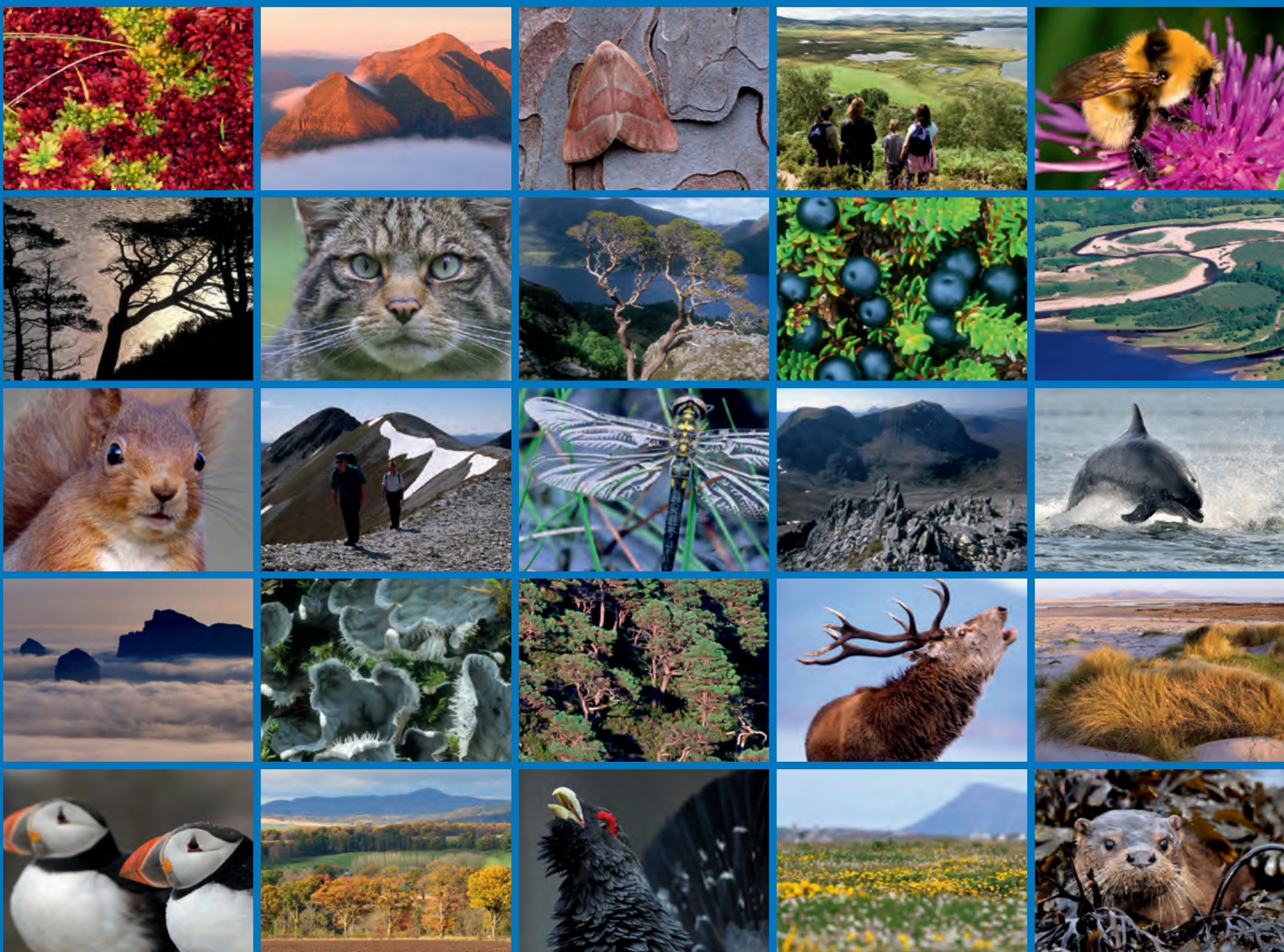
Scottish Natural Heritage
Commissioned Report No. 757

The presence and behaviour of wild bees on crops in Scotland - a preliminary study



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COMMISSIONED REPORT

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The presence and behaviour of wild bees on crops in Scotland - a preliminary study

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COMMISSIONED REPORT
Summary

The presence and behaviour of wild bees on crops in Scotland - a preliminary study

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Keywords

Pollination; bees; solitary bees; mining bees; bumblebees; oil seed rape; soft fruit.

Background

Recent concerns about possible yield limitation from shortages of crop pollinators have led to increasing interest in the ability of the environment surrounding cropped areas to support insects that provide this essential ecosystem service. Many such studies concentrate on honey bees or bumblebees, yet there are many other wild bee species whose role is not clearly understood. This study aims to provide a snap-shot of the current situation on two major pollinated crop types, oil seed rape and fruit, and to consider the potential of wild bees in Scotland.

Main findings

- The efficiency of crop-pollination by various bees depends on the type of crop and the behaviour of individual bee species.
- A range of spring-flying mining bees, as well as bumblebees and honey bees, have the potential to provide crop pollination services.
- The opportunities to support crop-pollinating insects are limited in the study area, with big differences in potential nesting sites for mining bees.
- If the provision of additional foraging resources is to be considered, this needs to be tailored to the specific bee species.
- Much greater knowledge of insect-plant interactions is required for specific crops.

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Acknowledgements

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1. BACKGROUND

Research being undertaken through the Centre for Ecology and Hydrology at Wallingford indicates that a better knowledge of the roles of managed and wild pollinators on commercial crops will greatly help define priorities for the targeting of agri-environment payments. For instance, on a study of three major bee types visiting oil seed rape (OSR) flowers, Woodcock *et al.* (2013) showed significant differences on the time bees spent on flowers, their dry pollen (therefore potentially viable) load, and the incidence of stigma contacts. The study suggested a trade-off between many visits by the honey bee (*Apis mellifera*), a poor quality pollinator, and fewer, but more efficient, visits by mining bees (predominately the genus *Andrena*). The outcome for bumblebees (predominately queens at the time of the study) was in between these two bee types. Unpublished results from the same group and others based at the University of Reading (Agriland Project) suggest similar outcomes for top and soft fruit pollination.

Most of these studies were carried out in the southern part of the British Isles, where the number and diversity of bees are higher than in Scotland. This study aimed to carry out a preliminary investigation of the occurrence and behaviour of the same three groups of bees (mining bees, bumblebees and honey bees) on OSR, top and soft fruit in the highly productive areas of Fife and Tayside. This was done under a similar protocol to that used by Woodcock *et al.* (2013).

In an attempt to provide some quantification as to whether the presence of bumblebee and mining bees on the target crops is affected by the surrounding environment, counts of mining bees and bumblebees were also made on flowers of nearby semi-natural areas. Honey bees were excluded because their presence and density are primarily determined by the number of beekeepers in an area and, in this way, they are more akin to agricultural stock than wild entities.

2. METHODOLOGY

At the start of 2013, with the help of local agronomist Iain Anderson, sites in Fife and Tayside where OSR and top or soft fruit crops are grown in reasonable proximity were identified. A search was made for paired sampling sites no more than 1 km apart (hence well within bees flight distances) among a set of farms in the primary arable areas of Scotland. In the original proposal, visits were to be made to paired crop and farm surrounds (semi-natural areas of margin/tracks/hedgerows). Cultivation in the study district tends to be hard against boundary features, and tracts of open semi-natural areas are often restricted to road verges, with little established margin present. Hence only one habitat category, semi-natural vegetation, was used for off-crop counts. In the event it proved difficult to achieve this close level of association between all sites, but we were able to find a landscape with both types of cropping intermingled: an area lying roughly in a triangle between Perth, Meigle and Dundee.

The relevant farmers were contacted for access permissions, and a preliminary visit to each farm was made by Brian and Stephanie Little between February and March to ascertain the location of the crop and likely areas of semi-natural habitats. Details of these locations were noted on maps kindly provided by CEH Wallingford. These maps were also helpful for identifying likely nesting areas (mostly south-facing).

Weather conditions were extremely poor over the period of flowering of the target crops. This meant that the original plan for co-ordinated visits to each crop type by two recorders at a time had to be replaced by individual recorders visiting the target areas as weather and individual availability allowed. In the event, the study commenced on 25 May but was not completed until 5 July, a rather longer period than the anticipated 3-4 weeks. This extended period may have implications for the numbers of bumblebees recorded, as rather more workers per nest would be expected at the end of the period.

At the time of the proposal it was not clear whether OSR would be flowering at the same time as the soft and top fruit crops. In the event there was no clear distinction between the flowering times, and crops were visited as they were available for study and the weather suited.

Recording took place by on-crop and off-crop 30 min samples for each farm. Where possible these were made sequentially on the same day. Ideally sampling should be carried out under sunshine, but this was not always achievable due to the weather. Thus comparisons between areas have potentially a high level of incompatibility.

Weather conditions - amount of sun, wind force (Beaufort scale), temperature and time of day - were recorded for each visit.

2.1 On-crop recording

Surveyors walked at a slow, steady pace over 20 m along a tramline, counting bees within 1 m of each side of the line (40 m^2 observation area). Sampling started 20 m from edges to avoid edge interactions. Fixed transects along tramlines/rows have practical reasons: access is easier and trampling is reduced.

Experience in England has shown that there is considerable variation in attractiveness of individual flowers, probably due to nectar/pollen factors that have not been investigated. However, these effects are not obvious field variables in recording pollinator activity over extensive areas of forage, unlike semi-natural habitats with typically much smaller and variable individual forage patches.
Recording of behaviour was done by the same criteria as for the studies in England

(Woodcock *et al.,* 2013). Only female bees were recorded, as these make the most consistently directed movements between flowers and hence have the highest potential for pollen transfer between flowers. The following measurements were made for each flower visit:

a) Bee type/species to at least functional groups: bumblebees, mining bees or megachilid bees (mason and leafcutter bees). All *Bombus terrestris* and *B. lucorum* were recorded as the aggregate *B. lucorum/terrestris*; differentiating these species is not consistently possible, especially when this includes the commercially available southern European form of *B. terrestris*. Bees were not collected for identification because behaviour was a significant component of the study, and removing bees for close observation would interfere with this. A further 20 min was occasionally spent investigating unidentified species independently of their behaviour, but only after the behavioural observations had been completed.

b) Length of time of bees on individual flower. A maximum of three visits to flowers by each individual bee was recorded on each transect.

c) Whether bee has obvious dry pollen on body (pollen wetted with nectar is unlikely to be transferred or viable).

d) Whether bee makes contact with the stigma, hence being likely to transfer pollen from body to stigma.

2.2 Off-crop recording

Thirty minutes were spent recording presence and numbers (some double-counting was inevitable) of non-*Apis* bees over an area of 100 x 3 m, flowers visited and signs of nesting activity for each off-crop sample area. The identification of these bees was as detailed as possible, including taking specimens for confirmation when necessary. Recording was done while walking, but stops for up to 5 min at a time were made for close observation if required.

2.3 Study sites, survey visits and observations

A survey team, comprising Brian and Stephanie Little, Murdo MacDonald, David Fotheringham, Jon Noad, Hayley Wiswell and Mike Edwards, was ready to begin survey in the last two weeks of May. Iain Anderson provided us with updates on the state of the crops, which were significantly delayed due to the cold, wet spring. We finally settled on the period 26-29 May as the starting point and assembled, in not very promising conditions, for a day running through the protocols as a joint first survey. In this we were joined by Athayde Tonhasca of SNH for the first day.

Unfortunately the forecast of more settled weather did not materialise, and after two days spent visiting every site, doing as much as possible, we decided to postpone. We agreed that surveys would be carried out as far as possible in pairs, as soon as the weather and individual availability allowed. We felt that trying to co-ordinate another period of concerted effort, especially given the poor prognosis for the weather for the following month, would be a waste of resources. The visits were rather less systematic than had been initially hoped for (Table 1).

Table 1 - Survey dates against sample sites, crops and surveyors. 1: Mike Edwards; 2: Brian and Stephanie Little; 3: Jon Noad; 4: David Fotheringham; 5: Hayley Wiswell; 6: Murdo MacDonald

			Surveyor					
Site	**Crop**	**Date**	**1**	**2**	**3**	**4**	**5**	**6**
Mill of Montague, Balbeggie	blackcurrant, raspberry, strawberry gooseberry	27/5	1	1	1	1	1	1
		2/6		1	1			
		11/6				1		
		16/6					1	
		5/7					1	
Crossford Bridge, Balbeggie airfield	OSR	27/5	1	1	1	1	1	1
		2/6			1			
		10/6				1		
		11/6				1		
		16/6					1	
		5/7					1	
Drumkilbo	blackcurrant	26/5	1	1	1	1	1	1
		2/6			1			
		10/6				1		
East Adamston	apple, blueberry	27/5	1	1	1	1	1	1
Dronley	OSR	27/5	1	1	1	1	1	1
		10/6				1		
		16/6					1	
		5/7					1	
Longlees	blackcurrant	2/6		1				
Stobcross	blackcurrant	26/5	1	1	1	1	1	1
		2/6		1	1			
		10/6				1		
Meikleour	OSR	26/5	1	1	1	1	1	1
		2/6			1			
		11/6				1		
Culfargie	OSR	27/5	1	1	1	1	1	1
		2/6			1			
		3/6			1			

3. RESULTS

The raw data, containing date, time and environmental conditions for each sampling event, comprise large documents and are provided separately: *On-crop results 2013* and *Off-crop results 2013*. Summaries of these sheets are provided in Tables 2-6. As the visits were not evenly distributed, care should be taken in making direct comparisons between sites. Photos 1-16 are examples of habitats and bee species observed in this study.

Table 2 - On-crop numbers of bees by types recorded at each sample site

Sample site	crop	mining bees	bumblebees	honey bees
Mill of Montague	soft fruit	7 (3 not on flower)	98	11
Balbeggie airfield	OSR	0	87	15
Culfargie	OSR (organic)	0	7	16
Dronley	soft and top fruit	0	3	4
Dronley	OSR	0	89	21
Drumkilbo	blackcurrant	1	6	0
Longleys	blackcurrant	0	3	0
Stobcross	blackcurrant	0	10	0
Meikleour	OSR	0	0	22

Table 3 - Off-crop numbers of bees by bee types recorded at each sample site

Sample site	crop	mining bees	bumblebees
Mill of Montague	soft fruit	0	49
Balbeggie airfield	OSR	0	65
Culfargie	OSR (organic)	1	3
Dronley	OSR, top and soft fruit	1	24
Drumkilbo	blackcurrant	2	14
Longleys	blackcurrant	0	15
Stobcross	blackcurrant	6	33
Meikleour	OSR	0	17

Table 4 - Off-crop numbers of bees by species recorded on OSR, soft and top fruit and off-crop

Bee species	OSR	soft and top fruit	off-crop
Apis mellifera	74	14	N/A
Andrena sp.	0	4	6
Andrena bicolor	0	1	0
Andrena haemorrhoa	0	0	4
Andrena helvola	0	2 (not on flower)	0
Lasioglossum calceatum	0	1 (not on flower)	0
Bombus sp.	0	0	11
Bombus hortorum	0	0	13

Bombus lapidarius	4	0	6
Bombus lucorum/terrestris	179	86	97
Bombus pratorum	0	17	22
Bombus pascuorum	0	17	71

Table 5 - Behaviour on crop flowers by bee species recorded on OSR

Bee type	Number of occurrences	Mean time on flower (seconds)	Nectar gathering % (n)	Pollen gathering % (n)	Making stigmal contact % (n)	Carrying dry pollen % (n)	Stigmal contact and dry pollen (n)
Mining bee	0	N/A	N/A	N/A	N/A	N/A	N/A
Bumblebee	183	2	99 (182)	83 (151)	81 (148)	21 (42)	21 (38)
Honey bee	74	5	93 (69)	46 (33)	20 (15)	46 (34)	19 (14)

Table 6 - Behaviour on crop flowers by bee species recorded on top and soft fruit

Bee type	Number of occurrences	Mean time on flower (seconds)	Nectar gathering % (n)	Pollen gathering % (n)	Making stigmal contact % (n)	Carrying dry pollen % (n)	Stigmal contact and dry pollen (n)
Mining bee	0	N/A	N/A	N/A	N/A	N/A	N/A
Bumblebee	183	2	99 (182)	83 (151)	81 (148)	21 (42)	21 (38)
Honeybee	74	5	93 (69)	46 (33)	20 (15)	46 (34)	19 (14)

Observations for each site are described below.

3.1 Mill of Montague, Balbeggie (various soft fruit) N186278

This was the most varied of the soft-fruit farms, with new and some very old plantings of gooseberry, raspberry, blackcurrant and strawberry, although only the first two were sampled. The site was sheltered with semi-natural areas on two sides, one of these a grazed field adjoining the margin to the field, the other a roadside and stream-side. Other areas of semi-natural habitat were scarce in the landscape. See appendix for location (Map 1), aspect (Map 2) and land use (Map 3).

The area is mostly on a rather north-facing slope, and hence cool and not ideal as nesting sites for aculeates (Figures 1 and 2). One small central area did have potential as a nest site: an access track with bare ground and short vegetation. The field opposite had steep, south-facing slopes and small areas which were not under the plough. However, these have not been grazed and had rather long vegetation (Map 2).

Figure 1 – Mill of Montague, raspberry crop with south-facing hillside in the background

Figure 2 – Mill of Montague, road verge used as off-crop sampling area

This site was not visited until 5 July, when three bumblebee species were plentiful on the raspberry flowers. Bees recorded on crop flowers were: *A. mellifera*, *Andrena bicolor*, *B. pascuorum*, *B. pratorum, B. terrestris/lucorum*. Two other mining bees were found sitting on the leaves of the crop (it being rather cold for activity), *Andrena helvola* and *Lasioglossum calceatum.*

There were off-crop records for the three *Bombus* species only. Off-crop flowers visited by wild bees were: dog rose (*Rosa canina* agg.), raspberry (*Rubus idaeus*), water avens (*Geum rivale*), tufted vetch (*Vicia cracca*), bush vetch (*V. sepium*), broom (*Cytisus scoparius*).

3.2 Balbeggie airfield NO161277

The OSR crop here was very late, so no real survey was possible until the middle of June. However, this meant that the crop was still well in flower as the bumblebee populations built up, with large numbers of *B. terrestris/lucorum* workers recorded on the final visit of 5 July.

The sample area had a fairly good south-facing aspect overall, but opportunities for nesting by mining bees were not present, except along the sides of the roadside ditch (Figures 3-5; Map 2, appendix).

Figure 3 – Balbeggie Airfield road verge used as off-crop sampling area, 26 May. Note the difference in crop flowering in both sides of the road

Semi-natural habitat was represented by the sides of the road running along the western edge of the field and on the opposite side of the road, alongside the small stream where there was a large stand of common comfrey (*Symphytum officinale*), which was very attractive to bumblebees. The road was, however, re-ditched during the survey and most of the flower resource was removed (probably temporarily) by 10 June. Other off-crop flowers recorded as used by wild bees were gorse (*Ulex europaeus*) and bush vetch.

On-crop bees recorded were *A. mellifera* and *B. lucorum/terrestris*. Off-crop wild bees were *B. hortorum, B. lapidarius, B. lucorum/terrestris* and *B. pascuorum.* No mining bees were seen on either sample.

Figure 4 – Balbeggie Airfield road verge used as off-crop sampling area, 26 May, before ditching

Figure 5 – Balbeggie Airfield road verge used as off-crop sampling area, 26 May, after ditching

3.3 Culfargie (OSR) NO181301

An extensive planting of organic OSR with a narrow corridor along an old track running between the fields and a flower-rich, but rather narrow, road verge (Figures 6 and 7) formed the off-crop sample area. See appendix for location (Map 4), aspect (Map 5) and land use (Map 6). The fields were open and fairly flat, although their aspects were slightly north-facing, except at the western end (Map 5). The surrounding landscape was intensively farmed (Map 6), with few suitable locations for mining bees nesting (Figure 8).

Figure 6 – Track through semi-natural sample area, Culfargie Estate

Figure 7 – Road verge at semi-natural sample area, Culfargie Estate

Figure 8 – The western-most field in the Culfargie sample area. Note the patchwork of oil-seed rape flowering in the landscape.

Bees recorded on crop flowers were *A. mellifera, B. lapidarius* and *B. lucorum/terrestris.* Wild bees recorded off-crop were *Andrena* spp., *Bombus* spp., *B. lucorum/terrestris* and *B. pascuorum.* Off-crop flowers visited by wild bees were sweet cicely (*Myrrhis odorata*).

3.4 Dronley (soft and top fruit) NO335353

This was a small apples and blueberries area situated at the foot of a north-facing slope, with verges along a south-facing minor road. See appendix for location (Map 7), aspect (Map 8) and land use (Map 9). The road verges formed the off-crop area, although these were cut during the study period (Figure 9).

These also formed the off-crop area for the Dronley OSR sample, which was growing at the top of the south-facing slope above the fruit area (3.5). There were a few small areas of semi-natural vegetation to the east of a larger road nearby, otherwise the area is intensively farmed (Map 9, appendix).

The day of the visit (25 May) was clear, but the area had been devastated by late, severe frosts and many of the blueberries were badly frost-damaged, with few flowers present. The numbers of apple flowers were much reduced. The ground between crop rows provided reasonable nesting sites for mining bees, although a more southerly aspect would have been better.

Figure 9 – Semi–natural road verge at Dronley. Part of it was cut, as above, during the sample period. Leaving large wads of cut material on the grass tends to reduce its floral variety. This effect can be somewhat reduced by redistributing the material

Due to the lack of flowers, few records were made on the crops. These were all *B. lucorum/terrestris*. The off-crop wild bees were *Andrena* spp., *Bombus* spp., *B. lapidarius, B. lucorum/terrestris, B. pascuorum* and *B. pratorum.*

Off-crop flowers with recorded wild bees were dog rose, raspberry, herb robert (*Geum robertianum*), hogweed (*Heracleum sphondylium*) and meadow vetchling (*Lathyrus pratensis*).

3.5 Dronley (OSR) NO335361

The situation for this OSR crop was described in 3.4. The crop was late in flowering and the last visit of the project on 5 July recorded even more *B. lucorum/terrestris* workers on-crop than honey bees, a most unusual situation. *Bombus lapidarius* was also recorded on-crop. The off-crop sample is described under section 3.4.

3.6 Blackcurrant plantings between Coupar Angus and Forfar

The next three sample areas were blackcurrant plantings fairly close together and running for 6 km along the A94 between Coupar Angus and Forfar. Observations for these areas are reported as a single unit, as many of the observations were common to all three.

The wide margins to these fields were short grassland with a reasonable variety of flowering plants, including white clover (*Trifolium repens*), dandelion (*Taraxacum* agg.), comfrey and white dead-nettle (*Lamium album*). The shelter-belts included flowering shrubs such as hawthorn (*Crataegus monogyna*), gorse and broom. All these plants were used by a range of mining bees and bumblebees.

The wide margins, kept short to facilitate their use as run-on harvest store areas, provided good mining bee nest areas where they were facing south and open to the sun. Two mining bee nests were found at Stobcross: *Andrena haemorrhoa* and, probably, *Andrena scotica* (not viewed well enough to be sure).

Although individually quite small, these areas provided the best combination of crop and potential wild bee habitat; a happy accident, but one that would be worth encouraging elsewhere.

Most on-crop visitation was by workers of *B. lucorum/terrestris*, many of these originating from nearby soft fruit grown under tunnels, with commercial colonies of *B. terrestris* present. This is the southern European, white-tailed, mid-yellow banded form most commonly used for commercial bumblebee production. Some queens of the British race *audax* were present.

The mining bee *Andrena haemorrhoa* (Figure 10) was recorded several times off-crop, once carrying pollen that could possibly be from blackcurrant (greenish-white), and also flying through or settled on the plants. An unidentified *Andrena* was also recorded on-crop during a timed count. A second species, *Andrena bicolor,* was also seen at the flowers, but not in a timed count. Off-crop bumblebees were *Bombus* spp., *B. hortorum, B. lapidarius, B. lucorum/terrestris, B. pascuorum* and *B. pratorum.* No honey bees were seen on-crop at any time.

Figure 10 – The honey bee-size Andrena haemorrhoa*, here sitting on a blackcurrant leaf, was the most frequently seen mining bee during the survey*

3.7 Drumkilbo (blackcurrant) NO299449

This site was flat to slightly north-facing (Maps 10 and 11 in the appendix) and set in the typically high intensity agricultural landscape of the study, although, according to the land use map, there is a small area of dwarf-shrub heath about 1 km to the south-east of the site (Map 12, appendix). This area was not visited, the off-crop sample being made around the edges of the field, which are more relevant to the crop (Figure 11).

Figure 11 - The margin and hedge at Drumkilbo, with flowering hawthorn and longer grass towards the hedge and short grass close to the crop; this was typical of the blackcurrant fields

3.8 Longleys (blackcurrant) NO268438

Much of this site was flat, but the northernmost field had a southerly aspect (Maps 13 and 14, appendix). According to the land use map (Map 15, appendix) there was a greater amount of low-productivity grassland in the immediate vicinity than in other areas, but whether this provided resources for bees was not ascertained. Again it was considered that the most immediate relevance was in the margins to the field.

3.9 Stobcross (blackcurrant) NO247419

This site had a gentle south-facing aspect on the lower, southern portion, where the two mining bee nests were found (Figure 12). Conditions were much the same as those on the other blackcurrant fields.

Figure 12 – The northern margin at Stobcross with plentiful dandelion, which is much liked by spring-flying wild bees

3.10 Meikleour beech hedge (OSR) NO164383

A sheltered location on the north bank of the River Isla, flat at the southern end, but rising with a gentle southward slope towards the north; see appendix for location (Map 16), aspect (Map 17) and land use (Map 18). There was a low bank against the wood with a fairly varied natural flora in parts. The constant small slippages along this bank made it appear a very suitable nesting site for mining bees, but no evidence of nesting was seen. The crop was the most advanced of all sampled, reflecting, in part at least, the sheltered nature of the location (Figure 13). However, this also meant that it was past flowering towards the end of the survey period and hence not surveyed later on.

Figure 13 – The oil-seed rape at Meikleour was probably the most even and least affected by the weather. Because of the sheer volume of flower resources, oil-seed rape was a far more likely attractant for mining bees and honey bees than the small area of comfrey

This field was in the most varied landscape of all the samples, with woodland edges, a road bank and banks of the river that provide semi-natural grassland of varying floral diversity. The land use map suggests several small areas of dwarf-shrub heath in the vicinity.

On-crop sampling showed just honey bees, but a late afternoon visit on 25 May (not a count) also provided on-crop records of two *Andrena haemorrhoa* and one *Andrena scotica* (flying around the crop). Off-crop bees were *B. hortorum, B. lucorum/terrestris, B. pascuorum* and *B. pratorum.* Off-crop flowers visited by wild bees were comfrey, white dead nettle and sweet cicely (Figure 14).

Figure 14 – Surrounds of Meikleour were also one of the most varied but dominated close to the crop by comfrey, a bumblebee-associated flower

4. DISCUSSION

One of the primary aims of this study was to provide some initial indication of the roles of both managed and wild pollinators on commercial crops in Scotland. Before further discussion, it is well worth considering the following extract from Michener (2000) concerning the interactions of bees and flowers in the process of pollination (Chapter 6, 'Floral relationship of bees'):

> *"The effectiveness of a bee as a pollinator depends on many factors, unfortunately not always studied by people investigating pollination. A bee that has come from other flowers on the same plant or the same clone is unlikely to cross-pollinate. A bee that combs pollen off most of its body and appendages for transport in the scopa (pollen transporting brushes or areas) is probably less likely to pollinate the next flower than a bee that leaves the pollen where it lodges on its body as it seeks more. A bee that moistens its pollen with nectar or oil for transport is presumably less likely to pollinate than a bee that carries its pollen dry and loose. And the location where pollen is deposited on the body of the bee can be critical for later pick-up by a floral stigma. Such factors depend not only on the floral structure but also on the movement patterns of bees, which may differ among different individual bees because they are partly learned, and will be different for different kinds of bees because they are partly species-specific. Students of pollination biology need to pay attention to these and many related matters. Too frequently the assumption is made that because a particular bee species visits a flower species, that bee is a pollinator of that flower. Another unfortunate assumption is that bees of a common size (usually small) can be lumped as a single functional pollinating unit."*

If the assumption that flower visitation by bees equals pollination is questionable, then so is the assumption that any flower-visiting insect is an effective pollinator, which lies behind the wholesale packaging of pollinators in a (probably well-meant) attempt to increase the appeal of insects as important components of the environment.

Some quantification of this 'likelihood of pollination' can be made through direct observation of what the bee is doing - collecting nectar, pollen or both; how long it spends on each flower; whether it is carrying dry pollen and whether it makes contact with the stigma during its visit.

It is readily accepted that practical considerations (especially the 2013 weather) make the sample size for the mining bee group smaller than for honey bees and bumblebees. Nevertheless, it is interesting that the indications presented here are broadly in agreement with those in Woodcock *et al.* (2013), and other as yet unpublished studies.

Many facets of the behaviour and pollen-collecting apparatus of the bee species in Britain were recently reviewed by Edwards (2013). For the purposes of this study, it should be noted that:

a) Mining bees carry their pollen dry on large areas of bushy hairs on the hind legs or sides of the thorax; bumblebees and honey bees carry their pollen wetted with nectar on a very restricted part of their hind legs.

b) As bumblebees are very hairy, pollen does get caught on other parts of their body. Honey bees are less hairy, and relatively little pollen gets trapped this way, but in both cases, pollen grains are regularly combed off, to be kept or discarded provided that the bee can reach them with its legs.

From Table 5 it can be seen that, for winter OSR, more bumblebees were recorded on-crop than honey bees. This could well be, in part, a result of the unusually late flowering, allowing bumblebee colonies to grow rather more than they would have done in a more normal flowering period.

Nevertheless, given that at this time of the year the numbers of honeybees in a hive are normally well in excess of 10,000, compared with 100-200 workers of *B. terrestris/lucorum* colonies, the contribution per colony to crop visitation by bumblebees can be much higher. This is even more marked if the figures for the proportion of visits from bees clearly carrying dry pollen and making contact with the stigma of the flower are taken into account.

A larger proportion of honey bees have dry pollen - usually on the face - than bumblebees, but a larger proportion of the latter makes stigmal contact. This illustrates well Michener's comments about the difference in movement patterns between bee types.

A honey bee worker seeking nectar will often insert its tongue between the corolla and the stamens, getting its face covered in pollen as it does so. However, as it then leaves the flower the way it came in, from the outside, this pollen does not get transferred to the central stigma (Figure 15). Thus the overall 'likelihood of pollination' is lower than expected from dry pollen only.

Figure 15 – A honey bee taking nectar from an oil-seed rape flower. Note it is getting pollen on its head from the stamens, but it is not touching the central stigma

A bumblebee, however, tends to trample over the flower as it probes for nectar, touching the stigma, which sticks up centrally, above the stamens, as it does so. However, as bumblebees are relatively large and long-legged, less of the body actually comes into full contact with the stamens and less pollen is therefore picked up. Add to this that some, at least, of the pollen is often combed off the body and moistened with nectar as it is transferred to the pollen collection area, the overall outcome is a lower 'likelihood of pollination' than expected from stigmal contact alone.

Although no visits by mining bees were observed during the fixed observation periods, this was seen on two of the occasions during preliminary training at Meikleour Hedge (by *Andrena haemorrhoa*). A female behaved in the same way as mining bees have been observed on many occasions - and filmed - during studies in England, Hungary and Australia. The bee spent over half a minute on the flower, crawling all over the stamens and stigma, collecting pollen which was then transferred, dry, to the pollen transport hairs, from where it came into regular contact with the stigma.

Although not on an OSR flower, the accumulated dry pollen in its transport brushes can be seen clearly in the photo taken on hawthorn flowers at the edge of one of the blackcurrant fields (Figure 16). Hawthorn is a member of the Rosacea, as are raspberry and apple, two of our target crops, with raspberry seen to be visited by mining bees.

Figure 16 – This Andrena haemorrhoa *is collecting pollen as it drinks nectar from the hawthorn flower. The dry pollen is carried out on special brushes on the hind legs and sides of the thorax. As the bee clambers around the flower, dry pollen can be easily rubbed off onto the stigma*

Similar considerations for top and soft fruit can be developed from Table 6, except that observations of mining bees (admittedly few) were made on top and soft fruit. These show a much higher 'pollination efficiency' measure, as measured by dry pollen and stigmal contact, than either honey bees or bumblebees, with also a considerably longer period spent on each flower.

This, however, may well not be the entire story, as the situation on the blackcurrant crop shows. This crop was not visited by honey bees at all (Table 2), but was by bumblebees and mining bees, the latter very few in numbers during the timed periods. Yet this crop is regarded as requiring active pollination from flower-visiting insects.

Visiting bumblebees did not collect any pollen and would take nectar standing over the flower, with just the mouthparts having any chance of contacting the stamens/stigma. It is possible that pollen was transferred this way, but very little available pollen could be seen during visitation.

It is possible that this is a case of the flower depositing small amounts of pollen in an inaccessible place on the bee - such as the base of the tongue, which needs to be thrust well into the flower - and this pollen subsequently being transferred to a stigma through the same action. Such a situation is known in several other crops, with a particularly complex one occurring in runner beans (personal observation).

Further studies of the actual process of pollination by insects, including filming of flower visitation, are of great interest and potential practical application in food production as well as the maintenance of the overall natural environment.

The second part of the study attempted to provide some guidance as to whether wild bees were equally well represented on crops as in the wider local environment. From Tables 2 and 3 it can be seen that there seem to be slightly more wild bees overall on crops than in the local environment. However, due to the peculiarities of the season, search times were not evenly matched. The actual numbers may reflect weather conditions at a specific sample site.

The much larger scale of the resources (pollen and nectar) available at the transects than at the off-crop areas, and hence with greater potential attraction, should also be considered. This may be offset, in turn, by a dilution effect, with very large resource areas making unlikely the finding of small numbers of individual flowers. This is most likely in crops such as OSR, where the noticeability of individual bees may reflect the size of the bee itself; it is much easier to see a large bumblebee queen flying into the crop, even at quite small distances, than a honey bee or mining bee.

Many studies of 'pollination' have attempted to control 'observer effects' by trapping, notably with pan traps. However, two factors argue strongly against this methodology, however useful it may be in faunistic contexts. Firstly, much has been made here, and by Michener (2000), about the need for direct observation of bees on flowers: traps do not record this, nor, indeed, do they tell whether the trapped insect was even visiting the crop flowers. Secondly, lethal trapping has a high potential to skew outcomes by continual removal of the target organisms.

Care should also be taken when considering enhancing pollination services by moving honey bee hives into an area. Honey bees have a nine-month flight period when they require feeding, not just when the target crop is in flower. Moving hives from one crop to another can offset this need, but the practice of feeding hives with sugar or soya protein just shifts the environmental cost elsewhere. The very large numbers of workers, plus the normal practice of removing the honey, increase the overall environmental load. As a commercial practice this may well be justified, but it is hard, on balance, to justify the costs on environmental grounds alone.

As to bumblebees, their numbers per nest are much lower and the main environmental load, the provision of flower resource, is biased towards the latter part of the flight season. However, mass-flowering crops, unless backed up by suitable amounts of later flowering resources, are unlikely to make a season-long contribution to overall population levels. The phenology profile of the colonies also means that most workers are present when, generally, they are least needed for crop pollination.

The situation for solitary bees, especially mining bees in the context of the spring-flowering crops under study here, is rather different. Mining bees fly and provision their nests for a restricted period, usually of about six weeks. For many species, this active period covers the flowering period of the crops under study here. For the rest of the year the next generation of bees are hidden underground, waiting for the correct time of year.

Whether suitable environmental measures can be put in place to support larger numbers of such bees requires some effort and experimentation under field conditions. The aspects needing exploration are the provision of flower resources over short periods at the right time of year when there may be a gap in crop flowering, and, probably more importantly, the provision of suitable, localised nesting sites within the landscape under cropping.

Mining bees can fly reasonable distances, over 1 km, to find provisions and return to the nest. Warm, undisturbed areas with short or little vegetation suitable for nesting are much scarcer and more localised. The question is, can such areas be provided in the farmed landscape? With improved environmental conditions, the relatively restricted Scottish bee fauna can reasonably be expected to increase beyond the low levels recorded in this study.

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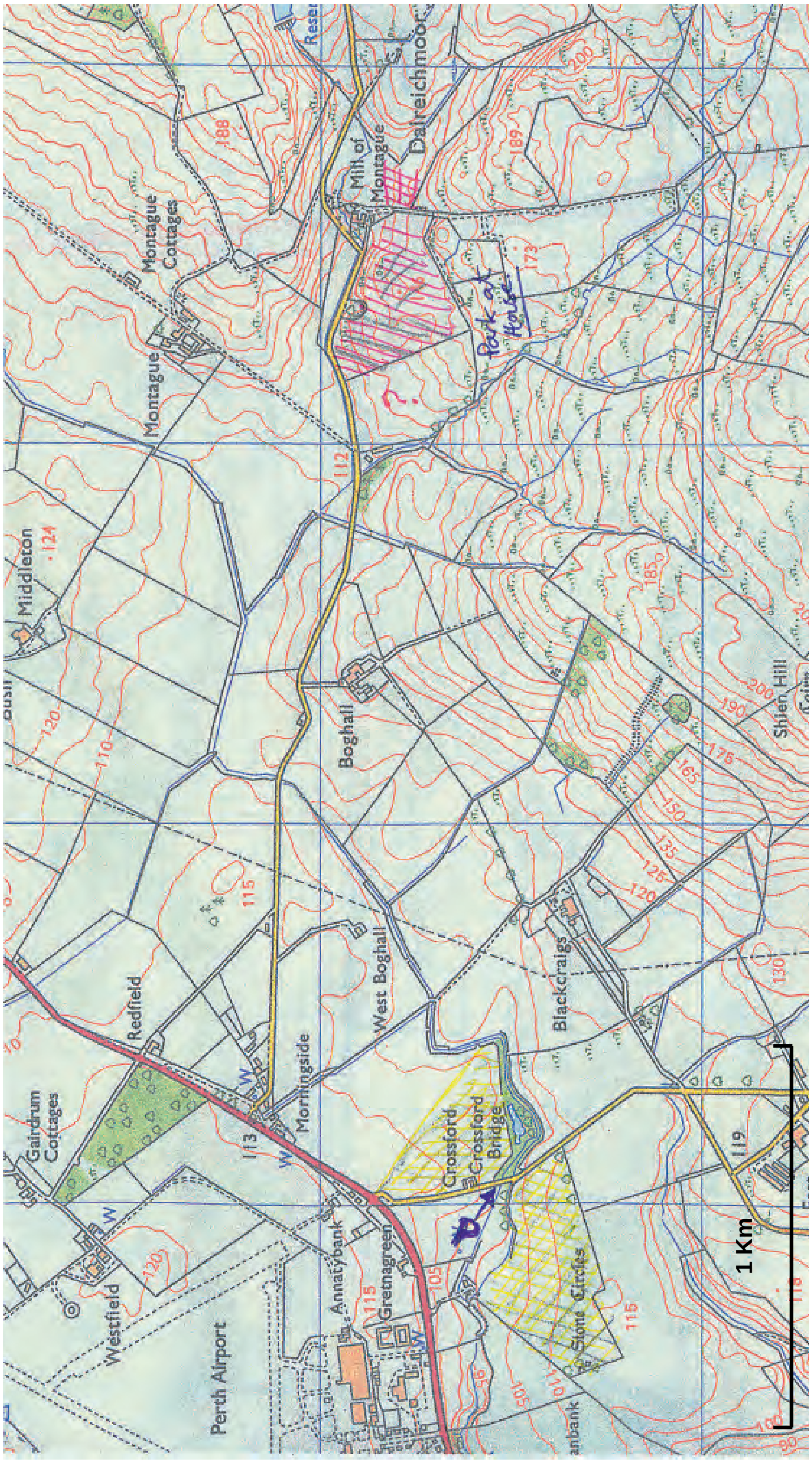
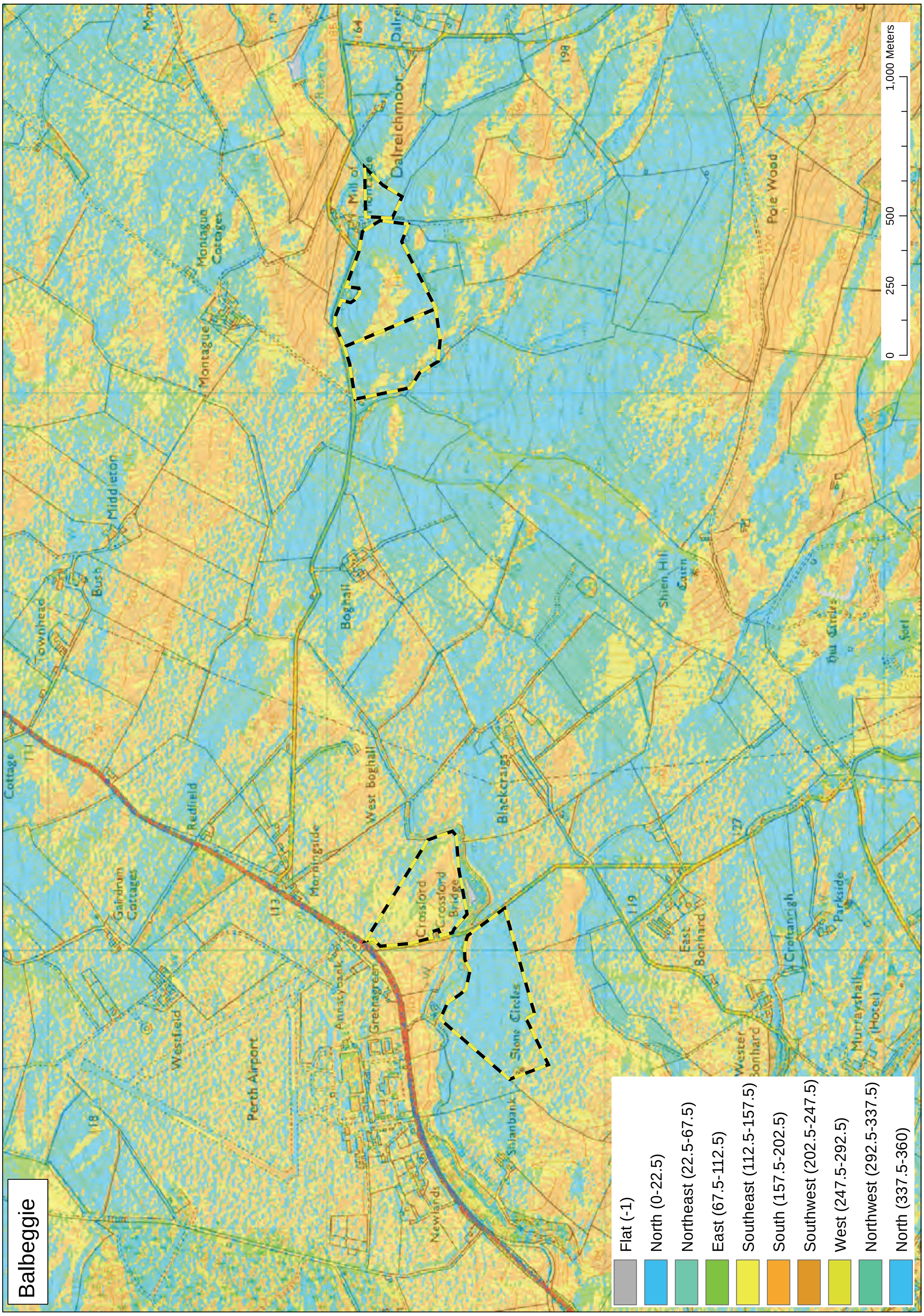
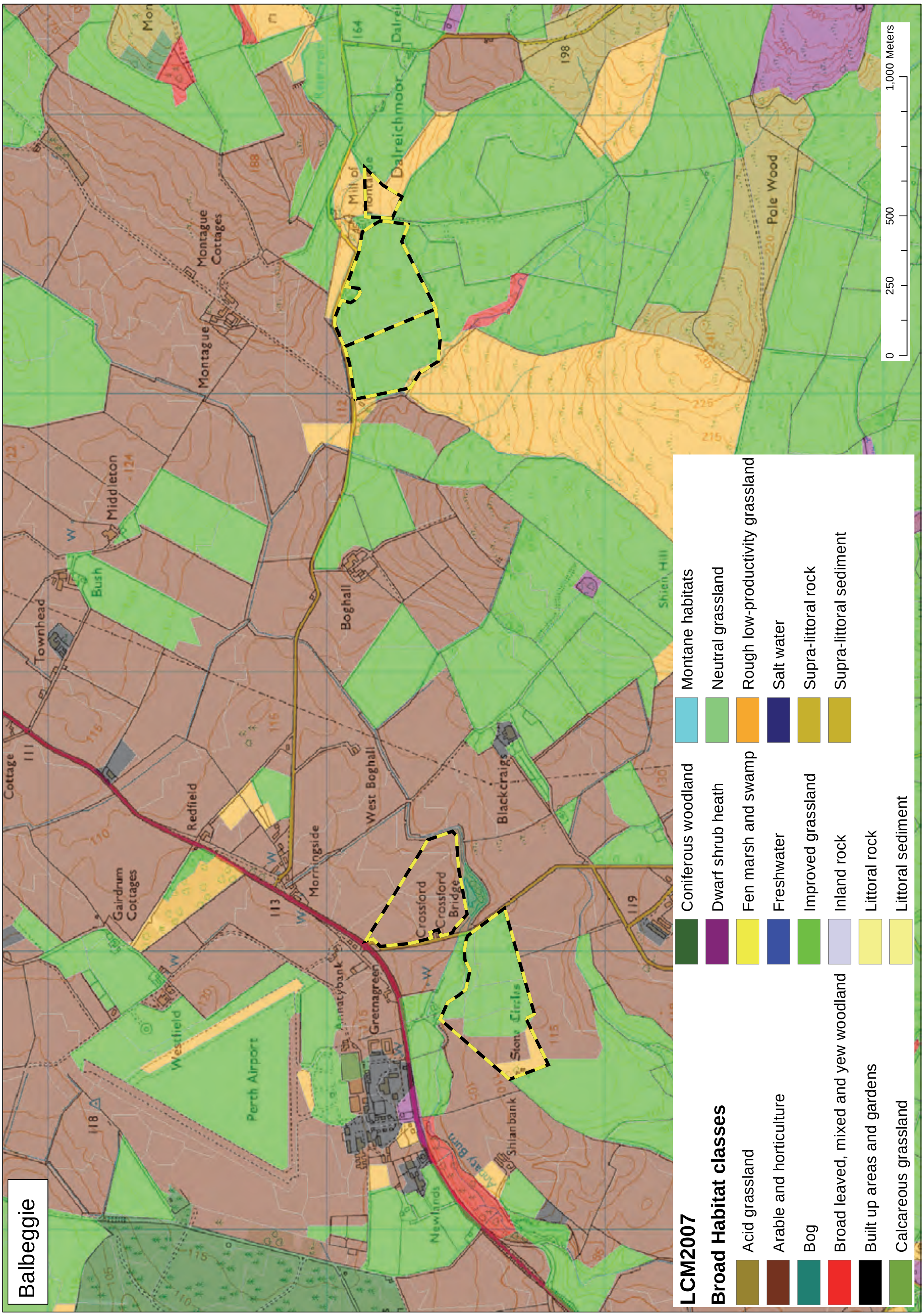
APPENDIX: MAPS



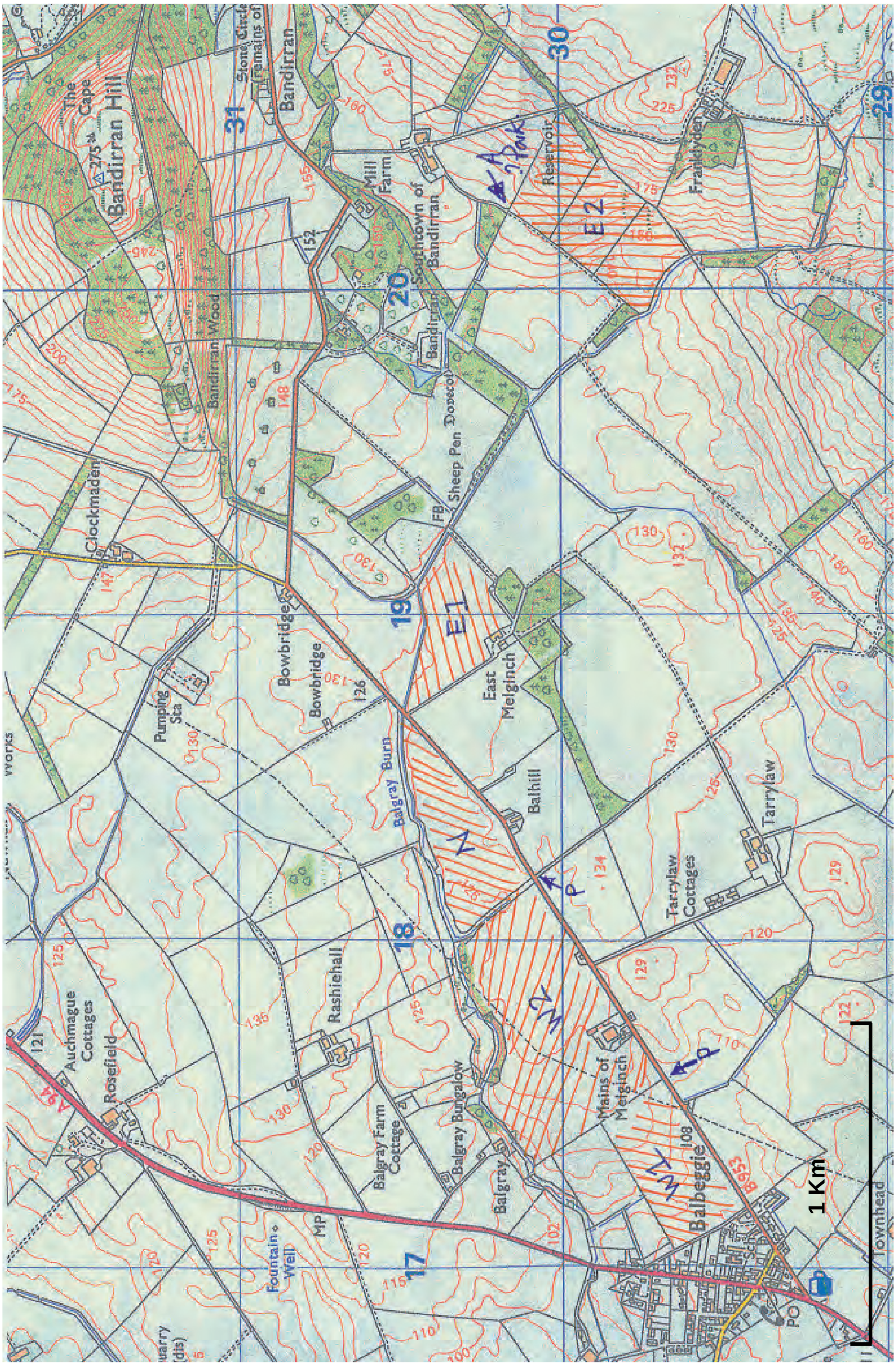
Map 1 - Location of Mill of Montague soft fruit and Balbeggie airfield (Crossford Bridge) oil-seed rape sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



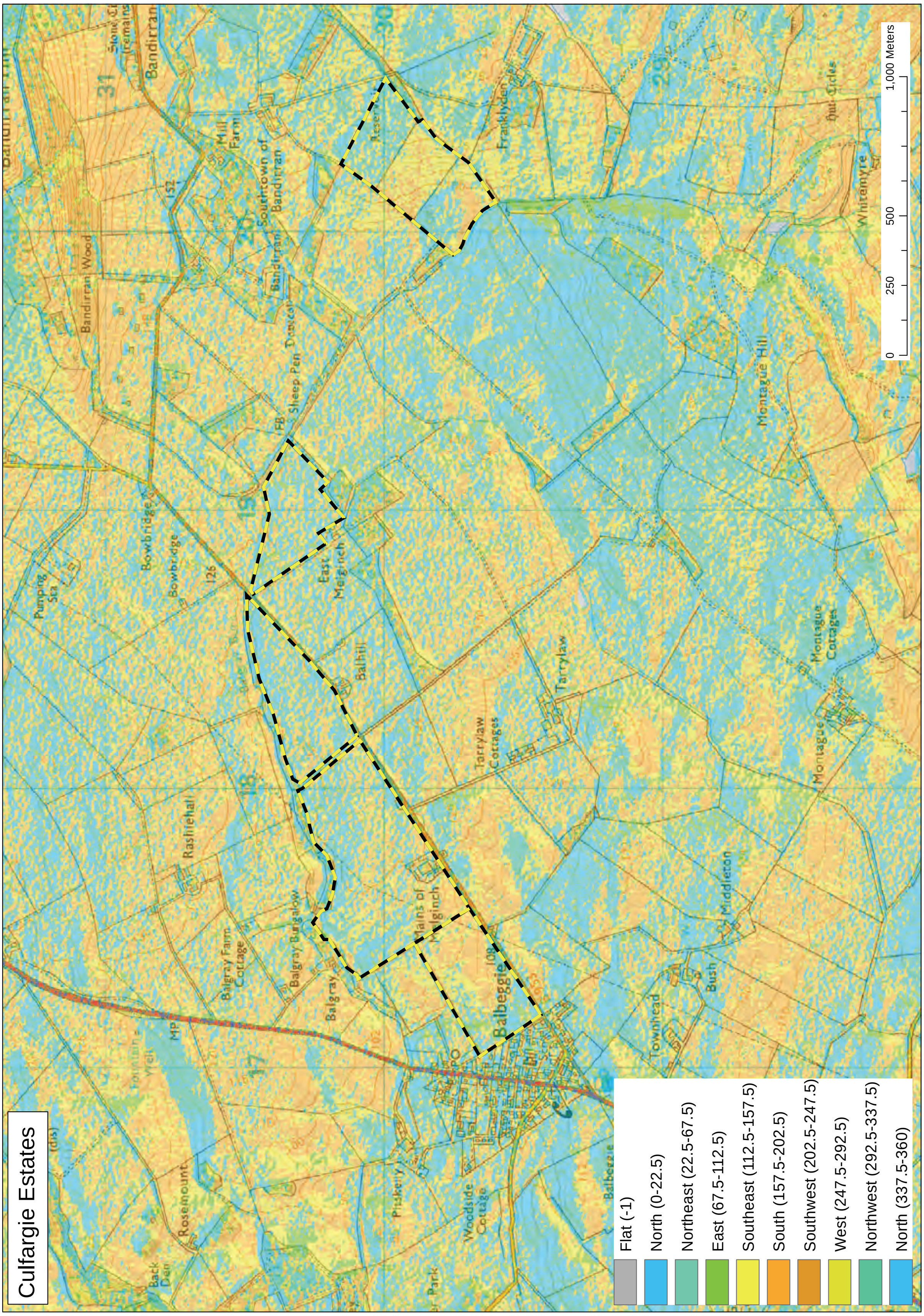
Map 2 – Aspect mapping of Mill of Montague soft fruit and Balbeggie airfield (Crossford Bridge) oil-seed rape sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



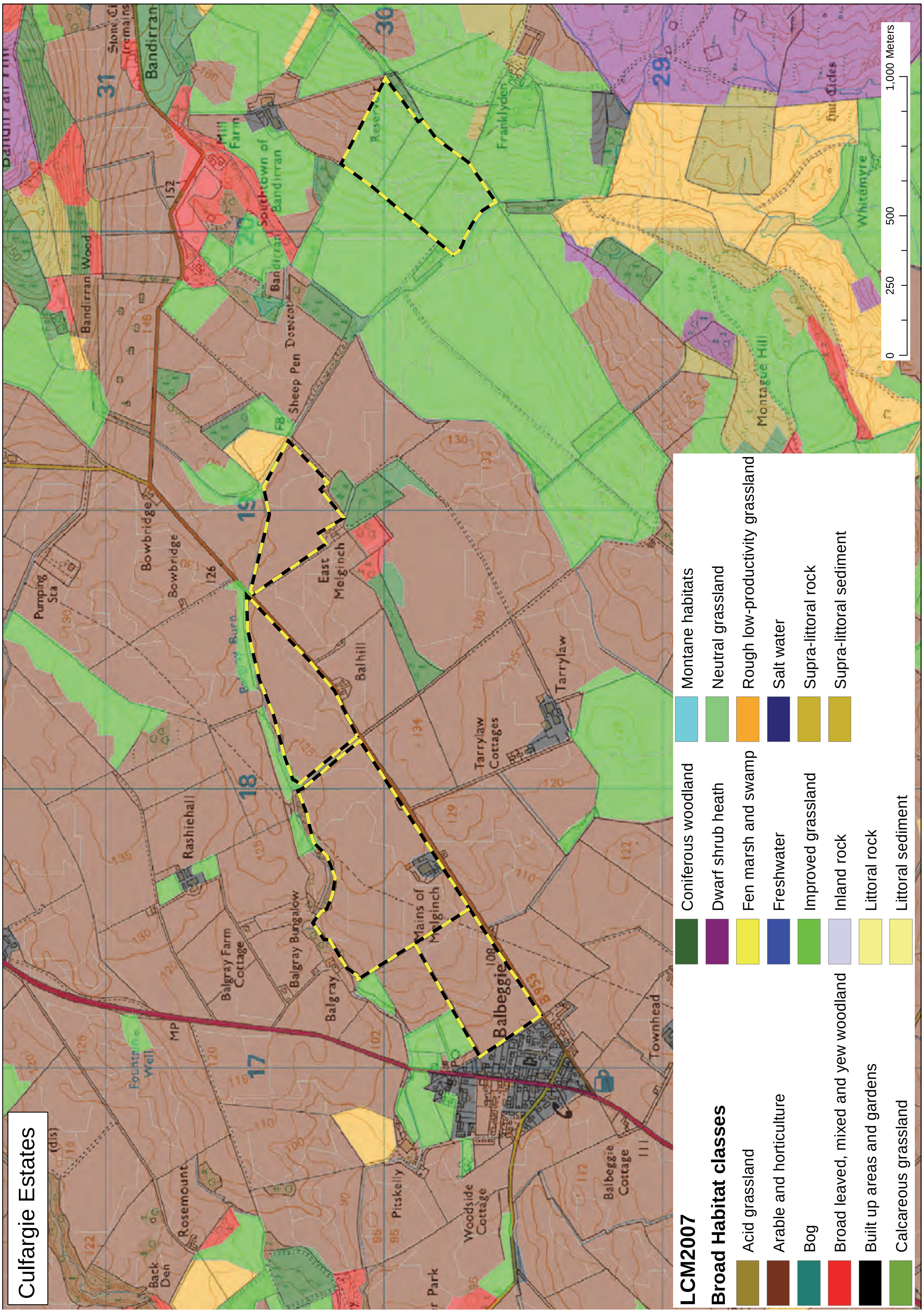
Map 3 – Land use mapping of Mill of Montague soft fruit and Balbeggie airfield (Crossford Bridge) oil-seed rape sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



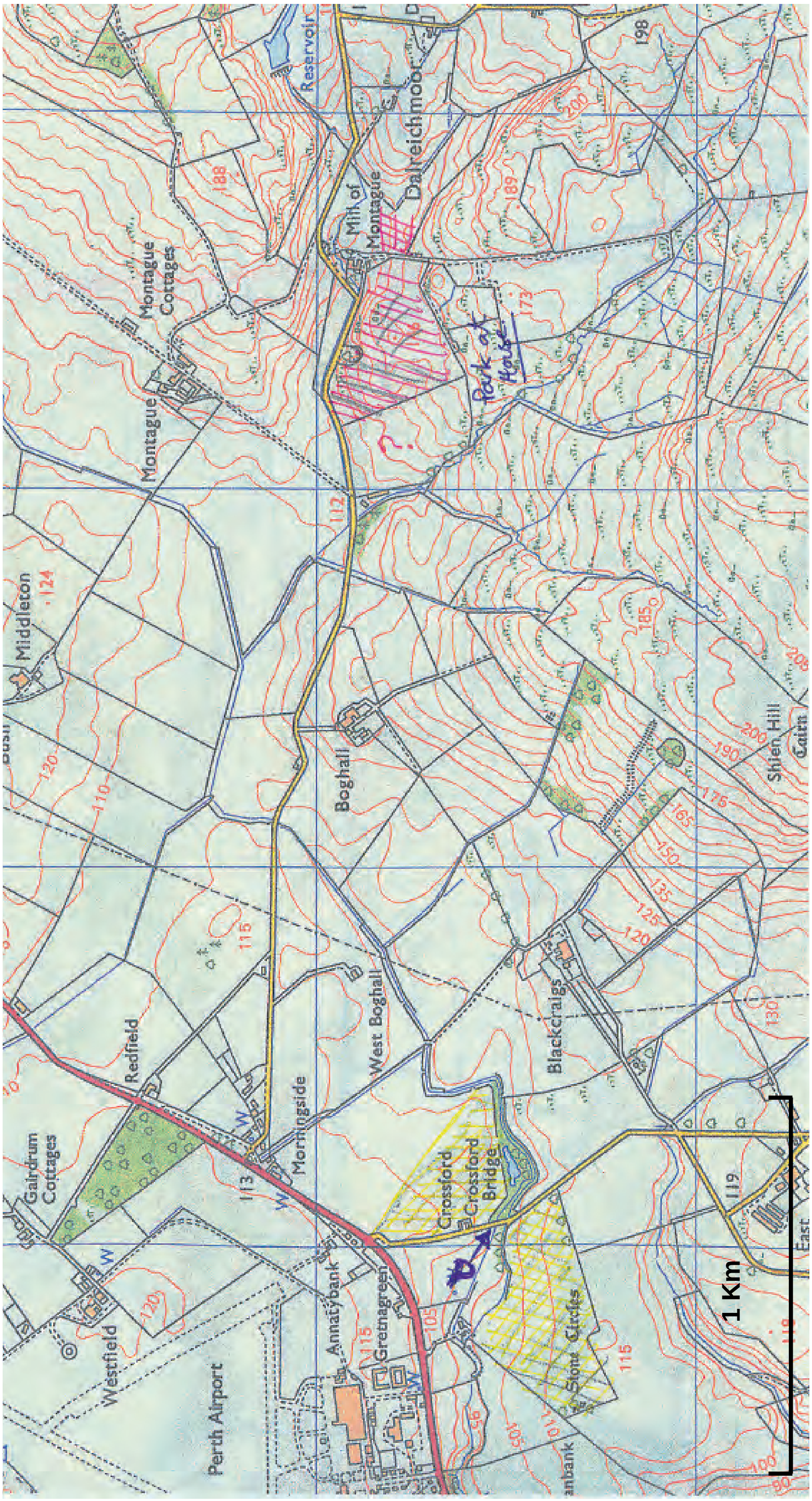
Map 4 – Location of Culfargie Estate oil-seed rape fields. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



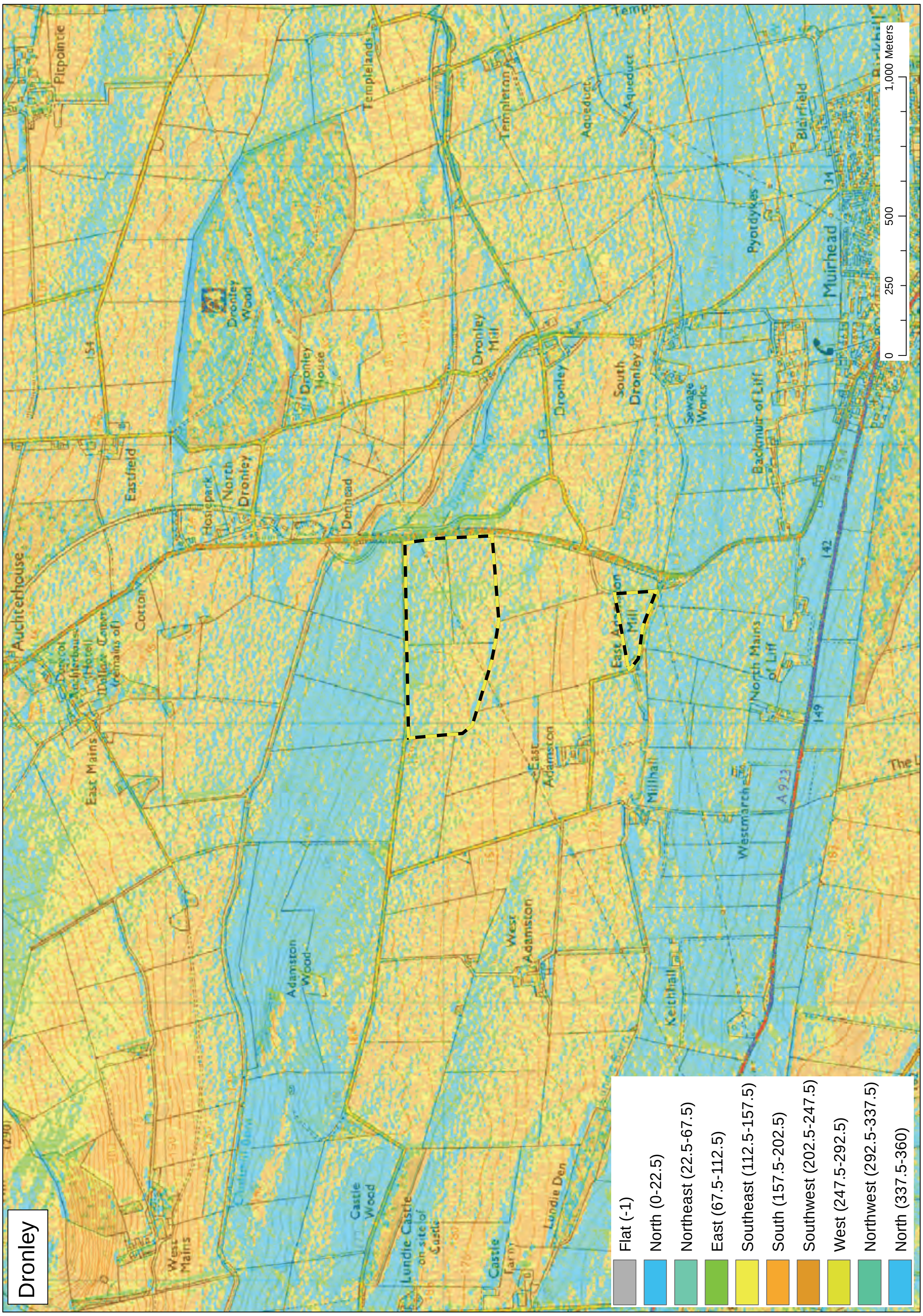
Map 5 – Aspect mapping of Culfargie Estate oil-seed rape fields. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



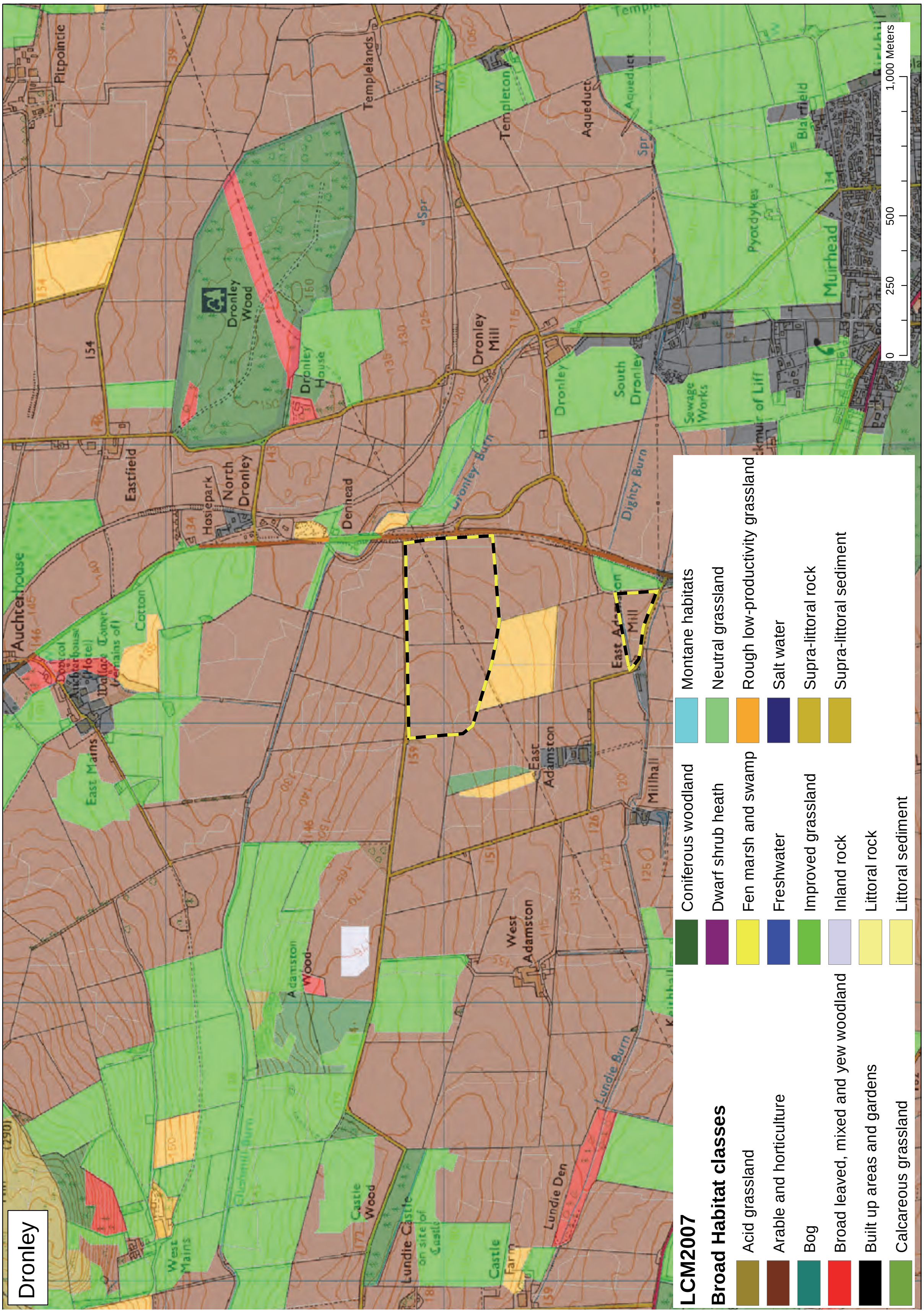
Map 6 – Land use mapping of Culfargie Estate oil-seed rape fields. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



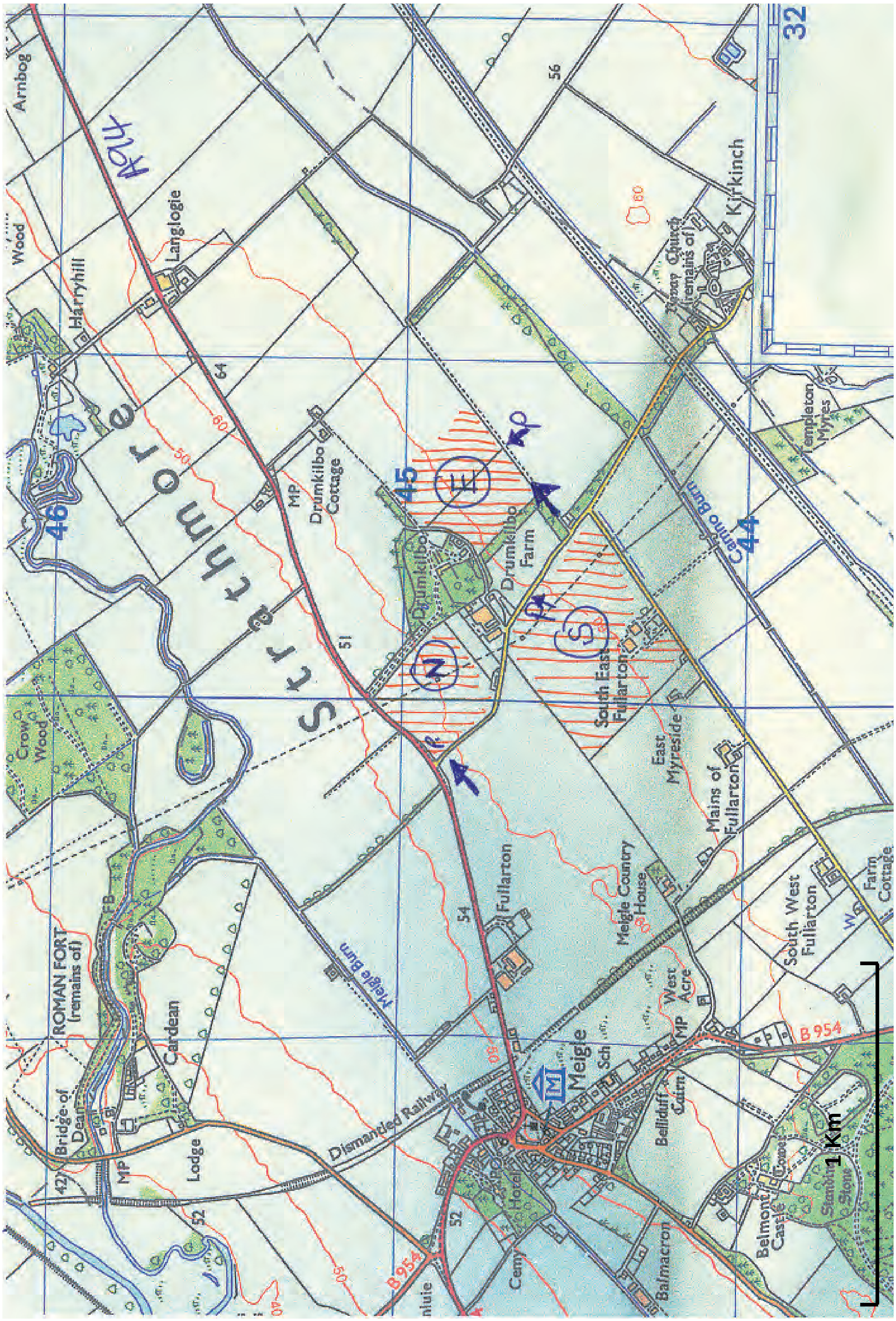
Map 7 – Location of Dronley top and soft fruit and oil-seed rape sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



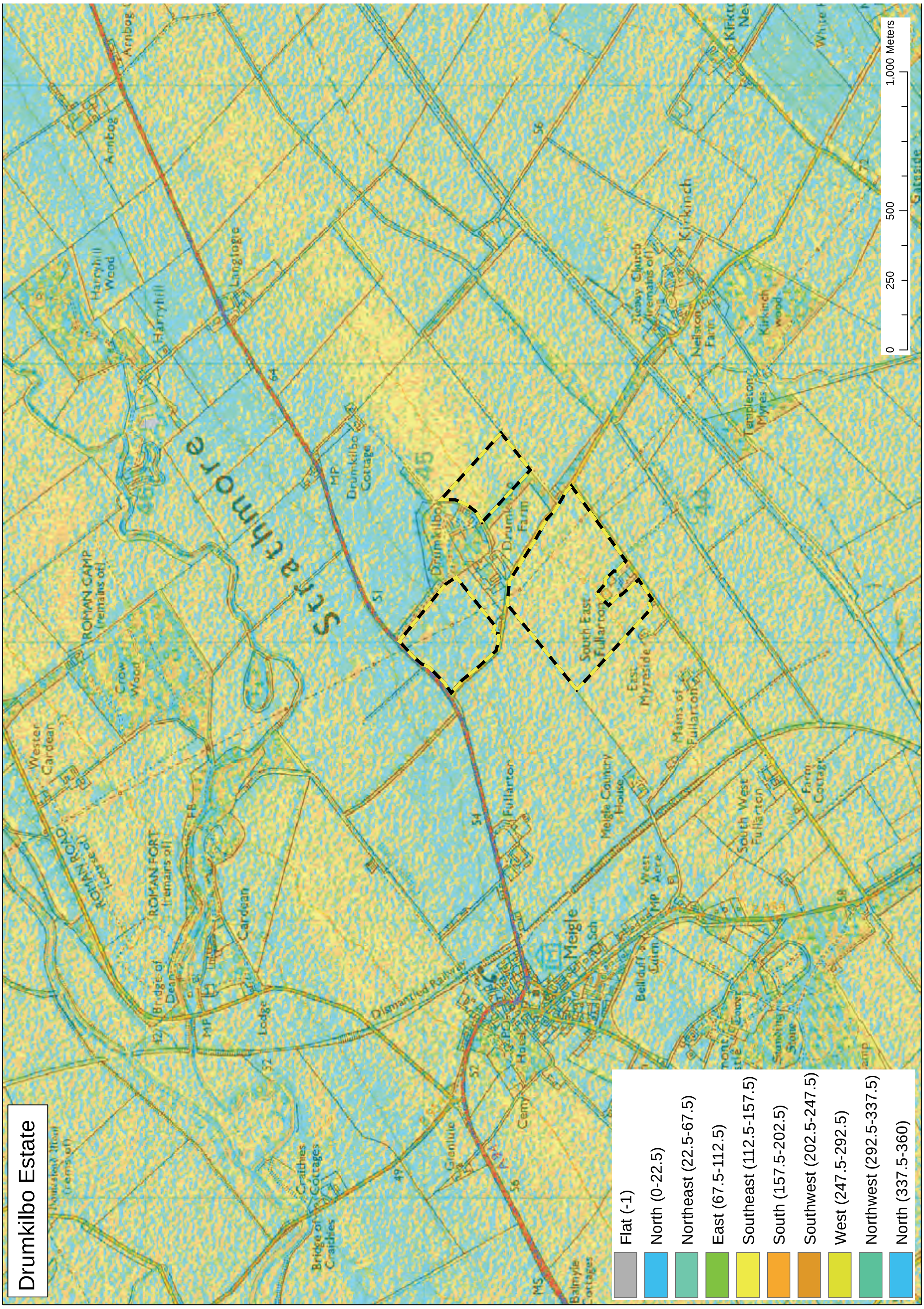
Map 8 – Aspect mapping of Dronley top and soft fruit and oil-seed rape sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



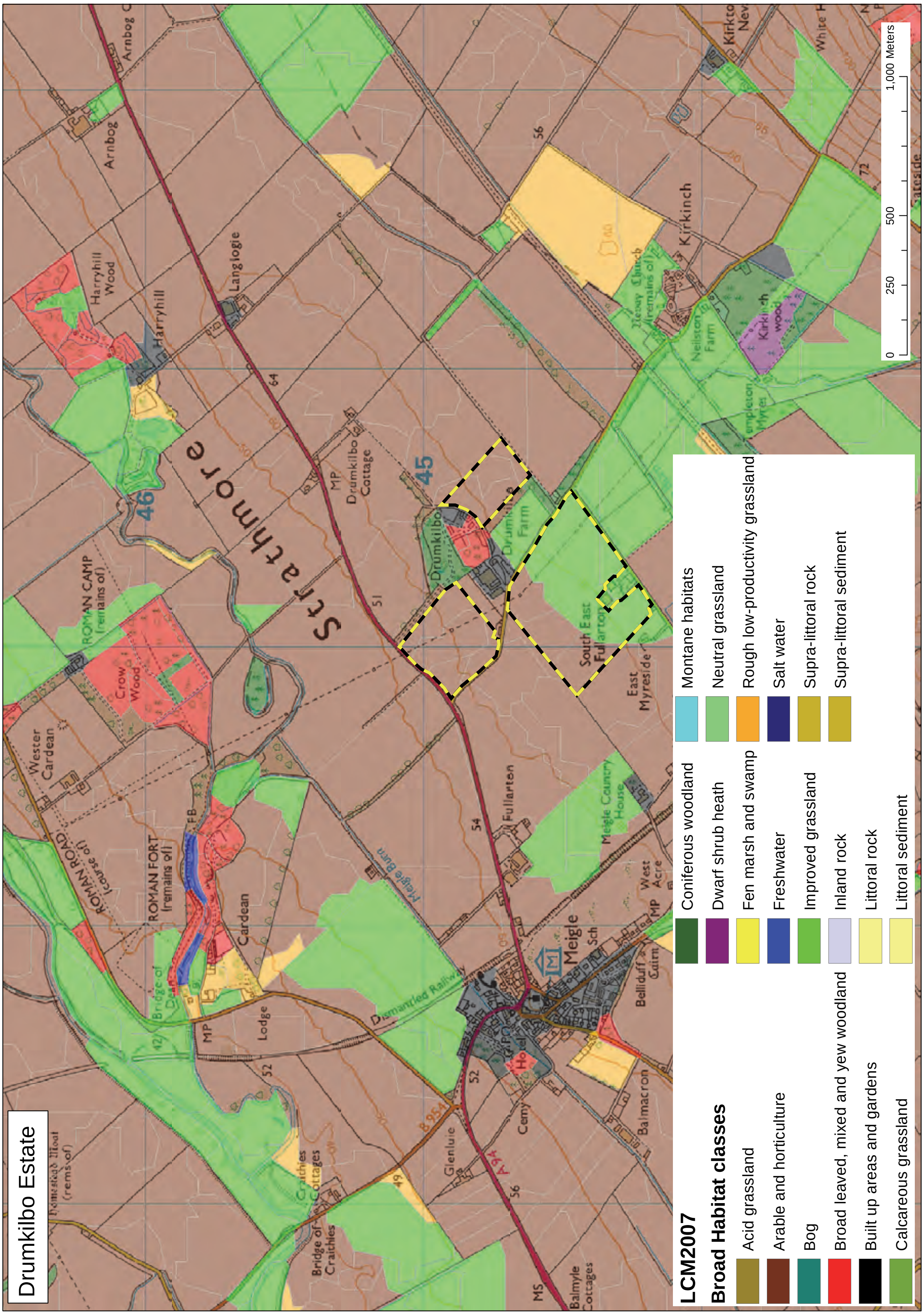
Map 9 – Land use mapping of Dronley top and soft fruit and oil-seed rape sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



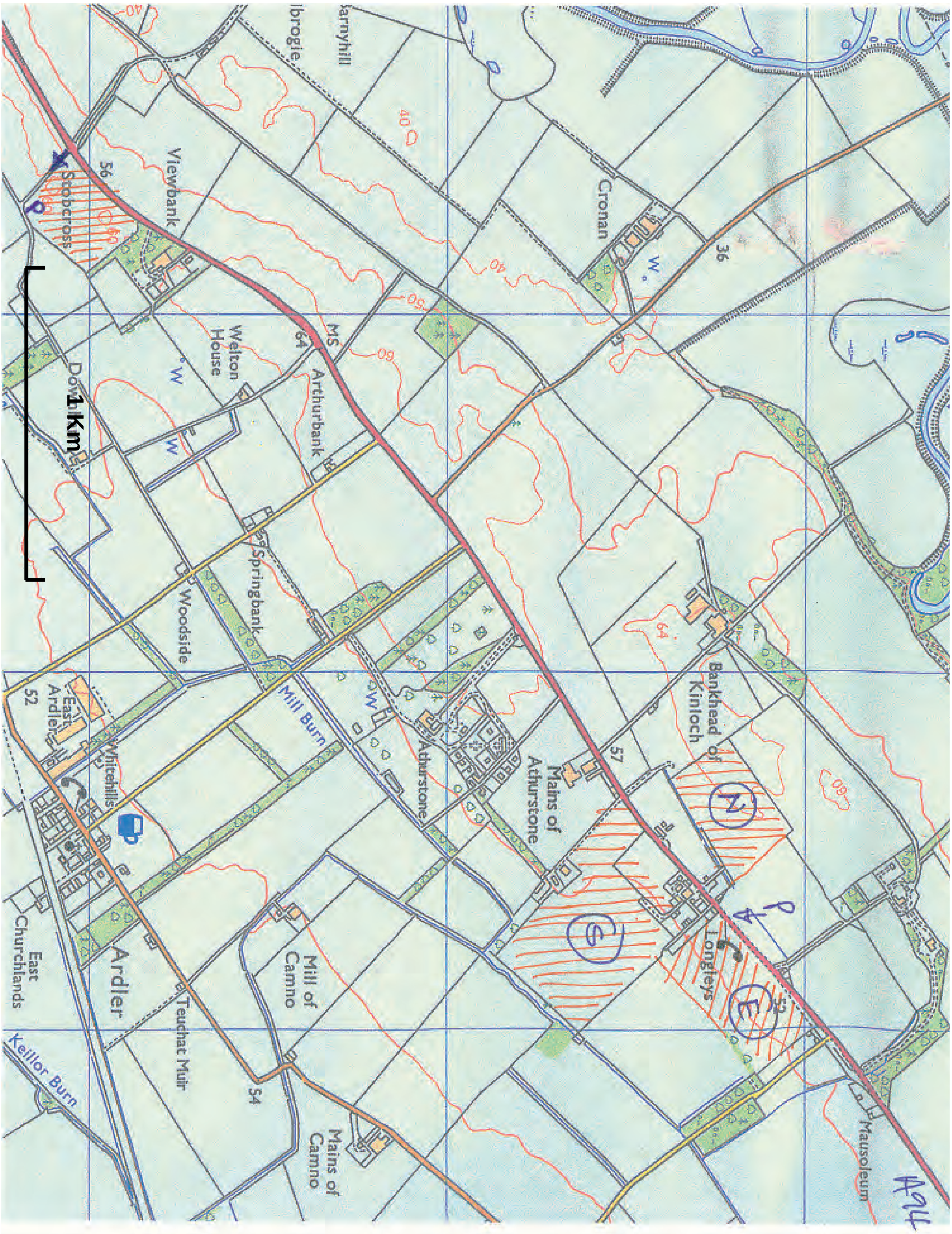
Map 10 – Location of Drumkilbo blackcurrant sample site. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



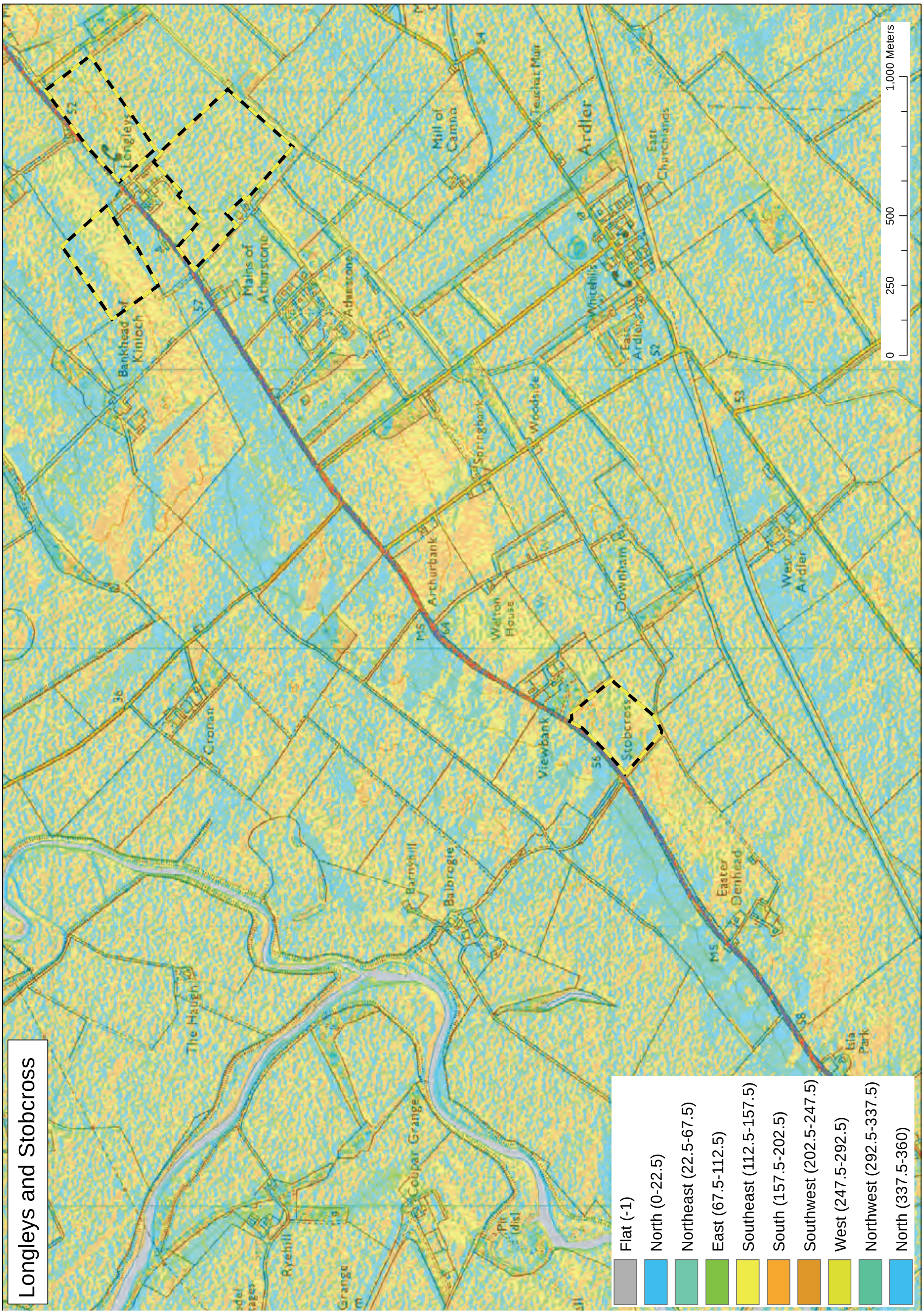
Map 11 – Aspect mapping of Drumkilbo blackcurrant sample site. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



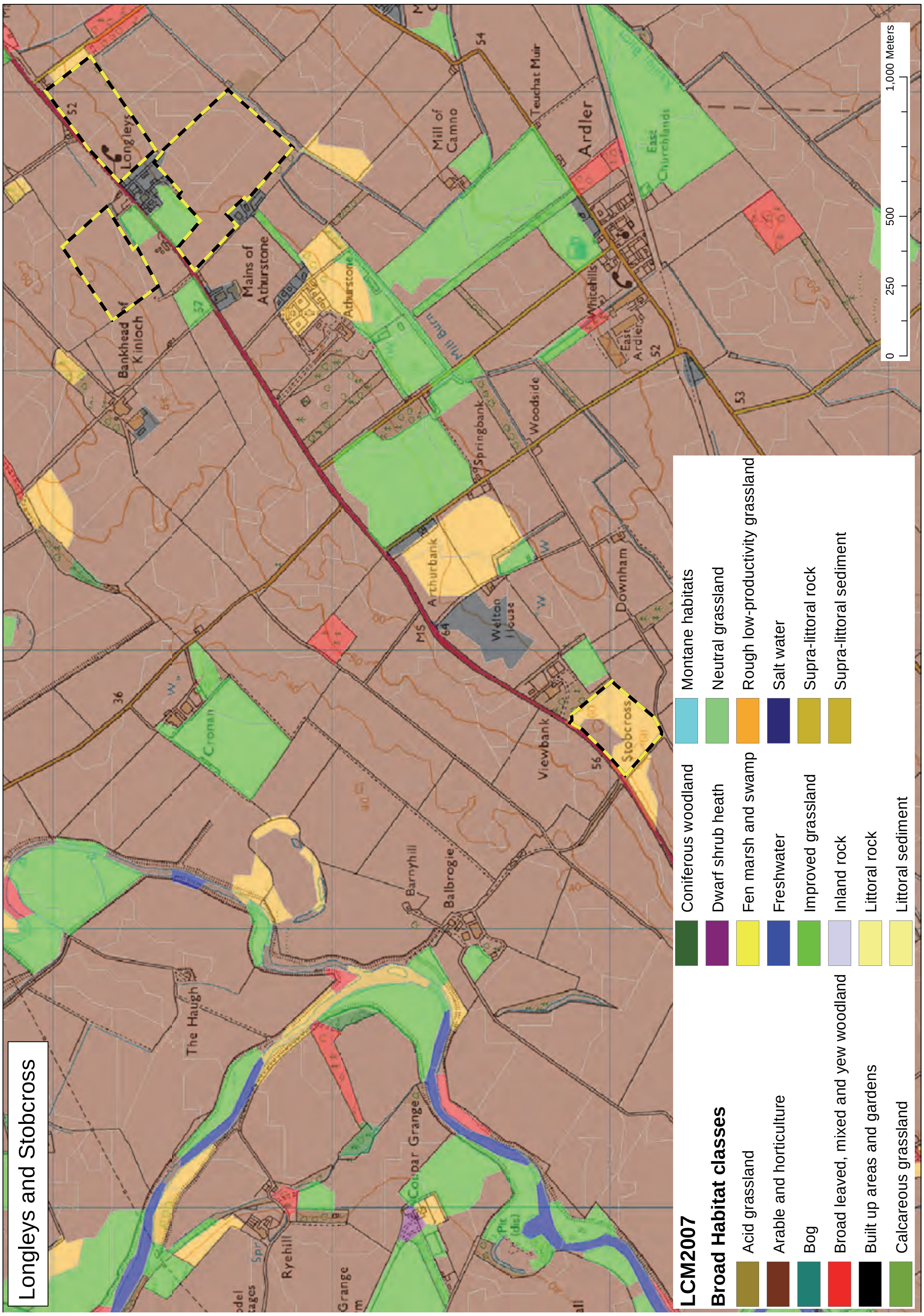
Map 12 – Land use mapping of Drumkilbo blackcurrant sample site. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



Map 13 – Location of Longleys and Stobcross blackcurrant sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908

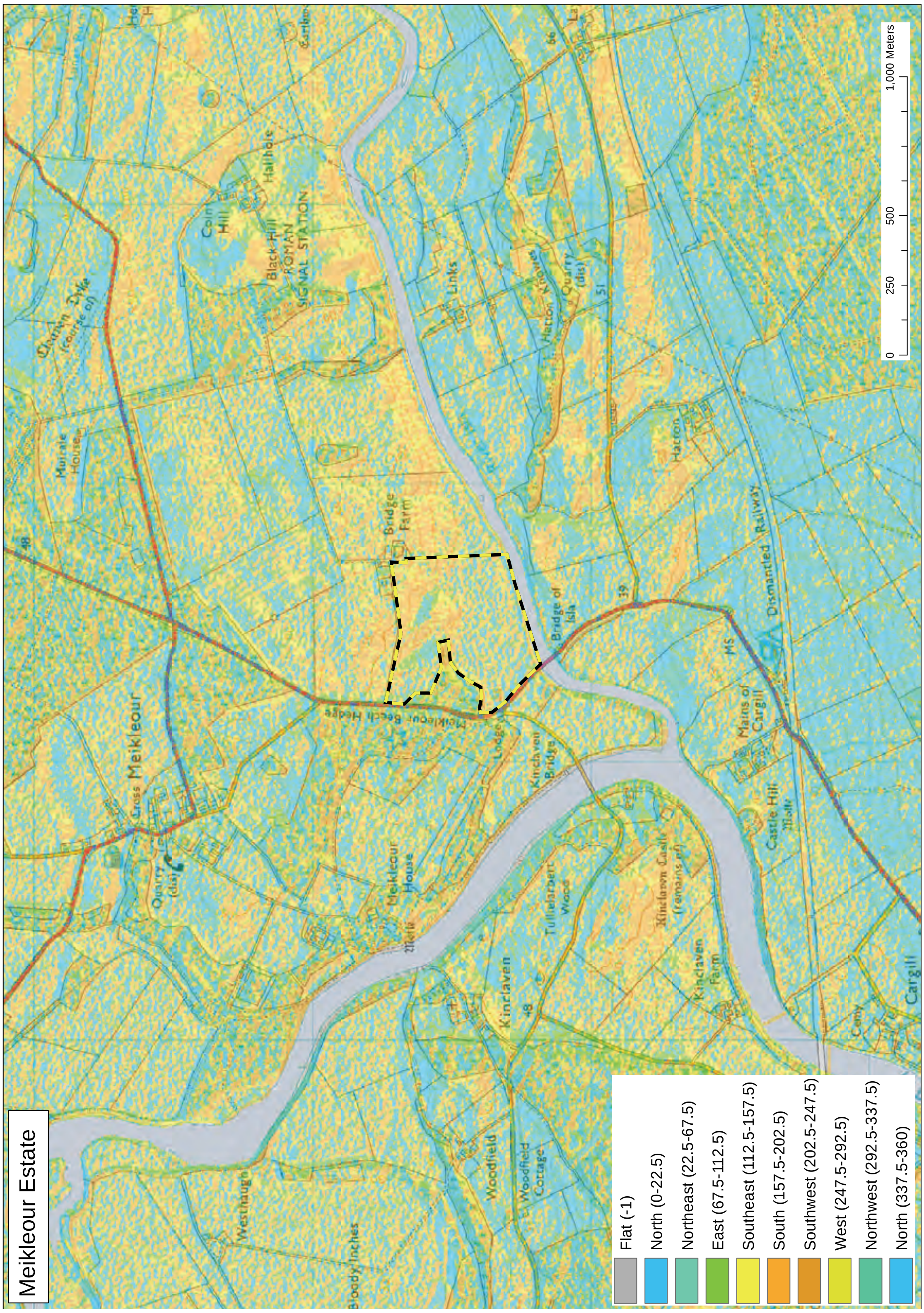


Map 14 – Aspect mapping of Longleys and Stobcross blackcurrant sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908

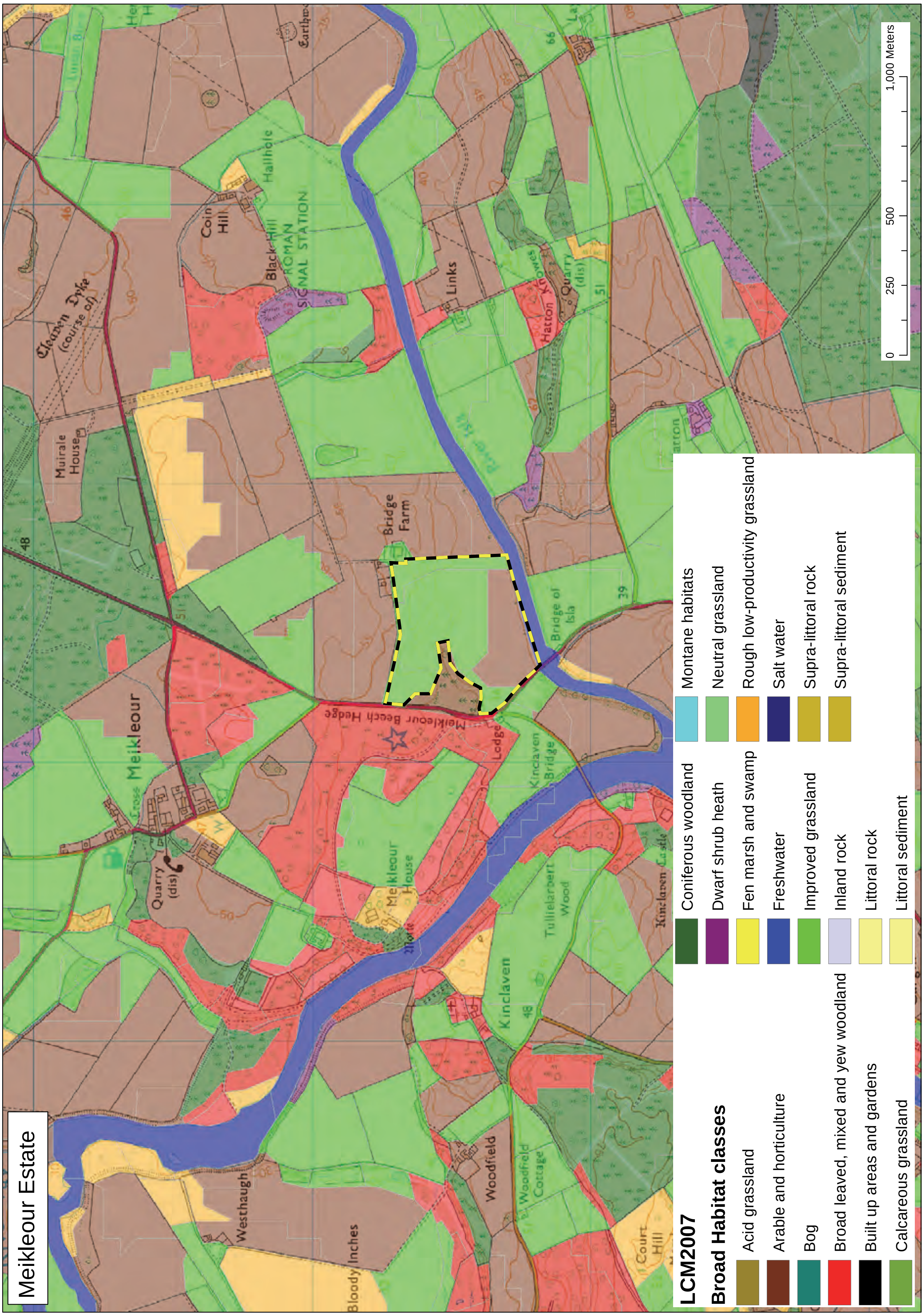


Map 15 – Land use mapping of Longleys and Stobcross blackcurrant sample sites. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908

Map 16 – Location of Meikleour oil-seed rape sample site. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



Map 17 – Aspect mapping of Meikleour oil-seed rape sample site. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908



Map 18 – Land use mapping of Meikleour oil-seed rape sample site. Based upon Ordnance Survey material with the permission of the Controller of HMSO © Crown copyright 1999 Licence no. 100017908

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