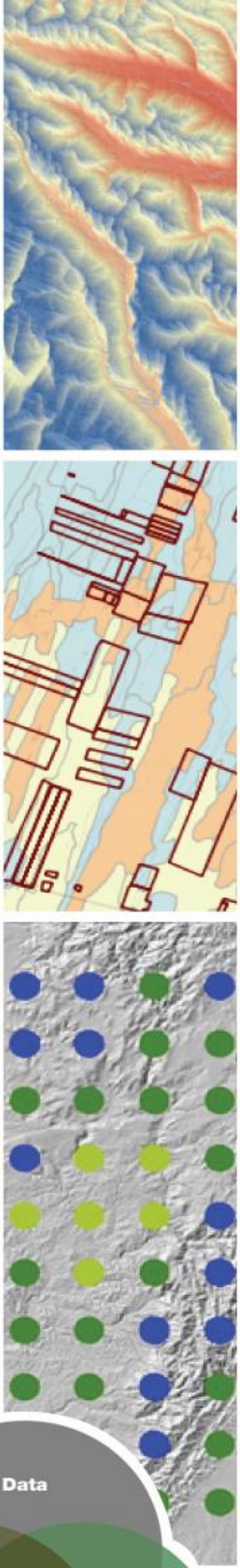
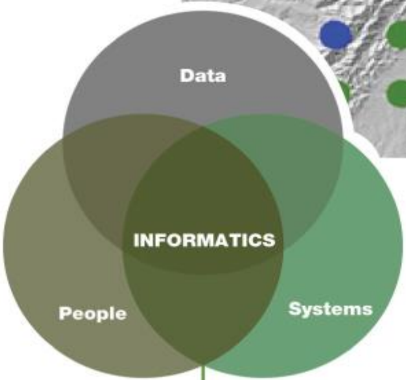
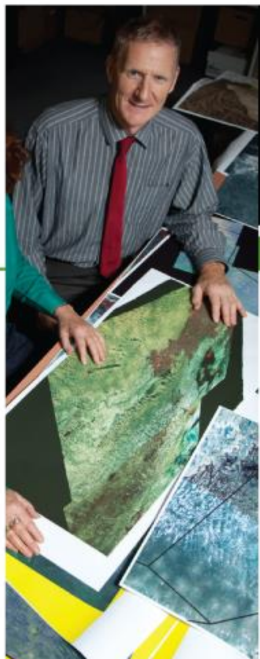
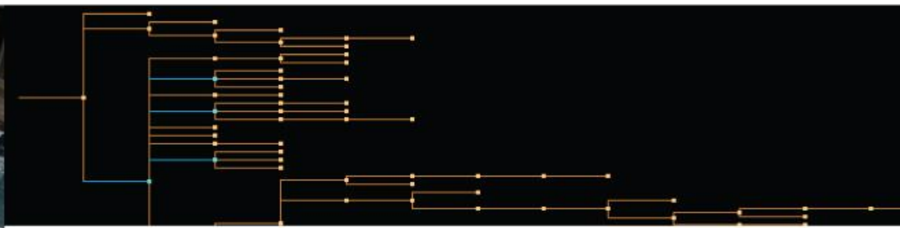


Winter livestock forage map – Southland Region 2014







Landcare Research
Manaaki Whenua

Winter livestock forage map – Southland Region 2014

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For Landcare Research

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Landcare Research

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Contents

Summary

Project and Client

Environment Southland contracted Landcare Research to produce a map of livestock forage in winter 2014 for the whole Southland Region. The mapping method used time-series satellite images, and was based on experience from a pilot study carried out previously for Environment Southland. From October 2014 to January 2015, Heather North was subcontracted by Landcare Research to work on the project.

Objectives

- Map winter livestock forage for the whole Southland Region (other than Stewart Island), including intensively farmed land and steeper farmed areas where development pressures are increasing.
- Carry out accuracy assessment of the resulting map using field data provided by Environment Southland, and provide a report describing methods and results.

Methods

- Acquire Landsat satellite imagery in the pre-grazing (March/April) and post-grazing (August/September) winter forage periods, as available. If coverage is insufficient, then infill with May–July imagery.
- For each image, carry out radiometric calibration and create a cloud/shadow mask. Also create a 'common mask' of all areas that are not agricultural land, and therefore are not to be analysed for winter forage (e.g. forest, scrub, sea, rivers, urban areas).
- Based on field data provided by Environment Southland, define a set of forage, non-forage and bare ground classes that are distinctive in the imagery, and derive spectral signatures for each of them.
- Classify each image in the sequence (both pre- and post-grazing) into the above classes.
- Develop and implement rules for combining evidence from the sequence of classifications to identify winter forage. These look for both the spectral appearance of known forage crops, and also the temporal pattern of winter forage, i.e. that a pixel should be vegetated in autumn, then bare soil in spring.
- Using a separate field dataset provided by Environment Southland, assess the accuracy of the resulting winter forage classification.

Results

- Winter livestock forage was mapped for the whole Southland Region. Non-agricultural areas (e.g. forest, scrub, sea, rivers, urban areas) were masked out, so that only the agricultural land (approximately 1 million hectares) was analysed.
- Over 70 000 ha were specifically mapped as winter livestock forage (6.7% of the mapped agricultural area) using a combination of forage-crop spectral signature with

the distinctive temporal pattern of being vegetated in autumn, then bare in spring. A further 55 000 ha (5.2%) also had this temporal pattern, but had the spectral signature of pasture or other vegetation. The latter category is often associated with winter forage paddocks, but can also be caused by other non-forage land uses such as spring pasture-renewal, so we termed these areas 'likely forage'.

- In a further 8.6% of the mapped agricultural area, the imagery was insufficient to conclude whether the land use was winter forage.
- Of 331 paddocks identified in Environment Southland's field data as forage, 95% (314 paddocks) were classified by our method into the 'specific' and 'likely' forage categories. Of the 43 paddocks identified by Environment Southland as non-forage land uses, 77% (33 paddocks) were correctly classified as such by our method.
- Classification does not appear to be affected greatly by hilly terrain, as similar accuracies were obtained for the paddocks that Environment Southland recorded as being gentle, moderate or steep in gradient.

Conclusions and recommendations

- Mapping winter forage has been successful at regional scale, with good accuracy levels.
- The image dataset was strongly affected by cloud, requiring a great deal of cloud-masking, and a complicated rule-set to pull together evidence from a large number of image dates. An image-set with less cloud cover would have allowed for a simpler mapping method, and likely higher accuracies.
- Some forage paddocks appeared to be planted later than the norm, not reaching full vegetation cover until after the April imagery we had available in this project. Future winter forage mapping would be improved if image coverage in May was included to aid identification of these paddocks.
- The paddocks that were not specifically classified as forage types in autumn since they had a pasture-like spectral signature, but which were bare soil in spring, make up a large part of our 'likely forage' category. Many of these are indeed forage paddocks, but others may be other land uses such as spring pasture-renewal. Additional imagery in winter or spring may be able to help resolve these classes.

1 Introduction

In 2013, Environment Southland contracted Landcare Research to investigate methods for mapping winter livestock forage in the region, using time-series satellite imagery for a small (40 × 47 km) study site around the Gore–Mataura area. Based on the results and experience from that pilot study, Environment Southland contracted Landcare Research to map livestock forage in winter 2014 for the whole Southland Region. From October 2014 to January 2015, Heather North was subcontracted by Landcare Research to work on the project.

2 Background

During winter, when there is little grass growth, cattle and sheep are often strip-grazed on specially-grown forage crops. In Southland, these are typically planted in late spring to early summer and reach full canopy cover around late-March/April. We have been advised by Environment Southland that grazing often starts in early May and many paddocks are already grazed out by late July, leaving completely bare soil after grazing. A lower level of forage grazing continues until early September.

Kale (*Brassica oleracea*) and swedes (*B. napobrassica*) are commonly used as winter livestock forage crops in Southland. There is also some use of other brassica varieties, fodder beet (*Beta vulgaris*), and oats (*Avena sativa*).

In our previous work for Environment Southland, we showed that brassica and swede crops tend to be spectrally separable from pasture in multispectral satellite imagery (North et al. 2014a). Thus it is often possible to identify them from their appearance in satellite imagery taken in the period of pre-grazing full-leaf-cover.

However there are several complications that make this simple crop identification inadequate for winter forage mapping:

- If the image captures a paddock at a time when it has low cover of vegetation over soil, brassica/swede is less separable from pasture.
- Spectral appearance of vegetation is modified by variations of light and shade in hilly terrain and in areas affected by cloud haze and shadow. Topographic effects can be significant because sun elevation is low in the late-March/April pre-grazing period (typically 25 to 30 degrees at the ~10 a.m. satellite image acquisition time).
- Some other forage crops, particularly oats, are not reliably separable from pasture by their spectral appearance, so would be missed by this method.

We also showed the inadequacy of simply classifying bare soil in the post-grazing period (September). There are reasons other than winter forage grazing that a paddock can be bare in September, including pasture renewal or the planting of summer arable crops. Timing for these crops varies, but it would be not uncommon for a paddock to be cultivated in early spring, or to still be sitting with the previous season's stubble/bare soil (in the case of cropping paddocks).

Therefore, as reported in North et al. (2014a), we trialled a range of classification methods that combined evidence from several image dates, with the aim of observing a winter forage paddock both at the stage of full canopy cover and also at the stage of post-grazing bare soil. This multi-temporal approach provided a more reliable discrimination, so the concept has been carried through to the current project.

3 Objectives

- Map winter livestock forage for the whole Southland Region (other than Stewart Island), including intensively farmed land and steeper farmed areas where development pressures are increasing.
- Carry out accuracy assessment of the resulting map using field data provided by Environment Southland, and provide a report describing methods and results.

4 Methods

4.1 Study site and acquisition of satellite image sequence

Figure 1 shows the study site, as outlined by the Southland Region boundary. Environment Southland decided to use only freely-available Landsat imagery in this study. The figure shows how three neighbouring Landsat satellite image scenes align with the region to cover the full area. The ideal would be to acquire these three scenes, cloud-free, in mid- to late April and again in early September.

Choosing not to purchase SPOT satellite imagery to augment the time-series does help to keep the data costs down, but also means that acquisition of cloud-free coverage of the study site is much less certain. This is because the fixed-orbit Landsat satellites (Landsat-7 and Landsat-8) each acquire imagery only every 16 days, whereas the pointable SPOT-5 satellite, when custom-programmed, has at least a dozen opportunities per month. Moreover, Landsat-7 suffers from a fault that causes large horizontal gaps in the data, so the coverage from this satellite service is not complete.

The Landsat images available in our periods of interest (those not completely cloud-covered) are listed in Table 1. Coverage of the study site requires a pair of images on satellite orbit Path 76 (see Figure 1) and a single image on Path 75. There is a large overlap between orbital paths at high latitudes, improving the likelihood of good image coverage. Conveniently, a path overlap occurs through the central part of the study site. However, as it transpired, the weather did not comply with our needs and most of our satellite images were partly or very cloudy.

Available images on the two paths are listed side-by-side in Table 1. In the ‘post-grazing’ (spring) period we have included an image acquired on 22 June 2014. This date is not ideal, as some winter forage grazing will still be occurring, but it was needed to fill in gaps where no other data were available, due to either cloud cover or Landsat-7 line drop-outs, or both.

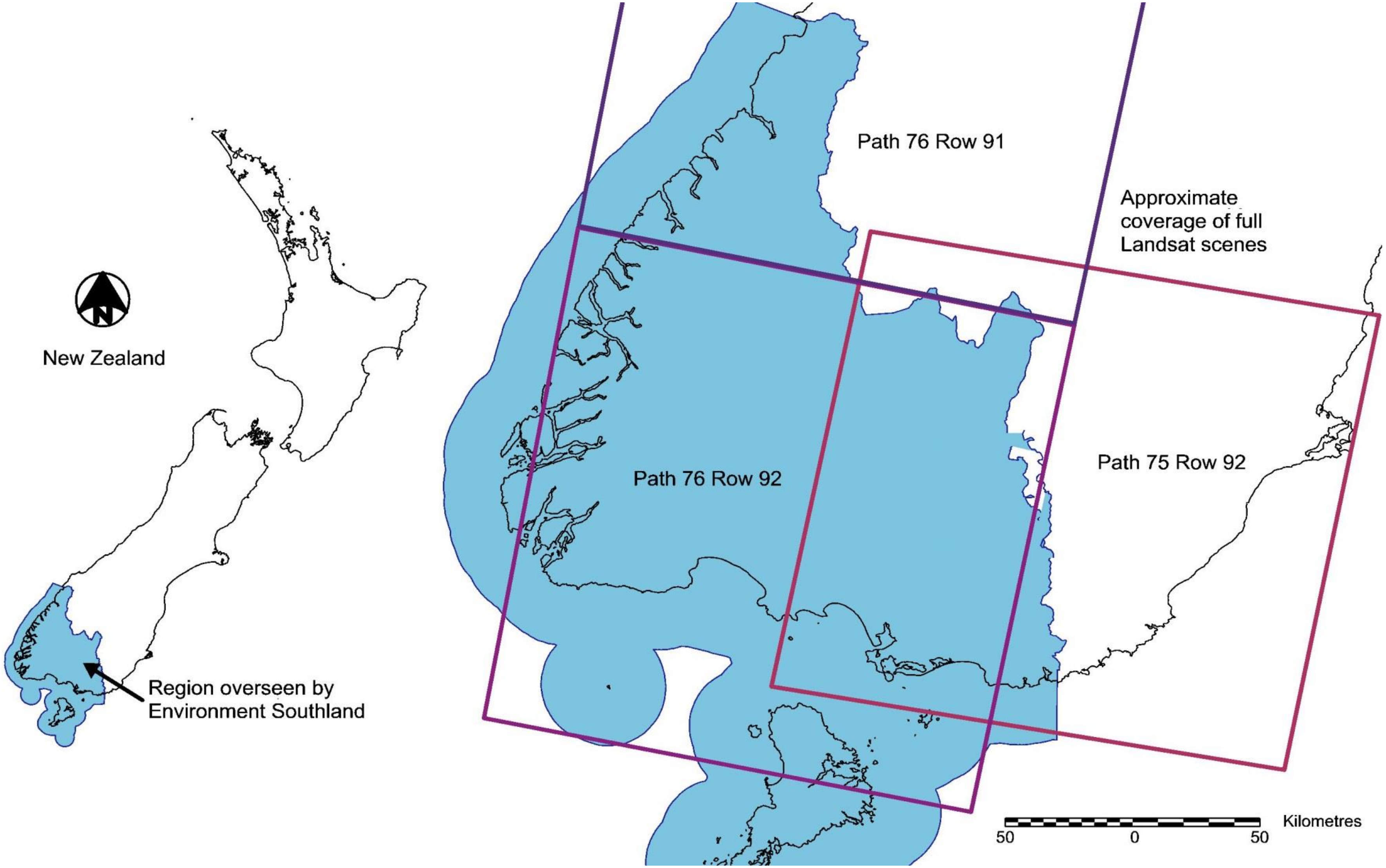


Figure 1 Location map showing Southland Region, New Zealand, and the approximate coverage of Landsat satellite scenes for the area. Scene coverage varies slightly from one date to another. The western third of the Southland Region is forest-covered mountains and fjords, so is not of interest in this project.

Table 1 List of Landsat images available in the 'pre-grazing' (autumn) and 'post-grazing' (spring) periods for the Southland study site. Coverage of satellite scene paths is shown in Figure 1

Path 76 (western side) – Rows 91 and 92	*Path 75 (eastern side) – Row 92*
Autumn images 2014	
10-March, Landsat-7	
	11-March, Landsat-8
26-March, Landsat-7	
	12-April, Landsat-8
19-April, Landsat-8	
Spring images 2014	
22-June, Landsat-8	
17-August, Landsat-7	
10-September, Landsat-8	
	19-September, Landsat-8
26-September, Landsat-8	

4.2 Image pre-processing and masking

The Landsat images were re-sampled to the New Zealand Transverse Mercator (NZTM) map grid, and were pan-sharpened to a 15-m pixel size using the panchromatic band of each image (Dymond & Shepherd 2004). They were then radiometrically calibrated to standardise the appearance of land covers from one image to another. The first calibration step is bi-directional reflectance correction (Shepherd & Dymond 2000) to adjust for the angles of sun and satellite at the time of image acquisition and the settings of the satellite sensor. Further steps correct for atmospheric and topographic effects. This 'flattens' the image by minimising the variations from light and shadow in hilly areas (Shepherd & Dymond 2003).

It should be noted that the topographic flattening method was developed for use with summer imagery; i.e. images with sun elevations of 40 degrees and over. Our images are thus not ideal for this method. Landsat images are acquired at around 10 a.m., so our autumn and spring images typically have sun elevations of only 25 to 30 degrees. Date-to-date standardisation was therefore not perfect, but we concluded that the topographic correction was sufficiently effective to continue with this rather than a more heuristic approach. The standardisation of the mid-winter image (22-June, sun elevation 13.39 degrees) was poor, but fortunately this image was only required as infill for a few small areas.

The next step was to create cloud-masks for each image, so that areas of cloud, cloud-shadow and snow could be removed. The cloud-masked images are shown in Figure 2. The remaining (unmasked) areas of imagery were used for processing. Though the worst of the cloud was removed, there appeared to be some areas of very thin haze (and associated shadow) remaining. It was necessary to use these areas in the analysis; otherwise we would not have had sufficient coverage of the study site. However, we used them with caution, because the cloud haze appeared to be affecting the land cover classifications. These 'low-trust' areas of possible haze and haze-shadow are outlined in Figure 2.

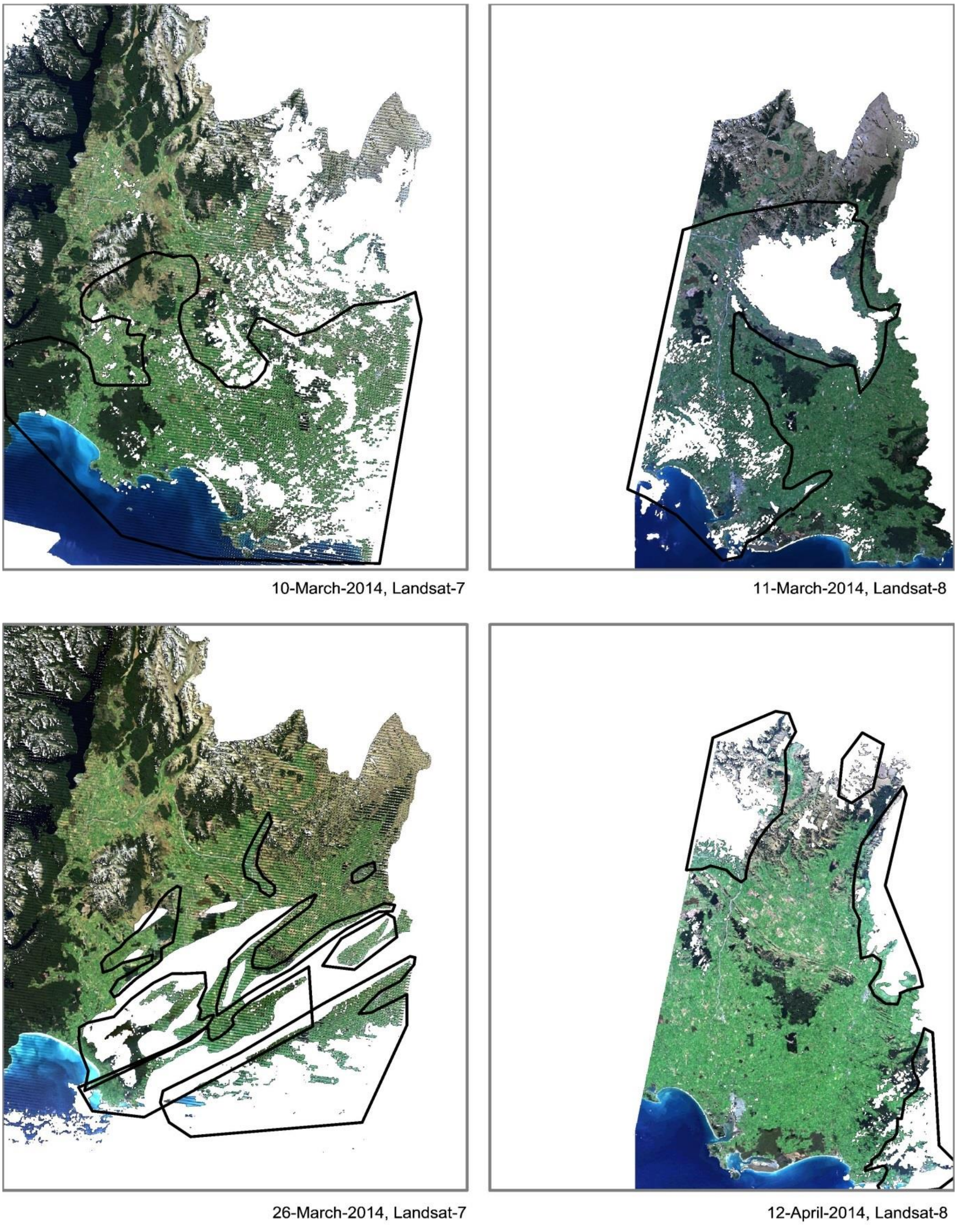


Figure 2 (page 1 of 3): First four images in the Southland Region time-series. White areas have been masked out to remove cloud, cloud-shadow, snow, Landsat-7 line drop-outs, and areas where the land is too steep for topographic correction to be successful. 'Low-trust' areas – where some slight remaining influence of cloud haze is suspected – have been outlined (black linework).

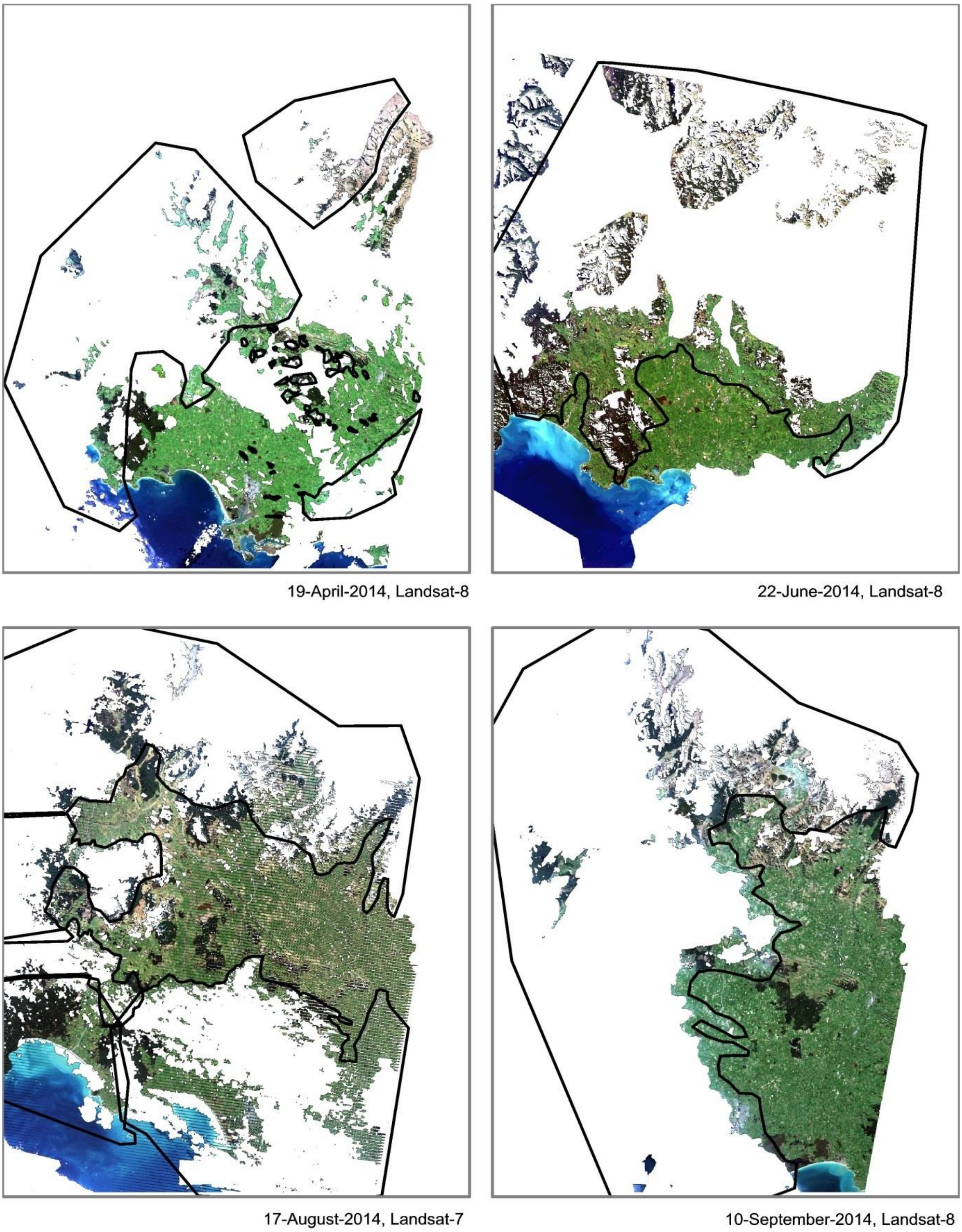


Figure 2 (page 2 of 3): Second set of four images in the Southland Region time-series. White areas have been masked out to remove cloud, cloud-shadow, snow, Landsat-7 line drop-outs, and areas where the land is too steep for topographic correction to be successful. 'Low-trust' areas – where some slight remaining influence of cloud haze is suspected – have been outlined (black linework).

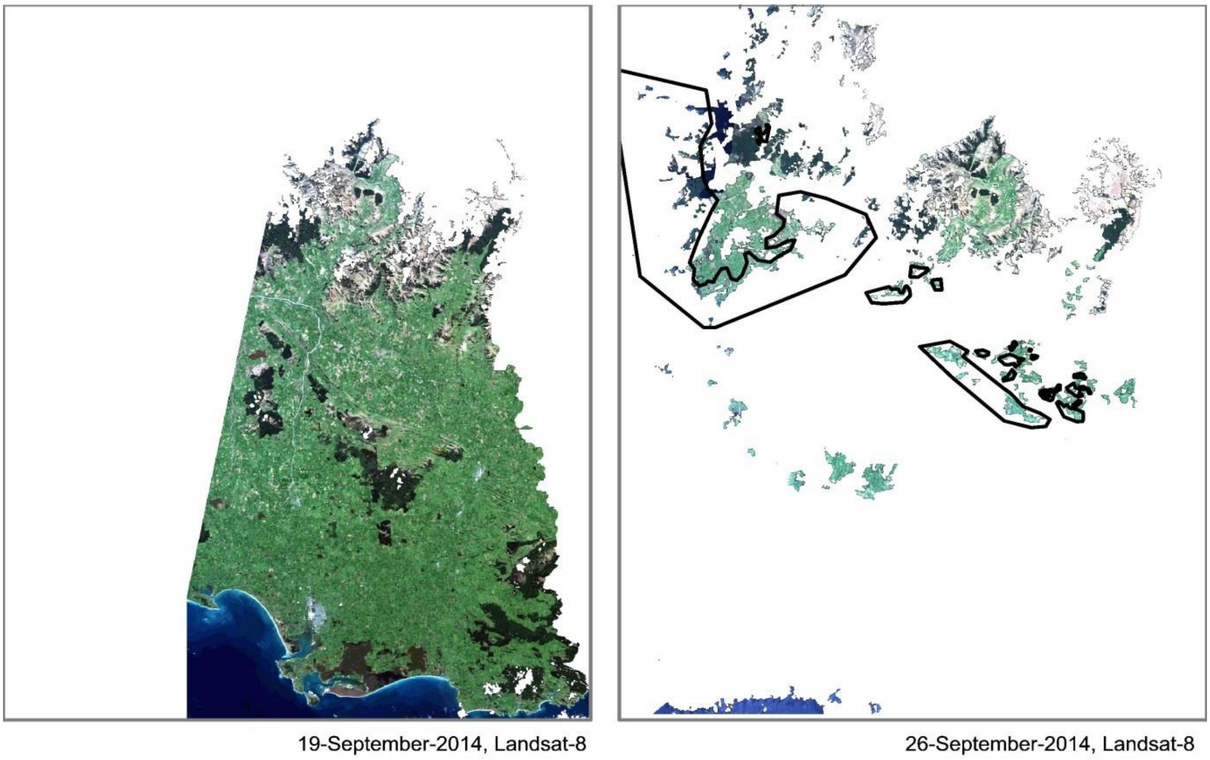


Figure 2 (page 3 of 3): Last two images in the Southland Region time-series. White areas have been masked out to remove cloud, cloud-shadow, snow, Landsat-7 line drop-outs, and areas where the land is too steep for topographic correction to be successful. ‘Low-trust’ areas – where some slight remaining influence of cloud haze is suspected – have been outlined (black linework).

The aim in this project was to identify winter forage in the agricultural landscape, so we created a ‘common mask’ to remove from consideration all non-agricultural areas – forest, shrubland, high-alpine tussockland, wetlands, rivers, sea, urban areas and quarries. This was done by fusing together the 10 images to form a single coverage and then carrying out a spectral classification of the various land covers. The resulting classification required manual ‘cleaning’ because the seasonal and radiometric variations between the images meant that the single set of spectral signatures derived and used for this process was not perfectly suited to all images. The resulting common mask is shown in Figure 3.

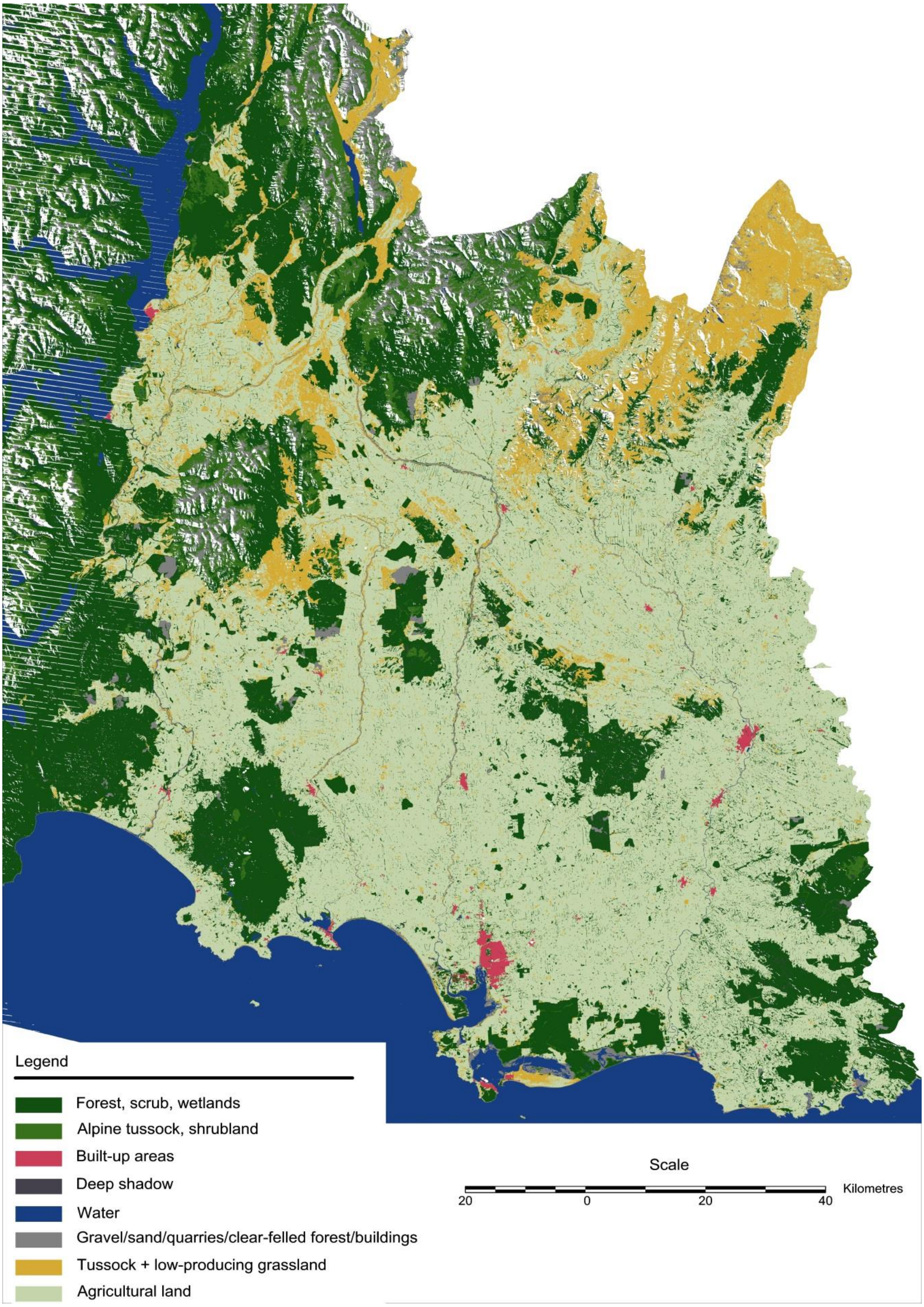


Figure 3 Common mask used to remove non-agricultural land from consideration. We analyse area in classes 'Agricultural land' and 'Tussock + low-producing grassland' – the latter motivated by Environment Southland's interest in checking the less-developed land for presence of winter forage, in addition to the more intensively farmed areas. White areas indicate no data (including areas masked out as too steep for topographic correction).

4.3 Per-image spectral classification of land cover

As discussed in the Introduction, our approach to classifying winter forage looks for two pieces of evidence: (a) whether the pixel has the spectral appearance of a known forage crop in autumn, (b) whether the pixel exhibits the temporal pattern of being vegetated in autumn and bare of vegetation in spring. This section deals with the former – spectral identification of bare soil, pasture and forage types in each individual image – while section 4.4 deals with the latter – introducing the temporal dimension to check whether pixels have changed from forage-type vegetation to a bare state.

4.3.1 Spectral training data

Environment Southland gathered a field dataset in September 2014. This was provided to us in two sections: (a) a training dataset of 202 polygons, provided in final checked form on 14 November 2014, with a raw version sent on 9 October; (b) a further 392 polygons provided on 22 December for the purpose of independent accuracy assessment.

Because the fieldwork was carried out in September, the grazing was complete on many paddocks, making it impossible to identify what type of forage crop had been there. This was the case for 72 (43%) of the 169 forage paddocks. Of the other forage paddocks, 68 were identified as swede, 26 as brassica and 3 as cereal/oats. None were identified as fodder beet, though we know from the pilot study that this forage type is used in Southland.

The dataset also contained 2 pasture paddocks and 24 paddocks identified as other land uses such as carrots/parsnips, market gardens, and arable cropping paddocks (the latter often had stubble from the autumn harvest still standing). Finally, there were 7 'unknown' paddocks. Most of these were identified as bare soil in the field data, but this is not sufficient for a conclusion as to whether the paddock formerly had winter forage in it. Other interpretations include a pasture paddock having been cultivated for pasture renewal, or an arable cropping paddock about to be replanted.

In order to differentiate 'not-forage' classes from the forage classes included in the field data, a good sample of pasture and bare soil paddocks is also needed in the training dataset. There were few pasture paddocks in the field dataset provided. Most of the forage paddocks were bare soil in at least some of the spring images, but we also needed to be able to identify bare soil in the autumn images. Therefore, we visually analysed the satellite imagery in both autumn and spring to identify additional training paddocks that appeared to be either pasture or bare soil/stubble all the way through the time period (March to September). This is not an ideal process for gathering training data (it is somewhat circular) but it was essential to include these 'not-forage' land covers in the spectral training dataset.

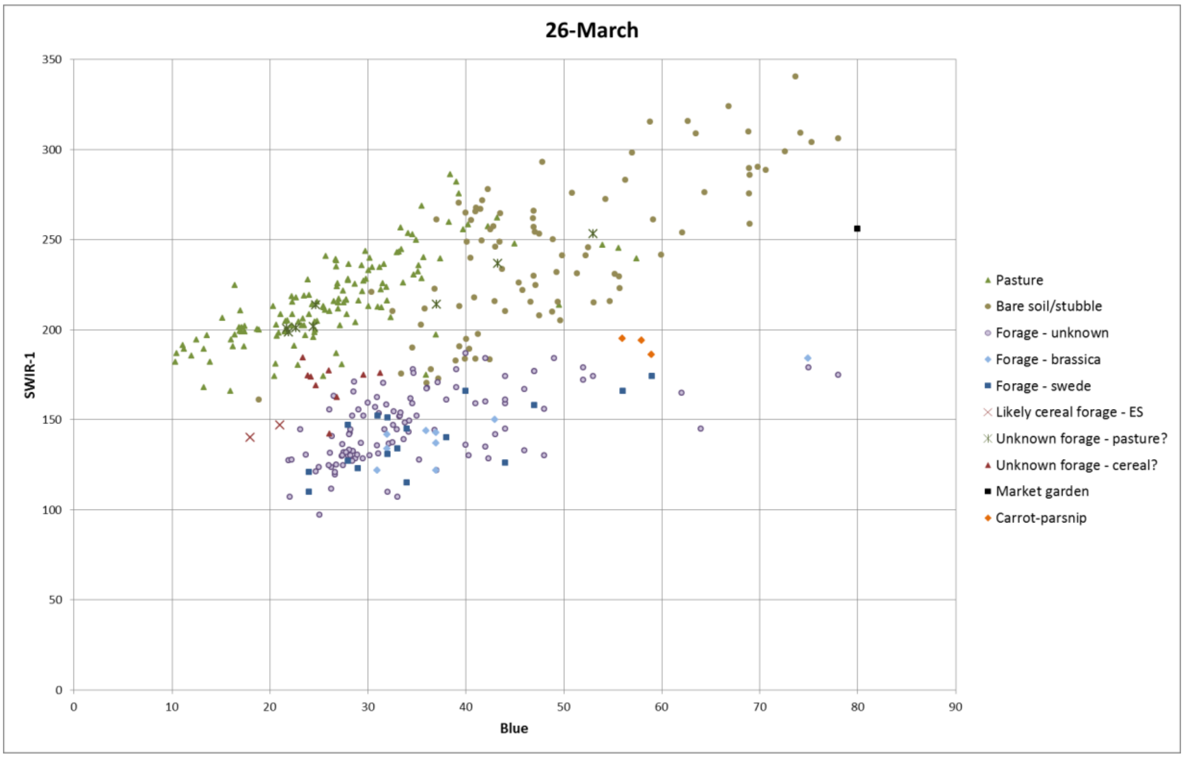
Environment Southland provided their field data in the form of shapefiles (polygons outlining paddocks) with field observations as attributes. We created shapefiles for our additional pasture and bare-soil paddocks. Spectral statistics from each band of each image were extracted for each paddock in the combined training dataset. This was done using a batch command process written in Erdas Imagine 2011, which used the 'zonal mean' function to extract spectral averages for each paddock and write them back to the shapefile as attributes.

4.3.2 Extracting spectral signatures

After analysis of the spectral data, we chose to use five spectral bands: blue, green, red, near-infrared (NIR) and the first of Landsat's two short-wave infrared bands (SWIR-1). We concluded that the second short-wave infrared band (SWIR-2) provided little further information for discriminating our land covers of interest.

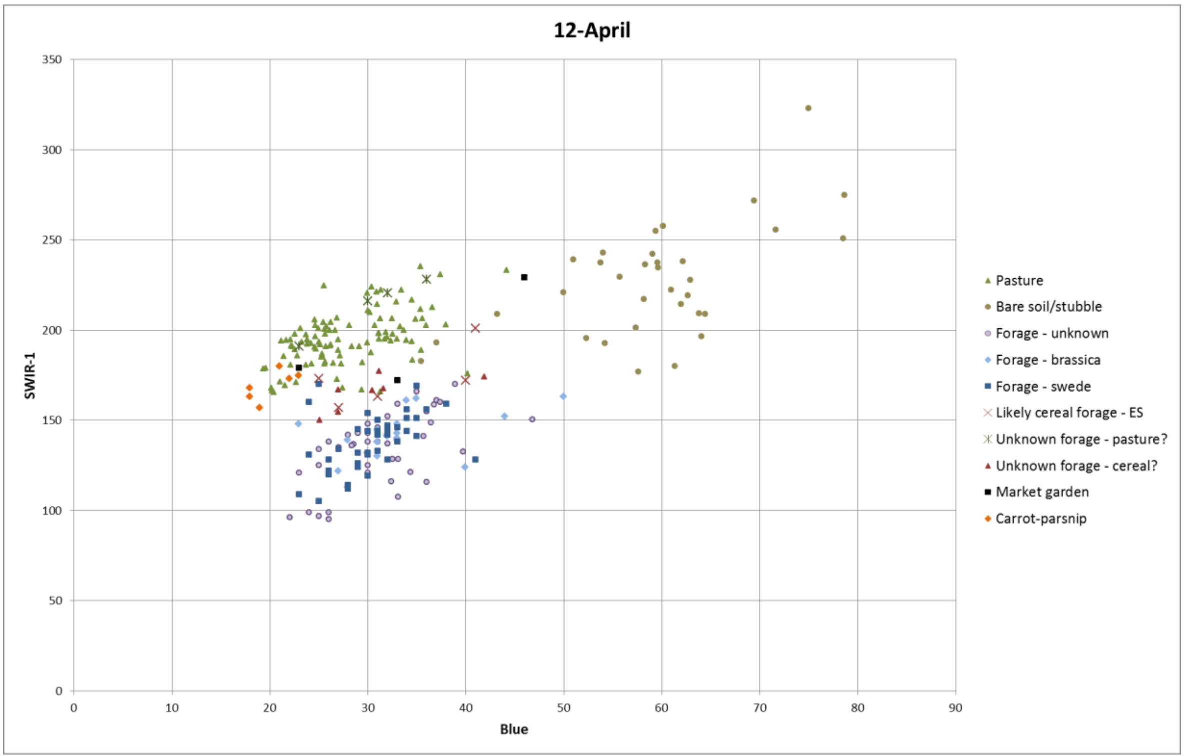
Figure 4 displays spectral data of our land covers for three of the image dates (26-March, 12-April and 19-September). Only two bands are graphed here (SWIR-1 vs blue), though all five chosen bands were used in the classification. At all three dates it can be seen that pasture is generally separated in spectral space from the swede and brassica forage types. Bare soil/stubble paddocks are high in both SWIR-1 and blue, and at the 'top end' of both pasture and forage are the paddocks with low cover of green vegetation over soil.

We found that the paddocks identified as swede and those identified as brassica were not spectrally separable from each other, so could be combined into a single class. However, the oats/cereal forage paddocks tended to be different, with spectral signatures midway between that of pasture and that of swede/brassica (and sometimes overlapping with each). Because cereal forage appeared to be genuinely different, we could not attempt to combine these paddocks into the same spectral class as swede/brassica, as this would have led to confusion between the pasture class and the swede/brassica class.

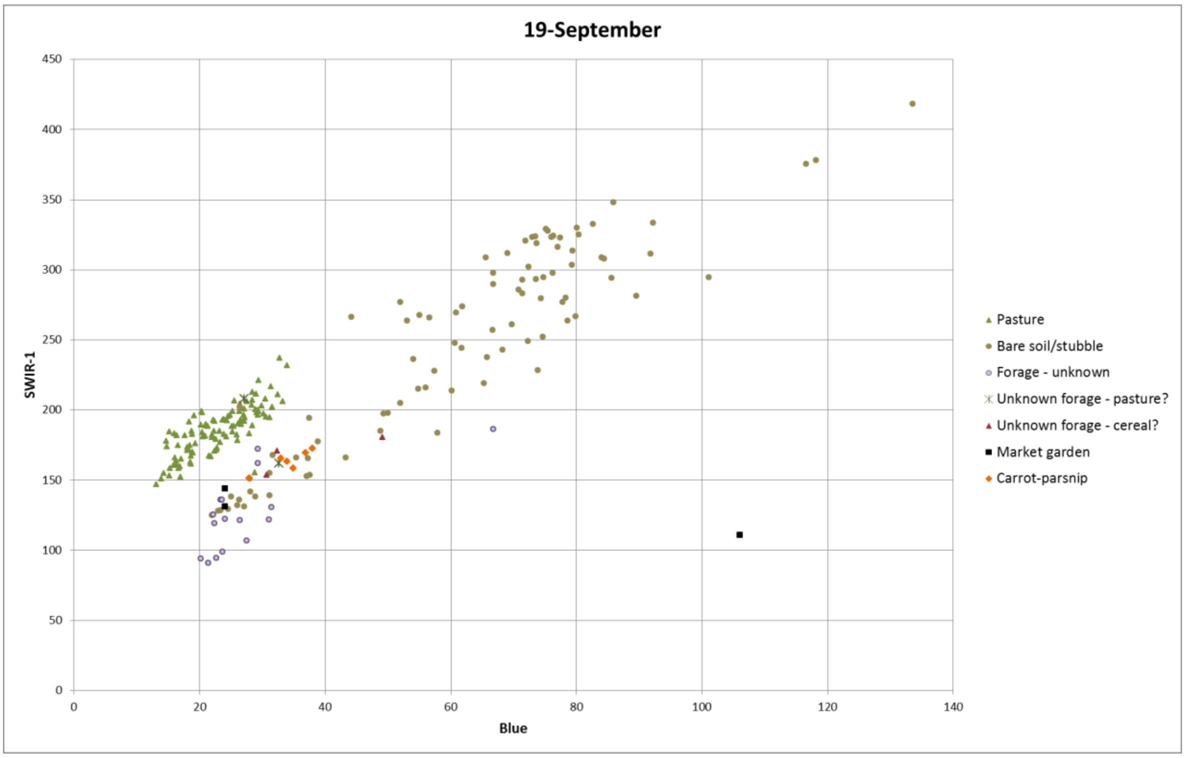


a

Figure 4 (page 1 of 2): Graphs of spectral data for the land covers of interest, showing just the SWIR-1 and blue bands; (a) spectral data extracted from the 26-March image. Note that the forage paddocks well out to the right of the graph (blue > 60) are affected by cloud haze that is causing a change in their spectral appearance.



b



c

Figure 4 (page 2 of 2): Graphs of spectral data for the land covers of interest, showing just the SWIR-1 and blue bands; (b) spectral data extracted from the 12-April image; (c) spectral data extracted from the 19-September image. Note the different axis scales for the two graphs. Few of the forage paddocks shown in the autumn graphs (a and b) still have forage cover by 19-September, so only a small number of points can be seen in (c).

The known cereal forage paddocks in the Environment Southland field dataset are marked by a red cross in the graphs of Figure 4. The paddocks symbolised by a green star (‘Unknown forage – pasture?’) and by a red triangle (‘Unknown forage – cereal?’) are in fact ‘Forage – unknown’ paddocks from the Environment Southland field dataset. However, because, in spectral space, they clustered around the known pasture and known cereal paddocks, respectively, we felt it would be unwise to include them in the swede/brassica forage spectral signature.

The ‘Unknown forage – pasture?’ paddocks were not used in any spectral signature due to the uncertainty of their identification. It is most likely that they are heavily strip-grazed pasture, but they could also be oats or another forage type. Of the ‘Unknown forage – cereal?’ paddocks, some were used to bolster the cereal forage spectral signature. We used only those that consistently looked like cereal forage through all images, and only because we had so few known paddocks of cereal forage in the training set provided. We consider this spectral signature to be more of an ‘other forage’ class, given the uncertainties, though it is modelled on oats. There could possibly be strip-grazed grass paddocks in this class, and we do not know where fodder beet fits into the picture as we have no data for this. The main purpose of the class is to separate its points (which cluster around the known oats paddocks) from the swede/brassica spectral signature.

The bulk of the ‘Forage – unknown’ points were indistinguishable from the group of known swede and brassica paddocks, so were included in the swede/brassica spectral signature.

The carrot and parsnip paddocks were not specifically included in any spectral signature. They appear to be grouped with the pasture paddocks in our spectral graphs (for the image dates at which they have vegetation cover), and this is in line with our experience in previous work (North et al. 2014b). Therefore we would expect vegetated carrot and parsnip paddocks to come out in the ‘pasture’ class, perhaps along with some other crop types that we have not specifically included. The important thing is that carrots/parsnips are spectrally different from swede/brassica forage (also in agreement with our previous experience).

4.3.3 Image classification

We considered deriving a single set of spectral signatures and applying them to all images in the time-series. However, some of the vegetation types do genuinely change in appearance during the winter (e.g. yellowing due to frost). Also, as discussed in section 4.2, the radiometric corrections may not always be perfect due to the low-solar-elevation images we are working with in this project (this is particularly visible in the June image). For these reasons, we decided to derive a set of spectral signatures for each image, and to classify each individually.

For all images, we used the classes: (a) bare soil or stubble – this also includes dead vegetation and brown-coloured vegetation, (b) pasture – which could also capture carrot/parsnip etc., (c) brassica/swede, (c) ‘cereal’ crops which, as discussed above, could also capture other similar forage crops.

The 10 classifications were carried out in Erdas Imagine 2011 using standard maximum-likelihood supervised classification.

4.4 Development of rule-set to identify winter forage

The next step in the classification was to introduce the temporal dimension by combining evidence from several image dates.

The normal expectation for winter forage paddocks is that they will be fully vegetated in autumn (April) and will be gradually strip-grazed until the whole paddock is bare. Because of the progressive strip-grazing, different pixels within a given paddock will become bare at different times. Also, because of our cloud-affected image-series, different paddocks, and different pixels within paddocks, will be observed in varying numbers and combinations of image dates. For example, a pixel identified in autumn as swede/brassica could be represented in all five spring images, perhaps initially as vegetated and then as bare. In a more image-sparse part of the region, another pixel identified in autumn as swede/brassica might only be represented in the 22-June image (with no data in later images), and could still be vegetated at that time. Figure 5 shows graphics of the number of image sources available at each pixel in autumn and in spring.

The rules we developed to combine the evidence from the 10 time-series classifications had to be sufficiently flexible to cope with the fact that we are observing different pixels at different times, and with different levels of certainty. Some pixels will have data available in autumn OR spring, but not both, as seen in Figure 5.

Our rules also needed to cope with the fact that some winter forage types can be identified spectrally – specifically our swede/brassica class – but others are much less distinguishable from pasture – such as oats and strip-grazed grass. The rules can look for pixels that are vegetated in autumn and bare in spring, but this temporal pattern alone does not provide certainty that the pixel is winter forage. Other land uses can also have this temporal pattern, such as a pasture paddock undergoing pasture renewal in the spring.

We split the classification process into two parts. The first set of rules produces a 'pre-grazing' (autumn) land cover map, by drawing together evidence from the five autumn land cover classifications. These rules (Table 2) judge whether a given pixel looks like swede/brassica, cereal, pasture, bare ground/stubble, or other vegetation in autumn (or whether no conclusion can be reached). The resulting pre-grazing land cover map has nine classes, plus 'unknown' and areas where there are no data.

The second set of rules introduces the temporal dimension by combining evidence from the pre-grazing map with the five spring land cover classifications (Table 3). Application of these rules results in a classification with 13 classes, plus 'unknown' and areas where there are no data. The rules we have developed are fully defined in the Appendix, with the main points described in Tables 2 and 3.

Note that, if we had a simpler set of images (e.g. complete coverage in a single narrow date-range for each of autumn and spring) then the rule set could be very much simpler. As it is, there are many complexities and variations that need to be accommodated because of our scattered (in time and space) fragments of imagery.

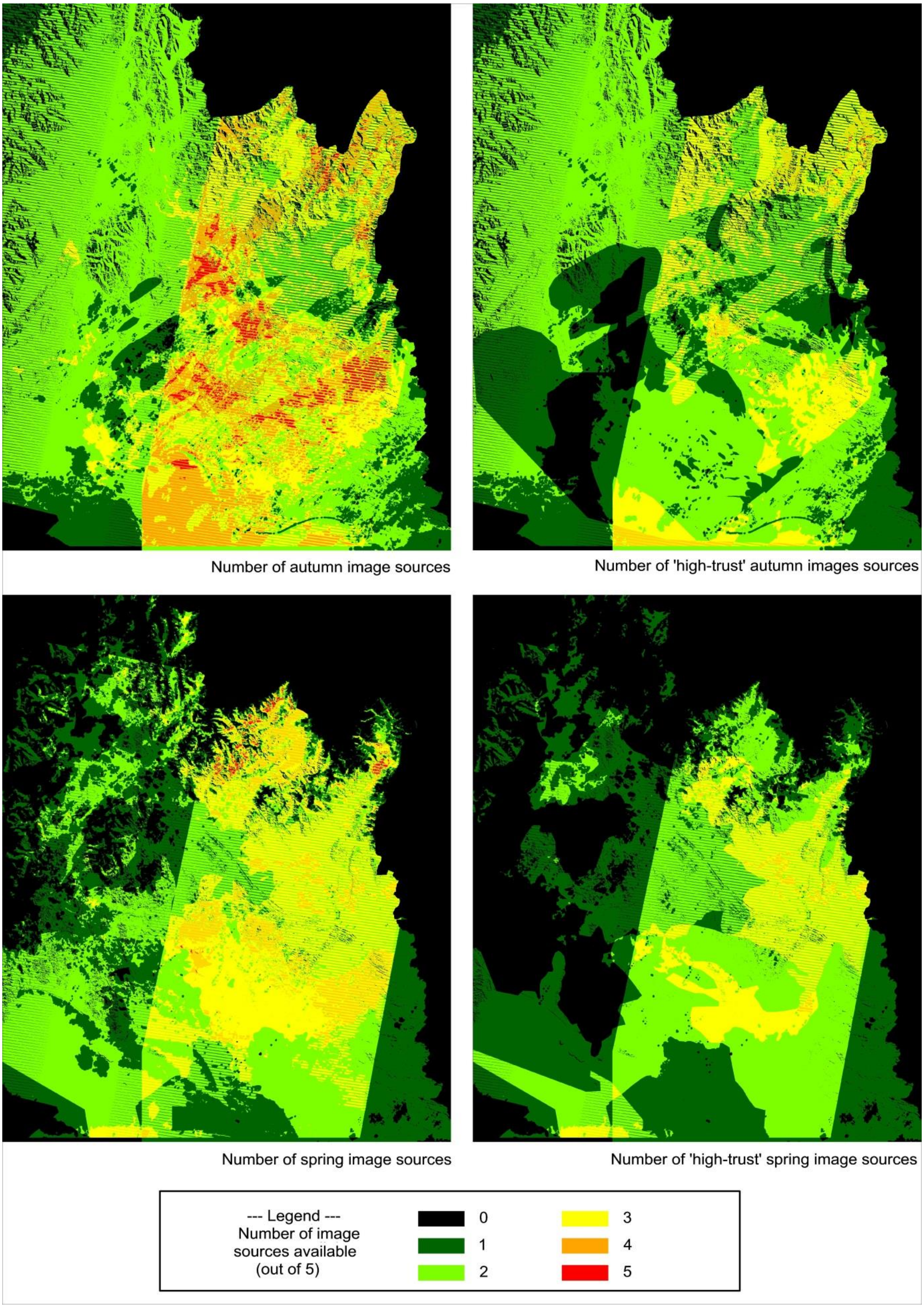


Figure 5 Number of image sources available at each pixel, out of a possible maximum of five for each of autumn and spring. These counts have been done from the cloud-masked images, so a pixel masked out for reasons of cloud, shadow, Landsat-7 line drop-outs, etc. is not counted as 'available'.

Table 2 Rules to create 'pre-grazing' (autumn) land cover map, by combining evidence from the five autumn land cover classifications. In the table, 'all sources' means 'all classifications that have data at that pixel' (i.e. ignoring those in which the pixel is masked out). For each of the bare ground, pasture, swede/brassica and cereal rules below, there are 'low-certainty' versions that come into play where there are fewer image sources available, or less agreement between image sources. The rules are defined in full in the Appendix

Class ('high-certainty' version)	*Description*
Bare ground/stubble/ brown vegetation	All sources must agree the pixel is bare ground. At least one source must be high-trust (or there must be two or more low-trust sources).
Pasture	All sources must classify the pixel as either pasture or cereal, with at least one source being high-trust pasture. Alternatively, there must be two or more low-trust pasture classifications with no disagreement from other sources.
Swede/brassica	There must be at least one high-trust swede/brassica classification, while the other sources must be a vegetation class (if this vegetation class is not swede/brassica, it must be low-trust). An alternative is where there are two or more swede/brassica classifications with low-trust, but no disagreement.
Cereal/other	All sources must classify the pixel as either cereal or pasture, with at least one source being high-trust cereal. Alternatively, there must be two or more low-trust cereal classifications with no disagreement from other sources.
Unknown vegetation	More than half the sources must be vegetated (there must be two or more sources). There is no 'low-certainty' version of this rule.

Table 3 Rules developed to assess whether a given pixel looks like winter livestock forage or not by combining evidence from the pre-grazing map and the five spring land cover classifications. There are also 'low-certainty' versions of the rules for swede/brassica forage, cereal forage, other forage (which can also fit the pattern for spring pasture renewal), and pasture throughout, for cases where there are fewer image sources available, or less agreement between image sources. The rules are defined in full in the Appendix

Class	*Description*
Pasture (or other vegetation) throughout period	Vegetated in pre-grazing map and all spring sources, as long as it does not fit the winter forage rules below.
Bare ground/stubble/brown vegetation throughout period	Bare ground in pre-grazing map (high or low certainty) and in all spring sources.
Swede/brassica winter forage	Brassica/swede in autumn (either high or low certainty) then all spring sources are either brassica/swede or bare ground (there must be at least one spring source).
Cereal winter forage	Cereal in autumn (either high or low certainty) then all spring sources are either cereal or bare ground (there must be at least one spring source).
Other/unknown vegetation with appearance of winter forage (but also fits the pattern for non-forage land use such as spring pasture renewal)	Pasture or other unknown/mixed vegetation, that becomes bare and stays bare in spring.
Newly-established pasture/crop	Bare ground in pre-grazing map, and becomes vegetated (and stays vegetated) in spring sources
Late-planted winter forage (a 'low-certainty' class – could also correspond to a short-lived flush of growth or weeds)	Bare ground in pre-grazing map, becomes vegetated in early spring (winter) sources then bare again.
Bare soil/stubble/brown vegetation in autumn but no spring data – unlikely to be winter forage, but not certain	
Bare soil/stubble/brown vegetation in spring but no autumn data – cannot conclude whether forage or not forage	

4.5 Accuracy assessment

An independent field dataset of 392 polygons, provided by Environment Southland, was used for accuracy assessment.

As described, the winter forage classification was carried out on a per-pixel basis, so it is possible for a paddock (as defined by the Environment Southland polygons) to include pixels of several classes. Figure 6 shows a very small area of the classification with the accuracy assessment polygons overlaid to illustrate this. The first task was to count the number of pixels in each polygon that fell in each of the 13 classes (plus ‘unknown’). We used the ‘Summary’ function in a small graphical model in Erdas Imagine 2011 to accomplish this. The output of the function is a matrix of pixel counts, where each row is a polygon and each column is a class.

The polygon layer input to the Summary function was a buffered version of the polygons provided by Environment Southland (buffered internally by 15 m, this being the image pixel size). This ensured that summary statistics excluded pixels of mixed land cover – these often exist on boundaries between paddocks or changing land covers. Figure 6 shows the original polygons in black and the buffered version in white.

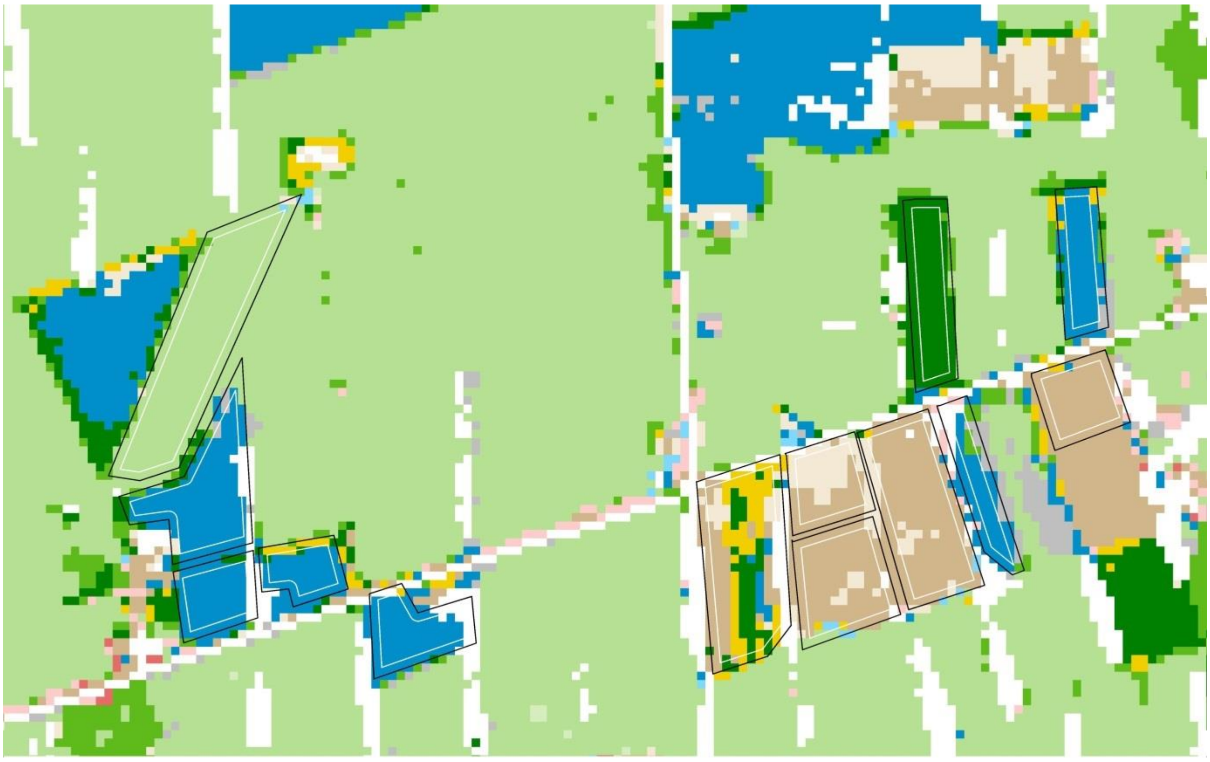


Figure 6 Accuracy assessment polygons overlaid on a very small section of the classification result. Environment Southland’s original polygons are displayed in black, with the buffered versions in white. The number of pixels in each class can be counted for each polygon, using Erdas Imagine’s ‘Summary’ function. The full classification result, along with its legend, is presented in the Results section.

We listed the summary counts in a spreadsheet alongside the relevant paddock IDs and the field observations that went with them. The percentage of pixels in each polygon that fell within 'forage' and 'not-forage' categories were calculated (Table 4). These percentages were then compared to the field identification of the paddock. In general, we judged the classification to be correct if 70% or more of the pixels matched the field identification.

If the paddock was 'unknown' in the field data, or if the classification was 90% or more 'unknown' pixels, then we left the paddock out of the accuracy statistics. We treated the class 'bare soil in spring, but no autumn data' as 'unknown' because it does not give any indication as to whether the pixel is forage or not. Also, if there were five pixels or fewer of classified data within the paddock area (the rest being 'unknown' or masked out), we also left that paddock out of the statistics.

Table 4 There are 13 classes in the winter forage classification map, plus 'unknown' and 'no data' areas. This table shows which classes are considered to be 'forage' and which 'not-forage' for the purposes of accuracy assessment

Forage category	*Classes in results map*
Not sufficient data to judge whether forage or not forage	• No data, or masked out • Unknown • Bare soil in spring, but no autumn data
Winter forage	• Winter forage – likely swede/brassica • Winter forage – possibly cereal • Low-certainty brassica/swede winter forage • Low-certainty cereal winter forage
Additional classes of likely winter forage (however, these also have possible non-forage explanations)	• Pasture/other vegetation in autumn, then bare soil in spring • Late-planted forage or temporary flush of green vegetation
Not winter forage	• Pasture/other throughout period • Bare soil/stubble/brown vegetation throughout period • Newly planted pasture/crop • Low-certainty pasture throughout period • Bare soil in autumn, but no data in spring
Additional classes that are likely to indicate 'not winter forage' (however, these also have possible forage explanations)	• Pasture/other, with a temporary dip to bare soil in spring • Also note that 'Pasture/other in autumn, then bare soil in spring' has been included as a likely winter forage class (see grey highlight above) but the class is problematic, as it can also indicate spring pasture renewal (a non-forage class)

5 Results and discussion

5.1 Winter forage map

Figure 7 shows the pre-grazing land cover map that was assembled from the five autumn images using the methods described in section 4.3 and the rule-set of Table 2 in section 4.4.

Figure 8 shows the final winter forage map constructed by drawing together evidence from the pre-grazing land cover and the five spring images using the rule-set of Table 3.

Both maps have been masked using the common mask (Figure 3). Areas where there are no valid data, due to lack of image coverage, clouds, Landsat-7 data gaps etc., are also part of this mask (white).

Figure 9 shows two enlarged areas of the final winter-forage map: their locations are indicated by the two black rectangles on Figure 8. In one area we have good image coverage in both autumn and spring, and in the second we have very poor coverage. In the latter, there are more pixels classified into ‘unknown’ and low-certainty classes. However, even here, the winter forage paddocks are mostly indicated by compact groups of pixels classified as one of the forage classes. In the area with good image coverage (Figure 8a), this is even more so, with the forage paddocks cleanly separated from the background pasture. Note, however, that among the forage pixels classified as ‘likely swede/brassica’ are also some pixels classified as ‘pasture/other in autumn; bare soil in spring’.

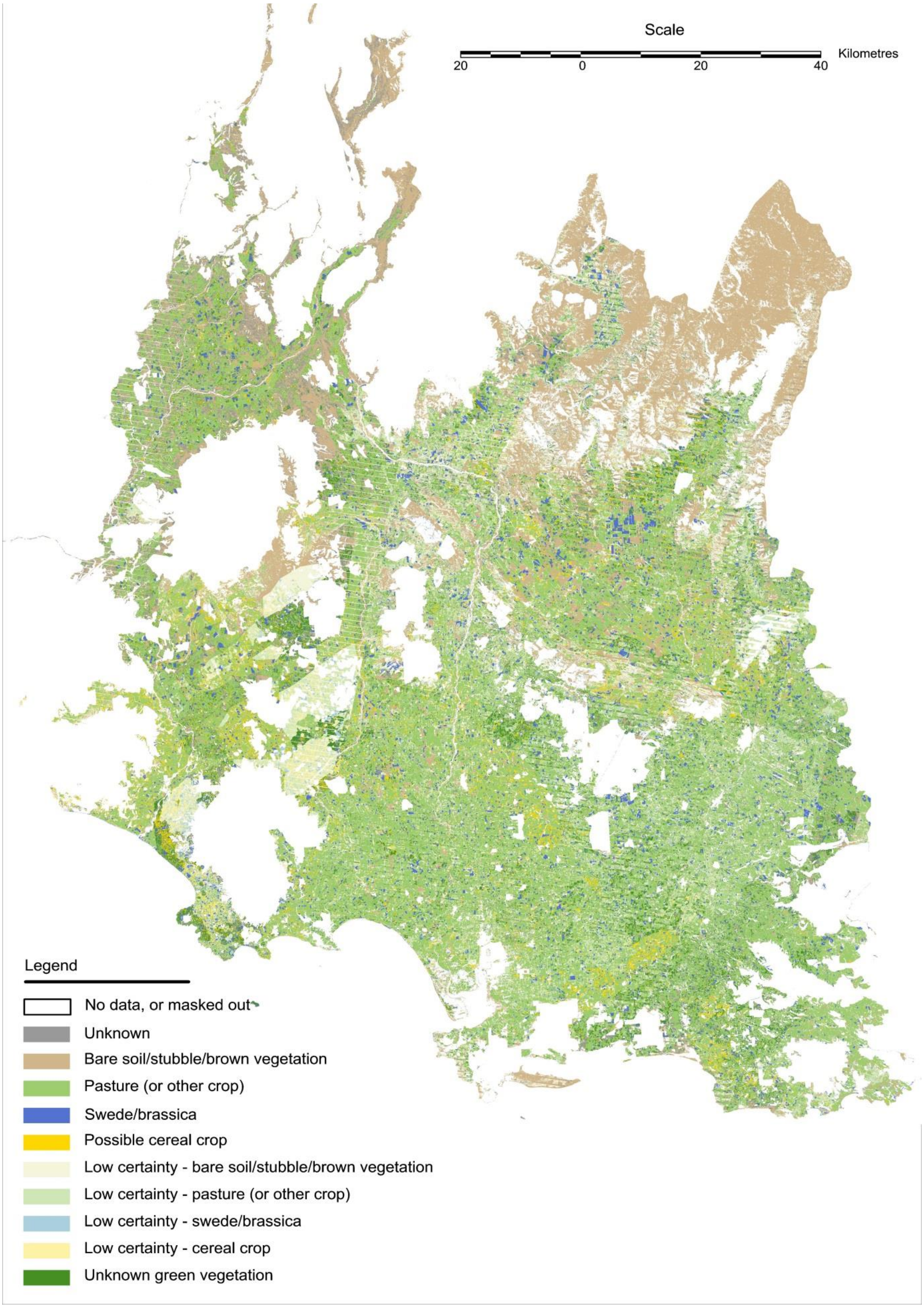


Figure 7 Southland Region, autumn 2014 – classification of agricultural land covers prior to winter forage livestock grazing.

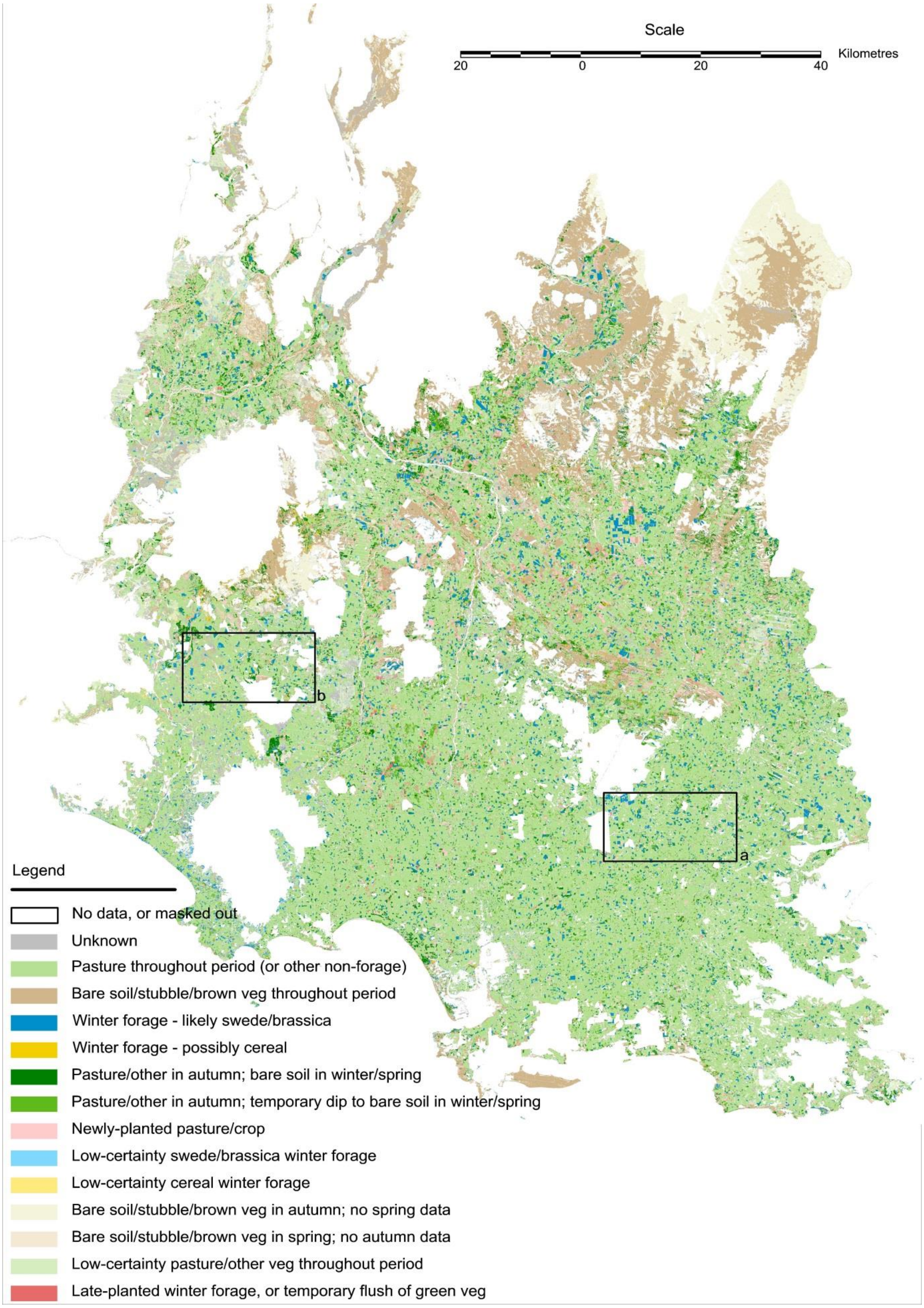


Figure 8 Southland Region, 2014 – map of agricultural land under winter livestock forage crops, plus other non-forage land. Enlarged areas (a) and (b) are shown in Figure 9.

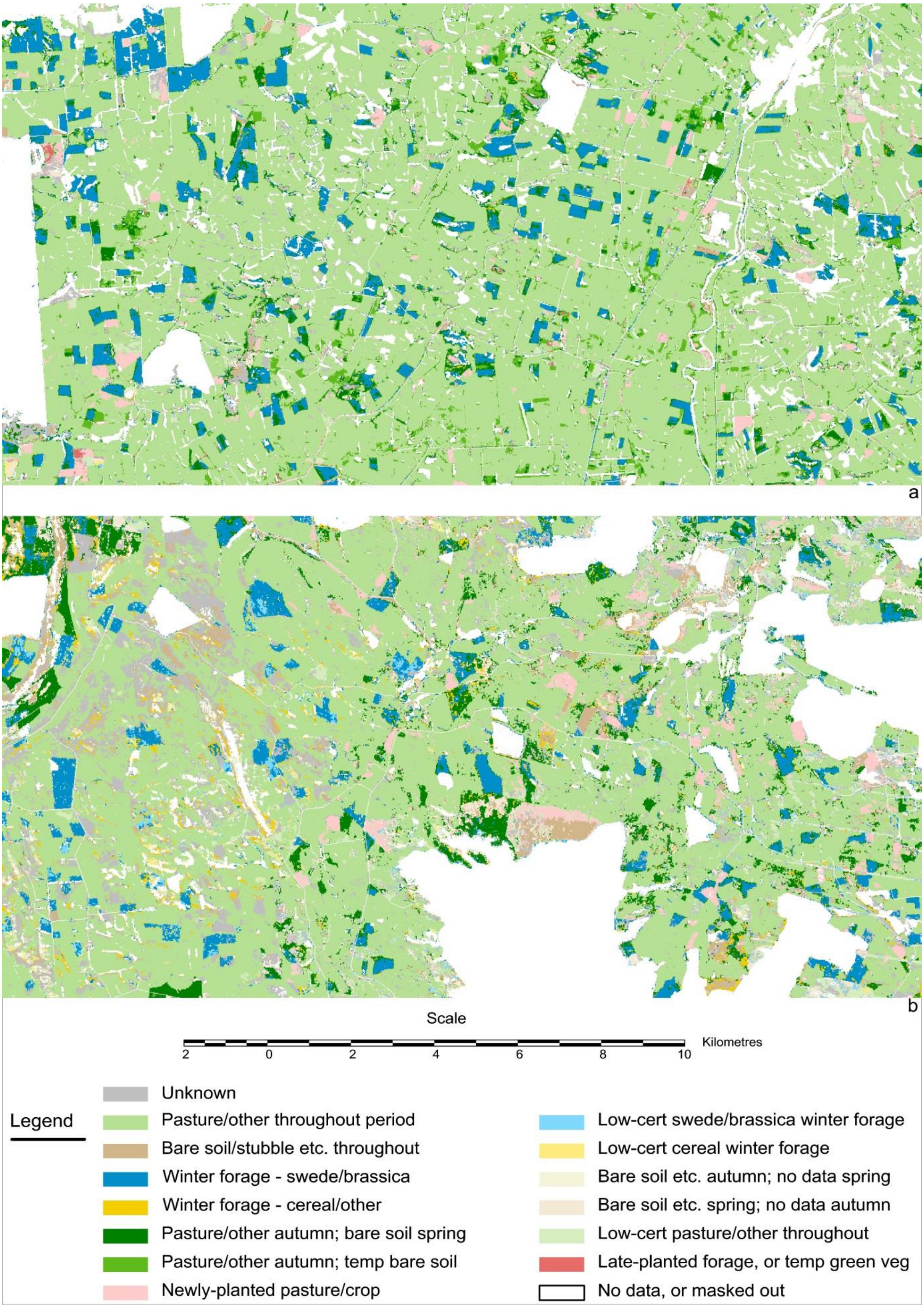


Figure 9 Enlarged areas outlined in Figure 8. Classifications are from: (a) good image coverage, where there are 2–5 autumn images (2–3 of these high-trust) and 2–4 spring images (2–3 of these high-trust); (b) poor image coverage, where there are 1–2 autumn images (0–2 of these high-trust) and 1–2 spring images (0–1 high-trust).

5.2 Accuracy assessment

Four tables are presented to summarise the accuracy of the winter forage classification (see section 4.5 for details on the accuracy assessment method). Tables 5 and 6 show the accuracy statistics for the training dataset (confusion matrix and summary, respectively), and Tables 7 and 8 show the accuracy assessment for the independent field data (also confusion matrix and summary, respectively).

In Tables 5 and 7, the land use categories from the field data are listed on the left – these are ***Forage*** (includes swede, brassica, oats and unknown), ***Pasture*** (which can be pasture right through the period, or can be heavily grazed in winter), and ***Other*** (includes arable cropping paddocks, carrot/parsnip, and market gardens). The figures in the tables indicate how many of these paddocks were classified into the broad classes listed in Table 4 (by 70% or more of the classified pixels in the paddock). In summary, the broad classes are:

- Specifically forage – swede/brassica or cereal/other, at both high and low certainty
- Likely to be forage, but also have non-forage explanations – pasture/other in autumn then bare in spring, late-planted forage (or temporary flush of green vegetation)
- Specifically not-forage – pasture/other throughout period (both high and low certainty), bare soil/stubble throughout or just in autumn, newly-planted pasture/crop
- Likely to be not-forage, but also have forage explanations – pasture in autumn with a temporary dip to bare soil in winter/spring.

Table 5 Confusion matrix for training field dataset (non-independent). Classification categories are defined in Table 4 and section 5.2. Figures are the numbers of paddocks falling in each category – those considered correct are shaded. The 'Combined forage' column is where neither the 'Specific' nor 'Likely' forage category has ≥70% of the pixels but the two combined do. The 'Combined not-forage' column is defined similarly

Classification category / *Field category*	Specifically forage class	Likely forage class	Combined forage	Specifically not-forage class	Likely not-forage class	Combined not-forage	Indeterminate: no category has ≥ 70% of pixels
Forage	127	7	21	7	0	0	4
Pasture	0	0	0	1	0	1	0
Other	1	8	0	9	0	1	3

Table 6 Summary accuracy assessment (% correct of the paddocks in the field category) for training dataset (non-independent), calculated from Table 5

Classification category / *Field category*	Forage (specific and likely)	Not-forage (specific and likely)	Indeterminate
Forage, 166 paddocks	93% (155 paddocks)	4% (7 paddocks)	3% (4 paddocks)
Not-forage (pasture/other), 24 paddocks	50% (12 paddocks)	37% (9 paddocks)	13% (3 paddocks)

Table 7 Confusion matrix for independent field dataset. Classification categories are defined in Table 4 and section 5.2. Figures are numbers of paddocks falling into each category – those considered correct are shaded. The 'Combined forage' column is where neither the 'Specific' nor 'Likely' forage category has ≥70% of the pixels but the two combined do. The 'Combined not-forage' column is defined similarly

Classification category / *Field category*	Specifically forage class	Likely forage class	Combined forage	Specifically not-forage class	Likely not-forage class	Combined not-forage	Indeterminate: no category has ≥ 70% of pixels
Forage	208	23	83	8	0	1	8
Pasture	0	2	0	3	0	0	0
Other	2	4	1	30	0	0	1

Table 8 Summary accuracy assessment (percent correct of the paddocks in the field category) for independent dataset, calculated from Table 7

Classification category / *Field category*	Forage (specific and likely)	Not-forage (specific and likely)	Indeterminate
Forage, 331 paddocks	95% (314 paddocks)	3% (9 paddocks)	2% (8 paddocks)
Not-forage (pasture/other), 43 paddocks	77% (33 paddocks)	21% (9 paddocks)	2% (1 paddock)

5.3 Discussion on classification details

Due to the low numbers of pasture/other paddocks in the accuracy assessment dataset, we also checked how our own pasture and bare soil paddocks were classified (i.e. the extra training polygons that we added for the purpose of gathering spectral signatures). All 184 pasture paddocks were classified into the 'not-forage' categories.

The bare-soil paddocks were more difficult to assess. These paddocks were initially selected if they looked like bare soil/stubble in at least one autumn and one spring image, so they could be expected to be bare most of the time. However, a temporary flush of green vegetation (such as late-planted forage) could still be present in some of these paddocks. Note that we excluded individual paddocks that looked particularly green on a certain date from the bare-soil spectral signature for that particular image. Accuracy results for the 101 paddocks (those with sufficient valid data) were 93 in the 'not-forage' categories, 2 in the 'Likely forage' category and 6 indeterminate.

For those paddocks where the type of forage was identified in the field, we have attempted to check our forage-type classification. The results are shown in Table 9, but should be treated with caution for the following reasons: (a) the fieldwork was carried out in mid-September when there was little forage crop remaining in the paddocks, leading to difficulties with identification, (b) no fodder beet was identified in the fieldwork, but it is known that this crop is used as winter forage in Southland, (c) we separated cereal/oats out as a class only because these paddocks appeared to be spectrally different to swede/brassica, but there were too few paddocks with too much uncertainty to derive a robust spectral signature.

Table 9 Assessment of forage type classification. Uncertainties in the field data suggest treating these figures with caution, but they do give an indication of the importance of the 'Likely forage' classes (pasture/other in autumn becoming bare ground in spring, and late-planted forage), particularly for the oats paddocks. 'Combined forage' is where none of the individual forage types have ≥ 70% of the pixels, but the combined forage types do. These figures include both training and independent field datasets

Classification / *Field identification*	Swede/brassica (high & low certainty)	Cereal forage (high & low certainty)	Pasture/other autumn; bare ground spring	Late-planted forage	Combined forage	Total paddocks in forage type class
Forage - brassica	68 (67%)	0 (0%)	2 (2%)	1 (1%)	25 (25%)	102
Forage - swede	122 (60%)	2 (1%)	12 (6%)	0 (0%)	58 (29%)	202
Forage – cereal/oats	1 (20%)	0 (0%)	2 (40%)	1 (20%)	1 (20%)	5

It is also interesting to look at the classification of the six paddocks recorded in the field as 'Pasture – grazed hard'. Of these, two are classified as pasture throughout, two in 'Pasture/other autumn; bare in spring', one in a mix of the 'Pasture/other in autumn' classes, and the last in the 'Bare soil throughout' class. It is unknown whether Environment Southland wishes to treat intensively-strip-grazed pasture paddocks as winter forage.

Environment Southland's field dataset also contained paddocks of 'Other' land uses that they considered could potentially be confused with winter forage paddocks due to being bare soil/stubble in spring. Table 10 shows how these paddocks were classified. The great majority of the arable cropping paddocks (having bare soil and cereal stubble through the autumn, winter and early spring) have been classified in our 'Bare soil/stubble throughout period' class, so are not being confused with winter forage. Market gardens are also often (though not always) classified as 'Bare soil throughout'. However, many of the carrots/parsnips paddocks are classified into our 'Pasture/other in autumn; bare soil in spring' class, which we consider to be a 'Likely forage' category, though also having other non-forage explanations.

Table 10 Classification of the 'Other' paddocks – number of paddocks classified into the stated class. Both training and independent data are included in these statistics

Classification / *Field Identification*	Bare soil /stubble throughout	Pasture/other autumn; bare soil spring	Mixed not-forage types	Mixed forage types	Indeterminate forage/not-forage
Arable cropping (summer/autumn-harvested grain crops) – 33 paddocks	30		1		2
Market gardens – 9 paddocks	5	2		1	1
Carrots/parsnips – 10 paddocks	1	8		1	
Other horticulture/vegetable crops (incl. lettuce, onions) – 3 paddocks	2			1	

Finally, the pilot project previously carried out for Environment Southland (North et al. 2014a) highlighted the difficulties of working in hilly terrain with winter imagery. The shadows and highlights due to topography appeared to affect the accuracy of the winter forage classification – particularly in terms of false positives in the hilly parts of the site – in spite of efforts to minimise topographic effects. In this project we have used a more comprehensive method of correcting for topography and, importantly, most of our imagery is in autumn and spring, rather than in mid-winter.

In Table 11, we have separated out the basic accuracy statistics according to the steepness of the paddock as recorded in the field. The table shows the percentage of the paddocks in the category that have been classified correctly in terms of 'forage' or 'not-forage'. The remainder of the paddocks are either incorrect or indeterminate in their classification. No formal analysis of difference has been carried out on these figures, but they strongly indicate no systematic difference in classification accuracy between the topographic classes.

Table 11 Checking for the effect of topography on classification accuracy. Figures are the percent of paddocks classified correctly as 'forage' or 'not-forage'

Topographic class *Land use category as recorded in fieldwork*	Gentle	Moderate	Steep
Forage paddocks	295/309 = 95%	135/146 = 92%	38/41 = 93%
Not-forage paddocks	34/53 = 64%	9/11 = 81%	2/3 = 67%

5.4 Area of winter livestock forage in the Southland Region

Table 12 presents summary statistics on the amount of winter livestock forage in the Southland Region. These areas and percentages are grouped into the forage and not-forage categories of Table 4. The only difference is that the 'unknown/insufficient data' category does not include the masked out or no-data areas. In other words, only the classified agricultural areas are included in Table 12 (total area 1 055 495 ha). These statistics are taken directly from the classification of Figure 8.

Table 5 Summary statistics from Figure 8 showing area and percentage of winter forage and other land uses in the agricultural areas of Southland Region. Percentages are out of the mapped area (i.e. excluding the no data/masked-out areas)

Land use category	*Area (ha)*	*Percentage of mapped area*
Unknown/insufficient data for classification	90 321	8.6
Specifically forage	70 238	6.7
Likely forage	55 356	5.2
Specifically not-forage	796 320	75.4
Likely not-forage	43 260	4.1

6 Conclusions

Winter livestock forage was successfully mapped for the whole Southland Region. Non-agricultural areas (e.g. forest, rivers, urban areas) were masked out, so that only the agricultural land (approximately 1 million hectares) was analysed.

Over 70 000 ha were specifically mapped as forage crops (6.7% of the mapped area) using a combination of spectral signature (the swede/brassica class is spectrally separable) and the distinctive temporal pattern of full vegetation cover in autumn followed by bare soil in spring. A further 55 000 ha (5.2%) were also mapped as having the temporal pattern of winter forage, but with the spectral signature of pasture or other vegetation. The latter category is often associated with winter forage paddocks, but can also be caused by non-forage land uses such as spring pasture-renewal. In 8.6% of the mapped area, the imagery was insufficient to conclude whether the land use was winter forage.

The mapping method used was to classify land covers in each of 10 time-series Landsat satellite images, and then develop rules to look for forage-type land covers in the autumn images, followed by bare soil for the corresponding pixel in the spring images.

Field data were provided by Environment Southland for training the classification, and a further (independent) dataset was provided for assessment of the map's accuracy. Of 331 paddocks identified by Environment Southland as forage, 95% (314 paddocks) were classified by our method into the 'specific' and 'likely' forage categories. Of the 43 paddocks identified by Environment Southland as non-forage land uses, 77% (33 paddocks) were classified as such by our method. Classification does not appear to be affected greatly by hilly terrain, as similar accuracies were obtained for the paddocks that Environment Southland recorded as being gentle, moderate or steep in gradient.

7 Recommendations

- The method and rule-set developed in this work is suitable for mapping winter forage at regional scale, with good accuracy levels.
- The image dataset was strongly affected by cloud, requiring a great deal of cloud-masking, and a complicated rule-set to pull together evidence from a large number of image dates. An image set with less cloud cover would allow for a simpler mapping method, and likely higher accuracies. To a first approximation, the money saved by not purchasing custom-programmed satellite imagery was then taken up by additional image preparation, especially cloud cleaning. Therefore, we would recommend future projects reconsider the image acquisition options.
- Some forage paddocks appear to be planted later than the norm, not reaching full vegetation cover until after the April imagery we had available in this project. If a similar exercise is done again in future, image coverage in May could be useful to identify these paddocks.
- The paddocks that were not specifically classified as brassica or cereal in autumn, but had a more pasture-like spectral signature, but which were bare soil in spring, make up a large part of our 'likely forage' category. Many of these are indeed forage paddocks, but others may be due to other land uses such as spring pasture-renewal. Further imagery in winter or spring may be able to help resolve these classes.

8 Acknowledgements

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Appendix 1 – Classification rules

In the tables below, classification rules are listed in the order in which they are executed. If a pixel matches a given rule, the program does not continue to check the following rules. Thus, the later rules in the tables are only triggered if the earlier ones are not true.

Pre-grazing (autumn) land cover map rules

These rules analyse the stack of five autumn classifications. Prior to executing the rules below, the program counts (at every pixel location) the number of autumn classifications (out of five) in the following categories: noveg_hi, pstr_hi, brs_hi, crl_hi (number of classifications of bare ground, pasture, swede/brassica, or cereal, in 'high-trust' areas), noveg_lo, pstr_lo, brs_lo, crl_lo (number of classifications of these land covers in 'low-trust' areas). Total number of sources (classifications that have valid data) is 'n'.

Class value	*Class name*	*Rule*
10	No data, or masked out	n=0
1	Bare soil/stubble/ brown vegetation	(noveg_hi≥1 AND noveg_hi+noveg_lo=n) OR (noveg_lo>1 AND noveg_lo = n)
2	Pasture (or other non-forage crop)	(pstr_hi≥1 AND pstr_hi+pstr_lo+brs_lo+crl_lo=n) OR (pstr_lo>1 AND pstr_lo=n)
3	Swede/brassica	(brs_hi≥1 AND brs_hi+pstr_lo+brs_lo+crl_lo=n) OR (brs_lo>1 AND brs_lo=n)
4	Possible cereal crop	(crl_hi≥1 AND crl_hi+pstr_lo+brs_lo+crl_lo=n) OR (crl_lo>1 AND crl_lo=n)
5	Low certainty – bare soil/stubble/ brown vegetation	(n=1 AND noveg_lo=1) OR (n>1 AND noveg_hi+noveg_lo>n/2 AND noveg_hi+noveg_lo<n) OR (noveg_hi=n/2 AND pstr_lo+brs_lo+crl_lo=n/2)
6	Low certainty – pasture (or other non-forage crop)	(n=1 AND pstr_lo=1) OR (n>1 AND pstr_hi+pstr_lo>n/2 AND pstr_hi+pstr_lo<n) OR (pstr_hi=n/2 AND noveg_lo+brs_lo+crl_lo=n/2)
7	Low certainty – swede/brassica	(n=1 AND brs_lo=1) OR (n>1 AND brs_hi+brs_lo>n/2 AND brs_hi+brs_lo<n) OR (brs_hi=n/2 AND noveg_lo+pstr_lo+crl_lo=n/2)
8	Low certainty – cereal crop	(n=1 AND crl_lo=1) OR (n>1 AND crl_hi+crl_lo>n/2 AND crl_hi+crl_lo<n) OR (crl_hi=n/2 AND noveg_lo+pstr_lo+brs_lo=n/2)
9	Unknown green vegetation	n>1 AND pstr_hi+brs_hi+crl_hi+pstr_lo+brs_lo+crl_lo>n/2
0	Unknown	Otherwise

Winter forage rules (combining pre-grazing map and spring classifications)

These rules analyse the pre-grazing land cover map (‘pgclass’), which is the product of the previous set of rules, along with the stack of five spring classifications (‘postgc’). The five classifications of the spring stack can be individually referred to by their layer name: ranging from postgc(1) (22-June classification) to postgc(5) (26-September classification). Several rules directly refer to these individual layers. In these cases the rules are checking whether the land cover in the particular layer is bare ground (1), pasture (2), swede/brassica (3) or cereal (4).

Prior to executing the rules below, the program counts (at every pixel location) the number of spring classifications (out of five) in the following categories: noveg_hi, pstr_hi, brs_hi, crl_hi (number of classifications of bare ground, pasture, swede/brassica, or cereal, in ‘high-trust’ areas), noveg_lo, pstr_lo, brs_lo, crl_lo (number of classifications of these land covers in ‘low-trust’ areas). Total number of sources (classifications that have valid data) is ‘n’.

Class value	*Class name*	*Rule*
14	No data, or non-agricultural land masked out	pgclass EQ 10 AND n EQ 0
3	Winter forage – likely swede/brassica	(pgclass=3 OR pgclass=7) AND brs_hi+brs_lo+noveg_hi+noveg_lo>0 AND brs_hi+brs_lo+noveg_hi+noveg_lo=n
4	Winter forage – possibly cereal	(pgclass=4 or pgclass=8) AND crl_hi+crl_lo+noveg_hi+noveg_lo>0 AND crl_hi+crl_lo+noveg_hi+noveg_lo=n)
5	Winter forage (pasture/other) in temporal pattern, but pattern can also be matched by non-forage land uses	pgclass>1 AND pgclass!=5 AND pgclass<10 AND noveg_hi>0 AND [(postgc(1)≤1 AND postgc(2)≤1 AND postgc(3)≤1 AND postgc(4)≤1 AND postgc(5)≤1) OR (postgc(1)!=1 AND postgc(2)≤1 AND postgc(3)≤1 AND postgc(4)≤1 AND postgc(5)≤1) OR (postgc(1)!=1 AND postgc(2)!=1 AND postgc(3)≤1 AND postgc(4)≤1 AND postgc(5)≤1)]
6	Pasture/other with temporary dip to bare ground in spring	pgclass>1 AND pgclass!=5 AND pgclass<10 AND noveg_hi>0
2	Bare soil/stubble/brown vegetation throughout period	(pgclass=1 OR pgclass=5) AND noveg_hi+noveg_lo>0 AND noveg_hi+noveg_lo=n
1	Green vegetation (mostly, but not all, pasture) throughout period	[(pgclass=2 OR pgclass=6 OR pgclass=4 OR pgclass=8 OR pgclass=9) AND pstr_hi+pstr_lo+crl_hi+crl_lo+brs_hi+brs_lo>0 AND pstr_hi+pstr_lo+crl_hi+crl_lo+brs_hi+brs_lo=n] OR [(pgclass=2 OR pgclass=6) AND pstr_hi≥1 AND noveg_hi=0 AND brs_hi=0 AND crl_hi=0]
…..Table continued next page…..		

7	Newly-planted pasture or crop	(pgclass=1 OR pgclass=5) AND pstr_hi+brs_hi+crl_hi>0 AND [(postgc(1)≤1 AND postgc(2)≤1 AND postgc(3)≤1 AND postgc(4)≤1 AND postgc(5)!=1) OR (postgc(1)≤1 AND postgc(2)≤1 AND postgc (3)≤1 AND postgc(4)!=1 AND postgc(5)!=1) OR (postgc(1)≤1 AND postgc(2)≤1 AND postgc(3)!=1 AND postgc(4)!=1 AND postgc(5)!=1) OR (postgc(1)≤1 AND postgc(2)!=1 AND postgc(3)!=1 AND postgc(4)!=1 AND postgc(5)!=1) OR pstr_hi+pstr_lo+brs_hi+brs_lo+crl_hi+crl_lo=n]
8	Low-certainty swede/brassica winter forage	[(pgclass=0 OR pgclass=10) AND brs_hi≥1 AND brs_hi+brs_lo+noveg_hi+noveg_lo=n] OR [pgclass=3 AND (n=0 OR noveg_lo+pstr_lo+brs_lo+crl_lo=n)]
9	Low-certainty cereal forage	[(pgclass=0 OR pgclass=10) AND crl_hi≥1 AND crl_hi+crl_lo+noveg_hi+noveg_lo=n] OR [pgclass=4 AND (n=0 OR noveg_lo+pstr_lo+brs_lo+crl_lo=n)]
10	Bare soil/stubble/brown vegetation in autumn, but no data in spring	(pgclass=1 OR pgclass=5) AND n=0
11	Bare soil/stubble/brown vegetation in spring, but no data in autumn	(pgclass=0 OR pgclass=10) AND noveg_hi≥1
13	Late-planted winter forage or temporary flush of green vegetation	(pgclass=1 OR pgclass=5) AND pstr_hi+brs_hi+crl_hi>0 AND noveg_hi>0 AND [(postgc(1)!=1 AND postgc(2)≤1 AND postgc(3)≤1 AND postgc(4)≤1 AND postgc(5)≤1) OR (postgc(1)!=1 AND postgc(2)!=1 AND postgc(3)≤1 AND postgc(4)≤1 AND postgc(5)≤1) OR (postgc(1)!=1 AND postgc(2)!=1 AND postgc(3)!=1 AND postgc(4)≤1 AND postgc(5)≤1) OR (postgc(1)!=1 AND postgc(2)!=1 AND postgc(3)!=1 AND postgc(4)!=1 AND postgc(5)≤1)]
12	Low-certainty pasture/other throughout period	[(pgclass=0 OR pgclass=10) AND pstr_hi≥1 AND pstr_hi+pstr_lo+noveg_hi+noveg_lo=n AND pstr_hi+pstr_lo≥noveg_hi+noveg_lo] OR [(pgclass=2 OR pgclass=9) AND (n=0 OR pstr_lo+brs_lo+crl_lo=n)] OR [(pgclass=2 OR pgclass=6) AND pstr_hi+pstr_lo>0]
0	Unknown	Otherwise