Ministry for the Environment
Manatū Mō Te Taiao

Land Use and Carbon Analysis System

SATELLITE IMAGERY INTERPRETATION GUIDE FOR LAND-USE CLASSES

2ND EDITION

LUCAS®

New Zealand Government

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Purpose

This interpretation guide aims to help users understand the Land Use and Carbon Analysis System (LUCAS) land-use classifications and to show how each land-use class is determined/inferred from vegetation cover seen in remotely sensed imagery. In particular, it aims to provide transparency and consistency to the process associated with mapping and verifying land-use, as has been recommended under international good practice guidelines (IPCC, 2003).

Background

LUCAS was established to enable New Zealand to meet its reporting and accounting obligations to the United Nations Framework on Climate Change (UNFCCC), and under Article 3.3 of the Kyoto Protocol (the first commitment period (CP-1), 2008–2012). Under these agreements, New Zealand must track and provide annual national statistics for greenhouse gas emissions and removals relative to a 1990 baseline for various sectors, including Land Use, Land-use Change and Forestry (LULUCF).

LUCAS has tracked LULUCF activities by establishing a land-use map for the baseline year 1990, and then mapping land-use changes for the time periods 1990–2008 and 2008–2012. The land-use mapping involves extensive use of satellite imagery and some aerial photography, along with other spatial layers and datasets.

This guide details the definition of New Zealand LULUCF reporting classes, describes the mapping process, and provides examples to aid the identification of these classes in satellite imagery and aerial photography.

Forest definition for New Zealand

This forest definition applies for mapping of all LULUCF activities (UNFCCC, 2001):

"Forest" is the minimum area of land of 0.05–1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10–30 per cent with trees with the potential to reach a minimum height of 2–5 metres at maturity in situ. A forest may consist of either closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground, or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10–30 per cent or tree height of 2–5 metres are included under forest. Forest also includes areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention, such as harvesting or natural causes, but which are expected to revert to forest.

New Zealand has selected the upper limits of the forest definition parameters, namely:

- minimum area of 1 ha
- more than 30 per cent canopy cover
- height of 5 metres or more (or the ability to reach this height under current management or in situ)
- 30-metre width at minimum (mean width, canopy-edge to canopy-edge).

Land-use classes

A general description of the land-use classes mapped and/or recorded for land-use mapping (LUM) in 1990 and later years (2008 and 2012) is shown in table 1. Additional information on the woody land-use classes (namely, Natural forest, Pre-1990 planted forest, Post-1989 forest and Grassland – with woody biomass) is provided on the following pages, including illustrations of commonly-encountered scenarios.

The definition of these land-use classes is in line with international good practice guidance (IPCC, 2003, chapter 2). The minimum mapping area specified in these definitions is one hectare and the minimum width mapped is 30 metres.

Table 1: Description of land-use classes

Land-use class mapped		Land-use/Land cover sub-categories
FOREST LAND	Natural forest **LUC_ID = 71**	Areas that at 1 January 1990 were: • tall indigenous forest • self-sown exotic trees such as wilding conifers and grey willows established before 1 January 1990 • broadleaved hardwood shrubland, manuka/kanuka shrubland and other woody shrubland (≥ 30 per cent cover, with potential to reach ≥ 5 m at maturity in situ under current land management within 30–40 years) • areas of bare ground of any size which were previously forested but, due to natural disturbances (eg, erosion, storms, fire) have lost vegetation cover • roads/tracks less than 30 m width within the above categories and areas which subsequently meet the above criteria on land which was forest land at 1990 (classed as Natural forest or Pre-1990 planted forest at 1990).
	Pre-1990 planted forest **LUC_ID = 72**	• radiata pine, Douglas-fir, eucalypts or other planted species (with potential to reach ≥ 5 m height at maturity in situ) planted before 1 January 1990, or replanted on land which was forest land as at 31 December 1989 • exotic forest species that were planted after 31 December 1989 into land that was natural forest • riparian or erosion control plantings that meet the forest definition and that were planted before 1 January 1990 • harvested areas within pre-1990 forest land (assumes these will be replanted, unless deforestation is later detected) • includes roads/tracks/skid sites/other temporarily un-stocked areas within forest that are less than the minimum area of 5 ha or width of 30 m • areas of bare ground of any size which were previously forested at 31 December 1989 but, due to natural disturbances (eg, erosion, storms, fire), have lost vegetation cover
	Post-1989 forest **LUC_ID = 73**	• exotic forest (with the potential to reach ≥ 5 m height at maturity *in situ*) planted or established on land that was non-forest land as at 31 December 1989 (eg, radiata pine, Douglas-fir, eucalypts or other planted species) • harvested areas within post-1989 forest land (assumes these will be replanted, unless deforestation is later detected) • forests arising from natural regeneration of indigenous tree species as a result of land management change after 31 December 1989

		• self-sown exotic trees such as wilding conifers or grey willows established after 31 December 1989 • riparian or erosion control plantings that meet the forest definition and that were planted after 31 December 1989 • includes roads/tracks/skid sites/other temporarily un-stocked areas within the forest that are less than the minimum area of 5 ha or width of 30 m • areas of bare ground of any size which were previously forested (established after 31 December 1989) but, due to natural disturbances (eg, erosion, storms, fire), have lost vegetation cover.
GRASSLAND	**Grassland – with woody biomass** **LUC_ID= 74**	• grassland with matagouri and sweet briar, broadleaved hardwood shrubland, manuka/kanuka shrubland, coastal and other woody shrubland (< 5 m tall and any per cent cover) where, under current management or environmental conditions (climate and/or soil), it is expected that the forest criteria will not be met over a 30–40 year time period • above timberline shrubland vegetation and intermixed with montane herbfields (does not have the potential to reach > 5 m height *in situ*) • grassland with tall tree species (< 30 per cent cover), such as golf courses in rural areas (and except where the Land Cover Databases (LCDB1 and LCBD2) have classified these as settlements) • grassland with riparian or erosion control plantings (< 30 per cent cover) • linear shelterbelts that are > 1 ha in area and >30 m mean width • areas of bare ground of any size which previously contained grassland with woody biomass but, due to natural disturbances (eg, erosion, fire) have lost vegetation cover
	Grassland – high producing **LUC_ID = 75**	• grassland with high quality pasture species • includes linear shelterbelts which are <1 ha in area or <30 m mean width (larger shelterbelts are mapped separately as grassland – with woody biomass) • areas of bare ground of any size which were previously grassland but, due to natural disturbances (eg, erosion) have lost vegetation cover
	Grassland – low producing **LUC_ID = 76**	• low fertility grassland and tussock grasslands • mostly on hill country • montane herbfields at either an altitude higher than above timberline vegetation or where the herbfields are not mixed up with woody vegetation • includes linear shelterbelts which are <1 ha in area or <30 m mean width (larger shelterbelts are mapped separately as grassland – with woody biomass) • other areas of limited vegetation cover and significant bare soil including erosion and coastal herbaceous sand dune vegetation
CROPLAND	Cropland – perennial **LUC_ID = 77**	• all orchards and vineyards • linear shelterbelts associated with perennial cropland
	Cropland – annual **LUC_ID = 78**	• all annual crops • all cultivated bare ground • linear shelterbelts associated with annual cropland
WETLAND	Wetland – open water **LUC_ID = 79**	• all open water ie, lakes, rivers, dams, reservoirs, estuaries (where within the defined coastline of New Zealand)

	Wetland – vegetated non forest **LUC_ID = 80**	• herbaceous and/or non-forest woody vegetation periodically flooded. Scattered patches of tall tree-like vegetation of <30% cover to be included as wetlands • estuarine/tidal areas including mangroves
SETTLEMENTS	Settlements **LUC_ID = 81**	• built-up areas and impervious surfaces • grassland within settlements including recreational areas, urban parklands and open spaces which do not meet the forest definition • major roading infrastructure • airports and runways • dam infrastructure • urban subdivisions under construction
OTHER LAND	Other **LUC_ID = 82**	• montane rock/scree • river gravels, rocky outcrops, sand dunes and beaches, coastal cliffs, eroded gullies with no vegetation, mines (including spoil), quarries • permanent ice/snow and glaciers • any other remaining land that does not fall into any of the other land-use categories.

The land-use mapping process

Under the UNFCCC and Kyoto Protocol, New Zealand must provide annual national estimates of greenhouse gas emissions and removals relative to a baseline year of 1990. For the Land Use, Land-Use Change and Forestry (LULUCF) sector land, the LUCAS approach involved national mapping (including offshore islands) of land use and tracking of land-use change activities throughout this period, in accordance with international good practice guidelines (IPCC, 2003).

LULUCF activities since 1990 were tracked by establishing a land-use map for the baseline year 1990, and then mapping land-use changes for the time period 1990–2008 (the beginning of Kyoto Protocol Commitment Period 1). At the time of writing, work is underway to map land-use changes for the time period 2008–2012 (the duration of Kyoto Protocol Commitment Period 1).

The 1990 land-use map is derived from 30-metre spatial resolution Landsat-4 and Landsat-5 satellite imagery taken in, or close to, 1990. The first of the images used were taken in November 1988 and the last in February 1993 (table 2). The 1990 mapping was assisted by manual comparison with a c. 2001 reference dataset. This reference dataset was derived from Landsat 7 imagery which had been sharpened to a 15 m spatial resolution (Newsome & Shepherd, 2009), as well as other available imagery, such as SPOT-2 and 3 data acquired 1996–1996 (table 3). The use of this higher resolution imagery, coupled with concurrent reference to aerial photography, increased the certainty of land-use decisions in the 1990 map.

The 2008 land-use map was compiled by mapping and verifying change with respect to the 1990 land-use map and the 2001 reference dataset (Shepherd & Newsome 2009) using imagery from the SPOT-5 satellite. The 2012 land-use map will be derived from SPOT-5 satellite imagery taken in, or close to, 2012.

Table 2 National satellite imagery datasets used to map land use at 1990, 2008 and 2012

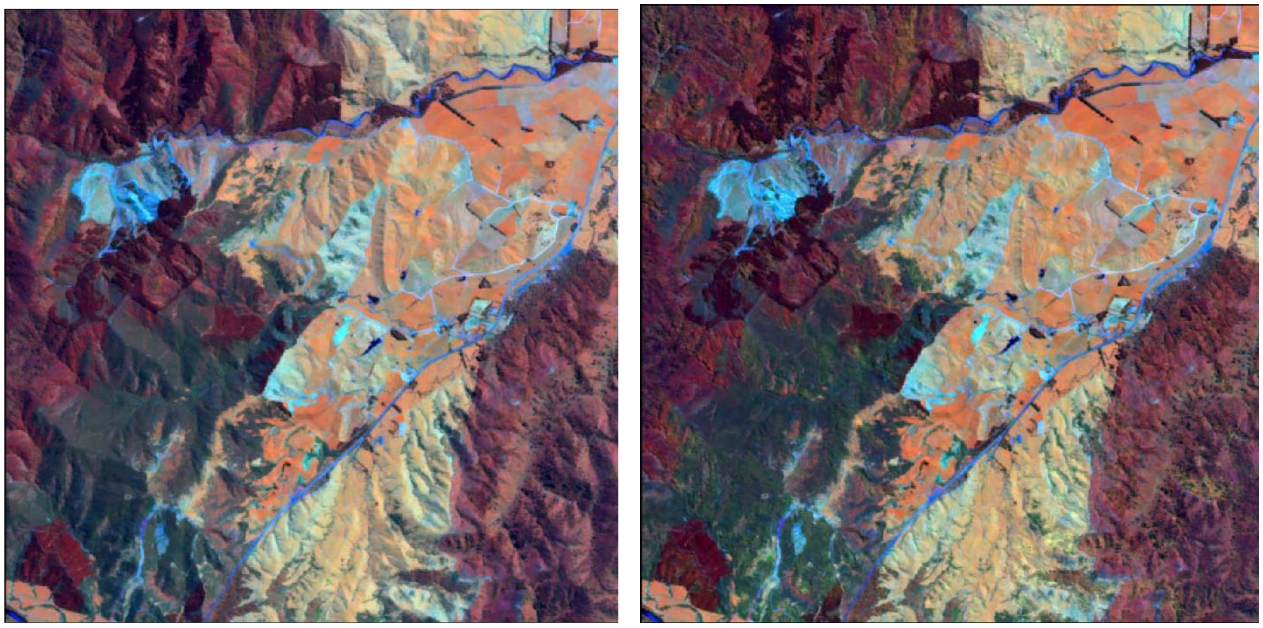
Time period	Satellite	Notes
c. 1990 (1989–1993)	Landsat 4 & 5	Some gaps in coverage infilled with SPOT data
c. 2001 (2000–2003)	Landsat 7	
c. 2008 (2006–2008)	SPOT-5	Acquired during two summer seasons Oct–Mar inclusive
c. 2012 (2011–2013)	SPOT-5	Planned acquisition over two summer seasons Oct–Mar inclusive

Table 3 Supplementary imagery datasets used to validate New Zealand land-use mapping

Time period	Satellite	Notes
c. 1996 (1996–7)	SPOT 2 & 3	
1994–2009	Aerial photography	Various scales, panchromatic and true colour imagery, coverage of most of New Zealand during this period at various dates
2005–2008	MODIS	
2008–2009	SPOTMaps	
2009	DMC	
2010–2011	SPOT-5	Selected regions imaged; not a national dataset – coverage of Northland, Waikato, the Bay of Plenty, Marlborough and Southland.

The Landsat and SPOT satellite images were standardised for spectral reflectance using the Ecosat algorithms documented in Dymond et al (2001), Shepherd and Dymond (2003) and Dymond and Shepherd (2004): this processing effectively models and removes the variability of reflectance across the imagery which is caused by topographic slope orientation versus the angle of illumination from the sun (figure 1).

Figure 1 2008 SPOT-5 standardised spectral reflectance



Note: 2008 SPOT-5 (left) and with spectral reflectance standardised (right).

The standardised images were used for automated mapping of woody classes, which were then mapped into the woody land-use classes used for reporting (figure 2). Woody land-use classes at 1990 included Natural forest, Pre-1990 planted forest and Grassland with woody biomass. At 2008 and 2012 an additional class containing forest established after 1989 is included: Post-1989 forest.

To determine the spatial location of the other non-woody land-use categories and subcategories as at 1990, 2008 and 2012 (ie, grassland, cropland, wetlands and settlements), information was used from two land-cover databases, LCDB1 (1996), LCDB2 (2001) (Thompson et al, 2003), LCDB3 (2008) as well as the New Zealand Land Resource Inventory (NZLRI) (Eyles, 1977) and hydrological data from Land Information New Zealand (Newsome & Shepherd 2009; Shepherd and Newsome, 2009) (table 4).

The NZLRI database was used to better define the area of high-and low-producing grassland. Areas tagged as 'improved pasture' in the NZLRI vegetation records were classified as grassland – high producing in the land-use maps. All other areas were classified as grassland – low producing. Figure 2 illustrates the end-to-end mapping process.

The 2008 and 2012 land-use maps (land-use as at 1 January 2008 and 31 December 2012) are derived from 10-metre spatial resolution SPOT-5 satellite imagery which is processed into standardised reflectance images, using the same approach as for the 1990 imagery. The SPOT-5 imagery for the 2008 mapping was captured over the summers of 2006–07 and 2007–08 (November to April), to establish a national set of cloud-free imagery. The SPOT-5 imagery for the 2012 mapping is scheduled for acquisition during the summers of 2011–12 and 2012–13. Where

the SPOT-5 imagery pre-dates the reference mapping date tied to the greenhouse gas reporting (1 January 2008 and 31 December 2012), a combination of aerial photography, SPOTMaps, Landsat-7 and DMC satellite imagery, and field verification are used to identify where deforestation has occurred to ensure the land-use maps are as accurate as possible.

Figure 2 Creating the New Zealand land-use map

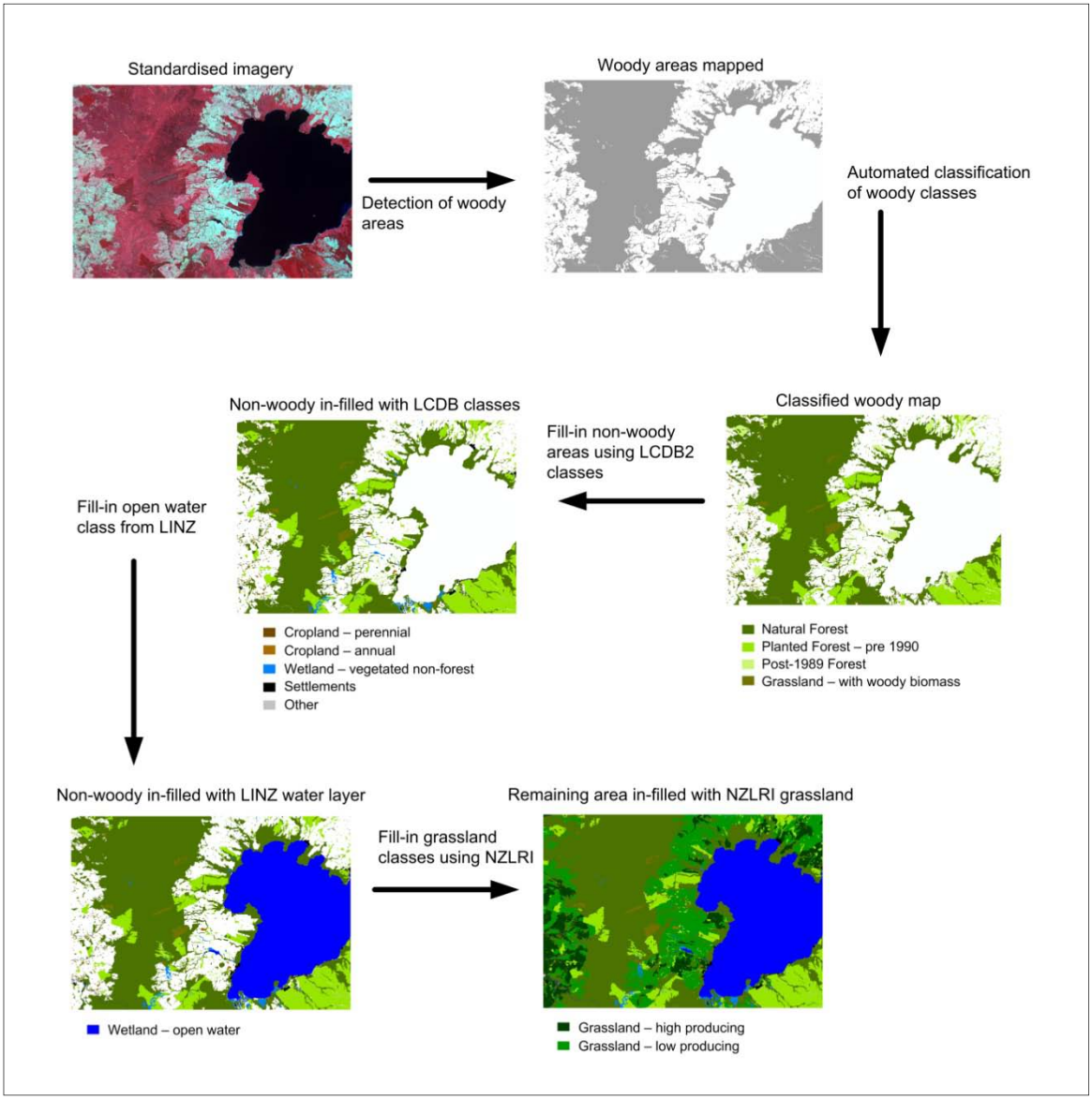


Table 4 Data sources for land-use classes in the 1990, 2008 and 2012 mapping

Land-Use Map	Land-Use Class	Mapping Source
1990	Forest (all)	Automated mapping from standardised Landsat 4 and 5 satellite imagery, refined via manual comparison against 2001 reference layer and other available imagery and datasets.
	Grassland – with woody biomass	
	Grassland – high- & low-producing	NZLRI
	Cropland (all)	LCDB1 classes from LCDB2 polygons Rivers delineated using LINZ 1:50,000 topography map vectors.
	Wetland (all)	
	Settlements	
	Other Land	
2008	Forest (all)	Automated mapping from standardised SPOT-5 satellite imagery, refined via manual comparison against 2001 reference layer and other available imagery and datasets. Harvested and deforested polygons confirmed via oblique aerial photography and field observations for some regions.
	Grassland – with woody biomass	
	Grassland – high- & low-producing	NZLRI
	Cropland (all)	LCDB2 and updates from LCDB3 Cropland mapping improved using Agribase Rivers delineated using LINZ 1:50,000 topography map vectors.
	Wetland (all)	
	Settlements	
	Other Land	
2012	Forest (all)	Automated mapping from standardised SPOT-5 satellite imagery, refined via manual comparison against 2008 land-use layer and other available imagery and datasets. Harvested and deforested polygons confirmed via oblique aerial photography and field observations in all regions.
	Grassland – with woody biomass	
	Grassland – high- & low-producing	NZLRI
	Cropland (all)	LCDB2, LCDB3 and updates based on satellite imagery
	Wetland (all)	LCDB2
	Settlements	LCDB2, LCDB3 and updates based on satellite imagery
	Other Land	LCDB2

Identifying woody class land use

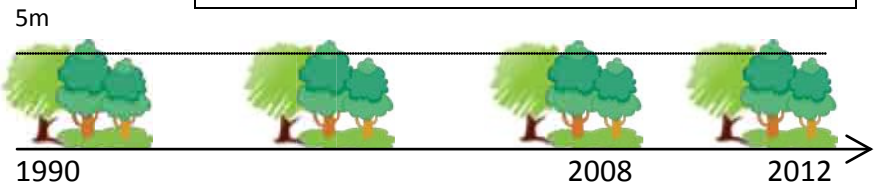
The LUCAS mapping requires land use to be mapped, rather than land cover. Land-cover maps are arguably easier to produce, because they contain a snapshot of the predominant land characteristics at the time of mapping. Land-use maps, on the other hand, rely on an understanding of how an area of land is used, or managed, over time.

The reference table below illustrates commonly encountered scenarios in the LUCAS rules for 'woody' land uses, based on the vegetation present over time. Examples are provided for the period from 1990 through to 2012, including how they would be classified in the LUCAS 1990, 2008 and 2012 land-use mapping (LUM). These are discussed individually and in more detail, with examples of the satellite imagery and aerial photography, later in this document.

Natural forest

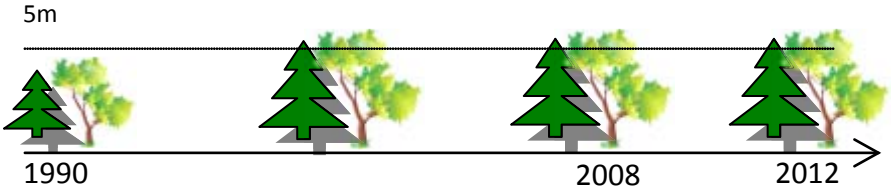
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

Areas that since 1 January 1990 were, and have remained tall indigenous forest (>5 m height).



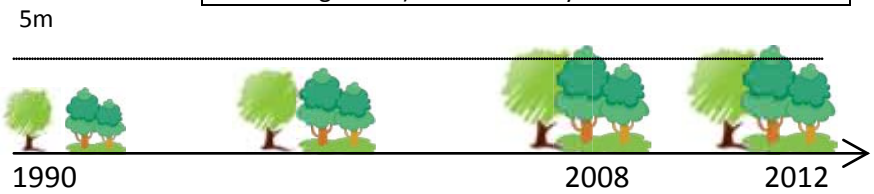
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

Self-sown exotic trees such as wilding conifers and grey willows established before 1 January 1990 and meeting forest definition.



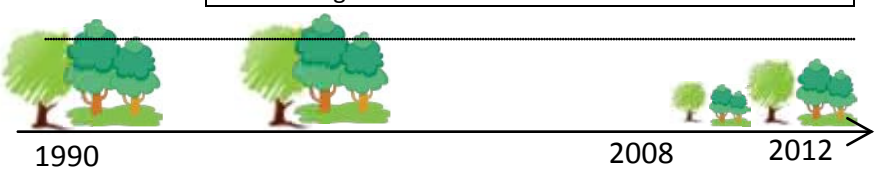
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

Shrubland (≥ 30 per cent cover, with potential to reach ≥ 5 m at maturity in situ under current land management) within 30–40 years.



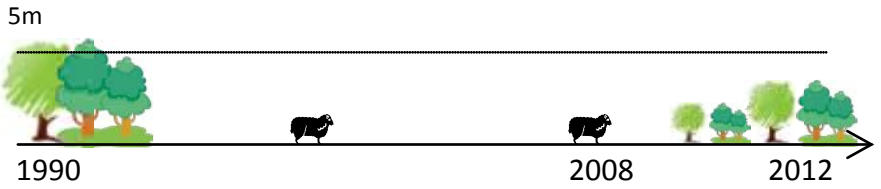
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

Bare ground of any size which was forested but, due to natural disturbances (eg, erosion, storms, fire) has lost vegetation cover.



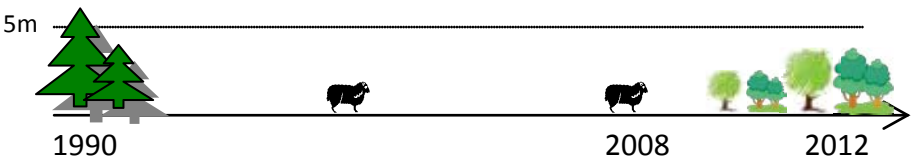
LUM 1990	LUM 2008	LUM 2012
Natural forest	Grass-land	Natural forest

Regenerating natural species at 2012 on land which was natural forest at 1990 but in a non-forest land use at 2008.



LUM 1990	LUM 2008	LUM 2012
Pre-1990 planted forest	Grass-land	Natural forest

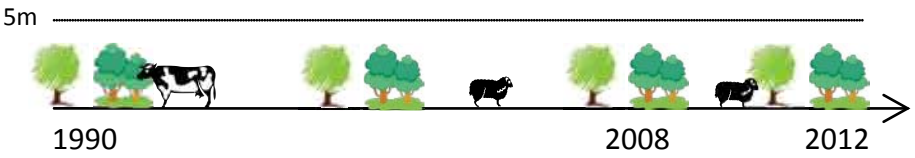
Regenerating natural species at 2012 on land which was forested at 1990 but in a non-forest land use at 2008.



Grassland – with woody biomass

LUM 1990	LUM 2008	LUM 2012
GWB	GWB	GWB

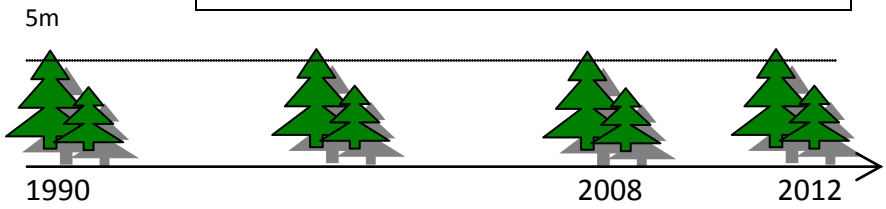
Shrubland where, under current management or environmental conditions, it is expected that the forest criteria will not be met.



Pre-1990 planted forest

LUM 1990	LUM 2008	LUM 2012
Pre-1990 planted forest	Pre-1990 planted forest	Pre-1990 planted forest

Planted forest (with potential to reach ≥ 5 m height at maturity in situ) established before 1 January 1990.

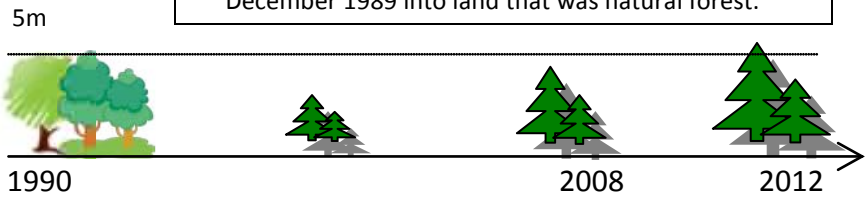


LUM 1990	LUM 2008	LUM 2012
Pre-1990 planted forest	Pre-1990 planted forest	Pre-1990 planted forest

Forest (with potential to reach ≥ 5 m height at maturity in situ) replanted on land which was forest land as at 31 December 1989.

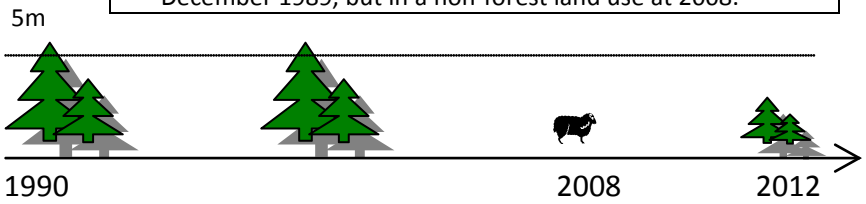
LUM 1990	LUM 2008	LUM 2012
Natural forest	Pre-1990 planted forest	Pre-1990 planted forest

Exotic forest species that were planted after 31 December 1989 into land that was natural forest.



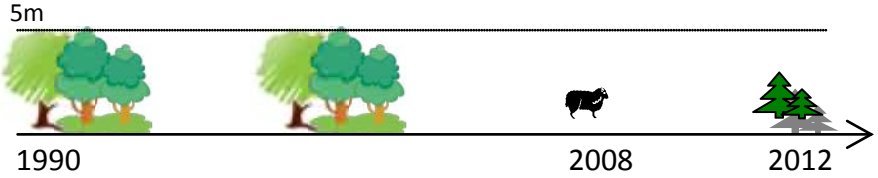
LUM 1990	LUM 2008	LUM 2012
Pre-1990 planted forest	Grass-land	Pre-1990 planted forest

Forest (with potential to reach ≥ 5 m height at maturity in situ) replanted on land which was forest land as at 31 December 1989, but in a non-forest land use at 2008.



LUM 1990	LUM 2008	LUM 2012
Natural forest	Grass-land	Pre-1990 planted forest

Forest (with potential to reach ≥ 5 m height at maturity in situ) replanted on land which was natural forest as at 31 December 1989, but in a non-forest land use at 2008.

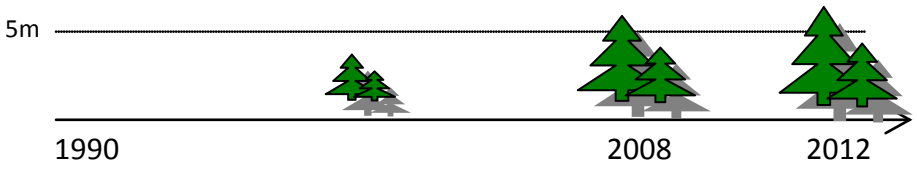


Post-1989 forest

LUM 1990	LUM 2008	LUM 2012
Non-forest land	*Post-1989 forest	Post-1989 forest

* If forest planted by 2008

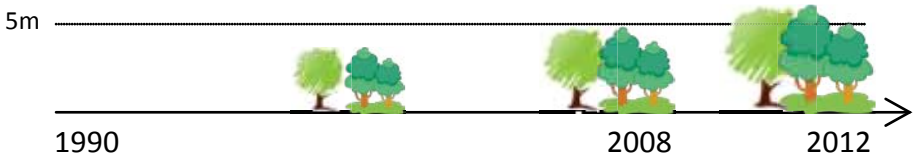
Exotic forest (with the potential to reach ≥ 5 m height at maturity *in situ*) planted on land that was non-forest land as at 31 December 1989



LUM 1990	LUM 2008	LUM 2012
Non-forest land	*Post-1989 forest	Post-1989 forest

* If forest species established by 2008

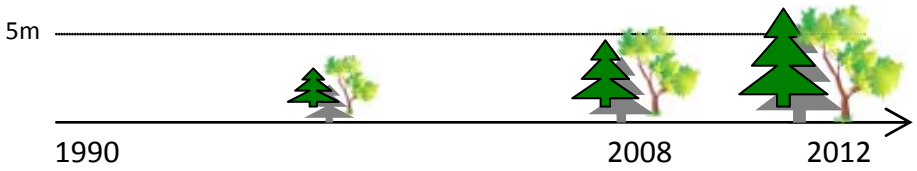
Forests arising from natural regeneration of indigenous tree species as a result of land management change after 31 December 1989



LUM 1990	LUM 2008	LUM 2012
Non-forest land	*Post-1989 forest	Post-1989 forest

* If forest species established by 2008

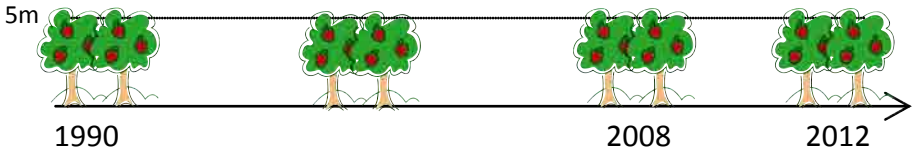
Self-sown exotic trees such as wilding conifers and grey willows established after 31 December 1989, where meeting forest definition

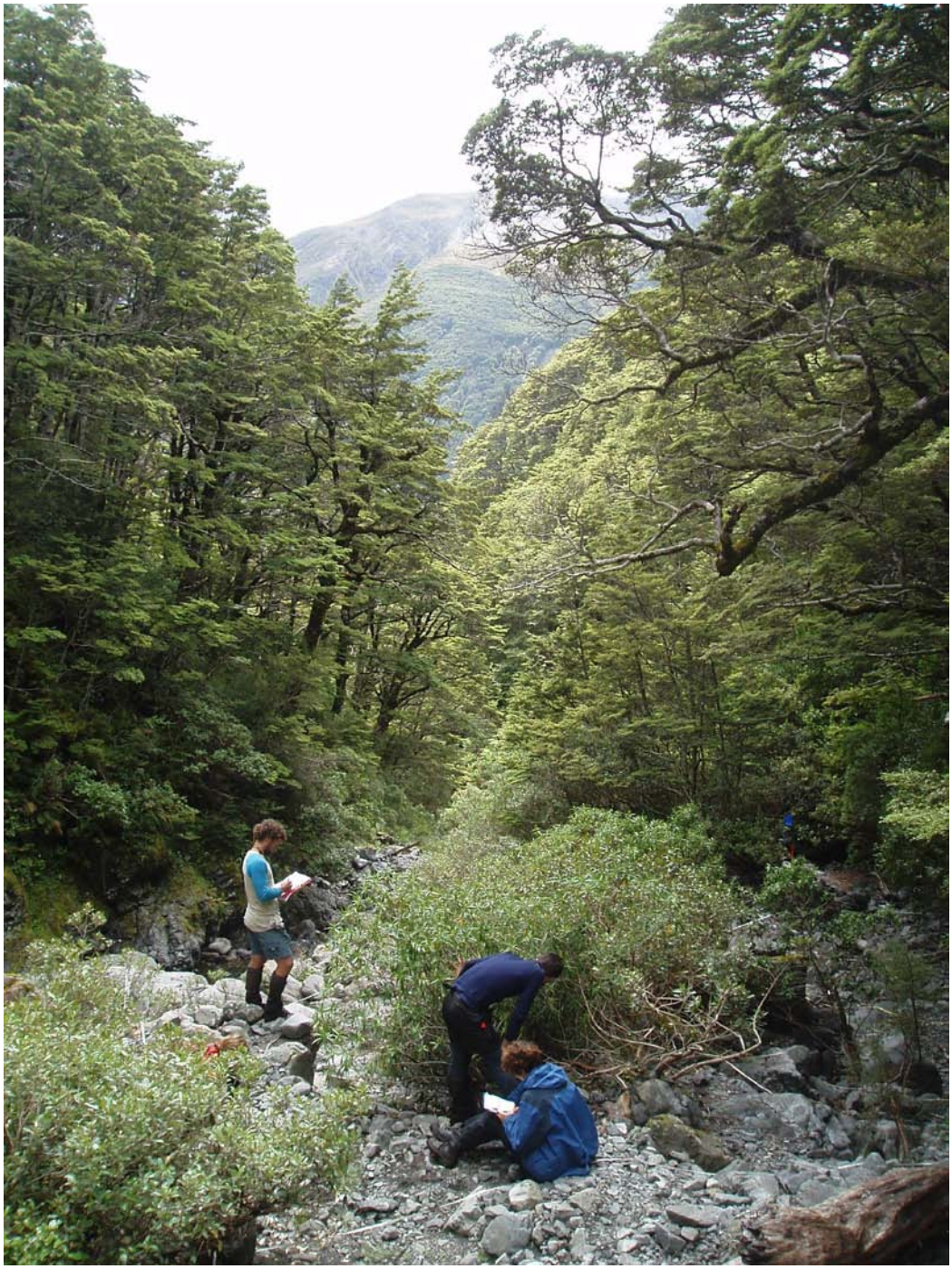


Cropland – Perennial

LUM 1990	LUM 2008	LUM 2012
Crop-land	Crop-land	Crop-land

All crop trees (orchards) are classed as perennial cropland.





Taking measurements in a natural forest plot.

Land-use classification illustrations

This section of the interpretation guide aims to show how each land-use class is inferred from vegetation cover seen in remotely sensed imagery. Common examples of land use and land-use change are shown in time-series of satellite imagery. In particular, it aims to provide transparency and consistency to the process associated with mapping and verifying land use, as has been recommended under international good practice guidelines (IPCC, 2003).
All of the satellite imagery is displayed in a false-colour composite format, which is designed to maximise the difference between indigenous and exotic forest species, and areas containing woody and non-woody vegetation. Where possible, a similar false-colour composite image is used, regardless of sensor; for specific technical details please see Appendix 1.

Natural forest (LUC ID = 71)

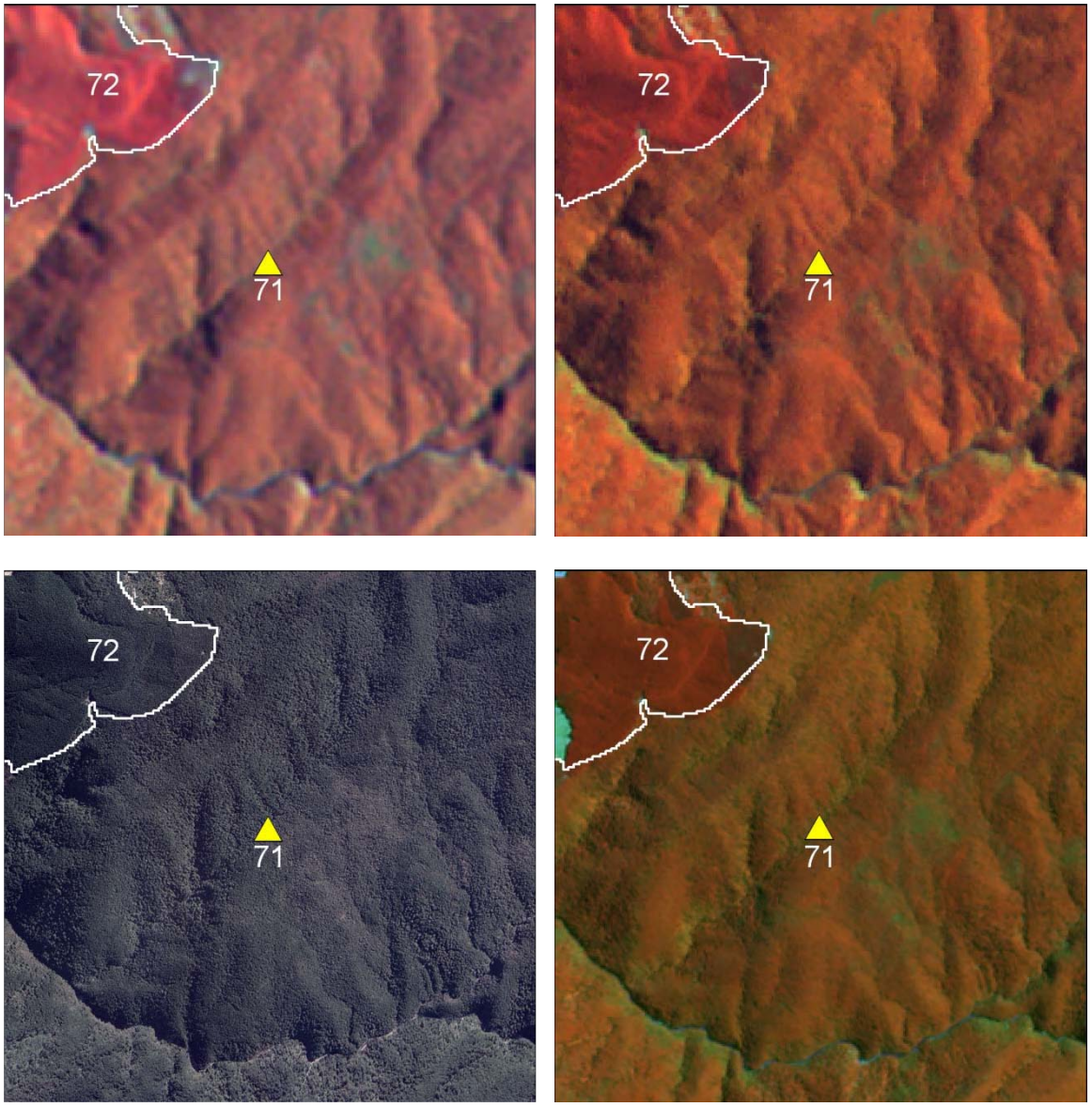
Natural forests are dominated by indigenous forest tree species, but may include trees arising from natural establishment and regeneration of exotic species. This land-use class includes forests that meet the forest definition, or have the potential to meet the forest criteria under the management regime in place at 31 December 1989.

Mapping this class requires particular attention. Satellite imagery provides clear evidence for established natural forests, but it provides less clear evidence of the land-use class where shrubland (broadleaved hardwood shrubland, manuka/kanuka shrubland and other woody shrubland) is present. Areas with a pre-dominance of such shrubland vegetation cover with more than 30 per cent canopy cover will require an "*in-situ*" assessment of available evidence, where height, width, surrounding land use, and the perceived land management practice determine the land-use classification. If an assessment of such areas shows that vegetation is likely to achieve forest height criteria (5 m) within 30–40 years, then the area is classified as natural forest.

Where there is evidence of erosion or other non-anthropogenic land-use change, the area retains the classification of natural forest regardless of the size of the area. The land-use intention of these areas continues to be natural forest.

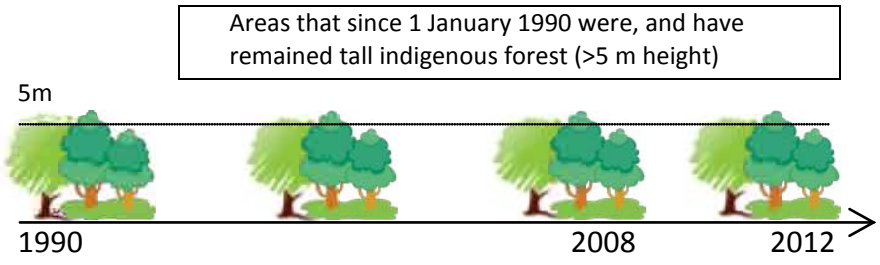
Natural forest

Example 1: Established natural forest



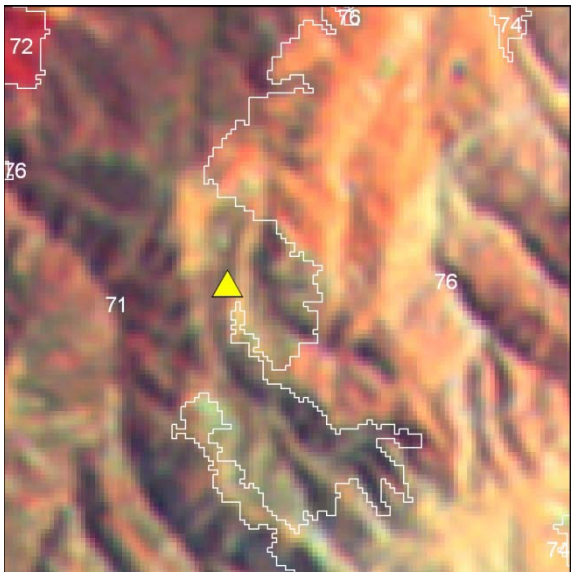
Imagery:	1990 Landsat-4 TM (upper left), 2000 Landsat-7 ETM+ (upper right) 2006 aerial photograph (lower left), 2008 SPOT-5 (lower right)
Scale:	1:40,000
Location:	16 km due south of Nelson, NZTM grid reference 1616100, 5407000
Explanation:	These images largely comprise mature natural forest (class 71), which is dominated by the orangey-brown tones in the Landsat and SPOT-5 images. Note the difference in tones between natural forest and the stand of mature exotic forest in the north-western corner (class 72), and also the differences in texture observed between these areas in the aerial photograph. Areas of mature natural forest are relatively easy to identify in Landsat and SPOT-5 satellite imagery. These forests have reasonably unique spectral signatures; however, there are some subtle variations depending on the predominant tree species. The trees in this area of natural forest are over 5 m in height with more than 30 per cent canopy cover.

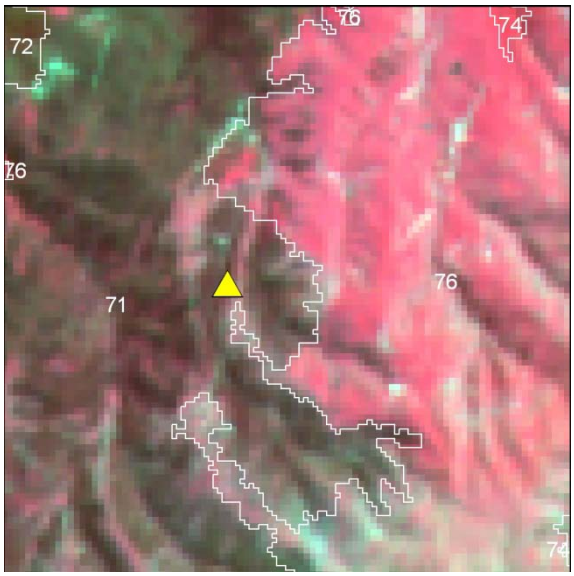
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

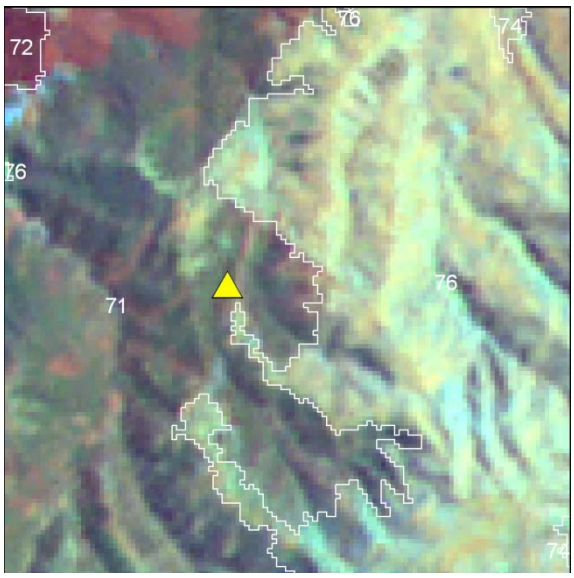


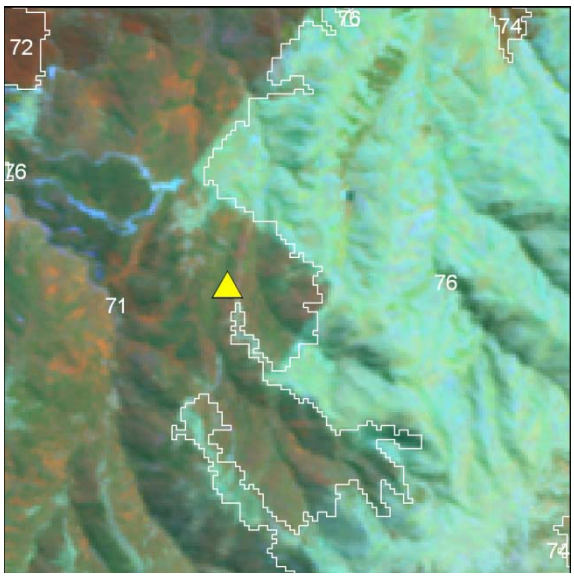
Natural forest

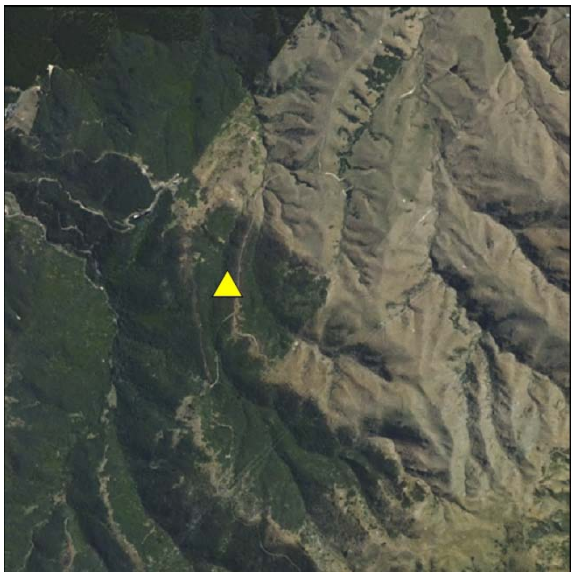
Example 2: Regenerating natural forest

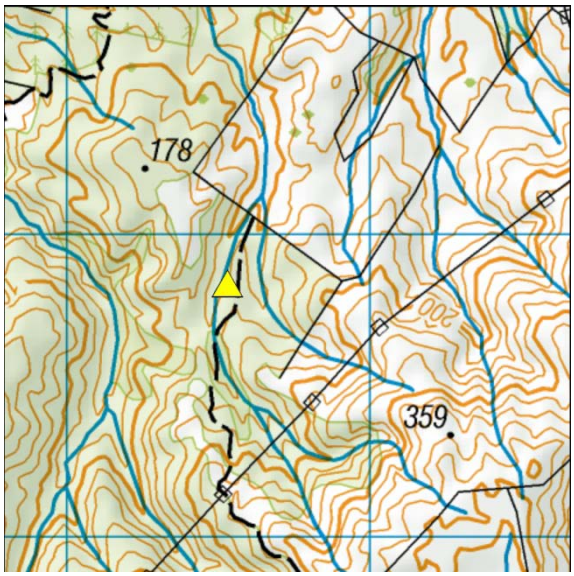








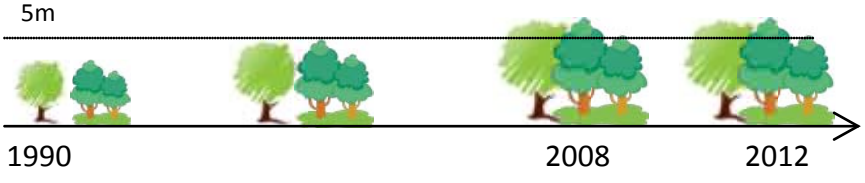




Imagery:	1990 Landsat-4 TM (upper left), 1996 SPOT-2 (upper right) 2000 Landsat-7 ETM+ (mid left), 2008 SPOT-5 (mid right) 2009 SPOTMaps (lower left), LINZ 1:50k topographic map (lower right)
Scale:	1:25,000
Location:	Northwest of Wellington, NZTM Grid Reference 1745201, 5433057
Explanation:	In the western half of this area, in the 1990 imagery the steep-sloped areas inside are inferred to be either manuka or kanuka shrubland, as the mixed green and mauve tones observed are typical of narrow-leafed shrubland vegetation. This contrasts with the area of grassland (likely to be grazing land) that dominates the eastern half of this image. In the time-series of imagery through 1996 SPOT-2 to 2000 Landsat-7 to 2008 SPOT-5, the deeper tones in the area of shrubland become increasingly dense, corresponding to increasingly dense vegetation cover, particularly along the boundary between shrubland and grassland. In the 1990 imagery there is a sharp linear boundary between the areas of shrubland and grassland. The sharp delineation persists and is increasingly evident in later years (eg, 2009 SPOTMaps image). Consulting the national 1:50,000 topographic map series confirms that parts of the sharp delineation coincide with fencing (solid black lines). *Note: as the topographic map series is a second-order data product (ie, derived from other imagery) it is recommended that it is used for supporting reference only.* In summary, the likely land management is that the shrubland areas were segregated from grazing areas, and the imagery shows that they: • have more than 30 per cent canopy cover • are larger than 1 ha • are likely to contain species with the potential to reach 5 m at maturity under the land management practice in this location. Therefore, this area has the potential to meet the forest definition within the next 30–40 years, so is assigned the Natural forest land-use class. *See also section on Grassland with woody biomass for examples of shrubland which will not reach the forest definition.*

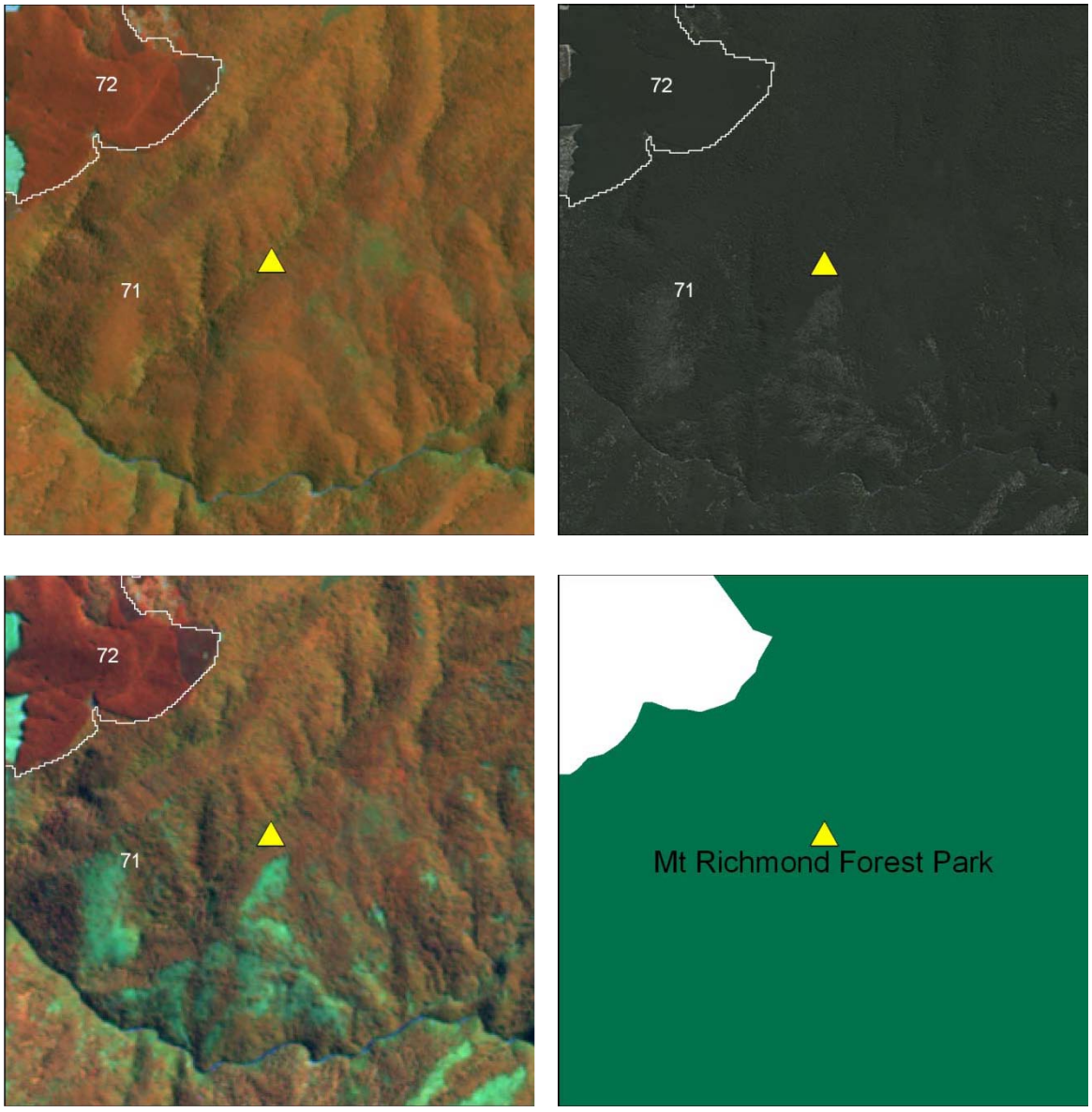
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

Shrubland (≥ 30 per cent cover, with potential to reach ≥ 5 m at maturity in situ under current land management) within 30–40 years



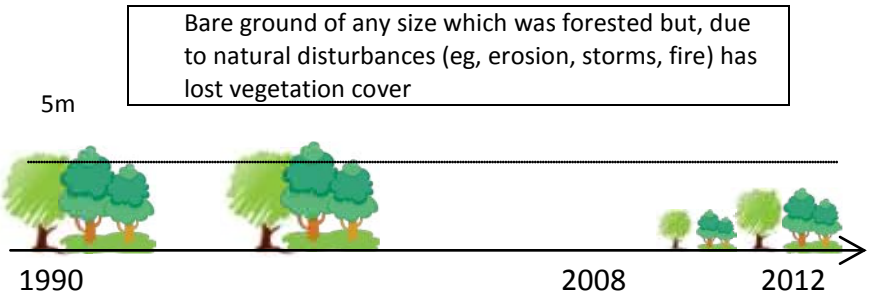
Natural forest

Example 3: Natural disturbance



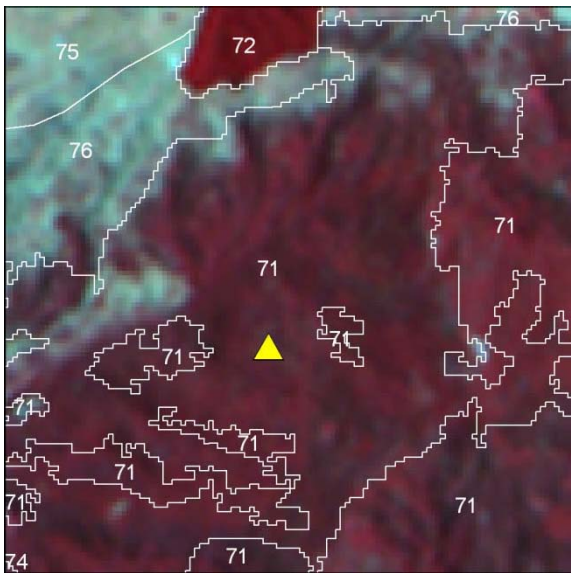
Imagery:	2008 SPOT-5 (upper left) 2009 SPOTMaps (upper right) 2010 SPOT-5 (lower left) Public Conservation Land layer (lower right)
Scale:	1:40,000
Location:	16 km due south of Nelson, NZTM grid reference 1616100, 5407000
Explanation:	After 2008, the southern half of the established forest in Natural forest Example 1 has developed bare patches (indicated by the pale patches within the forest in the 2009 SPOTMaps image and by the turquoise blue in the 2010 SPOT image). The edges of these patches appear diffuse and they contain scattered woody vegetation (unlike the next example). A map of Public Conservation Land (lower right) shows the area is managed by the Department of Conservation (DOC): the extent of the Mt Richmond Forest Park is indicated in green. Although we do not know what caused the decline in vegetation, we do know that the forest here is likely being managed as a conservation area. Therefore, with time the bare areas should regenerate because the land-use intention remains the same: Natural forest. This also applies to assessing natural disturbance in Pre-1990 planted forest, Post-1989 forest and Grassland – with woody biomass where the land use/management has not changed. Natural disturbance to woody vegetation cover can be caused by factors such as erosion, drought, storm damage, or wildfire.

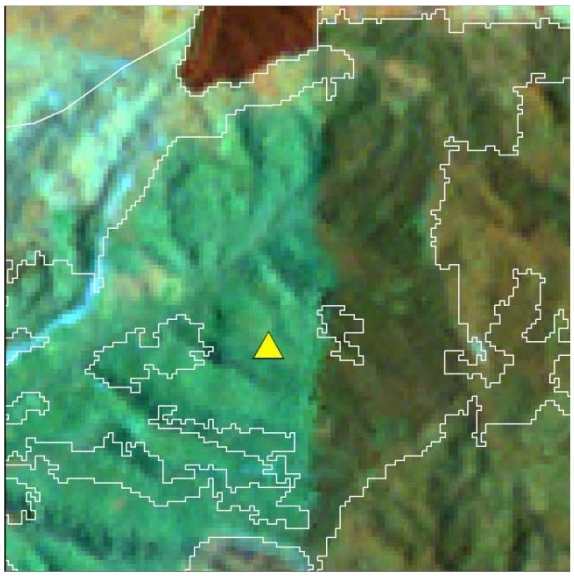
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

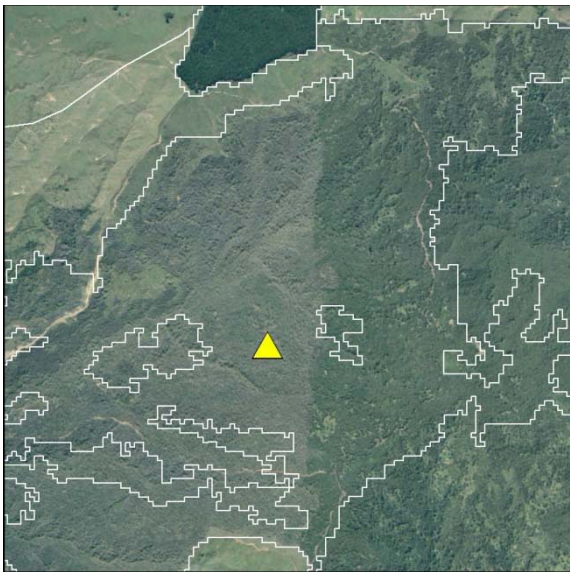


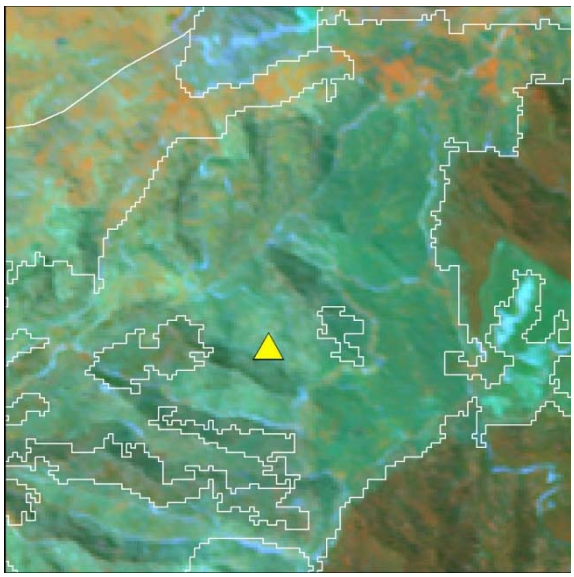
Natural forest

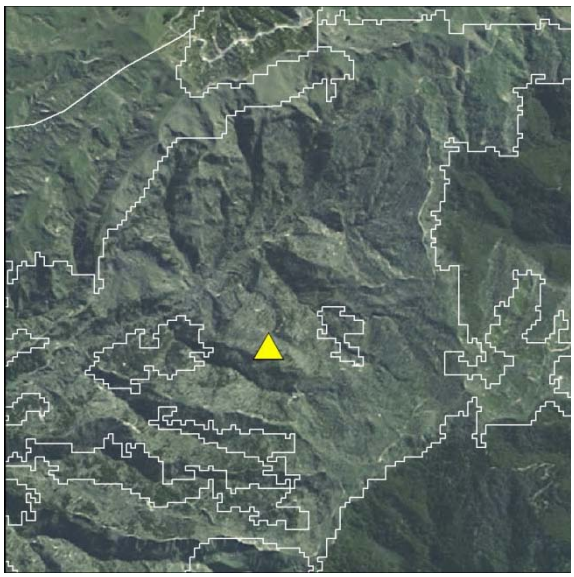
Example 4: Land-use change





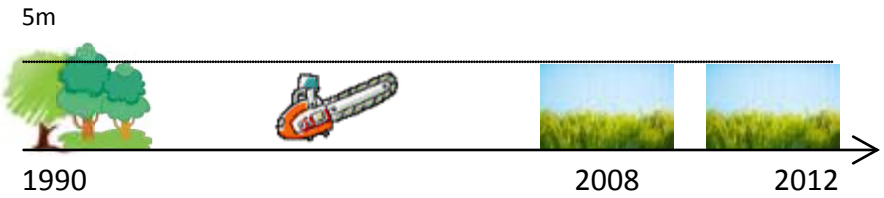






Imagery:	1996 SPOT-2 (upper left) 2000 Landsat-7 ETM+ (mid left), 2002 aerial photo (mid right) 2008 SPOT-5 (lower left), 2009 SPOTMaps (lower right)
Scale:	1:25,000
Location:	Hawke's Bay region, NZTM reference: 2,017,042, 5,669,112
Explanation:	This area contains established natural forest in 1990 (not shown due to patchy cloud cover in the imagery) and the forest is present at 1996 (deep red tones in the SPOT-2 image). In 2000, the imagery tones change (turquoise area on west relative to remaining forest tones in brown to east), and this is confirmed by the 2002 aerial photograph, which shows that the vegetation has been defoliated, presumably sprayed. By 2008, the area of vegetation removed has extended eastwards, and later SPOTMaps imagery confirms that the land use has been changed to Grassland – high-producing.

LUM 1990	LUM 2008	LUM 2012
Natural forest	Grassland	Grass-land



Grassland with woody biomass (LUC ID = 74)

This land-use class comprises areas of woody vegetation that do not meet the forest definition (in area, height and canopy cover), and that are unlikely to be forest within the next 30–40 years under the present land management or environmental conditions, including:

- managed grasslands where the woody vegetation may include scattered shrub species or tall trees, riparian vegetation, linear shelterbelts, and/or erosion control plantings or
- areas of shrubland (broadleaved hardwood shrubland, manuka/kanuka shrubland and other woody shrubland less than 5 m in height and any percentage cover) where the local conditions prevent the local vegetation meeting the forest definition ie, through altitude, aridity, exposure, or lack of adequate soil etc.

Where there are well-separated and isolated small clumps of woody vegetation (< 1 ha in area or <30 m mean width), these are not mapped, and the predominant surrounding land-use type is used to determine the mapped class. For example, in the grassland context, the use of either low- or high-producing is used instead of woody biomass.

It has been demonstrated, using temporal trends in land use (over the period 1964–2001, or a 30–40 year timeframe), and knowledge of farmers' land-use intentions and land management practices, that under business-as-usual pastoral farming, scattered manuka/kanuka shrubland and indigenous broadleaved shrubland do not exceed the crown cover and minimum area thresholds for Kyoto forest, and that where shrubland does regenerate to forest, it is through human intervention that favours shrubland establishment (Trotter and Mackay, 2005).

Accordingly, where evidence of grazing/grassland management exists and the vegetation present does not currently meet the forest definition as at 1990, the area is classified as grassland with woody biomass. Evidence of grassland management includes: pasture in immediate locality, fence lines, cattle troughs, farm tracks and accessibility to farm grazing stock.

Woody vegetation classification decision tree

The Grassland with woody biomass land-use class contains a diverse range of species, biomass densities and land management situations, and as a result it is one of the more difficult land-use classes to identify.

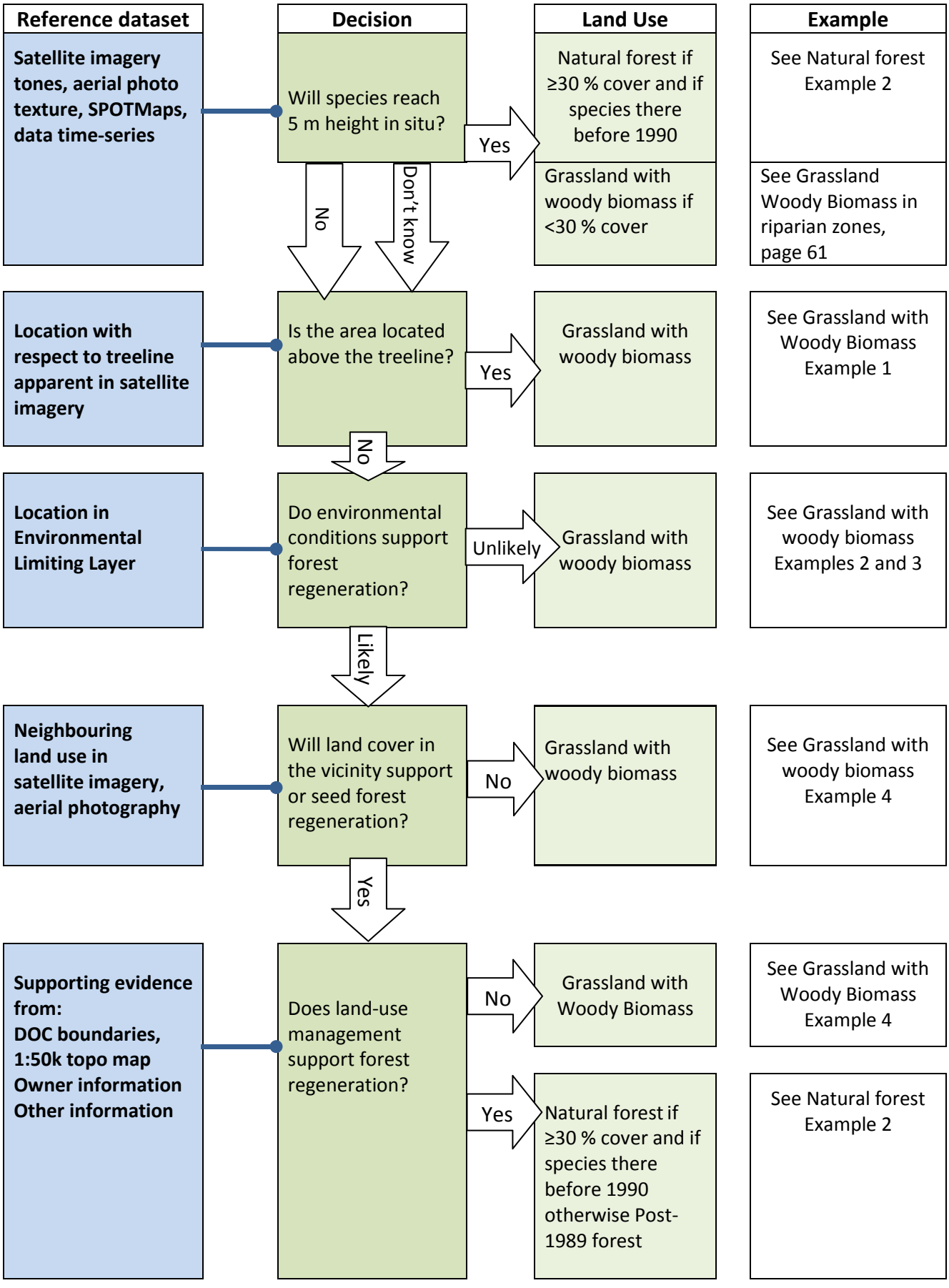
A decision tree and reference layers have been developed for assisting the classification of shrubland and land with scattered woody vegetation:

The reference layers include:

- Environmental Limiting Factors (ELF) layer – developed by Landcare Research as part of the 2012 Land Use Mapping Pilot project. This layer indicates where shrubland is unlikely to succeed to natural forest owing to the climate and/or soil constraints of the area. For more information on the ELF layer
  see appendix 4
- DOC boundary layer – showing the extent of areas managed by the Department of Conservation. Areas within the DOC estate are more likely to support regeneration.

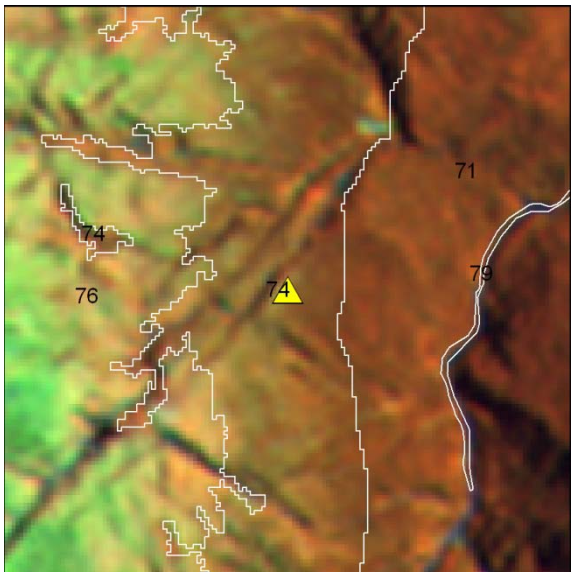
Figure 3 Woody vegetation classification decision tree

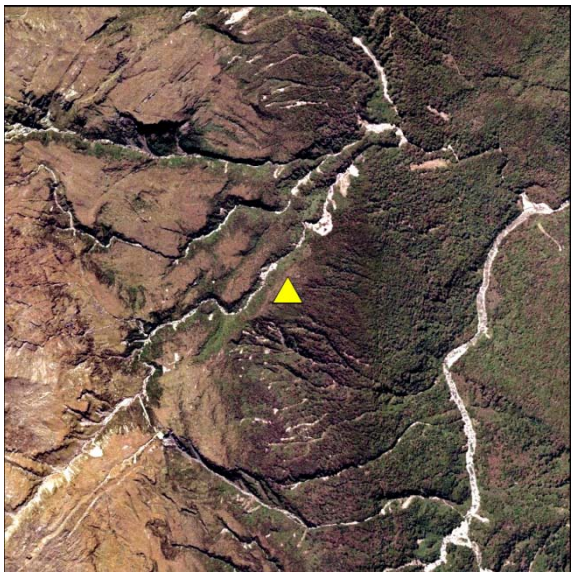
Note: Assumes that area meets minimum requirement of 1 ha in area and 30 m mean width

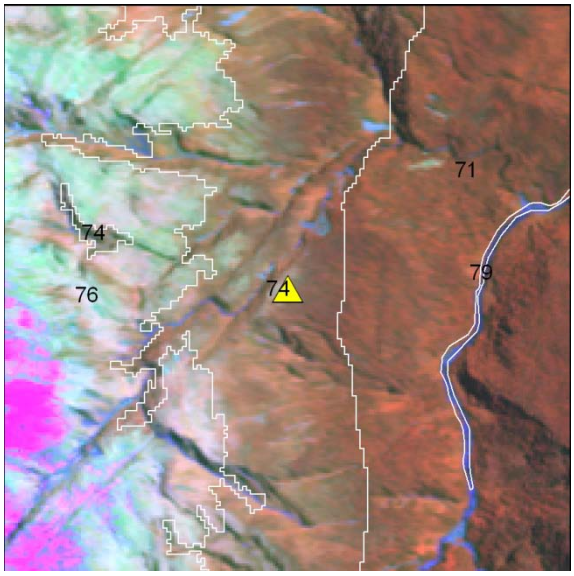


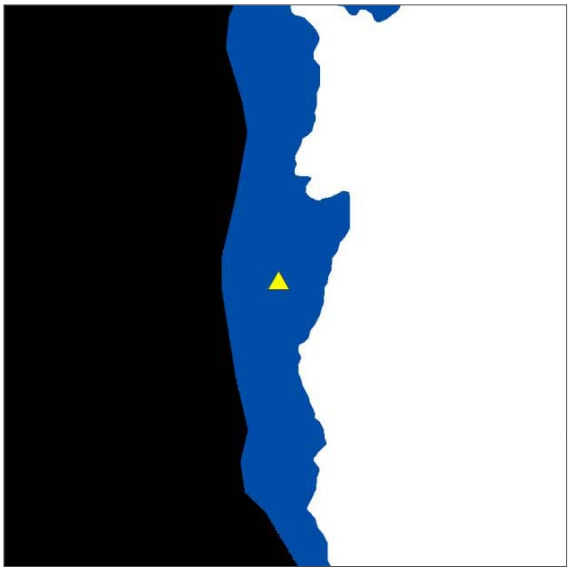
Grassland with woody biomass

Example 1: Sub-alpine shrubland





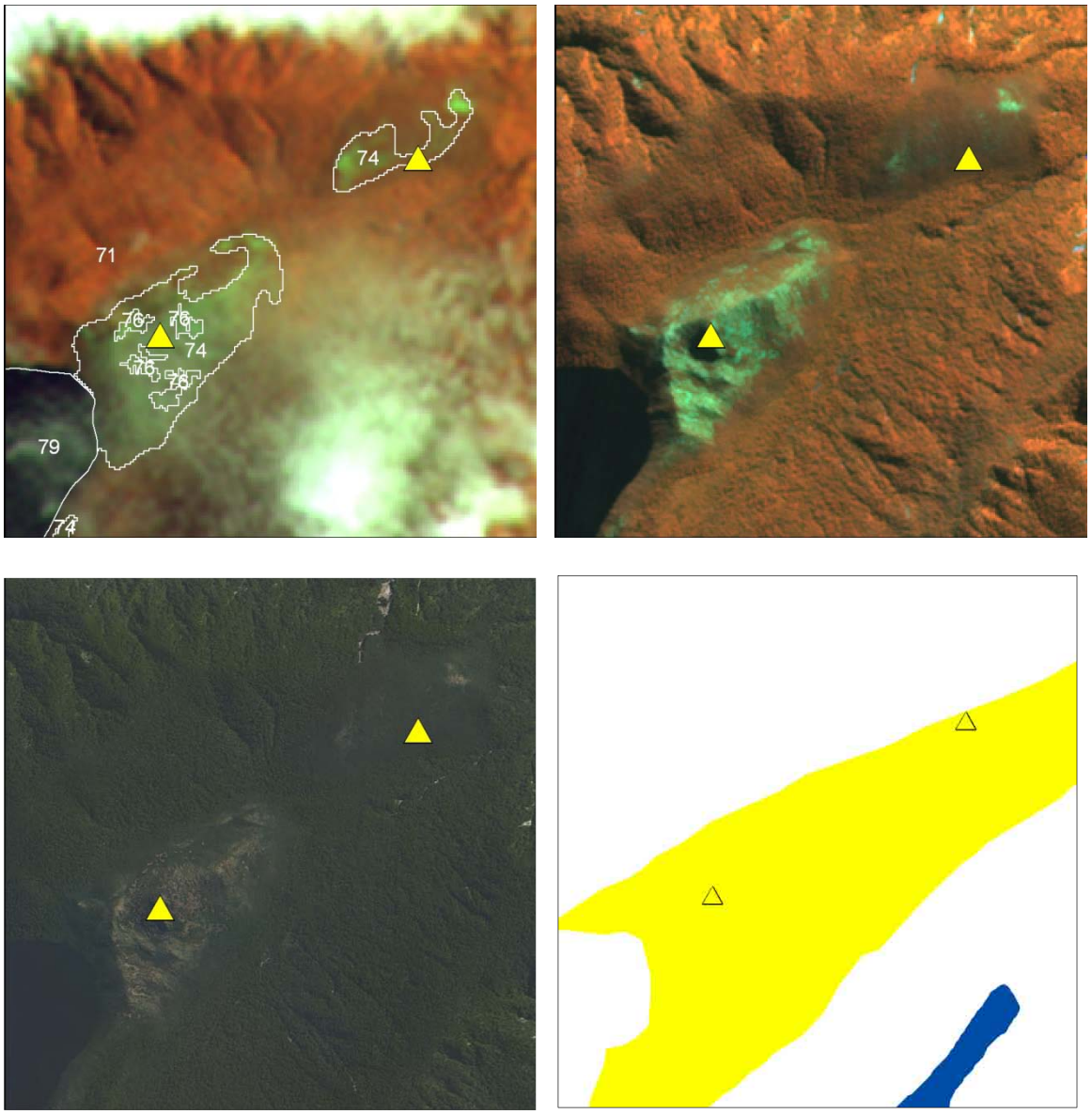




Imagery:	1990 Landsat-4 TM (upper left) 2002 aerial photograph (upper right) 2008 SPOT-5 (lower left) ELF vector layer (lower right)
Location:	Diedrichs Range, Southern Alps, NZTM grid reference: 1447300, 5240250
Altitude:	1000 m
Explanation:	The red tones in the 1990 Landsat image suggest extensive woody vegetation cover over the central and eastern areas of the image, but the vegetation running north-south in the centre of the frame has a different texture and colour in the 2002 aerial photograph relative to the mature natural forest to the east. The 2008 SPOT image shows the extent and density of woody vegetation is largely unchanged, inferring the land cover is at a steady state over time. The ELF vector layer (lower right) delineates areas which are not likely to reach the forest definition (over 5 m height) due to the elevation (shown as blue & black here). The ELF vector layer confirms this area is most likely alpine shrubland, and the area is mapped as Grassland with woody biomass.

Grassland with woody biomass

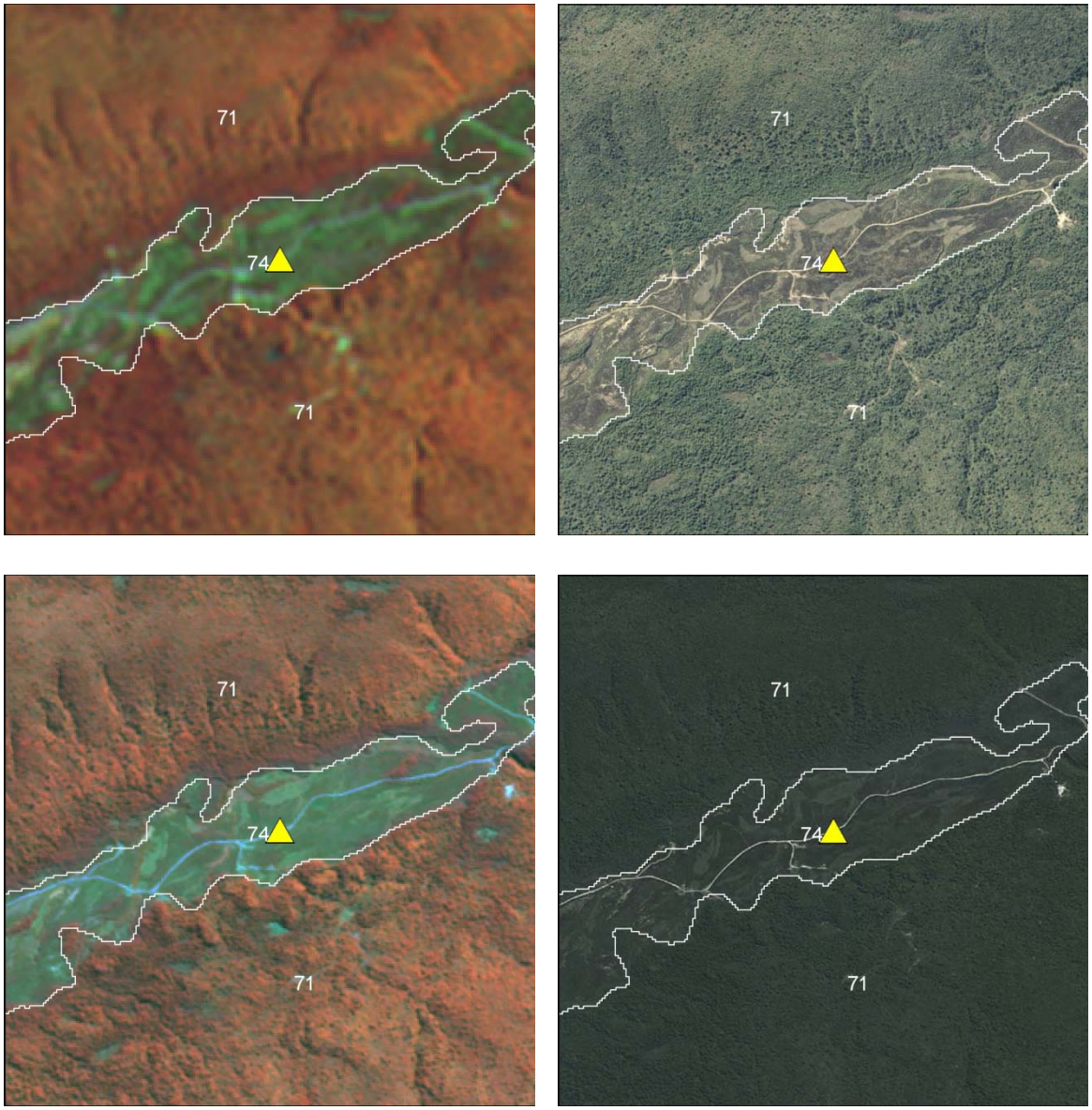
Example 2: Environmental factors (soil)



Imagery:	1990 Landsat-4 TM (upper left) 2008 SPOT-5 (upper right) 2009 SPOTMap (lower left) ELF vector layer (lower right)
Scale:	1:40,000
Location:	NW shore of Lake Ronald, Fiordland NZTM reference: 1182400, 5045500
Altitude:	500 m
Explanation:	Most of this frame comprises mature natural forest in this remote area of Fiordland. However, the turquoise tones in the (cloudy) 1990 Landsat image and the 2008 SPOT image show that the vegetation thins out, and does not regenerate over time. The SPOTMaps image confirms there is > 30 per cent vegetation cover, but will this vegetation reach the forest definition? Referring to the Environmental limiting factors (ELF) vector layer (lower right) confirms that some of the areas (in yellow) are unlikely to meet the forest definition due to local environmental factors, and are therefore classed as Grassland with woody biomass. In this case, these areas coincide with ultramafic soil, which has resulted in stunted forest growth (Payton et al 2007).

Grassland with woody biomass

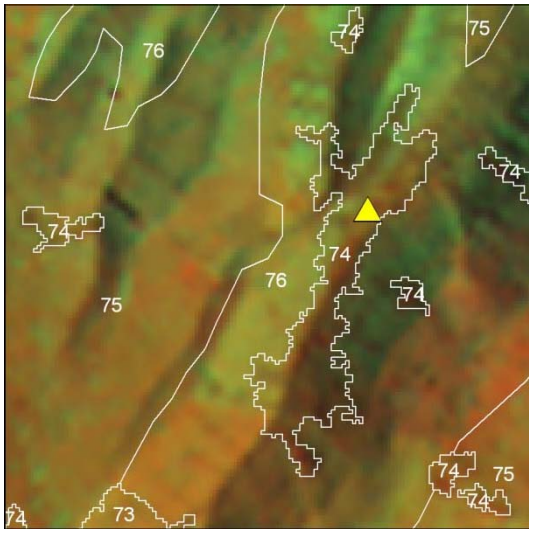
Example 3

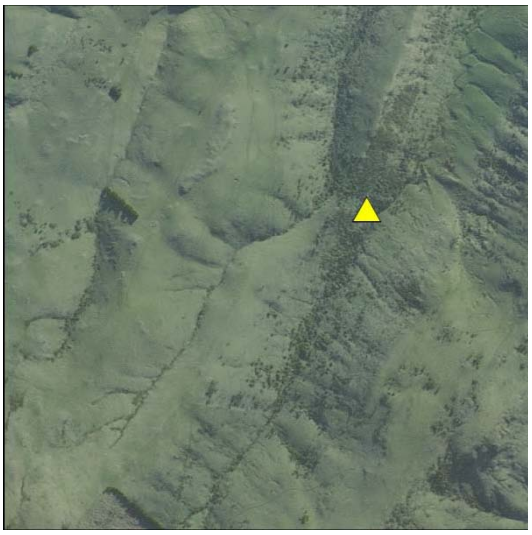


Imagery:	1990 Landsat-4 TM (upper left) 2003 aerial photo (upper right) 2008 SPOT-5 (lower left) 2009 SPOTMap (lower right)
Scale:	1:40,000
Location:	Upstream of Maniatangaroa Falls NZTM reference: 1825250, 5702850
Altitude:	750 m
Explanation:	The valley floor is surrounded by mature natural forest to the north and the south, but the texture of the vegetation in the aerial photograph confirms that it is lower in height. The time-series of imagery from 1990 through to 2009 shows that the vegetation cover is not changing or thickening substantially and that this area is unlikely to reach the forest definition in the near future. In this case, the classification of Grassland with woody biomass is correct; the area comprises low shrubland within a frost-flat, where local climatic conditions cause temperature inversions in the valley, resulting in stunted vegetation growth that is unlikely to reach 5 m in height.

Grassland with woody biomass

Example 4: Land management





Imagery:	1990 Landsat-4 TM (upper left), 2009 SPOTMaps (upper right)
Scale:	1:30,000 1:2,000,000 – 2009 SPOTMaps (lower)
Location:	Banks Peninsula NZTM grid reference: 1595850, 5165100
Explanation:	The woody vegetation in this grassland context (likely to be gorse or broom) indicated by the red-brown tones in the 1990 Landsat image is not delineated by sharp boundaries suggesting that the land management is such that it is unlikely to be fenced off from grazing. The area and density of scattered woody cover does not change significantly in the time-series of imagery since 1990 (1990 Landsat and SPOTMaps images shown here only), and there is also no forest land in the proximity as a seed source (1:2,000,000 SPOTMaps image). This shrubland is unlikely to develop into forest land in the near future, and is therefore assigned to a land-use of Grassland with woody biomass.

Pre-1990 planted forest
(LUC ID = 72)

All forest land that contains exotic tree species, and was forest land as at 31 December 1989, is referred to as pre-1990 planted forest. The most common tree species in these forests is radiata pine, with Douglas-fir the next most common species. This land use includes exotic forest planting occurring on land which had a natural forest land use at 31 December 1989. This land use also includes exotic species that have been planted before 31 December 1989 for erosion and river control purposes, such as willows and poplars.

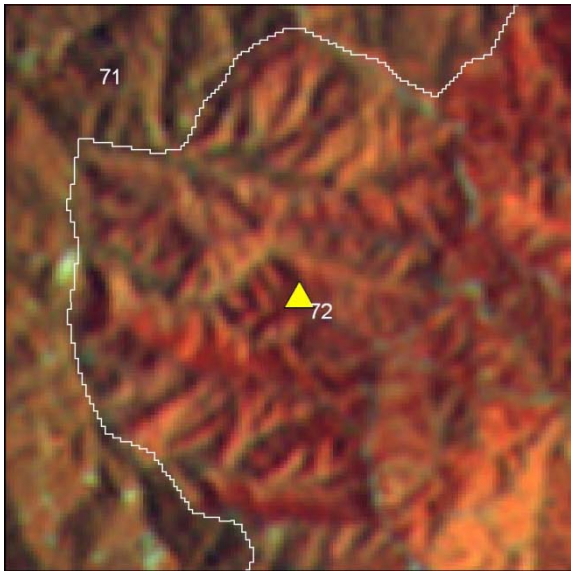
Where islands of land not containing exotic forest species (1 to 5 ha in area) occur within – and are totally surrounded by – pre-1990 planted forest these areas are also classified as pre-1990 planted forest. It is assumed the land-use management of the small, completely surrounded areas will be related to the forestry operations (ie, harvested land, skid sites etc), and thus these small areas have the same land use.

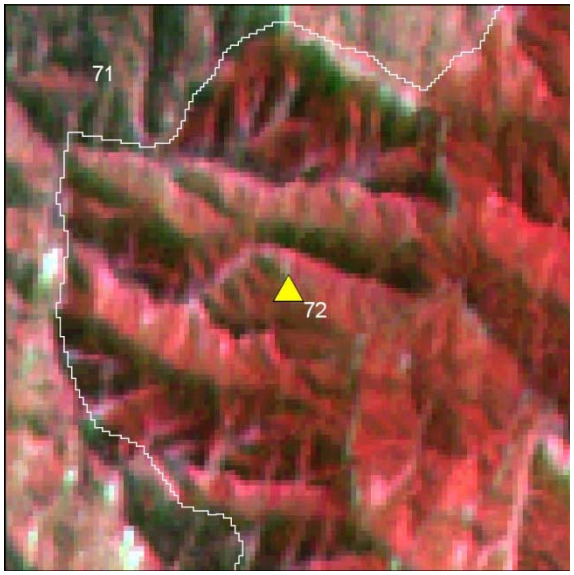
One exception to this rule: if the 1 to < 5 ha areas within the planted forest are natural forest they will retain their land-use classification, ie, natural forest (class 71).

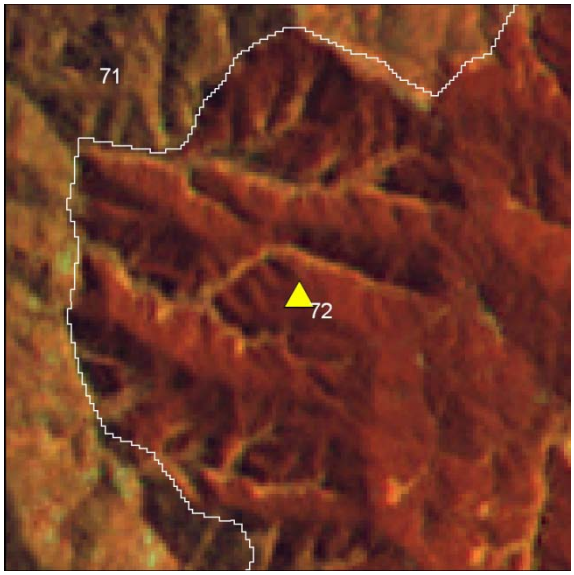
Sunlight filters through pine forest in Otago.

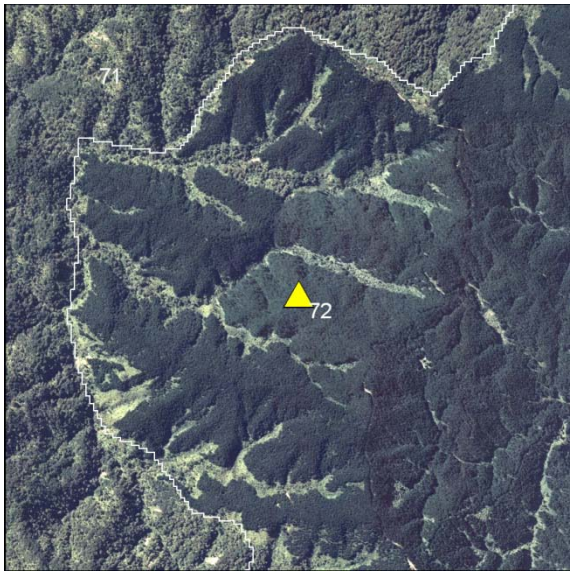
Pre-1990 planted forest

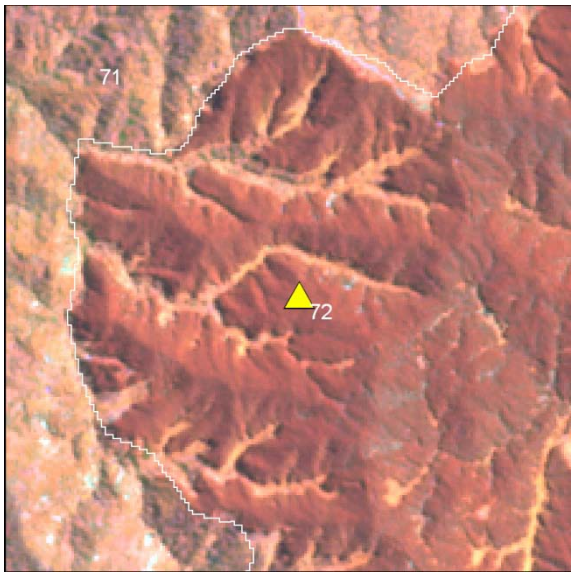
Example 1: Established exotic forest

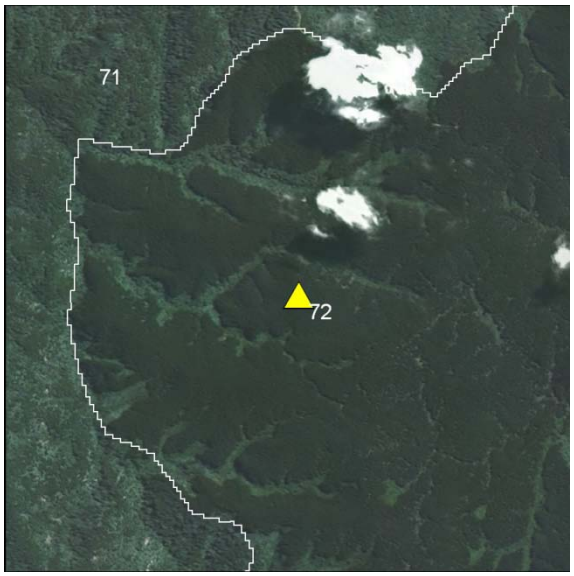






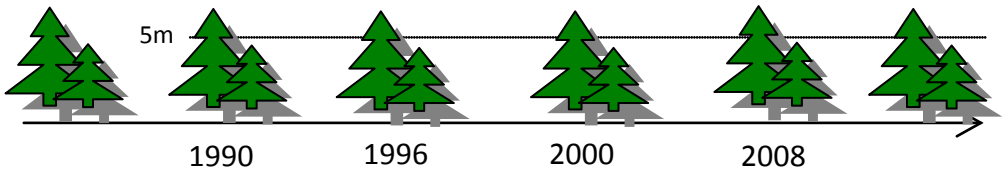






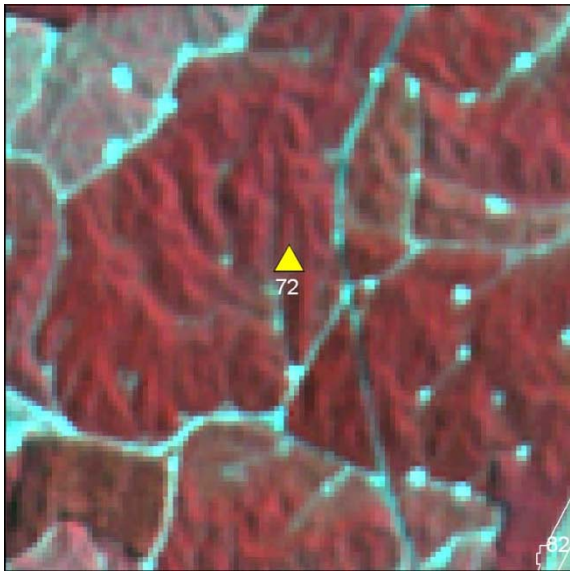
Imagery:	1990 Landsat-4 TM (upper left) 1996 SPOT-2 (upper right) 2000 Landsat-7 ETM+ (mid left) 2003 aerial photograph (mid right) 2008 SPOT-5 (lower left) 2009 SPOTMaps (lower right)
Scale:	1:30,000
Location:	Bay of Plenty, NZTM Grid Reference 1994950, 5783850
Explanation:	The central portion of the imagery contains planted forest, with established natural forest in the western and northern margins of the image. These planted forests have a brown-red colour in the Landsat and SPOT imagery with this false-colour composite band combination, which is distinct from the adjacent orange-brown natural forest. Note also the difference in the natural and planted forest canopy texture and colour observed in the aerial photograph and SPOTMaps image. The forest cover persists from before 1990 (the signal in the 1990 Landsat image indicates the presence of pine trees) and throughout the time-series to 2009, and is a classic example of Pre-1990 planted forest. Note: where gullies containing indigenous vegetation are present within the pre-1990 planted forest (particularly clear in the 2003 aerial photograph running west-east), these are mapped as the surrounding pre-1990 planted forest if they are less than 1 ha in size or 30m in width.

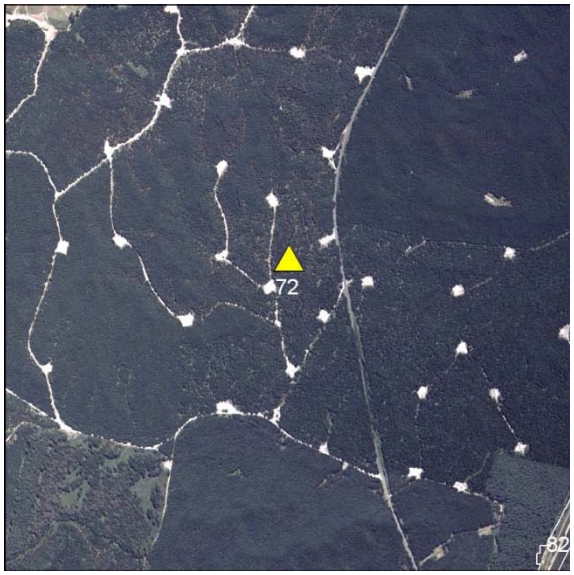
1990	2008
Pre-1990 planted forest	Pre-1990 planted forest

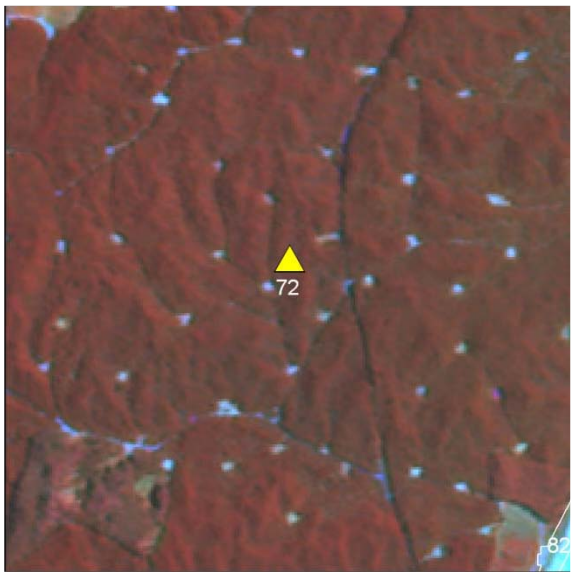


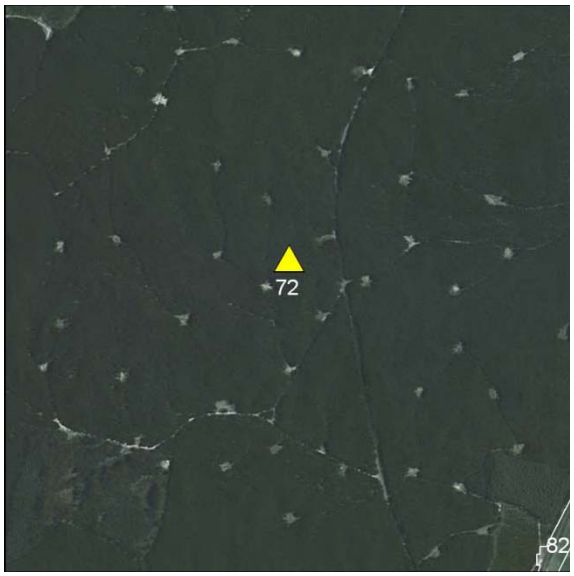
Pre-1990 planted forest

Example 2: Second rotation forest



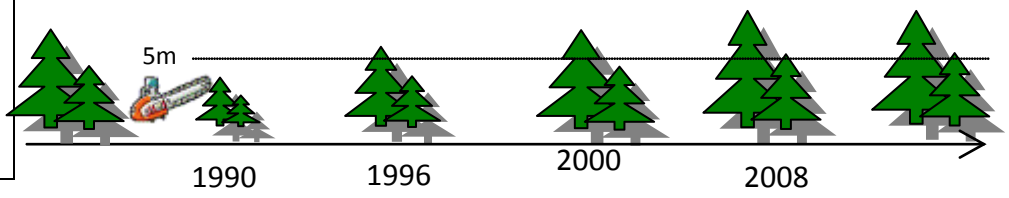






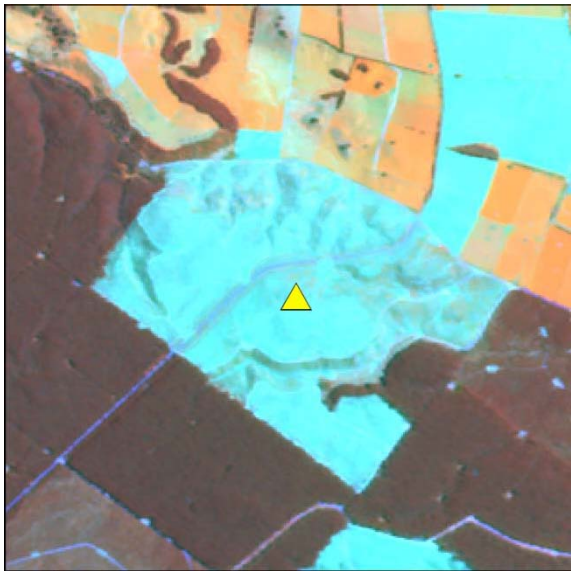
Imagery:	1990 Landsat 4 TM (upper left) 1996 SPOT 2 (upper right) 2000 Landsat 7 ETM+ (mid left) 2003 aerial photograph (mid right) 2008 SPOT-5 (lower left) SPOTMaps (lower right)
Scale:	1:30,000
Location:	Kaingaroa Forest, NZTM grid reference: 1926300, 5751550
Explanation:	Although the pale blue areas of the 1990 image in this example do not contain mature forest, skid sites are evident within the cleared area (small blue dots), which are a part of standard forestry harvesting activities. Therefore this land was in forest land use at 1990 and is classed as Pre-1990 planted forest. The slightly red tinge to the cleared area in 1990 indicates the land contains young saplings. Around six years later the 1996 SPOT-2 image confirms this: the canopy of these saplings has closed and shows the more characteristic signal for exotic forest species (in this case Radiata pine), and the land remains forested in later years through the time-series of imagery. The skid sites and tracks remain unvegetated through 1990 to 2009, but are an integral part of forestry activity, and are smaller than the minimum mapping area (<1 ha, <30 m wide), so are also classified as Pre-1990 planted forest.

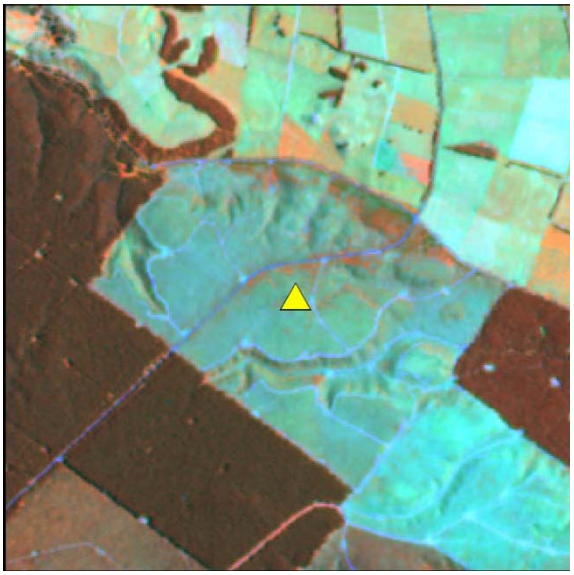
1990	2008
Pre-1990 planted forest	Pre-1990 planted forest



Pre-1990 planted forest

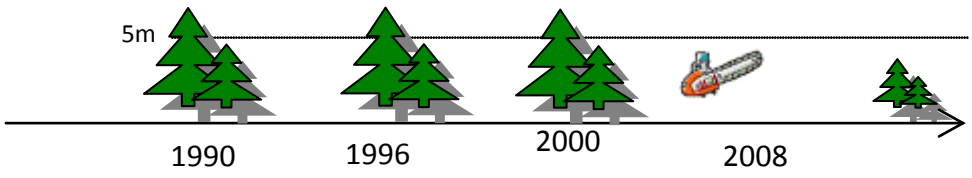
Example 3: Destocked land





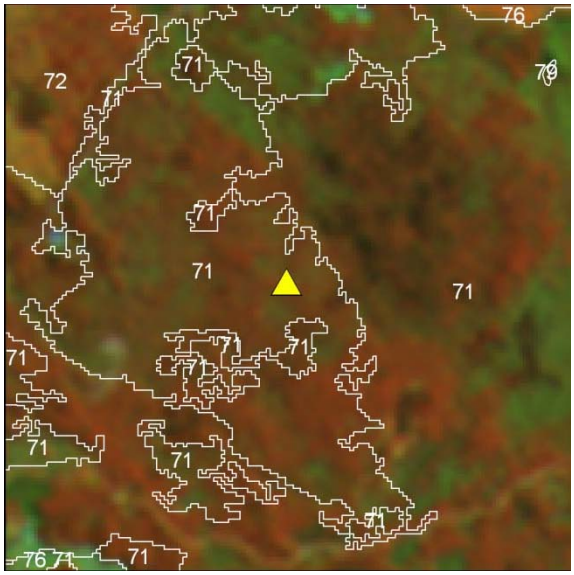
Imagery:	1990 Landsat-4 TM (upper left) 2003 aerial photograph (upper right) 2008 SPOT-5 (lower left) 2011 SPOT-5 (lower right)
Scale:	1:30,000
Location:	Kaingaroa Forest, NZTM grid reference: 1902350, 5728800
Explanation:	The Landsat 1990 imagery confirms this is pre-1990 planted forest and the land is still forested in 2003 (aerial photograph). Around 2008, the forest land was destocked, as indicated by the blue tones. The destocking activity is assumed to have been harvesting, and the land use remains as Pre-1990 planted forest, unless there is evidence to show there has been a land-use change. In this case, red tones suggesting that young saplings have been planted in the area, can been seen in the 2011 SPOT image, and later images should confirm this as the forest canopy grows and closes (see appendix 2 for examples). *Note: Destocked forest areas, as in this example, are also checked under a separate mapping exercise, which may include a site visit, to ensure they have not been deforested and converted to another land use.* See appendix 3 for examples of changes in tones in the imagery on the years after newly planted exotic forest is planted, and as the crown cover increases and closes.

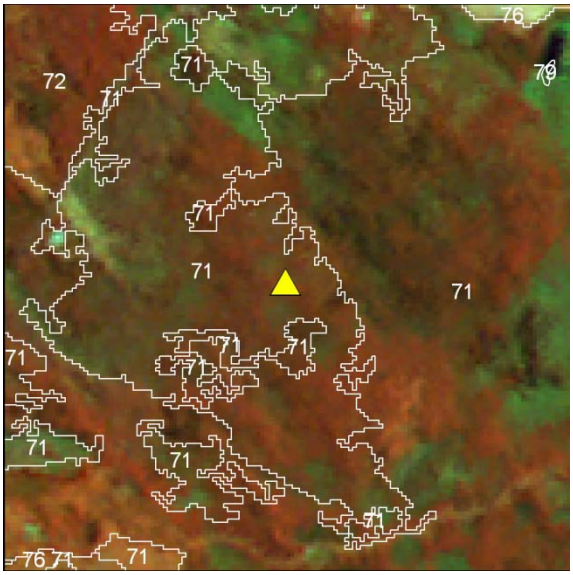
1990	2008
Pre-1990 planted forest	Pre-1990 planted forest

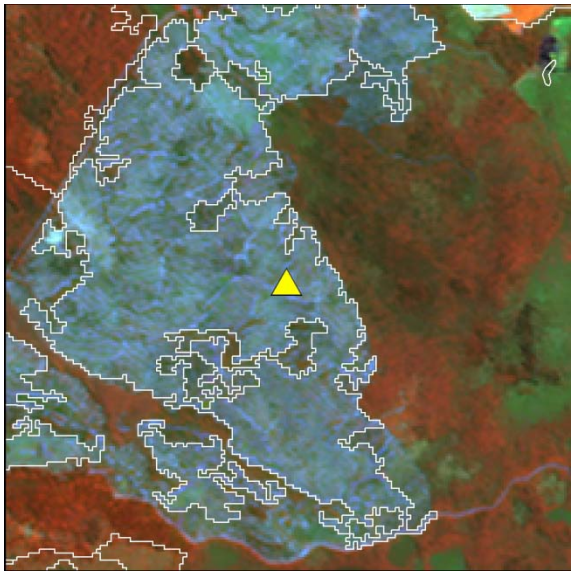


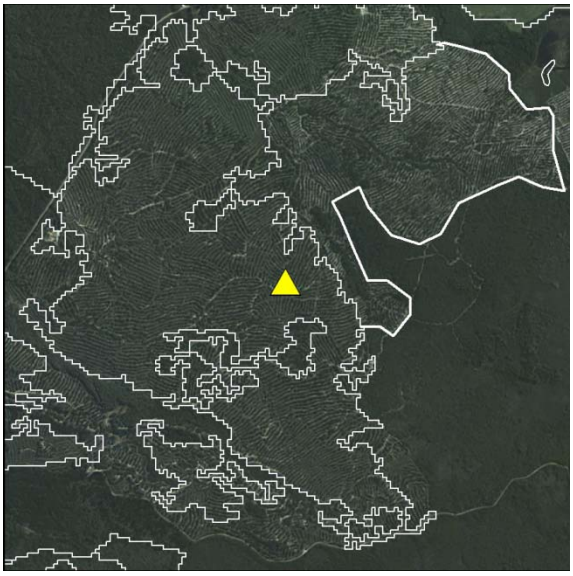
Pre-1990 planted forest

Example 4: Exotic species planted into natural forest



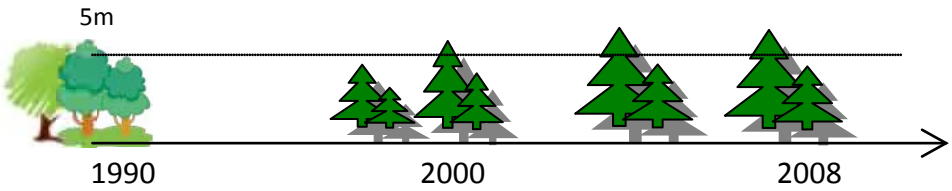






Imagery:	1990 Landsat-4 TM (upper left) 2000 Landsat-7 ETM+ (upper right) 2008 SPOT-5 (lower left) 2009 SPOTMaps (lower right)
Scale:	1:30,000
Location:	West Coast region, NZTM grid reference: 1434400, 5260400
Explanation:	The red-brown tones in the 1990 and 2001 Landsat imagery indicate the presence of broad-leaf indigenous vegetation. The indigenous forest is then cleared (light blue tones in the 2008 SPOT image) and the SPOTMaps imagery show that is has been planted in rows of exotic forest species. In this case, the area was natural forest land on 31 December 1989, but did not remain as natural forest. Although the exotic species were planted after 31 December 1989, the land was already forested, so the exotic forest cannot be classified as Post-1989 forest, which must be planted into non-forest land. The present land use is therefore classified as Pre-1990 planted forest.

1990	2008
Natural forest	Pre-1990 planted forest



Post-1989 forest
(LUC ID = 73)

All forest that meets the forest definition and that was established after 31 December 1989 onto non-forest land is classified as post-1989 forest. Generally, these forests are planted with exotic species, but may also arise from natural regeneration of indigenous tree species as a result of management change after 1 January 1990. This class also includes riparian or erosion control plantings (≥ 30 per cent cover, potentially ≥ 5 m height *in situ*) and wilding pines which have been established after 31 December, 1989.

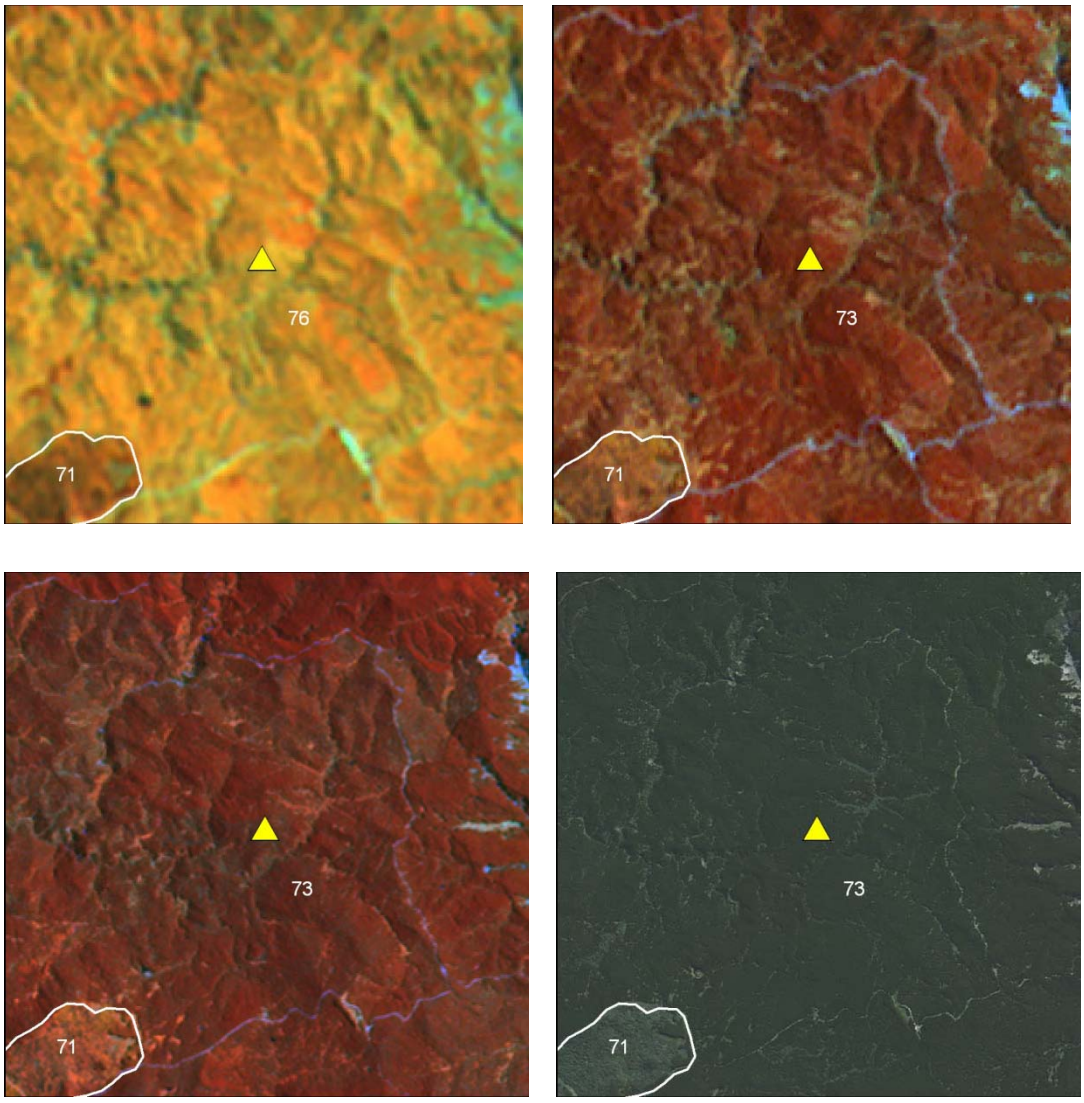
As was the case for pre-1990 planted forest, where islands of land not containing exotic forest species (1 to 5 ha in area) occur within – and are totally surrounded by – post-1989 forest, these 1 to 5 ha areas are also classified as post-1989 forest. It is assumed that the land-use management of the small, completely surrounded areas will be related to the forestry operations (ie, harvested land, skid sites etc), and thus that these small areas have the same land use.

The exception to this rule remains: if the 1 to < 5 ha areas are natural forest they will retain their land-use classification, ie, natural forest (class 71).

Young pine trees in Post-1989 forest.

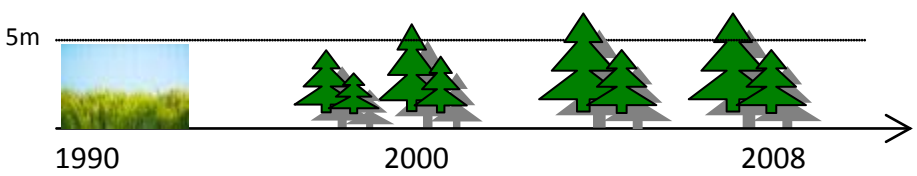
Post-1989 forest

Example 1: Exotic forest species



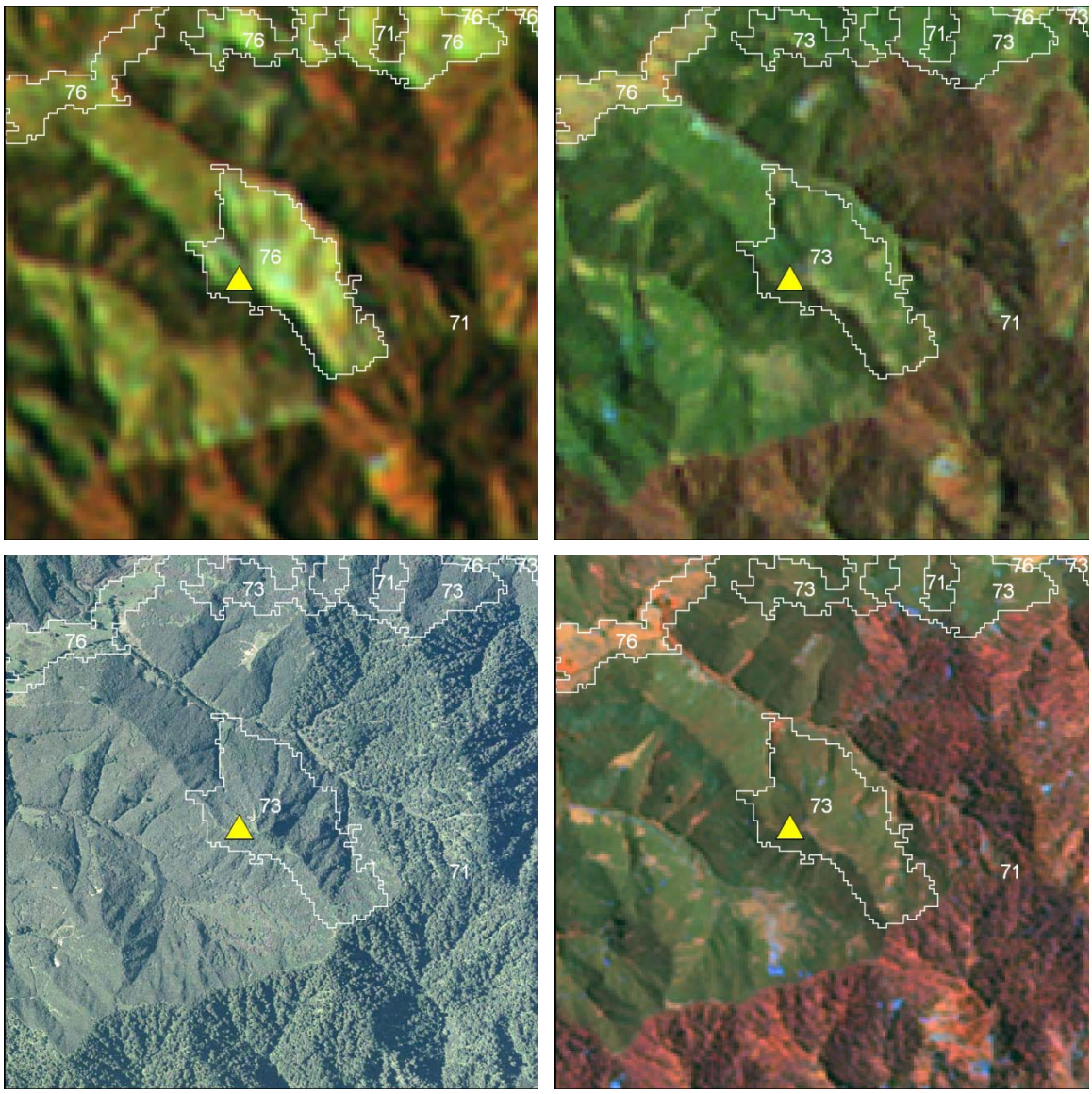
Imagery:	1990 Landsat-4 TM (upper left), 2000 Landsat-7 ETM+ (upper right) 2008 SPOT-5 (lower left), 2009 SPOTMaps (lower right)
Scale:	1:30,000
Location:	Otago region, NZTM Grid reference: 2,032,182, 5,751,940
Explanation:	At 1990, the land use is non-forest, as is evident by the yellow-orange grassland tones. By 2000, an exotic forest has been established, and has probably been established for several years (appendix 3). Bare areas associated with the forest, such as roads less than 15 m wide and skid sites, are also mapped as Post-1989 forest as they are an intrinsic part of the land-use activities.

1990	2008
Grassland	Post-1989 forest



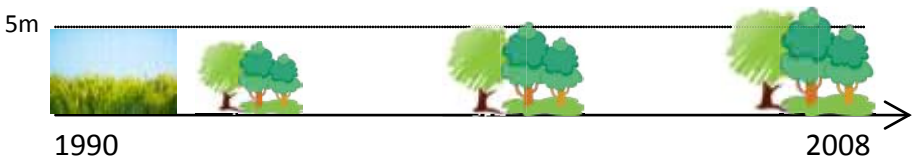
Post-1989 forest

Example 2: Regenerating Indigenous forest



Imagery:	1990 Landsat-4 TM (upper left) 2001 Landsat-7 ETM+ (upper right) 2002 aerial photograph (lower left) 2008 SPOT-5 (lower right)
Scale:	1:25,000
Location:	Taranaki region, NZTM Grid reference: 1,744,211, 5,623,869
Explanation:	The yellow-blue tones in the central portion 1990 Landsat imagery (within the white line) indicate the land was predominantly grassland at 1990. An area of established indigenous forest is present to the southeast, and the tones in the imagery suggest established, but younger indigenous forest to the northwest, with green tones indicating narrow-leafed tree species. The increasing density of vegetation cover through time is evident in the central area time-series of imagery. The reference layers confirm that indigenous species are likely to reach the forest definition under the environmental conditions in this area, and the adjacent areas would provide a seed source for indigenous species. Regenerating indigenous forest that is established after 31 December 1989 is classified as Post-1989 forest. Determining the establishment date (the point at which an adequate density of seedlings to meet the forest definition are present, and whether that point is before or after 31 December 1989) and the previous land use from this sort of imagery can be tricky. In this case, the observation has been confirmed by independent checks.

1990	2008
Grassland	Post-1989 forest

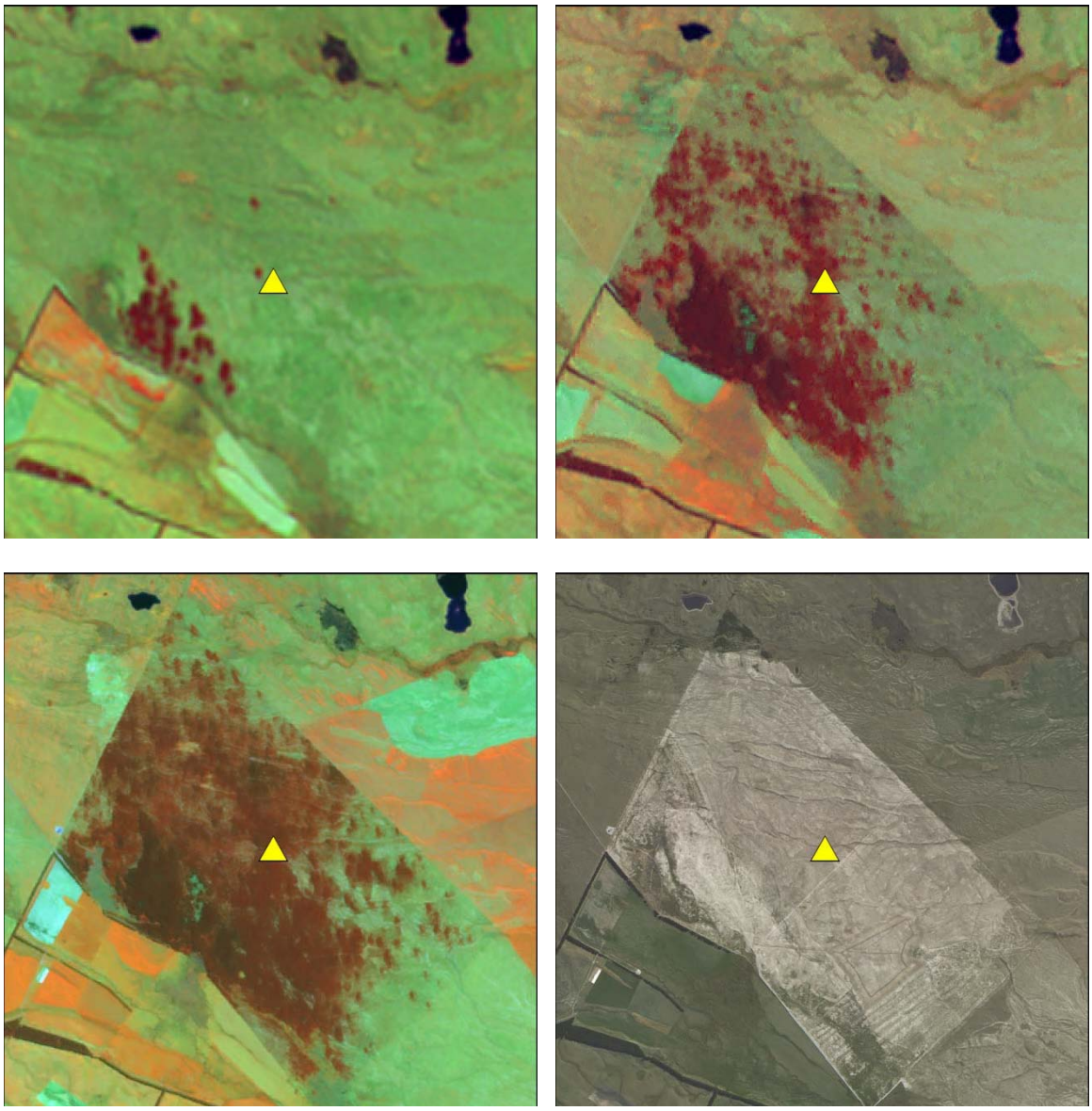


Tree Weeds
(LUC ID = 71 or 73)

Exotic species that are self-seeded and have not been actively planted, such as wilding pines, are considered weeds. They are particularly widespread through parts of the South Island, and in some wetland areas, self-sown grey willows are considered a highly-invasive pest species.

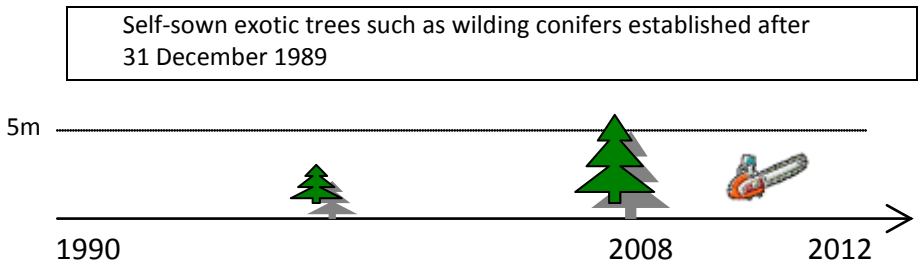
Where tree weeds meet the forest definition in area, cover and minimum height, they are classed as Natural forest or Post-1989 forest according to their establishment date.

Tree weeds
Example 1: Wilding pines established after 31 Dec 1989



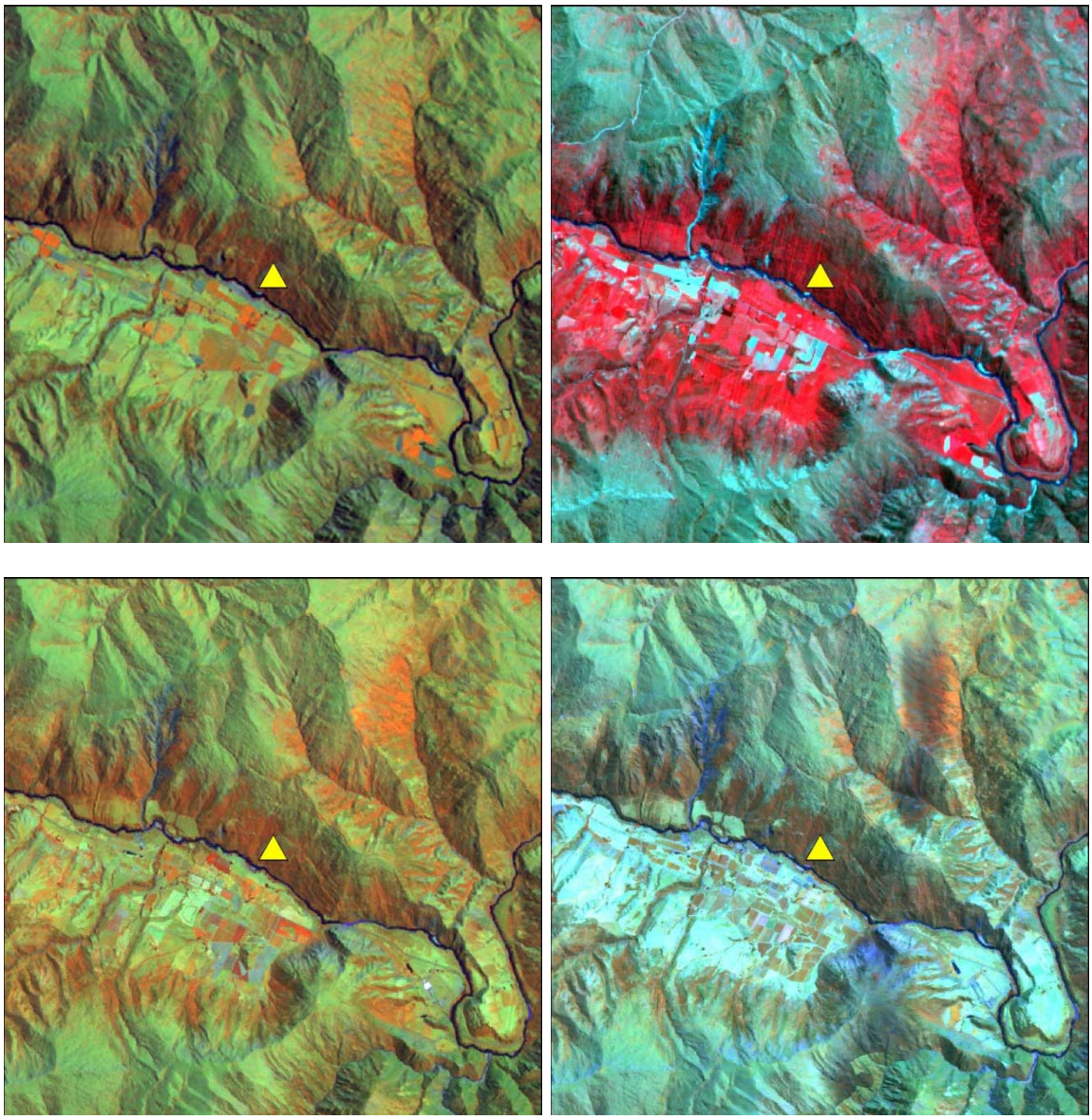
Imagery:	1990 Landsat-4 TM (upper left) 2000 Landsat-7 (upper right) 2008 SPOT-5 (lower left) 2009 SPOTMaps (lower right)
Scale:	1:30,000
Location:	Canterbury region, NZTM grid reference: 1351500, 5085500
Explanation:	In 1990, the area contains grassland adjacent to a small stand of pine trees (species unknown, but likely *Pinus nigra*, European Black pine). By 2000, the trees have seeded across the area, and by 2008 their coverage meets the forest definition across most of the land parcel, and is classed as Post-1989 forest. The 2009 SPOTMaps shows these tree weeds were subsequently controlled and removed (deforested).

LUM 1990	LUM 2008	LUM 2012
Non-forest land	*Post-1989 forest	Non-forest land



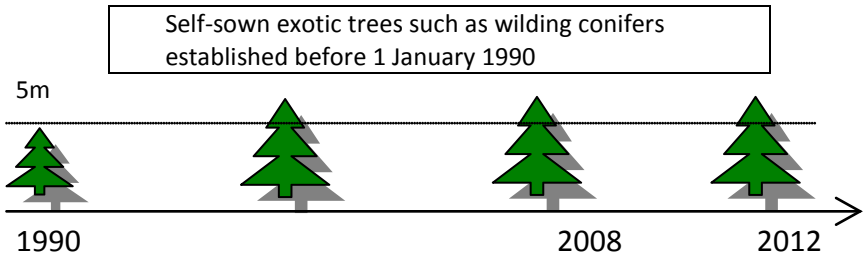
Tree weeds

Example 2: Wilding pines established before 1 Jan 1990



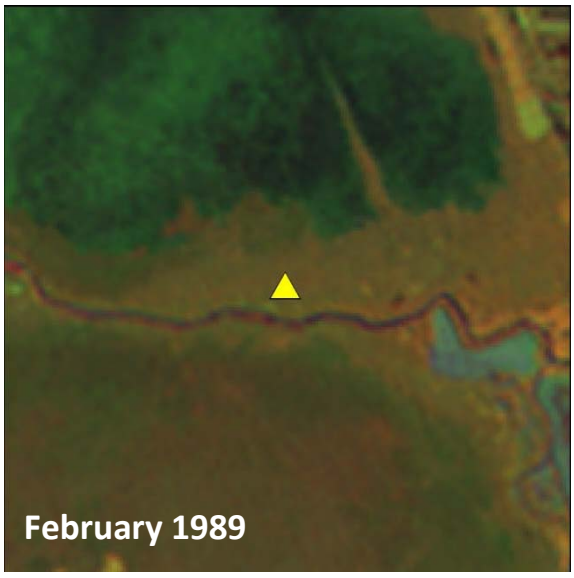
Imagery:	1990 Landsat-4 TM (upper left), 1996 SPOT (upper right) 2000 Landsat-7 (lower left), 2008 SPOT-5 (lower right)
Scale:	1:150,000
Location:	Otago region, NZTM grid reference: 1283650, 5006700
Explanation:	Douglas fir wilding trees are widespread in the Queenstown Lakes district. This time-series of images of the Gibbston valley shows the distinctive orange tones of Douglas fir (see appendix 2) were established on surrounding mountainside before 1990 and remain there at present.

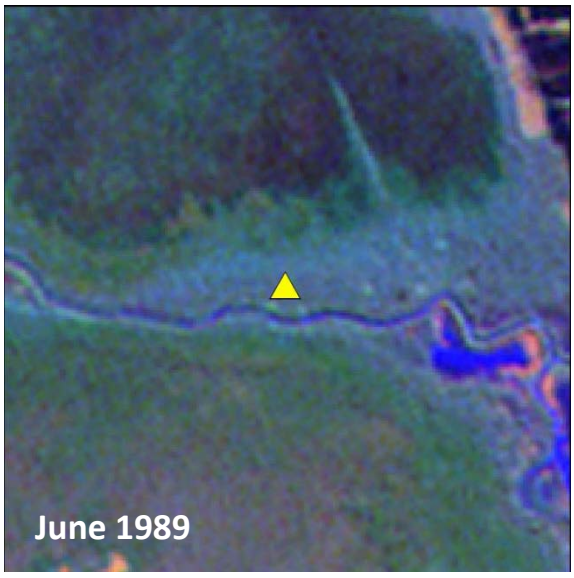
LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest

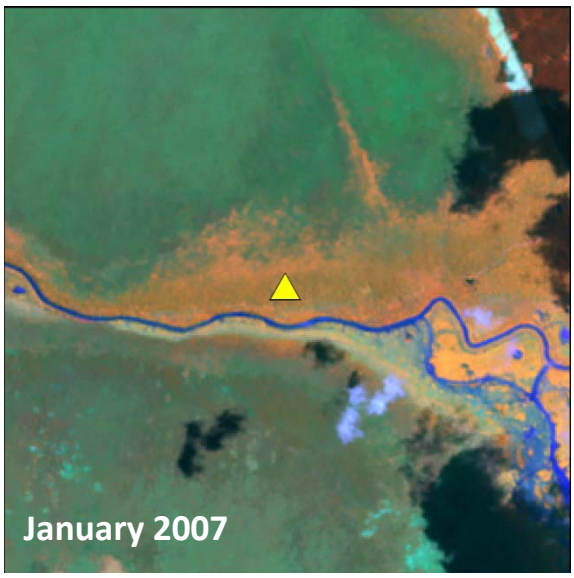


Tree weeds

Example 3: Self-seeded grey willows in wetland

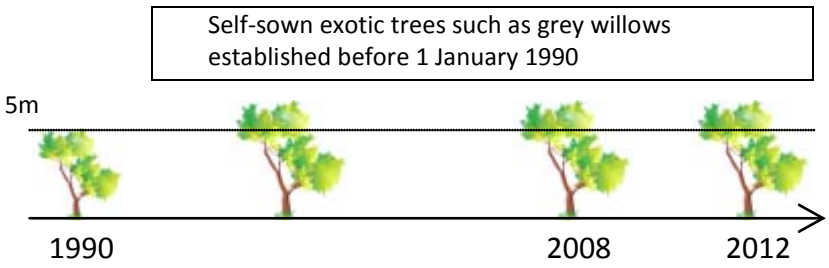






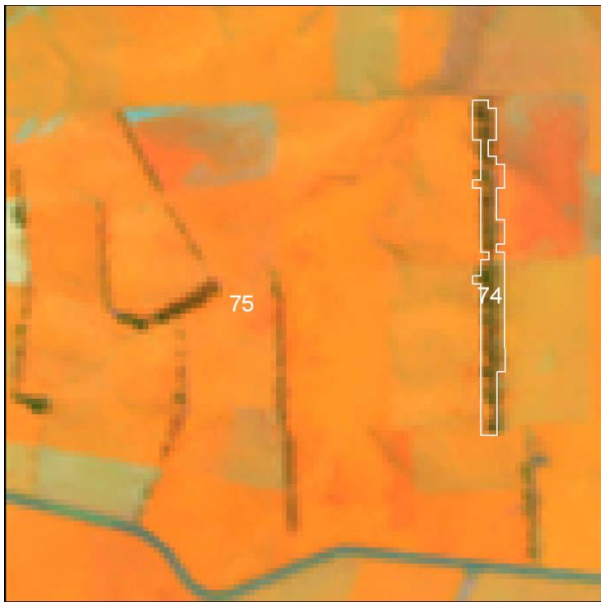
Imagery:	1990 Landsat-4 TM (upper left) 2000 Landsat-7 (upper right) 2008 SPOT-5 (lower left) 2009 SPOTMaps (lower right)
Scale:	1:40,000
Location:	Waikato region, NZTM grid reference: 1791548, 5864863
Explanation:	Grey willows are a tree weed species whose spread impacts wetland areas. In the February 1989 images, the orange shaded areas correspond to the extent of grey willows. However, in an image acquired four months later in June 1989, the satellite image tones are completely different – this is because grey willows are deciduous. This illustrates the importance of (a) using a time-series of data to determine land use, and (b) knowing acquisition date and seasonal differences in some vegetation types when interpreting imagery. In this case, the area is not classified as Wetlands – vegetated, as grey willows will reach > 5 m height and will meet the forest definition. Because they established before 1 January 1990 they are classed as Natural forest.

LUM 1990	LUM 2008	LUM 2012
Natural forest	Natural forest	Natural forest



Narrow strips of woody vegetation

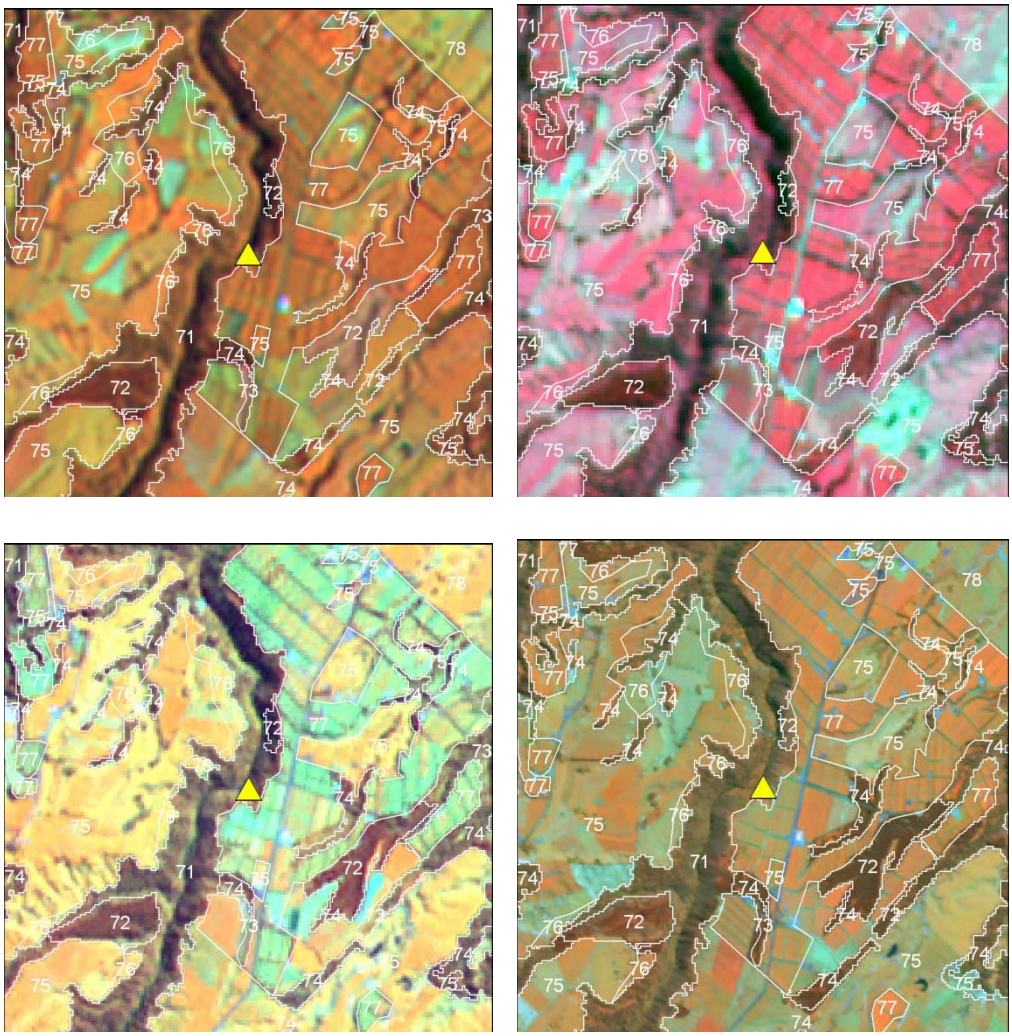
Example 1: Shelterbelts (LUC ID = 74, 75, 76, 77 or 78)



Imagery:	2008 SPOT-5
Scale:	1:15,000
Location:	Southland region, NZTM grid reference: 1288950, 4899350
Explanation:	Shelterbelts in a grassland context that do not meet or exceed the forest definition minimum area of 1 ha or 30 m average width, and do not abut forest land, are assigned to the predominant surrounding land-use class (in this case the shelterbelts on the left are assigned to land-use class '75', Grassland – high producing). If a shelterbelt exceeds the minimum area of 1 ha or 30 m average width, as in the shelterbelt on the right, its boundary is mapped and it is assigned to Grassland – with woody biomass (land-use class '74'). Where multiple shelterbelts meet, the mean width is measured from the width of the individual shelterbelts, and not the width of the network of multiple shelterbelts. Shelterbelts associated with Cropland classes (land–use classes 77 and 78) are assigned to the predominantly surrounding Cropland land use.

Narrow strips of woody vegetation

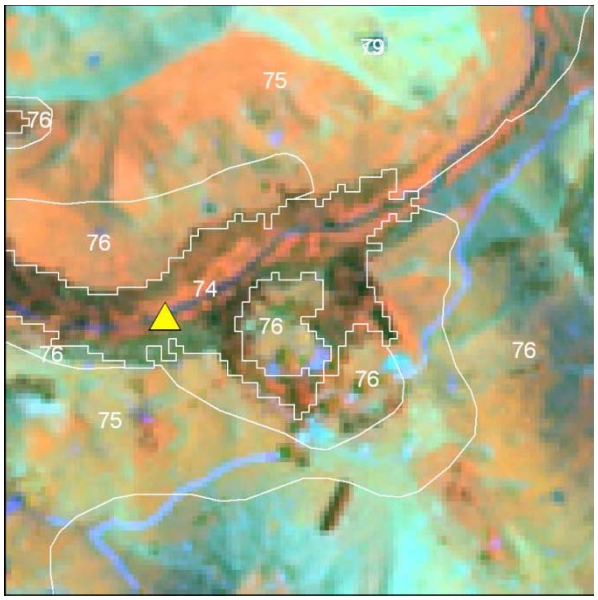
Example 2: Riparian zones and gullies (LUC ID = 71, 72 or 74)



Imagery:	1990 Landsat-4 (upper left), 1996 SPOT-2 (upper right) 2000 Landsat-7 ETM+ (lower left), 2008 SPOT-5 (lower right)
Location:	NZTM grid reference 1890409, 5803484
Scale:	1:40,000
Explanation:	The time-series of imagery shows that the incised gully in the centre of this image is fenced off and managed differently to the flat terraces where the land use is either cropland (kiwifruit) or grassland – high producing. The vegetated area is wider than 30 m, greater than 1 ha in size, has nearly 100 per cent canopy cover, and is composed of tree species that have not been planted and will exceed 5 m in height, so it is classified as Natural forest. To the east, another gully has been planted in exotic species, as denoted by the redder tones relative to the natural forest. The area meets the forest definition, and the trees were established before 1 January 1990, so is classified as Pre-1990 planted forest.

Narrow strips of woody vegetation

Example 3: Grassland with woody biomass in riparian zones



Imagery:	2008 SPOT-5
Scale:	1:15,000
Location:	NZTM grid reference 2011450, 5725550
Explanation:	The woody vegetation along this waterway has < 30 per cent crown cover throughout the time-series from 1990 to 2009. (Note: aerial photography confirms that the orange tones are not grey willows.) The area is wider than 30 m, greater than 1 ha in size, but it is located within a grassland/potentially grazed environment, and its diffuse margins suggest it has not been fenced off or managed differently. The area looks unlikely to reach the forest definition in the near future. Grassland – with woody biomass (land-use class: 74).

Cropland – Perennial
(LUC ID = 77)

Crop trees, such as apple, avocado and nut orchards, are mapped as the land use: Cropland – perennial (LUC_ID = 77), which includes all orchards, vineyards and the linear shelterbelts associated with this land-use activity.

During the production of the 2008 LUM layer, the cropland classes were not mapped from the satellite data: the LCDB2 layer was used to locate perennial cropland, and the 2008 land-use mapping was later updated and improved using the Agribase spatial database.

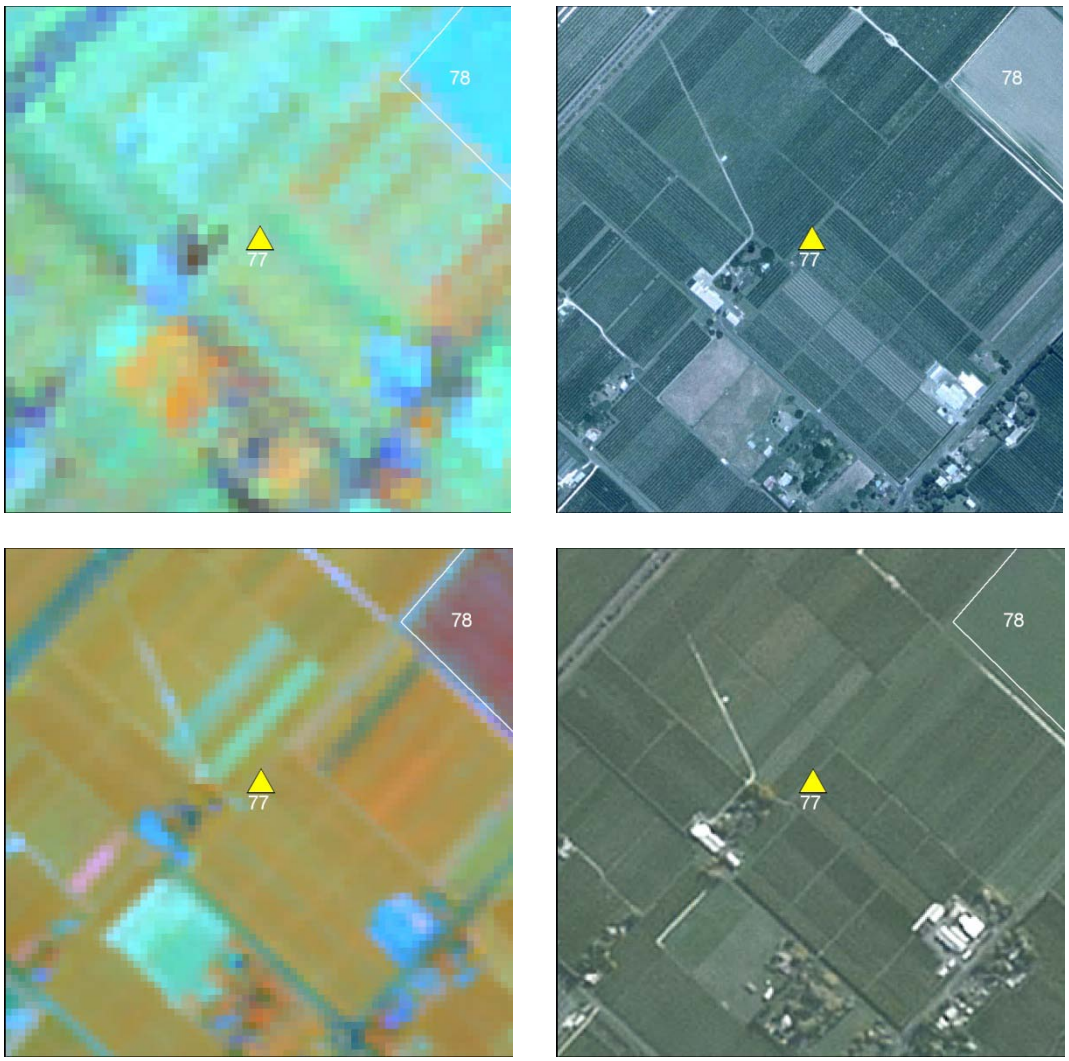
The 2008 LUM layer will be further improved with perennial cropland mapping from LCDB3 as part of the 2012 Land Use Mapping project. Further areas of perennial cropland, appearing for the first time in 2012 satellite imagery, will be mapped into the 2012 Land-use Map based on the boundaries evident in satellite imagery.

The woody component of trees in orchards is distinctive in the imagery from that of natural forest and planted forest, as the following example shows.

Ascension Wine Estate, Auckland.

Cropland – perennial

Example 1: apple orchards



Imagery:	2000 Landsat-7 ETM+ (upper left), 2004 aerial photograph (upper right), 2008 SPOT-5 (lower left), 2009 SPOTMaps (lower right)
Scale:	1:10,000
Location:	Hawke's Bay, NZTM grid reference: 1928250, 5602650
Explanation:	The tones in the 2008 SPOT false-colour composite are orange, in this case more similar in tone to broad-leaf natural forest than the exotic pine species we have reviewed in earlier examples, but paler. Orchards are generally organised in elongated, parallel blocks that are visible in both satellite imagery and aerial photography. The rows of individual trees are visible in most aerial photography. Note the difference in the spectral signature in the 2000 Landsat image: this image was acquired in Spring (September). Apple trees are deciduous, and in Winter/Spring when the branches are relatively bare of leaves, the signal from the underlying ground dominates.

References

Dymond JR, Shepherd JD, Qi J. 2001. A Simple Physical Model of Vegetation Reflectance for Standardising Optical Satellite Imagery. *Remote Sensing of Environment*. 37: 230–239.

Dymond JR, Shepherd JD. 2004. The spatial distribution of indigenous forest and its composition in the Wellington region, New Zealand, from ETM+ satellite imagery. *Remote Sensing of Environment* 90: 116–125.

Eyles GO. 1977. NZLRI worksheets and their applications to rural planning. *Town Planning Quarterly* 47: 38–44.

IPCC (Intergovernmental Panel on Climate Change), 2003. Penman, J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe K, and Wagner F (Eds.). Good Practice Guidance for Land Use, Land-use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme. Published for the IPCC by the Institute for Global Environmental Strategies: Tokyo, Japan.

Ministry of Agriculture and Forestry (MAF), 2011. National Exotic Forest Description as at 1 April 2010, 66 p.

Ministry for the Environment, 2006. New Zealand's Initial Report under the Kyoto Protocol.

Newsome P, Shepherd JD, 2009. Establishing New Zealand's Kyoto Land Use and Land-Use Change and Forestry 1990 Baseline Map, Landcare Research Contract Report LC0809/103, 27 p.

Newsome P, Shepherd JD, Meurk C, Smale M, Sutherland A, Heke H, Willoughby J, 2011. 2012 Kyoto Land Use Mapping Pilot – Regional image mosaics, environmentally limiting factors, tree-line assessment, and trial land-use mapping, Landcare Research Contract Report LC 833, 33p.

Payton J, 2007. Distinguishing "grassland" from forest land" on public land managed for conservation where above-ground woody biomass is present, Landcare Research Contract Report: LC0607/120

Pratt J. 2007. LUCAS Project Glossary.

Shepherd JD, Dymond JR. 2003. Correcting satellite imagery for the variance of reflectance and illumination with topography. *International Journal of Remote Sensing* 24: 3503–3514.

Shepherd JD, Newsome P. 2009. *Establishing New Zealand's Kyoto Land Use and Land-use Change and Forestry 2008 Map*. Landcare Research Contract Report LC0809/133, 34 p.

Thompson S, Grüner I, and Gapare N. 2003. New Zealand Land Cover Database Version 2 Illustrated Guide to Target Classes. Ministry for the Environment, Wellington.

Trotter C and Mackay A. 2005. Contract 04/05-0410-L: Potential Forest Land, an Interim Report, Contract report for Ministry for the Environment.

Trotter C, Shepherd J, Belliss S, Berben P, Newsome P, Sutherland A, Willoughby J, and Lynn I. 2008. Determining the area of change in Kyoto-related land cover between 1990 and 2000, Landcare Research contract report LC0708/162

Appendix 1

Characteristics of satellite imagery

The LUCAS land-use mapping relies on data from instruments on board a number of satellites, listed here in table I-i. This appendix provides further background information for operators making visual interpretations from this guide but who may be non-specialist in the technical aspects of remote sensing.

Table I-i National satellite imagery datasets used to map and validate land use

Time period	Satellite	Notes
c. 1990 (1989–1993)	Landsat-4 & -5	Some gaps in coverage infilled with SPOT data
1994–2009	Aerial photography	Various scales, panchromatic and true colour imagery, coverage of most of New Zealand during this period at various dates
c. 1996 (1996–7)	SPOT 2 & 3	
c. 2001 (2000–2003)	Landsat-7	
c. 2008 (2006–2008)	SPOT-5	Acquired during two summer seasons Oct–Mar inclusive
2008–9	SPOTMaps	
2009	DMC	Acquired in the summer of 2009–10
2010–2011	SPOT-5	Selected regions imaged; not a national dataset
c. 2012 (2011–2013)	SPOT-5	Planned acquisition over two summer seasons Oct–Mar inclusive

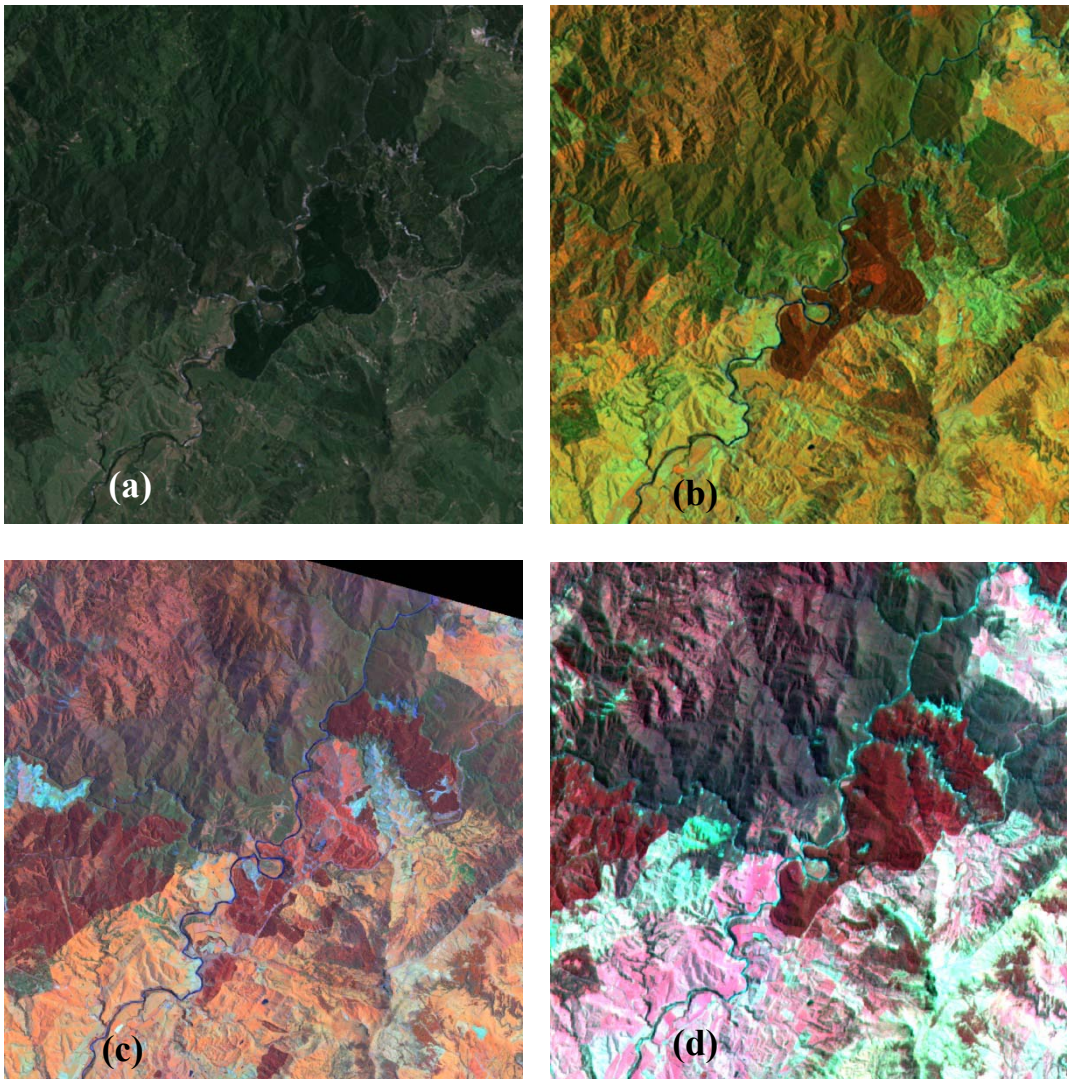
The instruments on board these satellites capture the imagery in discrete sections of the visible and infrared range of the electromagnetic spectrum (termed bands). The satellite sensor imaging specifications are shown in table I-ii.

Table I-ii Satellite sensor specifications

Band	Landsat 4 & 5	SPOT-2	Landsat-7	SPOT-5	SPOTMaps product	DMC	Wavelength (µm)
Blue-green	Band 1		Band 1		"Natural colour"		0.45 – 0.52
Green	Band 2	B1	Band 2	B1		Green	0.50 – 0.60
Red	Band 3	B2	Band 3	B2		Red	0.61 – 0.69
Near infrared	Band 4	B3	Band 4	B3		NIR	0.76 – 0.90
Mid infrared (short-wave IR)	Band 5		Band 5	B4			1.55 – 1.75
Mid infrared (short-wave IR)	Band 7		Band 7				2.08 – 2.35
Thermal IR (long-wave IR)	Band 6		Band 6				10.40 – 12.50
Resolution (m)	30	20	30	B1-B3: 10 B4: 20	2.5	22	
Post-processing resolution (m)	15	N/A	15	10		22	
LUCAS data holdings	1989–1993	1996–1997	1999–2003	2006–2008 2010–2013	2008–2009	2009–2010	

Obtaining infrared data is advantageous as infrared wavelengths can be more sensitive to certain surface features, and the imagery can be displayed to enhance features that may not be readily apparent in the visible spectrum. Different image band combinations are assigned to the red, green and blue outputs projected on the computer monitor. The image that results from displaying these band combinations is called a false-colour composite (figure I b, c and d).

Figure I Example of satellite sensor band combination and false-colour composite



In Figure I (a), the Landsat-5 image (1990) displayed in “true colour” ie, as the human eye would see this area. The false-colour composite of the same Landsat-5 image in figure I (b) picks up the differences in land cover more clearly than the true colour image. The SPOT-5 image (2008) in figure I (c) is displayed in the equivalent band combination to (b) but has a finer pixel resolution so is more detailed.

The Landsat and SPOT-5 data in the imagery examples given in this document are displayed in the NIR-SWIR-Red (as red-green-blue in the computer monitor) false-colour composite. This band combination is well-known for maximising the contrast between areas containing woody and non-woody vegetation cover.

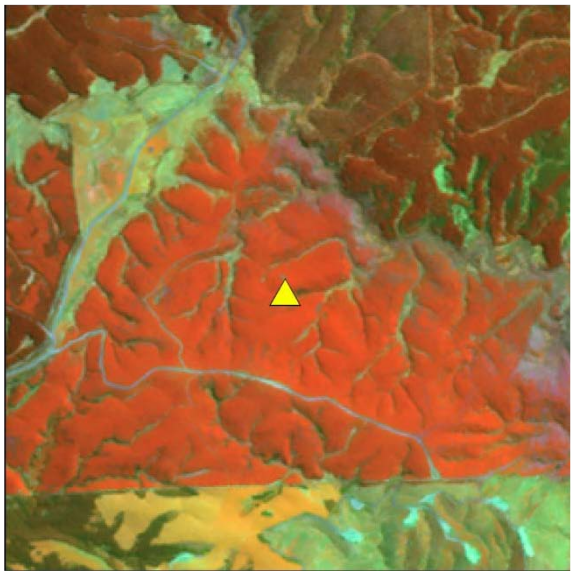
Figure I (d) shows a SPOT-2 image (1996): this instrument has three bands and lacks band at the SWIR wavelengths (table I-ii), it is displayed here in a 1-2-3 band combination.

Appendix 2

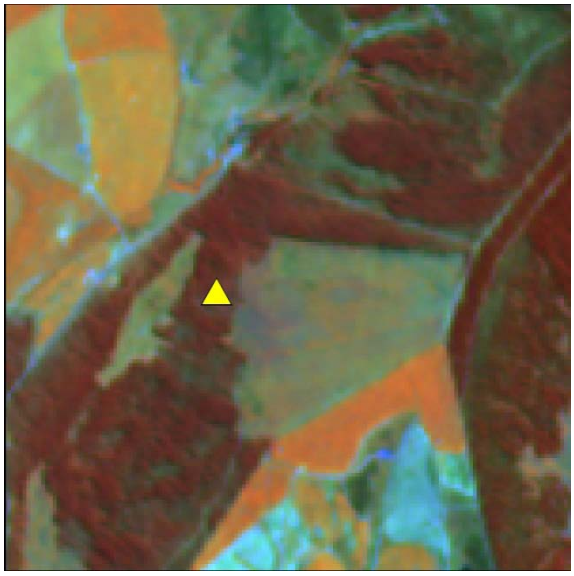
Spectral signatures of exotic forest species common in New Zealand

The planted forest examples given in the main body of this guide are largely *Pinus radiata* forest, as this species presently accounts for ~89.5 per cent of exotic planted forest species in New Zealand (MAF 2011). The remaining exotic planted forest consists of Douglas fir (~6.5 per cent), various eucalypts (~1.5 per cent), various Cypress species (~0.5 per cent), and other hardwoods and softwoods (~2 per cent).

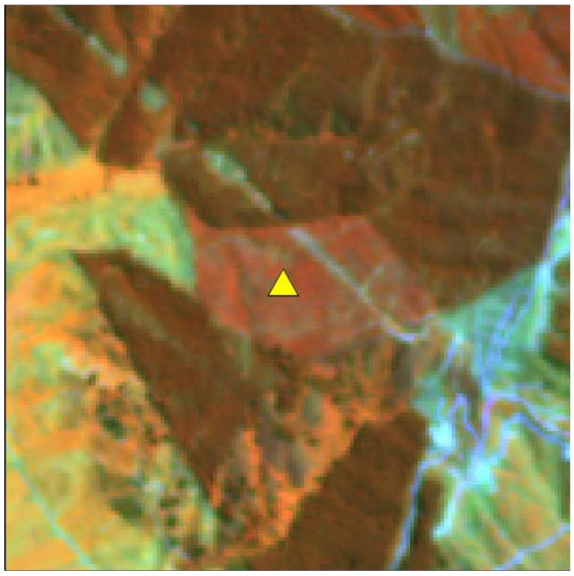
Here, examples are provided to show how some of these species appear in SPOT-5 false-colour composite images.



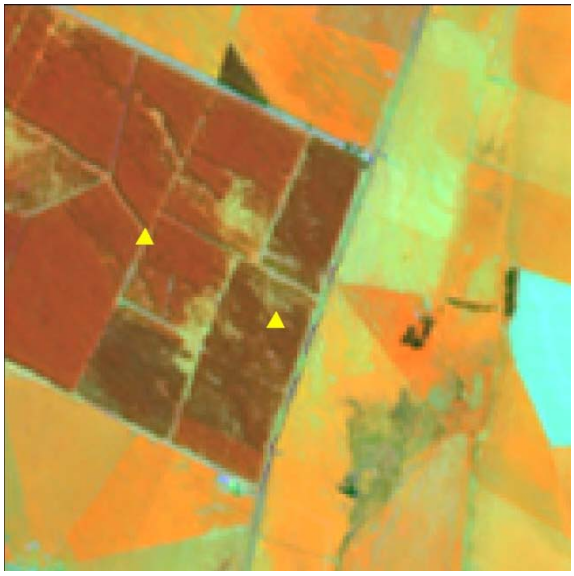
Douglas fir *(Pseudotsuga menziesii)*



Eucalypts (tones slightly pinker than *radiata*)



Mexican cypress (*Cypressa lucitanica*)

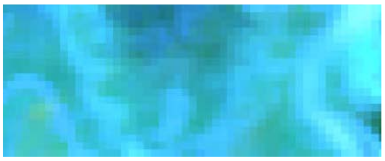


On left: Douglas fir
On right: Macrocarpa (*Cupressus macrocarpa*)

Appendix 3

Canopy closure of *Pinus radiata* observed in SPOT-5

Note: These SPOT-5 image tones are *indicative* only, as: (a) the rate of canopy closure in an area can vary depending on local environmental conditions and stocking density, (b) tones vary between satellite images according to imaging angle, land slope and aspect, and sun angle at acquisition time, and (c) the management of the forest in the first years can impact how the area appears in the satellite data (eg, thinning, undergrowth release management).

Central North Island		Tasman Region	
Forest age	**SPOT-5**	**Forest age**	**SPOT-5**
0.5 years		0.5 years	
1.5 years	No image available	1.5 years	No image available
2.5 years		2.5 years	
3.5 years		3.5 years	
4.5 years	No image available	4.5 years	No image available
5.5 years		5.5 years	
6.5 years		6.5 years	
7.5 years		7.5 years	
8.5 years		8.5 years	

Appendix 4
Environmental limiting factors reference layer

The environmental limiting factors (ELF) reference layer was created by Landcare Research to provide guidance on areas where the local environmental conditions are likely to prevent shrubland reaching forest definition in a 30–40 year timeframe.

Because of the variability in detail and accuracy of the spatial layers which were used to construct the ELF layer, it should only be considered as a guide in land-use classification. There may be situations where imagery evidence contradicts the ELF layer and indicates the presence of forest in a zone of limitation. In these instances the imagery evidence should be considered authoritative.

The following description of the environmental limiting factors reference layer is reprinted from Newsome *et al*. 2011.

The object of this work was to create a geographic layer identifying a set of environmental conditions that would inhibit growth of newly-established woody vegetation to 'Forest' (defined as greater than 30 per cent cover of trees of 5 m height) within a 30–40 year timeframe.

Drivers of forest exclusion

Our approach was to examine the limiting conditions for forests or tall woody vegetation, across the major environmental gradients of temperature, moisture availability, edaphic conditions, coastal exposure and land instability. Soils and underlying geology are generally surrogates for major thresholds in these factors. These factors are inevitably mixed so, for simplicity, we have examined them one by one and defined reproducible conditions for each environmental factor.

These conditions have been matched against pre-existing databases of soil, climate, topography and land cover to produce a geographic layer of environmentally limiting factors for forest growth (ELF). In the following assessments, we exclude biotic considerations such as herbivory, competition, external gene pools, availability of seed sources and dispersers, etc, and also fire.

Temperature

Too cold

Upper forest boundary

The standard relationship of tree line with temperature, both abroad and in NZ, is an approximate coincidence with a 10ºC mid-summer isotherm. However, it has long been recognised by Wardle (1985) and others (Meurk 1984) that tree line conditions in oceanic New Zealand were more benign, with longer growing seasons, than those of continental montane regions. Wardle coined the term pen-alpine to cover the area above our indigenous tree line occupied by tall tussock and scrub – corresponding to continental sub-alpine environments. This discrepancy is also apparent in the experiments done by Wardle on plant growth of both native and exotic species on the Craigieburn Range. He demonstrated progressive height growth of exotic conifers and eucalypts up to 300 m above the natural tree line.

Indigenous tree limit ranges from about 1600 m in the north to 750 m on Stewart Island, 100 m on sheltered parts of the Auckland Islands and 25 m on Campbell Island. However, this is dependent on the definition of 'tree' which Meurk (1984) set as 2.5 m to reflect the tree height at actual beech tree lines.

Nonetheless, trees attain 5 m height only a short distance below these boundaries. A review of evidence regarding tree line and its climatological determinants is currently being carried out by Ellen Cieraard, Matt McGlone and Janet Wilmshurst of Landcare Research (pers. comm. Colin Meurk).

As an aid to classification in the LUM, a reference tree line layer was created from the New Zealand Land Cover Database version 2 (LCDB2). This layer simply comprised the classes: Alpine gravel and rock, Permanent snow and ice, Alpine grass/herbfield, Tall tussock grassland, Sub-alpine shrubland.

The upper required boundary for this condition is the regional line at which indigenous trees can attain 5 m height within 30 years. Notwithstanding usual sigmoid growth curves this equates to an annual vertical growth rate of about 16 cm. This will be some distance below the indigenous tree limit. Based on scanty information derived from Wardle (1985), we can calculate that annual height increments of mountain beech (the highest potential, native tree line species in New Zealand) just below tree line are 5–6 cm, and at 1100 m (some 210 m below the local tree limit) are 17 cm, the canopy also being at least 5 m height at that elevation.

On the basis of this we propose a "Forest boundary" line at 225 m below the "Tree limit boundary". The processing rule to delineate this condition is:

The near tree limit line is defined to be 225 m below the LUM reference tree line layer.

In practice, it was discovered that the LUM reference tree line layer was both too discontinuous and inaccurate in many respects to support this condition without intervention. The problems originate from the inclusion of red tussock (*Chionochloa rubra*), a temperate/montane species in the tall tussock class and the variable mapping of the LCDB, which includes widespread inclusion of sub-alpine/alpine classes at lower elevations. To reduce this problem, tall tussock grassland and obvious low-elevation outliers were removed from the defining LUM reference tree line layer before processing.

Frost flat boundary

There are almost no thermally inverted tree lines in New Zealand that are not compounded by other factors such as water-logging of substrates, fire history, climatic or edaphic aridity, acidity and physical disturbance effects of valley floor river flooding. The only detailed frost flat descriptions are by Smale (1990) and Smale et al (2011). Circumscription of the critical conditions preventing tree growth can only be approximated. For instance, they report up to 230 ground frosts per year and extreme ground temperatures of –15.8 º C (June) and –7.5 º C (December). It is generally the rare extreme events that stall successional development.

The controlling criteria for a 'frost flat hollow' forest exclusion zone were determined to be:

- inter-montane hollows/depressions/plateaux above 700 m in Central Volcanic Plateau or 500 m in South Island – and
- with > 200 ground frosts per year including at least one in December/January of < –5C and –15C in winter over a 10 year period – and
- annual rainfall < 700 mm in South Island
- flat topography.

Such sites are likely to be found in hollows where severe cold air drainage can occur – above 700 m in the North Island and above 500 m in the South Island. Such places are referred to as frost flats (North Island) or inter-montane basins (South Island). The processing rules to delineate these conditions are:

South Island inter-montane basins were compiled from two rasters satisfying the conditions:

- sites > 500m elevation from Landcare Research's 15m Digital Elevation Model
- sites with > 200 ground frosts per year from Landcare Research's 100m frost free days layer (pers. comm. John Leathwick).

North Island frost flats were manually drawn by Mark Smale from field sheets and field knowledge and then digitised.

Too hot

Geothermal areas

Elevated substrate temperature is the main factor excluding forest from geothermal sites (Burns 1997). Non-forested geothermal vegetation was mapped for all significant sites in the Waikato Region by Wildland Consultants (Wildland Consultants 2005) and in the Bay of Plenty Region by Landcare Research (Fitzgerald & Smale 2010). This condition has also been studied by Burns (1997).

Given this considerable resource is already existing, the processing rule to delineate this condition was:

Geothermal area mapping owned by Environment Waikato and Environment Bay of Plenty were obtained and incorporated into the ELF layer.

Moisture

Too dry

There are almost no situations in New Zealand where there is inadequate moisture per se for forest growth at rates exceeding 5 m in 30–40 years, unless there is also edaphic dryness exacerbating the low rainfall. Semi-arid soils and those free-draining Raw or Recent soils in low rainfall situations is the sort of situation that would limit growth to forest stature in a 30–40 year period.

The processing rule to delineate this condition was:

Areas too dry to support growth to forest in 30–40 years were those satisfying the following conditions in two layers held by Landcare Research:

- from Landcare Research's Fundamental Soils Layer, sites with New Zealand Soil Classification of 'S' (Semiarid), or 'WX' (Rocky Raw), or 'RXA' (Acidic Rocky Recent) or 'RXT' Typic Rocky Recent) and
- from Landcare Research's 100 m mean annual rainfall layer (pers. comm. John Leathwick), sites with < 800 mm rainfall per annum (North Island) or < 600 mm rainfall per annum (South Island).

Too wet

Wetlands have been comprehensively mapped in a desktop modelling and mapping study by Ausseil et al (2008) commissioned by the Department of Conservation. This spatial database arising from this work is known by the acronym WONI (Waters of National Importance). Of these, the sites whose conditions would be limiting on growth to forest stature were determined to be those on organic soils, not already supporting forest vegetation.

The processing rule to delineate this condition was:

Areas too wet to support growth to forest in 30–40 years were those satisfying the following conditions in the WONI database held by Landcare Research:

- the vegetation field does not contain any of the forest classes (VEG does not contain 'n' or 'N') and
- the field NZSC is true for organic soils (NZSC first character = 'O').

Soil/Edaphic limitations

Gumlands

Gumlands are shrub-covered, flat to rolling land in northern New Zealand, which have deposits of kauri gum. Soils are strongly leached (mostly podzols), derived from deeply weathered old consolidated sands, sandstones and claystones. They are very infertile, acidic, seasonally waterlogged, and mostly have a thin siliceous topsoil (sometimes with peat) above a slowly permeable or cemented horizon.
Gumlands cannot be identified solely from soil mapping, but can be drawn by hand from personal knowledge so the processing rule to delineate this condition was:

Gumlands were manually drawn by Mark Smale from field sheets and field knowledge and then digitised.

Pakihi

Pakihi are a type of wet heath occurring on the west of the South Island where they are widely scattered, particularly on old outwash gravels characterised by very infertile soils with an impervious horizon and little or no peat. In South Westland, pakihi have developed as a result of natural processes of inundation of soils where there is impeded drainage combined with soils becoming very infertile as a consequence of developing in areas of very high rainfall. These soils are too infertile to support closed forest. Pakihi-type vegetation, as occurs in northern Westland, has also been induced by human fire.

Much of this area will overlap with wetlands in WONI but a specific processing rule to delineate this condition was:

Pakihi heathlands that will not support growth to forest in 30–40 years were extracted from the WONI database held by Landcare Research as those sites where wetland type equals Pakihi (WLTYPE=1)

Podzols

Podzol soils are strongly acid soils that usually have a bleached very infertile horizon immediately beneath shallow topsoils. This bleached horizon is the source of aluminium and iron oxides that have accumulated, in association with organic matter, in an underlying dark or reddish coloured horizon often forming a consolidated pan that impedes drainage and further inhibits plant growth.

The processing rule to delineate this condition was:

Podzol soils that will not support growth to forest in 30–40 years were extracted from the New Zealand Fundamental Soil Layer and New Zealand Land Resource Inventory as sites where the New Zealand Soil Classification Order equals Podzol (ORDER='Z') and vegetation does not contain forest (VEG does not contain 'n' or 'N').

Ultramafic

Ultramafic rocks contain very little quartz or feldspar and are composed essentially of ferromagnesium silicates, metal oxides and native metals. They form soils with low concentrations of major nutrients and high concentrations of toxic metals such as nickel, chromium and cobalt. These soil conditions result in vegetation that is often characterised by stunted, slow growing, small-leaved trees and shrubs.

The processing rule to delineate this condition was:

Ultramafic areas that will not support growth to forest in 30–40 years were extracted from the New Zealand Land Resource Inventory as sites where the rock is identified as ultramafic (ROCK contains 'Um').

Saline soils

Saline soils are not extensive in New Zealand but occur in coastal estuarine situations and rarely as salt pans in areas where in the absence of leaching, soluble salts have accumulated to such an extent that they are moderately to highly alkaline (pH > 7). In the latter instance, the salts are derived from ancient marine or lake sediments or deeply-weathered schist and they accumulate in low-lying flattish areas. Salt pans can often be identified by the presence of a grey-white crust on the surface of seemingly bare ground and vegetation that is often characterised by stunted, slow growing, small-leaved trees and shrubs.

These areas tend to be small in individual (and aggregate) area and so are generally under-represented on maps. Nonetheless, the processing rule to delineate this condition was:

Saline soils that will not support growth to forest in 30–40 years were extracted from the New Zealand Land Resource Inventory as sites where the dominant New Zealand Soil Classification is identified as Mottled Fluvial Recent Soils (RFQ), or Mottled-saline Fluvial Recent Soils (RFMQ), or Fluid-saline Gley Raw Soils (WGFQ) or Saline Gley Raw Soils (WGQ).

Salt/coastal exposure

Very few spatial databases exist to map coastal exposure which involves a complex interaction between proximity and exposure to the sea and prevailing wind direction and speed. This condition is exacerbated by unstable and shifting sands that militate against plant establishment and growth.

The processing rule to delineate this condition was:

Areas likely to have a salt exposure condition that might mitigate against growth to forest in 30–40 years were those satisfying the following conditions in four layers; median annual wind speed (obtained from NIWA), the New Zealand coastline (obtained from LINZ, InfoMap 260 data), the New Zealand Fundamental Soil layer, 100 m mean annual rainfall layer (pers. comm. John Leathwick), and a bare ground classification extracted from Landcare Research EcoSat mapping.

These data were combined where they satisfied the following conditions:

- median annual wind speed <4m/s and distance to sea <250m OR
- median annual wind speed >4 and <6m/s and distance to sea <500m OR
- median annual wind speed >6m/s and distance to sea <1000m OR
- New Zealand Soil Classification is windblown sand and distance to sea <1000m and mean annual rainfall < 1000 OR
- New Zealand Soil Classification is windblown sand and distance to sea <1000m and bare ground cover >25).

Result

The resulting ELF layer is a polygon geodatabase in New Zealand Transverse Mercator projection (figure 1). A suite of binary attribute fields identifies for each polygon record which of the above limiting conditions are satisfied.

The accuracy of this analysis is, in large measure, a product of the fidelity of the input layers which, for several factors is rather coarse. Some conditions are difficult to validate and will remain theoretical until more extensive study improves our understanding with additional data – the treeline setback condition for example. This condition would also be improved by generating a better treeline reference layer for its benchmark.
Other conditions, for want of readily available data, appear to have their extent over-estimated and these could be improved with further refinement – the salt/coastal exposure condition for example.

However, despite its shortcomings, as a collation of present knowledge and data, this will be a useful evidential layer of factors limiting growth to forest stature, and will assist particularly in making the decision between Grassland with woody biomass and Natural forest for newly-observed woody vegetation.

Figure 1: The ELF layer. Areas where environmental factors are considered to limit growth to forest stature in 30–40 years are shaded dark green.

For more information

See the LUCAS website:
www.mfe.govt.nz/issues/climate/lucas/

View the latest LUCAS newsletter:
http://www.mfe.govt.nz/publications/climate/looking-at-lucas/looking-at-lucas-issue-12.html

See the latest New Zealand Greenhouse Gas Inventory report:
http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2012/index.html

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