

Evaluating remote sensing data classification techniques for mapping freshwater habitats: Trial application in the Tongariro River delta, Lake Taupo

CBER Contract Report 87

A report prepared for
Environment Waikato

by

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THE UNIVERSITY OF
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List of Abbreviations:

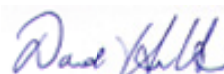
ALOS	Advanced Land Observing Satellite
AP	Aerial Photograph
AVNIR-2	Advanced Visible and Near Infra-red Radiometer type 2
CBER	Centre for Biodiversity and Ecology Research
EW	Environment Waikato
GPS	Global Positioning System
HIS	Intensity Hue Saturation
LUCAS	Land Use Carbon Analysis System
PAN	Panchromatic
PCA	Principal Component Analysis
PRISM	Panchromatic Remote Sensing Instrument for Stereo Mapping
QB	QuickBird
TM	Thematic Mapper
UoW	The University of Waikato
WRAPS	Waikato Region Aerial Photograph Syndicate

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Executive Summary:

The overall goal of this study is to evaluate different classification techniques that can be applied to multi-source satellite remote sensing data to map different freshwater habitat zones. The Tongariro River delta at the southern side of the Lake Taupo was used as a test site to evaluate these techniques.

Based on the review of satellite sensors available in NZ for aquatic mapping (Ashraf et al., 2007), three data options were identified and appropriate images were purchased for the case study area. These data options are Landsat-5 (30m resolution), ALOS (10m and 2.5m), and QuickBird-2 (2.4m and 0.6m). There is no one perfect option available as each option is a compromise between spatial, spectral, radiometric, temporal resolution, and cost. The Quickbird-2 option is feasible because of the “KIWImage” initiative to purchase Quickbird-2 data for all of New Zealand. Developing tools and classification techniques using Quickbird-2 will be useful to Environment Waikato for studying aquatic environments. The only area of concern is its relatively slow acquisition plan that may take 3-5 years. ALOS is a relatively new satellite with a large data swathe but limited data archive. It is also cost-effective, especially if the non-commercial pricing option is used. The availability of satellite data for the Waikato Region, which is often cloudy, may cause problems. Landsat-5 offers an extensive temporal archive and relatively cheap acquisition with good radiometric and spectral resolution but heavily compromised spatial resolution. The Waikato Region Aerial Photograph Syndicate (WRAPS) initiative also offers an opportunity to use its recently captured low spectral resolution (3 band colour). These high spatial resolution but low spectral resolution aerial photographs can be merged with medium spatial resolution multispectral satellite images, such as ALOS, Landsat-5, and QuickBird. These options were compared for the study area using standard supervised classification and advanced sub-pixel classification. The use of WRAPS and QuickBird images showed the best results especially when using the sub-pixel classification technique.

Future research could focus on the use of the multispectral SPOT images made freely available to Government agencies through the Land Use and Carbon Analysis System (LUCAS), which was initiated by the Ministry for the Environment. These images could be used in conjunction with the WRAPS images, because they have been captured at a similar time. To obtain the most from these datasets, it is also recommended to collect in-situ spectral reflectance data for the predominant species and species assemblages of terrestrial, emergent and submerged vegetation. This will improve the capability to use remote sensing to map wetland habitats.

Introduction

Environment Waikato wishes to explore the feasibility of mapping the ecological condition along the margins of the large water bodies (lakes and large rivers) using remote sensing. This is because conventional field-based mapping based on direct ground surveys is labour intensive and feasible only for small and easily accessible areas (Nelson et al., 2006). Also riparian vegetation is heterogeneous and features tend to be very small and irregular. Capturing this type of detail with conventional manual mapping is not cost effective (Congalton et al., 2002). Information on lake and large river systems within the Waikato Region is limited and mostly focused on particular areas such as the Waikato River, Lake Taupo and the Waipa Peat Lakes.

To assess lake ecological conditions, the LakeSPI (Lake Submerged Plant Indicator) is determined for 41 varied-size lakes of the region. It is a field-based tool that ranks different lakes based on its native and invasive submerged plant conditions and provides a synoptic indicator about the ecological condition of the lake (Edwards et al., 2007). This can also be used as a benchmark against which remote sensing methods can be evaluated.

Remote sensing offers a potential tool for mapping and monitoring the physicochemical characteristics and ecological condition of areas inundated by freshwater, such as littoral, riparian and floodplain zones. The habitat characteristics that can be obtained from remotely sensed information may include landcover types and the identification of vegetation species.

The current research looks into mapping and monitoring two distinct but contiguous habitat zones associated with the freshwater. These are:

- i) Inland riparian buffers, and
- ii) Emergent and shallow submerged aquatic vegetation along rivers or around wetlands.

Each of these habitat zones requires separate data and image processing techniques to map and monitor. It has been learnt from previous studies (Shanmugam et al., 2006; Valta-Hulkkonen et al., 2003; Vis et al., 2003) that the following four parameters influence the ability to accurately map aquatic vegetation:

- Characteristics of the target habitat which include the geometry of foliage, density or openness of the canopies and its phenology.
- Environmental and physical conditions of the surrounding matter (i.e. water and atmosphere) such as water quality (which depends on the concentration of chlorophyll *a* and suspended sediments), height of water column above submerged vegetation and atmospheric condition, e.g. high concentration of the suspended aerosols such as water or dust due to humidity or other factors.
- Metrological conditions of image capture such as weather and time of day.
- Remotely sensed data characteristics and quality.

The characteristics and the quality of remotely sensed data are the most manageable among these listed factors. In recent years, there have been advancements that have improved the spatial, spectral, radiometric and temporal resolutions of remotely sensed images. Enhanced image processing techniques have enabled additional information to be extracted from the remotely sensed data thus providing useful information for the management of aquatic ecosystem health, water resources and more detailed characterisation of the narrow littoral and riparian vegetation zone (Goetz, 2006; Shanmugam et al., 2006).

Given the range of remote sensing sensors (from high spatial resolution to hyper-spectral) and techniques currently available (like soft and sub-pixel classifications), the prime interest of this research is to evaluate remote sensing as a cost and time effective tool to map aquatic environments.

1.1. Purpose of the study

The overall goal of this study is to evaluate different classification techniques applied to multi-source satellite remote sensing data to map different freshwater habitat zones in the Tongariro River delta at the southern side of the Lake Taupo. This study area and preliminary evaluation of classification techniques are part of a larger programme funded by the Environment Waikato (EW), the Centre for Biodiversity and Ecology Research (CBER) and The University of Waikato (UoW), towards characterising different freshwater habitat zones of large rivers and lakes of the Waikato region. The research is directed towards achieving the following objectives;

1. Compare different classification algorithms such as supervised and sub pixel classification using the case study area (Tongariro River delta) and the ALOS, Landsat-5, Quickbird-2, and WRAPS images.
2. Combine (fuse) ALOS, Landsat-5, and WRAPS images to increase the spectral and spatial resolutions and assess the fused image performance with a range of classification techniques.
3. Collect *in-situ* spectral reflectance data for dominant species and species assemblages (of emergent and submerged vegetation) for the case study area. This will improve sub-pixel classification accuracy and will also help in identifying suitable spectral bands.
4. Make recommendations for Year 3 to develop remote sensing capabilities that will enable EW to remotely monitor the specified ecological conditions of large rivers and lakes.

1.2. Study area

To achieve the above purposes, the Tongariro River delta region was selected for the study area because it holds a unique combination of riparian and littoral aquatic ecosystem elements, and also because recently archived images are available from the different satellite-based sensors. These sensors were identified as potential sources for spatial RS data suitable for the aquatic mapping purposes in the preliminary investigation (Ashraf et al., 2007).

The South Taupo wetland is a large continuous area of relatively unmodified wetland (c. 1540ha) between the towns of Waihi and Motuoapa on the southern shores of Lake

Taupo. The wetland's extent has increased since the installation in 1941 of control gates on the outlet of Lake Taupo to regulate water flow of the Waikato River for the purpose of hydropower generation. The lake level was raised up to 1m above its natural levels during the first 10 years of operation, and has since been operated more closely to its natural levels. This wetland is a complex mosaic of vegetation types influenced mostly by drainage and to some extent by past disturbance. Much of the area is composed of pumice and greywacke alluvium deposited by the three major catchments draining into the southern end of Lake Taupo from the Mt Tongariro, Mt. Ngauruhoe, Mt. Ruapehu and Kaimanawa mountains (Cromarty and Scott, 1996; Eser and Rosen, 2000; Eser and Rosen, 1999).



Figure 1: The location of the study area (Tongariro River delta) is shown as a dotted red rectangle in the context of the South Taupo wetland (highlighted with black outline)

The study area broadly consists of the Tongariro River delta (or Turangi wetland) which is a natural wetland that lies at the western end of the South Taupo wetland and is formed as a result of high rates of sediment (all alluvial material ranging in size from large boulders to fine clay) supply. Some sediment comes from the Kaimanawa Range and large amounts of volcanic ash, pumice and lava fragments come from the Central North Island volcanoes. The delta has an elongated, lobe cusped form and the wetland has developed in areas where the processes of delta formation have isolated low-lying surfaces. Prior to forming the present delta mouth, that has been relatively stable since 1900; the river flowed into the lake through different mouths whose paths can be seen in underwater contours in Stump Bay of Lake Taupo (Smart, 2005).

Farming was established with the European colonization of the Taupo Basin in the 1850s, and by 1941 large areas of manuka and kanuka scrub/forest backing the wetland had been cleared. Attempts were made to drain localised areas of wetland, but the raising of the lake level by almost a metre in 1941 meant that many of these low-lying areas became poorly drained. As a result, wetland vegetation and manuka scrub became re-established. The current vegetation of the wetland is influenced by drainage and this past disturbance

and manipulation of water levels (Chagué-Goff et al., 1999). It contains a wide range of representative vegetation types and provides breeding habitat for populations of common and vulnerable wetland birds. Elevated areas, such as the beach ridges and old river banks, are covered in vegetation composed predominantly of kanuka (*Kunzea ericoides*), manuka (*Leptospermum scoparium*), kowhai (*Sophora tetraptera*), kohuhu or kohukohu (*Pittosporum tenuifolium*), lancewood (*Pseudopanax crassifolius*), cabbage tree (*Cordyline australis*), gorse (*Ulex europaeus*), and grey willow (*Salix cinerea*). Away from the main river channels the area is less well drained. Such inundated areas have peaty substrates with variable levels of silt level that are colonised by herbaceous communities composed primarily of flax (*Phormium tenax*), toetoe (*Cortaderia toetoe*), raupo (*Typha orientalis*), oioi (*Leptocarpus/Apodasmia similis*), sedge (*Carex spp.*) and rush (*Baumea rubiginosa*). Spatial variation in the abundance of these species reflects the influence of topography, drainage and fertility. Areas of semi-permanent surface water forming inlets and lagoons close to the lake support raupo reed-land (Cromarty & Scott 1996; Eser and Rosen, 2000).

1.3. Remotely sensed data and processing software

Currently there are many remote sensing (RS) satellites capable of capturing the visible to near infrared part of the electromagnetic spectrum. These have varied ranges of spatial, spectral, radiometric and temporal resolutions. Three satellite - Landsat-5, ALOS and QuickBird-2, were identified as potentially suitable for the aquatic mapping of the study area. A careful choice was made between low to medium to high spatial resolution satellites as all these data have varying compromises between low cost, high repeatability and ease of data processing etc. Keeping in mind the heterogeneous aquatic environment, 30m resolution Landsat-5 data is relatively a low spatial resolution, however, it possesses the most comprehensive data archive for the New Zealand (as it is the most successful imaging satellite in remote sensing history). It is a general worry that it is an old satellite which has operated much longer than its expected life and holds a recent history of malfunctioning of its aging devices. It may phase out by 2010-2011 before the launch of its successor i.e. Landsat-8 or LDCM (Landsat Data Continuity Mission) satellite.

Although SPOT-5 covers the same study area and is free to Government agencies under the LUCAS project, ALOS was preferred due to its ability to capture data in the blue spectral band which holds better capability to detect vegetation in the shallow water environments due to less attenuation of light by the water in this spectral range. There are many high spatial resolution satellites (with spatial resolution of 1m or better) but there are only few satellites that have cover New Zealand, and in particular the Waikato region. QuickBird-2 satellite has already been selected to provide data for all of New Zealand through the KIWImage (correct spelling) initiative headed by Joint Geospatial Support Facility (JGSF) of the New Zealand Defence Force (NZDF) which signed a formal contract on 28th April 2008 with Sinclair Knight Merz Pty Ltd (SKM). The KIWImage Project is an *All of Government* initiative to purchase satellite imagery of New Zealand, selected South West Pacific islands for which New Zealand has responsibility and the Ross Dependency for use by NZ Government departments and Local Government. This offers a great opportunity window to EW as they can use this data to optimise aquatic mapping in detail.

As an alternative to satellite data, Waikato Regional Aerial Photography Syndicate (WRAPS) offers complete coverage of aerial photography for the region at three different

time instances i.e. 1992/93, 2001/02 and 2006/07 and known as WRAPS 1993, WRAPS 2002 and WRAPS 2006. Its latest acquisition was started in June 2006 when Coromandel Peninsula and Firth of Thames estuary were surveyed in order to upgrade the WRAPS inventory. For other regions, aerial photography was postponed due to the consistently bad meteorological conditions (such as persistent cloud cover) during the summer months of 2006/07. The remaining parts of the region were surveyed during the summer months of 2007/08. Latest WRAPS aerial photographs were not available for the study area at the time of this research. As a result, WRAPS 2002 data were used to experiment its fusion with low spatial resolution LANDSAT and ALOS data. WRAPS 2002 was flown in 2001/02 summer for most of the region except for Coromandel Peninsula and Lake Taupo (i.e. Oct 2002).

All satellite data was identified through online data search websites by the satellite operators or their regional data distribution partners. For the Landsat-5 data, Landcare Research (Crown Research Institute in New Zealand) provides data from this satellite through a data download facility at Australian Centre for Remote Sensing (ACRES) who also offers the sale of ALOS data. Their web based data search and low resolution quick-looks helped in identifying the right scenes for LANDSAT and ALOS satellites. After the import, it was realised that these scenes have environmental or climatic factors that resulted in degraded data for the purpose of mapping. A small patch of cloud/haze in the LANDSAT-5 image near the mouth of Tongariro River could cause confusion in the classification. Similarly, ALOS satellite image was captured soon after a flood in the river which washed a plume of sediment into the lake which attenuated the reflection of light from the submerged aquatic vegetation beds around the mouth of the river.

The following table describes the RS data attributes and related characteristics;

Table 1: Characteristics and attributes of satellite data used for the study

Satellite	Sensor	Spatial resolution	Spectral resolution		Radiometric resolution	Area covered (km)	Acquisition date & time (NZDT ¹)		Pre-processing details		Solar elevation	Solar azimuth	Viewing angle
		m	bands	Range (µm)	(grey shades)		(dd-mm-yyyy)	(hh:mm)	Correction	Format	(degrees)	(degrees)	(degrees)
Landsat-5	Thematic Mapper	30	B	0.45 – 0.52	0-255	185x185	31-01-2007	10:54	L1R (CCRS based radiometric correction)/ Systematic Geo-correction	EOSAT Fast Format/BSQ (KD16 re-sampled, WGS84 datum, UTM60S projection)	51.67	68.49	-0.18
			G	0.52 – 0.60									
			R	0.63 – 0.69									
			NIR	0.76 – 0.90									
			SWIR	1.55 – 1.75									
		SWIR	2.08 – 2.35										
120	TIR	10.4 – 12.5	0-63										
ALOS	AVNIR-2	10	B	0.42 – 0.50	0-255	70 x 70	01-12-2006	11:19	L1B1	CEOS Format	61.68	60.73	0
			G	0.52 – 0.60									
			R	0.61 – 0.69									
			NIR	0.76 – 0.89									
	PRISM	2.5	P	0.52 – 0.77	35 x 35								
QuickBird-2	Multispectral	2.4	B	0.45 – 0.52	0-2047	5 x 5 sub-scene	23-03-2007	10:45	L1G	GeoTiff (NN re-sampled, WGS84 datum, UTM60S projection)	44.45	35.75	6.3
			G	0.52 – 0.60									
			R	0.69 – 0.69									
			NIR	0.76 – 0.90									
	Panchromatic	0.6	P	0.45 – 0.90									
WRAPS Aerial Photographs	Large format photographic plate camera	2.5	B	0.4 – 0.5	0-255	Mosaic	Summer (2002-03)	Ortho-rectification	GeoTiff (1949 datum, NZ Map Grid Projection)	–	–	–	
			G	0.5 – 0.6									
			R	0.6 – 0.7									

For image processing such as geo-rectification, high-resolution merge and supervised and sub-pixel classification, *ERDAS Imagine 9.1/9.2* software is used. All the maps were prepared in *ARCGIS 9.1* software.

¹ NZDT – New Zealand Daylight Time; it is 13 hours ahead of Coordinated Universal Time (UTC)

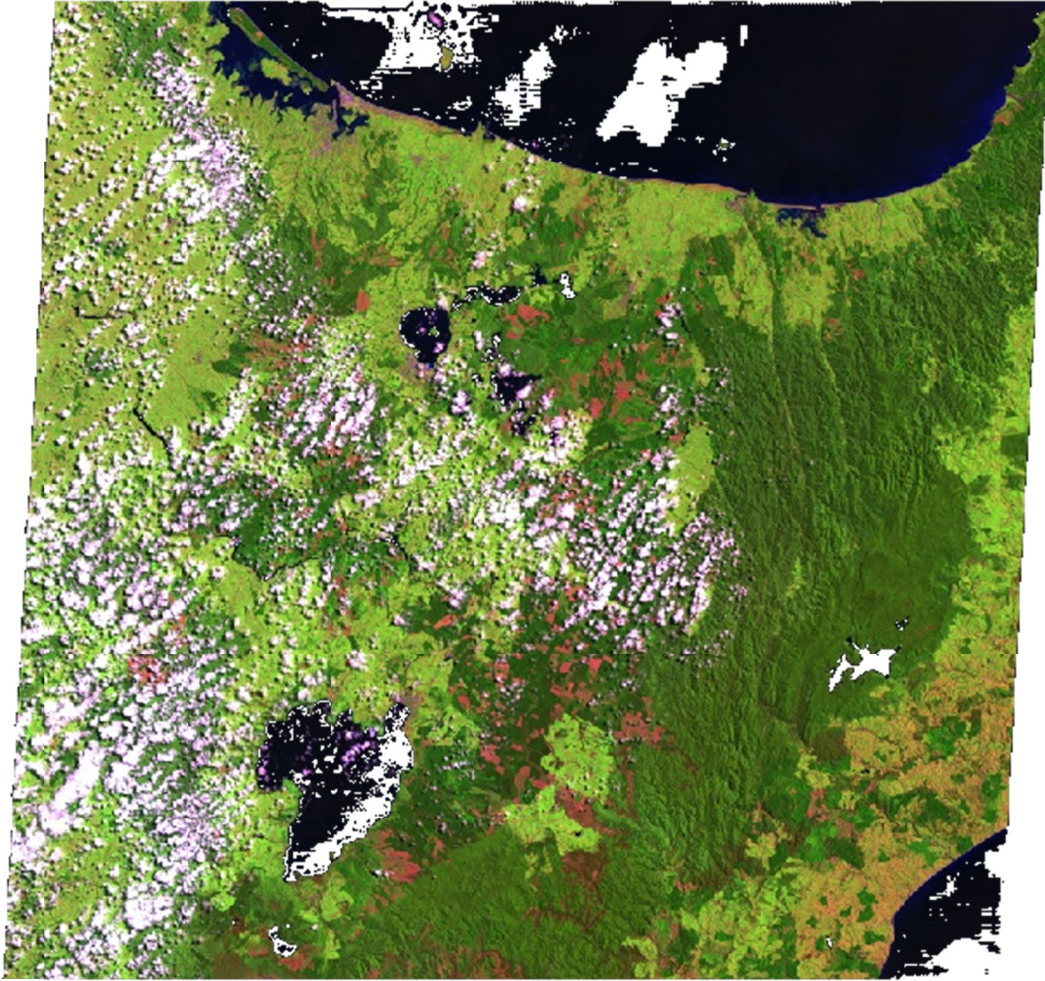


Figure 2: Full scene of Landsat-5 TM data captured on 31-01-2007

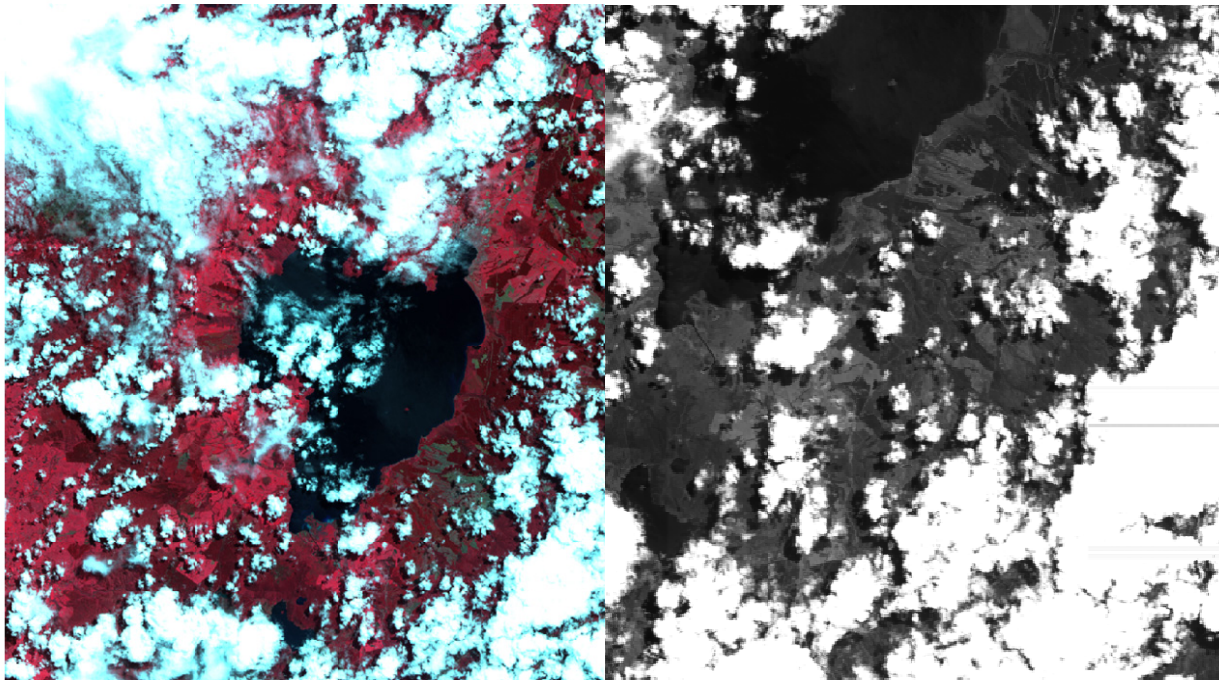


Figure 3: Full scenes of ALOS AVNIR-2 and PRISM data captured on 01-12-2006

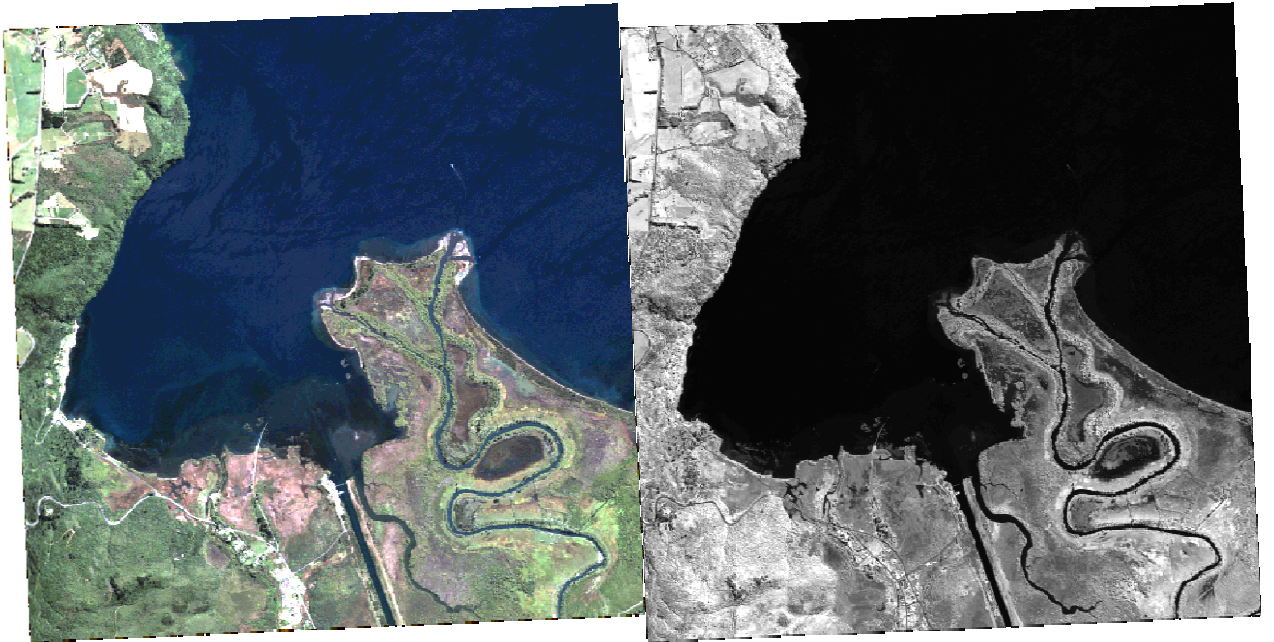


Figure 4: Sub-scenes of QuickBird-2 multispectral and panchromatic data captured on 23-03-2007



Figure 5: WRAPS aerial imagery mosaic (flying year 2002/03)

Methodology & Results

2.1. Pre-processing of acquired images

Pre-processing involves the correction of deficiencies and removal of flaws present in the data. This includes geo-rectification, which is concerned with providing the correct spatial location to the data with the real-world coordinates) is often performed prior to any advanced processing of the data and falls under the category of pre-processing as well.

2.1.1. Data import and artefact removal

Landsat data were acquired in LANDSAT EOSAT fast format. ERDAS Imagine software provides a specific import utility for this format, which converted the data into ERDAS *Imagine* format for further processing. QuickBird and aerial photographs were originally supplied in GeoTiff format and these were converted into ERDAS *Imagine* format. There was no direct import utility available in ERDAS *Imagine 9.1* software for the ALOS satellite data which was supplied in JAXA CEOS format. It was imported into the system using generic binary utility using parameters shown in Fig. 6. Later in *ERDAS Imagine version 9.2*, an import utility was added to directly read JAXA CEOS format.

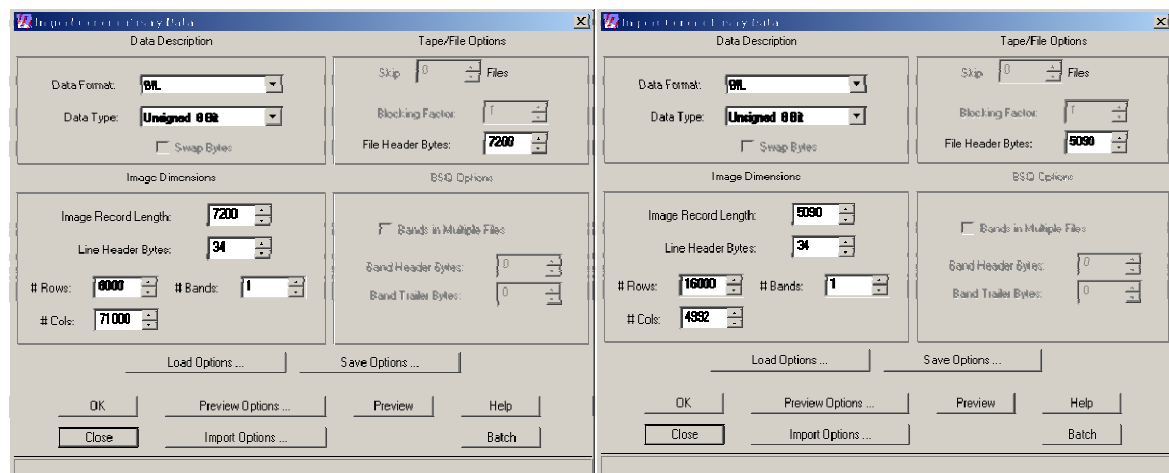


Figure 6: Data import parameters for ALOS AVNIR-2 and PRISM data (L1B1 format) in ERDAS *Imagine*

The AVNIR-2 data required additional processing due to certain inherent disorders. This is due to a shift of 5-7 pixels between even and odd number columns. This shifting number is dependent upon the pointing incident angle of the sensor. This shifting number is not recorded in the data; however it was measured manually and found to be 5 in the given dataset.

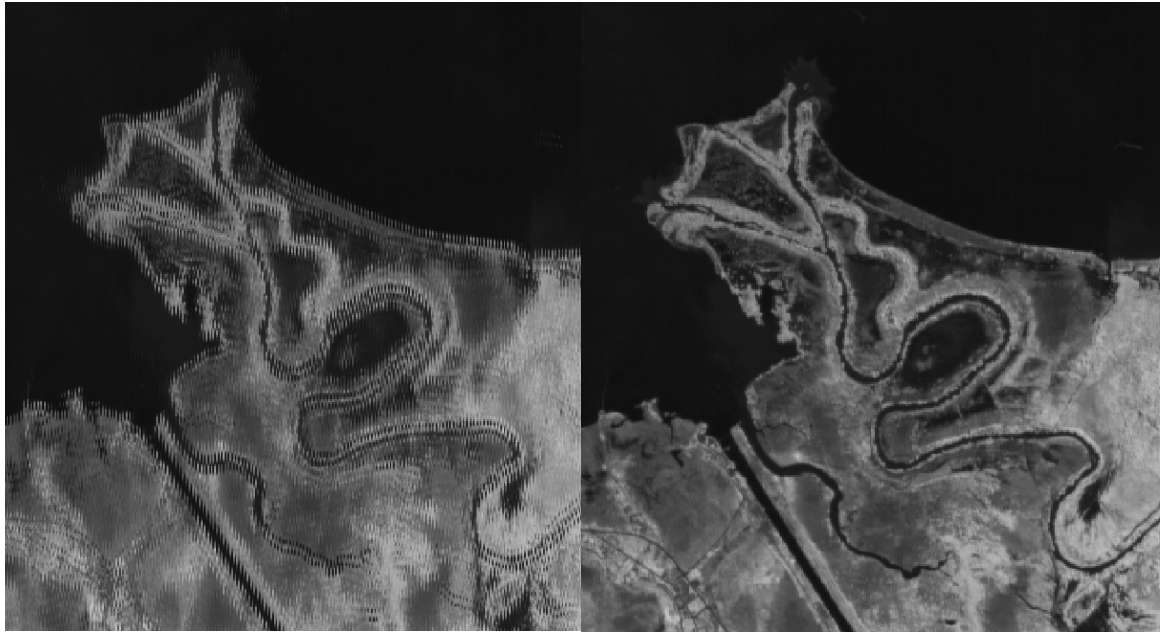


Figure 7: Staggering effect (visible in left image) has vanished (in the right image) after applying a stagger correction algorithm

To solve this problem, a model was developed using ‘Spatial Modeler’ in ERDAS Imagine software (as shown below) which yielded a corrected image for further processing.

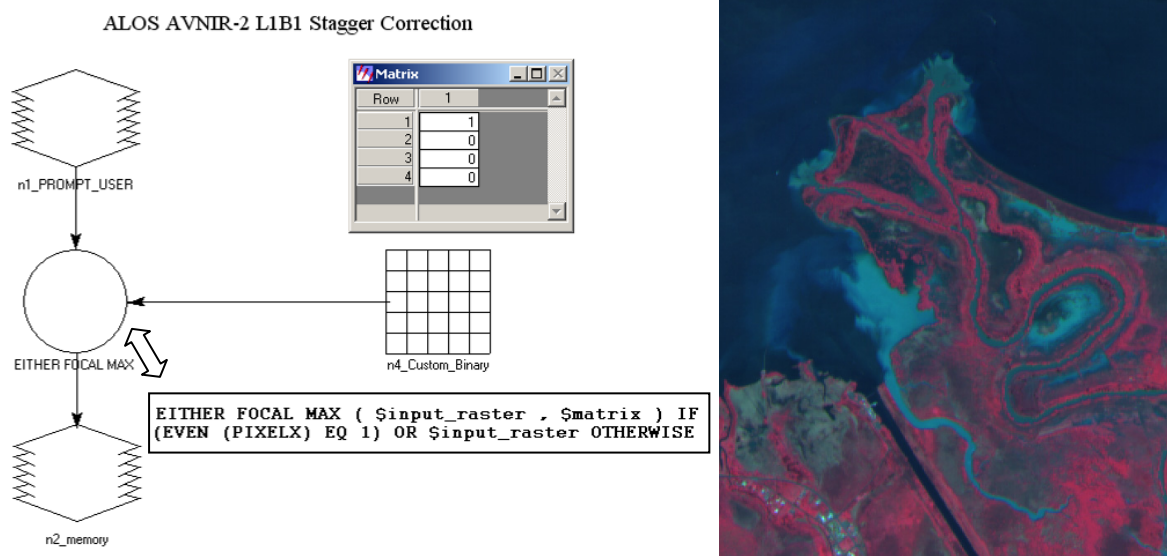


Figure 8: Explanation of stagger correction algorithm and resultant de-staggered AVNIR-2 data

Like ALOS AVNIR-2 data, the Landsat-5 dataset has a stripping effect but in the horizontal plane. This stripping defect resulted from an error at either the detector level or at the scan level in Landsat-5 and -7 data. Bands 1–3 of Landsat-5 Thematic Mapper (TM) show narrow striping (detector-by-detector variability) that arises from a miscalibration of individual detectors during systematic radiometric processing (Masek et al, 2001). This artefact was removed (as shown in Fig. 9) using ‘Destripe TM Data’ utility available in *ERADS Imagine* software.

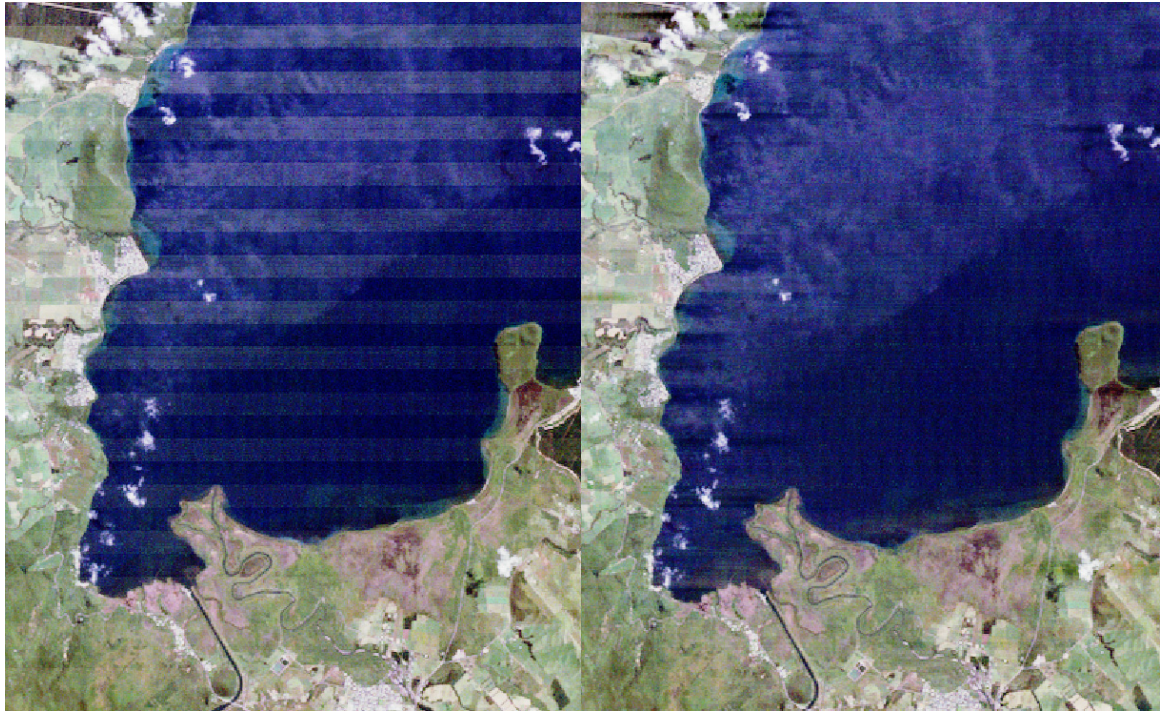


Figure 9: Horizontal strips in the Lake Taupo (left) and de-stripped LANDSAT TM data (right) after processing

2.1.2. Georectification

Georectification is the locating of remotely sensed data in its correct spatial location and orientation. A variety of algorithms can be used to resample and rectify these images such as Nearest Neighbour, Bilinear Interpolation and Cubic Convolution transformations. Each algorithm has its own effect on the positional accuracy and variability in the DN values of the resampled and the georeferenced image. The nearest neighbour (NN) algorithm was preferred over others as it does not perform an interpolation. Instead, the nearest pixel is selected for the resampled output image. It is often said that this resampling best reflects the original pixel values as observed by the sensor. However, NN resampling is not as visually appealing to the eye as other algorithms.

For the georectification of the RS data, *MapToasterTopo* software was used to identify GCPs using New Zealand Transverse Mercator (NZTM) projection. For the Landsat image, instead of georectifying the entire image, a de-stripped subset of Lake Taupo and its surroundings was used. ALOS AVNIR-2 and PRISM data were geo-rectified using the NZTM projection.

QuickBird data were georectified by the supplier who used NN resampling and projected data using Universal Transverse Mercator (UTM) projection. WRAPS aerial images on the other hand were orthorectified (i.e. geocorrected and terrain distortions removed) to the New Zealand Map Grid (NZMG) projection. The 2002-03 photos are available at the University of Waikato at 1m resolution. Their spatial resolution was degraded to 2.5m before merging with 30m Landsat data.

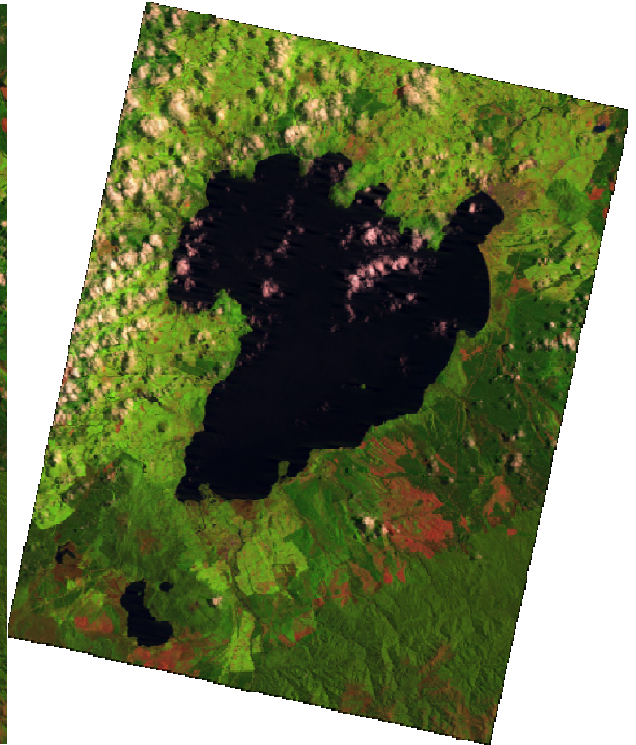
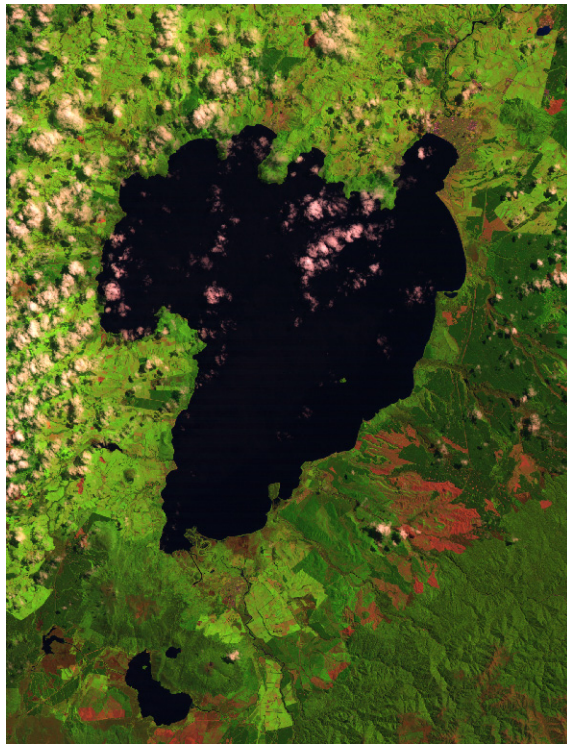


Figure 10: Geo-rectification of Landsat TM data

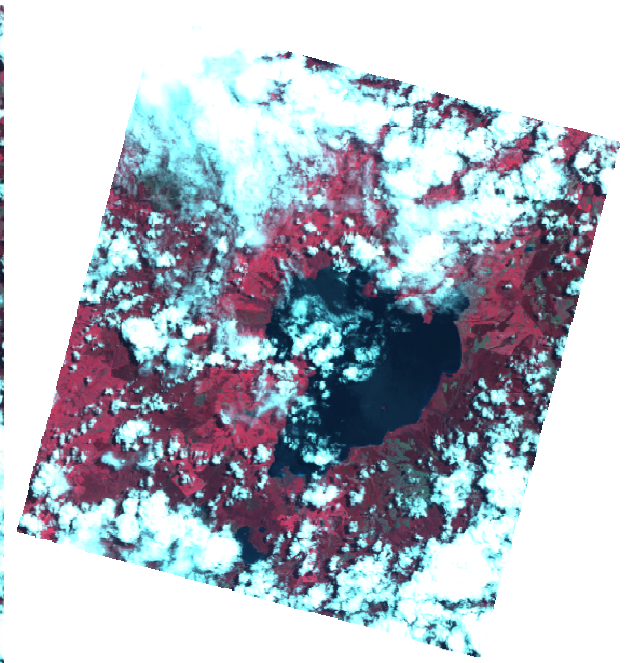
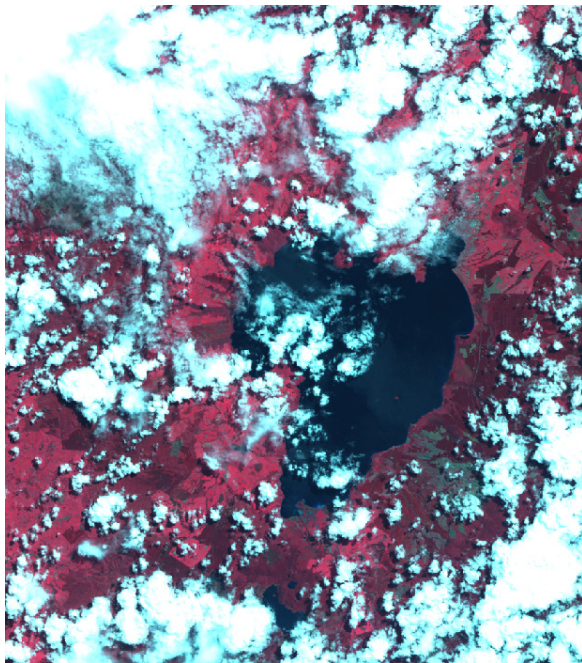


Figure 11: Geo-rectification of ALOS AVNIR-2 data

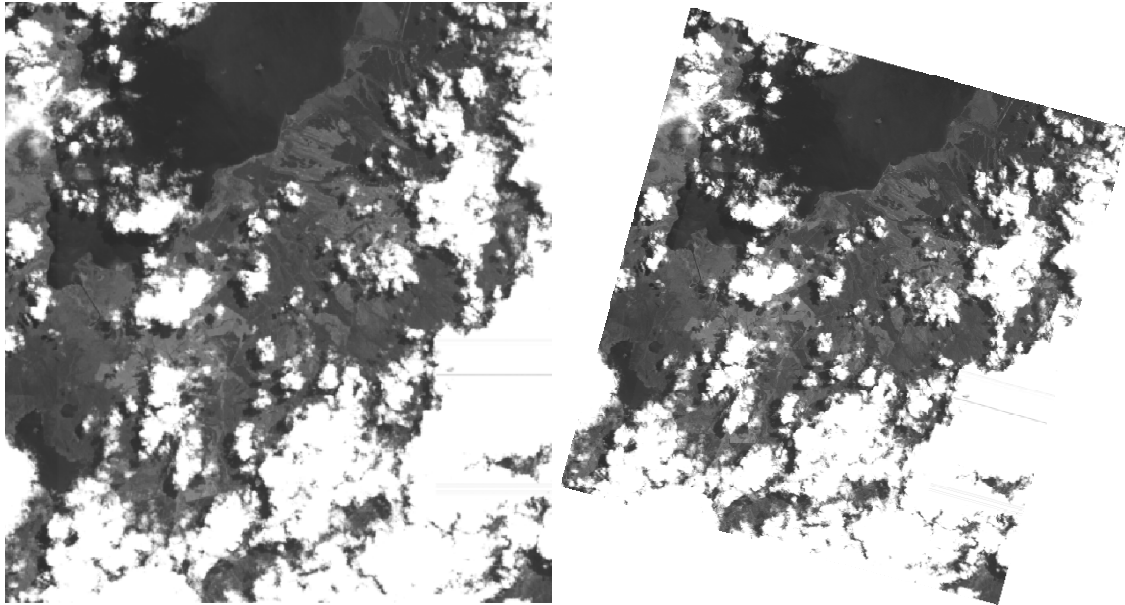


Figure 12: Geo-rectification of ALOS PRISM data

2.2. Data fusion/resolution merging

Several merging techniques have been developed in the past to combine multi-sensor multi-spectral data with high spatial resolution data to improve the spatial information content of low resolution multispectral images for visual interpretation. Ideally the method for merging datasets with high spectral and spatial resolution should not distort the spectral characteristics (Ahmad and Singh, 2002). Keeping in mind this objective, different data fusion techniques (such as Principal Component Analysis, Intensity Hue Saturation, High Pass Filter and Subtractive resolution merge) were applied.

The Principal Component method is used in applications that require the original scene radiometry (colour balance) of the input multispectral image to be maintained as closely as possible in the output file. As this method scales the high resolution data set to the same data range as Principal Component 1, before the Inverse Principal Component calculation is applied, the band histograms of the output file closely resemble those of the input multispectral image. Unfortunately, this radiometric accuracy comes at the price of a large computational overhead. Another result of this methodology is that the output file tends to have the same data range as the input multispectral file.

Intensity Hue Saturation (IHS) is one of the frequently used methods to merge multi-sensor image data (Hyden et al., 1982; Welch and Ehlers, 1987). The IHS method consists of the transformation of a low spatial resolution data set from the RGB to IHS colour-space system, with the intensity component replaced by the high resolution data before carrying out the inverse transformation of the IHS to RGB space. Normally, the biggest limitation of a method based on IHS processing is that it can only process three bands at a time.

The Modified IHS resolution merge function enables images with more than three bands to be merged by running multiple passes of the algorithm and merging the resulting layers in an output with both excellent detail and a realistic representation of original multispectral scene colours (Siddiqui, 2003). In the current use, QuickBird bands 4,3,2 and QuickBird 3,2,1 bands automatically layer stacks 4,3,2 bands from the first merge

with the band1 from the second to produce a merged image of all four QuickBird bands. The technique works by assessing the spectral overlap between each multispectral band and the high resolution panchromatic band and weighting the merge based on these relative wavelengths. Therefore, it works best when merging images (and bands) where there is significant overlap of the wavelengths.

The High Pass Filter (HPF) method has been earlier used by Chavez (1986) and Chavez and Bowell (1988) in which a high pass filter has been applied to the high spatial resolution data and the result has been added pixel by pixel to the lower spatial resolution. This has allowed the higher resolution image to add equally to each of the lower resolution images using the simple pixel addition method without distorting the spectral balance.

The Subtractive Resolution Merge (SRM) is a contemporary pan-sharpening technique. The input consists of overlapping high spatial resolution panchromatic (pan) and low spatial resolution multispectral (MS) images. The output is a high resolution MS image that retains the colours of the original MS image while maintaining the spatial detail of the pan image. This algorithm was designed specifically to provide a solution that was fast, yet produced quality results for the most common types of sensors whose spectral bands weights are pre-defined. Specifically, it was designed for Quickbird, Ikonos and Formosat images that have simultaneous acquisition of the pan and MS, with all 4 MS bands present, and a spatial resolution ratio between the MS and pan image pixels sizes of 1:4. Other sensors that have similar capabilities should also work well with this algorithm.

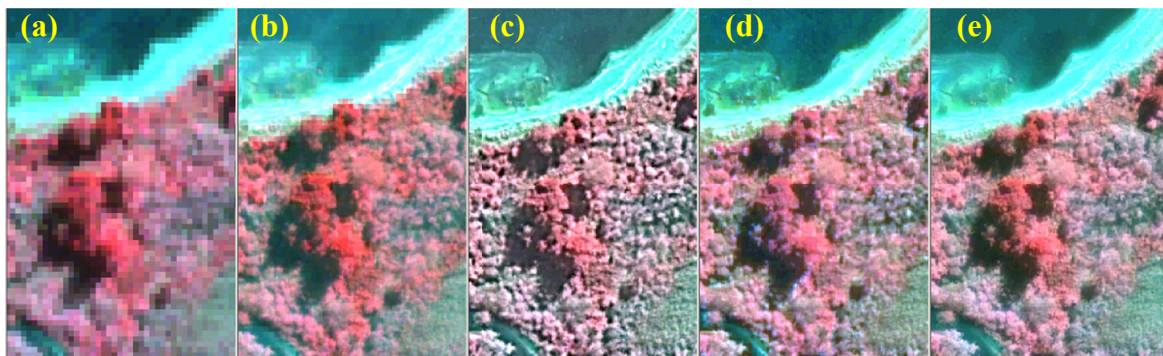


Figure 13: (a) QuickBird original multispectral image; QuickBird PAN sharpened images using (b) PCA resolution merge, (c) modified IHS merge, (d) HPF merge, and (e) subtractive resolution merge techniques

Statistical parameters such as mean and standard deviation of the original dataset are shown in a matrix below along with the panchromatic band merged datasets for different data fusion techniques.

Table 2: Mean and standard deviation values of original and merged QuickBird-2 data

QuickBird Multispectral	Data Statistics	Original Data	PCA merge	Modified HIS merge	HPF merge	Subtractive resolution merge
Band 1	Mean	139.43	134.80	137.22	129.36	139.15
	S.D.	15.35	14.91	21.24	35.81	16.15
Band 2	Mean	163.07	152.69	159.88	151.00	162.74
	S.D.	41.18	33.46	41.73	55.96	42.05
Band 3	Mean	75.16	67.26	73.29	69.25	75.02
	S.D.	38.96	33.52	37.55	41.76	39.64
Band 4	Mean	244.04	182.49	238.96	226.71	243.81
	S.D.	261.97	165.21	256.39	258.37	266.11

In order to map the aquatic vegetation of the entire Waikato Region, reliance on cheap remotely sensed data is a prerequisite. WRAPS aerial photographs which are under process of acquisition at 0.5m spatial resolution (flying year 2007/08) can be incorporated as an alternative to high resolution panchromatic data to be used with the number of wider swathe medium resolution multispectral satellite data such as ALOS, SPOT or even with Landsat-5 TM. An attempt was made to fuse WRAPS aerial data of the study area with the Landsat-5 image. Although WRAPS images (for the flying year 2002/03) are actually available at 1m spatial resolution, an attempt was made to fuse its degraded 2.5m resolution version available at LINZ website with 15m Landsat-TM data. As the WRAPS aerial photography consists of colour images (captured in Red, Green and Blue), there is a need to convert 3 channels (RGB) data into greyscale first before applying any data fusion technique. RGB to greyscale is a transformation of a combination of 3 channels data to greyscale palette. IHS define an alternative colour space where intensity (I), hue (H) and saturation (S) represent three positioned parameters (in lieu of R, G and B). This system is advantageous in that it presents colour more closely as perceived by the human eye where intensity is the overall brightness of the scene, saturation represents the purity of the colour, and hue is representative of the colour or the dominant wavelength of the pixel (Buchanan, 1979). The intensity band is equivalent to greyscale data.

Another simple solution is to add the R, G, and B parts together and divide by 3. Since the human eye sensitivity is different to different colours, this algorithm is, however, unlikely to give exact result. It is suggested to weight different colours accordingly before adding them. Commonly methods as used by Adobe Photoshop software apply weighted sum and saturation removal techniques to convert colour images into greyscale using the following formulae. The blue channel of an AP contains most noise and can appear granular. The blue channel contribution is therefore weighted lower than its other counterparts. The saturation removal however yields poor contrast.

$$\text{Greyscale} = 0.59 \times G + 0.3 \times R + 0.11 \times B$$

$$\text{Greyscale} = [\max(R, G, B) + \min(R, G, B)]/2$$

These three techniques generated the following results.

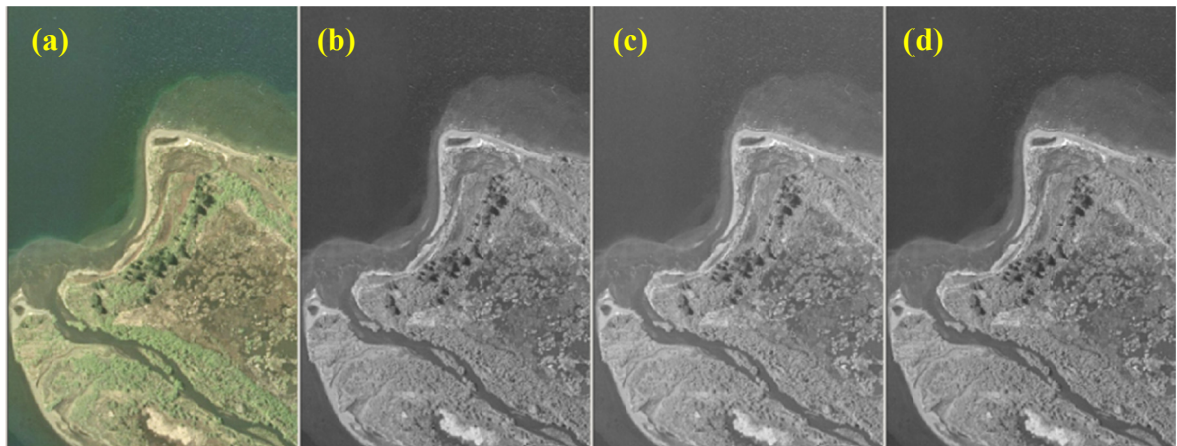


Figure 14: (a) Original WRAPS aerial image; RGB to greyscale conversion using (b) IHS, (c) Weighted average, and (d) Saturation removal techniques

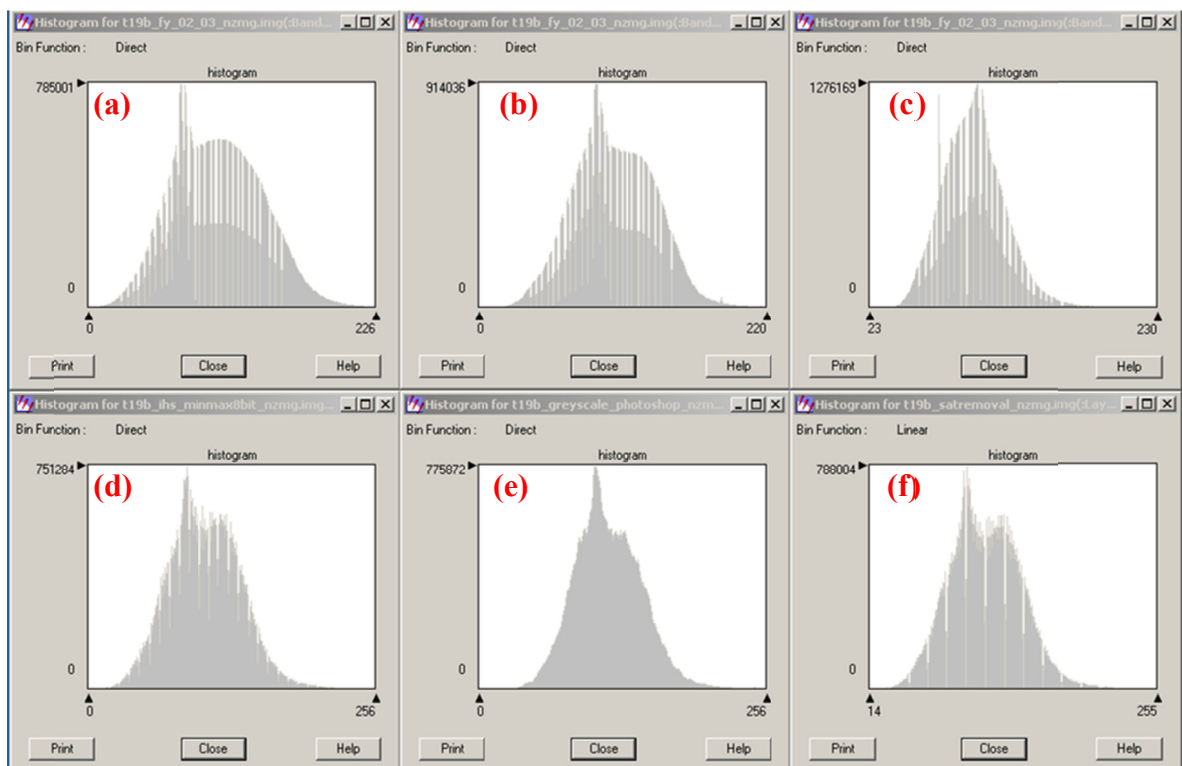


Figure 15: Histograms of WRAPS aerial image (a) Blue band, (b) Green band, (c) Red band, and histograms of resultant grey scale data using (d) HIS, (e) Weighted average, and (f) Saturation removal techniques

As the subtractive resolution merge is limited to 4 band multispectral data, a high spatial resolution aerial photographic dataset was fused with the Landsat TM subset carrying the first 4 bands.

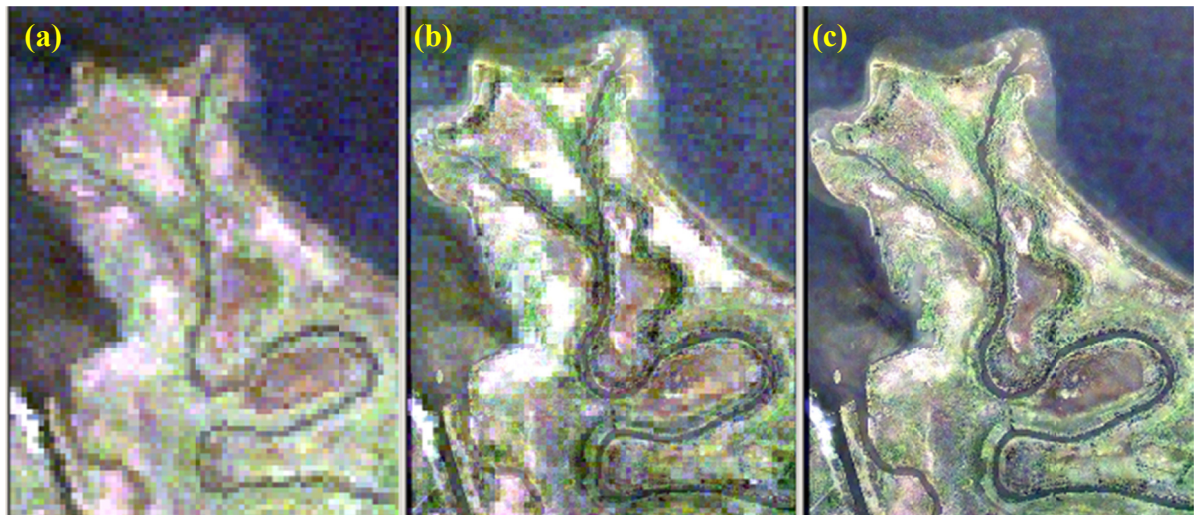


Figure 16: (a) Original TM and WRAPS aerial photo merged with Landsat TM using (b) PCA, and (c) Subtractive resolution merge techniques

Table 3: Mean and standard deviation values of original Landsat Thematic Mapper (first 4 bands) and Aerial Photograph merged data

Landsat TM	Estimates	Original Data	PCA	Subtractive
Band 1	Mean	70.98	71.43	70.40
	S.D.	3.64	3.57	6.51
Band 2	Mean	22.96	23.87	22.78
	S.D.	4.29	3.50	5.14
Band 3	Mean	21.41	22.69	21.41
	S.D.	6.27	5.62	7.49
Band 4	Mean	47.73	22.69	49.46
	S.D.	35.97	5.62	35.62

2.3. Field visit

A reconnaissance visit was made to the study area on 20th and 21st June, 2008 with the purpose to gain first-hand knowledge about the vegetation that exists in the region. This field trip identified some homogenous tracts of dominant vegetation types that helped to train the pixels in supervised and subpixel classifiers.

The dominant plants of the study area are monocotyledons which include grasses, reeds, rushes, sedges, cabbage trees and New Zealand flax. An account of general observations related with this visit is documented as:

2.3.1. Macrophytes

Submerged aquatic vegetation is visible as a dark shade in the lake. At some places, these macrophytes are floating and can be visualised as bright patches in the image. Hornwort (*Ceratophyllum demersum*) was the most abundant species observed. It was present at all three locations from where submerged macrophyte samples were collected. At one location Oxygen weed (*Lagrosiphon major*) was also collected.

Global Positioning System (GPS) based locations (using WGS84 datum) for these sample sites are shown in the Table (see also Fig. 18).

Table 4: Location of aquatic macrophytes sample collection sites

Sr. No.	Latitude	Longitude	Species observed
1	38° 57' 11.0"	175° 45' 54.8"	Hornwort
2	38° 57' 07.2"	175° 45' 41.6"	Hornwort & Oxygen weed
3	38° 56' 54.0"	175° 46' 12.0"	Hornwort

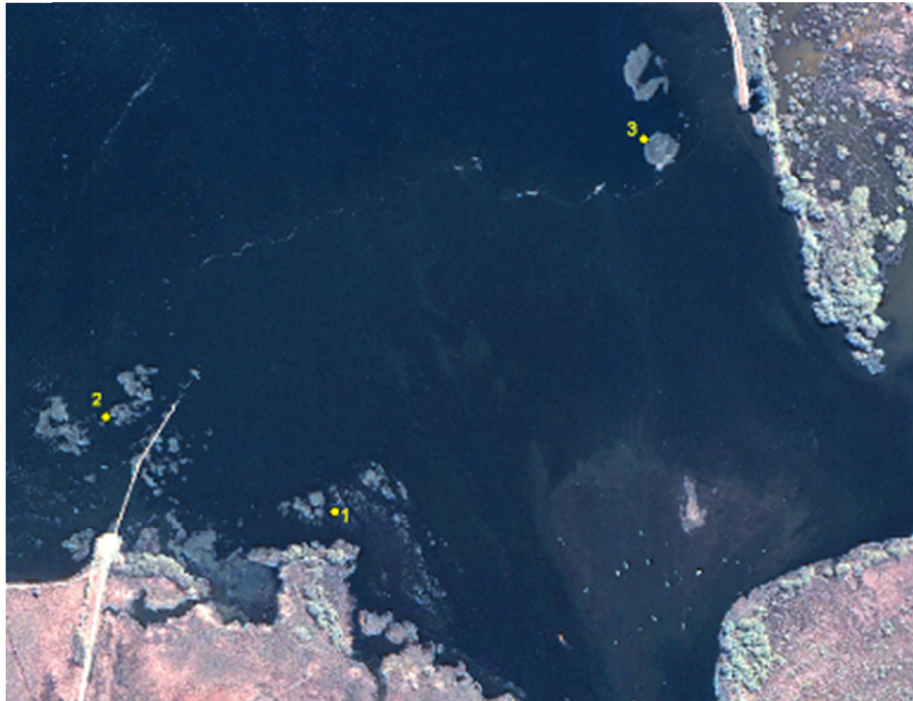


Figure 17: QuickBird satellite image showing location of aquatic macrophyte sample collection sites



Figure 18: (a) Submerged; (b) floating-leaved macrophyte and (c) their corresponding locations in the QuickBird satellite image.

2.3.2. Reeds

Raupo or bulrush (*Typha orientalis*) is a tall reed that formed dense leafy stands and observed as the most abundant of all other aquatic vegetation in the study area (Fig. 19).

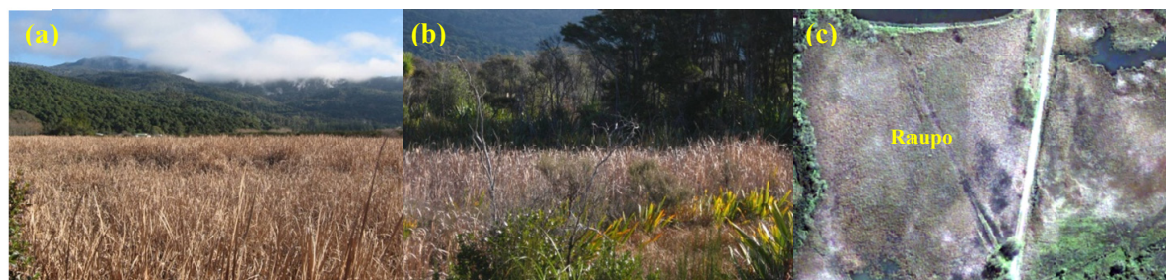


Figure 19: (a) & (b) Raupo habitat; (c) Pan sharpened QuickBird image showing Raupo habitat in bands 3,2,1 as R,G,B

Harakeke or New Zealand flax (*Phormium tenax*) also formed dense and leafy stands in the lowland swamps. Its distribution was mainly restricted along Tokaanu Tailrace Canal where it was dominated species found in association with raupo, rushes and sedges (as shown in Fig. 20).



Figure 20: (a) & (b) New Zealand flax with Raupo in the backdrop; (c) Pan sharpened QuickBird image showing flaxland habitat in bands 3,2,1 as R,G,B

2.3.3. Rushes

Rushes are typical wetland plants which can be leafy and grass-like while some are leafless and consist of clumps of stems. *Juncus* spp. (Wiwi) were found at the lake shore as well as at other moist places in the form of big clumps in association with Raupo (Fig. 21 and 22). Distribution of Spike Rush (*Eleocharis sphacelata*) was also observed as an emergent reed at the lake shoreline.

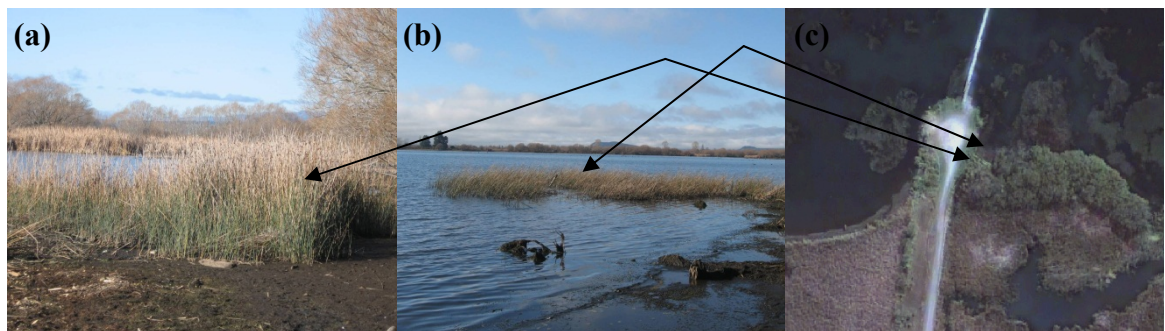


Figure 21: (a, b) Rushes and (c) their ground observation sites on QuickBird image.

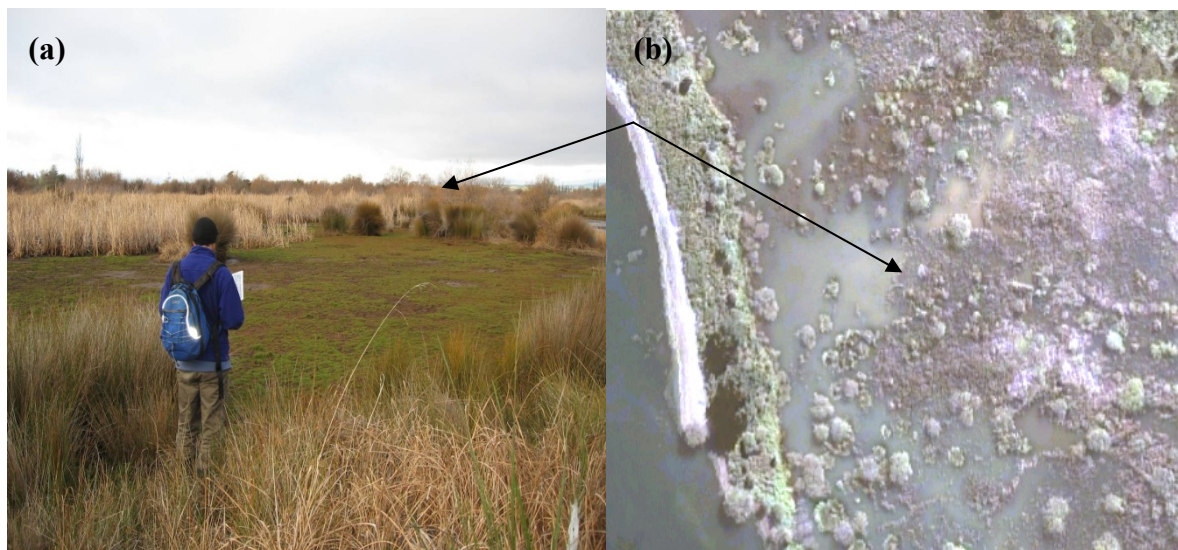


Figure 22: (a) Rushland and (b) its associated location on the QuickBird satellite image

2.3.4. Sedges and grassland

There are various sedge species in the study area such as Purei (*Carex secta*) and *Baumea* spp. It was observed that these species exist in a linear way on the raised land or in association with pastureland (as shown in Fig. 23 and 24).

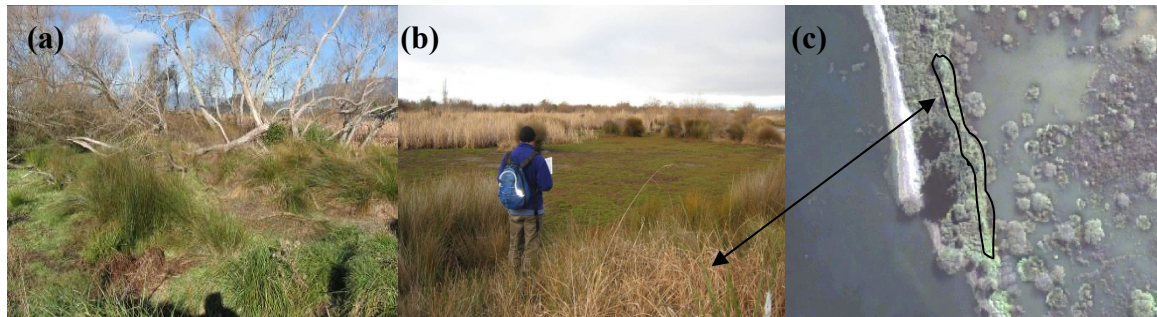


Figure 23: (a) Sedgeland; (b) and (c) grassland and its associated location on the QuickBird satellite image.

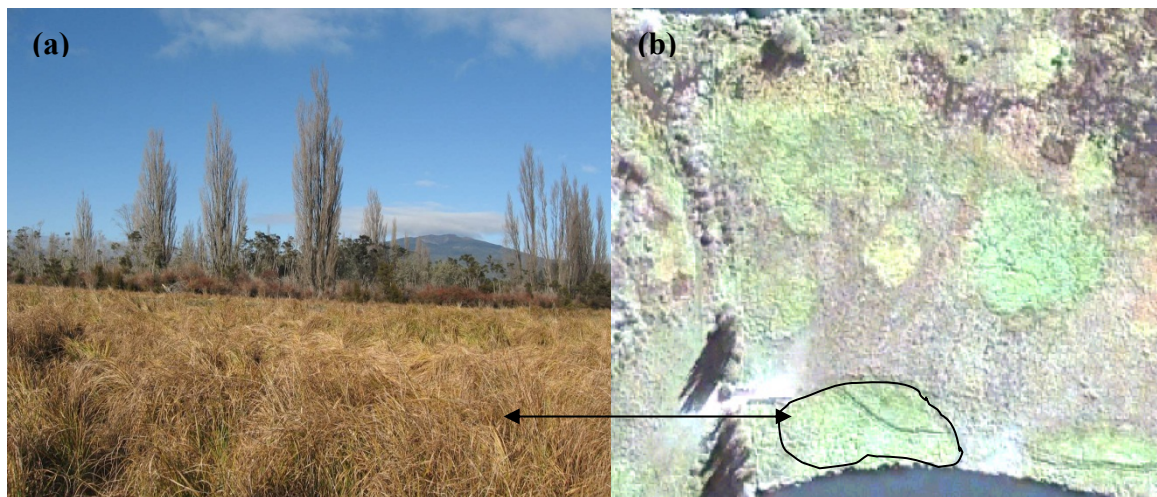


Figure 24: (a) Grassland and (b) its associated location on the QuickBird satellite image

2.3.5. Scrub

Blackberry (*Rubus fruticosus*), Hawthorn (*Crataegus monogyna*), Broom (*Cytisus scoparius*) and Gorse (*Ulex europaeus*) are the common scrub species observed on the raised/dried parts of the delta (Fig. 25 and 26).

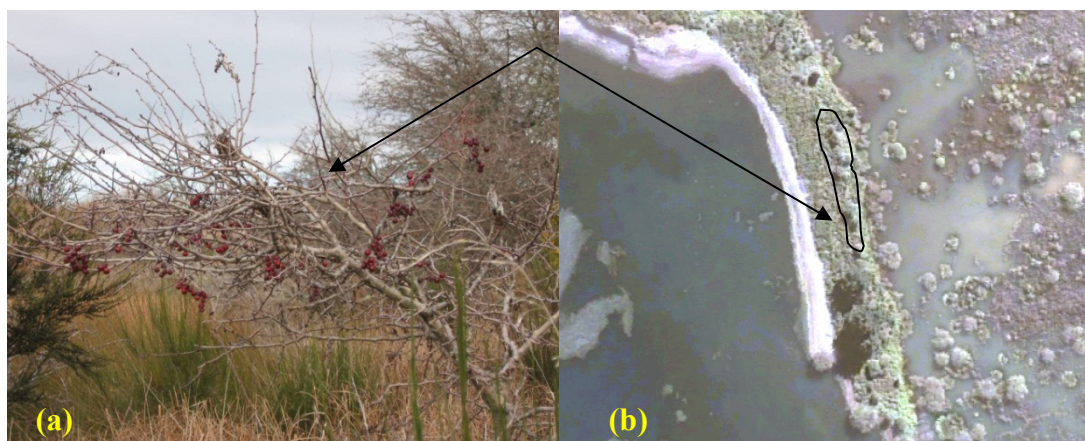


Figure 25: (a) Hawthorn habitat and (b) its location on the QuickBird satellite image

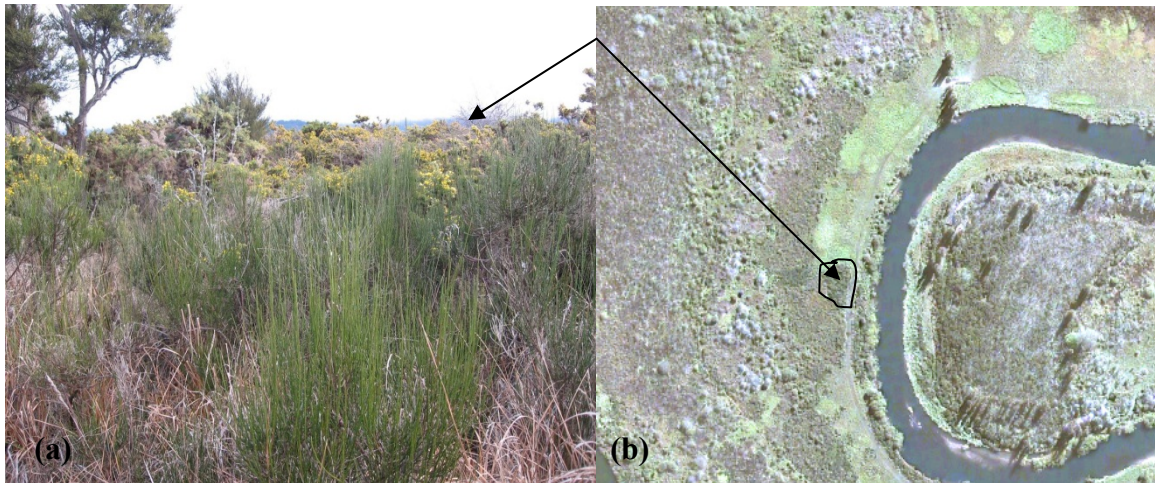


Figure 26: (a) Gorse habitat (in the background) and (b) its location on the QuickBird satellite data

2.3.6. Shrubs

Manuka (*Leptospermum scoparium*) and Kanuka (*Kunzea ericoides*) are the most abundant shrubby plants found in the study area (Fig. 27).

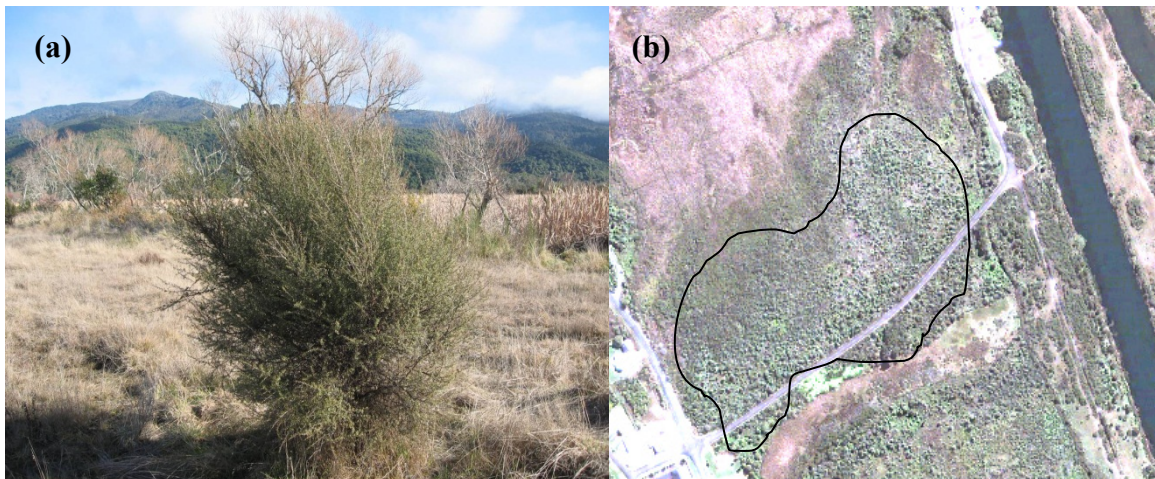


Figure 27: (a) Manuka plant and (b) location of dominant manuka habitat on the QuickBird satellite image

2.3.7. Treeland

Grey willow (*Salix cinerea*) dominates along the river bank and the lake shoreline. This species is present in the field in association with cabbage tree and other scrub and exotic trees (such as poplar or pine) (Fig. 28).

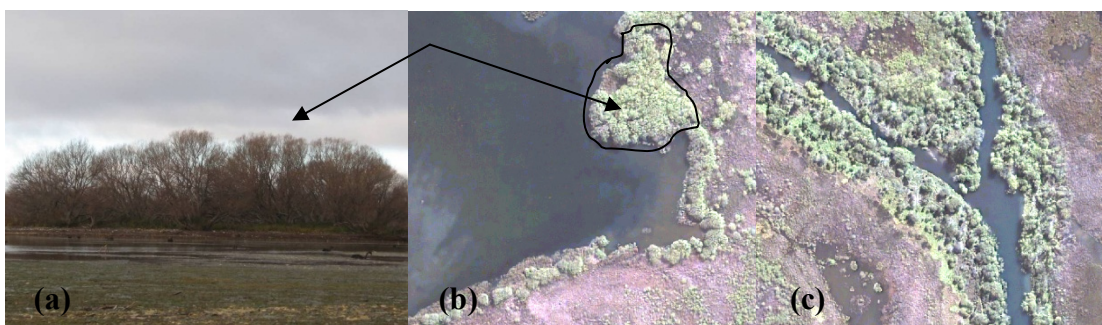


Figure 28: (a) Grey willow trees in the field; (b) as visible in the QuickBird satellite image; (c) willow trees making a riparian buffer along Tongariro River

2.4. Image classification

The most widely used method for extracting information on surface cover from remotely sensed data is image classification. With this technique, each image pixel is allocated exclusively to one of a small number of categories. The resulting thematic map can be used to estimate the area of each category. The field survey helped towards precise classification using standard and advanced image classification techniques.

To identify and isolate particular terrestrial features and proceed in a smooth and systematic manner, the data need to be grouped in a suitable framework. Unsupervised and supervised classification procedures (explained in the following sections) were adopted for identifying different land features. For the moment, different landcover features are classified using structural classes. Structural level classification is concerned with the general growth form or structure (i.e. physiognomy) of vegetation, or leading type of ground surface (Johnson and Gerbeaux, 2004). These classes are mentioned below:

1. Scrub
2. Shrubland
3. Reedland
4. Rushland
5. Sedgeland
6. Grassland
7. Emergent macrophytes
8. Submerged macrophytes
9. Non-vegetated substrates

2.4.1. Unsupervised classification

The unsupervised classification process uses “Iterative Self-Organizing Data Analysis Technique Algorithm” (ISODATA) which repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. “Self-Organizing” refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration.

The ISODATA utility repeats the clustering of the image until either:

- A maximum number of user-specified iterations has been performed, or
- A maximum percentage of unchanged pixels has been reached between two iterations.

To avoid this algorithm from running indefinitely, maximum number of iterations was set to 6 while convergence threshold was set to 95% which means that as soon as 95% or more of the pixels stay in the same cluster between one iteration and the next, the utility should stop processing. In other words, as soon as 5% or fewer of the pixels change clusters between iterations, the utility stops processing.

QuickBird 2.4m multispectral data were used for the physiognomic level classes. The resultant image (as shown in Fig. 29) was classified into 75 spectrally discrete clusters which were visually interpreted and recoded into 13 different thematic types.

Class Names	Color	Area
Unclassified		0
Water		207.946
Substrate		69.2963
Shallow water		34.2605
Submerged macrophytes		124.265
Emergent macrophytes		18.3352
Reeds		144.465
Rushes		18.3485
Shrub (Kanuka/Manuka)		69.6943
Scrub & Treeline (willow)		56.5235
Sedgeland		21.145
Grass		34.5514
Bare Soil/Impervious		20.084
Confusion b/w pine/shade		7.30714

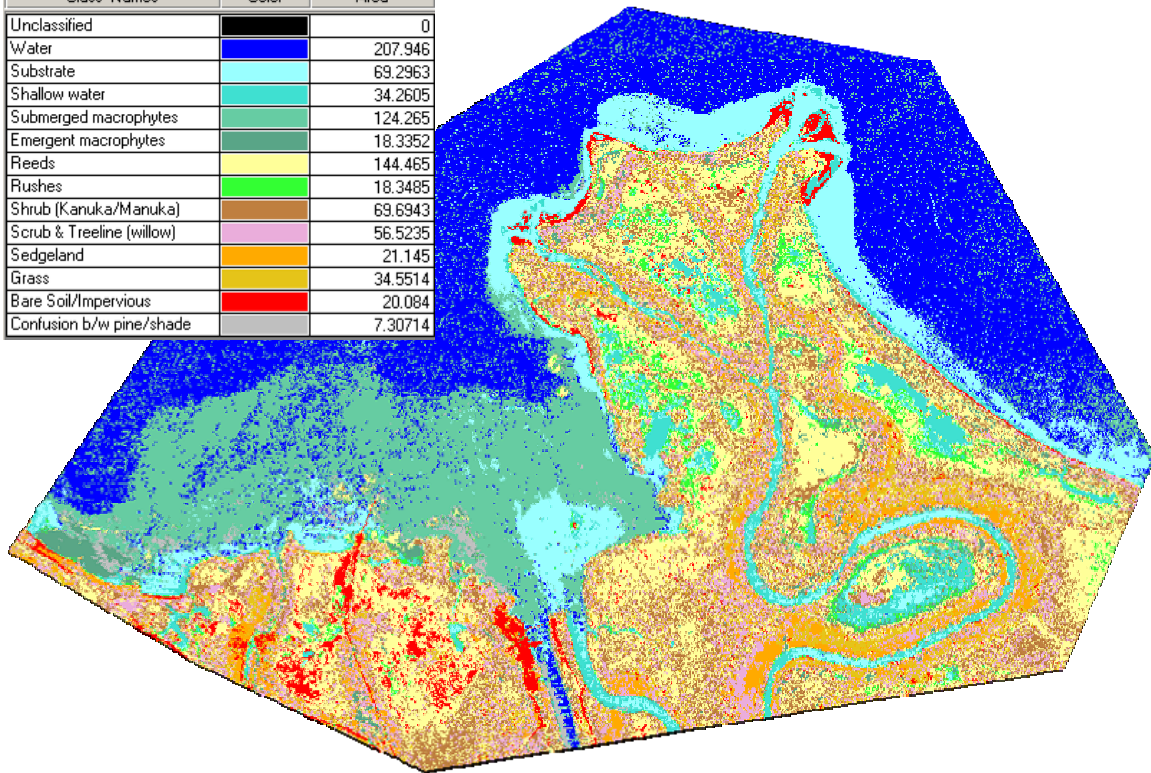


Figure 29: Unsupervised classification of QuickBird multispectral data, recoded into 13 landcover classes along with the colour index and surface area of these classes.

2.4.2. Supervised classification

Maximum likelihood is the most common supervised classification method which classifies the pixels in an image to one of the cover types or classes. It is achieved through training the sample data. In this supervised training process, pixels that represent patterns or land cover features are recognized or identified with help from other sources, such as aerial photos, ground truth data, or maps. Knowledge of the data, and of the classes desired, is required before classification. The result of training is a set of signatures that defines a training sample or cluster. These signatures are visualized in different feature spaces (as shown in Fig. 30) that define its spectral range for these classes. Each signature corresponds to a class, and is used with a certain decision rule to assign the pixels in the image file to a class.

After the signatures are defined, the pixels of the image are sorted into classes based on the signatures by use of a classification decision rule. The decision rule is a mathematical algorithm that, using data contained in the signature, performs the actual sorting of pixels into distinct class values. These decision rules are either parametric or nonparametric. For the supervised classification both nonparametric and parametric decision rules were applied which resulted in the following Fig. 31.

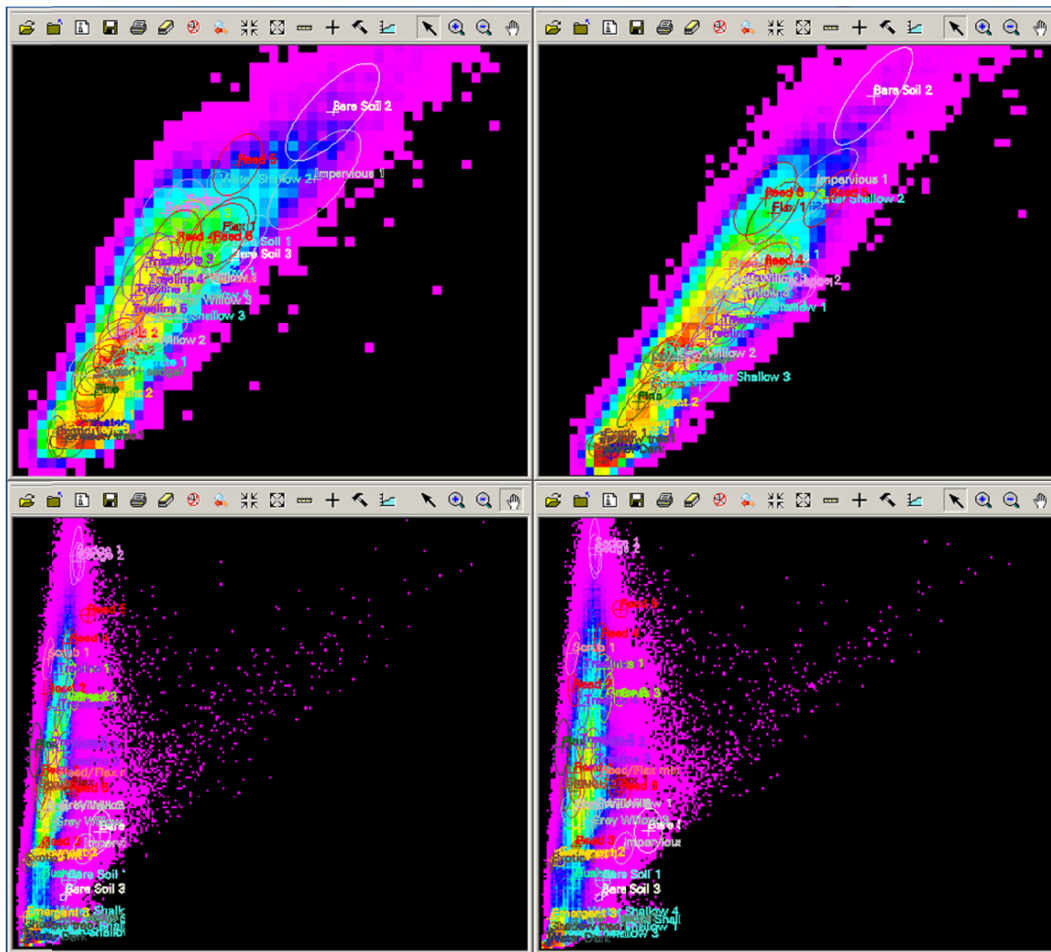


Figure 30: Distribution of training classes on different feature spaces. Top Left: band1 vs. band2; Top Right: band2 vs. band3; Lower Left: band2 vs. band 4 and Lower Right: band3 vs. band4.

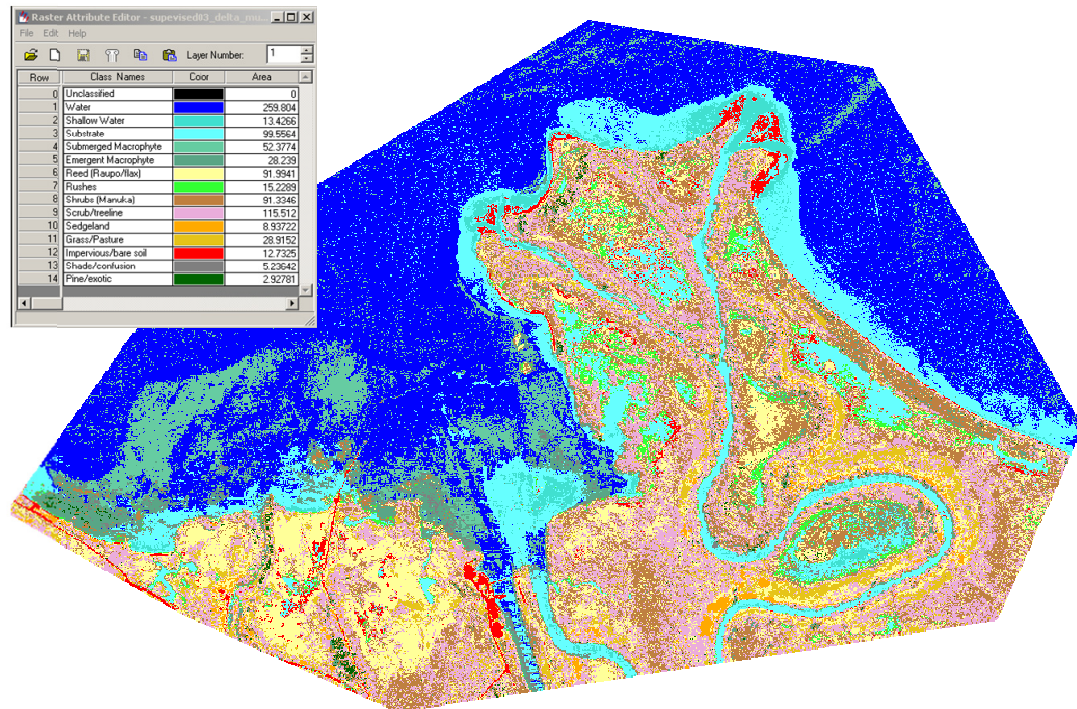


Figure 31: Supervised classification of QuickBird 2.4m multispectral data along with the colour index of classification types and their surface area.

2.4.3. Subpixel classification

IMAGINE Subpixel Classifier is a suite of processing programs that prepares image for classification, derives signatures, and performs Material of Interest (MOI) classification. The basic steps in processing an image are:

Preprocessing: It is an automated process that must be run prior to initiating other subpixel classifier processes. This process surveys the image for backgrounds that will be removed during signature derivation and MOI classification.

Environmental Correction: Environmental Correction compensates for unwanted spectral variations in scene pixels. These variations are caused by differences in atmospheric and other environmental conditions. The process automatically calculates environmental correction factors and outputs them to a file. One of the benefits of this correction is that signatures derived from the corrected images are scene-independent. This means that signatures derived from a scene may be used for classification in other scenes covering different geographic regions or having different acquisition times (but the same sensor).

Signature Derivation: The Signature Derivation process allows the development of a signature (if required) for materials that occupy either 'all of the pixel' (whole-pixel) or part of a pixel (subpixel). In either case, the signature developed can be used to make both whole-pixel and subpixel detections. Whole pixel occurrences of the signature material are the best source of training set pixels. Pixels that contain less than 90% of the signature material (subpixel occurrences) can also be used effectively but require estimating the Material Pixel Fraction (MPF) for the signature material.

Signature Combiner: It allows existing signatures and environmental correction factors to be combined for input into the IMAGINE Subpixel Classifier Multiple Signature Classifier among other things.

Material of Interest (MOI) Classification: It is the process of finding those pixels within the scene which have spectral properties that are similar to a given signature material of interest. This process applies a signature to an image to locate pixels containing the material of interest (MOI). Output from MOI Classification is an image that indicates the location of the MOI within the original image. The classification image is made up of output classes that indicate the fractional amount of material within a given pixel.

Subpixel classification was applied initially on a Landsat TM data using vague data entry parameters to identify exotic trees (mainly pine) within the study area. The subpixel analysis shows some success, however some misclassified pixels are also visible (as shown in Fig. 32).

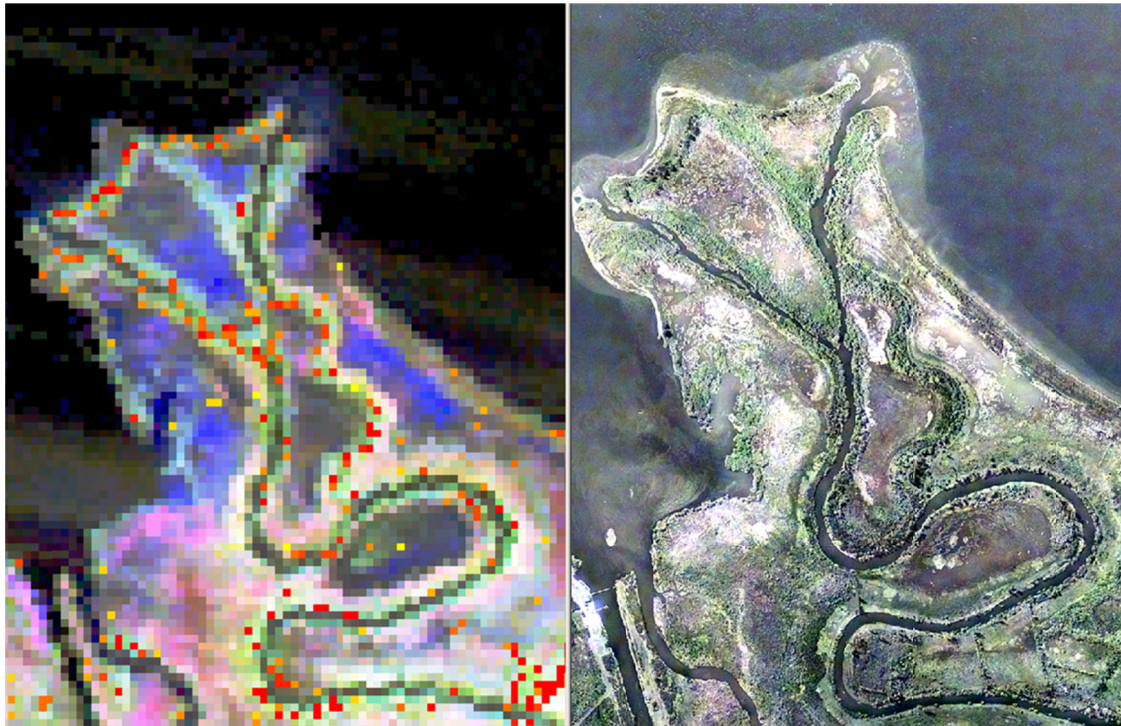


Figure 32: Subpixel distribution of exotic tree species (mainly *Pinus radiata* and *Populus sp.*) overlaid on LANDSAT TM indicating red as >90% and yellow as up to 20% MOI (on the left) while high spatial resolution WRAPS aerial data fused with LANDSAT TM is highlighting the overall area in visible bands 3,2,1 as R,G,B (on the right).

Subpixel distribution of shrub (mainly manhuka/kanuka) was developed using ALOS AVNIR-2 10m resolution data and classification results are shown in Fig 33. Preliminary results indicate that shrubby vegetation is relatively overestimated if its distribution is based on per-pixel classification (see right hand side image in Fig 33) where all the yellow pixels are representing shrub. Using sub-pixel classification, existence of shrubby plants have been represented with yellow pixels (as low as 20%) to orange (from 40%-60%) to red pixels (as high as 90%) shrub per 10m pixel of ALOS AVNIR-2 data (see left hand side image in Fig 33).

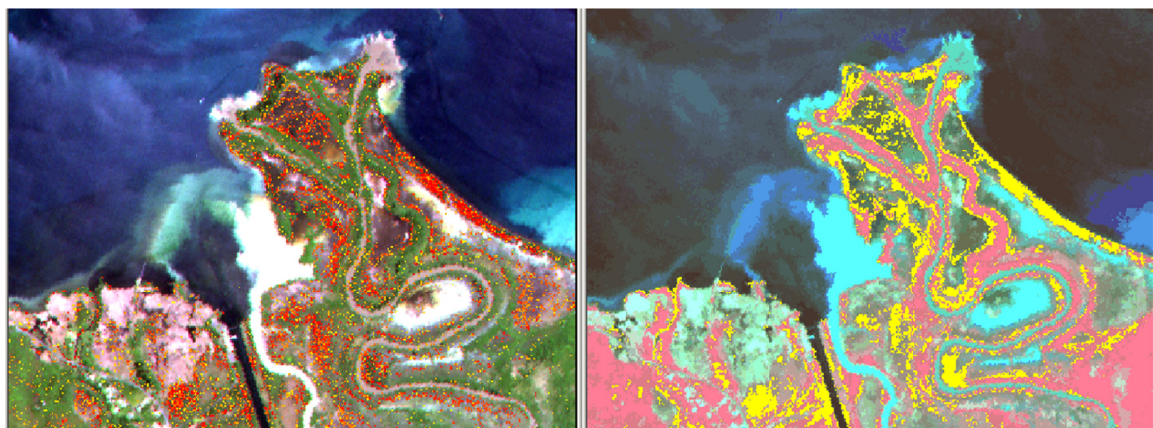


Figure 33: Subpixel distribution of shrub overlaid on ALOS AVNIR-2 data (left) and unsupervised classified image showing distribution of shrub as yellow colour (right).

2.5. *In situ* reflectance data of dominant flora

To improve the accuracy of classification, it was suggested to generate an *in-situ* reflectance of significant end-members. *In-situ* reflectance data can help the lowermost level of classification (i.e. composition of vegetation) and allows wetland types to be named from one or more of the dominant plants in the vegetation.

The University of Waikato has Ocean Optics USB2000 fibre optic spectrometer available with it. This spectrometer required few modification (such as single line fibre probe and cosine corrector) before it could be used in the field for the purpose of capturing reflectance data of dominant flora. To calibrate absolute spectral response, a calibrated light source is also needed. The equipment shortfall has been identified, and it will be ready to use in the field for the *in-situ* reflectance data capture from this summer.

To experiment with the equipment, a spectral response of bush lily (*Astelia sp.*) leaf under mixed incandescent and florescent light condition was generated which showed improper reflectance peaks (Fig. 34). However, with the proper calibration in the sunlight, absolute reflectance curves can be achieved.

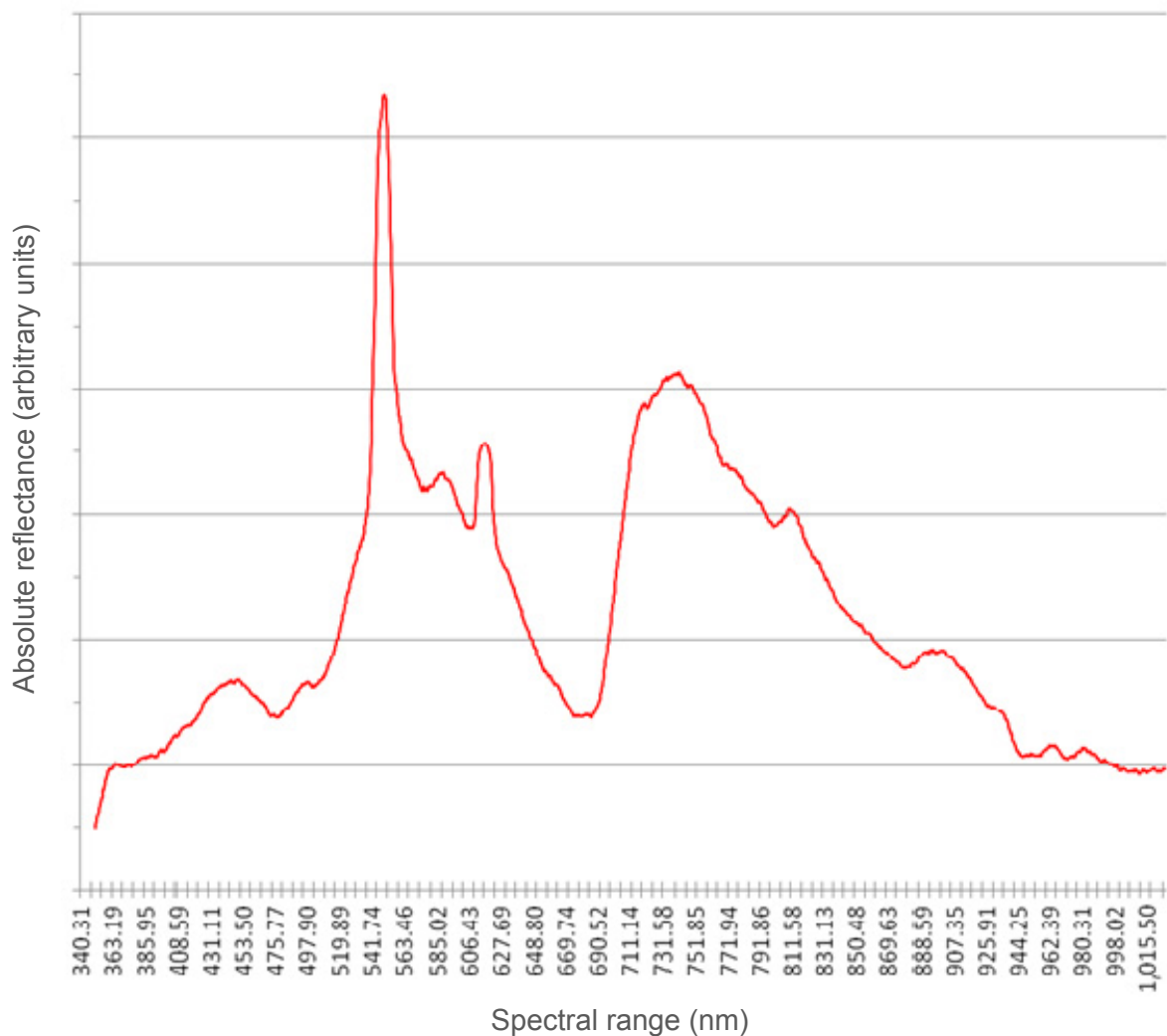


Figure 34: Reflectance curve of *Astelia sp.* using digital spectrometer

Discussion and Recommendations

The evaluation of different image processing techniques (including data fusion and image classification) highlight the effectiveness of high resolution satellite data towards delimiting structural level wetland and submerged habitat types for the study area. As far as *in-situ* reflectance data collection in the field is concerned, the shortfall of the equipment has been identified and it will be addressed in the coming summer prior to the field visit.

Detailed discussion on the results of the experiment has been discussed in the following categories as;

3.1. Data fusion techniques

There were 4 spatial resolution merging techniques applied. All the data fusion methods were found to improve the spatial resolution and the features present in the image. Significant observations related with these merging techniques are described as:

- PCA resolution merge retained pixel radiometry (i.e. colour balance) of the input multispectral image, however, it produced a pixelated result particularly when used with nearest neighbourhood resampling technique. The outcome was visually not appealing due to this pixelated effect.
- HPF resolution merge resulted in a blurry (like a water colour) effect in the outcome data. This technique offers a control to adjust the weighting of the spatial content in the merge.
- IHS resolution merge has an inherent limitation to merge high spatial contents with the three band data at a time however modified IHS technique works by assessing the spectral overlap between each multispectral band and the high resolution panchromatic band and weighting the merge based on these relative wavelengths. Therefore, it worked best when merging images (and bands) where there is significant overlap of the wavelengths. This technique can be used to merge different sensors (such as merging SPOT 4 data with Landsat5) however its utilisation for grey scale data from colour aerial imagery (i.e. visible range panchromatic data) did not produce good results when merged with LANDSAT.
- Subtractive resolution merge is a new technique which shows higher degree of colour balance with the original multispectral image. It offers a control to adjust the weighting of spatial content in the merge. The mean of the merged data shows the best match with the input multispectral image, its higher standard deviation value indicates wider distribution of data in the histogram. These comparisons highlight that the subtractive resolution merging technique is the most appealing and can be investigated as a possibility for future data processing. Its major disadvantage is its ability to deal with only 4 band multispectral data. Knowing the fact that the future

spatial data for the Waikato Region is either 4 band SPOT or QuickBird images, this technique will be useful to merge either WRAPS images or QB panchromatic data with the multispectral data source. A degraded spatial resolution (i.e. 2.5m resolution) WRAPS coloured aerial photo-mosaic was successfully turned into a greyscale image which when merged using this technique with 30m Landsat data successfully improved its details. A limited literature is available on how the ‘subtractive resolution merge technique’ works in practice. Further investigation in this direction can improve its use for this research.

3.2. Classification and accuracy

Results from the initial per-pixel classification (unsupervised and supervised) clearly show limitations (such as misclassification of features) when applied on 4m multispectral QuickBird data. In general, supervised classification has provided more control to classify different features over unsupervised technique. To an extent, this technique identified tall trees (mainly pine and poplar) as a separate class whereas unsupervised could not discern between shade and dark reflection of tall trees.

The classification results of the supervised and unsupervised techniques are listed in Table 5.

Table 5: Per-pixel classification based area estimation of different feature classes using QuickBird satellite data

Class Name	Unsupervised		Supervised	
	Area (Ha)	Percentage	Area (Ha)	Percentage
Water	207.9	25.16	259.8	31.45
Substrate	69.3	8.39	99.6	12.06
Shallow water	34.3	4.15	13.4	1.62
Submerged macrophytes	124.3	15.04	52.4	6.34
Emergent macrophytes	18.3	2.21	28.2	3.41
Reeds	144.5	17.49	92.0	11.14
Rushes	18.3	2.21	15.2	1.84
Shrub (Kanuka/Manuka)	69.7	8.44	91.3	11.05
Scrub & Treeland	56.5	6.84	115.5	13.98
Sedgeland	21.1	2.55	8.9	1.08
Grass	34.6	4.19	28.9	3.50
Bare Soil/Impervious	20.1	2.43	12.7	1.54
Confusion (tall tree/shade)	7.3	0.90	5.2	0.63
Exotic trees	-	-	2.9	0.35
Total	826.2	100.00	826.2	100.00

Although, both per-pixel classification techniques have yielded some results but these results require accuracy assessment process to evaluate classified image files and establishes error matrix which simply compares the reference class values to the assigned class values to gauge an overall accuracy.

Similarly, for the sub-pixel level classification, initial results for some individual classes have been developed. As in sub-pixel classifier, each pixel tells the percentage of a

particular class against the mixing of the other features, the area estimation of that particular class is less than the area of a pixel unless it is classified as a pure pixel. Table 6 shows the number of pixels classified as ‘shrub’ and their associated area coverage based on unsupervised and subpixel classification for 10m ALOS AVNIR-2 data.

Table 6: Comparison of area estimation using per-pixel and sub-pixel classification for 10m ALOS AVNIR-2 satellite data

Class Shrub	Unsupervised	Sub-pixel
No. of Pixels	8157	8525
Area (Ha)	81.57	56.50

3.3. Conclusion

This trial application in the Tongariro River delta and South Taupo wetland region identifies the effectiveness of sub-pixel classification against standard per-pixel classification techniques. In short, it is a procedure that classifies one target class at a time and generates its distribution map based on its purity per pixel.

A quick reconnaissance visit to the field helped in interpreting pure pixels from the image. Similarly, high resolution data such as aerial photographs can be used for to refine training areas and estimate classification accuracy. Different data fusion techniques suggest that subtractive resolution merge performs better than other tested techniques and improved the spatial content of the multispectral data as well as retain its spectral range.

This trial has successfully demonstrated that the use of subpixel classification and data merging. In order to effectively map the entire Waikato Region, there are two options that EW could consider.

1. EW could use WRAPS aerial photography 2007/08 data with the LUCAS project SPOT images for the Waikato Region as these images are captured at a similar time. The subtractive resolution merge technique, combined with sub-pixel classification, could be applied to map target species such as macrophytes.
2. There is a strong likelihood that KIWImage data may take up to 3 years to capture data for the Waikato Region. Data merging and subpixel classification techniques can map wetland vegetation using KIWImage data. This will provide high spatial resolution data suitable for detailed vegetation mapping.

3.4. Recommendations for future work

Both the options that are discussed above have certain advantages as well as disadvantages. For example, KIWImage-QuickBird offers spectrally more sound data (as it includes blue, green, red and NIR) for aquatic mapping, while LUCAS SPOT has a quick revisit and is cost effective as well as being easy to process. However, LUCAS SPOT’s 10m multispectral data lacks the blue band, which will restrict identification of deep submerged macrophytes. A high spatial (0.625m) WRAPS 2008 photo-mosaic can improve the visual content and assist with overall vegetation mapping.

An *in-situ* reflectance database of the local vegetation will help identify the true mixing of different vegetation types. It will be useful to analyse, how these two approaches (i.e.

SPOT/WRAPS or KIWImage) address 'vegetation composition level mapping' in the quickest time and with the least human input for data processing.

We recommend the following work in relation to the data sets discussed above:

1. Test subpixel classification and subtractive resolution merge techniques on other lakes and the lower Waikato River, and if possible around whitebait spawning sites to map different habitat types. This includes researching the accuracy of the classification using SPOT multispectral and WRAPS 2008 datasets as well as any other data (e.g. KIWImage), if available.
2. Acquire in-situ reflectance data of the dominant or important aquatic plant species.

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