Applications of Remote Sensing and GIS to Wetland Inventory: upland bogs

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Abstract

Vegetation cover was classified via varied image analysis procedures conducted on three *Systeme Pour l'Observation de la Terre* (SPOT) medium resolution satellite images acquired by the Taieri and Southern Rivers Programme, Zoology Department, University of Otago. Results are compared to the vegetation classification included in the New Zealand Resource Inventory (NZLRI). These comparisons allowed the resolution and accuracy of each data set to be assessed using a case study habitat: upland bogs in the upper catchment of the Taieri River, Lammerlaw Range, Otago.

Keywords and phrases: SPOT, vegetation classification, wetlands, NZLRI, GIS, remote sensing.

1 Introduction

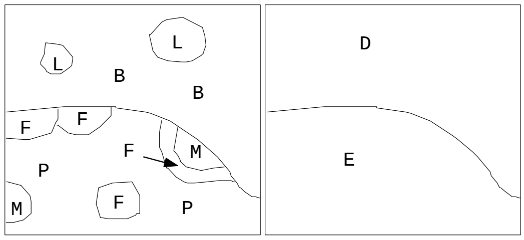
Geographic information systems (GIS) are used to collect, store, analyse, disseminate and manipulate information that can be referenced to a geographical location. Remote sensing is the technique of obtaining information about an object, area or phenomenon using a device that is not in contact with the object, area or phenomenon under investigation (Lillesand and Kiefer, 1994). The integrated use of GIS and remote sensing can be applied to describe ecosystems, identify a species distribution and habitat use, and to organise conservation strategies for both endemic and introduced species (Scott *et al*, 1987).

As with many other types of analyses, the accuracy of geographic data is critical in determining its utility and relevance for specific applications. This accuracy depends on the type of remotely sensed data used, the interpretation of these data and the spatial analysis that is carried out to produce information for planning and management. For remote sensing and GIS to be useful for conservation objectives, the characteristics and applicability of the data used and the objectives of each study must be thoroughly defined *a priori*.

The aim of this paper is to explore two problems inherent in applying GIS and remote sensing techniques to habitat inventories: data accuracy and resolution. Vegetation cover was classified using several image analysis procedures conducted on three *Satellite Pour l'Observation de la Terra* (SPOT) medium resolution satellite images as part of the Taieri and Southern Rivers Programme, Zoology Department, University of Otago. Results are compared to the vegetation classification included in the geographical database of the New Zealand Land Resource Inventory (NZLRI), National Water and Soil Conservation Organisation (NAWASCO, 1975-79; Newsome, 1992). The information content of each data set was assessed using a case study habitat the upland bogs present in the Great Moss Swamp complex in the upper catchment of the Taieri River, Lammerlaw Range, Otago. The Great Moss Swamp complex contains numerous upland bogs. Upland bogs are unique habitats that are relatively small in size, ranging from tens of square meters to tens of hectares and their limited extent makes them difficult to remotely sense and map accurately. Rather than a uniform habitat type, upland bogs represent an assemblage of wetlands ranging from "plumb pudding" bogs, liverwort bogs, sedge meadows, meander ponds and sphagnum bogs (Stephenson, 1983). Upland bogs are important because of their plant biodiversity and because they function as "sponges" that regulate the yield of water supplied to streams in the lower Taieri catchment (Johnson, 1986).

1.1 Remote Sensing of Wetlands

The accuracy and utility of classifications of wetlands from remotely sensed data are dependant on resolution, types of spectral bands, ground referenced effort (gathering of descriptive field data to aid interpretation and test classifications), computer analysis techniques and actual detail required for final outputs. There are a number of sources of commercial imagery available in New Zealand. Imagery can be obtained in New Zealand through Landcare Research NZ Ltd and Land Information New Zealand (LINZ), and TerraLink. Archived cloudless coverage of the country is available in Landsat MSS images (full coverage) and SPOT images (full coverage on-going). Landsat TM coverage is limited because programmed coverage of New Zealand is currently not funded. Because of the acknowledged importance of wetland ecosystems, (Stephenson, 1983, Williams, 1990) the methodology of remote sensing these areas and the ability to accurately delineate wetland resources via satellite imagery has received considerable attention (Johnson and Barson, 1993, Rutchey and Vilcheck, 1994). Johnston and Barson (1993) evaluated Landsat TM data for the Australian wetland inventory and classification by comparing data from three ground surveyed and mapped study sites with mapping and classifications derived from satellite imagery. The Landsat data were in poor agreement with the previously mapped vegetation, primarily because of the inability of the imagery to accurately define the species composition of the vegetation. Rather than define species composition, satellite image classifications of vegetation seem most efficient at defining vegetation density, vigour and moisture status. A study by



(a, Scale 1:5000) (b, Scale 1:50000)

Figure 1: Influence of minimum mapping unit size on interpretation of vegetation. (a): Forest types mapped using a small MMU: B=Birch; L=Larch; F=Fir; M=Macrocarpa; P=Pine. (b): Forest mapped with large MMU: D=Deciduous; E=Evergreen.

Jensen *et al*. (1986) also highlighted the importance of the dimensions of the minimal mapping unit (MMU). This unit defines the smallest size of a real entity that can be accurately interpreted (Figure 1). Whether the spatial precision and accuracy of a given classification is appropriate for a given GIS project depends on the minimal mapping unit.

Jensen *et al*. (1986), required a MMU of less than 0.5 ha for their study emphasising that detailed classification and mapping of wetlands often requires data very small MMUs. This level of detail generally requires high-resolution data that has been extensively ground referenced and combined with aerial surveys to enhance spatial detail. However, because of their large MMU, available data sets often have a restricted value for conservation management planning. For example, the National Wetland Inventory maps of the United States are compiled at a scale of 1:100,000 and provide an MMU of approximately 6.5 ha. However many of the local and state regional authorities require maps with MMU's of less than 4 ha for planning and management activities. The need of the conservation managers and available spatial data sets are clearly incompatible.

1.2 Vegetation Cover in New Zealand

New Zealand's vegetation has been described in detail in many publications (Hunter and Blaschke, 1986; Newsome, 1987; Wardle 1991). The primary digital database available at a scale suitable for landscape management objectives is the New Zealand Land Resource Inventory (Newsome, 1995). The NZLRI (National Water and Soil Conservation

Organisation, NWASCO 1975-79) was originally produced as 1:63360 scale maps with accompanying interpretation worksheets. It includes spatial data on land-use capability, rock, soil, slope, erosion and vegetation. These data have been updated on numerous occasions since the first publication and are presently available as a 1:50000 geographic database. The Vegetative Cover of New Zealand (VCNZ, Land Management Group, Landcare Research Ltd NZ, 1987), is another important source of data describing generalised vegetative cover. Produced at a nominal scale of 1:1000000 because of time and funding constraints, these data are nonetheless suitable for national and regional planning and for educational purposes (Newsome, 1987). These data accurately describes communities down to a MMU of 20-60 ha and 500 ha, respectively. However, both databases have become outdated due to increased development of exotic forestry and reversion of cleared areas to shrubland (Newsome, 1995). In the NZLRI, vegetation is classified according to Hunter and Blaschke (1986). For a detailed description of the New Zealand Land Resource Inventory vegetation cover classification method see (Hunter and Blaschke, 1986).

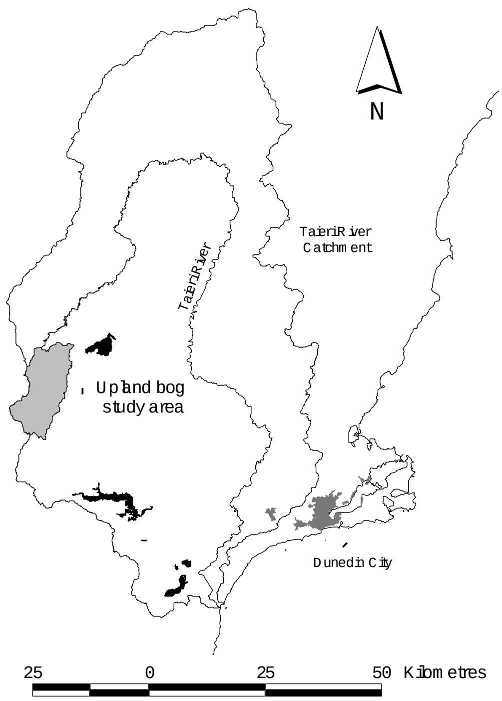


Figure 2: Upland bog study area

2 Methods

2.1 Study area

The study area encompasses the upper reaches of the Taieri River catchment (Figure 2).

2.2 Vegetation Classification in the study area

GIS information layers were produced from two sources (NZLRI and SPOT imagery) to assess the influence of data type on the perception of the numbers of upland bogs and their spatial distribution.

Vegetation cover GIS layers consisted of:

1. Sub scene classification of a SPOT satellite image.
2. The New Zealand Resource Land Inventory data set.

2.2.1 Upland bog classification – Satellite imagery

A sub-image (the upland bog study area) was sub-sampled from a mosaic of three SPOT (HRV1, 20-meter resolution) multispectral images that were commissioned on the 26th of February 1994. Computer aided interpretation of the images was conducted using ERDAS Imagine™ image processing software and ESRI™, ARC/INFO and ARCVIEW GIS software. A supervised classification was then conducted on the sub-image. This approach produces more accurate results that an unsupervised classification if areas of interest are ground surveyed in detail (Lillesand and Kiefer, 1994). Training data from this image were used to conduct a supervised classification of the upland bog study area. Vegetation cover was represented by nine classes (Table 1). The overall classification accuracy was 89% (Kappa 0.88). The error matrix is shown in Figure 3.

2.2.2 NZLRI classification of study area

A GIS coverage of the study area was prepared using NZLRI data (Figure 4). This area was extracted from the NZLRI database for the South Island of New Zealand. Vegetation cover present in each map unit was interpreted from the classification codes provided by the NZLRI (Table 2).

No formal measure of the accuracy of the NZLRI is given in the data information manual. However, Newsome, (1992) noted that the data had become outdated due to reversion of areas of pasture to scrubland and the planting of production forest.

Thematic Class	*Cover Description*	*Dominant Species*
Barren	Barren ground, areas of hawk weed short tussock, sweet vernal and scabweeds	Hieracium spp, Poa spp, Anthoxanthum ordoratum, Raoulia spp
Cloud	Cloud	n/a
Grassland_1	Short tussock/grazed long tussock, spear grass, recent tussock burn	Chionochloa rigidia, Festuca spp, Poa cita, Aciphylla spp,
Grassland_2	Long tussock grassland	Chionochloa rigidia, C. rubra
Pasture	Pasture grasses, brown top, cocksfoot, yorkshire fog and sweet vernal	Agrostis capillaris, Dactlyis glomerata, Holcus lanatus, Anthoxanthum ordoratum, Trifolium pratense, T. repens
Scrub	Scrub: Matagouri, sweet brier, hebe, turpentine, (intermixed with short and long tussock grasses)	Discaria toumatou, Rosa rubiginosa, Hebe spp Dracophyllum longifolium
Shadow	Areas of cloud and hill shadow	n/a
Wetland_1	Upland peat bogs, sedges, tussock and cushion bogs	Sphagnum spp, Baumea spp
Wetland_2	Seepage areas, often dominated by pasture grasses with some bog species	Trifolium pratense, T. repens

Table 1: Study area supervised classification vegetation classes.

Vegetation Code	*Vegetation interpretation*
H4 p4	Upland bog vegetation covers more than 40% of the unit, Snow tussock covers less than 40% of the unit
P2 p4 m4 m5	Low producing pasture covers more than 40% of the unit, Snow tussock, Fern, and Sub alpine scrub cover less than 40% of the unit
P3 p2 p4 m11	Short tussock grassland covers more than 40%, Low producing pasture, Snow tussock and Matagouri less than 40% of the unit
P3 p4	Short tussock grassland covers more than 40%, Snow tussock covers less than 40% of the unit
P4	Snow tussock covers more than 40% of the unit
P4 H4 m5	Snow tussock covers more than 40% of the unit, Upland bog vegetation covers more than 40% of the unit, Sub alpine scrub covers less than 40% of the unit
P4 h4	Snow tussock covers more than 40% of the unit, Upland bog vegetation covers less than 40% of the unit
P4 h4 m5	Snow tussock covers more than 40% of the unit, Upland bog vegetation and Sub alpine scrub cover less than 40% of the unit.
P4 p2	Snow tussock covers more than 40% of the unit, Low producing pasture less than 40% of the unit
P4 p2 h4 m5	Snow tussock covers more than 40% of the unit, Low producing pasture, Upland bog vegetation, sub-alpine scrub less than 40% of the unit
P4 p3	Snow tussock covers more than 40% of the unit, Short tussock grassland covers less than 40% of the unit.

Table 2: Vegetation classification of study area using NZLRI data. Vegetation codes and interpretation obtained from the NZLRI Vegetation Cover Classification and NZLRI ARC/INFO Data Manual (Hunter and Blaschke, 1986, Newsome, 1992). H4 code represents Upland bog vegetation for map units in the Old Man Range and Lammerlaw Range.

CLASS	1	2	3	4	5	6	7	8	9			Users accuracy
Barren	206	37	268	1	24	0	0	1	18		555	37%
Cloud	12	326	0	0	0	0	0	0	0		338	96%
Grassland_1	19	0	2968	161	5	1	1	0	2		3157	94%
Grassland_2	1	0	152	3723	2	21	34	40	0		3973	94%
Pasture	0	0	11	1	892	0	0	2	43		949	94%
Scrub	0	0	0	2	0	156	78	13	2		251	62%
Shadow	0	0	0	26	0	43	725	46	0		840	86%
Wetland_1	0	0	0	108	3	14	12	483	0		620	78%
Wetland_2	0	0	2	0	26	0	0	1	1029		1058	97%
										10508		
	238	363	3401	4022	952	235	850	586	1094		11741	
Producers accuracy	87%	90%	87%	92%	94%	66%	85%	82%	94%			89%

Figure 3: Error matrix for the supervised classification.

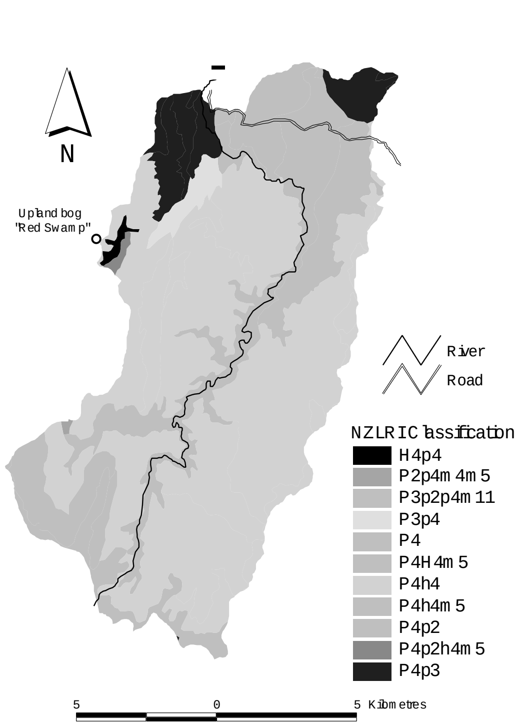


Figure 4: NZLRI vegetation classification of the study area

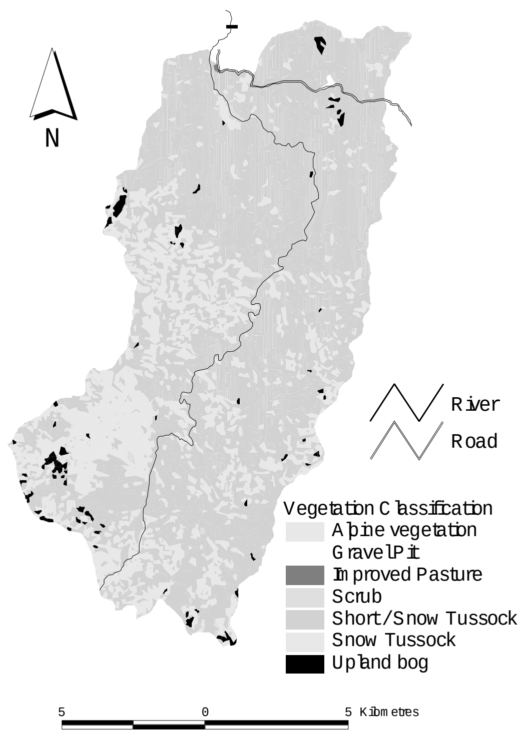


Figure 5: SPOT satellite derived vegetation classification of the study area

2.2.3 Integrated interpretation of the study area

The final satellite classification was produced by merging the supervised classification and with additional spatial information to produce a detailed map of upland bogs (Figure 5). Topographical maps have features of interest such as roads and rivers. These features were digitised from 1:50,000 maps to produce separate information layers and then superimposed to form one figure. Attribute data associated with individual polygons of the miss-classified vegetation classes in the supervised classification were re-coded to represent known cover types (Table 3). These polygons represent known vegetation classes from areas located on the ground referenced aerial photo's and ground surveys.

2.3 Identification of upland bog areas

The total number of mapped bogs was calculated from each database by summing the number of map units of each class that represented an upland bog areas greater than 1 ha in size that occurred within the study area. One hectare was chosen as the MMU because of the resolving limits of SPOT data. A standard approach to determining the MMU for a classification is to consider the resolution if the image data (20m for SPOT) and multiply by 5 on each axis (hence a MMU of 1 hectare). The classification was then generalised so the overall MMU was 1 hectare for all classes. The total coverage of each vegetation class was calculated from the different GIS databases. SPOT data provides less variable area calculations because the value calculated from actual areas of upland bogs, not a general interpretation. The supervised classification provided different totals for upland bog area and total number to that of the integrated classification. This difference is associated with the classification accuracy of each class. Pasture, which has sub-classes representing image signatures of vigorous growths of clover pasture or fodder crops are not spectrally separable from those of the vigorous growth of vegetation in the upland bog seepage's. The upland bogs-class is also confused with some tussock grassland areas. This is primarily because of the close affinity of these vegetation covers. This inaccuracy resulted in misclassification of pixels representing other vegetation covers during image analysis. The integrated classification provides greater detail because all the cover types present in

Vegetation Class	*Description*	*Species Present*	*Area (Hectares)*
Alpine Vegetation	Barren ground, areas of hawk weed short tussock, sweet vernal and scabweeds	Hieracium spp, Poa spp, Anthoxanthum ordoratum, Raoulia spp	2134.2
Gravel Pit	Excavated and barren area		12.8
Pasture	Pasture grasses, brown top, cocksfoot, yorkshire fog and sweet vernal	Agrostis capillaris, Dactlyis glomerata, Holcus lanatus, Anthoxanthum ordoratum, Trifolium pratense, T. repens	4.1
Scrub	Scrub: Matagouri, sweet brier, hebe, turpentine, (intermixed with short and long tussock grasses)	Discaria toumatou, Rosa rubiginosa, Hebe spp Dracophyllum longifolium	42.0
Short / Long Tussock	Short tussock/grazed long tussock, spear grass, recent tussock burn	Chionochloa rigidia, Festuca spp, Poa cita, Aciphylla spp,	11478.9
Long Tussock	Dense long tussock grassland	Chionochloa rigidia, C. rubra	1698.9
Upland bog	Bogs, seepage areas, sedges, tussock and cushion bogs	Sphagnum spp, Baumea spp	189.8

Table 3: Spot satellite derived vegetation map classes.

the study area were checked using aerial photo's and re-classified if needed.

Reinterpretation of the supervised classification gave rise to a small number of the upland bog map units being reclassified as another cover type and other vegetation classes classified as upland bog. The major changes occurred in the other cover classes, including barren ground being re-coded as alpine vegetation. The total area of upland bog changed to a value of 118 Ha to 189Ha and a total number of 66 map units. Because the spectral misclassifications have been removed based on specific ground knowledge and aerial photo interpretation, it can be surmised that the accuracy of the reinterpretation would be improved from that of the supervised classification. Using the NZLRI to define upland bogs information varies considerably. This variability is primarily a result of how you must interpret the vegetation classification codes present in the NZLRI database. For example, one particular unit of the NZLRI data set was classified as having upland bog vegetation as the primary cover (H4p4). Since this unit had a total coverage of 58 ha, H4 implies that upland bog covers between 40% and 100% of the total area, based upon this interpretation, upland bog vegetation must cover somewhere between 23 ha and 58 ha. Two other map units are classified as having upland bog vegetation as a secondary but still significant cover P4H4m5. Most other units classified by the NZLRI have upland bog vegetation as a minor cover component. Because one unit was coded as having significant upland bog vegetation cover, this area could be loosely interpreted as an upland bog so I have recorded it as such. (Table 4).

3 Discussion

3.1 Study area - review of data classification and spatial accuracy

The NZLRI survey is a multi-factor compilation derived from an interpretation of available single factor information, interpretation of aerial photographs and fieldwork. Within constraints imposed by classifications and scale it shows the distribution of the mapped factors at the time of compilation. Because of these constraints, users deriving or using single factor plots clearly need to be familiar with the compilation technique (Newsome, 1992). Survey data for the NZLRI were compiled in 1975-79 (first edition) and again in 1992 (second edition, Digital Geographic database) and information relating to the upland bog study area is over fifteen years old. The age and recording technique of vegetation may create problems for the user when spatially interpreting and deriving current information from the classification of vegetation. Another problem for the application of this data for environmental GIS arises from discrepancies in the NZLRI data lineage. Without accuracy assessment of interpretations, there can be no quantification of error in the number patches and area covered by a given vegetation type. Any assumptions made on the location and extent of that vegetation type are therefore questionable. However, the satellite derived classification a specific minimum value of number and area of vegetation types can be included in the results of a given GIS analysis and as an accuracy declaration of the GIS database. Given this measure of uncertainty, users of these data can immediately assess its relevance and appropriateness for a given use. The NZLRI has been described as a valuable resource management and planning tool in national and local applications (Newsome, 1992). However, it does not include a formal assessment of accuracy. Derived information on vegetation cover from this database can only reflect gross interpretations of actual land cover. The spatial detail is quite limited as seen in Figure 4. Detail is clearly reliant on the resolution and methodology by which the primary data was collected.

	SPOT supervised classification	**SPOT vegetation map**	**NZLRI**
Total Number	30	66	1
Total Area (Ha)	118	189	(553 to 4717)

Table 4: Upland bog areas (ha), number of individual mapped bogs (area greater than 1 ha).

3.2 Application of GIS for upland bog conservation management in New Zealand

At present environmental GIS is not widely used in New Zealand. Implications can be derived from my analysis for the conservation of unique ecosystems (such as the upland bogs) using a GIS based analysis. The Department of Conservation have considered utilising NZLRI data for an ecological re-interpretation of the vegetation classification to map "ecosystems" for the whole of New Zealand. Our study illustrates there are severe limitations to the use of this information toward the high-resolution analysis that this type of application would require. The most the important considerations for the use of the NZLRI database in this activity is once again, the minimum mapping unit. If the NZLRI is to be the base map to which all other information is to be registered, users would be limited to a minimal mapping unit of greater than 20 ha and the uncertain boundaries to which the units of the NZLRI are classified. For some habitats (e.g. upland bogs of the Great Moss Swamp complex) this resolution will not provide the locational, or descriptive accuracy that is required for their resource management objective. For example, a plot of the frequency of upland bogs of varying size identified in the upland bog study area illustrates that all of these habitats are smaller than 20 ha in size, with most smaller than 5 hectares in size (Figure 6). Clearly the diversity of these habitats would be unrepresented, and if conservation priorities using GIS technology were based on the NZLRI vegetation classification alone they would have to apply to very large habitats.

The problems associated with scale have been highlighted in a review of a major environmental GIS project in the United States (Short and Hestbeck, 1995). The GAP analysis programme (Scott, *et al*, 1993; Scott, 1994) is a state wide landscape-scale assessment of biotic resources throughout the United States. The results of this programme are to be used to estimate biodiversity and organise conservation management objectives of varied ecosystems by the National Biological Service (NBS). GAP databases are used to map variables such as vegetation, animal presence, biodiversity and habitat use, at 1:100000 scale (MMU 100 ha). Short and Hestbeck, (1995) state that the hypothesis that landscape-scale maps with a MMU of 100 ha adequately depict or differentiate habitats necessary for individual species is likely to be false. Because many species have ranges of less than a few hectares, the critical habitat criteria cannot be accurately determined with a MMU of 100 ha. Because land-scape scale maps do not record habitats smaller than the MMU they usually cannot identify small wetlands, riparian zones and cannot map the distribution of species, species density or habitat quality (Scott *et al*, 1993). Because the MMU is set at a large scale of resolution, these land-scape scale predictors of habitat biodiversity probably will not provide legally defensible or useful data to conservation managers (Short and Hestbeck, 1995). In our study we have compared the utility and relevance of a GIS based on a large scale historical inventory (NZLRI) with one based on contemporary remote sensing (SPOT). The various data sets used in the analysis all have their weaknesses, but the objective of our analysis was not to discredit any one particular database, but to highlight the need to assess the appropriateness of GIS data before any accurate spatial interpretations can be performed. The NZLRI data is much less appropriate than SPOT data for investigation of the number and area of upland bogs or for other habitats that occur in patches of less than 20 ha in size. Large satellite images such as the SPOT image require exhaustive analysis and interpretation before they can be used to answer complex ecological questions. However, benefits exist in the

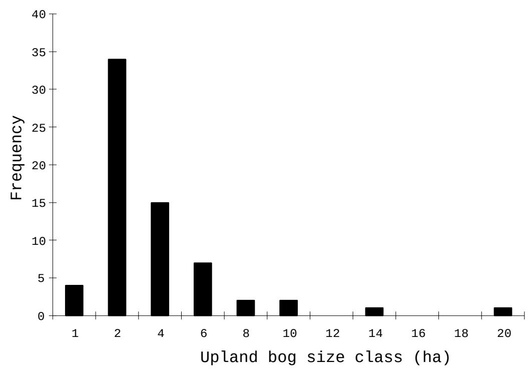


Figure 6: Frequency histogram of upland bogs of varying size classes.

use of either or both databases if the limits of the application of each database are assessed thoroughly.

From the results of this study we make the following recommendations regarding the use of GIS and remote sensing to inventory the upland bogs of the upper Taieri River, Otago and the applied use of GIS databases for conservation strategies.

1. High resolution data is required for the inventory of upland bog formations by remote sensing techniques. These data have to be extensively ground referenced to provide a method to thoroughly assess errors in the automated classification.

2. SPOT image data, though of adequate resolution for upland bog identification, lacks the spectral information content that other satellites (Landsat TM) provide. This in turn increases the confusion between spectral classes. Vegetation classifications produced from SPOT data therefore require some classes of vegetation to be aggregated as a super-class to overcome inaccuracies in automated classification.

3. New Zealand Land Resource Inventory geographic data is not appropriate for detailed classification of small habitats (<20 ha). If re-interpretation is based only on the vegetation present in the NZLRI attribute data, many small habitats would not be represented in the GIS database.

4. Conservation management organisations such as the Department of Conservation have to fully research their application of Geographic Information System technology. Geographic data must be evaluated as with any other scientific data. Its availability, integrity, accuracy and appropriateness for ecological/environmental use should be determined before GIS analysis is considered a panacea for a given project.

5. Because the intrinsic resolution of GIS data determines the minimal mapping unit studies involving detailed assessment of land cover and habitat patches must define a required resolution for a given objective. Clear *a priori* statements of objectives will allow available geographic data sources to be assessed for their ability to meet the project output requirements.

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