Environ Manage (2007) 39:316–325
DOI 10.1007/s00267-005-0223-1

RESEARCH

Rapid Mapping and Prioritisation of Wetland Sites in the Manawatu–Wanganui Region, New Zealand

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Received: 20 July 2005 / Accepted: 10 April 2006

Abstract The extent of wetland in New Zealand has decreased by approximately 90% since European settlement began in 1840. Remaining wetlands continue to be threatened by drainage, weeds, and pest invasion. This article presents a rapid method for broad-scale mapping and prioritising palustrine and estuarine wetlands for conservation. Classes of wetland (lacustrine, estuarine, riverine, marine, and palustrine) were mapped using Landsat ETM+ imagery and centre-points of palustrine and estuarine sites as ancillary data. The results shown are for the Manawatu–Wanganui region, which was found to have 3060 ha of palustrine and 250 ha of estuarine wetlands. To set conservation priorities, landscape indicators were computed from a land-cover map and a digital terrain model. Four global indicators were used (representativeness, area, surrounding naturalness, and connectivity), and each was assigned a value to score wetland sites in the region. The final score is an additive function that weights the relative importance of each indicator (i.e., multicriteria decision analysis). The whole process of mapping and ranking wetlands in the Manawatu–Wanganui region took only 6 weeks. The rapid methodology means that consistent wetland inventories and ranking can now actually be produced at reasonable cost, and conservation resources may therefore be better targeted. With complete inventories and priority lists of wetlands, managers will be able to plan for conservation without having to wait for the collection of detailed biologic information, which may now also be prioritised.

Keywords Conservation management · Landsat ETM+ · Landscape indicators · Mapping · Multicriteria decision analysis · Prioritisation · Wetland

Introduction

In New Zealand, wetlands are important habitats for indigenous birds and freshwater fish. They also have high recreational and cultural values and perform vital ecosystem services, such as improving water quality and decreasing flood risks. Natural wetlands once covered extensive parts of the country, but their area has decreased markedly since European settlement began in 1840, and they are now among the most at-risk ecosystems. *The State of New Zealand's Environment* (Ministry for the Environment 1997) estimated a loss of approximately 90% of wetlands within a century and a half, which is among the most rapid rates in the world. This dramatic decrease has resulted in major biodiversity losses – and that are continuing. As a signatory to the Convention on Biologic Diversity and the Ramsar Convention on Wetlands, New Zealand is obliged to protect wetlands. Under the Resource Management Act, regional councils are responsible for protecting natural areas, including wetlands. Consequently, wetland protection is becoming a priority, and environmental managers need cost-effective management tools for monitoring and protection.

As a first goal toward wetland conservation, environmental managers should compile an exhaustive

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inventory of wetland sites. This inventory can be collated from a combination of local knowledge, reports on protected areas, and interpretation of aerial photographs (Mitsch and Gosselink 2000); but it is time-consuming, often taking years for large regions. Interpretation of satellite imagery offers some advantages compared to interpretation of aerial photographs (Ozesmi and Bauer 2002). For example, standardised imagery permits automatic classification, which is rapid and repeatable (Chopra and others 2001; Houhoulis and Michener 2000; Kingsford and Thomas 2002; Klemas 2001; Nelson and others 2002). However, small or narrow wetlands are difficult to differentiate because of the lack of spatial resolution, and different wetland types are difficult to separate because of confusion in their spectral signatures (Gluck and others 1996). Consequently, wetlands have usually been studied at the site scale (Harvey and Hill 2001; Henderson and others 2002; Kushwaha and others 2000; Schmidt and Skidmore 2003). When studied at a regional scale, satellite data are usually associated with ancillary data and visual interpretation (Kingsford and others 2004).

Once an inventory is available, an evaluation of each wetland site is needed to allocate conservation resources efficiently. Many published articles discuss the assessment and ranking of natural areas according to their biodiversity value for decision making; a thorough review can be found in Margules and Pressey (2000). Wetlands are generally assessed on their ecologic condition (e.g., species diversity and rarity). Different ranking systems have been designed focus on flora (Fensham and Price 2004; Thompson and others 2002; Turpie and others 2002), on fauna (Turpie 1995), or on a specific ecologic service such as connectivity (Kentula 1997), sediment trapping (Vellidis and others 2003), improvement of water quality (Richardson and Gatti 1999), or flood control (McAllister and others 2000). Such information is rarely available for all wetland sites in a region and is therefore more applicable at a local scale.

We present a rapid method for mapping and prioritising wetlands at the regional scale that does not require field-based information. Broad classes of wetlands (lacustrine, estuarine, riverine, marine, and palustrine) were mapped using Landsat Enhanced Thematic Mapper (ETM+) imagery and using information on global positioning system location of palustrine and estuarine sites as ancillary data. Wetland sites were ranked using landscape indicators that are easily and consistently retrieved from satellite images and soil maps as in Lee and others (2001) or Lindenmayer and others (2002). The ranking methodology uses Multi-Criteria Decision Analysis (MCDA) (Beinat 1997), a methodology that combines criteria from different sources of information into one overall evaluation. This approach was used for site ranking because it provides a rational basis for evaluation. It produces a first-cut priority list of wetlands that can be used to optimise site visits and hasten the protection of the most valuable wetlands. The method is demonstrated for the Manawatu–Wanganui region, the second-largest region in the North Island of New Zealand (22,215 km^2).

Table 1 Description of the LANDSAT images for the Manawatu-Wanganui Region, New Zealand

Image	Date	Area contribution to the Manawatu-Wanganui Region (in 10^3 ha)	Sun elevation
1	29/09/1999	355.1	43.1
2	04/12/2002	407.7	55.8
3	25/11/2000	600.7	56.5
4	29/09/1999	671.7	41.8
5	25/09/2001	154.8	40.8

Mapping Methods

Preprocessing

Five Landsat ETM+ scenes covering the Manawatu–Wanganui region were used as the basis for wetland mapping (Table 1). After cloud masking and mosaicking, we obtained a cloud-free coverage of the region of 98.6%. The first processing step was to derive a land-cover map from the raw imagery. This map was used as a basis for the different categories of wetlands.

The six 30-m resolution spectral bands of each ETM+ scene were combined with the 15-m resolution panchromatic layer to produce 15-m multispectral pixels (Dymond and Shepherd 2004). This pan-sharpening process enabled the data to be used at 1:50 000 scale. The pan-sharpened imagery was then orthorectified using a digital elevation model (DEM). Ground-control points were derived from black-and-white orthophotographs at 2.5-m pixel resolution. The orthorectification was processed with ERDAS IMAGINE software to a 20-m root mean square mapping error.

Because the Manawatu region is very large, manual mapping is not a viable option, and landscape features must therefore be classified automatically. We needed to use standardised imagery that was not influenced by topography, the geometry of satellite and sun position, and atmospheric conditions. For this purpose, we used the Shepherd and Dymond (2003) topographic effects

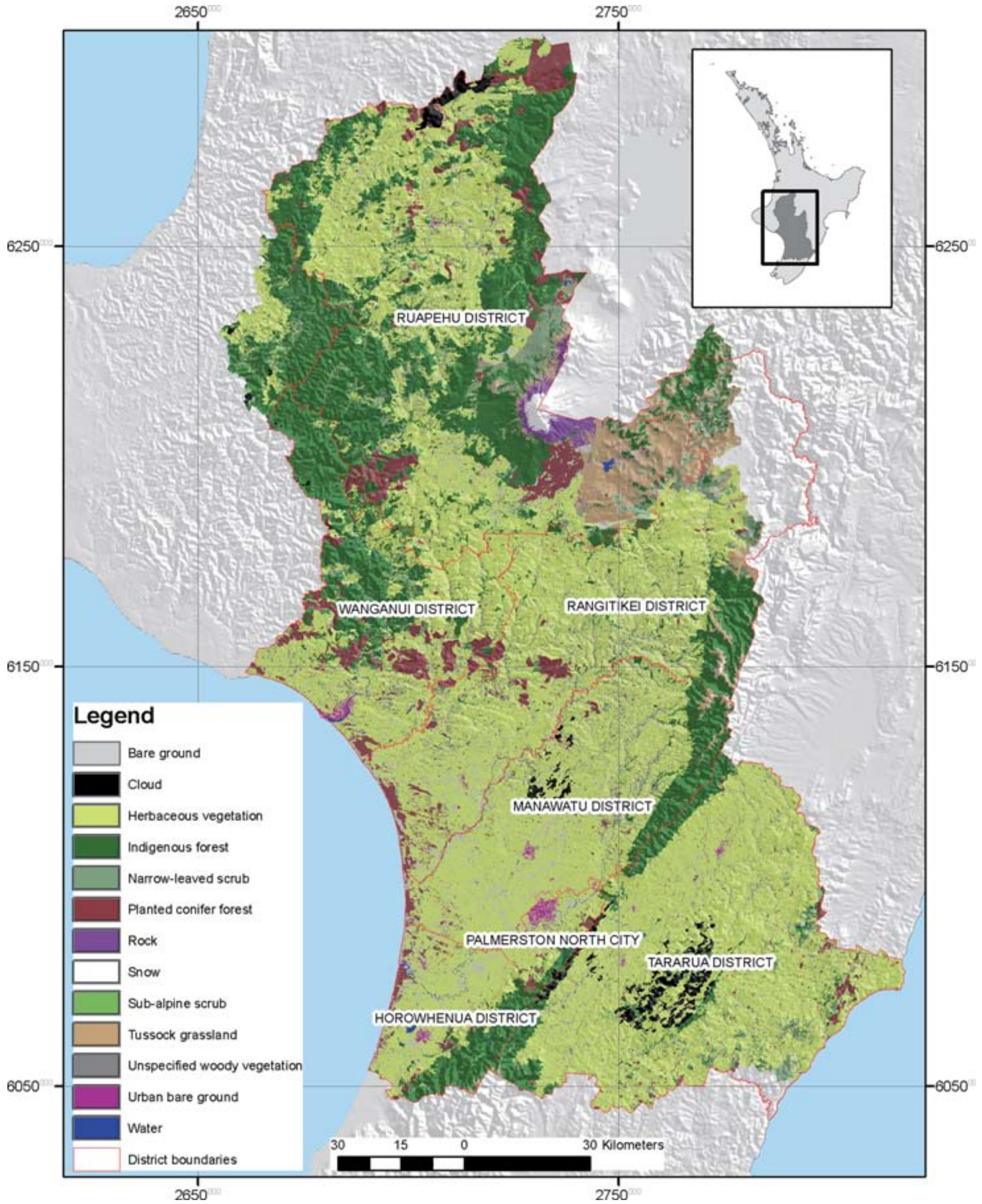

Fig. 1 Land cover map of the Manawatu Wanganui region

physical model, which predicts the flat surface reflectance of a sloping pixel independently of atmospheric effects. The process requires a DEM and data on the atmospheric composition on a monthly mean profile. The resulting image gives a standardised spectral reflectance that can automatically classify landscape features based only on the spectral properties of the cover with limited distortion from topography, geometry of satellite and sun position and atmospheric condition. The process is repeatable for images at different dates. Dymond and Shepherd (2004) then developed spectral rules to classify land automatically based on a decision-tree analysis. Land-cover classes include water, bare ground, indigenous forest, herbaceous vegetation, cloud, seawater, narrow-leaved scrub, planted conifer forest, unspecified woody vegetation, urban bare ground, rock, tussock grassland, snow, and subalpine scrub (Fig. 1).

Wetland Map

Wetlands were mapped into five basic classes defined by the New Zealand Ministry for the Environment (UNEP/GRID 1999): lacustrine (standing open water, i.e., any lake or pond), estuarine (periodically or permanently inundated by estuarine water); riverine (continually or intermittently flowing open fresh water); marine (includes saline open waters, seabed,

Table 2 Classification of wetlands at the hydrosystem level

	Vegetation	Water	Bare ground
Lacustrine		Standing water (lakes, ponds)	Lake margins
Estuarine	Vegetation in the estuaries	Brackish estuary water	Intertidal zone
Riverine	Vegetation in the river bed	Rivers	Water course
Marine		Sea shore	Beach
Palustrine	Vegetation emergent over standing water		

and foreshore); and palustrine (where vegetation emerges permanently or seasonally higher than freshwater). Within each of the five basic wetland classes, vegetation, bare ground, and water were differentiated (Table 2).

Lacustrine, estuarine, riverine, and marine wetlands were derived directly from the basic land cover map. First, water and bare ground were automatically classified from the standardised reflectance image using spectral rules. This classification provided a map of all open waters in the region. Second, water and bare ground pixels were classified according to their contexts into the defined wetland categories. Therefore, pixels initially classified as water were further classified as lacustrine, estuarine, marine, or riverine. Estuarine and marine water were categorised within estuary and marine areas by visual interpretation. Water within a buffer zone of 5 pixels (75 m) around a nationally available vector network of rivers from Land Information New Zealand was defined as riverine water. Any remaining water pixels were considered lacustrine. As for bare-ground pixels, we considered a buffer zone of 10 pixels (150 m) around the stream network. We then automatically categorised all bare ground zones that had at least half their area within the buffer zones as riverine, thus classifying streambeds without including bare pasture or urban areas; however, some manual editing was necessary. Any bare ground within a specified buffer zone along the sea was defined as marine bare ground. Both lacustrine and estuarine bare ground were manually categorised because those zones were small.

Palustrine and estuarine vegetation were too difficult to map using spectral rules because there was spectral confusion with many other vegetation types. The only additional information we could use was a database of point locations provided by the local regional council. These points were derived from a combination of old surveys on natural areas that could contain a wetland and local knowledge of regional council staff. Some of these locations points have been collected from hard copy map coordinates and do not always correspond to a wetland area. The point location can also refer to a natural area “containing wetlands,” which involves some visual interpretation of the imagery. After correcting or checking that the location points actually occurred in wetland visible on the satellite imagery, seeding points were defined for the region-growing algorithm in ERDAS IMAGINE, which then rapidly mapped wetland boundaries. A spectral threshold was manually determined for each location point; the threshold corresponds to the maximum Euclidean distance in spectral space away from the seed point for all pixels in the region. On occasion, several points were needed to map fragmented wetland sites or sites with different wetland vegetation types. The threshold and the seed points were recorded in a database for future use when detecting change. Most location points had the same threshold.

Criteria for Scoring Wetland Sites

We chose a MCDA framework (Beinat 1997) for scoring wetland sites because such a framework provides an objective and transparent system for combining many criteria. The score is defined in Equation 1:

$$\text{Score} = \sum_{i=1}^{n} w_i V_i$$

where n is the number of criteria, V_i is the value associated with criterion i, and w_i is the weight associated to that criterion. Each criterion is described by an indicator mapped to a value normalised between 0 and 1 using a value function. We used four criteria: representativeness, area, surrounding naturalness, and connectivity (Fig. 2). Value functions and constants are listed in Table 3.

Representativeness

Representativeness is a crucial criterion because it accounts for “the extent to which an ecosystem and habitat exemplifies the ecologic patterns and communities that existed in the original natural landscape” (Ministry for the Environment 1998). It involves comparing the ex-

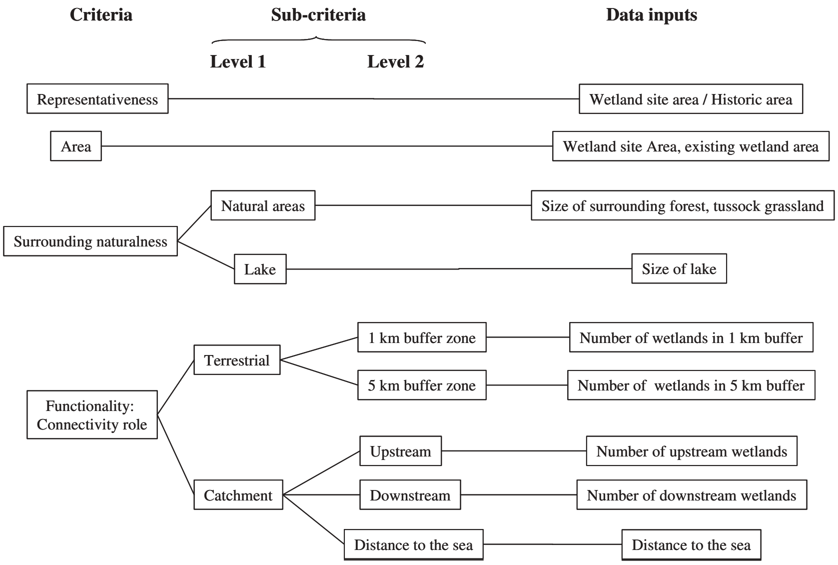

Fig. 2 Schematic summary of the criteria used for the priority ranking

isting and historic vegetation to determine how ‘‘representative’’ a natural site could be depending on the different ecosystems in the landscape. Clarkson and Stephens (2000) discussed this issue by comparing the utility of different frameworks for estimating land environments (LEs) in New Zealand. The Land Environments of New Zealand, defined by Leathwick and others (2003), is a suitable classification because it is based on quantitative values of climate, landform, and soil descriptors related to vegetation patterns. LENZ provides objectivity and consistency with time and has four levels of classification for different scales.

To compute the representativeness of wetlands in each environmental domain, we created a historic map of wetlands based on the Land Resource Inventory of New Zealand (Eyles and Newsome 1990). This polygon-based database contains information on soil type and wetness. We selected all LRI polygons with high wetness and refined these by selecting areas with a DEM slope $< 7°$.

We then computed the ratio of actual wetland area (Δa) against historic wetland area (a) in each LE (Equation 2):

$$R_{ED} = \left(\frac{\Delta a}{a}\right)_{\mathrm{LE}}$$

The representativeness R_{ED} of each site was then assigned a value V_1 using a simple decreasing exponential function with constant values listed in Table 3. The representation of this function assumes that the rarer the site compared with the historic extent (small), the more value V_1 it has.

Table 3 Constant estimation for value functions of all indieators

Indicator	Value function formula	Constant *b*
Representativeness		
Area	$V = e^{-bx}$	4
Surface	$V = 1 - e^{-bx}$	0.05
Size contribution	$V = 1 - e^{-bx}$	7
Habitat diversity		
Natural area extent	$V = 1 - e^{-bx}$	0.07
Standing water extent	$V = 1 - e^{-bx}$	0.07
Connectivity		
Terrestrial		
Number of wetlands in 1-km buffer zone	$V = 1 - e^{-bx}$	0.1
Number of wetlands in 5-km buffer zone	$V = 1 - e^{-bx}$	0.05
Aquatic		
Number of wetlands upstream	$V = 1 - e^{-bx}$	0.5
Number of wetlands downstream	$V = 1 - e^{-bx}$	0.5
Distance to the sea		
Distance	$V = 1 - e^{-bx}$	0.02
Elevation	$V = 1 - e^{-bx}$	0.005

Area

Because wetland site affects the long-term viability of species, communities, and ecosystems, fauna and flora in a larger wetland site are more likely to persist as they are better buffered against human disturbances (Whaley and others 1995).

Two subindicators have been considered for the area criterion of wetlands: (1) the actual surface area of the wetland and (2) the contribution the wetlands' area makes to the total wetland area in the listed LE. For these indicators, an increasing value function was used (constants defined in Table 3) such that the surface value increases rapidly for smaller wetlands and more slowly for larger wetlands. The value of the area V_2 was then the weighted sum of the wetland surface and the size contribution.

Surrounding Naturalness

A palustrine or estuarine area is more likely to be in pristine condition if it is surrounded by natural areas (Mitsch and Gosselink 2000), and open water is important for many birds for breeding and food gathering. We therefore designed a computer program to search the land cover layer for natural vegetation (indigenous forest, tussock grassland) and open water in a buffer zone of 2 pixels approximately each wetland site. These two indicators were both assigned an increasing value function, and the surrounding naturalness value V_3 was then the weighted sum of the natural vegetation value and open water value.

Wetland Connectivity

Wetlands are often part of a connected network, and their proximity is important for bird and fish migration (Haig and others 1998).

Terrestrial Connectivity

Because terrestrial connectivity is used to represent bird migration value, we computed two buffer zones of 1 and 5 km around each palustrine site. We then assigned two value functions depending on the number of palustrine sites located in the same buffer zone (1 and 5 km, respectively). These value functions are increasing exponentials because the value increases with the number of wetlands. The terrestrial connectivity value was the weighted sum of the 1- and 5-km buffer zone values.

Aquatic Connectivity

Aquatic connectivity is important for fish migration. This connectivity was determined by subcatchment hierarchy analysis, which shows wetland subcatchments flowing into the next wetland subcatchment. We then constructed a logical connectivity network using the geometric network tool in ARC/INFO. We counted the number of wetlands located upstream and downstream for each site. The value function increases with the number of wetlands in the network, and the aquatic connectivity was the weighted sum of upstream and downstream values.

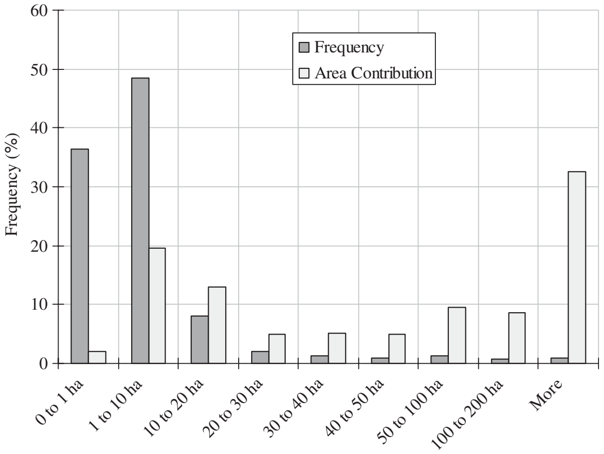

Fig. 3 Distribution of the area of palustrine sites in the Manawatu-Wanganui region

Distance to the Sea

Joy (1999) found that elevation and distance to the sea were important factors explaining fish distributions, so we used these factors as indicators for each wetland site. The value functions developed for the distance to the sea and the elevation were decreasing exponentials. Overall, the connectivity value V_4 is the weighted value of the sum of terrestrial connectivity, aquatic connectivity, and distance to the sea.

Aggregating the Criteria

Values from the four criteria were aggregated into a single score using Equation (1). The weights w_i were designed to balance the relative importance of each criterion. For the analysis listed here, these weights were equally assigned a value of 1 to arrive at a better idea of the influence of each criterion.

Results

In the Manawatu–Wanganui region, 297 palustrine wetlands, totalling 3060 ha, and 14 estuarine wetlands, totalling 256 ha, were mapped. Most wetlands were <10 hectares, and their contribution to the total area was relatively low (Fig. 3). More than 30% of the total area of wetlands came from just four sites, showing that the remaining palustrine sites were fragmented and small.

Table 4 Error matrix for palustrine wetlands in the Horowhenua and Wanganui districts

Netland	Palustrine wetland (satellite)	Nonpalustrine wetland (satellite)	Total number of pixels
Palustrine wetland (ground truthed)	15237601	5762	15243363
Nonpalustrine wetland (ground truthed)	10069	18847	28916
Total number of pixels	15247670	24609	15272279

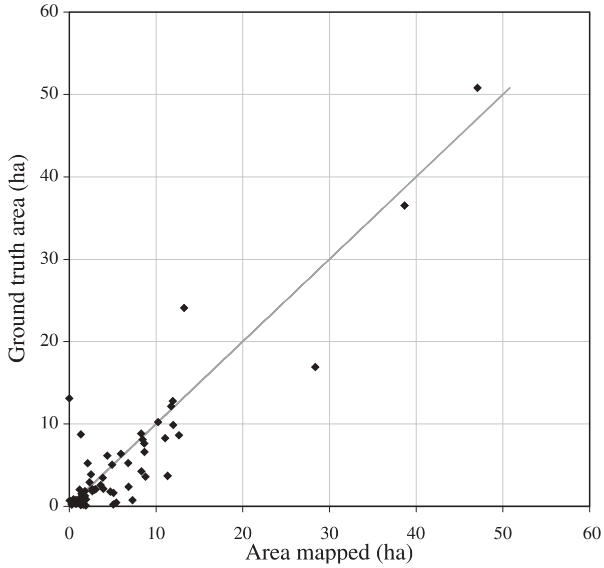

Fig. 4 Correlation mapped by remote sensing and ground truthed areas

To determine mapping accuracy, we compared the mapped area of 79 wetlands with the area mapped from aerial photographic interpretation. The comparison was made in two districts (Horowhenua and Wanganui), which were field-checked and mapped by regional council staff. The field-checking map (vector file) was converted into a raster file at 15-m resolution on the same grid as the satellite image. Table 4 lists the confusion matrix. The user's accuracy was 76%, and the producer's accuracy was 65%. The Khat assessment (Congalton & Green 1999) was 70%, which shows a moderate agreement between the two maps. However, because this analysis did not provide the uncertainty of the total wetland area, we also compared wetland areas site by site. The correlation coefficient between the two datasets was 0.96, with an SD of 3.46 hectares (Fig. 4), providing an uncertainty of ±138 ha for the total area of palustrine wetlands mapped by satellite.

Most of the top 10 wetland sites, identified using the priority system listed in Table 3, are on the flat plains of the Horowhenua district (Table 5). Because this area was once a single large wetland, the representativeness ratio is very small, which clearly indicates the importance of retaining the remaining wetlands. Lake Otamangakau is the only Ruapehu district wetland represented in the top 10. It stands out because it is large (374 ha) and because of its surrounding indigenous habitat (lake >100 ha, native forest, and tussock grassland areas).

We conducted a sensitivity analysis to determine if any of the four criteria had a disproportionate effect on the aggregate score by computing a pairwise correlation between individual criteria as described in Copolillo and others (2004). Scores did not covary strongly (Table 6), indicating that the four criteria are mostly independent and contribute equally to the final score. Consequently, the weighting part of the system will be the main driver to balance the four criteria.

Constants were estimated empirically for each value function (Table 3). The estimation was based on the expert knowledge of regional council staff to set the most appropriate input parameter for a 0.5 output value.

Table 5 List of the 10 first wetlands ranked by score order

Wetland name	District name	V_1 (size)	V_1 (representativeness)	V_1 (naturalness)	V_4 (connectivity)	Score	Rank
Whitiki bush and swamp	Horowhenua	0.68	0.97	0.93	0.83	0.85	1
Lake Papaitonga	Horowhenua	0.37	0.97	0.98	0.50	0.71	2
Moutoa Conservation Area	Horowhenua	0.99	0.96	0.11	0.56	0.65	3
Lake Rotomahana	Horowhenua	0.60	0.91	0.25	0.80	0.64	4
Lake Horowhenua west bush	Horowhenua	0.08	0.97	0.67	0.79	0.63	5
QE2 (Willis)	Horowhenua	0.62	0.88	0.27	0.71	0.62	6
Pukepuke Lagoon	Manawatu	0.54	0.97	0.33	0.64	0.62	7
Te Hakari wetland	Horowhenua	0.61	0.97	0.37	0.44	0.60	8
Simpsons reserve	Rangitikei	0.61	0.99	0.48	0.29	0.59	9
Lake Otamangakau	Ruapehu	0.94	0.38	1.00	0.05	0.59	10

Table 6 Correlation coefficients among categories

Correlation	Areal extent	Representativeness	Surrounding naturalness	Connectivity
Areal extent	1			
Representativeness	−0.15	1		
Habitat diversity	0.26	−0.17	1	
Connectivity	−0.08	0.25	−0.18	1

Discussion

The first goal of this project was to develop a rapid and cost-effective method to map wetlands in a region. The method we developed took one person 6 weeks to map the wetlands of the Manawatu–Wanganui region. This is considerably faster than the manual digitisation of wetlands from aerial photographs, which we estimated would have taken several years. This method is in fact rapid enough to deliver a national inventory of wetlands in New Zealand with approximately one person-year of effort. Not only is the method more rapid than manual digitisation of aerial photographs, but it is also more repeatable because the spectral thresholds for each wetland are recorded in a database and are therefore available for future use. The main limitation of the method is the need for a priori location points for the palustrine and estuarine wetlands. To obtain complete coverage, these points can be obtained from a range of information sources, but there is always the possibility of missing some. To minimise the number of missing wetlands, we field checked all water occurring in historic wetlands.

The second goal was to develop an objective scheme to rank wetlands in order of priority. The developed scoring scheme uses indicators based on quantitative data and thus lessens subjective human interpretation. Although the setting of weights is subjective, it is completely transparent and can be adjusted according to conservation goals (animal conservation, plant conservation, planning, restoration, etc.). The flexibility of the scheme also permits newly discovered wetlands to be easily integrated into the wetlands ranking. In the future, the empirical value functions could be enhanced by modelling the knowledge of wetland experts (Beinat 1997). The weights, which were arbitrarily made equal, could also be better assessed by using a pairwise comparison protocol (Anselin and others 1989, Beinat 1997, Saaty 1977).

Although the assessment shows moderate agreement, it corresponds to the general range found in the literature when using satellite imagery and confirms that remote sensing should be seen as complementary to conventional mapping techniques (Ozesmi and Bauer 2002, Wright 2004). Several possible explanations exist as to why the assessed mapping accuracy is only moderate. There is a temporal discrepancy between the acquisition dates of the satellite images (1999 to 2002) and the field surveys (2003 to 2005): this discrepancy can add errors because wetland extent varies with seasonal moisture content. There is a major difference in scale: The ground-truth areas were mapped on a vector basis at a 1:5000 scale compared with the satellite mapping, which was mapped at 1:50,000 on a raster basis. There are edge effects in the satellite pixels, especially around the lakes where the signature is not pure enough to be classified as vegetation. Finally, because of the very different scales between the two datasets, there could be misregistration and resulting geometric displacement, which would be significant on small areas of wetlands.

The methods developed here have significant implications for regional and national environmental managers. The rapid-inventory method means that consistent wetland inventories can now actually be produced at reasonable cost. Once inventories are made, conservation resources may be better targeted to the more important wetlands. In New Zealand, for example, the Department of Conservation has adopted the inventory method to produce the *first* nationally consistent inventory of wetlands. With complete inventories and priority lists of wetlands, managers will be able to proceed with conservation planning without having to wait for the collection of detailed biologic information, which may now also be prioritised and further used to refine conservation priorities.

Conclusion

The combination of ancillary data with region growing on standardised satellite imagery provides a rapid method for mapping wetlands. The cost-effectiveness of the method means that environmental managers can proceed quickly with making wetland inventories of large areas to plan conservation efforts. It is possible to rank wetland sites for importance using landscape indicators only to produce an initial priority list for conservation planning. The wetlands ranking can also be used for prioritising field collection of more detailed biologic data, which can be further used to prioritise conservation efforts.

Acknowledgments This research has been funded by the Foundation for Research Science and Technology (grant No C09X0115) and Horizons Regional Council, Palmerston North. We thank O. Ausseil for providing advice and data for this project.

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