Landscape structure and ecosystem conservation: an assessment using remote sensing

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Summary

Analyses of landscape structure are used to test the hypothesis that remotely sensed images can be used as indicators of ecosystem conservation status. Vegetation types based on a classified SPOT satellite image were used in a comparison of paired, reserve (conservation area) and adjacent more human modified areas (controls). Ten reserves (average size 965 ha) were selected from upland tussock grasslands in Otago, New Zealand. While there were equal numbers of vegetation types and the size and shape distribution of patches within the overall landscapes were not significantly different, there was less of ‘target’ vegetation in controls. This was in smaller patches and fewer of these patches contained ‘core areas’. These control ‘target’ patches were also less complex in shape than those in the adjacent reserves. These measures showed that remotely sensed images can be used to derive large scale indicators of landscape conservation status. An index is proposed for assessing landscape change and conservation management issues are raised.

Introduction

The objective of the research described in this paper is to test the hypothesis that remotely sensed indices of landscape structure can be used as indicators of the intactness of indigenous ecosystem processes (for economy 'conservation status'). This is applied to areas in Otago, particularly those containing upland tussock grassland.

There is an increasing requirement for national/regional assessments of conservation status and ecosystem change, however there are few techniques available to measure landscapes at this large scale (Stoms and Estes 1993), especially those which focus on the biodiversity component. It is widely recognised (World Resources Institute 1992) that biodiversity should be considered at the ecosystem level, and that factors such as the arrangement, functioning and interaction of components must be taken into account to derive such a measure in any assessment. In this paper remote sensing and spatial statistics are employed to measure landscape factors and relate them to known conservation status to generate a more general index.

Much of the landscape is affected by agricultural practices. Swift and Anderson (1994) pointed out that agricultural systems generally result in a homogenising effect and a purposeful reduction in species richness. They discussed the benefits to the agricultural system of maintaining biodiversity (stability etc). There are also conservation benefits. Pienkowski *et al.* (1996) argued that "site-safeguard can only be one component of an effective nature conservation strategy" (pg20) and discuss the effect of landuse polices in agriculture on conservation, stating the "integration of nature conservation requirements into other land-use policies is a feature at the heart of the Convention on Biological Diversity" (pg12).

Much conservation monitoring work using remote sensing has been performed in forested areas. This is partly based on notions that forests are areas of high biodiversity, but also because it is relatively easy to see that a forest has been logged. However it is more difficult to identify a degrading grassland. Further, many of the remote sensing studies that purport to be examining biodiversity are preliminary and do not extend beyond indicating the area that has been developed or logged. To assess ecosystem biodiversity, it is important to measure the pattern of distribution and shape of the remaining forest. Schulze and Gerstberger (1994) argued that "in most cases we recognise a loss in species diversity with a loss in landscape structure" (pg464).

Meltzer and Hastings (1992) used fractal analysis to study the impact of increased cattle grazing in Zimbabwe. They were able to follow changes in the landscape and found a pattern of continuous disintegration with patches of grass and forest being broken down into smaller patches, with many disappearing entirely. While the forest area lessened over time, the area of grass increased.

We recognise two approaches to analysis of change in landscape features. The first is a slice-in-time approach. In these studies historical data, either based on descriptions or early remote sensing are used as the baseline along with contemporary remote sensing. Using this method, Ripple *et al.* (1991) showed an increase over time of fragmentation of landscape features as a result of human settlement. This approach is limited to areas with historical map coverage, which may not be valid or accurate. Aldridge and Benwell (1995) pointed out the dangers of relying on historical data while Arbuckle (1995) found the Land Resource Inventory inappropriate for comparisons involving upland bogs in Central Otago. The Land Resource Inventory did not identify most of the bogs considered important in ecological terms. Even if multi-date remote sensing images are available, Green *et al.* (1994) warn that the effects of season, water levels and radiance differences may render invalid maps derived from simple image subtractions.

Another approach is to compare areas of differing management that are otherwise alike, that is, infer temporal change from a spatial comparison. To assess the landscape biodiversity value of agricultural areas, one could analyse the landscape structure of these areas but this may not prove informative as the indices are open ended and not calibrated. A calibration is needed with areas of known biodiversity. Areas set aside for conservation may be assumed to have higher biodiversity values than corresponding non-reserve areas. Although some reserves are 'historical accidents', most reserve areas have been selected by the nature of their ecological stature and management practice is aimed at 'maintaining biological value' (McCabe, *pers comm.;* Department of Conservation, Dunedin, NZ, May 1996). Inferring temporal change from spatial comparison assumes that, with the exception of the variable of interest, the set of variables affecting both areas are similar.

It would be expected that non-reserves would show more fragmentation than reserve areas. This would be expressed in a reduced representation of vegetation types, less of the 'target' vegetation and less core vegetation. The target vegetation is defined as the principle vegetation type in the reserve while the core vegetation is that part of a patch not affected by edge effects with bordering areas. It would be expected that with development, both the overall landscape and target areas would become less complex in their arrangement and contain less target vegetation within core areas.

Method

The approach adopted involves comparing landscape structure in reserves and adjoining areas in upland areas of Otago. Ten reserve areas in Otago were selected for this study (Table 1)[1]. The perimeters of these areas were digitised from Department of Conservation management plans and 1:50,000 map sheets. Control areas (non reserves), adjacent but not contiguous to the reserves were also selected. The selection of these areas aimed to include similar landscapes such as the same range of altitude and morphology. A mix of cadastral, fence-line and contour lines defined the control boundaries in a pattern that approximated the reserve boundaries. Reserve areas are subject to conservation management whereas control areas undergo commercial management, predominantly sheep grazing, the extensiveness of this largely depending on the altitude. Some areas are cropped and commercial forestry occurs.

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[1] Waipori, Mill Creek, Maungatua and Lee Creek form a series of reserves across the Maungatua Range. Size and complexity allows them to be studied separately. Names may not reflect actual reserve names.

Table 1: Approximate locations of sample sites

	New Zealand Map Grid Coordinates of Surrounding Rectangle				Area of Reserve (ha)	Area of Control (ha)
	Min X	Max X	Min Y	Max Y		
Blackrock	2265000	2271000	5488000	5494000	487	678
QPR	2263000	2272000	5475000	5481000	893	550
Deepstream	2251000	2264000	5483000	5494000	2803	3337
Lee Creek	2283000	2290000	5478000	5485000	946	1555
Waipori	2273000	2282000	5470000	5479000	1694	1410
Maungatua	2275000	2285000	5481000	5490000	770	1562
Mill Creek	2280000	2286000	5472000	5477000	846	689
McCrae	2303000	2314000	5520000	5530000	746	1330
Scroll Plain	2257000	2266000	5516000	5526000	158	2540
Sutton Salt	2281000	2284000	5509000	5515000	313	262

Table 2: Summary statistics for QPR (see text for explanation of terms)

		% landscape	# patch	LPI%	core%	#core	LSI	AWMSI	Area
Control	River	13.42	122.00	2.25	5.32	60.00	6.50	2.79	119.80
	Exotic forestry	0.37	9.00	1.71	0.08	4.00	1.71	1.74	3.32
	Tussock	20.88	102.00	11.90	12.55	48.00	6.53	3.55	186.52
	Cropped Grass	28.75	106.00	18.90	13.09	97.00	11.46	8.72	256.92
	Long Grass	36.58	37.00	8.60	25.74	39.00	7.16	2.95	3326.8
	Landscape	100.00	376.00	18.90	56.79	248.0	14.41	4.71	893.50
Reserve	River	12.37	81.00	1.77	4.61	37.00	1.77	2.26	68.12
	Exotic forestry	0.50	1.00	0.50	0.27	1.00	2.65	1.45	2.76
	Tussock	44.52	39.00	31.92	31.44	34.00	7.55	4.71	245.20
	Cropped Grass	14.75	70.00	4.35	3.73	70.00	7.95	4.45	81.24
	Long grass	27.85	18.00	12.20	20.21	14.00	4.99	3.10	153.40
	Landscape	100.00	209.00	31.92	60.26	156.0	10.82	3.91	550.72

Previous researchers have classified a February 1994 SPOT image that covers the areas included in this study (Arbuckle 1995). Marr and Bacon's (1996) classification, which was used as the basis for the current classification, had a focus on exotic forestry so some additional local supervised classification was performed to distinguish agricultural grasses from tussock. Marr and Bacon (1996) reported an overall internal accuracy of 72%. Clouds were identified and designated as background. The resolution was 20 metres.

Both reserve and control for each sample were run through FRAGSTATS (McGarigal and Marks 1994), a program designed for analysis of landscape structure. As an example the classification image for the 'QPR' sample is shown in Figure 1. Summary statistics for each landscape class were analysed according to McGarigal and Marks (**Error! Reference source not found.** gives an example of some of the summary statistics for the QPR sample). All comparisons underwent a Student's t-test, paired, with two tails; significance values are indicated. The background for each landscape metric is given in the results.

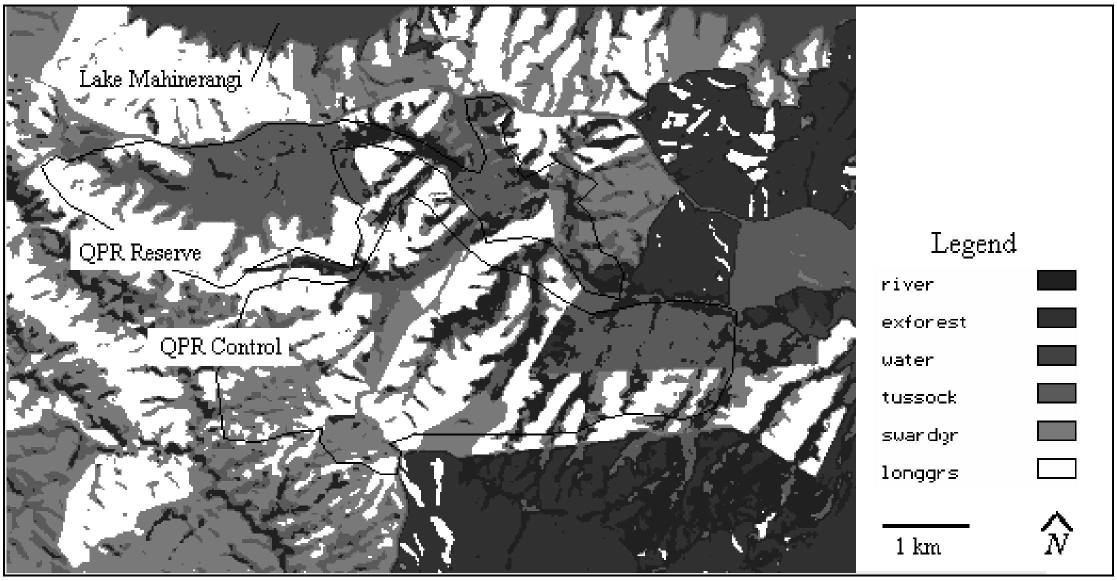

Figure 1: 'QPR' image classification and sample boundary

Results

A simple measure of landscape diversity is to count the patch classes. However, except for features such as lakes and exotic forestry the frequency of classes did not change between reserves and the control (Figure 2 gives a schematic illustration of the results for each of these metrics. Figure 2a). Diversity is more often taken to include the distribution of the landscape area into classes (similar to community ecology diversity indices such as the Shannon-Wiener). Diversity of the landscape includes diversity and evenness. The Modified Simpson's Diversity Index (MSDI) measures the probability of two patches being of a different class. This value increases as the landscape becomes more diverse, usually with more patches and more even distribution of patches into sizes. Simpson's Evenness Index (SEI) gives a value of 0 for uneven distribution to 1 for perfectly distributed patch sizes.

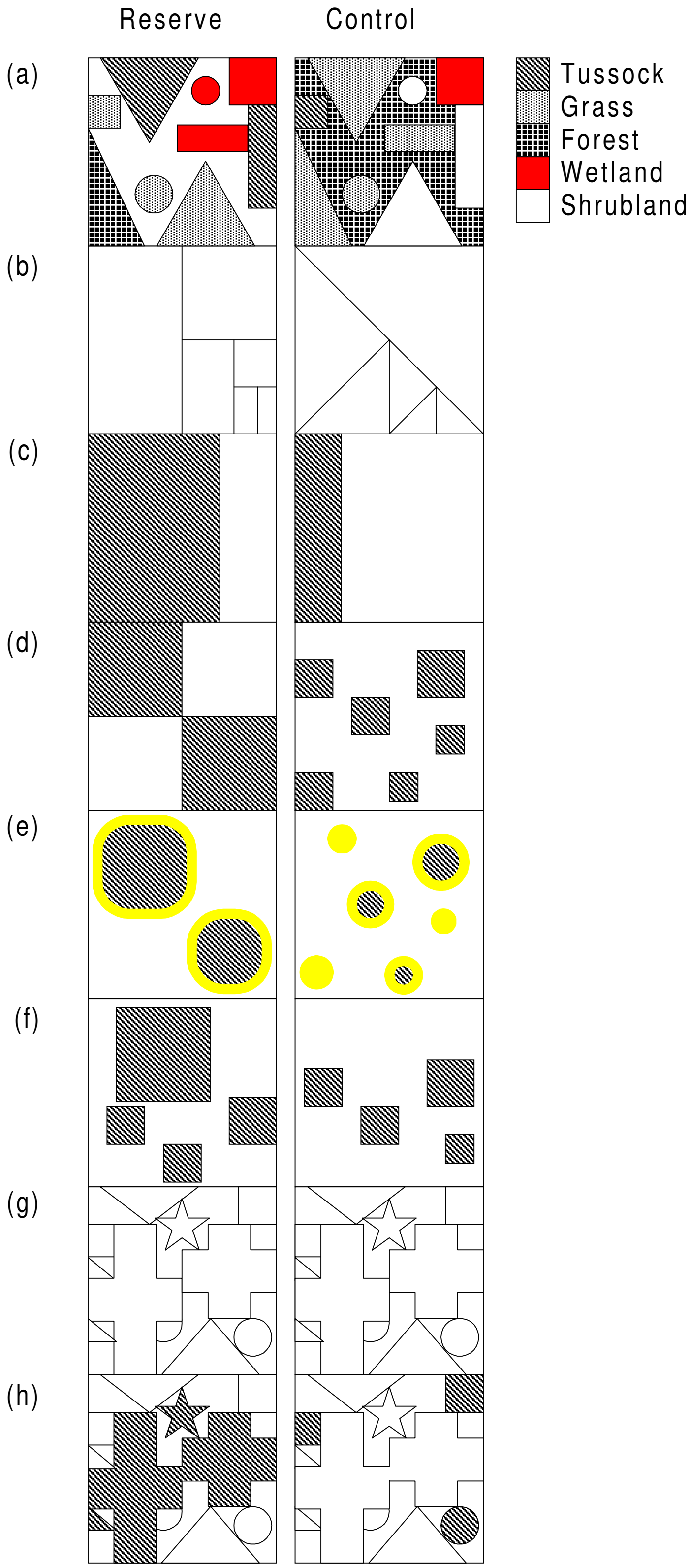

Figure 2: Schematic results. Equal numbers of vegetation types (a), size distribution of patches same (b), less of 'target' vegetation in control (c) in smaller patches (d) with less creating core (e) and few large patches. Shapes of overall landscape same (g) but 'target' vegetation in control in less complex shapes (h).

The MSDI (Figure 3) and SEI (Figure 4) show no consistency (NS) in the relationship between the reserve and control for each sample. While this suggests no consistent change in the overall patch structure, these diversity measures do not convey any information on landscape composition or patch arrangement (Figure 2b).

For the seven samples where a 'target class' could be identified (native bush in Waipori and tussock in all others) a number of combined statistics were calculated[2]. To identify areas of core vegetation, an arbitrary edge of 20 metres was used.

Figure 5 shows that the percentage of target class is less in the control than the reserve (*P<0.01,* Figure 2c). There are however, a greater number of target patches in the control, as Figure 6 demonstrates (*P=0.16,* Figure 2d). The vertical axis on Figure 7 represents the ratio of the number of patches containing core (i.e. excluding the edge of 20 metres) to the number of total patches of that class. The ratio of core forming patches is consistently lower in the control areas (*P=0.01,* Figure 2e).

The Largest Patch Index computes the percentage of the landscape contained in the largest patch of a given class. Figure 8 shows how with the exception of Mill Creek, there was much larger patches in the reserve (*P=0.03,* all samples, Figure 2f). This is not simply a function of having more area as Figure 9 indicates that in the reserve a higher percentage of the target class in the largest patch (*P=0.02*).

The complexity of the landscape as a whole can be measured in terms of the shape of the patches it contains. The Area Weighted Mean Shape Index (AWMSI) measures the complexity of each patch shape relative to a standard shape (square), the value increasing as the patch becomes increasingly convoluted (non-square). This perimeter to area ratio is then averaged over all patches based on area. Figure 10 shows the AWMSI for each sample landscape which indicates that there is no consistent change in landscape shape complexity between the reserves and the controls (*P=0.54,* Figure 2g). A related index, the Landscape Shape Index (LSI), gives similar results.

Figure 11 shows a ratio of the AWMSI metric for target class shape to that for the overall landscape. Above unity (one) indicates that the target is more complex than the overall landscape. The values for the reserves are above or near to one while the controls are much lower in most cases (*P=0.05,* Figure 2h). This suggests that while the overall landscape is not any more or less complex in the controls the shape of the target is becoming less complex in the control. This is confirmed by Figure 12 which shows a ratio of target-AWMSI for control to reserve. With the exception of Mill Creek, all samples show reduced complexity in the control (greater than one, control more complex).

Mill Creek is an outlier in many of these measures. It may have been inappropriate to include this site in the group of sites with identifiable targets. The site is rather mixed with large areas of beech, 'scrub' and grass complimenting the nominal tussock target.

An index of landscape structure dissimilarity (LSD) is considered. Four of the consistent measures: i) core numbers, ii) patch size distribution, iii) area, and iv)

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[2] Deepstream and Blackrock were not included in this analysis as patterns could not be discriminated, while the Scroll Plain was not included as no single class could be identified as a target.

shape, are combined using summed normalised values (reserve - control/reserve + control). The value for each area is additive, without weighting. This index allows a ranking of areas according to their dissimilarity with reserve areas. In this example (Figure 13), the McCrae control is similar to the reserve whereas at Lee Creek and Sutton Salt Lake the surrounding areas (controls) are dissimilar.

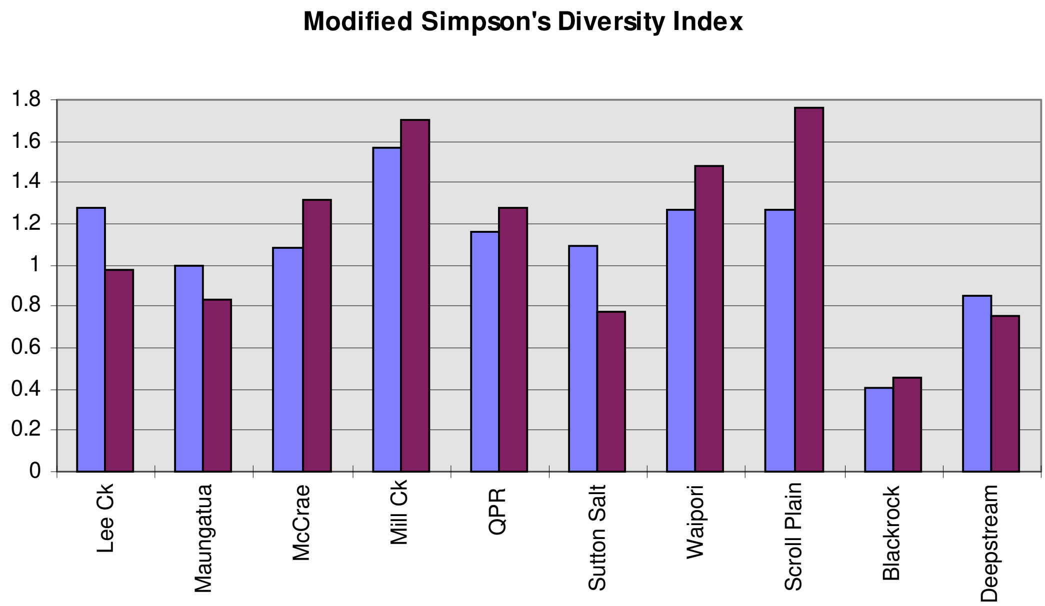

Figure 3: Modified Simpson's Diversity Index Larger values, more diverse. (Reserve, control)

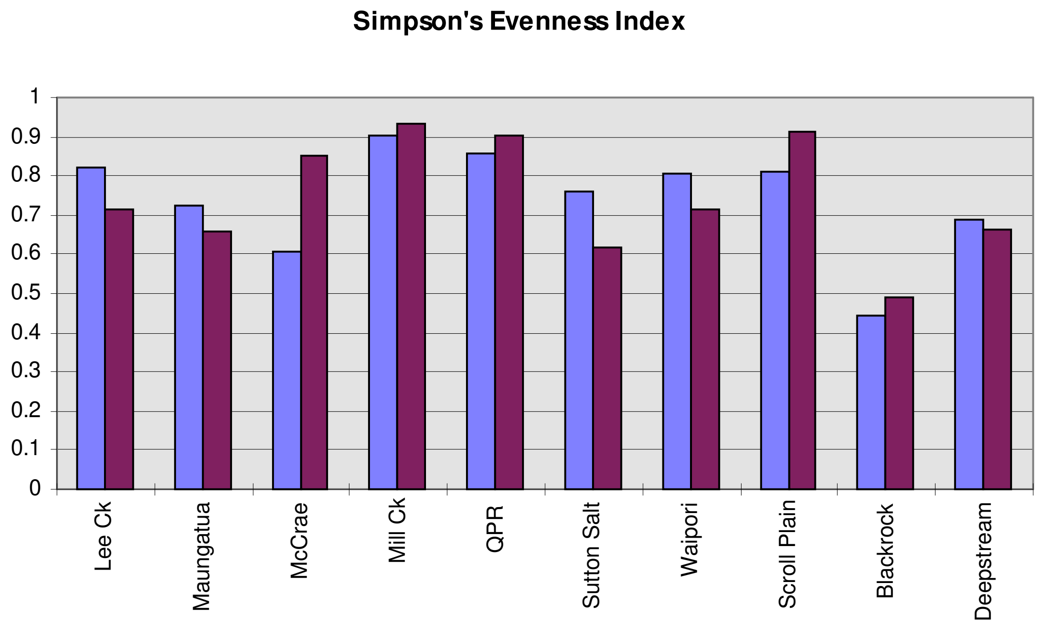

Figure 4: Simpson's Evenness Index (0 uneven distribution, 1 perfectly distributed)

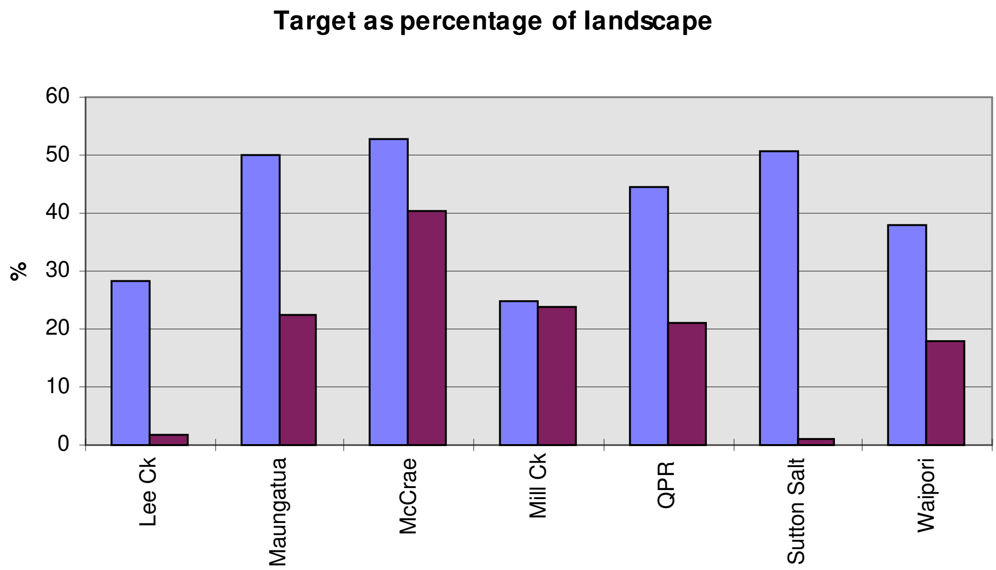

Figure 5: Target as a percentage of landscape

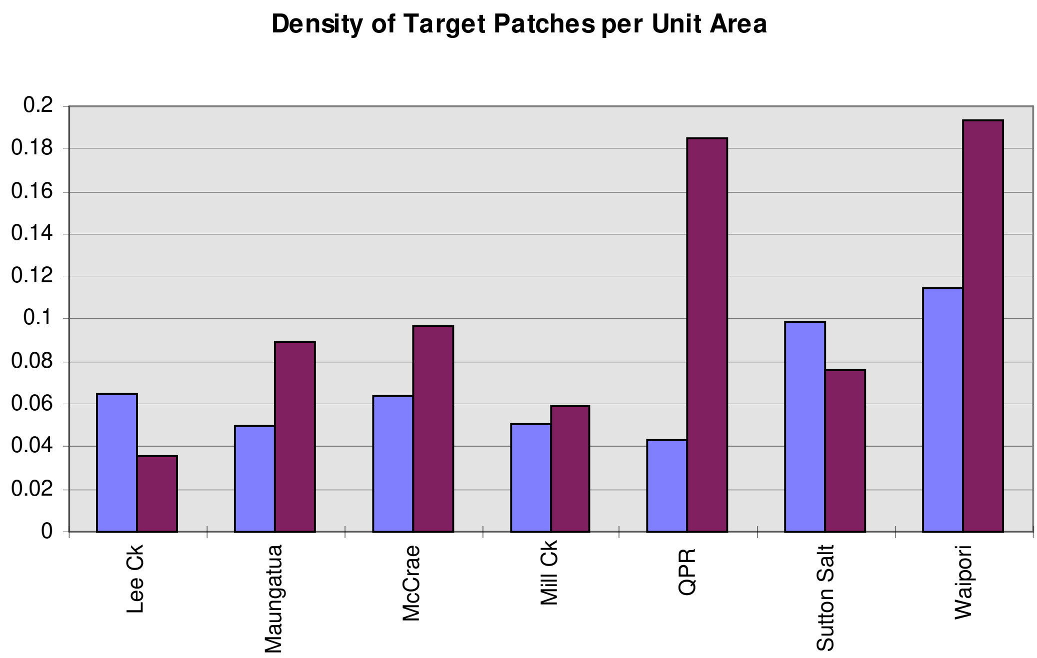

Figure 6: Density of target patches per unit area

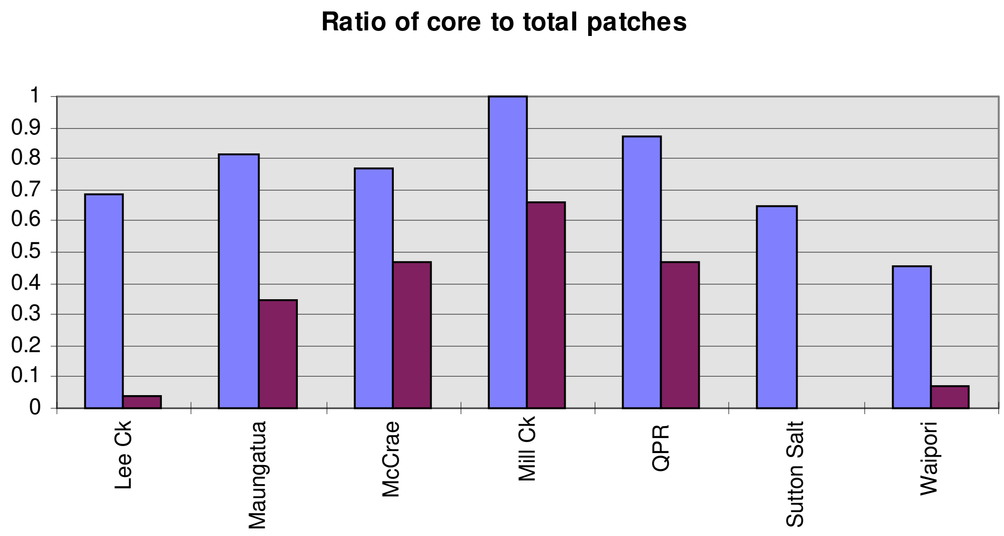

Figure 7: Ratio of core to total patches

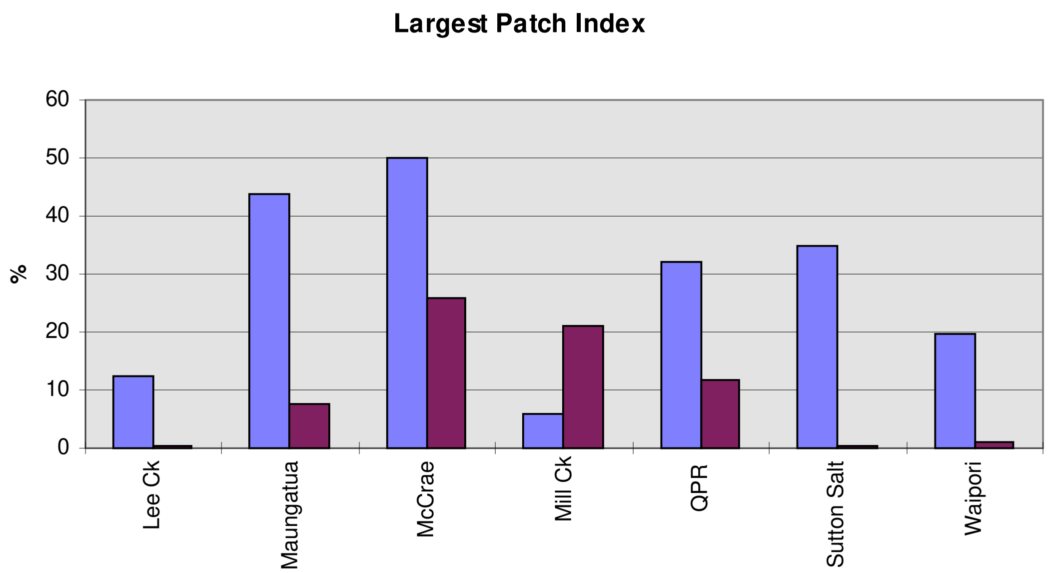

Figure 8: Largest patch index (percentage of landscape within largest patch of target)

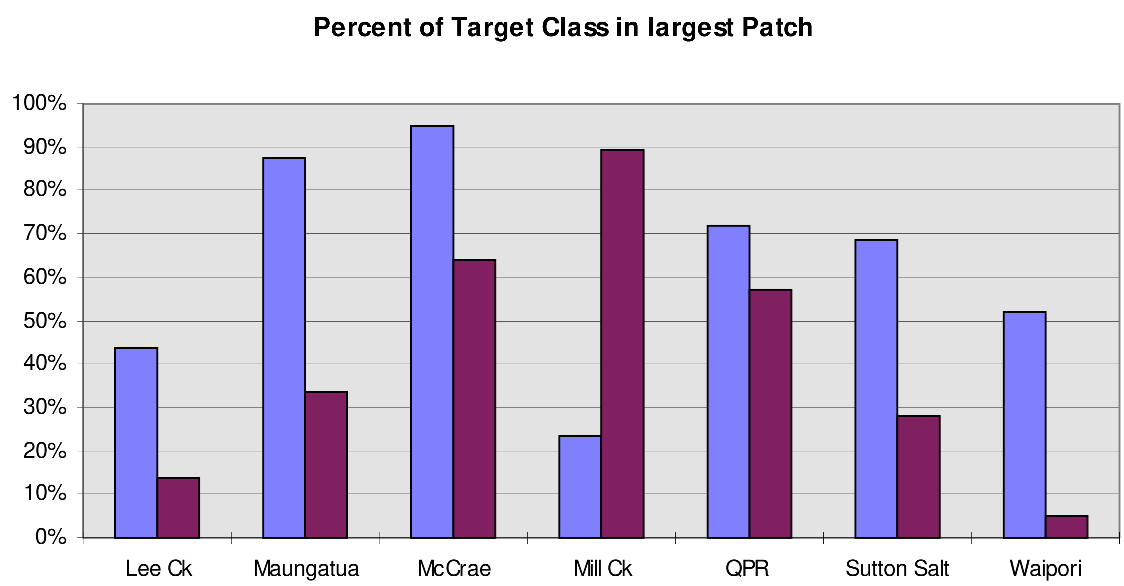

Figure 9: Percentage of target class in largest patch

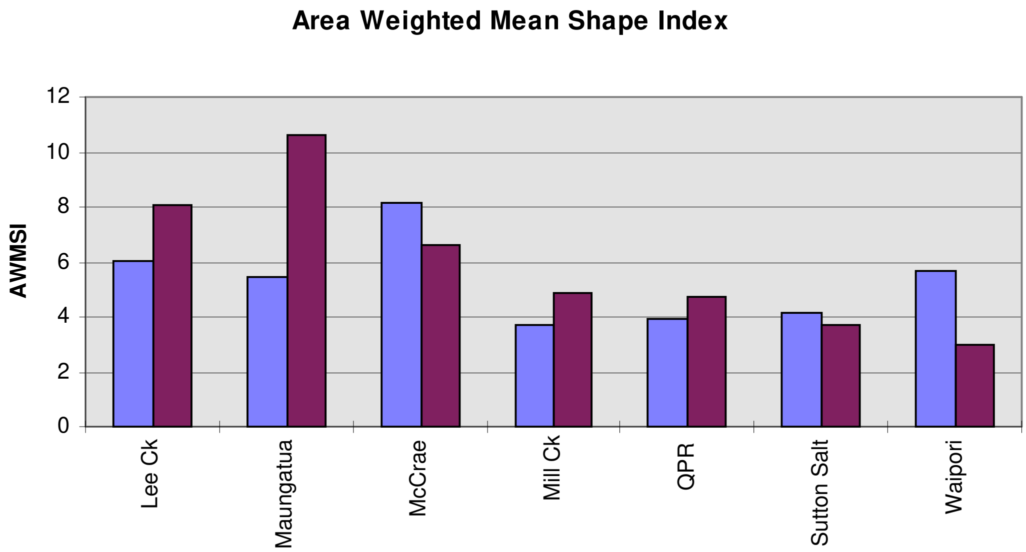

Figure 10: Area Weighted Mean Shape Index (Greater values, more complex shapes)

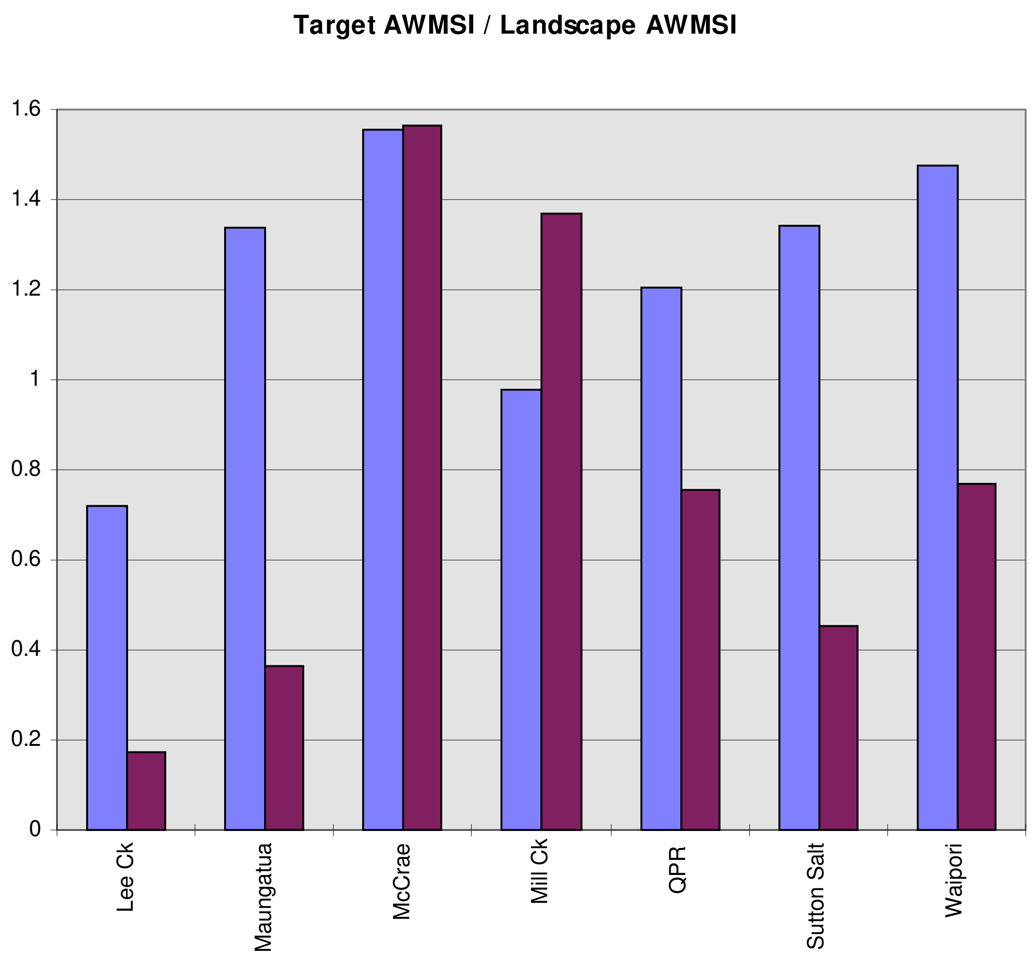

Figure 11: Target AWMSI/Landscape AWMSI (above 1, target shape more complex than overall landscape)

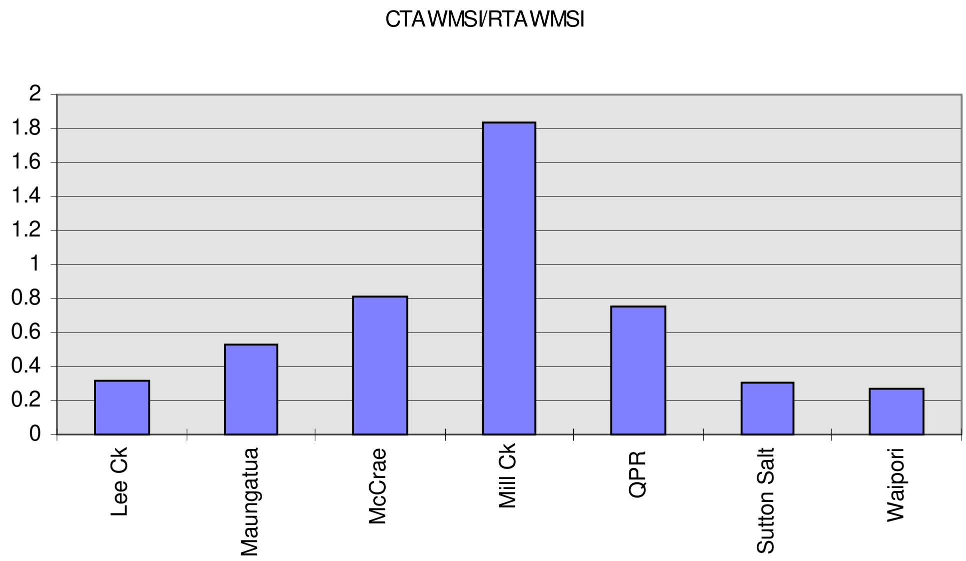

Figure 12: Ratio of target-AWMSI control:reserve (greater than one, control more complex)

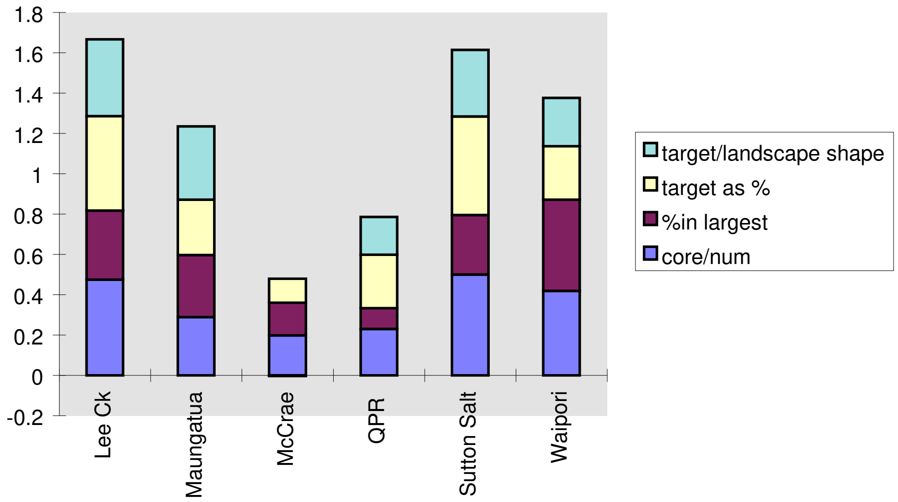

Figure 13: Landscape Structure Naturalness Dissimilarity. Low values control landscapes more similar to reserves

Discussion

Protected Natural Area reserves are assumed to have higher conservation status than adjoining non-reserve areas and this should be expressed in landscape diversity. This study examines whether this diversity is a measurable landscape statistic by comparing 10 conservation reserves in Otago with nearby developed areas.

Despite there being no change in overall landscape patch size distribution, nor in numbers of vegetation classes between the control and the reserves, the percentage of target vegetation decreased greatly in the control samples. This reduced vegetation however was in almost twice the number of patches, leaving no large patches and few patches with core vegetation. There was no consistent change in landscape shape complexity but the shapes of the target vegetation were less complex in the control. This suggests that the remainder of the landscape is becoming more homogeneous but the target vegetation patches are becoming smaller and less variable.

The index of landscape structure dissimilarity (LSD) identified differences in areas according to their dissimilarity with reserve areas. The McCrae control is similar to the reserve whereas at Lee Creek and Sutton Salt Lake the surrounding areas (controls) are dissimilar. This has two management consequences. First, it highlights the isolation of the reserves surrounded by dissimilar environments. Such reserves may be seen as 'ports in a storm' but also perhaps vulnerable to incursion from the surrounding environment. Second, when focusing on non-reserve areas for conservation effort it may be appropriate to 'give up' on areas that are extensively modified from the original. Conversely, areas such as that containing the McCrae control which are more similar to the reserve may be worthy candidates for inclusion into the reserve network.

The combined LSD was additive without weighting. It would be a simple matter to add weights according to the perceived importance of factors. Other information such as species data from field data could also be included. The indices could also be measured periodically to give an indication of changes through time in landscape structure under a particular management regime.

An implicit assumption of this work is that the classifications of vegetation features derived from remotely sensed information capture features of ecosystem condition at the landscape scale. The identified vegetation classes would, at best approximate functional groups, the important species in the vegetation. Korner (1994) however pointed out dangers in this approach, dominants depend on the fate of their seedlings, and the importance of hidden elements (eg. rare species present in the seedbank) should not be overlooked. This landscape scale approach then, should not be confused with the species considerations. The indices derived in this paper were applied to areas with an identified 'target' vegetation and rogue results were obtained for an area that did not have an appropriate target. Further, it is difficult to apply the approach to dynamic areas such as the Scroll Plain, which has a complex of riverine vegetation types that are the focus of the reserve rather than a specific vegetation type. Further work may enable the application of these indices to such complex areas.

There has been some questioning of the biodiversity concept to conservation management (Bowman 1993) particularly the difficulties in constructing an objective metric. Smith, Bruford *et al.* (1994) also questioned the reliance on a measure that usually lacks information about the fundamental ecological and evolutionary processes that produced the patterns in the first place. They dismissed total species approaches but favour methods that include measures such as habitat fragmentation. The indices used in this paper follow this and go some way to alleviating these criticisms. Spatial analysis of landscape structural attributes derived from satellite remote sensing data has been shown to provide at least some measures that correlate with conservation status.

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