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Chapter 5:
Landscape analysis of case study region in Northland
Strong contrast between pastoral and indigenous forest cover (in the foreground) near Mangakahia Rd.

(Photo/ L. Colantoni)
5.1. Introduction

As identified in chapter 4, Northland has experienced significant land-use changes. Despite this, there has been no quantitative analysis of landscape changes. In this chapter, the purpose was to examine the question of whether or not landscape changes occurred, and their relationship with the socio-economic drivers of historical land use changes. In particular, it was assessed how landscape composition and configuration changed through time, and what type of land conversion occurred.

Spatial analysis of landscape change required the generation of land cover maps from the study area for different years. Two approaches were then taken: the quantification of changes in landscape patterns by a set of metrics, and the quantification of land cover conversions by transition matrices (Fig. 5.1). The results were compared with the previous historical analysis of the region to see how both trends were related.
5.2. Methods

5.2.1. Land cover data preparation

Land cover maps to analyse landscape characteristics were generated by the interpretation of panchromatic aerial photographs for the years 1942, 1961, and 1984. Also interpretation from combined bands was carried out on LANDSAT satellite images from 1999 and 2006. The details of each data source are showed in Table 5.1.

The landscape was classified in four discrete land cover classes, as they were significant in the Northland landscape analysis (Chapter 3). They were: Indigenous Forest, Scrub, Planted Forest and Pastoral/Other (following the LCDB nomenclature\(^1\)). Pastoral/Other class was not only a strictly herbaceous cover; it also contained all cover not included in the other classes (i.e. what was not Indigenous Forest, Scrub or Planted Forest was classified as Pastoral/Other cover).

\(^1\) See Appendix 1.
Table 5.1.
Details of remote sensing data sources used in this chapter.

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Date</th>
<th>Scale/ Resolution</th>
<th>Agency</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942</td>
<td>Panchromatic Aerial photo</td>
<td>2/10</td>
<td>1:6,500</td>
<td>NZAM (1942)</td>
<td>* 1</td>
</tr>
<tr>
<td>1961</td>
<td>Panchromatic Aerial photo</td>
<td>20/3; 2/10</td>
<td>1:16,500</td>
<td>NZAM (1961)</td>
<td>* 1</td>
</tr>
<tr>
<td>1984</td>
<td>Panchromatic Aerial photo</td>
<td>20/2; 21/2</td>
<td>1:50,000</td>
<td>NZAM (1984)</td>
<td>* 2</td>
</tr>
<tr>
<td>1999</td>
<td>Landsat 7 ETM+ (Orthorectified)</td>
<td>26/8</td>
<td>30 x 30 m</td>
<td>NASA (1999)</td>
<td>* 3</td>
</tr>
<tr>
<td>2006</td>
<td>Landsat 5 TM (Orthorectified)</td>
<td>6/12</td>
<td>30 x 30 m</td>
<td>NASA (2006)</td>
<td>* 1</td>
</tr>
</tbody>
</table>

* 1 University of Auckland.
* 2 Tonkin and Taylor Consultancy NZ

It would be desirable that the aerial photographs and satellite images were both cloud-free and coincident in the time of the year taken to minimize vegetation differences from seasonal changes. However, the availability of cloud-free coverage is limited, and the concordance in season or month of every photo/image was not possible because these were the only available data sets. This represents a data limitation, even though the main interest covers (indigenous forest) are typically evergreen community, *(ergo: no deciduous foliage)* and they could not be too much affected by seasonal changes.
5.2.2. Data extraction

5.2.2.1. Aerial photographs

The black and white aerial photographs were viewed in pairs under a stereoscope and land cover classes visually interpreted and mapped onto clear polyester film overlaid on the photos.

The first set of photos interpreted was from 1984. As historical data the classification is hard to corroborate because of no ground truthing. To overcome this limitation and improve the accuracy of the photo interpretation, the vegetation map from Waipoua forest done by Burns and Leathwick (1992) was used to recognise and discriminate the land covers in the area. The accuracy of this inventory was considered high because it was made through 294 field samples during 1984–1985. What was indigenous forest, scrub and exotic planted on the Waipoua map, was searched on the photos, and then shape, size, tone, texture, shadow and pattern of each land cover was used for the visual interpretation of the rest of the area. The basis of this approach was transferred to the other two sets of aerial photos (1942 and 1961).

There were several common concepts defined for the visual interpretation of the aerial photos. Indigenous Forest was identified by a textured pattern where it was assumed that varying texture indicated complexity of the forest structure (large emergent trees and several tiers of vegetation)\(^2\). Indigenous forest patches also required to have a +50% tall forest canopy component to be included into this class (similar to the identification in the LCDB). Scrub often appeared as a non-textured uniform (crustose lichen-like) grey, assuming that the almost mono-specific type of scrubs (manuka/kanuka) produced such a pattern\(^3\). Planted Forest (in general *Pinus radiata* plantations), could be distinguished from Indigenous Forest by the presence of planting lines and the intensity of roads. There were also some observable tone and texture differences (again the mono-specificity of the trees showed a more uniform pattern). Areas of Planted Forest that had been logged, but

\(^2\) “Viewed from above, the forest presents an irregular, ruffled appearance, with the crowns of emergent podocarps spreading over a generally closed, mixed broadleaved canopy of matai, miro totara and kahikatea. Kauri is also prominent” (Newsome 1987).

\(^3\) “It's canopy exhibits a smooth, soft, brush-like texture standing between 1 and 3 metres high in young stands” (Newsome 1987).
not yet replanted were classified as Pastoral. Also, recent planting of exotic forest (less than 3 years) could be included in pastoral cover. These were limitations in the identification of Planted Forest; some areas could be classified as pastoral cover, even though the land use had not changed. As a consequence, it could underestimate the planted forest area for the period.

To avoid geometric distortions only the central part of the photos was interpreted. Single photo interpretations were scanned at 210 dpi resolution. Then each interpretation was geo-referenced and rectified to 1:50,000 New Zealand digital topographical maps. Highly variable topographic relief such as in the study area may limit the registration accuracy even under optimal registration conditions (Kennedy and Spies 2004). Because of this a Direct Linear Transformation (DLT)\(^4\) was performed for each photo-interpretation by ERDAS Imagine 8.7\(^5\). This method of geo-referencing/geometric correction allowed correct tilt, radial and relief displacement with the use of a DEM. Fiducial marks and the camera’s focal length were not available for the 1942’s photo set, therefore a orthophoto referencing was not possible. Nevertheless, according to Rossiter and Hengl (2002) the direct linear method gives almost equal results to orthophoto if tiepoints are accurate. An average of 10 tiepoints, well distributed was defined in each photo to improve the accuracy of referencing.

The corrected photo-interpretations were then combined into a mosaic to create land cover maps for each year digitalized into ArcGIS 9.1 as vectors.

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\(^4\) Geo-reference is the procedure to specify the relation (tiepoints) between ground coordinates and remote sensing products. There are three methods for geo-referencing: (1) Projective: corrects tilt and radial displacement only, suitable for relatively flat areas only. (2) Direct linear: corrects tilt, radial, and relief displacement; requires a DEM; does not use fiducial marks. It corrects the external orientation of the photo. (3) Orthophoto: corrects tilt, radial, and relief displacement; requires a DEM, fiducial marks and the camera’s focal length. It corrects both external and internal orientation of the photos (Rossiter and Hengl 2002).

\(^5\) ERDAS IMAGINE 8.7. Copyright©1991-2003 by Leica Geosystems GIS & Mapping LLC.
5.2.2.2. Satellite images

Two LANDSAT satellite images were used, one from 1999 and the other from 2006. The 1999 LANDSAT 7 ETM+ image was geo-referenced to a 1:50,000 New Zealand topographical map in ERDAS Imagine 8.7. Nearest-neighbour re-sampling algorithm was used, and a RMS error (Root Mean Square) of less than 0.5 pixels (<15 m) was obtained. The 1999 image served as the basis to rectify the 2006 image via image-to-image registration. Therefore they were converted to the same projection and datum (New Zealand Map Grid, New Zealand Geodetic Datum 1949).

The 2006 satellite image was a LANDSAT 5 TM. After July 14, 2003 LANDSAT 7 ETM+ scenes were collected with a failure in the Scan Line Corrector (SLC) (SLC-off mode) resulting in loss, duplication or gaps of data (USGS 2005). Therefore LANDSAT 5 TM was the best satellite image available.

A first attempt at supervised classification for the 1999 image was carried out with ERDAS Imagine 8.7. With more than 100 training points, classification accuracy did not go above 70%. Shadows from high elevations produced a confusion between Planted and Indigenous Forest\(^6\), giving as a result a mixture of both classes, a characteristic “salt and pepper” effect (Chuvieco 1999) very difficult to discriminate. As a consequence, another method for classification was chosen.

Visual interpretation of previously combined bands 4, 5, 3 of the scenes was carried out. Digitalization on the screen in ArcGIS 9.1 enabled the creation of land cover maps for 1999 and 2006. The final 2006 land cover map was developed with an ASTER image (2005) as ancillary data. The ASTER Image, with a best resolution (15 m vs. 30 m of LANDSAT), was useful for the discrimination between Indigenous and Planted Forests. Even though these satellite images are not very often used in New Zealand, their band combinations, great detail and lower prices made them very convenient\(^7\).

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6 This problem was first identified for Northland by Segedin (1982) but has not subsequently been followed up.
7 ASTER captures high spatial resolution data in 14 bands, from the visible to the thermal infrared wavelengths; and provides stereo viewing capability for digital elevation model creation. [http://asterweb.jpl.nasa.gov](http://asterweb.jpl.nasa.gov)
Visual interpretation applied to satellite images was time consuming compared to the usually used per-pixel numerical classification (e.g. Spies et al. 1994; Turner et al. 1996; Hayes et al. 2002; Southworth et al. 2002; Arroyo-Mora et al. 2005). But the advantages were to obtain more spectral information than that produced by automatic processes. Form, size, border, texture, and context were additional information used in the identification of the classes (Townshed et al. 2000). These features have been used to resolve confusion when discriminating thematic categories that show spectral overlapping (Gastellu-Etchegorry and Ducros-Gambart 1991; Cohen and Spies 1992; Gong et al. 1992). Any map, as generalized and simplified abstractions of reality are based on subjective decisions. And although the subjectivity in visual interpretation is a limitation and is larger compared to numerical classifications, it increased significantly the accuracy of the classifications (Petit and Lambin 2001).

Two field trips were carried out to ground-truth the 2006 classification. It involved recording the class of land cover at 100 points spread across the study area (geo-referenced with a GPS). Classification accuracy was then assessed on the basis of the field sample. An overall accuracy of 93% was found. The discrepancies were corrected and a final classification derived.

As result of these data extractions a total of five land cover maps were obtained one for each time point, which were used as GIS databases.

With two types of remotely sensed data (photographs and imagery) there was a risk that differences between time periods may result from differences in data collection rather than from actual changes taking place on the ground (Agarwal et al. 2000). Possible errors were minimized in the following way:
1. Application of a uniform classification system over all time points to avoid thematic inconsistencies (Chrisman 1989; Vuorela et al. 2002). Besides, only four broad land cover classes were identified (indigenous forest, scrub, planted forest and pastoral); they could be clearly distinguished on both photographs and images.

2. Inclusion of ancillary data (Table 5.2) to increase classification accuracy by enhancing the quality of classification (Bolstad and Lillesand 1992). Discrimination of pattern, texture and tone from photographs were checked before the interpretation with ancillary maps from the study area. Information from two types of satellite images (LANDSAT and ASTER images) was compared to improve the classification. Topographical maps from different years were used to double check dubious land cover.

3. Interpretation of both photographs and images by the same person to reach constancy or to minimize possible interpretation errors (Pan et al. 1999; Hietel et al. 2004).

4. Rasterization and re-sampling of all maps to achieve a common resolution of 10 m x 10 m.

5. Utilization of the same technique for the production of the maps to be compared: visual interpretation (Petit and Lambin 2001).
Table 5.2.
Details of ancillary data sources used in this chapter.

<table>
<thead>
<tr>
<th>Data</th>
<th>Date</th>
<th>Details</th>
<th>Scale/Resolution</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topographical maps</strong></td>
<td>1942</td>
<td>Kaikohe (N15)</td>
<td>1:63,360</td>
<td>Land and Survey Department</td>
</tr>
<tr>
<td></td>
<td>1944</td>
<td>Hokianga (N14)</td>
<td>1:63,360</td>
<td>Land and Survey Department</td>
</tr>
<tr>
<td></td>
<td>1965</td>
<td>Kaikohe (N15)</td>
<td>1:63,360</td>
<td>Department of Lands and Survey</td>
</tr>
<tr>
<td></td>
<td>1969</td>
<td>Mangakahia (N19)</td>
<td>1:63,360</td>
<td>Department of Lands and Survey</td>
</tr>
<tr>
<td></td>
<td>1972</td>
<td>Hokianga (N14)</td>
<td>1:63,360</td>
<td>Department of Lands and Survey</td>
</tr>
<tr>
<td></td>
<td>1975</td>
<td>Waipoua (N18)</td>
<td>1:63,360</td>
<td>Department of Lands and Survey</td>
</tr>
<tr>
<td></td>
<td>1987</td>
<td>Aranga (260- O07)</td>
<td>1:50,000</td>
<td>Department of Survey and Land Information</td>
</tr>
<tr>
<td></td>
<td>1989</td>
<td>Mangakahia (260- P06)</td>
<td>1:50,000</td>
<td>Department of Survey and Land Information</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>Kaikohe (260- P05)</td>
<td>1:50,000</td>
<td>Department of Survey and Land Information</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>Rawene (260- O05)</td>
<td>1:50,000</td>
<td>Department of Survey and Land Information</td>
</tr>
<tr>
<td></td>
<td>2002</td>
<td>Waipoua (260- O06)</td>
<td>1:50,000</td>
<td>Department of Survey and Land Information</td>
</tr>
<tr>
<td><strong>Digital Elevation Model</strong></td>
<td>2001</td>
<td>North Island DEM</td>
<td>25 x 25 m</td>
<td>Landcare Research</td>
</tr>
<tr>
<td><strong>DEM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ASTER Image</strong></td>
<td>14/1/2005</td>
<td>AST_L1A.0 03:2027471228 scene</td>
<td>15 x 15 m</td>
<td>USGS and Japan ASTER Program.</td>
</tr>
</tbody>
</table>

Source of all ancillary data: University of Auckland.
5.2.3. Data analysis

5.2.3.1. Landscape composition and configuration

Land cover classes were analyzed for each individual map at each time point by using a set of landscape metrics from Fragstat 3.3 (McGarigal et al. 2002). The following class statistics were calculated:

(1) To define composition characteristics:
   - Total class area (CA): land cover extension in hectares.
   - Percentage of the landscape (PLAND): proportion of each class relative to the entire map in per cent.

(2) To define spatial configuration:
   - Total number of patches (NP): number of disjunct patches of the class in the landscape.
   - Mean Class Area (A_MN): average patch size for the class in hectares.
   - Mean Euclidean Nearest -Neighbor Distance (ENN_MN): average cell centre-to-cell centre distance between a patch and its nearest neighbour (of the same patch type) in the landscape, in metres.
   - Standard Deviation Euclidean Nearest -Neighbor Distance (ENN_SD) in metres.

Mean Euclidean Nearest-Neighbour Distance is an assessment of average class isolation. Standard Deviation Euclidean Nearest -Neighbor Distance is a measure of class dispersion when compared with the values of mean distance. Dispersion connotes the tendency for patches to be regularly or contagiously distributed with respect to each other. If the variance is greater than the mean, then the patches are more clumped in distribution than random, and if the variance is less than the mean, then the patches are more uniformly distributed (McGarigal et al. 2002).

A decision tree-model (Figure 5.2) was created to help the interpretation of the changes in landscape structure (a modified version of Bogaert et al. (2004)) relating different metrics. The process identification was carried out through the determination of: total class area, total number of patches and mean class area, and
comparison between successive maps. The processes represented a sequence of possible dynamics of the landscape leading to different landscape configurations.

---

**Decision tree- model**

1. $\text{CA}_1 > \text{CA}_0$ (gain) then:

   - **If** $\text{NP}_1 > \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 > \text{A}_\text{MN}_0$: Creation of large patches
     - Or $\text{A}_\text{MN}_1 < \text{A}_\text{MN}_0$: Creation of small patches
     - Or $\text{A}_\text{MN}_1 = \text{A}_\text{MN}_0$: Creation of similar patches
   - **If** $\text{NP}_1 < \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 > \text{A}_\text{MN}_0$: Aggregation
   - **If** $\text{NP}_1 = \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 > \text{A}_\text{MN}_0$: Enlargement

2. $\text{CA}_1 < \text{CA}_0$ (loss) then:

   - **If** $\text{NP}_1 > \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 < \text{A}_\text{MN}_0$: Fragmentation
   - **If** $\text{NP}_1 < \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 > \text{A}_\text{MN}_0$: Attrition of small patches
     - Or $\text{A}_\text{MN}_1 < \text{A}_\text{MN}_0$: Attrition of large patches
     - Or $\text{A}_\text{MN}_1 = \text{A}_\text{MN}_0$: Attrition of similar patches
   - **If** $\text{NP}_1 = \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 < \text{A}_\text{MN}_0$: Shrinkage

3. $\text{CA}_1 = \text{CA}_0$ then:

   - **If** $\text{NP}_1 > \text{NP}_0$,
     - Then $\text{A}_\text{MN}_1 < \text{A}_\text{MN}_0$: Dissection
   - **If** $\text{NP}_1 = \text{NP}_0$: Shift (other metrics should be analyzed to difference them, such as area-perimeter relationships)

---

Figure 5.2. Decision tree model for identification of landscape processes, based on the increase or decrease of: Total class area ($\text{CA}$), Total number of patches ($\text{NP}$) and Mean Class Area ($\text{A}_\text{MN}$) in Time 0 and Time 1.

---

8 Assuming that as dissection is caused by equal-wide lines, such as roads, the overall area would not show a significant change in size ($\text{CA}_1 = \text{CA}_2$).
In addition, the following landscape statistics were estimated for each year:

- Total number of patches (NP)
- Largest patch index (LPI): It represents the proportion of the landscape accounted for by largest patch, and indicates the extent to which the landscape is dominated by a class type.
- Interspersion and Juxtaposition index (IJI): This index developed by McGarigal and Marks (1995) refers to the intermixing of patches of different types and is based entirely on patch (as opposed to cell) adjacencies. The index increases in value as patches tend to be more evenly interspersed (i.e., equally adjacent to each other) in a "salt and pepper" mixture, whereas lower values characterize landscapes in which the patch types are poorly interspersed (i.e., disproportionate distribution of patch type adjacencies).

### 5.2.3.2. Land cover transitions

Identification of conversion processes provides pattern information complementary to the detailed description of patterns using spatial statistics or metrics (Koffi et al. 2007).

Data on changes in land cover through time were obtained by comparing chronologically sequenced maps (Duncan et al. 1999; Reid et al. 2000; Pan et al. 2001; McConnell et al. 2004). To quantify land cover transitions a GIS overlay procedure was used (ArcGIS 9.1, Raster Calculator). This procedure used cover classes from a given state time \( t_0 \) to clip out cover classes from the next state \( t_1 \) (Moreira et al. 2001; Alados et al. 2004). The pixel-by-pixel comparison generated matrices of transitional frequencies (i.e. number of pixels converted) (White and Mladenoff 1994; Cousins 2001) for each of four time intervals (1942-1961, 1961-1984, 1984-1999, 1999-2006).

From those transition frequency matrices, probability matrices were derived to explore the direction of change in the landscape. These new matrices represented the percent of transitions made from one category to another expressed for the total landscape (Table 5.3).
From these data, information about persistence frequencies could be derived. They were defined as the proportion of pixels belonging to a land cover class in a given map that belonged to the same type in the previous map (Moreira et al. 2001). This persistence value, showed on the diagonal of the matrix, was used to compute gains and losses (Pontius et al. 2004). The bottom row showed the quantity lost for each class and the right-hand column showed the quantity gain for each class. The losses were the differences between the column totals and persistence. The gains were the differences between row totals and persistence.

Table 5.3.
Landscape transition matrix for comparing two maps from two different points in time. The number of classes depends on the map classification (in this thesis, 4 classes were considered). P is expressed as proportion of the total landscape (100%).

<table>
<thead>
<tr>
<th>Time 1</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
<th>Total Time 1</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>( P_{11} )</td>
<td>( P_{21} )</td>
<td>( P_{31} )</td>
<td>( P_{41} )</td>
<td>( P_{+1} )</td>
<td>( P_{+1} - P_{11} )</td>
</tr>
<tr>
<td>Class 2</td>
<td>( P_{12} )</td>
<td>( P_{22} )</td>
<td>( P_{32} )</td>
<td>( P_{42} )</td>
<td>( P_{+2} )</td>
<td>( P_{+2} - P_{22} )</td>
</tr>
<tr>
<td>Class 3</td>
<td>( P_{13} )</td>
<td>( P_{23} )</td>
<td>( P_{33} )</td>
<td>( P_{43} )</td>
<td>( P_{+3} )</td>
<td>( P_{+3} - P_{33} )</td>
</tr>
<tr>
<td>Class 4</td>
<td>( P_{14} )</td>
<td>( P_{24} )</td>
<td>( P_{34} )</td>
<td>( P_{44} )</td>
<td>( P_{+4} )</td>
<td>( P_{+4} - P_{44} )</td>
</tr>
<tr>
<td>Total</td>
<td>( P_{+1} )</td>
<td>( P_{2+} )</td>
<td>( P_{3+} )</td>
<td>( P_{4+} )</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Loss</td>
<td>( P_{+1} - P_{11} )</td>
<td>( P_{2+} - P_{22} )</td>
<td>( P_{3+} - P_{33} )</td>
<td>( P_{4+} - P_{44} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To analyse in more detail the probability of transition for class, the absolute frequencies of transitions were divided by columns totals (Table 5.4). In this way the per-class transition matrix was obtained (Chust et al. 1999).
Table 5.4.
Per-class transition matrix for comparing two maps from two different points in time. $P$ is expressed as proportions of each class total.

<table>
<thead>
<tr>
<th></th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>$P_{11}$</td>
<td>$P_{21}$</td>
<td>$P_{31}$</td>
<td>$P_{41}$</td>
</tr>
<tr>
<td>Class 2</td>
<td>$P_{12}$</td>
<td>$P_{22}$</td>
<td>$P_{32}$</td>
<td>$P_{42}$</td>
</tr>
<tr>
<td>Class 3</td>
<td>$P_{13}$</td>
<td>$P_{23}$</td>
<td>$P_{33}$</td>
<td>$P_{43}$</td>
</tr>
<tr>
<td>Class 4</td>
<td>$P_{14}$</td>
<td>$P_{24}$</td>
<td>$P_{34}$</td>
<td>$P_{44}$</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The degree of change was analysed through a Kappa statistic (Monserud and Leemans 1992; Hagen 2002; Slootweg et al. 2004) for the landscape and for each class. Kappa statistics represented the agreement between two maps and was obtained from the transitional frequency matrices (Pontius and Cheuk 2006). These statistics have been interpreted as a measure of the strength of change (Chuvieco 2002; Romero-Calcerrada and Perry 2004) with low levels of agreement representing significant changes whereas high levels indicating stability (Calvo-Iglesias et al. 2006). To summarise, the agreement between maps can be interpreted as stability or permanence, when the matrices are used to express change.

The formula for the landscape Kappa statistic ($K$) is:

$$K = \frac{P_o - P_e}{1 - P_e}$$
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Where \( P_o = \sum_{i=1}^{c} P_{ii} \)

And \( P_e = \sum_{i=1}^{c} P_i + P + i \)

The per-class Kappa index \((k_i)\) was used to estimate the degree to which a particular class agreed between the two dates (Chust et al. 1999; Romero-Calcerrada and Perry 2004; Calvo-Iglesias et al. 2006). The per-class Kappa index is defined as:

\[
k_i = \frac{P_{ii} - P_i + P + i}{P_i + P + i}
\]

where \( P_{ii} \) is the proportion of the map where the class \( i \) belongs to the two images; \( P_{i+} \) is the proportion of the class \( i \) in map 0 (the reference map) and \( P_{+i} \) is the proportion of the class \( i \) in map 1. Kappa ranges in value from –1 to +1 \(^9\), with its magnitude reflecting the strength of agreement between the maps (Chust et al. 1999), i.e. Kappa coefficient equals +1 when there is complete agreement.

5.3. Results

5.3.1. Abundance changes

Land cover class analysis for all five years (1942, 1961, 1984, 1999 and 2006) showed changes of abundance in the area covered by Pastoral, Planted Forest, Indigenous Forest and Scrub land cover classes in the study region (Table 5.5, Figure 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9).

\(^9\) If Kappa is positive, the observed agreement exceeds chance agreement. If Kappa is negative, the observed agreement is less than chance agreement.
In the earlier times, the landscape was dominated by Pastoral\textsuperscript{10} cover (52\% of the total area), followed by Indigenous Forest (39.6\%). Scrub represented 6.4 \% of the total, while Planted Forest was relatively insignificant in the total cover (2\%). By 1999 there was a reversion in the dominance in the landscape. Indigenous Forest became dominant, but not because it increased in area but because of the reduction of Pastoral area, and both increment of Scrub and principally Planted Forest. By 2006, there was an increment in Indigenous Forest area, occupying the highest percentage in the landscape (43.9\%). As result, Pastoral was no longer dominant (31.8\%).

Except for Planted Forest, which increased in area since 1942, none of the other land covers changed in a continuous way (Fig. 5.3). Indigenous Forest experienced net losses and gains in area over the same period (Table 5.5). Among the land cover classes Indigenous Forest has shown the least amount of change, remaining largely steady throughout the study period (Fig. 5.4). In contrast, Pastoral and especially Scrub were more dramatically affected.

Table 5.5.
Changes of selected land cover classes in the study area (79,879 ha) from 1942 to 2006, expressed as area (ha) and as percentage of the landscape (%).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
<td>ha</td>
</tr>
<tr>
<td>Indigenous Forest</td>
<td>31601</td>
<td>39.56</td>
<td>31479</td>
<td>39.41</td>
<td>34299</td>
</tr>
<tr>
<td>Scrub</td>
<td>5169</td>
<td>6.47</td>
<td>11917</td>
<td>14.92</td>
<td>5471</td>
</tr>
<tr>
<td>Planted Forest</td>
<td>1550</td>
<td>1.94</td>
<td>2488</td>
<td>3.11</td>
<td>4817</td>
</tr>
<tr>
<td>Pastoral / Others</td>
<td>41559</td>
<td>52.03</td>
<td>33995</td>
<td>42.56</td>
<td>35292</td>
</tr>
</tbody>
</table>

\textsuperscript{10} In Results: Pastoral/Others cover is shortened in the text for Pastoral.
Figure 5.3. Area of land cover classes and their changes from 1942 to 2006.

Figure 5.4. Land cover changes expressed as net differences (%) for each period.
1942: Land Cover Map
Chapter 5: Landscape analysis
Chapter 5: Landscape analysis
The landscape level transition matrix (Table 5.6) suggested that there were differences in landscape dynamics between years, and some general trends were demonstrated:

- Principal conversion to Scrub in the period 1942-1961 principally at expense of Pastoral.
- Conversion to Pastoral from 1961 to 1984, at expense of Scrub.
- Conversion to Planted Forest during 1984-1999, with high losses from Pastoral.
- Multiple conversions included those to indigenous cover in the last period (1999-2006).

In general terms the most common conversions were at the expense of Pastoral and throughout this whole period, Planted Forest was the least converted to other classes.

The results of per-class matrices (Table 5.7) showed that in those periods with net losses in Indigenous Forests, conversions were principally to Scrub in 1942-1961, while in 1984-1999 they were similar for Scrub and Pastoral. In this period conversion to Planted Forest became more significant than in the previous ones. Periods of net gain in Indigenous Forest area were associated principally with conversion from Scrub. Nevertheless, Indigenous Forest had the highest permanence values in every period (per-class Kappa index always above 0.81). Its highest retention frequency (94.5%) was during 1961-1984 coincident with the lowest retention for Scrub (26.8%).

In terms of the study region’s landscape, the period 1984-1999 was the most unstable (Kappa=0.62), which was coincident with a lower permanence in all the land covers (per-class Kappa ranging from 0.48 to 0.81). Other behaviour could be seen during 1961-1984: the landscape also showed a moderate stability (Kappa=0.68), but this time only Scrub showed very low permanence (per-class Kappa=0.22).
Table 5.6.

### Frequency matrix (%)

<table>
<thead>
<tr>
<th></th>
<th>Indigenous</th>
<th>Scrub</th>
<th>Planted</th>
<th>Pastoral</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1961</td>
<td>Indigenous</td>
<td>36.37</td>
<td>0.74</td>
<td>0.03</td>
<td>2.27</td>
</tr>
<tr>
<td></td>
<td>Scrub</td>
<td>2.01</td>
<td>4.37</td>
<td>0.18</td>
<td>8.36</td>
</tr>
<tr>
<td></td>
<td>Planted</td>
<td>0.04</td>
<td>0.04</td>
<td>1.65</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td>Pastoral</td>
<td>1.14</td>
<td>1.32</td>
<td>0.08</td>
<td>40.02</td>
</tr>
<tr>
<td>Subtotal</td>
<td>39.56</td>
<td>6.47</td>
<td>1.94</td>
<td>52.03</td>
<td>100</td>
</tr>
<tr>
<td>Loss</td>
<td>3.19</td>
<td>2.10</td>
<td>0.29</td>
<td>12.01</td>
<td></td>
</tr>
</tbody>
</table>

### Kappa statistics (K)

- 1942: K = 0.79
- 1961: K = 0.68
- 1999: K = 0.62
- 2006: K = 0.75

Indigenous = Indigenous Forest.
Planted = Planted Forest.
Per-class transition matrix for the four land cover classes for periods (1942 and 1961, 1961 and 1984, 1984 and 1999, and 1999 and 2006). Per-class Kappa index \((k)\) is calculated for each land cover in each period.

**Frequency matrix (%)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>Indigenous= Indigenous Forest</td>
<td>Scrub</td>
<td>Planted= Planted Forest</td>
<td>Pastoral</td>
<td></td>
</tr>
<tr>
<td>1942</td>
<td>Indigenous</td>
<td>91.93</td>
<td>11.46</td>
<td>1.62</td>
<td>4.36</td>
</tr>
<tr>
<td></td>
<td>Scrub</td>
<td>5.09</td>
<td>67.54</td>
<td>9.28</td>
<td>16.06</td>
</tr>
<tr>
<td></td>
<td>Planted</td>
<td>0.09</td>
<td>0.61</td>
<td>85.07</td>
<td>2.67</td>
</tr>
<tr>
<td></td>
<td>Pastoral</td>
<td>2.89</td>
<td>20.39</td>
<td>4.03</td>
<td>76.92</td>
</tr>
<tr>
<td>(k)</td>
<td>0.87</td>
<td>0.62</td>
<td>0.89</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>Indigenous</td>
<td>94.50</td>
<td>25.49</td>
<td>0.58</td>
<td>4.41</td>
</tr>
<tr>
<td></td>
<td>Scrub</td>
<td>1.34</td>
<td>26.81</td>
<td>0.76</td>
<td>5.40</td>
</tr>
<tr>
<td></td>
<td>Planted</td>
<td>0.73</td>
<td>9.70</td>
<td>76.21</td>
<td>4.52</td>
</tr>
<tr>
<td></td>
<td>Pastoral</td>
<td>3.43</td>
<td>38.00</td>
<td>22.45</td>
<td>85.67</td>
</tr>
<tr>
<td>(k)</td>
<td>0.90</td>
<td>0.22</td>
<td>0.76</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>Indigenous</td>
<td>88.65</td>
<td>17.52</td>
<td>5.91</td>
<td>6.32</td>
</tr>
<tr>
<td></td>
<td>Scrub</td>
<td>4.23</td>
<td>53.09</td>
<td>4.37</td>
<td>6.90</td>
</tr>
<tr>
<td></td>
<td>Planted</td>
<td>2.37</td>
<td>7.10</td>
<td>69.43</td>
<td>20.50</td>
</tr>
<tr>
<td></td>
<td>Pastoral</td>
<td>4.74</td>
<td>22.29</td>
<td>20.29</td>
<td>66.28</td>
</tr>
<tr>
<td>(k)</td>
<td>0.81</td>
<td>0.48</td>
<td>0.65</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Indigenous</td>
<td>91.71</td>
<td>18.09</td>
<td>6.90</td>
<td>7.14</td>
</tr>
<tr>
<td></td>
<td>Scrub</td>
<td>2.39</td>
<td>58.66</td>
<td>1.10</td>
<td>5.52</td>
</tr>
<tr>
<td></td>
<td>Planted</td>
<td>2.80</td>
<td>9.95</td>
<td>78.18</td>
<td>7.26</td>
</tr>
<tr>
<td></td>
<td>Pastoral</td>
<td>3.10</td>
<td>13.30</td>
<td>13.82</td>
<td>80.08</td>
</tr>
<tr>
<td>(k)</td>
<td>0.85</td>
<td>0.54</td>
<td>0.73</td>
<td>0.71</td>
<td></td>
</tr>
</tbody>
</table>

\(^{13}\) Indigenous= Indigenous Forest  
\(^{14}\) Planted= Planted Forest
Results from the transition matrices not only gave information about direction and degree of change. They also provided positional information because retention probabilities indicated permanence in location of a land cover (pixel \( x, y \) in the map time 0 that remains in the same condition in the map time 1). From this, two trends could be observed: that a high proportion of the area of Indigenous Forests remained in the same position through time, whereas Scrub was shifting spatially. In consequence, Indigenous Forest had the advantage of long term retention.

### 5.3.2. Spatial pattern changes

Landscape analysis of spatial patterns was used as complementary information to the dynamic of the landscape.

The spatial pattern of the four land cover classes changed since 1942 (Fig. 5.10)\(^{15}\). Class metrics used for configuration description revealed that the most significant changes in Indigenous Forest were from 1984 to 1999 because of an important drop in the number of patches, accompanied with an increase of almost three times, of mean class area.

Scrub showed changes in configuration with an important increment in number of patches (almost the double) and in mean area for the period 1942-1961. By 1984 the Scrub mean area decreased significantly, but after that, it increased again with a marked reduction in the number of patches. In 1961, Pastoral decreased in mean area; nevertheless from 1984 to 1999, Pastoral configuration showed evident changes not only in average patch size but also in number of patches. Even though Planted Forest showed in all the periods a continuous increase in number of patches with reduction of mean area, these pattern changes were more significant since 1984.

\(^{15}\) For the complete values of metrics, see Appendix 2.
Figure 5.10. Mean area (dots) in hectares and number of patches (squares) for each land cover class for each year.
Chapter 5: Landscape analysis

The proposed decision-tree approach allowed a general description of the processes that changed the composition and configuration of each land cover class (Table 5.8).

Table 5.8.
Landscape processes in the study area. Analysis of processes for each land cover class in the different periods (1942-1961, 1961-1984, 1984-1999, and 1999-2006), according to the increase or decrease in area, number of patches, and mean class area.

<table>
<thead>
<tr>
<th>Indigenous Forest</th>
<th>Area</th>
<th>No. patches</th>
<th>Mean class area</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942-1961</td>
<td>&lt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>loss/fragmentation</td>
</tr>
<tr>
<td>1961-1984</td>
<td>&gt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>gain/creation of small patches</td>
</tr>
<tr>
<td>1984-1999</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>loss/attrition of small patches</td>
</tr>
<tr>
<td>1999-2006</td>
<td>&gt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>gain/aggregation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scrub</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1942-1961</td>
<td>&gt;</td>
<td>&gt;</td>
<td>&gt;</td>
<td>gain/creation of large patches</td>
</tr>
<tr>
<td>1961-1984</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&lt;</td>
<td>loss/attrition of large patches</td>
</tr>
<tr>
<td>1984-1999</td>
<td>&gt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>gain/aggregation</td>
</tr>
<tr>
<td>1999-2006</td>
<td>&lt;</td>
<td>&lt;</td>
<td>0</td>
<td>loss/attrition of similar patches</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planted Forest</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1942-1961</td>
<td>&gt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>gain/creation of small patches</td>
</tr>
<tr>
<td>1961-1984</td>
<td>&gt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>gain/creation of small patches</td>
</tr>
<tr>
<td>1984-1999</td>
<td>&gt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>gain/creation of small patches</td>
</tr>
<tr>
<td>1999-2006</td>
<td>&gt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>gain/creation of small patches</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pastoral</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1942-1961</td>
<td>&lt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>loss/fragmentation</td>
</tr>
<tr>
<td>1961-1984</td>
<td>&gt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>gain/aggregation</td>
</tr>
<tr>
<td>1984-1999</td>
<td>&lt;</td>
<td>&gt;</td>
<td>&lt;</td>
<td>loss/fragmentation</td>
</tr>
<tr>
<td>1999-2006</td>
<td>&lt;</td>
<td>&lt;</td>
<td>&gt;</td>
<td>loss/attrition of small patches</td>
</tr>
</tbody>
</table>

>: increase; <: decrease; 0: stable

Metrics were relative to the landscape described. For example, what small patches mean for indigenous cover, could be biased by the large size of the principal patch in the central part of the study area.

Mean Euclidean Nearest-neighbour distance and variance values gave insight about the changes in isolation and dispersion of the classes (Fig. 5.11). Indigenous Forest isolation was minimum in 1984 and maximum in 1999. Since 1984, Indigenous Forest changed a more uniform distribution in the landscape to a clumped one; but by 2006 it became more regularly distributed. Scrub showed a clumped distribution in the landscape and, with exception of 1961, there was an increasing spacing between patches. This probably resulted from a removal (attrition) of patches between areas of aggregation. Planted Forest showed the highest values of isolation in 1942; by 2006, the class was less isolated and more uniformly distributed.
Figure 5.11. Values of mean Euclidean Neighbor Distance (ENN_MN) and Standard Deviation (ENN_SD) in metres for each land cover class in each year.
Finally, the landscape metrics showed that the effects of 64 years of human activities produced in the whole landscape a reduction of the total number of patches below the values for 1942, with changes in the dominance of the land covers and a more evenly interspersed pattern among them (i.e. land covers are equally adjacent to each other)(Table 5.9).

Table 5.9.
Landscape metric results from 1942 to 2006.

<table>
<thead>
<tr>
<th>Years</th>
<th>Number of patches</th>
<th>Dominance (LPI)</th>
<th>Juxtaposition (IJI )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942</td>
<td>800</td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>1961</td>
<td>1048</td>
<td>32</td>
<td>71</td>
</tr>
<tr>
<td>1984</td>
<td>1131</td>
<td>43</td>
<td>71</td>
</tr>
<tr>
<td>1999</td>
<td>677</td>
<td>36</td>
<td>87</td>
</tr>
<tr>
<td>2006</td>
<td>716</td>
<td>38</td>
<td>92</td>
</tr>
</tbody>
</table>

To summarise, vegetation cover of the study area was dynamic and multidirectional between 1942 and recent times. This was demonstrated by the net changes in area, in landscape pattern shifts and in transitions among land covers. The most unstable periods were: between 1961-1984 when area and configuration changes in the landscape were at the expense of scrub, and between 1984-1999 where all land covers changed. The landscape transitioned from one with dominance of pastoral cover to other in which the area of indigenous forest is significantly larger than any other land cover. The changes consisted mainly of a decrease in pastoral areas, increase of planted forest, quasi-stability of indigenous forest, and continuous change of scrub. For indigenous forests an active exchange with scrub was shown.
5.4. Comparison with historical analysis

Predictions about historical changes affecting land cover were compared with the characterization and measurement of landscape changes in the study area from 1942 to 2006.

The approach was to examine the degree to which the patterns of landscape change could be attributed to a set of historical factors that were identified as significant at broader scales for Northland.

The majority of the predictions were confirmed (Table 5.10) except for some trends of indigenous forests (1961 to 1984 and 1984 to 1999).

Table 5.10.
Expected trends in landscape change (from Table 4.4 in Historical analysis) against observed net values obtained by the landscape change analysis.

<table>
<thead>
<tr>
<th>Transition years</th>
<th>Indigenous Forest</th>
<th>Scrub</th>
<th>Planted Forest</th>
<th>Pastoral</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942-1961</td>
<td>-/ -</td>
<td>+or-/+</td>
<td>+/ +</td>
<td>- or +/ -</td>
</tr>
<tr>
<td>1961-1984</td>
<td>-/ +</td>
<td>-/ -</td>
<td>+/ +</td>
<td>+/ +</td>
</tr>
<tr>
<td>1984-1999</td>
<td>0/ -</td>
<td>+/ +</td>
<td>+/ +</td>
<td>-/ -</td>
</tr>
<tr>
<td>1999-2006</td>
<td>+/-</td>
<td>-/ -</td>
<td>+/ +</td>
<td>-/ -</td>
</tr>
</tbody>
</table>

(+: increase; -: decrease; 0: steady)

The land cover description in 1942 set the start point of the analysis. It was a pastoral landscape with separate remnant indigenous forest masses, consequence of an intensive deforestation of its principal timbers in former years, some dispersed scrub, and a small area of exotic plantations. This was characterised as the stage of land development and agricultural predominance in the country.
The development of an expanding scrub cover during the period 1942-1961, may be due to an encroachment into pastoral lands due to a lack of resources for production. This caused the pastoral land to become fragmented because the interspersion of scrub cover. The dynamic conversion between scrub and other land covers could be an indication of the important government incentives to production during the second part of this period. It was visible from the 1961 map: the Waimamaku river valley had less scrub cover while the west area (by Mataraua Rd) retained large patches of scrub. More favourable physical conditions or existing farms developed previously in the area could explain the difference.

Until 1961, there were few natural reserves. Indigenous forest exploitation was still possible, because of the lack of conservation legislation. Fragmentation of the native forest may have been a consequence of this activity, e.g. construction of roads made in the forest, together with logging. Clearance of merchantable timber could expose the sub-canopy, explaining conversion to less stratified covers such as scrub.

Plantation of exotic timber was increasing due to government large-scale planting and the large size of the plantations. The few exotic plantations did not compete for the same space with indigenous forests. New planted forests were developed principally on marginal pastoral lands (Le Heron and Roche 1984). Encroachment of scrub had happened in areas of clear cut.

**During 1961-1984** the impetus was directed to improve productive activities and this could be seen in the landscape change. The highest conversion was at expenses of scrub lands, principally by clearance to pasture. But exotic plantations also began to occupy this “idle” land coming into competition with agricultural uses (McLean 1978). Scrub was removed allowing pastoral land to merge, resulting in a less fragmented cover, and becoming again dominant. This was the most stable period for pastoral cover in terms of the area of this land cover in the study area.
Important incentives to pastoral production were supposed to have a marked extension in pasture area, but the gain was not so evident. During the 1970s an increment of beef cattle at the expense of dairying occurred (Blunden et al. 1995). According to Maunier et al. (1985) farms that remained in dairying, in fact, increased their area in pasture mainly by converting scrub to pasture, but non-dairy farms did not improve the quality of their land cover leaving the scrub.

It had been assumed that incipient protection legislation before 1984 and the strong incentives for pastoral and forestry development would produce losses of indigenous forests; however, it did not happen in this way. Contrary to the prediction, indigenous forest had a net gain in area. It could be explained by two conditions. (1) A great part of the study area was under protection measures. (2) Indigenous forest permanence could be due to physical characteristics of the land that make it unsuitable for other productive activity. Both the Ministry of Works (1964) and McLean (1978) identified that the physical margins for pastoral development had been reached with all capable land cleared or forested. In this period no pressures on the native forest were observed. Losses of indigenous forest to agriculture lands occurred, but they were compensated by gains from the scrub vegetation.

Exotic plantations were in the same position, but new plantings were favoured by important forestry subsidies. This was the first time that the private sector exceed the state afforestations since the mid 1930s (Wheeler and Moran 1985) and this may explain the smaller areas incorporated into this activity compared with the large scale planting of the government in previous years.

**The 1984-1999 period** was characterised by important political and administrative changes which was reflected in the changes of the landscape in land covers.

---

16 The number of beef farms in Northland increased from 5 per cent in 1960 to 26% in 1980 respect the total percentage of all farms, while dairying decreased from 52% in 1960 to 22% in 1980. The number of sheep farms also reduced their proportion: from 13% in 1960 to 6 % in 1980 (Blunden et al. 1995).
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There were still some signs of indigenous forest exploitation: their loss in area for example, contrary to the prediction for this period. Total protection of state indigenous forests and higher restrictions should have relaxed the pressure on native forests. This was not obviously reflected in the land cover changes. With a high proportion of the indigenous forest protected by this date, the losses of small areas were probably due to private land exploitation.

What was notable was the increase in area of planted forest, as this represented the 3rd plantation boom in the 1990s. Even though new large areas were planted close to existing patches especially in the East zone, the mean class area decreased because the largest existing area was partially logged. It was the first time that exotic plantations competed with pastoral land (which became fragmented) rather than with scrub lands.

According to the Northland Regional Council (1993) a decline in animal stocking rates and reduced fertilizer inputs may have led to the reversion of scrub. This was noticeable from the increase in area of this land cover.

In the last period (1999-2006) even though the general changes in the landscape were minor, multiple conversions occurred, together with changes in abundance and composition. The increase of indigenous forest was probably due to the incoming protection mechanisms on private lands.

To summarise: indigenous forests were influenced by social and economic conditions that changed or shifted the appropriation of natural resources and land use. They passed from a timber product to a protected resource. This could be seen in the net increase of area from 1942 to 2006. Nevertheless, the most interesting observation is the lack of gross variation in indigenous forest cover in the study area.
Chapter 6:
Indigenous forest analysis
Waipoua forest: largest remnant of kauri forest in Northland.

(Photo/ A.Aleksa)
Chapter 6: Indigenous forest analysis

6.1. Introduction: the spatial conditioners

According to the previous chapter, two main outcomes were highlighted:
- Changes in the area of indigenous forest between 1942-2006 did not always follow the historical expectation that I hypothesized for my Northland study area.
- Indigenous forest was the most stable land cover.

To understand where land use change is likely to take place, requires the identification of natural and cultural landscape attributes that may act as spatial conditioners of change. This chapter was aimed to observe human-environment conditions that could differently reshape the vulnerability of indigenous forest. In this case the analysed conditions were: land protection and physical attributes.

Formal protection means that areas are set aside from productive land conversion, becoming a limitation on the extent of change. This is achieved through the establishment of a network of protected areas\(^1\).

---

\(^1\) In New Zealand a Protected Natural Area (PNA) is a legally protected area, characterised by indigenous species or ecosystems, in which the principal purpose of management is retention of the indigenous state (Myers et al. 1987).
It has been widely documented that changes in forest cover revealed a strong influence from the underlying topographic complexity (Pan et al. 1999; Pan et al. 2001; Hoersch et al. 2002; Turner et al. 2003). Indigenous forest distribution in the study area was found to have a strong relationship with physical characteristics; such as: elevation, slope, soil type, aspect (Eadie et al. 1985; Burns and Leathwick 1996; and Chapter 3 of this thesis). Moreover, physical characteristics represent constraints for human land use (McConnell et al. 2004).

Because of these physical conditions, it becomes possible for some of the native forest area to not change through the years even without formal protection. If vulnerability was described as the probability of loss, it also becomes important to describe those areas that did not change. Description of the characteristics that made them non-vulnerable in 64 years was an indication of persistence (i.e. probability of permanence).

### 6.2. Methods

Indigenous forest cover changes were related to data about formal protection and physical variables (Table 6.1) to assess whether incentives to land production were conditioned by these variables.

From the land cover maps produced in Chapter 5, indigenous forest cover for each year was separated into two sets of indigenous cover classes: protected and non-protected. Information was obtained from a digital database: NationalMap2 (Critchlow New Zealand 2006) with cadastral information. Data about purpose of conservation and year gazetted were used to organize the maps. Therefore, the new maps had the following classes: protected indigenous forest, non-protected indigenous forest, scrub, planted forest and pastoral cover.
To examine pixel-to-pixel changes between indigenous forest and other land covers, each pair of consecutive maps was overlaid using ArcGIS 9.1. Land cover change maps were obtained (1942-1961, 1961-1984, 1984-1999, 1999-2006).

Those non-protected indigenous forests that had not changed over the period of study, the “permanent forests”, were detected by overlaying the land cover maps of each year. The maps were combined together to create a single map. In this new map each pixel included information on land cover for all five dates. Those pixels with indigenous forest in all years formed the map of permanent indigenous forest.

Physical attributes related with suitability for productive activities such as elevation and land capability were used as independent variables. Elevation data was obtained directly from the 25 m-Digital Elevation Model (DEM)\(^2\) and the following classes were grouped (as general groups of elevation identified significant in the Chapter 3): < 150 m, 150-300 m, 300-450 m, 450-600 m, and > 600 m.

<table>
<thead>
<tr>
<th>Database</th>
<th>Variable</th>
<th>Date</th>
<th>Scale/Resolution</th>
<th>Agency</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM (raster)</td>
<td>Elevation</td>
<td>1999</td>
<td>25 x 25 m</td>
<td>LINZ</td>
<td>* 1</td>
</tr>
<tr>
<td>LRI (vector)</td>
<td>LUC classes</td>
<td>1984</td>
<td>1:50,000 (2nd Edition)</td>
<td>NWASCO/ Landcare Research</td>
<td>* 1</td>
</tr>
<tr>
<td>NationalMap2 (vector)</td>
<td>Cadastre</td>
<td>2006</td>
<td>1:50,000</td>
<td>Critchlow NZ</td>
<td>* 2</td>
</tr>
</tbody>
</table>

* 1 University of Auckland
* 2 Tonkin and Taylor Consultancy NZ

Land capability was extracted from the New Zealand Land Resource Inventory (NZLRI)\(^5\). The NZLRI is a national database of physical factors: rock type, soil type, slope, erosion degree and type, and vegetation. Land Use Capability (LUC)

\(^2\) Database steward: Land Information New Zealand. Database custodian: Terralink NZ Ltd.
\(^5\) Database steward: Landcare Research Ltd. Database custodian: Landcare Research Ltd.
classification is an assessment of land, taking into account the ability of those physical factors (considering also climate, flood risk, land use practices and erosion history) to provide sustained agricultural production (Water and Soil Division 1979).

Land capability classes were indicators of potential land transformation risks and therefore of native vegetation vulnerability (Pressey and Taffs 2001; Wessels et al. 2003). For example, the LUC was found to be the factor that best determined land use in the Nelson region (Nagashima et al. 2001).

The LUC classification has three categories: a class, a subclass, and a unit. Class is the broadest category and it is an assessment of land’s versatility for sustained production giving the general degree of limitation to use (Harmsworth 1996). There are eight classes represented but for this analysis they were grouped in three:
- Classes 1 to 4: suitable for arable use, and may be also for pasture or forestry.
- Class 5 to 7: not suitable for arable, but suitable for pastoral or forestry use.
- Class 8: unsuitable for agriculture or production forestry.

Elevation data and LUC categories were overlaid into ArcGIS 9.1 to develop a new map of 15 combinations. Proportions for each combination were obtained.

The land cover change maps were overlaid with the elevation/LUC combination map. This allowed the investigation of the distribution of indigenous forest changes with these independent variables and analysis of the spatial association with each combination (Pan et al. 1999; Southworth et al. 2002).

To test the strength of spatial association between indigenous forest changes and the combination of independent variables, the electivity index was calculated (Pastor and Broschart 1990; Host et al. 1996; Pan et al. 1999). The basic premise was that if changes in indigenous forest segregate according to some elevation and LUC combination, then they should be associated with that attribute to a greater or lesser

---

6 The capability subclass divided the land according to the major kind of limitation to use in relation with erosion, wetness, soil, and climate.
7 The capability unit groups together land inventory units which require the same kind of management and the same kind a intensity of conservation treatment (Water and Soil Division 1979). They were not taken into account for this study.
8 Land use capability classes in Appendix 3.
degree than would be expected at random. Electivity index takes a value of zero for
random association and deviates from zero as a combination of variables is preferred
(positive) or avoided (negative).

The formula is:

\[ E_{ij} = \ln \left( \frac{r_{ij}}{(1-p_j)} / \frac{(1-r_{ij})}{p_j} \right) \]

Where \( E_{ij} \) is the electivity index for land cover change type i to combination category
j, \( r_{ij} \) was the proportion of land cover change type i on combination category j, and \( p_j \)
was the proportion of the landscape occupied by the combination category j. These
electivity indices were tested against the chi-square distribution for significance of
positive or negative association according to the formula (Pan et al. 1999; White and Host 2000):

\[ \chi^2 = \frac{E^2_{ij}}{1/x_{ij} + 1/(m_j - x_{ij}) + 1/y_i + 1/(n_t - y_i)} \]

Where \( x_{ij} \) is the area of land cover change type i on combination category j; \( y_i \) is the
total area of land cover change type i in the landscape; \( m_j \) is the area of combination
category j; and \( n_t \) is the area of the entire landscape. The calculated \( \chi^2 \) was compared
with \( \chi^2 \) distribution with one degree of freedom at a significance level \( p=0.005 \).

6.3. Results

6.3.1. The non-protected indigenous forests

The analysis of indigenous forest showed that after 1984 there was a noticeable
increase in the state protected forests (Table 6.2 and Fig. 6.1). 63.7% of the existing
indigenous forest became protected. Today the protected indigenous forest covers
27% of the 79,879 hectares of the study area and is represented principally by
conservation areas and a wildlife refuge.

Visual analysis from the maps of the different years (Fig. 6.2, 6.3, 6.4, 6.5, and 6.6)
revealed the increase in number of protected area since 1943 was through the
creation of separate patches until 1984. From that time protection of indigenous forest was primarily through the incorporation of areas proximate to the existing reserves. No new reserves were declared since 1999.

Table 6.2.
Area (ha) covered by protected and non-protected indigenous forests in the study area from 1942 to 2006.

<table>
<thead>
<tr>
<th>Year</th>
<th>Indigenous Forest</th>
<th>Up to 1942</th>
<th>Up to 1961</th>
<th>Up to 1984</th>
<th>Up to 1999</th>
<th>Up to 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected</td>
<td>2265</td>
<td>4322</td>
<td>4581</td>
<td>21570</td>
<td>21650</td>
<td></td>
</tr>
<tr>
<td>Non- Protected</td>
<td>29336</td>
<td>27157</td>
<td>29718</td>
<td>12310</td>
<td>13446</td>
<td></td>
</tr>
<tr>
<td>Total (ha)</td>
<td>31601</td>
<td>31479</td>
<td>34299</td>
<td>33880</td>
<td>35096</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.1. Proportion of protected and non-protected indigenous forest in relation with total area from 1942 to 2006.
Results of the analysis of physical characteristics for the study area displayed a great proportion of land unsuitable for cropping/agriculture purposes (Fig 6.7). There was no LUC class 1-4 above 600 m asl.

During 1942-1961 changes from indigenous forests to planted forests and pasture occurred in lowlands with LUC class 5-7 i.e. in productive lands (Table 6.3). Changes > 450 m elevation were primarily those to pasture and scrub in low LUC classes. Non-protected indigenous forests remained associated with uplands, but also in LUC class 8 at lower elevations. Protected areas were positively associated with LUC 8 at elevations from 150 to 450 m asl, and with LUC 5-7 at higher elevations.

---

10 With lowlands defined as land below 300 metres and uplands as land above this altitude, for the Northland region (Segedin 1982).
Table 6.3.
Electivity index for indigenous forest conversions to elevation and LUC classes for the period 1942 to 1961. Zero values mean that the conversion class is distributed randomly, (+) or (-) means that the conversion is associated to a greater or lesser degree than would be expected at random.

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>LUC Class</th>
<th>Indigenous to Scrub</th>
<th>Indigenous to Planted</th>
<th>Indigenous to Pastoral</th>
<th>Indigenous to Protected</th>
<th>Indigenous to Indigenous</th>
<th>Total Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150</td>
<td>1-4</td>
<td>1.27</td>
<td>0.35</td>
<td>0.08</td>
<td>-3.14</td>
<td>0</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.69</td>
<td>1.28</td>
<td>0.17</td>
<td>-3.75</td>
<td>-1.16</td>
<td>-1.15</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.05</td>
<td>-0.83</td>
<td>-0.8</td>
<td>-0.91</td>
<td>-3.14</td>
<td>0</td>
</tr>
<tr>
<td>151-300</td>
<td>1-4</td>
<td>-1.39</td>
<td>0.13</td>
<td>0.19</td>
<td>-2.14</td>
<td>-2.14</td>
<td>-0.81</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.71</td>
<td>-0.09</td>
<td>0.46</td>
<td>-1.9</td>
<td>0.02</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.05</td>
<td>-0.42</td>
<td>1.59</td>
<td>0.63</td>
<td>0.51</td>
<td>0.15</td>
</tr>
<tr>
<td>301-450</td>
<td>1-4</td>
<td>0.01</td>
<td>-1.07</td>
<td>0.57</td>
<td>-0.64</td>
<td>-0.64</td>
<td>-0.64</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.39</td>
<td>-1.18</td>
<td>-0.36</td>
<td>0.64</td>
<td>-0.42</td>
<td>-0.42</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-1.5</td>
<td>-1.11</td>
<td>2.35</td>
<td>0.25</td>
<td>-0.6</td>
<td>-0.6</td>
</tr>
<tr>
<td>451-600</td>
<td>1-4</td>
<td>1.96</td>
<td>0.92</td>
<td>0.49</td>
<td>-1.87</td>
<td>-1.87</td>
<td>-1.87</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>1.09</td>
<td>-1.04</td>
<td>0.37</td>
<td>1.04</td>
<td>-1.03</td>
<td>-1.03</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-2.95</td>
<td>-2.33</td>
<td>2.53</td>
<td>-0.05</td>
<td>-3.57</td>
<td>-3.57</td>
</tr>
<tr>
<td>&gt;601</td>
<td>1-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>1.5</td>
<td>-2.42</td>
<td>2.11</td>
<td>0.71</td>
<td>-0.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>-2.6</td>
<td>2.9</td>
<td>-0.09</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant associations shown for $X^2$, 1 df, $p<0.005$

Indigenous forest to Indigenous forest is a non-protected indigenous forest that has not changed. Conversion from other covers to indigenous forest is grouped in: Total addition.

From 1961 to 1984 conversions from indigenous forest to planted forest and pasture were positively associated with lowlands with LUC 5 to 7, and to pasture between 450 and 600 m asl at LUC 1-4 class (Table 6.4). Conversions to scrub were associated with lowlands at LUC 5-7. Gains from other land covers to indigenous forest were associated with elevations higher than 600 m asl and LUC 5-7 (areas of limited production suitability).

\[^{11}\text{Indigenous}\] = Indigenous Forest
\[^{12}\text{Planted}\] = Planted Forest
\[^{13}\text{Protected}\] = Protected Indigenous Forest
Table 6.4. Electivity index for indigenous forest conversions to elevation and LUC classes, for the period 1961 to 1984. Zero values mean that the conversion class is distributed randomly, (+) or (-) means that the conversion is associated to a greater or lesser degree than would be expected at random.

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>LUC Class</th>
<th>Indigenous to Scrub</th>
<th>Indigenous to Planted</th>
<th>Indigenous to Pastoral</th>
<th>Indigenous to Protected</th>
<th>Indigenous to Indigenous</th>
<th>Total Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150</td>
<td>1-4</td>
<td>-0.44</td>
<td>0.20</td>
<td>-0.04</td>
<td>-5.27</td>
<td>-2.74</td>
<td>-1.23</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.84</td>
<td>0.16</td>
<td>-0.34</td>
<td>1.06</td>
<td>-1.06</td>
<td>-0.82</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.27</td>
<td>-1.49</td>
<td></td>
<td></td>
<td>-0.93</td>
<td>-1.86</td>
</tr>
<tr>
<td>151-300</td>
<td>1-4</td>
<td>-1.55</td>
<td>-1.15</td>
<td>-0.16</td>
<td>-2.53</td>
<td>-2.18</td>
<td>-0.82</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.24</td>
<td>1.13</td>
<td>0.81</td>
<td>1.48</td>
<td>0.00</td>
<td>-0.99</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.70</td>
<td>-0.91</td>
<td></td>
<td></td>
<td>0.65</td>
<td>-1.49</td>
</tr>
<tr>
<td>301-450</td>
<td>1-4</td>
<td>0.74</td>
<td>-1.52</td>
<td></td>
<td></td>
<td>0.56</td>
<td>-1.63</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.35</td>
<td>-0.35</td>
<td>-0.06</td>
<td></td>
<td>0.63</td>
<td>-1.10</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.24</td>
<td>-3.48</td>
<td></td>
<td></td>
<td>0.26</td>
<td>-2.78</td>
</tr>
<tr>
<td>451-600</td>
<td>1-4</td>
<td>-1.29</td>
<td>1.18</td>
<td></td>
<td></td>
<td>0.39</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.81</td>
<td>-0.42</td>
<td></td>
<td></td>
<td>1.02</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>-0.06</td>
<td></td>
<td></td>
<td>-0.06</td>
<td>-7.60</td>
</tr>
<tr>
<td>&gt;601</td>
<td>1-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-3.74</td>
<td>-1.47</td>
<td>-5.24</td>
<td>0.71</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.10</td>
<td></td>
</tr>
</tbody>
</table>

Significant associations shown for $X^2$, 1 df, $p<0.005$

Indigenous forest to Indigenous forest is a non-protected indigenous forest that has not changed. Conversion from other covers to indigenous forest is grouped in: Total addition.

During the 1984-1999 period (Table 6.5.) conversions to planted forest were positively associated with elevations from 150 to 450 m asl with LUC class 5-7 and from 450 to 600 m asl with LUC 1-4. Conversions to pasture were associated with LUC 8 at 150-300 m asl and LUC 1-4, 5-7 at elevations from 450 to 600 m asl. Changes to scrub occurred on lowlands of LUC classes 1-4 and 5-7. New protected areas were on uplands of LUC class 5-7.
Table 6.5.
Electivity index for indigenous forest conversions to elevation and LUC classes, for the period 1984 to 1999. Zero values mean that the conversion class is distributed randomly, (+) or (-) means that the conversion is associated to a greater or lesser degree than would be expected at random.

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>LUC Class</th>
<th>Indigenous to Scrub</th>
<th>Indigenous to Planted</th>
<th>Indigenous to Pastoral</th>
<th>Indigenous to Protected</th>
<th>Indigenous to Indigenous</th>
<th>Total Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150</td>
<td>1-4</td>
<td>0.02</td>
<td>-0.43</td>
<td>0.04</td>
<td>-5.17</td>
<td>-2.26</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.89</td>
<td>-0.17</td>
<td>0.06</td>
<td>-1.56</td>
<td>-0.64</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-1.99</td>
<td>-0.65</td>
<td>0.08</td>
<td></td>
<td></td>
<td>-0.01</td>
</tr>
<tr>
<td>151-300</td>
<td>1-4</td>
<td>0.46</td>
<td>-0.40</td>
<td>-0.23</td>
<td>-2.66</td>
<td>-1.69</td>
<td>-0.11</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.11</td>
<td>0.99</td>
<td>-0.06</td>
<td>-0.08</td>
<td>-0.04</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-0.04</td>
<td>-2.92</td>
<td>1.26</td>
<td>-1.65</td>
<td>1.46</td>
<td>-0.50</td>
</tr>
<tr>
<td>301-450</td>
<td>1-4</td>
<td>0.09</td>
<td>-0.31</td>
<td></td>
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<td></td>
<td>-0.22</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.83</td>
<td>0.29</td>
<td>-0.22</td>
<td>0.71</td>
<td>0.40</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-0.36</td>
<td>-0.06</td>
<td>-1.03</td>
<td>0.97</td>
<td></td>
<td>-1.81</td>
</tr>
<tr>
<td>451-600</td>
<td>1-4</td>
<td>1.03</td>
<td>0.51</td>
<td></td>
<td>-0.22</td>
<td></td>
<td>-0.51</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-1.01</td>
<td>-1.04</td>
<td>0.26</td>
<td>1.25</td>
<td>0.72</td>
<td>-0.77</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-1.96</td>
<td>-2.58</td>
<td>-0.57</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;601</td>
<td>1-4</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-3.40</td>
<td>-0.24</td>
<td>0.84</td>
<td>1.00</td>
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<td>-2.62</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>-0.07</td>
<td>-0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant associations shown for $X^2$, 1 df, p<0.005

Indigenous forest to Indigenous forest is a non-protected indigenous forest that has not changed. Conversion from other covers to indigenous forest is grouped in: Total addition.

The last period from 1999 to 2006 (Table 6.6) showed indigenous forest conversions to other covers positively associated with lowlands at all LUC’s. No new protected areas were declared for this period. Additions to indigenous forests principally occurred on lowlands of LUC 5-7.
Table 6.6.
Electivity index for indigenous forest conversions to elevation and LUC classes, for the period 1999 to 2006. Zero values mean that the conversion class is distributed randomly, (+) or (-) means that the conversion is associated to a greater or lesser degree than would be expected at random.

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>LUC Class</th>
<th>Indigenous to Scrub</th>
<th>Indigenous to Planted</th>
<th>Indigenous to Pastoral</th>
<th>Indigenous to Indigenous</th>
<th>Total Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150</td>
<td>1-4</td>
<td>0.02</td>
<td>-0.16</td>
<td>0.40</td>
<td>-2.14</td>
<td>-0.53</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.99</td>
<td>0.80</td>
<td>0.20</td>
<td>-0.74</td>
<td>0.32</td>
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<tr>
<td></td>
<td>8</td>
<td>-0.92</td>
<td>1.47</td>
<td>-0.59</td>
<td>-0.11</td>
<td>-0.04</td>
</tr>
<tr>
<td>151-300</td>
<td>1-4</td>
<td>-0.24</td>
<td>-0.99</td>
<td>0.35</td>
<td>-1.49</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.45</td>
<td>0.41</td>
<td>0.12</td>
<td>-0.03</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.14</td>
<td>1.04</td>
<td>1.31</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>301-450</td>
<td>1-4</td>
<td>-3.09</td>
<td>-1.12</td>
<td>0.13</td>
<td>-1.72</td>
<td>-0.60</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.66</td>
<td>-0.67</td>
<td>-0.13</td>
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</tr>
<tr>
<td></td>
<td>8</td>
<td>-0.97</td>
<td>-0.89</td>
<td>0.91</td>
<td>-0.35</td>
<td>-0.35</td>
</tr>
<tr>
<td>451-600</td>
<td>1-4</td>
<td>-1.75</td>
<td>0.54</td>
<td>-0.25</td>
<td>-0.49</td>
<td>-0.49</td>
</tr>
<tr>
<td></td>
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<td>-1.15</td>
<td>0.72</td>
<td>-0.12</td>
<td>-0.12</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.35</td>
<td></td>
<td></td>
<td>-2.37</td>
<td>-2.37</td>
</tr>
<tr>
<td>&gt;601</td>
<td>1-4</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-2.40</td>
<td>0.95</td>
<td>-0.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-0.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant associations shown for $X^2$, 1 df, p<0.005

Indigenous forest to Indigenous forest is a non-protected indigenous forest that has not changed. Conversion from other covers to indigenous forest is grouped in: Total addition.

The non-protected indigenous forest was always negatively associated with land <150 m asl elevation during the complete study period. There were positive association between 150 - 300 m asl only with LUC 8. Between 1942 and 1984, the strongest positive associations were expressed on uplands at any LUC class. Nevertheless after 1984, non-protected indigenous forests showed negative association with LUC 1-4 above 300 m asl, i.e. high elevation good quality land was going to production. These results agreed with studies on indigenous forest and LUC classes in the Nelson region, South Island New Zealand (Nagashima et al. 2001) during the period 1980-1996; they found that indigenous forests were principally distributed on LUC class 7 and 8.
The two periods when indigenous forests increased in area (1961-1984 and 1999-2006), showed that conversions from indigenous forest occurred only on lowlands. In the periods with losses of indigenous forests, conversions were positively associated with a wider range of elevation and LUC classes.

The results clearly showed that certain topographic positions were more likely to experience losses of indigenous forest cover. Specifically, areas at lower elevation and on better productive lands were more likely to change to non-forest cover.

Protected indigenous forests were generally located uplands, or at lower elevations only in LUC class 5 to 8.

### 6.3.2. The permanent indigenous forest

During the whole study period 7,573 ha of non-protected forest persisted. These forests were distributed and positively associated with elevation above 300 m and LUC classes 5 to 8. In lowland regions these forests were restricted to LUC class 8 (Table 6.7).

A visual analysis of the map of permanent forests (Fig. 6.8) showed that this type of forest is located principally between protected and other indigenous forest covers.

Permanent forests typically occurred on sites where topography, soil and other biophysical characteristics strongly limit land use development options within current socio-economic norms.
Chapter 6: Indigenous forest analysis

Table 6.7.
Electivity index for Permanent Indigenous Forests to elevation and LUC classes. Zero values mean that the conversion class is distributed randomly, (+) or (-) means that the conversion is associated to a greater or lesser degree than would be expected at random.

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>LUC Class</th>
<th>Permanent Indigenous Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150</td>
<td>1-4</td>
<td>-3.45</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-1.02</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-0.15</td>
</tr>
<tr>
<td>151-300</td>
<td>1-4</td>
<td>-2.43</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>-0.22</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.52</td>
</tr>
<tr>
<td>301-450</td>
<td>1-4</td>
<td>-3.24</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.15</td>
</tr>
<tr>
<td>451-600</td>
<td>1-4</td>
<td>-0.18</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.89</td>
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<tr>
<td></td>
<td>8</td>
<td>0.64</td>
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<tr>
<td>&gt;601</td>
<td>1-4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Significant associations shown for $X^2$, 1 df, p<0.005

To summarise, protected forests always increased in area while non-protected indigenous forests have showed net losses and gains of forest cover. These changes reflected the particular physical conditions of the study area: Non-protected indigenous forests were located in lands with increasing limitations to use.

Permanent forests were almost restricted to uplands, sharing this distribution with protected areas. Both were on lands with less capability of productive activities.
Chapter 7:
The vulnerability of indigenous forest to socio-economic drivers
Interspersed planted forest between indigenous forests near Marlborough Rd.

(Photo/ A. Aleksa)
Chapter 7: The vulnerability of indigenous forests to socio-economic drivers

7.1. Discussion

Socio-economic drivers have led to a distinct pattern of landscape change in Northland. Nevertheless, the extent that these socio-economic drivers of land production are related to indigenous forest vulnerability can be discussed according to the obtained results.

* Indigenous forests were more vulnerable in some periods than in others in my Northland study area. They were more vulnerable during 1942-1961 and 1984-1999. Nevertheless those were very different historical times with respect to production and conservation incentives.

In the 1942-1961 period vulnerability to clearance from productive activities was principally in the lowlands and good quality lands, when incentives for pastoral activities and forestry became important (especially in the last part of the period). Changes in the uplands could be explained by extraction of merchantable trees which results in a transition to scrub and by clearance (transition to pastoral). Nevertheless, overall, indigenous forests were quite stable because of no large net losses, and a process of fragmentation rather than disappearance of patches.
Chapter 7: Vulnerability of indigenous forests

A separate set of conditions appeared to be present during 1984-1999. Despite strong conservation measures and with ca. 64% of the indigenous forest protected, the remainder became more vulnerable than before. Observed changes in composition, configuration and transitions suggest a very dynamic period. These changes can probably be related to increasing exotic afforestation (Blunden et al. 1995). Development of planted forest at higher elevations and on lower quality lands could compete with indigenous forest. Attrition of patches of indigenous forests created a more vulnerable configuration as the remnants became more isolated.

Indigenous forests were less vulnerable during 1961-1984 and 1999-2006 periods, as shown by the net gains in area. Surprisingly, despite a major increase in productive activities from 1961 to 1984, it seemed that indigenous forest was not vulnerable to conversion even with few conservation measures available. In fact, from a conservation management point of view, it was the best time with the appearance of new patches resulting in a more uniform distribution in the landscape, improving connection among remnants (habitat connectivity has been identified as one of the most important factors preserving dispersion among populations (Taylor et al. 1993; Pearson et al. 1996)). Such pattern can be attributed to a kind of “protection” from scrub. Scrub became the vulnerable cover, as seen by the major conversion of scrub areas to productive uses (pastoral the principal by this period). Scrublands were part of the land resource available “as of right” for agricultural expansion (Le Heron and Roche 1984), easing the pressure on indigenous forests. Nevertheless other results were found by Anderson et al. (1984) in some areas of Northland, where 7.5% of forest and scrub area was lost during 1978-1983.

The most recent period of study (1999-2006) can be characterised by the maximum conservation, protection and a change to sustainability attitudes which is probably the explanation for the reduction in vulnerability. A slight increase in indigenous forest areas were also found in the Nelson region (Nagashima et al. 2002). According to them, plantations had been established predominantly on pasture lands. Consequently there was a relaxed pressure on indigenous forests and scrub was allowed to regenerate. Nevertheless, in other areas there was a lost of 868 ha of indigenous forest in the period 1997-2002 in Northland (Ewers et al. 2006).
Land use changes have been conceptualized as opposite trends of intensification\(^1\) and extensification\(^2\) (Plieninger 2006). The general assumption is that landscapes go from a less intensive to a more intensive use over time, resulting in a loss of native resources (Pinto-Correa and Mascarenhas 1999). These trends are principally found in developing countries due to increasing population and new settlement processes, e.g. Brazil (de Barros Ferraz et al. 2005) and Bolivia (Millington et al. 2003). Pressure for agricultural development has been shown to produce deforestation, e.g. Madagascar (McConnell et al. 2004) and Brazil (Blanco Jorge and Garcia 1997). In North America the cause of land use intensification is due principally to suburbanization (Turner and Ruscher 1988; Bélanger and Grenier 2002).

Nevertheless, other trends can be observed. A reverse effect, from intensive to extensive land use, has been observed in Portugal, where Moreira et al. (2001) found that land abandonment and rural emigration were related to an increase in the area of forest. This disintensification process (Reid et al. 2000) has occurred in several countries of Europe due to increased economic growth and urbanisation leading to a net reforestation (Nikodemus et al. 2005; Rudel et al. 2005). “No inexorable march from less to a more intensive system” has been found in countries as diverse as: Ethiopia (Reid et al. 2000), USA (Turner et al. 2003), Costa Rica (Arroyo-Mora et al. 2005).

On the other hand, a land use dualism can arise in the same landscape. In Spain (Plieninger 2006) and in other Mediterranean countries (Vos 1993; Lyrintzis 1996) land abandonment on marginal sites and intensification of favoured areas was observed.

Processes of extensification (encroachment of scrub in pastoral lands, change of dairy for beef cattle) and intensification (change from sheep cattle to dairy, horticulture, as examples) occurred in New Zealand (MacLeod and Moller 2006) and in Northland (Blunden et al. 1995) but neither in a lineal way.

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1 Intensification is defined as a rise of the level of inputs per area of land (Stephens 1998) for example in the form of mechanized agriculture and increased stocking rates

2 Extensification is defined as a reduction of input levels of capital, labour and fertilizer (Stephens 1998) or as land abandonment (land is downgraded to a lower category of production or goes completely out of production) (Grove and Rackham 2001).
In this study area, indigenous forest instead of a uni-directional degradation sequence went through a multi-directional sequence represented in their net gain and loss of area across time. Consequently, *a priori* assumptions of ongoing degradation are not always valid (Lunt and Spooner 2005).

* Indigenous forests were less vulnerable than other land covers. It was quite notable that indigenous forest was the most stable cover. This raises the question as to what conditioners have limited changes.

First, the reservation of areas was shown to be an important limitation to change. In fact, more than 60% of the remaining indigenous forest is now protected by the Department of Conservation, or through other legal means such as covenants⁴.

Nevertheless, from the outset the allocation of protected areas has been principally at higher elevations and for land with limited production use. As has happened worldwide, conservation of remnant vegetation can be explained by the “worthless lands hypothesis” (Runte 1977). This contends that most native vegetation was preserved in areas of minimal economic utility, such as on steep mountains or infertile soils (Pressey 1994; Pressey et al. 1996a). This has two direct consequences.

On one hand, they have been biased in terms of the types of protected environments. As Ogden (1995) said, the known patterns of endemism and biodiversity were not reflected in the general geographical distribution of reserves in New Zealand because such criteria were not seen as important at the time reserves were gazetted.

On the other hand, it tended to protect areas without urgent need for protection from extractive uses (Pressey et al. 1996b). This was confirmed with the characteristics of those forests which were permanent during the 64 year-analysis. They were principally on uplands and in areas not suitable for production, given available options for forestry development in New Zealand.

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⁴ For Northland more than 50% of native vegetation is under protection (NRC 2002).
During the last two decades several explicit and/or systematic techniques for prioritizing and selecting protected areas for conservation have been developed (Margules and Pressey 2000). In New Zealand the Protected Natural Areas Programme (PNA) initiated in the early 1980s, took this approach. It was prompted by the realization that several types of ecosystem (e.g. lowland forest below 300 m altitude) were under-represented in reserves (Mark 1983; Kelly and Park 1986). The country was divided into 268 Ecological Districts according to differences in landform, vegetation, fauna, and climate. The plan was to survey these districts in order to define areas requiring protection (McEwen 1987). To date the programme is unfinished and relatively few reservations have resulted from the process (N. Mitchell pers. comm.).

Second, physical characteristics restricted the pattern of land use. Areas of native forest more vulnerable to conversion were and are concentrated in the lowlands and in lands suitable for conversion to productive activities, as was found in several studies in other countries (Pan et al. 1999; de Blois et al. 2001; Etter et al. 2006b). The relative stability of indigenous forests could be related to an agricultural frontier. It is possible that by the 1960s all land that could technically and economically be capable of agricultural or pastoral development had already been cleared (Ministry of Works 1964; McLean 1978). If this is correct it could explain why even with incentives for pastoral production (1961-1984) it was the most stable period for the native forest. If an “agricultural frontier” had been reached, it could make the landscape less vulnerable to pastoral-indigenous forest conversion. However, there could still have been pressure coming from plantation forestry. This raises the question: if there was or could be a forestry frontier. Exhaustion of the most suitable areas and the consequent shifting of attention to less suitable areas (as happened in the period 1984-1999) could still have made indigenous forests vulnerable in the absence of conservation measures.

Physical deterministic arguments could explain the constraints of land uses and then the stability of the indigenous forests. Nevertheless, it was also showed that socio-economic drivers conditioned the other land cover changes in the landscape. Physical constraints can be overcome when the investment is worthwhile, such as when demand for primary products is high and productive land is in great demand (Pan et
al. 1999). This is when current legislation (e.g. RMA Act 1991; Forest Accord 1991; Forest Amendment Act 1993) plays a significant role in the control of activities.

Third, other surrounding land covers had contributed to the stability of indigenous forests, especially conversion of scrub.

Scrub was always easier to remove than indigenous forests in spite of being protected to some degree (Conning 2001). Scrub was also the most vulnerable cover in the Nelson region of New Zealand’s south island (Nagashima et al. 2002).

Throughout the study period scrub land was considered marginal for production and for conservation. That land was brought into pastoral or to forestry production when the economic and technological conditions made it possible and convenient. If not, scrub land not suitable for cultivation was left undeveloped (Nagashima et al. 2002). Nevertheless, it is often used as fire wood resource, because it is still allowed to be removed under conditions of the RMA Act (1991).

Indigenous forest, principally because of increasing measures of protection, became less vulnerable than scrub. The consequence was a shifting of threats of clearing and logging to scrub areas. Thus, scrub can be considered a dynamic vegetation formation that plays an intermediate role between productive land uses and indigenous forest (Chust et al. 1999). As such, scrub was accidentally mitigating deforestation impacts (Alves et al. 2003) acting as a buffer to indigenous forest.

Scrub is not only important because of its associated biota (Dickinson et al. 1998), but also as an area of indigenous forest regeneration (Bergin and Kimberley 1995). Mixed indigenous scrub represents an advanced successional stage in forest regeneration (Newsome 1987; Meurk 1995). Manuka (Leptospermum scoparium) and kanuka (Kunzea ericoides) in particular are noted for their function as a “nurse” community, protecting the soil surface and allowing other trees and shrubs to establish beneath their canopy. In time, manuka canopy becomes less dense admitting more light, and forest species are able to emerge and finally overtop the original scrub (Newsome 1987).
High retention probabilities of indigenous forest demonstrated that they were almost in the same location for 64 years, but it was not the case of scrub. This implies that scrub could be threatened in its probability of sustaining long term communities. Scrub communities are seral stages to indigenous forest, and the changes that scrub suffers could delay or interrupt the regeneration cycle of indigenous forest. In this sense, regeneration of native forests is a vulnerable phase of forest persistence.

Thus scrub should be considered in the analysis of restoration and conservation management activities as part of the indigenous forest ecosystem.

* Indigenous forests showed different degrees of vulnerability. Vulnerability was defined in this study as the likelihood of area loss of a vegetation cover. Values of vulnerability could range from zero vulnerability (or no vulnerability) to high vulnerability (Pressey and Taffs 2001; Wilson et al. 2005b). No vulnerability was found for protected indigenous forest and non-protected sites that have not changed over the period of study (the permanent forest). Those non-protected forests that have changed presented the highest vulnerability.

* Some indigenous forests are still vulnerable risking their sustainability. The fact that indigenous forest became less vulnerable did not mean that there was a total halt in the loss of remnants. Conversions to other covers were observed at all periods. Although legislation is set to control timber harvesting of native forest, conversion to other land uses are still occurring. In Northland between 1999 and 2001 there has been an increase in the numbers of consents\(^4\) issued for vegetation clearance in private lands (NRC 2002).

It is also clear that the indigenous forests in New Zealand have improved their situation in terms of valorisation. Legislation, management, and considerable public opinion based on preservationist ideals, demand the sanctity of native land biodiversity (Craig et al. 2000). Under these precepts the government protects the forests on state lands making them less vulnerable to change. The question is: is

\(^4\) In relation with the RMA (1991) regulation.
preservation enough to make these forests invulnerable and how sustainable is this kind of management?

Productivism and post-productivism concepts can be used for framing the question. They are referred to as the shift of agriculture and forestry practices from a basic production of food, fibre or wood (productivism) towards the incorporation of conservation and sustainable management of remnant wildlife habitats on these lands (post-productivism) (Mather 2001; Evans et al. 2002). These shifts are conditioned by policy, farming practices, attitudes and ideology changes. Under the same concepts Holmes (2002) proposed a relationship with spatial occupation. Those intensively agricultural/forested lands are seen as productivist occupation, and unlogged or sustainably managed indigenous forest as post-productivist occupation. The interface between them could be from one of a strong contrast up to a desirable multifunctional territory, where both kind of activities co-exist allowing the sustainability of the indigenous forests.

The conservation history of indigenous forest in New Zealand can be characterised by a shift from a totally productive use to their absolute protection. Mechanisms used by the state to conserve the remnants of indigenous forest in state lands follow the mutually exclusive land-use option: preservation or production as highlighted by the Reserves Act 1977 (Norton 1998) and later in the Conservation Act and National Parks Act. This is also reflected in the management of indigenous reserves. For example, the concept of mainland islands⁶ – at least in its definition- separate both type of occupancy.

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⁶ “Mainland islands are areas that are being intensely managed to restore former natural habitats and ecosystems. They are called islands because they are often surrounded by very different ecosystems or geographic features which effectively isolate them, and because the techniques being applied to them have been learnt and refined from our experience of restoring real islands. DoC has chosen the mainland island management approach as a focus for stemming local biodiversity decline. Concentrated efforts at combating pest and weed threats are combined with the recovery of threatened species in an attempt to restore entire ecosystems” (DoC and MfE 2000).
Preservation is viewed by Wilson and Memon (2005), in their analysis about indigenous forest management and conservation in New Zealand, as an “extreme post-productivism”, where no human interference is allowed in the protected indigenous forests.

In this thesis, productivism and extreme post-productivism are interpreted as two faces of the same coin. Productivism does not integrate land uses, for example agriculture and forestry, with the surrounding “natural” ecosystem. The benefits and services obtained from these natural ecosystems are regarded as externalities of the productive system. In the same way, when the “natural” ecosystems are managed as reserves, it is usual that the surrounding productive land uses are not integrated. Therefore they could be named as a “non-productivism” case.

The state incorporates private indigenous forest land into the network of protected areas through a system of covenants or purchase. These forests become locked-up in perpetuity, turning them into a non-productivist use. Similarly for the carbon sink credits after the Kyoto Protocol signed in 2002 and entered into force in 2005. As Wilson and Memon (2005) said the difference here lies in that exotic planted forest will also be included, moving this kind of production to a post-productivism concept. But not in the case of native forests, they will remain as non-productive use.

Other mechanisms support conservation of native forests on non-state lands (i.e. outside the network of protected areas). The Resource Management Act (1991) aims for sustainable use of natural resources where indigenous conservation should occur together with productive activities rather than in conflict (Norton 1998) in a real post-productivism way. For this orientation, new recommendations have been suggested, such as the New Zealand Biodiversity Strategy (2000) which refers to “sympathetic management”. It means the management of productive lands in a way that recognises or supports the needs of indigenous biodiversity.
In consequence, there are two options for conservation: by preservation\(^6\), in a network of protected areas and by sustainable management in private lands. As Wilson and Memon (2005) said the problem of loss of indigenous forests lies in private land management. Some day-to-day farming activities do not fall under the jurisdiction of the RMA Act simply because of their scale, even though the effects of these activities may be cumulatively significant (Cocklin et al. 2000). But also the conceptualization of the system of conservation areas (preservation) and their management is not yet totally resolved to sustain indigenous forests.

Protected remnants of indigenous forests are set aside from the surrounding land producing continuing conflicts at the “edges” (Wilson and Memon 2005). But a protected area network does not exist in isolation of other land uses. In fact it is demonstrated that reserves can no longer persist without management (Craig 1998) (e.g. pest eradication, habitat alteration and weed control). However an interface of strong contrast between productivism and non-productivism still exists, rather than a multifunctionary territory in the protected areas. One of the present paradigms is that “production and conservation happen in different places”, instead of integrating production and conservation (Mitchell and Craig 2000). Conditions in the matrix and landscape heterogeneity were found to be fundamentally important in the state of the native forests, and deserve equal attention in research and management as the remnants of native vegetation. It is also clear that the state today regulates the clearance of the native forests and in fact reduces the rate of loss. But as suggested by Seabrook et al. (2007) this may result in a more intensive use of the cleared matrix, e.g. more regular clearing of re-growth (which is also possible under the RMA Act 1991\(^7\)) and hence a reduction in regeneration possibilities.

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\(^6\) According to New Zealand legislation: “Conservation equals preservation, and the best way to prevent further losses of indigenous species and ecosystems is to set aside areas free from normal human enterprises and exploitation; protection is best achieved through the purchase, acquisition or covenanting of areas containing native plants, or through regulation or other planning mechanisms. Conservation includes preservation, but exists within a broader continuum that includes non-extractive uses, such as, enjoyment of wilderness, through to the ecologically sustainable use of natural resources” (PCE 2002).

\(^7\) Under 5 ha it is not necessary to ask for a Resource Consent.
Chapter 7: Vulnerability of indigenous forests

Perhaps there are other possibilities to move to a post-productivism concept incorporating the full landscape context (the interface with productivism lands). One type of conservation with this orientation is the Reserves of Biosphere’s model from the United Nations. A biosphere reserve is a representative ecological area with a conservation and sustainable development approach. They are part of the UNESCO scientific programme and there are 507 sites worldwide in 102 countries under national sovereign jurisdiction (UNESCO 1995-2005). These reserves are organized into three interrelated zones: the core area, the buffer zone and the transition area. Only the core area requires legal protection and hence can correspond to an existing protected area such as nature reserve or a national park. The assignment of land units to specific uses, known as zoning, is a useful option to mitigate conflicts (Walther 1986) and in this way to facilitate the integration of the protected areas into the wider landscape. This zoning scheme is applied in many different ways to adapt to geographical conditions, socio-cultural contexts, available legal protection measures and local constraints.

The lack of zoning and management prescriptions is common for most protected areas in developing countries and, as a consequence, many protected areas exist only on maps and in legislation (Sabatini and Rodríguez Iglesias 2006). This kind of zoning management is also not developed for the Northland. Nevertheless some recommendations orientated to this type of management were suggested by the Northland Conservancy of the Department of Conservation. A Strategic Planning project has established areas of protected lands which have a high priority for conservation management. Unprotected lands adjacent to these areas are considered to be a high priority for protection where the habitat has similar values to the protected lands and may therefore support similar biodiversity, and also as a buffer to these important habitats or linkage between fragmented protected areas. Strengthening the extent and viability of core areas is considered a priority for the long term sustainability of the ecosystems of the region (Conning 2001).\(^8\)

\(^8\) The first Regional Policy Statement for the Northland region has been prepared by the Northland Regional Council in accordance with the requirements of the Resource Management Act 1991 the purpose of which is to promote the sustainable management of the region’s natural and physical resources (NRC 2007).
Other than this management approach, another possibility could be the extension of covenants not only to remnants of indigenous forest, but to any other kind of land surrounding important areas of indigenous forest. This would allow buffering of the protected areas and support restoration activities and research.

* Indigenous forest vulnerability was related to changes in conservation attitudes. Today remnants of native forest are the legacy of former land use decisions. But historically, there have been changes in the way society valued indigenous forests. Definition of what is a resource for a society in a specific historical period is determined through cultural conditions of perception, meaning, utilisation and consumption (Bifani 1980; Leff 1981). Scientific and technological conditions allow its exploitation and transformation; economic issues define its valorisation and profitability; institutional and political aspects deals with appropriation and access; and environmental conditions define productivity, regeneration and spatial distribution.

Historical description has shown changing social values towards nature. In the study area, native forests were more vulnerable when they were a timber resource, and when settlement and land production were priorities. Today, native forests could be less vulnerable to land production, because of the value placed on them for conservation (in its broadest context); it appears that they now hold a similar status to productive activities. Policies and strategies are increasingly built on concepts of sustainability, offering the opportunity to integrate conservation, use and development. Central government is changing the nature of incentives. Production and conservation activities sometimes have worked separately and sometimes have converged. What not clear is, if incentives changed as a response to societal philosophical changes about conservation and sustainable use or to economic pressures.
New Zealand, as a signatory country to the Convention on Biological Diversity (1992), has agreed to promote strategies for sustainable development. As a country, it has recognized that biological diversity is about the variety of life on Earth and their natural patterns, and is the consequence of billions of years of evolution, shaped by natural processes and increasingly, by the influence of humans. The three main goals of the Convention focus on conservation of biological diversity, sustainable use of their components and a fair and equitable sharing of the benefits from the use of genetic resources. In this sense, conservation should be regarded as a balance between natural and human productivity to achieve indigenous forest sustainability (Mitchell and Craig 2000).

Detection of a pattern between incentives to production and conservation, biophysical conditions and change in cover areas, can not be assumed as an explanation of underlying causal processes, but it does reflect human interest and conflicts on natural resources. As such, the description of these environmental changes is of critical importance for land management and the conservation of biodiversity.

In summary, the trajectory of indigenous forest vulnerability and the present trend is part of the necessary knowledge to their conservation. This demands an integrated conceptual framework to guide future research, restoration and conservation management activities, tailored for each specific landscape. Through such methods, reduction of the vulnerability of indigenous forest areas, would result in increasing the likelihood of their persistence.
Chapter 8: Conclusions
Waipoua Forest: State Highway 12 and Waipoua river crossing

(Photo/A. Aleksa)
Chapter 8: Conclusions

8.1. Vulnerability of indigenous forests in changing landscapes

8.2. Recommendations

8.2.1. Review of methods
8.2.2. Implications for biological conservation and ecologically sustainable natural resource uses

8.1. Vulnerability of indigenous forests in changing landscapes

The aim of this study has been to analyse the vulnerability of indigenous forest to a reduction in area, using a region of Northland, New Zealand, as a case study. This study provided a “on the ground” observation about the influences of incentives to production and conservation trajectories, on changes in indigenous forest area.

The main findings of this research were:

It was found that vulnerability of indigenous forests changed between periods:

- Period 1942- 1961: Incentives to production (including European settlement incentives) affected most suitable areas, making the native forests vulnerable. Spatial claims for production and native timber extraction reduced and fragmented the area of indigenous forests.

- Period 1961- 1984: Incentives to both pastoral and exotic forest production have affected scrub areas rather than indigenous forests, making them less vulnerable.

- Period 1984- 1999: Incentives to forestry production overrode incentives to conservation, making it the most vulnerable period for indigenous forests. Spatial claims of competing land use were high and patches of indigenous forests disappeared.
Period 1999-2006: Increasingly conservation incentives and reduction of incentives to production made this period the least vulnerable for indigenous forests. Less spatial pressure allowed recuperation of indigenous forests.

Revision of past and present incentives to production and protection showed that native forests have been subjected to intense human pressure over at least the past 150 years, primarily due to timber extraction and conversion to agricultural land following European colonization. These pressures were intensified in recent decades with development of the forest industry, which lead to establishment of extensive plantation forests, primarily exotic pine. Nevertheless, there is an increasing conservation/sustainability incentive trend that could favour retention of indigenous forest cover.

When there were important production incentives, e.g. during 1961-1984, scrub became vulnerable, which appeared to eliminate pressure on indigenous forest. However, if scrub communities are successional stages of indigenous forest, the resultant permanent changes could delay the regeneration cycle of native forest.

Shifting socio-economic and cultural values have played a significant part in changing land cover composition and configuration, and the trajectory of the landscape as a whole. These socio-economic drivers were related to two principal threat processes: vegetation clearing and timber extraction. Nevertheless, indigenous forest was the most stable land cover. Comparatively, the location of native forests was more important than socio-economic drivers of land use production in determining the proportion of remnant indigenous forest.

In conclusion, the initial hypothesis was verified: there is no unidirectional relationship between incentives to production and the vulnerability of indigenous forests. The direction of this relationship has changed by the presence of other land covers in the landscape, such as scrub cover and by physical site characteristics of indigenous forest that precluded conversion.
Chapter 8: Conclusions

Increasing the degree of protection of any area reduced the vulnerability of area loss. But there were 7,573 ha of non-protected forest that persisted along the 64 years of study period, even without formal protection. The physical characteristics of their locations made them unsuitable for productive activities.

In consequence, two categories of indigenous forests were highlighted and their degree of vulnerability would be:
- Protected indigenous forests and non-protected indigenous forests that have not lost area over the study period represent the invulnerable forests.
- Non-protected indigenous forests that have lost area over the study period are the vulnerable forests. Areas at lower elevation and on better productive lands were more likely to change to non-forest cover.

Vulnerability of the resource should suggest what to conserve. There is no urgency to extend new reserved areas in the uplands. These areas do not have urgent need for protection from extractive uses. Mechanisms such as covenants or purchase of private lands should, as priority, be directed to lowland indigenous forests.

At a scale of decades, changes in indigenous forest were non-linear and reversible. The area of indigenous forests in the study area is larger now than in 1942. This highlights the potential of indigenous forest to quite quickly recover in the landscape.

The results highlight that vulnerability of any vegetation cover is dependent on both temporal and spatial domains. In the temporal domain, the effects of history of management of natural resources (included the protection of indigenous forests) are important agents that account for the state of indigenous forests today. In the spatial domain, the vulnerability of indigenous forests has to be considered in the context of the whole landscape. Their state depends on the situation of the other vegetation covers, physical characteristics, and land tenure, i.e. on the landscape heterogeneity. In this way, knowledge of spatial and temporal changes of indigenous forests will aid to define their management for retention and hence their sustainability.
Chapter 8: Conclusions

8.2. Recommendations

8.2.1. Review of methods

The utilisation of land cover, as units of the landscape, was very useful because they allowed integration of abiotic, biotic and human elements. Land cover is one expression of how heterogeneous arrangements of landscape characteristics have developed and how these characteristics may influence vulnerability of indigenous forests.

The construction of a time-series database using remote sensing photos and satellite image and change detection methods coupled with GIS analysis techniques provided a useful tool to describe indigenous forest change through time. The grid-based structuring provided analytical tools that represented contextual spatial relationships, such as relationship among land covers. The different characteristics of the available sources, aerial photos from 1942, 1961 and 1984, and satellite images from 1999 and 2006 presented a difficulty in the classification of the land cover. But the visual interpretation produced final products with increased classification accuracy and comparable between them. In this study original products were obtained, such as the land cover maps for the study area for the years 1942, 1961, 1984, 1999 and 2006 covering gaps of information.

In terms of production of maps, new automatic methods such as object oriented classification (Darwish et al. 2003) could be used. They are based on the same procedure used in this thesis, but through software, where information based on objects rather than pixels provide different information: colour, size, form, texture and context (Chuvieco 1999). They would be less time consuming.

Analysis of land cover was based on the only primary data available. This became a limitation in the selection of the span of time researched in this study. On the other hand, the several digital databases available in New Zealand were an advantage and fundamental in this study. All these elements are basic for land and conservation management, and essential tools for administrative decision-making.
Although the specific results of this thesis are applicable to the study area, the methods can be applied to most regions. Land cover transition matrices could be used for making projections of landscape changes. These matrices coupled with cellular automata models of land cover or landscape change over space and time (e.g. Soares Filho 1998), could provide future predictions of vulnerability.

8.2.2. Implications for biological conservation and ecologically sustainable natural resource uses

This study reinforces several conceptualizations regarding conservation research, planning and management.

- Incorporate an assessment of area and biodiversity vulnerability to modification to obtain more effective conservation actions. It would help to focus limited conservation resources on areas most at risk (Margules and Pressey 2000). In general terms, the information can be utilized to identify areas where the risk of habitat loss is particularly high, to develop zones of management, and ultimately to devise more effective strategies for habitat conservation and restoration.

- Analyse the persistence and sustainability of natural resources in a landscape context. Patch or island-alike ignore interaction among the components of the landscape. However, landscape heterogeneity deserves equal attention in research and management as patches of native vegetation (Fischer and Lindenmayer 2007). Any system has a structure and a dynamics that are determined, not by the elements themselves but by the particular relationships among them (Gallopin 1983). As Lindenmayer et al. (2007) say, it is necessary to “manage the entire mosaic, not just the pieces”.

Understanding trends on the general landscape provides insight into potential causal factors of other phenomena such as erosion, flooding, or fire risk.
In this orientation, future research could be focused on analysis of the effects at the interface between pastoral and indigenous forest cover, between exotic planted forest and indigenous forest, and between scrub and indigenous forest cover.

In management practices, it would be desirable to “smooth” the interface between productive and conservation lands. The integration of production and conservation in space can create a multifunctional area to mitigate conflicts. These practices are possible by zonification (such as Reserves of Biosphere concept), by creation of fuzzy limits between natural reserves and surrounding landscape (e.g. co-management such as introduction of cattle in reserves for weed control), by extension of covenants not only to remnants of indigenous forest, but to scrub and other land cover, allowing restoration and research activities.

Consider that systems, natural and social, have changed, are changing and will continue to do so. Conservation has to be adapted to landscapes and human decision changes, but also to indigenous forest changes. As Ogden (1995) highlighted, changes have happened and will occur during the next few centuries, leading to a new composition and structure in the remnant forest cover of mainland New Zealand. Compositionally unique and interesting assemblages may develop in the modified and managed forests of the future (Mitchell and Craig 2000). It implies the recognition that most “natural areas” have more cultural history than assumed.

A forest patch that historically has been fragmented could function differently to one that historically was more intact. Physical differences in edge and interior alters the way in which that forest patch will function in terms of available incident energy from the sun, water filtration, dispersal mechanisms, species richness, and supported types of species (Young and Mitchell 1994). The likelihood of features persisting within a network of protected areas also changes with time, depending on events outside the networks as well as the way in which the network is designed and managed. Some of the events that occur outside protected areas may enhance extinction risk within those areas. Future research could be aimed to analyse biodiversity, composition and structure of the three classes of indigenous forest identified in this study, i.e. those protected, non-protected and permanent for the period of study. This could evaluate the goals of formal protection of natural areas.
Alternative development and conservation strategies should be discussed at high political levels. The separation of production and conservation objectives through different incentives, as viewed in this study, represents potentially conflicting objectives. Instead of this, policies and strategies should lead to sustainable relationship between them.

Results of this thesis showed that area and configuration changes of the indigenous forests were manifestations of competition between spaces and between land uses. As land uses are the result of human decisions, the landscape patterns reflect the decision-making processes. The current state of indigenous forest is the result of past and current conservation strategies. Conservation strategies ranged from non-intervention to intervention through planning, management, policy-making, regulation, and control. Conservation issues are not politically neutral. But certainly, the extant indigenous forests are also influenced by past and current development strategies. In that way, sustainability of indigenous forests would rely on the interplay of both conservation and development decisions.

In any policy, there is convergence of particular interests that could favour some actors to the detriment of others. Nevertheless, some interesting participatory methods and associated management\(^1\) have been carried out in Latin America in the process of formulation and elaboration of policies and plans about natural resources (e.g. Aleksa et al. 1989; Boverini et al. 1989). This type of method incorporates the social participation and the possibility of co-management as a central element, in other words, the associated decisions between the State and the people. Participatory planning binds the policy-maker with the policy-taker (Robirosa 1986). This bond supposes that the relationship between State-society should be based on explicit pacts and clear distribution of responsibilities. It implies a transformation in the decision-making method because it includes in the same space of discussion different actors (politician, technician, scientists, etc.), sectors (production and conservation), and scales (Central government, regional and local actors) in order to solve or negotiate conflicts aimed at viable solutions.

\(^1\) Metodologías de Planificación Participativa y Gestión Asociada, Facultad Latinoamericana de Ciencias Sociales (FLACSO). www.flacso.org.ar
Socio-economic drivers of vulnerability of indigenous forest are the consequence of political strategies of development of the country. Therefore, conservation strategies should be efficient and not vulnerable to other policies to achieve the goal of sustainability of indigenous forests.

- Develop long-term sustainability and quantifiable objectives. A weak point is that, everywhere, much conservation is undertaken without consideration of goals (Lindenmayer et al. 2007) (e.g., the fact that most protected areas are uplands identify a gap in the goals of conserving the wide spectrum of biodiversity) or whether goals are achievable given ecological, social and economic constraints and conflicts (e.g. competition with forestry promotions). Conservation policies are usually discussed, approved, and applied. The consequences and outcomes are not often evaluated (Baskent and Yolosigmez 1999; Ferraro and Pattanayak 2006). Most seldom conservation policies are organized and related to existing legislation about production/development.

Conservation strategies could focus on several issues about indigenous forest conservation: How much indigenous forest would be lost if there had no been conservation legislation? Are the conservation policies enough by themselves to achieve the sustainability of indigenous forests? Are counter-outcomes likely? Is the present trend in extant indigenous forest likely to be up or down with the current policies? Do other government policies un-intentionally affect conservation goals because of conflicts of objectives? (e.g. maximizing timber production vs. maintaining biodiversity). What is more expensive: to expand the network of reserves or to manage the surroundings?, etc.

To respond to these questions, evaluation and comparison of alternative policies should be carried out by placing policy objectives and conservation outcomes in an evaluation framework. These frameworks should reflect interrelationships, uncertainty, processes of decision-making, quantitative and qualitative information, under a spatial context of the landscape.
Scenario analysis is a method usually used to explore alternative management actions and policies (Veldkamp and Fresco 1997; Wollenberg et al. 2000; Verburg et al. 2006). They have been used in corporate and governmental decision making since the 1970s because of their inherent advantages over expert judgements and other planning approaches (Ahern 1999). A scenario should include a description of the current situation, a potential future state, and a means of implementation (Swart et al. 2004). Scenarios are neither predictions nor forecasts: they do not attempt to predict the expected future. In contrast, scenarios answer a series of “if then” questions (Ahern 1999).

In this way, policy recommendations can be developed rather than see the consequences later when policies are implemented. As Walker and Young (1997) said: “intended consequences of policy decisions often occur, but unintended consequences always occur”.

This is encapsulated in the concept of adaptative management (Holling 1978; Lee 1993). It suggests that management processes should be circular rather than linear processes: information concerning the past is used to feed back and improve management of resources. Decisions are hypotheses to be tested, therefore managers and policy-markers learn from the consequences of their decisions and alter their decisions (and implement new decisions) accordingly (Ellison 1996). In this way strong and efficient conservation strategies would reduce the vulnerability of indigenous forests.

Finally, this research exemplifies and reinforces the necessity of interdisciplinary work: the articulation of natural and social knowledge.
The interdisciplinary process generates an interaction of subjects, of subjectivities produced by disciplinary practices, and produces confrontation and collaboration, to common objectives (Leff 1986). As Montes and Leff (1986) highlighted, it is a dialectic process because of the contradictions that characterize the effort to interrelate different disciplines and languages. It is a systemic process, because it forces analysis of interrelationships dynamically. It is iterative, because it is an approach by approximations; and not restrictive (open), because it looks for alternatives of mutual enrichment between the two (or more) forms of knowledge.

The challenge of the interdisciplinary framework is to understand complex problems and situations, where all externalities, ecological or social, are internalized in the research and practice of conservation strategies.
Waima Forest

(Photo/ A. Aleksa)
References


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New Zealand Land Resource Inventory (NZLRI). A national physical resource inventory designed for the promotion of sustainable land use. 2nd Edition: 1:50,000.


Appendices
Near Twin Bridges
(Photos/ L. Colantonio)
Appendix 1
Land Cover Definitions

The classification of land covers according LCDB is:

Artificial Landscapes:
- Urban: built up areas, includes any contiguous group of buildings larger than the MMU (1 ha).
- Urban open space: sports fields, parklands, etc. Mines, gravel pits and dump sites.

Cultural Landscapes:
- Primarily pastoral: exotic pasture, enclosure distinguishes this from grasslands. Includes arable land.
- Primarily horticultural: orchards, kiwifruit and market gardens.
- Planted forest: plantation or exotic forest inclusive of recent replanting. Riparian willow.

Natural Landscapes:
- Grassland Tussock: or unenclosed grassland.
- Shrubland: woody vegetation in which the cover of shrubs and trees in the canopy is > 205 and in which shrub cover exceeds that of any other growth form or bare ground. Shrubs are woody plants.
- Indigenous forest: forest cover dominated by indigenous tall forest canopy species.
- Bare ground: non-pastoral exposed soil and rock.
- Coastal sands: beach sands and dunes.
- Inland water: lakes, ponds and rivers.
- Mangrove: sea level mangrove swamp land.
Appendix 2
Study area: total area, number of patches and mean area per land cover class through 1942 to 2006.

### Indigenous Forest

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<thead>
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### Scrub

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<td>2006</td>
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### Planted Forest

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### Pastoral/ Others

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## Appendix 3
Land Use Capability Classes (Water and Soil Division 1979)

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<tr>
<th>Class</th>
<th>Cropping Suitability</th>
<th>General Pastoral and Production Forestry Suitability</th>
<th>General Suitability</th>
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<tbody>
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<td>I</td>
<td>High</td>
<td>High</td>
<td>Multiple use land</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Medium</td>
<td></td>
<td>Pastoral or Forestry land</td>
</tr>
<tr>
<td>IV</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Unsuitable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td></td>
<td>Medium</td>
<td></td>
</tr>
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<td></td>
</tr>
<tr>
<td>VIII</td>
<td></td>
<td>Unsuitable</td>
<td>Catchment protection land</td>
</tr>
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Increasing limitations to use