# MEASURING AND ENHANCING ROADSIDE BIODIVERSITY

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# MEASURING AND ENHANCING ROADSIDE BIODIVERSITY

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## EXECUTIVE SUMMARY

This research has developed a new method of biodiversity assessment to characterize the biodiversity values of roads across New Zealand. The methodology blends rigorous probability sampling and PNAP sampling methodology with environmental domains analyses, to characterize the biodiversity attributes of a highway segment. It demonstrates the usefulness of this methodology in allowing regional reporting and integrating biodiversity conservation with road management by applying it to a particular road segment, State Highway 3 from Hamilton to New Plymouth. The data, gathered over the period November 1998 to June 1999, was also used to develop an overall biodiversity enhancement and restoration plan for the studied segment of road.

Methods

- Using environmental domains analyses, the highway was classified by climate, landform, and top rock into sectors of similar environment.
- Using a probability sampling scheme, vegetation in the road reserve was quantitatively sampled using variable-area plots at 172 random points along SH3, and in 16 paired plots 50 metres from the road reserve.
- Survey techniques of the New Zealand Protected Natural Areas Programme (PNAP) were used to identify and describe important native-dominated remnants in the road reserve along the entire highway.
- Data collected from the probability survey were analysed to characterize the biodiversity values of the road reserve and the factors (such as land use) that influence these values. Biodiversity indices were predicted for the entire highway and summarised for each environmental sector.
- The results of the PNAP survey were used to identify, describe, and map important fragments along the highway.
- The results of the probability sampling and the PNAP survey were combined to develop a biodiversity enhancement and restoration plan for the study area of SH3.

Results

Six environmental sectors were defined that had distinct differences in their climate, landform and geology: Hamilton, Waipa, King Country, Awakino Gorge, North Taranaki, and Egmont (Figures 2 and 3).

- All six indicators of indigenous biodiversity (refer section 5.1.3) were highest in the Awakino Gorge and North Taranaki sectors, and the index indicating the increase in native cover resulting from full restoration was also highest in these sectors. Biodiversity indicators were lowest in the lowland Hamilton and Waipa sectors (Table 2 and Figures 6, 7 and 8).

- All six indicators of indigenous biodiversity (refer section 5.1.3) were highest in the Awakino Gorge and North Taranaki sectors, and the index indicating the increase in native cover resulting from full restoration was also highest in these sectors. Biodiversity indicators were lowest in the lowland Hamilton and Waipa sectors (Table 2 and Figures 6, 7 and 8).

- Indigenous biodiversity in the road reserve was strongly related to surrounding land cover, being highest where the road was surrounded by natural vegetation, and lowest in areas most highly modified by human use (Figure 5).

- Results of paired sampling showed that the road reserve within indigenous forest had lower biodiversity values than surrounding forest, but that the reserve within pasture had similar values to surrounding pasture (Figure 9).

- Eighty-three sites containing predominantly native vegetation in or abutting the road reserve were described, and vegetation/landform combinations summarised by sector and top rock (Figure 10, Appendix 4). At least half these are regarded as significant.

Conclusions

The methodology developed here was very effective for characterizing and understanding the biodiversity attributes of the road reserve and developing methods for integrating biodiversity conservation with road management. The probability survey provided a rigorous, unbiased measurement of biodiversity attributes. The PNAP survey identified, described and mapped important fragments. The biodiversity attributes of the road reserve differed markedly between the environmental sectors, and showed a strong effect from the surrounding land cover.

Our results indicate that the road reserve is both a biodiversity asset and a potential threat. The road reserve is an asset, in that it provides public lands for conservation that are highly visible to the public, often in habitats that are under-represented in the reserve network, and can provide links between existing reserves.

The road reserve may be a liability in that it has reduced biodiversity value in the surrounding forests and can act as corridors for the spread of weeds into agricultural areas or indigenous forests. Effective integration of biodiversity conservation and road management can increase these assets and reduce these liabilities. This can be achieved by changing policy at all levels (Transfund NZ, Transit NZ, other roading authorities), by increasing awareness of the biodiversity value of road reserves, and by providing specific guidelines for the management and protection of roadside biodiversity.

## ABSTRACT

A new method of biodiversity assessment is developed to characterize the biodiversity values of roads across New Zealand. The methodology blends rigorous probability sampling and PNAP sampling methodology with environmental domains analyses to characterize the biodiversity attributes of highways. It demonstrates the usefulness of this methodology in allowing regional reporting and integrating biodiversity conservation with road management by applying it to a particular road segment, State Highway 3 from Hamilton to New Plymouth.

The data gathered is also used to develop an overall biodiversity enhancement and restoration plan for the studied segment of road. The biodiversity attributes of the road reserve differed markedly between the environmental sectors, and showed a strong effect from the surrounding land cover. Results indicate that the road reserve is both a biodiversity asset and a liability.

The road reserve is an asset, in that it provides public lands for conservation that are highly visible to the public, often in habitats that are under-represented in the reserve network, and can provide links between existing reserves. The road reserve may be a liability in that it has reduced biodiversity value in the surrounding forests and can act as corridors for the spread of weeds into agricultural areas or indigenous forests.

Effective integration of biodiversity conservation and road management can increase these assets and reduce these liabilities. This can be achieved by changing policy at all levels (Transfund NZ, Transit NZ, other roading authorities), by increasing awareness of the biodiversity value of road reserves, and by providing specific guidelines for the management and protection of roadside biodiversity.

# 1 INTRODUCTION

New Zealand is a signatory to the International Convention on Biological Diversity which aims to conserve biodiversity – the diversity of genes, species and ecosystems on Earth (Reid et al. 1992, Burhenne-Guilmin 1995). In addition, statutory requirements such as the Resource Management Act (1991) seek to ensure sustainable management of physical resources, ecosystems and their associated biodiversity. Effective management of ecosystems for the maintenance of native biodiversity requires an understanding of biodiversity attributes on private land, as well as on public land of different types.

The road reserves of New Zealand state highways and motorways provide a unique contribution to public land. They extend for more than 14 000 km (Simpson 1997) and contain an unquantified biodiversity resource that is threatened by a lack of knowledge of the extent and value of biodiversity represented, and by management practices that modify, degrade or destroy that resource. Not only may the road reserve have significant biodiversity values in its own right but it also provides important links and corridors for the biodiversity of the existing network of protected and unprotected natural areas (Farmar-Bowes 1997). Management of road reserves elsewhere in the world has been the subject of some controversy. Egler (1975) documented practices destructive of the biodiversity of American road reserves and made an impassioned plea for more sensitive management of them.

This report, prepared for Transfund New Zealand, has two aims. Firstly, it describes a method of biodiversity assessment, using vascular plant species as a surrogate for the full biodiversity of the road reserve, that is new to New Zealand and can be applied to characterize the biodiversity values of road networks across New Zealand. Secondly, it demonstrates the usefulness of this method for regional reporting and management of road reserves by applying it to a particular road segment, State Highway 3 from Hamilton to New Plymouth. The method developed uses the complementary strengths of two established techniques for obtaining environmental information : the exhaustive survey techniques of the Protected Natural Area Programme (PNAP), and a rigorous probability sampling scheme. The data gathered by the two methods is also used to signal overall enhancement and restoration possibilities for biodiversity in the road segment investigated.

The information presented in this report will be useful for a range of end-uses. It serves as a framework for councils and the Department of Conservation in resource consent situations, and allows them to determine the contribution the road reserve makes to regional biodiversity. The locations of important fragments in or near the road reserve can be used by contractors to avoid damaging the fragments. Perhaps most important, this report also provides the basis to begin changing highway management practice and policy to enhance and protect roadside biodiversity.

# 2 BACKGROUND

## 2.1 Environmental Domains

Environmental domains analysis is an established method of identifying areas of similar environmental character. Such an analysis of a region entails classifying a region into domains (groups) on the basis of similarity of environmental characteristics (e.g., climate, substrate, landform) that are known to influence ecosystem character. Environmental domains have gained international acceptance (Belbin 1993, Bailey 1995, Host *et al.* 1996, Hutchinson *et al.* 1996, Leathwick & Overton 1998), and this approach has gained recent support in New Zealand, with national domains under continued development, as well as higher resolution domains being developed for the Waikato and Canterbury Regions. The national environmental domains classification of New Zealand has recently been given high prominence as a spatial context for New Zealand's Draft Biodiversity Strategy (Department of Conservation and the Ministry for the Environment 1999).

## 2.2 Probability Sampling

Probability sampling schemes are rigorous methods that allow the characterization of an area (such as a road segment or an entire road network) by sampling portions, and then making estimates for the whole, thus removing the need to carry out exhaustive surveys over the entire area. Probability sampling schemes use a random probability that a given part of the area will be sampled, which means that the estimates of the area will be unbiased and have a known uncertainty. Furthermore, they provide objective information that can be repeated by other researchers. Because of these advantages, probability sampling schemes are the basis for environmental monitoring programs in other countries (e.g., the Environmental Monitoring and Assessment Program [EMAP] of the United States Environmental Protection Agency [EPA]). The disadvantage of sampling schemes is that since they do not sample the entire area, small yet important parts may not be sampled.

A simple example of a probability sampling scheme would be one used to estimate the number of names in a phone book. Counting all of the names in even a moderately sized phone book would be a tedious, time-consuming, and often inaccurate method (imagine losing count halfway through!). A much more efficient method would be to count the number of names on a page and then multiply by the number of pages. An even better way would be to randomly choose (sample) a number of pages and find the mean number of names per page and multiply this mean by the number of pages. This would be a simple probability sampling scheme and would result in an unbiased estimate of the number of names in the phone book plus or minus a known uncertainty in the estimate that would depend upon how many pages were counted. Applying this idea to the characterization of road reserves would entail measuring the characteristics of the road reserve at randomly chosen locations.

## 2.3 PNAP Sampling

PNAP survey techniques characterize an ecological district/region by using rapid inventory to describe natural areas within the district/region. Thus, to characterize the biodiversity of a road reserve, the road is driven, and areas along the road that have predominantly native communities are noted and described. The advantage of the PNAP survey techniques is that it gives good information over the entire area, incorporating existing data and expert knowledge about the area. The disadvantages are that the survey requires exhaustive searching of the entire district/region, and does not give unbiased estimates of the entire district/region. Furthermore, the information gathered by these techniques is more subject to the interpretations of the observers.

## 2.4 The Combined Approach

By combining the two techniques described above, we use the respective strengths of the two methods to complement each other. The probability sampling scheme designed provides an objective, unbiased characterization of the biodiversity of the road reserve, independent of previous conceptions. This is supplemented with a PNAP survey to assess the native-dominated communities in the road reserve botanically and identify special features that might have been missed by the probability survey, e.g., occurrence of rare species.

Inevitably, both PNAP survey techniques and probability sampling schemes are limited by the amount of time and money invested in gathering the information. More intensive and detailed PNAP surveys will better characterize known fragments and have a lesser chance of missing important fragments. Greater sampling intensity and more intensive sampling of plots in probability sampling schemes will reduce the uncertainty of estimates and allow more variables to be measured.

## 2.5 The Study Area

State Highway 3 (SH3), between Hamilton and New Plymouth, is approximately 235 km in length (Figure 1). From north to south, it passes through five cities/towns (Hamilton, Te Awamutu, Otorohanga, Te Kuiti, and New Plymouth) , and 19 small settlements (Ohaupo, Kihikihi, Kiokio, Hangatiki, Piopio, Arapae, Paemako, Mahoenui, Awakino, Mokau, Tongaporutu, Ahititi, Uruti, Urenui, Onaero, Motunui, Waipapa, Brixton, and Bell Block), some of which are now represented by only a road sign. The highway also spans five Ecological Regions (Waikato, King Country, Tainui, Taranaki, and Egmont), and six Ecological Districts (Hamilton, Waipa, Waitomo, Herangi, North Taranaki, and Egmont). Fifteen scenic or allied reserves abut or lie adjacent to the highways road reserve (Appendix 3).

This stretch of highway spans a range of environmental conditions, landforms and human land uses. It begins in Hamilton, in the low-lying Waikato basin where pasture dominates the land cover (Hamilton sector, Figure 2). It continues south into the southern Waikato, which is also largely low-lying and pastoral (Waipa sector, Figure 2). Southwest of Te Kuiti the landscape changes into rough hill country, with significant areas of limestone, that is also largely pastoral but with an increasing incidence of primary and secondary forest remnants (King Country Sector, Figure 2). Continuing southwest it passes through the distinctive narrow river canyon of the Awakino Gorge, with its steep often unstable hillslopes and significant areas of remaining primary forest (Awakino Gorge sector, Figure 2). Emerging from the southern end of the Awakino Gorge, it follows the largely pastoral coastline to Tongaporutu, where it heads inland, passing over the predominantly forested distinctive massif of Mt Messenger and down through the Mimi River valley (North Taranaki Sector, Figure 2). The highway returns to the coast just north of Urenui, passing through the northern edge of the Mt Taranaki (Egmont) ring plain, where pasture again dominates the land cover (Egmont Sector; Figure 2).

## 3 OBJECTIVES

To develop a methodology that blends rigorous probability sampling and PNAP sampling methodology to characterize the biodiversity attributes of a highway segment, by applying it to a case study of SH3.

This entailed:

- classifying the highway by climate, landform, and top rock into environmental sectors;

- quantifying the biodiversity values of the road reserve, and assessing its importance to biodiversity conservation, by a combination of probability sampling techniques and the well-established methods of the New Zealand Protected Natural Areas Programme (Myers et al. 1987);

- analysing the data collected from the road segment survey, in the context of the environmental domains, and providing indices of biodiversity importance for each environmental sector of SH3;

- assessing the relative biodiversity values of the road reserve in the environmental sectors for their contribution to overall biodiversity values ; and

- compiling an enhancement–restoration plan for SH3.

**Figure 1.**
**Location Map - State Highway 3 from Hamilton to New Plymouth**

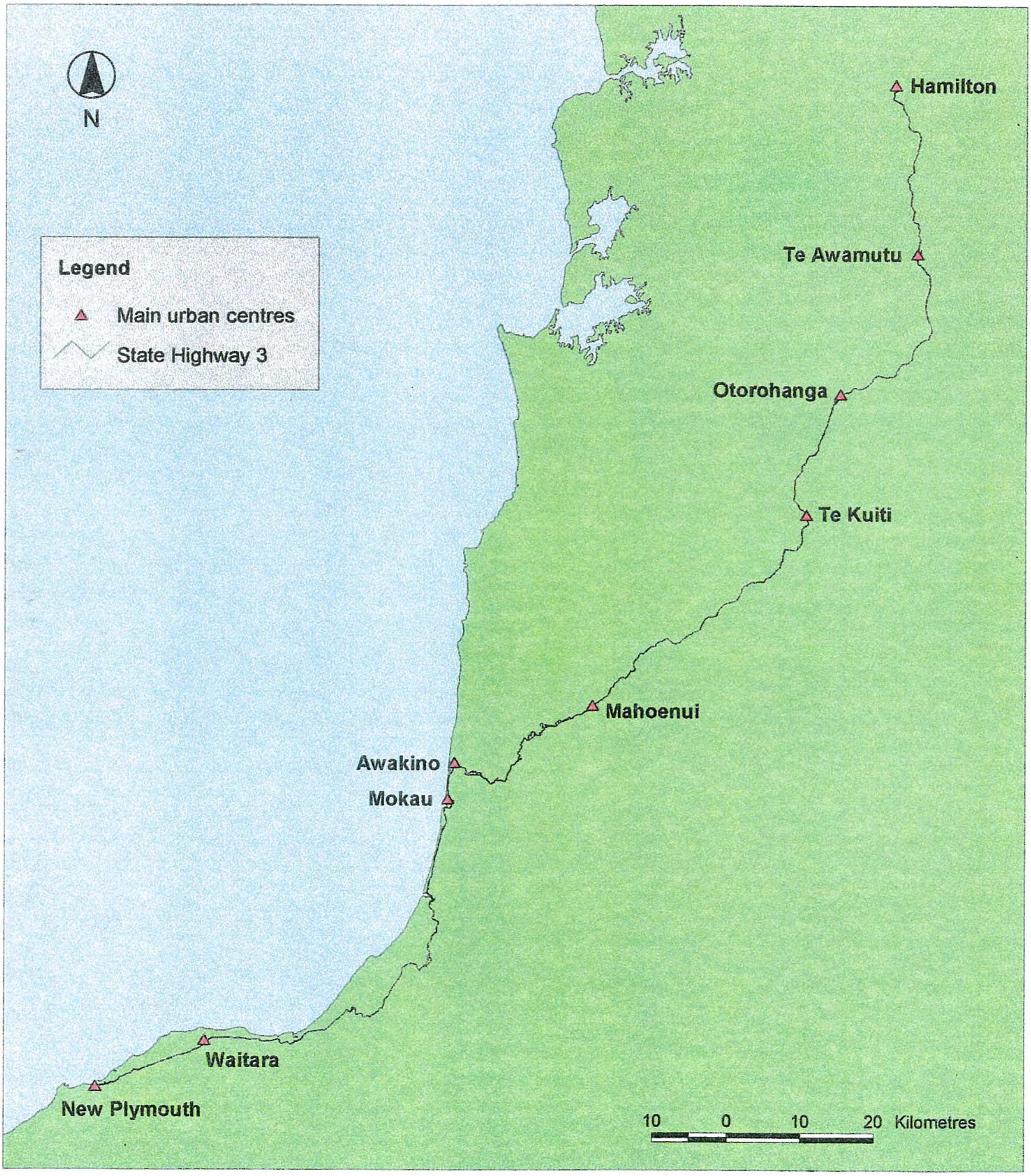
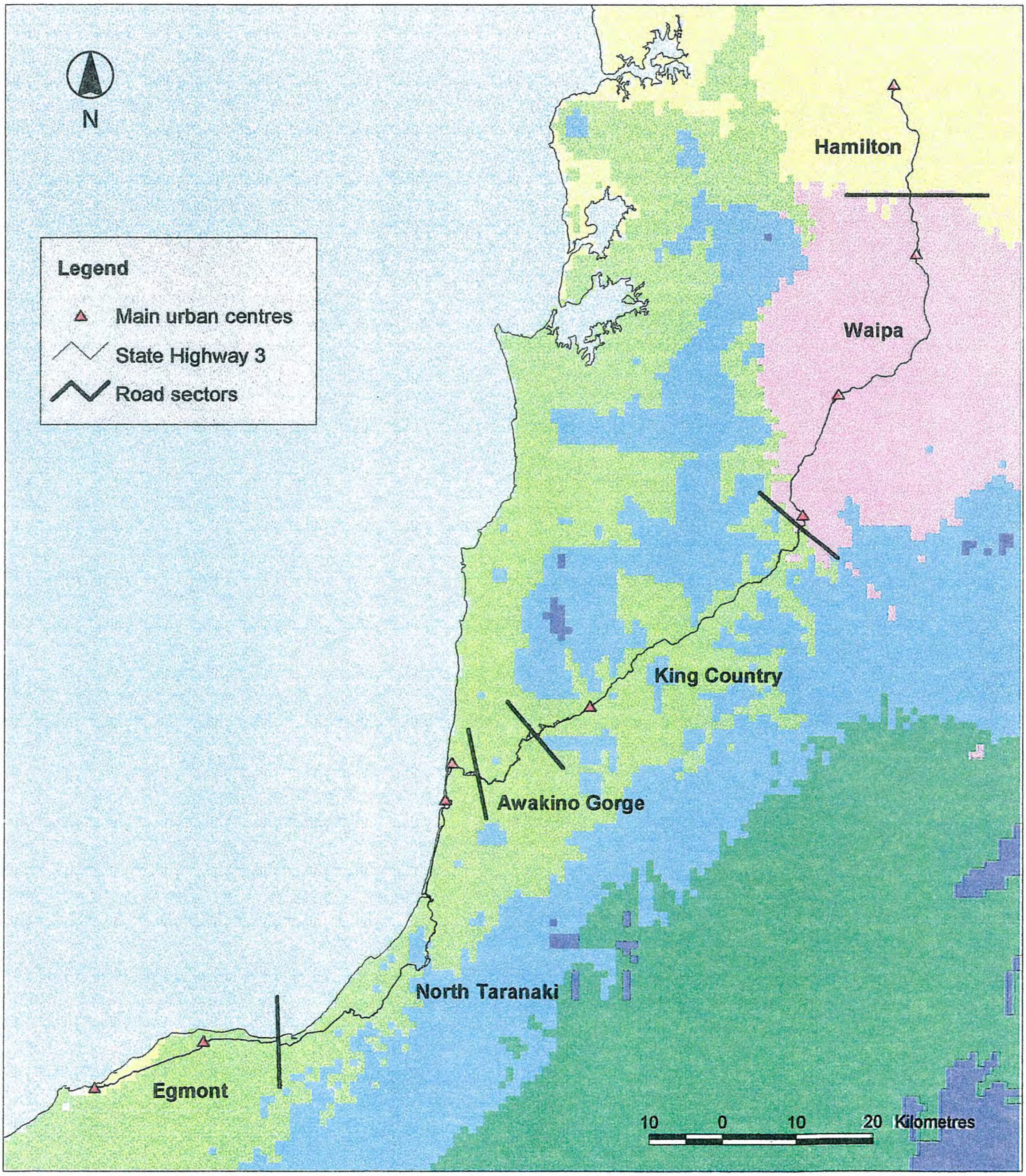


**Figure 2.**
**Road sectors of SH3 overlying climatic domains.**



# 4 ENVIRONMENTS OF STATE HIGHWAY 3 FROM HAMILTON TO NEW PLYMOUTH

Environmental domains analysis was used to divide the highway into sectors of similar climatic character. National climatic surfaces (Leathwick *et al.* 1998) were used to subdivide the road into sectors of climatic similarity in a national context. To make these domains, New Zealand was depicted by 1x1 km pixels, with seven climatic or derived climatic variables predicted for each pixel. Four basic climatic variables were used: mean annual temperature, minimum winter temperature, mean annual solar radiation, and winter solar radiation. Two interaction climatic variables, designed to incorporate physiologically meaningful interactions between the basic climatic variables were also used: October vapour pressure deficit, and the minimum ratio of rainfall to potential evapotranspiration. Pixels were then clumped into 80 categories according to their similarity in these seven climatic variables. The categories from the domains analysis provide national climatic domains. The study section of the highway passed through three main climatic domains, and a small part of a fourth (Figure 2).

The geological substrates for each climatic domain were identified using the variable 'Toprock' from the New Zealand Land Resource Inventory (NZLRI.) The largest of the climatic domains (coloured green in Figure 2) was quite heterogeneous in geological substrate and landform. The highway within this climatic domain was then further subdivided into four sectors on the basis of landform and geological substrate.

## 4.1 GIS and Database Development

A Geographic Information System (GIS) database was developed in Arcview (ESRI 1996) that contains much of the information collected in this project. The database contains cadastral coverage of the highway reserve obtained from Terralink, climatic domains and road environmental sectors, locations of all probability sampling locations, and locations of roadside fragments surveyed using PNAP methodology. This GIS database could form an important reference for resource consent applications and resource management. The GIS database is available (as an Arcview project file) for use in public good applications, research or teaching. Other requests will be considered on a case-by-case basis.

## 4.2 Environmental Sector Descriptions

The six environmental sectors of the highway are shown in Figure 2 and described below.

### Hamilton

The Hamilton sector extends from Hamilton to Ohaupo. The sector runs south through a major inland basin with alluvial plains that have extensive peatlands and minor lakes. The basin includes part of the Hinuera surface: old alluvium carried down by the ancestral Waikato River from the central Volcanic Plateau. Its southern boundary approximates that of the Hamilton Ecological District (in the Waikato Ecological Region).

**Waipa**

The Waipa sector also lies in an inland basin, the southern extension of the Waipa graben, mostly of valley downlands of pumiceous alluvium and conglomerate, with smaller areas of peat bogs and swamps compared with the Hamilton sector. It extends south from Ohaupo to Te Kuiti, with its boundary approximating that of the Waipa Ecological District (in the Waikato Ecological Region).

**King Country**

The King Country sector extends from Te Kuiti to the northern end of the Awakino Gorge. It is a complex transitional zone between the volcanic regions to the east and sedimentary hill country to the west, and includes significant areas of limestone. The boundaries of the sector approximate those of the Waitomo Ecological District (in the King Country Ecological Region)

**Awakino Gorge**

This sector bisects the southern end of the sedimentary Herangi Range. The gorge is characterised by steep, often unstable hillslopes, and narrow alluvial terraces above the Awakino River. The boundaries of the sector match those of the southern end of the Herangi Ecological District (in the Tainui Ecological Region).

**North Taranaki**

The North Taranaki sector incorporates very finely dissected sedimentary hill country, mostly below 300 m a.s.l., narrow valley floors near the coast, and narrow bands of uplifted marine terraces along parts of the coastline. It extends from the southern end of the Awakino Gorge south to the Onaero River, with its boundaries matching those of the North Taranaki Ecological District (in the Taranaki Ecological Region) .

**Egmont**

The Egmont sector extends from the Onaero River to the intersection of SH3 with SH45 in New Plymouth. Its northern boundary is also that of the Egmont Ecological Region. It includes the tephra covered ring plains of lahar, debris flow, and tephra deposits that surround Mt Egmont/Taranaki, and bands of uplifted marine terraces along the coast.

# 5 PROBABILITY SAMPLING METHODS AND RESULTS

## 5.1 Probability Sampling Methods

### 5.1.1 Sampling design

We used a stratified random sampling scheme to characterize the road reserve. The sampling of SH3 was stratified by the land cover immediately adjacent to the road reserve. Due to lack of land cover data, this could not be done in advance. Therefore, the length of the road was driven, and stops were made at every 0.5 km. On both sides of the road at each stop, the land cover immediately next to the road reserve was characterized into 14 classes (Table 1). These classes are consistent with the cover classes used by the Land Cover Data Base (LCDB).

At each 0.5 km-stop, each side of the road was considered independently. On each side, there was a random probability that the road side reserve was sampled. The probability of sampling depended upon the land cover type adjacent to the road reserve (Table 1). If a location was sampled, then there was a 10% chance that a paired plot would be located 50 m outside the road reserve. By chance, a low number of paired plots were sampled in the initial sampling. To achieve a minimum sufficient number of paired plots, a number of additional paired plots were sampled (chosen by convenience) to compare with those roadside locations already sampled.

**Table 1. Land cover classes used in the study.**

These cover classes are generally consistent with the cover classes used by the LCDB. In some cases, new cover categories were created either to deal with road specific issues (e.g., bridges) or to add important resolution to the cover classes (e.g., indigenous shrubland). Some of these cover classes were subdivided in the field data. For each cover category, the sampling probability and the proportion of stops with that cover category adjacent to the road reserve are given.

| Land Cover category | Psample | Proad | Count |
|---|---|---|---|
| Primarily pastoral | 0.09 [1] | 0.704 | 651 |
| Urban open space | 0.25 [1] | 0.0173 | 16 |
| Urban settlement | 0.25 [1] | 0.0823 | 76 |
| Riparian | 0.56 | 0.053 | 49 |
| Indigenous forest | 1 | 0.0476 | 44 |
| Planted forest | 0.45 | 0.0368 | 34 |
| Industrial | 0.5 | 0.013 | 12 |
| Indigenous shrubland [2] | 1 | 0.0119 | 11 |
| Primarily horticultural | 1 | 0.0043 | 4 |
| Quarry | 1 | 0.0011 | 1 |
| Shrubland | 1 | 0.0011 | 1 |
| Rural open space [2] | 0.56 | 0.0011 | 1 |
| Bridge [2] | 0 | 0.0065 | 6 |
| Secondary road [2] | 0 | 0.0162 | 15 |

[1] These sampling probabilities were 0.11, 0.56 and 0.56, respectively for the initial 37 km of road. They were subsequently lowered to reduce the number of samples in these cover classes.

[2] Cover classes not found in the LCDB.

### 5.1.2 Plot sampling

The road reserve was sampled at the precise location of the 0.5 km stop, using between one and three quadrats located at uniform random distances from the road. The size of the quadrats depended on the reserve width and vegetation structure: 1×1 m for grassland; 2×2 m for shrubland; 5×5 m for low forest; and 10×10 m for high forest. All native and exotic plant species, the tier they occurred in and their percent cover were recorded for each quadrat. Slope, road reserve profile (ditch, flat, slope upwards, slope downwards), distance to the edge of the road, and the management (none, close mown, flail mown, rough mown, herbicided, rough mown and herbicided, grazed, intensive grazing, occasionally grazed, garden, seal, slip debris, or native amenity plantings) were also recorded for each plot.

For each sampled location, the width of the road reserve was estimated by the field team using the cadastral coverage in conjunction with fence locations. Any birds observed in the road reserve during plot sampling, or within 100 m of the location, were recorded. Sampled locations were recorded as six-digit grid coordinates and then converted to full eastings and northings for inclusion into GIS (Geographic Information System) packages.

### 5.1.3 Statistical analysis

For each plot, a number of summary measures were used to characterize the biodiversity attributes of the plot locations:

Richness (Species Richness = total number of plant species in plot) Richness is a simple measure of the plant diversity at a plot. In our study, using richness alone is somewhat problematic, since the stature of the vegetation was so variable, and our plot sizes varied.

Simpson (Simpson's index of diversity = as 1/sum(pi^2), where pi=proportion of total cover accounted for by species i) Simpson's index of diversity takes into account the evenness of species abundances, and is less sensitive to plot size and stature of the vegetation.

Propnat (The proportion of species that are native) This simply tells the level of naturalised plant species in the plot, and is independent of plot size or vegetation stature.

Propnatc (The proportion of the total cover that is accounted for by native species) This is similar to Propnat, but takes into account the cover of each species.

Shtcov (The sum over species of the product of height×cover of the species = Vegetation volume ) Height times cover is related to the biomass that each species represents on the plot, so the sum over species is an index of the overall amount of plant mass on the plot. Since cover is in percent cover, this should also be independent of plot size.

Natcresw (The linear density of native cover in the road reserve = sum of native cover times the reserve width). This gives, for every metre along the road, the number of square metres of native cover in the road reserve. Thus, it can be considered as a measure of the native plant biodiversity value of a

Natcresw (The linear density of native cover in the road reserve = sum of native cover times the reserve width). This gives, for every metre along the road, the number of square metres of native cover in the road reserve. Thus, it can be considered as a measure of the native plant biodiversity value of a unit length of the road reserve that incorporates both the amount of native cover in the road reserve and the width of the road reserve. Natcresw is highest in areas with many native species and wide road reserves.

Potincr (The potential increase in native cover from fully restoring the road reserve = Reserve width times [1-Propnatc]) This index gives, for every metre along the road, the number of square metres of native cover that would be gained if the roadside reserve was converted to 100% native cover. Similarly to Natcresw, this index gives a linear density along the road, and is thus highest in areas of wide road reserves. However, unlike Natcresw, Potincr increases with the amount of exotic cover on the roadside and is thus highest where there are few native species, indicating high potential gains for restoration of the reserve.

Sampling probabilities (Table 1) were used to weight statistical analyses, when appropriate. Statistical analyses were performed in Systat 7.0 or S-Plus 4.5. Prediction techniques used to generate Figures 6, 7 and 8 are discussed in Appendix 7.

## 5.2 Results

### 5.2.1 Overall highway and survey characteristics

The road was sampled from the northern beginning of the highway at the junction with State Highway 1 in Hamilton, to its intersection with SH45 in New Plymouth. In the process of random sampling, the field team stopped at every 0.5 km along the road. A total of 462 stops were made (over 231 km) (Figure 4). On both sides of the road at each stop, the land cover immediately adjacent to the road was characterized, leading to 924 locations at which the land cover of the surrounding land was known for the highway. The proportion of these locations that fell into each cover category is given in Table 1 for the entire highway and in Figure 4 for each road sector. The majority of the highway was surrounded by pasture (70.4%), with significant amounts in urban areas (9.9%), rivers or streams (5.3%), indigenous forest (4.8%), and plantation forest (3.7%).

Each of these 924 locations had a probability of being sampled that depended upon the land cover adjacent to the road reserve (Table 1). This sampling scheme resulted in a total of 172 locations being sampled with vegetation plots. Plant biodiversity measures were calculated for each sampled location.

The only sectors of SH3 between Hamilton and New Plymouth for which comprehensive species lists of indigenous vascular flora are available are North Taranaki (from the North Taranaki Ecological District survey report; Bayfield *et al.* 1991) and Egmont (Druce 1986). The Egmont list covers altitudinal zones that do not occur in the road reserve in this sector, and so is not comparable. A total of 151 native species were recorded in the road reserve of the North Taranaki sector, one third of the indigenous vascular flora (446 species) listed for the Ecological District. The group best represented in the road reserve was conifers (50%), with native monocotyledons (grasses, sedges, rushes, orchids, lilies, etc) the most poorly represented (18%). Because the North Taranaki sector – along with the Awakino Gorge sector – contains the highest indigenous biodiversity, other sectors are likely to contain lower proportions of the indigenous flora of their respective ecological district/environmental domains.

### 5.2.2 Biodiversity attributes in each highway environmental sector

Most biodiversity attributes varied widely between the environmental sectors defined in Section 4. The proportion of native species (Propnat) varied 5-fold, from 5% in the Waipa sector to 25% in the Awakino Gorge and North Taranaki sectors, a pattern reflected in proportion of cover native (Propnatc). Differences between sectors in vegetation volume (Shtcov) were even more dramatic, with an 18-fold variation between the Hamilton and Awakino Gorge sectors. The amount of native cover varied 8-fold, between the low of 3% in the Hamilton sector and the high of 29% in the Awakino Gorge sector. The linear density of native cover (Natcresw) varied most dramatically of all, incorporating both the differences between sectors in reserve width as well as the amount of native cover, with a 51-fold variation between the low of 0.13 $m^2$ of native cover per metre of road in the Waipa sector, and the high of 6.6 $m^2/m$ in the Awakino Gorge sector.

**Table 2 Summary of biodiversity indices for the entire highway and for each highway sector. Highway sectors are defined in 4.1, and biodiversity indices are defined in 5.1.3**

| | Simpson | Propnat | Propnatc | Shtcov | Natcover | Natcresw | Potincr |
|---|---|---|---|---|---|---|---|
| **Entire highway** | 4.11 | 0.164 | 0.159 | 79.26 | 15.33 | 2.88 | 6.67 |
| Hamilton | 3.37 | 0.08 | 0.07 | 12.04 | 3.25 | 0.18 | 5.60 |
| Waipa | 4.39 | 0.06 | 0.05 | 34.35 | 2.49 | 0.13 | 4.44 |
| King Country | 4.51 | 0.18 | 0.19 | 57.30 | 19.57 | 3.03 | 6.17 |
| Awakino Gorge | 3.64 | 0.26 | 0.23 | 217.12 | 28.89 | 6.55 | 10.81 |
| North Taranaki | 4.15 | 0.25 | 0.23 | 109.65 | 23.36 | 5.33 | 8.05 |
| Egmont | 3.14 | 0.16 | 0.19 | 121.82 | 12.55 | 1.11 | 6.44 |

Natcresw increases with both the amount of native cover in the road reserve and the width of the road reserve. The road reserve tends to be widest in the areas of indigenous forest (where native species are relatively abundant) and narrowest in pastoral areas (where there are very few native species). This leads to the wide range of Natcresw values between the sectors. Conversely, the potential increase in native cover (Potincr) varied much less dramatically, showing only a 2.5-fold variation between the highest in the Awakino Gorge and the lowest in the Waipa sector. The reduced variation comes from the fact that the areas where the road reserve is widest, and thus represents the most area for restoration, also tend to be the areas where there is already a reasonable amount of native species. Thus the narrow areas of road reserve through pasture represent a reasonably high potential increase in native cover, simply because there are so few native species to begin with.

### 5.2.3 Qualities of road reserve as a function of land cover

#### 5.2.3.1 *Analysis of roadside sampling*

The width of the road reserve (distance from the edge of the road seal to the edge of the road reserve) is an important attribute of the road reserve, since it determines the amount of area contained in the reserve. The overall mean reserve width for SH3 (Hamilton to New Plymouth) is 9.3 metres, on each side of the road carriage. This means there is approximately 1.8 ha of reserve per km of road or approximately 416 ha

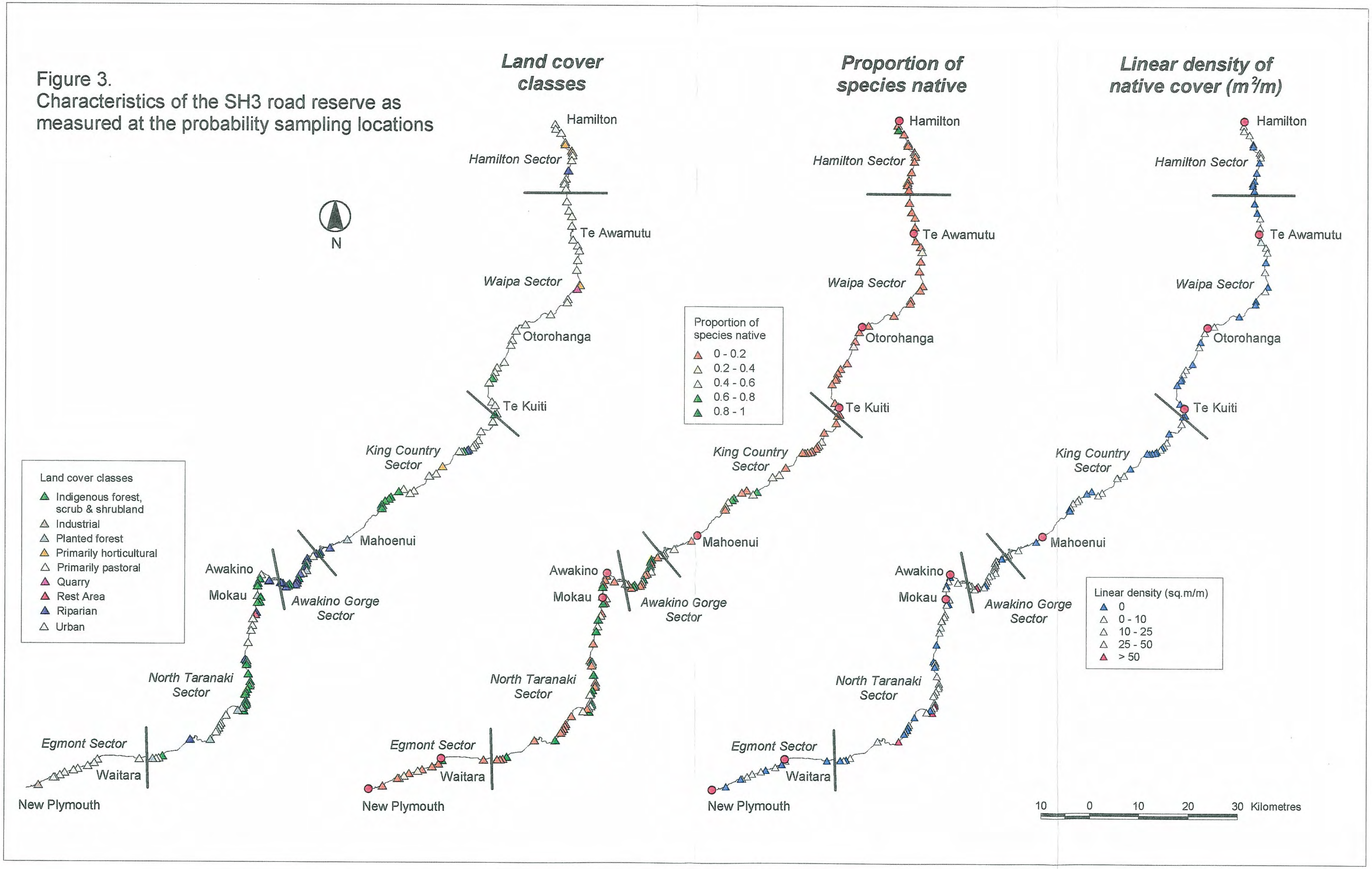



Figure 3.
Characteristics of the SH3 road reserve as measured at the probability sampling locations

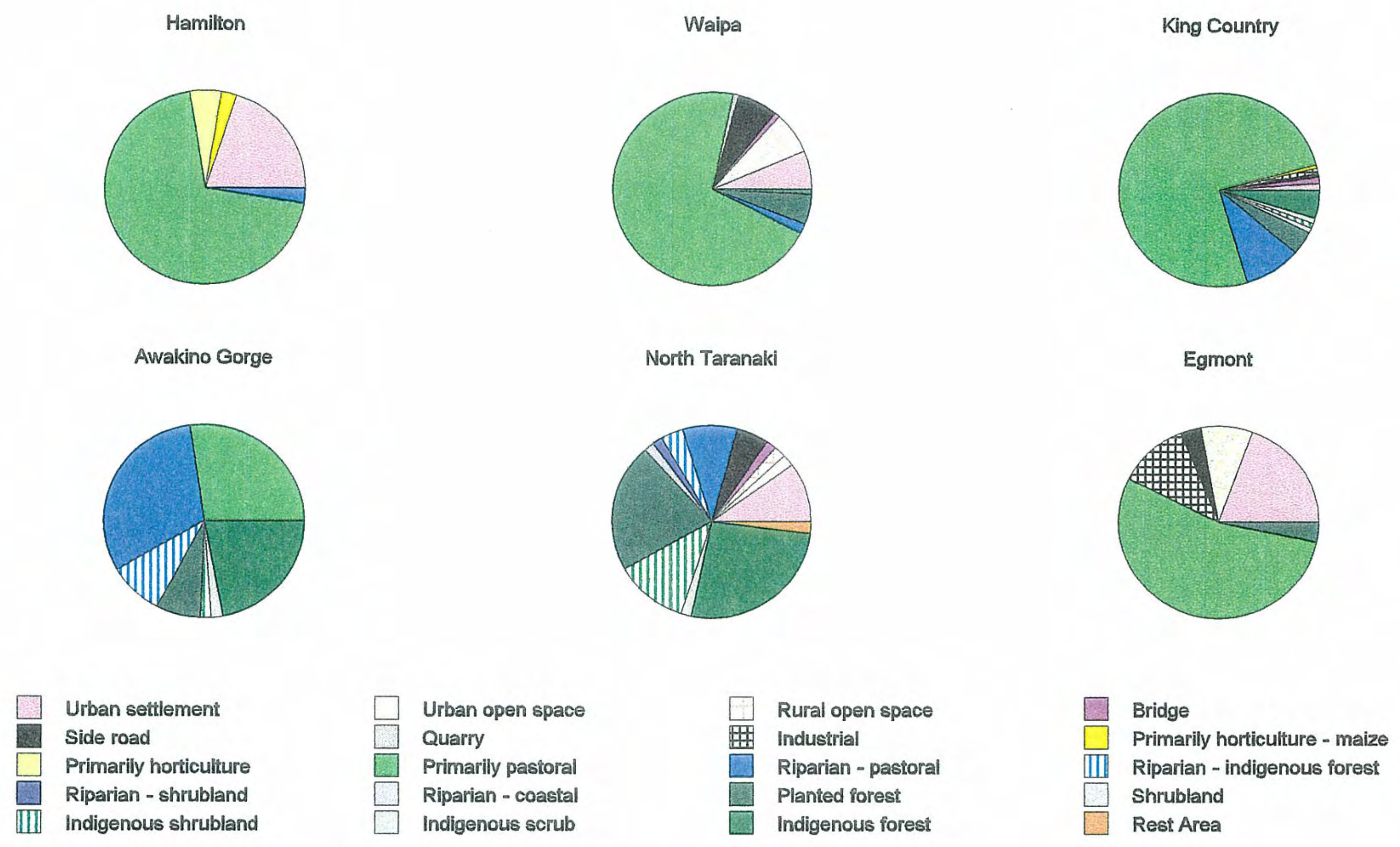



Fig. 4 The proportion of each 0.5km stop in each land cover category by sector.

for the section of SH3 studied. However, the width of the road reserve varied widely between the different surrounding land covers, extending an average of 6.8 m (95% CI = [5.58, 7.98]) from the seal edge in pastoral areas, and reaching a mean width of 39.6 m (95% CI = [20.49, 58.68]) in indigenous forest (Figure 5). Combining these reserve areas with the quality of the areas allows us to make estimates of the biodiversity values of the road reserve.

Overall, the surrounding land cover had a significant effect on most of the biodiversity attributes that were measured (Figure 5) within the road reserve, showing many similar patterns for the various attributes. The proportion of species in the road reserve plots that were native (Propnat) was highest in indigenous forest and shrubland, lowest in pastoral, urban, industrial and horticultural areas, and intermediate in planted forest and riparian areas. A similar pattern is seen in the effect of land use on the proportion of cover in a plot that was accounted for by native species (Propnatc). The only notable difference between Propnat and Propnatc is in rest areas. This indicates that rest areas have larger numbers of planted native species, along with many adventive grasses and herbs. Vegetation volume (Shtcov) shows a similar pattern, indicating that the areas with the most native species and cover were also the areas with the largest amount of vegetation. This arises because many of the native species encountered in the road reserve were trees or shrubs, while most of the adventive species were weedy herbs or grasses. The linear density of native cover (Natcresw) shows the effects both of road width and vegetation composition. Indigenous forest has the highest value of Natcresw, with indigenous shrubland, rest areas, planted forests and riparian areas having intermediate values, and urban, pastoral, industrial and horticultural areas having the lowest values.

The strong relationship between surrounding land cover and biodiversity attributes seen in the road reserve sample locations, allows the possibility of using this relationship to predict the biodiversity attributes for each 0.5 km stop, for which only the distance along the highway and the surrounding land cover are known. Predictions for the entire highway of the linear density of native cover (Natcresw), proportion of species native (Propnat) and benefits from restoration (Potincr) are given in Figures 6, 7 and 8. These predictions were made using regression techniques (GAMs – generalised additive models) to establish the relationships between these biodiversity attributes and land cover and distance from Hamilton seen in the sampled locations. These relationships were then used to predict the attributes for every 0.5 km stop. The methods and models used in the predictions are given in Appendix 7.

#### 5.2.3.2 *Analysis of paired sampling*

The paired sampling of the land cover adjacent to the sampled plots in the road reserve allows comparisons of the road reserve with the surrounding land cover. The plot in the road reserve and the paired plot in the surrounding area are in close proximity, differing only in that one is in the road reserve. This paired design enhances the power to distinguish the differences of road reserve from the surrounding area by holding constant other factors, such as environmental conditions, that can affect the biodiversity attributes.

Only 16 pairs of plots were sampled: of these, 6 were in pasture and 7 in indigenous forest (7 plots). Because of the low number of sites in indigenous scrub (2 plots) and

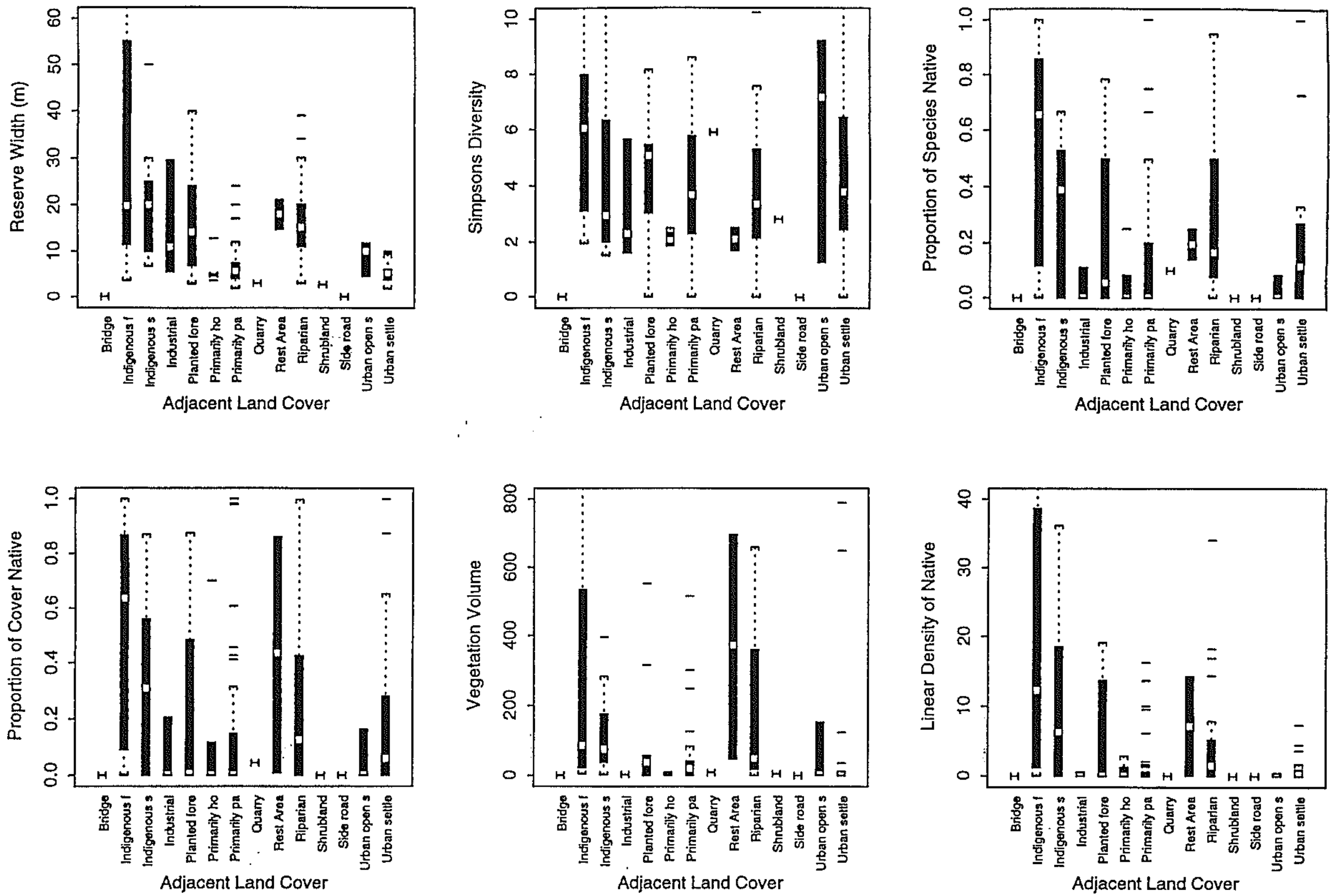



**Fig. 5** The effects of land cover through which the road is passing on reserve width and five biodiversity attributes of the road reserve. Land cover has a significant effect on all variables. The vertical bars for each group indicate the middle 50% of the distribution, with the mean of the group at the middle of the bar and the median indicated by a small white box. Dotted lines indicate 99% of the distribution, with hash marks at outliers.

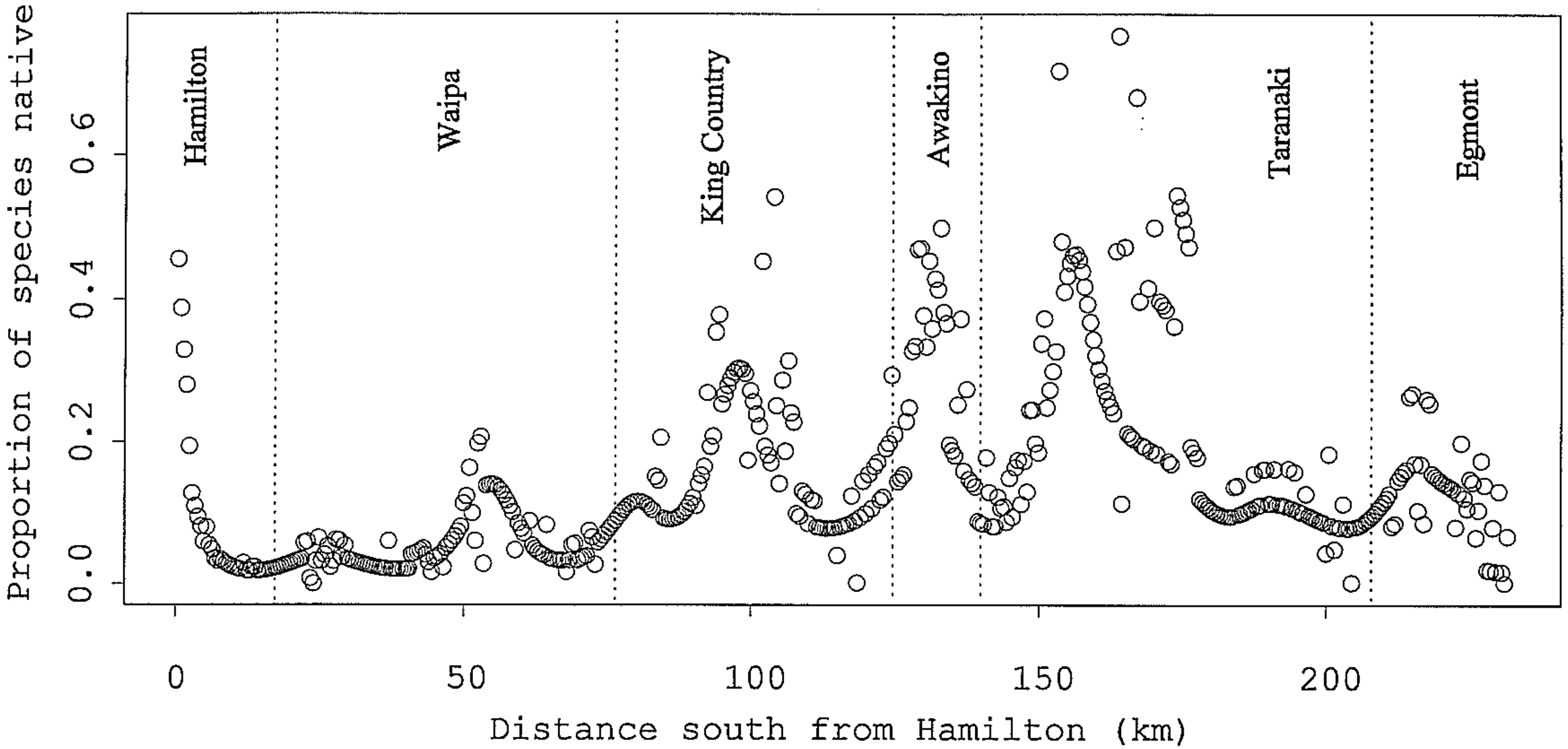



Figure 6 Predictions of the proportion of species native (Propnat) for the study highway segment. Predictions are made for both sides of the road at every 0.5 km stop, using the relationships between the proportion of species native and nearby land cover (Figure 5) and the distance along the road. Appendix 7 gives a full account of prediction techniques.

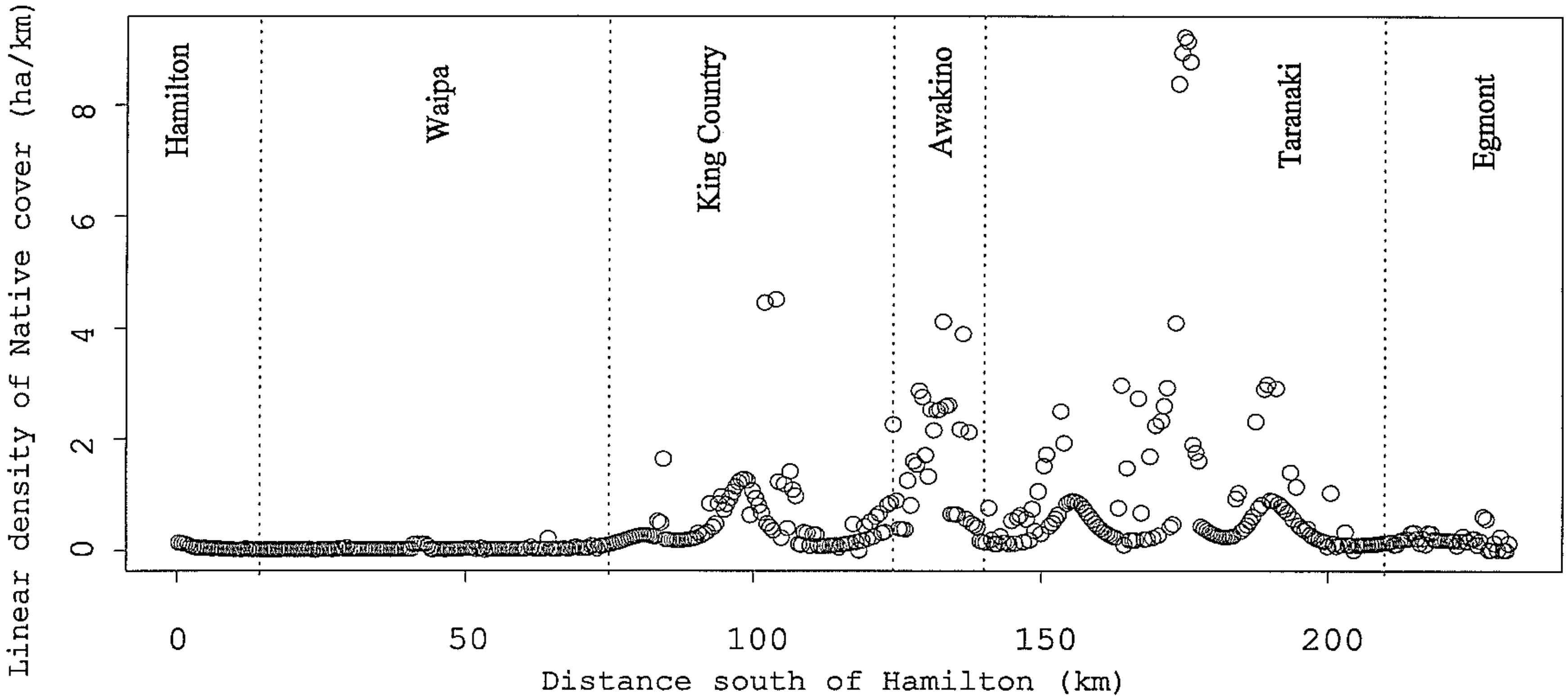



**Figure 7** Predictions of Linear density of native cover (Natcresw) for the study highway segment, as in Figure 6.

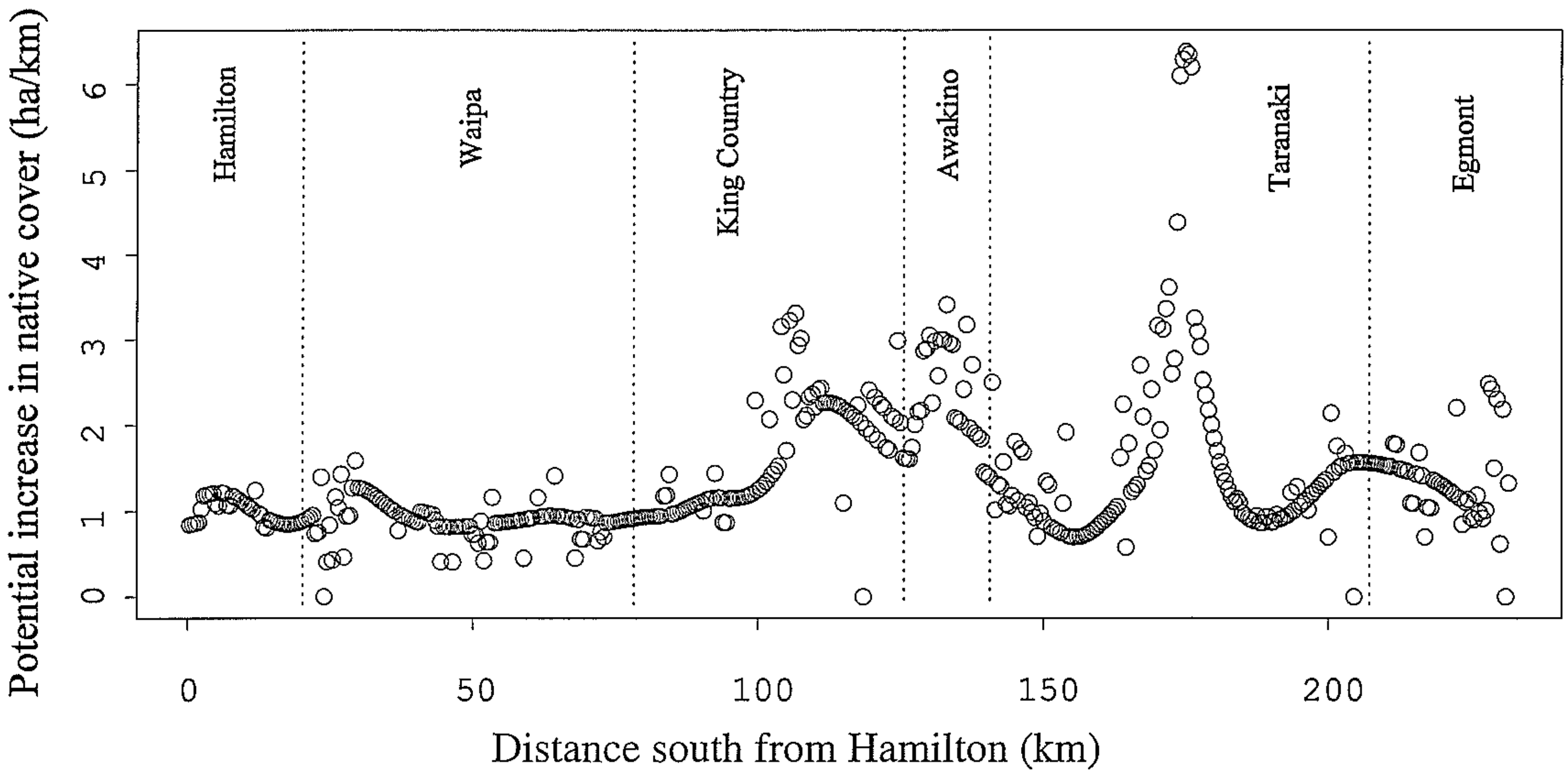



**Figure 8 Predictions of Potential increase in native cover (Potincr) for the study highway segment, as in Figure 6.**

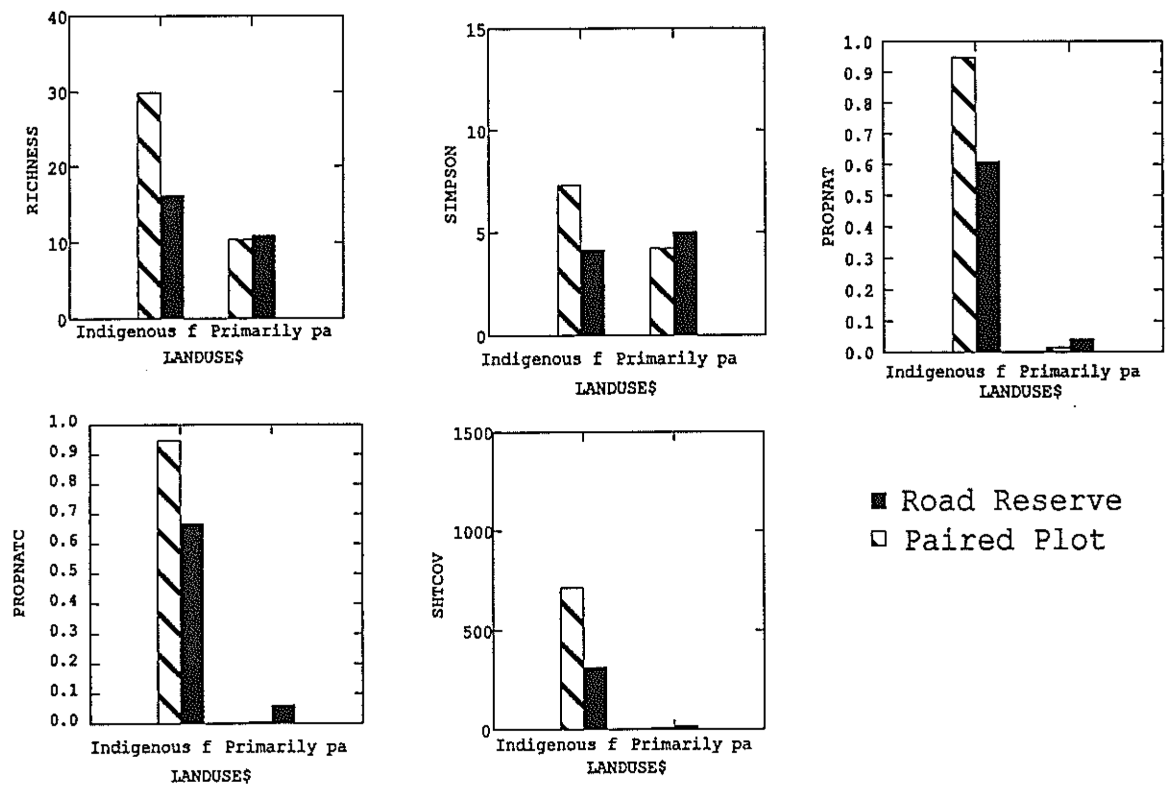



Figure 9 A comparison of the road reserve with surrounding land covers, from the results of the paired plot sampling. The values of five biodiversity indices are shown for plots in the road reserve and paired plots positioned 50 m into the surrounding land cover. Note that when the road passes through indigenous forest, all the biodiversity indices are significantly higher in the paired plot in the nearby forest adjacent land cover than in the road reserve. The converse is true in pastoral areas, where the biodiversity indices are slightly higher in the road reserve than in the surrounding pastures.

primarily horticultural land covers (1 plot), the analysis focus on pasture and indigenous forest.

Figure 9 compares five biodiversity attributes between the road reserve plots and the paired plots for indigenous forest and pastoral areas. For each of these attributes, there are two significant differences. The first comparison compares between indigenous forest and pasture in the biodiversity values. The differences seen in the attributes between indigenous forest and pasture reflect those seen in Figure 5. Richness and Simpson (which treat native and exotic species equally) are similar in the road reserve in indigenous forest and pasture. However, the proportion of species native (Propnat), the proportions of cover accounted for by native species (Propnatc), and vegetation volume (Shtcov) were all greater in indigenous forest.

Differences between the road reserve and the surrounding land cover were also important. Here, pastoral areas and indigenous forests on adjacent land show an opposite effect of the road reserve on biodiversity. When the road passes through indigenous forest, all the biodiversity indices are higher in the paired plot in the nearby forest adjacent land cover, than the corresponding plots in the road reserve (Figure 9). The converse is true in pastoral areas, where the biodiversity indices are slightly higher in the road reserve than in the surrounding pasture.

Most of these differences between road reserve and adjacent land when passing through indigenous forest are statistically significant, whereas none of the differences for the pastoral areas are significant. Since the plots are paired at a particular location, the correct way to assess the statistical significance is to compare the differences between plots in a pair. That is, for each road location with both a roadside plot and a paired plot, subtract the values of the variable of the interior plot from the plot in the road reserve. Thus, the difference will be positive if the road reserve has a higher value than the interior plot, and negative if vice versa. For indigenous forest areas, the probabilities that the differences between road and paired plots seen in Figure 9 are due to random chance are: Richness, $p=.014$; Simpson, $p=0.098$; Propnat, $p=0.009$; Propnatc, $p=0.013$; and Shtcov, $p=0.073$. None of the differences seen for pastoral areas are statistically significant.

# 6 PROTECTED NATURAL AREA (PNAP) SURVEY METHODS AND RESULTS

## 6.1 Methodology

Every area of predominantly native vegetation within and adjacent to the SH3 road reserve, between Hamilton and New Plymouth, was described using the PNAP methodology of Myers *et al.* (1987). This was done in the context of the six environmental sectors defined by the environmental domains analysis (described in section 4).

## 6.2 SH3 PNAP Results

A total of 84 sites of indigenous vegetation were surveyed during the PNAP survey of SH3 (Figure 10). These are summarised in Appendix 4.

From the PNAP survey data descriptions of the vegetation are provided for each sector by each toprock type/landform. A schedule of significant native plant communities is also presented at the end of the descriptions. 'Significance' was assessed using the criteria of Myers *et al.* (1987), paying particular attention to 'representativeness'.

### 6.2.1 Hamilton environmental sector

Apart from Lake Serpentine Wildlife Management Reserve, no substantial areas of predominantly natural vegetation remain within or immediately adjacent to the road reserve of SH3 in this sector.

### 6.2.2 Waipa environmental sector

Only a few substantial areas of predominantly natural vegetation remain within or immediately adjacent to the road reserve in this sector.

A stand of secondary short broadleaved forest dominated by kamahi, mangeao, mahoe, and mamaku occupies a **sandstone** slope just south of Te Kuiti.

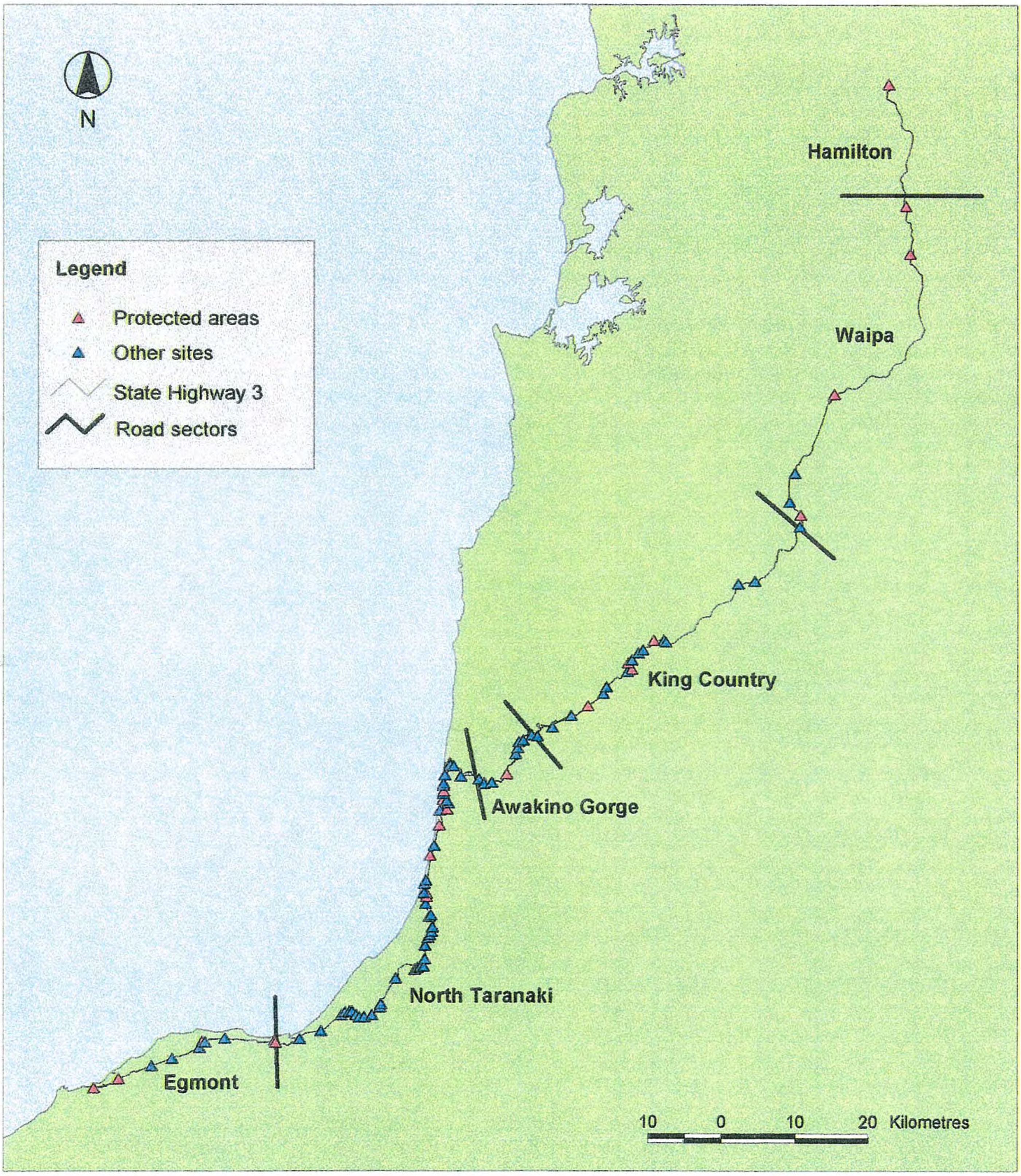
Secondary kahikatea stands are a feature of alluvium in the Te Kuiti district; two such stands abut the road reserve just north of the town and contain other conifers (e.g., rimu, totara) and broadleaved species such as pukatea, tawa, titoki, pokaka, tarata, swamp maire, mahoe, mapou, and kohuhu.

### 6.2.3 King Country environmental sector

Tall treeland of titoki with some kahikatea occupies **alluvium** south of Mahoenui. Upstream of the Mangaparo S. bridge is a fertile raupo swamp with harakeke.

Cuttings in **rhyolitic tephra** support shrubland of karamu, koromiko, manuka, and ferns; totorowhiti is locally present. Young secondary vegetation is bracken fernland; older vegetation on hillslopes comprises short broadleaved forest of lacebark, tree fuchsia, and wineberry. A small stand of secondary short conifer forest (matai with some totara and kahikatea) occurs on footslopes near the Pangaki Stream. Primary forest on hillslopes comprises scattered rimu and rewarewa emergent over tawa and kamahi.

**Figure 10.**
**Location of the 84 sites with indigenous vegetation surveyed using PNAP methodology**



Road cuttings on **mudstone** support shrubland dominated by manuka, tutu, and koromiko. Young secondary vegetation is dominated by manuka, older vegetation by broadleaved scrub→short forest containing a wide range of species; kamahi, mahoe, tree fuchsia, lacebark, pate, rangiora, and karamu are common. Dense stands of young totara occur on **mudstone** just south of Totoro Rd, and tall conifer/broadleaved treeland of kahikatea over lacebark, pate and putaputaweta on lower slopes nearby. A small remnant of primary tall conifer/broadleaved forest of scattered kahikatea, rewarewa, and pukatea over tawa occurs in this vicinity.

Secondary manuka scrub on **sandstone** contains a range of other species, including mingimingi and *Pittosporum colensoi*. Ridges near the entrance to the Awakino Gorge carry tall hard beech forest.

**Argillite** in the lower reaches of the Mangaotaki River supports secondary scrub on cuttings of tutu, koromiko, kanuka, manuka, and *Pittosporum colensoi*. Short forest on hillslopes comprises mixtures of kanuka, mahoe, lacebark, and manuka. Primary tall conifer forest in places on midslopes comprises kahikatea, rimu, totara, and matai over mahoe; and on footslopes occurs tall conifer/broadleaved forest of scattered kahikatea, totara, pukatea, and rewarewa over tawa and titoki with a mahoe subcanopy.

**Limestone** faces above the Waitomo Stream support a variety of trees (e.g., mahoe, tree fuchsia), grasses (e.g., *Poa anceps*), and ferns (e.g., common shieldfern, *Pneumatopteris pennigera*). Secondary broadleaved scrub→short forest on hillslopes comprises manuka and lacebark with a range of other species. Older secondary forest is dominated by lacebark, mahoe, titoki, putaputaweta, and pate. Primary forest on hillslopes in Mangaotaki Scenic Reserve comprises scattered kahikatea, pukatea, and rewarewa emergent over tawa, titoki, and hinau. Matai occurs as an emergent on lower slopes.

### 6.2.4 Awakino Gorge environmental sector

Remnants of primary tall broadleaved treeland→forest, degraded by past logging and grazing (which are in many places ongoing) are a feature of **alluvium** in the Awakino Gorge. Pukatea emerges over canopies dominated by younger pukatea, lacebark, and titoki, with subcanopies dominated by mahoe and understoreys by kawakawa. Kahikatea is present in places.

Cuttings on **mudstone** support shrubland of manuka, karamu, totorowhiti, mingimingi, and koromiko. Secondary short broadleaved forest on lower slopes are mainly comprised of mahoe, pate, and kawakawa. Older secondary forest is dominated by kamahi with *Pittosporum colensoi*, mahoe and wheki.

**Sandstone** is common in the lower Awakino Gorge. The original forest pattern consists of primary tall conifer/broadleaved forest dominated by tawa and kamahi on hillslopes with enclaves of hard beech forest on ridges. Rimu, rewarewa, and epiphytic puka occur as scattered emergents on upper and mid slopes; pukatea is a common emergent on lower slopes and in gullies. Miro, hinau, mangeao, mamaku, and gully tree fern are widespread canopy associates of tawa and kamahi on middle and lower slopes; puriri and karaka are also common within 8 km of the coast, but kohekohe extends a little further inland. Titoki is common on footslopes. Subcanopies are dominated by mahoe, and pigeonwood also on lower slopes.

Younger cuttings and slip faces are largely bare, with scattered manuka, koromiko, buddleia, and *Poa anceps*. Older ones support manuka-toetoe shrubland with some wharariki and koromiko. Bluffs carry wharariki, kohuhu, *Olearia townsonii*, manuka, mapou, and puka.

Young secondary scrub on **sandstone** is dominated by manuka. Other widespread species are mamaku, mahoe, heketara, mingimingi, mapou, and karamu. *Olearia townsonii* is locally present. Older secondary short broadleaved forest on hillslopes comprises scattered rewarewa emergent over kamahi.

A burnt **sandstone** ridge just inland of Awakino supports young secondary manuka scrub and older secondary short conifer forest, of scattered rewarewa emergent over dense tanekaha with some rimu. Older secondary hillslope forest here comprises kamahi and mangeao, with scattered tawa and a range of other species on moister, more fertile lower slopes.

A small area of **greywacke** is intersected by the highway. Broadleaved scrub→short forest containing a range of species (kamahi, mangeao, titoki, mahoe, pigeonwood, fivefinger) occupies mid and lower slopes, and mamaku treefernland gullies. Older secondary forest is dominated by mangeao and kamahi. Bluffs above the highway support tutu-mahoe-rangiora scrub.

**Limestone** bluffs about the Awakino road tunnel support shrubland of wharariki, mingimingi, cotoneaster, and tree fuchsia in some places, with herbs (e.g., tuhara, *Poa anceps*), and ferns (e.g., common maidenhair, kiokio) elsewhere.

### 6.2.5 North Taranaki environmental sector

**Andesitic tephra** supports secondary short broadleaved forest with rewarewa emergent over mahoe and mamaku on riparian slopes about a tributary of the Mimi River.

In Kawau Pa Historic Reserve and near the mouth of the Rapanui Stream, coastal broadleaved scrub→short forest is dominated by karaka, with mahoe, kawakawa, hangehange and karamu common; local stands of harakeke occur on the same substrate.

Cuttings in **andesitic tephra** near the coast support herbaceous communities containing a range of native shrubs (e.g., tauhinu, manuka), forbs (e.g., harakeke, shore lobelia, *Tetragonia trigyna*, *Haloragis erecta*), and ferns (e.g., common maidenhair).

The largest stand of tainui in New Zealand grows on **rhyolitic tephra** in Tainui Scenic Reserve between Awakino and Mokau. Adjacent secondary short broadleaved forest on lower slopes is comprised of mahoe, mamaku, and kawakawa.

Secondary scrub on **rhyolitic tephra** just south of Awakino comprises mixtures of trees (mahoe), shrubs (e.g., karamu, hangehange, kawakawa, manuka, mingimingi, tauhinu, coastal koromiko), forbs (e.g., wharariki, *Haloragis erecta*, tuhara), and ferns (e.g., bracken).

**Alluvium** in the Mimi valley supports degraded remnants of primary tall broadleaved treeland→forest of rewarewa and pukatea emergent over mahoe and titoki, with kawakawa and ramarama common in the understorey.

Secondary **alluvial** communities in the Tongaporutu valley comprise short forest dominated by mahoe and wineberry with a range of other small trees and shrubs, including lacebark and kowhai, present.

Poorly drained **alluvium** supports fertile raupo swamps with harakeke and cutty grass just north of the Mohakatino River and with marsh clubrush near the mouth of the Rapanui Stream. More extensive brackish swamps near the mouth of the Awakino River contain a range of communities dominated variously by raupo, sea rush, and marsh clubrush. Lake sedge and *Carex geminata* agg. are also widespread. A poorly drained terrace at the southern end of the Mt Messenger massif supports tall conifer forest of kahikatea over swamp maire and lacebark.

Cuttings in **windblown sand** between Awakino and Mokau support broadleaved scrub of young pohutukawa, mahoe, kawakawa, hangehange, koromiko, karamu, and harakeke. Exposed west-facing cutting here carry wharariki flaxland containing a range of trees (e.g., pohutukawa, mahoe, mapou), shrubs (e.g., coastal koromiko, taupata, kawakawa, karamu, hangehange), grasses (e.g., toetoe, *Poa anceps*, cutty grass), and ferns (e.g., bracken). Just south of the Mokau River estuary, one such cutting supports scattered shrubs of a coastal pimelea, *Pimelea urvilleana*, and tauhinu.

A belt of **mudstone** in the Mimi River valley supports a variety of secondary communities on cuttings and slopes: small-leaved scrub dominated by manuka – and occasionally gorse – and short broadleaved forest by mahoe. Common associates of manuka are mahoe and tutu, with totorowhiti in places; mamaku occurs commonly in manuka scrub. Primary tall conifer/broadleaved forest on this substrate comprises scattered rimu and rewarewa emergent over tawa and kamahi, with a mahoe subcanopy.

**Sandstone** is extensive in the district. The original forest pattern survives on the largest block crossed by SH3, the Mt Messenger massif: primary tall conifer/broadleaved forest dominated by tawa and kamahi on hillslopes with enclaves of hard beech forest on ridges. Northern rata, rimu, and rewarewa occur as scattered emergents on upper and mid slopes; pukatea is a common emergent on lower slopes and in gullies. Miro, Hall's totara, hinau, and mamaku are widespread canopy associates of tawa and kamahi. Tawheowheo is a common canopy associate on upper slopes, gully tree fern on lower slopes. Subcanopies are dominated by mahoe, with pigeonwood also on lower slopes.

Cuttings and slip faces carry distinctive herbaceous communities of tuhara, kiokio, toetoe, parataniwha on moister, more fertile sites, and a suite of small herbs including panakeake, and the locally endemic spider orchid *Corybas papa*. **Sandstone** bluffs just inland of Awakino support a variety of shrubs (e.g., tutu, karamu, koromiko), forbs (e.g., wharariki, tuhara), and grasses (e.g., *Poa anceps*).

Young secondary scrub on **sandstone** is dominated by manuka. Other widespread species are mamaku, mahoe, mingimingi, karamu, tuhara, kiokio, and wharariki. Totorowhiti, *Pittosporum colensoi*, and *Olearia townsonii* are locally present. Older secondary short broadleaved forest comprises scattered rewarewa emergent over kamahi and often has pukatea-dominant remnants of primary forest surviving in gullies.

A burnt **sandstone** ridge just inland of Awakino supports young secondary manuka scrub and older secondary short forest of scattered rewarewa emergent over dense tanekaha with some rimu. Older secondary hillslope forest here comprises kamahi and mangeao, with scattered tawa and a range of other species on moister, more fertile lower slopes.

On **sandstone** in Tongaporutu Conservation Area near the mouth of the Tongaporutu River, remnants of primary coastal tall broadleaved forest dominated by karaka, puriri, and kohekohe – with tawa on sheltered sites – survive on lower slopes and in gullies in mosaic with secondary mahoe forest on midslopes and secondary manuka-mingimingi scrub on upper slopes and ridges. Nikau stands are a feature of coastal forest margins here. About the estuary itself, scattered rewarewa emerge above a karaka-kohekohe-kowhai canopy with a mahoe subcanopy and kawakawa understorey in Pou Tehia Historic Reserve.

Just north of the Mokau River estuary, primary tall coastal forest on **sandstone** slopes comprises scattered rewarewa emergent over mixtures of karaka, mangeao, titoki, and kohekohe, with a mahoe subcanopy and kawakawa understorey.

Eroding coastal bluffs on **sandstone** just south of the Mokau River mouth support gorse-mahoe scrub in some places on the lower slopes and primary short karaka-kowhai-kohekohe forest with mahoe subcanopies and kawakawa understories in others.

#### 6.2.6 Egmont environmental sector

**Andesitic tephra** (volcanic ash) from Mt Egmont/Taranaki is the predominant 'toprock' underlying natural areas in this sector, all of which are near or in the coastal zone. Karaka dominates the canopies of tall broadleaved forest, most of which appears to be secondary, with mahoe dominating the subcanopy, and kawakawa the understorey. Rewarewa is commonly emergent above the canopy; titoki, puriri, kohekohe, ngaio, puka and mamaku are variously present in the canopy. Tawa is locally present on sheltered sites. Younger secondary short forest on these substrates is dominated by mahoe and mamaku, as along Waitoetoe Stream.

There are also several substantial stands of artificial broadleaved shrubland→short forest, planted over the past two decades for amenity purposes on **andesitic** substrates. The largest, just north of the Waitara intersection, contain a range of native species both indigenous to the district, e.g., karaka, titoki, puriri, ngaio, akeake, whau, tarata, and kanuka, and alien, e.g., Chatham Island akeake, houhere, houpara and broadleaf. Some exotics, e.g., tree lucerne have also been planted. Regeneration of some planted native species as well as others is occurring beneath these stands, suggesting that selfsustaining native forest communities have inadvertently but fortuitously been created on these sites.

A small fertile swamp dominated by harakeke, *Carex secta*, raupo, and rushes occurs on poorly drained **andesitic** substrates in Katere Scenic Reserve (Clarkson & Boase 1982).

On **alluvium**, primary tall broadleaved forest in Onaero River Scenic Reserve is dominated by rewarewa emergent over karaka and kowhai, with kawakawa dominant in the understorey (Clarkson & Boase 1982). Kohekohe and mamaku are also common in the canopy and in wetter places, pukatea.

A small fertile swamp dominated by raupo is present on poorly drained **alluvium** in Onaero River Scenic Reserve.

Similar primary forest with tawa also common in the canopy occurs on steep **sandstone** faces in Onaero River Scenic Reserve

## 6.3 Schedule of Native Plant Communities in or Immediately Adjacent to the Road Reserve of SH3 from Hamilton to New Plymouth (* adventive species)

### 6.3.1 Hamilton sector

Apart from Lake Serpentine Wildlife Management Reserve, no substantial areas of predominantly natural vegetation remain within or immediately adjacent to the road reserve of SH3 in this sector.

### 6.3.2 Waipa sector

**Sandstone**

*Secondary*

- Tall broadleaved forest (kamahi-mangeao-mahoe-mamaku) on hillslopes
- Alluvium

*Secondary*

- Tall conifer forest (kahikatea) on river flats

### 6.3.3 King Country sector

**Alluvium**

*Primary*

- Tall treeland (titoki-kahikatea) on river flats
- Fertile swamp (raupo) on river flats
- Rhyolitic tephra

*Secondary*

- Fernland (bracken) on lower slopes
- Shrubland (karamu, koromiko, manuka, and ferns) on cuttings
- Short conifer forest (matai) on footslopes
- Short broadleaved forest (lacebark-tree fuchsia-wineberry) on hillslopes

*Primary*

- Tall conifer/broadleaved forest (rimu-rewarewa/tawa-kamahi) on hillslopes

**Mudstone**

*Primary*

- Tall conifer/broadleaved forest (kahikatea-rewarewa-pukatea/tawa/mahoe) on hillslopes

*Secondary*

- Shrubland (manuka, tutu, koromiko) on cuttings
- Small-leaved scrub (manuka) on hillslopes
- Short broadleaved forest (containing a wide range of species) on hillslopes
- Short conifer forest (totara) on hillslopes
- Tall conifer/broadleaved treeland (kahikatea/lacebark-pate-putaputaweta) on lower slopes

**Sandstone**

*Primary*

- Tall broadleaved forest (hard beech) on ridges

*Secondary*

- Small-leaved scrub (manuka) on hillslopes

**Argillite**

*Primary*

- Tall conifer forest (kahikatea-rimu-totara-matai/mahoe) on midslopes
- Tall conifer/broadleaved forest (kahikatea-totara-pukatea-rewarewa/tawa-titoki/mahoe) on footslopes

*Secondary*

- Short broadleaved forest (kanuka-mahoe-lacebark-manuka) on lower slopes
- Limestone

*Primary*

- Tall conifer/broadleaved forest (kahikatea-pukatea-rewarewa/tawa-titoki-hinau) on hillslopes

*Secondary*

- Mixed communities (trees (e.g., mahoe, tree fuchsia), grasses (e.g., *Poa anceps*), and ferns (e.g., common shieldfern, *Pneumatopteris pennigera*)) on cuttings
- Broadleaved scrub→short forest (manuka-lacebark) on hillslopes
- Broadleaved short forest (lacebark-mahoe-titoki-putaputaweta-pate) on hillslopes

### 6.3.4 Awakino Gorge sector

**Alluvium**

*Primary*

- Tall broadleaved treeland→forest (pukatea/pukatea-lacebark-titoki/mahoe/kawakawa) on river flats

**Mudstone**

*Secondary*

- Short broadleaved forest (mahoe-pate-kawakawa) on lower slopes
- Short broadleaved forest (kamahi) on hillslopes
- Shrubland (manuka, karamu, totorowhiti, mingimingi, koromiko) on cuttings

**Sandstone**

*Primary*

- Shrubland (wharariki, kohuhu, *Olearia townsonii*, manuka, mapou, puka) on bluffs
- Tall conifer/broadleaved forest (rimu-rewarewa/tawa-kamahi) on hillslopes
- Tall broadleaved forest (hard beech) on ridges

*Secondary*

- Shrubland (manuka, koromiko, *buddleia, *Poa anceps*) on younger cuttings and slip faces
- Shrubland (manuka-toetoe) on hillslopes
- Small-leaved scrub (manuka) on hillslopes
- Short broadleaved forest (rewarewa/kamahi or kamahi-mangeao) on hillslopes
- Short conifer forest (rewarewa/tanekaha) on ridges

**Greywacke**

*Primary*

- Broadleaved scrub (tutu-mahoe-rangiora) on bluffs

*Secondary*

- Broadleaved scrub→short forest (kamahi, mangeao, titoki, mahoe, pigeonwood, fivefinger) on mid and lower slopes
- Treefernland (mamaku) in gullies
- Tall forest (mangeao-kamahi) on hillslopes

**Limestone**

*Primary*

- Shrubland (wharariki-mingimingi-*cotoneaster-tree fuchsia) on bluffs
- Shrubland (tuhara, *Poa anceps*, common maidenhair, kiokio) on bluffs

### 6.3.5 North Taranaki sector

**Andesitic tephra**

*Coastal secondary*

- Shrubland (tauhinu, manuka, harakeke, shore lobelia, *Tetragonia trigyna*, *Haloragis erecta*, common maidenhair) on cuttings
- Broadleaved scrub→short forest (karaka-mahoe-kawakawa-hangehange-karamu) on hillslopes

*Inland secondary*

- Short broadleaved forest (rewarewa/mahoe-mamaku) on riparian slopes

**Rhyolitic tephra**

*Inland secondary*

- Scrub (taupata-wharariki) on cuttings
- Short broadleaved forest (tainui or mahoe-mamaku-kawakawa) on hillslopes

**Alluvium**

*Coastal primary*

- Semi-saline swamp (raupo, sea rush, *Bulboschoenus fluviatilis*) on poorly drained flats
- Freshwater swamp (raupo) on poorly drained flats

- *Inland primary*
- Tall conifer forest (kahikatea/swamp maire-lacebark-putaputaweta-kaikomako) on foorly drained terrace
- Tall broadleaved treeland→forest (rewarewa-pukatea/mahoe-titoki/kawakawa-ramarama) on poorly drained river flats

*Inland secondary*
- Short forest (mahoe-wineberry)
- Windblown sand

*Coastal primary*
- Flaxland (wharariki) on seaward faces

*Coastal secondary*
- Broadleaved scrub (pohutukawa-mahoe-kawakawa-hangehange-koromiko-karamu-harakeke) on cuttings
- Broadleaved shrubland (*Pimelea urvilleana*-tauhinu) on cuttings

**Mudstone**

*Inland primary*
- Tall conifer/broadleaved forest (rimu-rewarewa/tawa-kamahi/mahoe) on hillslopes

*Inland secondary*
- Small-leaved scrub (manuka) on cuttings and slopes
- Short broadleaved forest (mahoe) on hillslopes

**Sandstone**

*Coastal primary*
- Tall broadleaved forest (karaka-puriri-kohekohe) on lower slopes and in gullies
- Tall broadleaved forest (rewarewa/karaka-kohekohe-kowhai/mahoe/kawakawa) on seaward slopes
- Tall broadleaved forest (rewarewa/karaka-mangeao-titoki-kohekohe/mahoe/kawakawa) on seaward slopes
- Short broadleaved forest (karaka-kowhai-kohekohe/mahoe/kawakawa) on the lower slopes of seaward bluffs

*Coastal secondary*
- Scrub (*gorse-mahoe) scrub on the lower slopes of eroding bluffs

*Inland primary*
- Tall forest (hard beech) on ridges
- Tall conifer/broadleaved forest (northern rata-rimu-rewarewa/tawa-kamahi/mahoe) on mid slopes
- Tall conifer/broadleaved forest (rimu-Hall's totara/miro-kamahi-tawheowheo) on upper slopes
- Tall conifer/broadleaved forest (rimu-pukatea/tawa-kamahi/mahoe) on lower slopes and in gullies
- Shrubland (tutu-karamu-koromiko-wharariki-tuhara-*Poa anceps*) on bluffs

*Inland secondary*
- Semi-coastal scrub (manuka-mingimingi) on upper slopes and ridges
- Semi-coastal short forest (mahoe) on midslopes
- Shrubland (tuhara, kiokio, toetoe, parataniwha) on cuttings and slip faces
- Small-leaved scrub (manuka) on hillslopes
- Short broadleaved forest (rewarewa/kamahi) on hillslopes
- Tall broadleaved forest (kamahi-mangeao) on hillslopes
- Short conifer forest (rewarewa/tanekaha) on ridges

### 6.3.6 Egmont sector

**Andesitic tephra**

*Artificial*

- Broadleaved shrubland→short forest (karaka-titoki-puriri-ngaio-akeake-whau-tarata-kanuka-Chatham Island akeake-houhere-houpara-broadleaf-tree lucerne) on rolling country

*Secondary*

- Short broadleaved forest (mamaku-mahoe) on hillslopes
- Tall broadleaved forest (rewarewa/karaka/mahoe/kawakawa) on hillslopes

**Alluvium**

*Primary*

- Tall broadleaved forest (rewarewa/karaka-kowhai/kawakawa) on river flats
- Fertile swamp (raupo) on poorly drained flats
- Sandstone

*Primary*

- Broadleaved forest (rewarewa-pukatea/tawa-kohekohe/kawakawa) on steep faces

## 6.4 Noteworthy Species Occurrences

**Geographic (southern) limits**

| | |
|---|---|
| neinei (*Dracophyllum latifolum*) | near Mt Messenger Scenic Reserve |
| *Gahnia lacera* | Mimi Scenic Reserve |
| napuka (*Hebe speciosa*) | near Pukearuhe Scenic Reserve |
| mangeao (*Litsea calicaris*) | Uruti Scenic Reserve |
| *Lycopodium deuterodensum* | Uruti Scenic Reserve |
| Crimson rata (*Metrosideros carminea*) | Onaero River Scenic Reserve |
| *Olearia albida* | Kawau Pa Historic Reserve |
| karo (*Pittosporum crassifolium*) | Urenui Scenic Reserve |

**Local endemics**

| | |
|---|---|
| *Corybas papa* | Mt Messenger Conservation Area and road reserve |

**Nationally or regionally threatened and local species**

| | |
|---|---|
| king fern (*Marrattia salicina*) | Tongaporutu valley |
| tainui (*Pomaderris apetala*) | Tainui Scenic Reserve |

# 7 SYNTHESIS AND DISCUSSION OF RESULTS

## 7.1 Uses of the Information Presented in this Report

### 7.1.1 Methodologies for biodiversity assessment

The methodology developed in this report can be used to characterize the biodiversity of any highway. The probability sampling design was stratified by land cover (Table 2) and sampled plots along the entire highway (Figure 3). Our results demonstrate the utility of a blend of rigorous probability sampling methods and descriptive approaches, using protected natural area surveys, for biodiversity assessment.

### 7.1.2 Environments of road sectors

The road sectors, defined by environmental domains analysis, provide an important spatial framework for understanding the biodiversity assets and liabilities of the road reserve. The sectors were defined as regions of similar environment (climate, landform, geology) using environmental domains analysis (Figure 2). The measured biodiversity attributes in the road reserve show a wide variation between these sectors. (Table 2, and Figures 6, 7 and 8)

### 7.1.3 Factors influencing the biodiversity of the road reserve

The information in this report provides insights to the factors that influence the biodiversity assets and liabilities of the road reserve. Both the area and the amount of native cover contained in the road reserve are higher when the road passes through native forest (Figure 5) making the road reserve a more important biodiversity asset in areas of indigenous forest. Paradoxically, the road reserve is also a greater potential liability in native forest, since it harbors many more adventive species than does the surrounding forest (Figure 9), and can act as a source and corridor for weeds. In contrast, the road reserve in pastoral areas is generally narrow and has little native vegetation, though this may represent the only indigenous cover in the area. However, these sites have a reasonable potential increase in native cover (Figure 8). This benefit however may be restricted by the width of the reserve.

### 7.1.4 A catalogue of the biodiversity assets along State Highway 3

Information on the biodiversity assets of the road reserve of State Highway 3 is available in the form of general estimates for the highway or highway sectors (Table 3), and in the form of locations of particular fragments that are of particular value (Appendix 3, Figure 10). This information could be used for resource consent applications, or to avoid damaging important fragments during road maintenance. The GIS database containing the locations of these fragments is available for public use, research or teaching.

### 7.1.5 Restoration and enhancement

All the information in this report is ultimately useful in managing the road reserve to increase the biodiversity benefits and mitigate the adverse effects of the road reserve/road management. Improving the benefits of the road reserve includes increasing the amount of native species and enhancing the value of the road reserve as a corridor for bird dispersed/more mobile native species. Mitigating the adverse impacts involves making the road reserve less of a weed source and reducing its potential to act as a corridor for adventive weeds. To these ends, Section 8 provides specific recommendations for protecting and enhancing the road reserve.

### 7.1.6 Changing highway policy and practice

The information in this report serves as the basis to begin changing the way in which highways are managed the better to integrate highway management with biodiversity conservation. At the highest management levels, policy can be changed to protect the biodiversity values of the road reserve that are identified here and also to mitigate the negative influence of roads and their management on surrounding areas. The information in all sections, especially Section 8, can be used to create specific guidelines and policies for the roading authorities and agencies responsible for managing the highways.

## 7.2 A Rigorous Method for Biodiversity Assessment

The combining of probability sampling techniques with PNAP survey techniques provides a robust method for assessing biodiversity. The probability sampling provided quantitative, objective measures of biodiversity attributes. This allows the influence of surrounding land cover on these biodersity attributes to be investigated (Figure 5). Alternatively, these attributes could be estimated for each sector (Table 2), or predicted for the entire highway (Figures 6, 7, and 8). There is wide application of these methods beyond biodiversity analyses (Section 9; Future Directions).

## 7.3 Factors Influencing the Biodiversity Attributes of the Highway

The six road sectors differ greatly in the biodiversity attributes of their road reserves (Table 2). The human use of land is determined to a large extent by the same factors that we used to identify the sectors – climate, geology and landform. Many of the differences in biodiversity attributes of the road reserve can be attributed to the different land uses in the regions they traverse.

Land use (measured in our study by land cover) has a strong effect on the biodiversity values of the road reserve (Figure 5). The road reserve is narrower and supports less native vegetation when the road passes through areas of high human use (pastoral, urban or industrial areas) than when it passes through natural areas. Thus the road reserve has much lower biodiversity indices in lowland areas such as the Hamilton and Waipa sectors (Table 2) than in the Awakino Gorge. Overall, there are dramatic differences along the highway in the biodiversity value of the road reserve (Figure 7).

The situation is somewhat less clearcut when one considers the potential increase in native cover from fully restoring the road reserve to 100% native vegetation (biodiversity index Potincr). The differences between sectors in the potential increase in native cover are much smaller than the differences in the linear density of native cover, seen both in Table 2 and in the prediction of potential increase in native cover along the highway (Figure 8). This is because, while the road reserve is quite narrow in lowland pastoral areas, it also has very little native cover initially, and thus benefits more from restoration. Furthermore, lowland pastoral areas are often those in which natural ecosystems are poorly protected in the reserve network, making the restorations of the road reserve more valuable.

Somewhat paradoxically, the road reserve also appears to be more of a liability when the road passes through native forest. Compared with the surrounding forest, the road reserve has lower values than all the native biodiversity indices (Figure 9). When the road passes through pasture, however, the road reserve is slightly higher (but not significantly) than the nearby pasture. This means that the presence of the road reserve decreases biodiversity in native forest. The road reserve also has the potential to act as a reservoir or a corridor for weeds, with its increased proportions of adventive species. This leads to the situation that while the road reserve is more valuable in forest, since it is wider and contains more native species than the pastoral areas, it is also more of a liability, since it acts as a refuge from which adventive species can colonise areas of native vegetation.

## 7.4 Significant Fragments along the Highway

The results of the PNA survey are in close agreement with the predictions of the probability sampling about where the biodiversity assets of the road reserve are highest. Those sectors that exhibited the lowest biodiversity values in the road reserve and adjoining areas were also those in which few natural areas remained (e.g., Hamilton, Waipa), while those that had high biodiversity were those that still retain a significant amount of native vegetation (e.g., Awakino Gorge, North Taranaki).

Ecological Districts PNA surveys have only been carried out for two of the regions surrounding our six environmental sectors of the highway, so ecological districts cannot be used as a context within which to rank natural areas in or adjacent to the road reserve. In some sectors (e.g., Waipa, Egmont), so few natural areas remain that all extant areas are 'significant' while in others, only single examples of particular vegetation/landform combinations remain in most instances. A selection of the most 'significant' natural areas inventoried in the PNA survey are listed below.

***Hamilton sector***

- No significant natural areas remain in the road reserve.

***Waipa sector***

- No significant natural areas remain in the road reserve.

***King Country sector***

- The roadside slope on mudstone on the southern side of the highway immediately south of the Totoro Rd intersection supports dense stands of young totara forest in a matrix of manuka scrub, the only such totara stand in the segment (site 68).

- Paemako and Mangaotaki Scenic Reserves are the most important natural areas remaining beside the road reserve in this sector, and so those sections of the road reserve contiguous with them are also significant natural areas (sites 71, 72 and 76).

*Awakino Gorge sector*

- Remnants of pukatea-dominant forest on alluvium in the Awakino Gorge, some of which are in the road reserve, retain a high level of significance despite degradation by grazing.

- A mudstone road cutting on the northern side of the highway above the Awakino River supports an assemblage of species characteristic of such sites, e.g., the shrubs totorowhiti and *Olearia townsonii* (site 63).

- All sections of the road reserve bordering forested hillslopes in the Awakino Gorge, most of which are in the large Arorangi Scenic Reserve, are significant (sites 54–62).

*North Taranaki sector*

- Road cuttings in rhyolitic tephra overlying windblown sand between Awakino and Mokau supporting predominantly native communities are all significant (sites 46, 48, 49, 50). Similar cuttings in andesitic tephra overlying windblown sand with comparable communities between Mokau and Tongaporutu (sites 40, 42, and 45) are similarly significant.

- Tongaporutu Conservation Area and Pou Tehia Historic Reserve contain important stands of primary coastal forest, and sections of the road reserve bordering them are significant (site 35).

A stand of secondary riparian forest in the road reserve beside the Tongaporutu River (site 33) is significant.

The wide forested road reserve bordering SH3, mostly on sandstone, on Mt Messenger and further north in the lower Tongaporutu Valley provides a valuable buffer for Mount Messenger Conservation Area, Mount Messenger Scenic Reserve, and forest in freehold tenure as well, and is of high significance (sites 22-32). Road cuttings in this area support distinctive vegetation, including kiokio fernland, and communities of small herbs. A stand of kahikatea forest with swamp maire on a poorly drained terrace, at the southern end of Mt Messenger, is particularly important (site 26).

Road cuttings in the Mimi Valley, predominantly in mudstone, contain a range of communities and are significant (sites 14–20).

*Egmont sector*

Onaero River Scenic Reserve contains the most significant natural area adjacent to the road reserve in this sector, and so those sections of the road reserve which are contiguous with them are also significant natural areas (site 8).

## 7.5 The Road Reserve: Good or Bad for Biodiversity?

The answer as to whether the road reserve is a biodiversity asset or liability is – it depends. The biodiversity value of the road reserve depends upon the type of land use through which it passes, and the way in which the road reserve is managed.

The road reserve represents a sizeable amount of public land that can contribute to the overall natural reserve network in an area. However, the road reserve differs in two important aspects from other reserve components. First, the primary use of the road reserve is as a transport corridor. Thus, the management of the road reserve for traffic and safety issues is of primary importance, with scenic and native biodiversity concerns of secondary importance. Secondly, the road reserve has a unique spatial pattern: it is a very narrow, but very long reserve. Also, it is grazed in places.

The linear arrangement of the road reserves means they have the potential to act as corridors for species movement. The role of corridors in species management is often debated, but proponents suggest that corridors that allow the movement of plant propagules or animals between natural reserves increase the effective size of the reserves and allow species to redistribute themselves with shifting climate. Corridors might be beneficial, if they allow native species to move between reserves, or detrimental, if they provide for the spread of weeds into agricultural lands or indigenous vegetation.

The potential for road reserves to act as beneficial corridors for the movement of native species is at present limited for two reasons. First, for the greater part of its length, the road passes through human settlements and pastoral land, rather than native forest. This reduces the number of natural reserves connected by the highway (Figure 10). Second, our results indicate that roads running through pastoral areas are not dramatically different from the pastures themselves (Figure 9), thus they present limited habitat for native species (i.e., the vascular plant component of biodiversity). Both these effects limit the present usefulness of road reserves as corridors for native species. However, this does not preclude the possibility of improving this potential biodiversity asset of the road reserve. While the position of the highway is unlikely to change, it is possible to increase the amount of native species in the road reserve, thus improving the potential as a corridor.

The potential for the road reserve to act as an undesirable corridor for the movement of weeds into natural areas is much higher. Road reserves penetrate and bisect natural areas. Road reserves in indigenous forest have much lower proportions of native species (and thus higher amounts of adventive species) than do the surrounding native vegetation (Figure 9) reflecting the disturbance associated with roading activities. This indicates that they may act as both a weed source for surrounding forest and also a corridor for the intrusion and spread of weeds across long distances. Furthermore, roads through native vegetation divide the area and present barriers for dispersal between the two halves (Figure 10).

The role of roads in the spread of agricultural weeds is probably of even greater importance. The same reasons that make the road reserves of limited usefulness as corridors for native species make them ideal for the spread of pastoral or horticultural weeds. Native vegetation often presents a barrier for the spread of these weeds, since they cannot grow in closed forest environments. By their intrinsic design, road networks connect areas of human influence, i.e. pasture and horticulture. Our results show that road reserves contain a significant amount of adventive species, even when they pass through native forest. Thus, they provide ideal corridors of suitable habitat for the spread of weeds across barriers of native vegetation.

Yet, despite these limitations as corridors for native species, and liabilities as corridors for adventive weeds, the area of the road reserve represents a sizeable and important contribution to the natural reserve network of a region. But the actual area tells only part of the picture. While the narrow configuration means that native communities in or adjacent to the road reserve will suffer from edge effects, it also means that they will extend across large areas. More important, though, road reserves are in important areas. There are many more roads and thus road reserves in lowland areas of high human productivity – and these same areas are very poorly represented in the national system of reserves.

Thus, we conclude that the main biodiversity asset of road reserves is likely to be the actual area of public land that could potentially support native biota. The role of road reserves as corridors should not be neglected, however, and the enhancement of particular sections that connect particular fragments should definitely be considered. Fortunately, the enhancements that improve the value of the area of the road reserve also improve the biodiversity value of the road reserve as a corridor.

## 7.6 Changing Highway Policy

For biodiversity conservation to be effectively integrated with highway management, highway management policy and practice needs to be changed at all management levels. Transfund policy should be changed to reflect both the importance that has been placed on biodiversity at the national level and the importance of road reserves in maintaining and enhancing national biodiversity. For instance, Appendix A8 of the Transfund Highway policy "bible" could be amended so that roading authorities would be required to enhance and protect native biodiversity whenever consistent with transport and safety. Furthermore, Transfund should require that roading authorities provide them with reports that describe the status and health of roadside biodiversity in the road reserves in their area and how they are managing the road reserves to protect and enhance biodiversity. At middle management levels, road controlling authorities need to be involved by more specific guidelines. For state highways, Transit NZ needs a best-practice guide that would serve as policy both within Transit NZ and also for maintenance contractors. Maintenance and construction contractors would need to be informed of how to conserve native biodiversity and mandated to do so.

# 8 RESTORATION AND ENHANCEMENT PLAN

## 8.1 Opportunities for Restoration/Enhancement

While the primary concern of managing the road reserve is transport efficiency and safety, many things can be done to enhance its value for the conservation of indigenous biodiversity. Management of the road reserve to increase its contribution to regional and national native biodiversity consists of both improving the sections of the highway reserve with low biodiversity value (restoration), and protecting and improving those that already have high value (enhancement). The information in this report can be used for both purposes; the probability samples give information on important factors influencing the road reserve and identify the environmental sectors with highest value, while the PNAP survey identifies and locates specific natural areas worthy of protection or improvement.

In terms of the biodiversity and conservation resources of SH3, a number of scenarios present opportunities for ecological restoration/enhancement. The first is in areas of higher native biodiversity, e.g., Mt Messenger and the Awakino Gorge, where significant proportions of the landscape still maintain native vegetation cover. In these areas the opportunities lie in maintaining integrity and connectivity between surrounding natural areas. This includes establishing native cover on new cuttings created by re-alignment and road widening, and slip faces. In these situations the genetic integrity of the plants used is of considerable importance, to prevent pollution of the gene pool. In all cases, stock or seeds should be "eco-sourced" from plants in the particular Ecological Region, or preferably from within the Ecological District.

Another possibility for enhancement lies in those areas where the original vegetation has been largely removed and what is left is highly fragmented, e.g., along much of the Hamilton and Waipa sectors (Figure 11). In these situations the road reserve can act as a refuge for native species and a corridor/link between widely dispersed fragments. Planting of native species, as has been done between Waitara and New Plymouth in the Egmont sector, would greatly enhance the biodiversity values of the road reserve and enhance its aesthetic and conservation values. Eco-sourcing is also relevant in these situations.

Long stretches of SH3 (e.g., the King Country and much of North Taranaki) fall into an intermediate category, with a number of small but significant remnants of the original vegetation still remaining. In these areas, links and maintaining genetic integrity are both issues.

Amenity plantings around lookouts and rest areas also offer potential for restoration and enhancement, if the species are chosen carefully to reflect the original vegetation of the area, and the plants sourced locally ("eco-sourced").

## 8.2 Appropriate Techniques

The choice of restoration technique employed at a particular site will depend on environmental and ecological factors including topography, soil type, climate, degree of disturbance (e.g., a newly cleared site *vs* an older grassed area), and extent of original vegetation in the immediate area/landscape, in addition to the resources available. Each site will have an optimum mix of techniques.

***Assisting native regeneration***

This technique is appropriate in small, moist (south-facing or moderate to high rainfall) areas where there is ample supply of appropriate indigenous seed (e.g., colonising/early seral species) nearby (e.g., in the Awakino Gorge or on Mt Messenger) and grazing animal pests (e.g., goats) are controlled (Porteous 1993, Simcock & Ross 1995). It initially involves selective herbiciding/clearance of weeds from the site, followed by selective weeding/spraying around the native plants that have established c. 1 year later (depending on the rate of weed growth and the size of the established plants). Regeneration can be enhanced by creating a rough surface (i.e. by discing or ripping of the site) and spreading salvageable forest material (collected before construction) e.g., logs, branches, and stumps (Simcock & Ross 1995).

***Brush laying (fascining)***

This technique involves laying tree branches with ripe seed, most often manuka in New Zealand, onto a prepared site (i.e., herbicided, ripped, etc.) The branches and dried leaves that fall from them form an ideal microclimate for seed germination and seedling growth, provided the brush is applied thinly enough to allow sufficient light to penetrate for seed germination and seedling growth. It is appropriate for a range of sites, with availability of manuka shrubs the main limiting factor. Branches on steeper or windier sites may require pegging down.

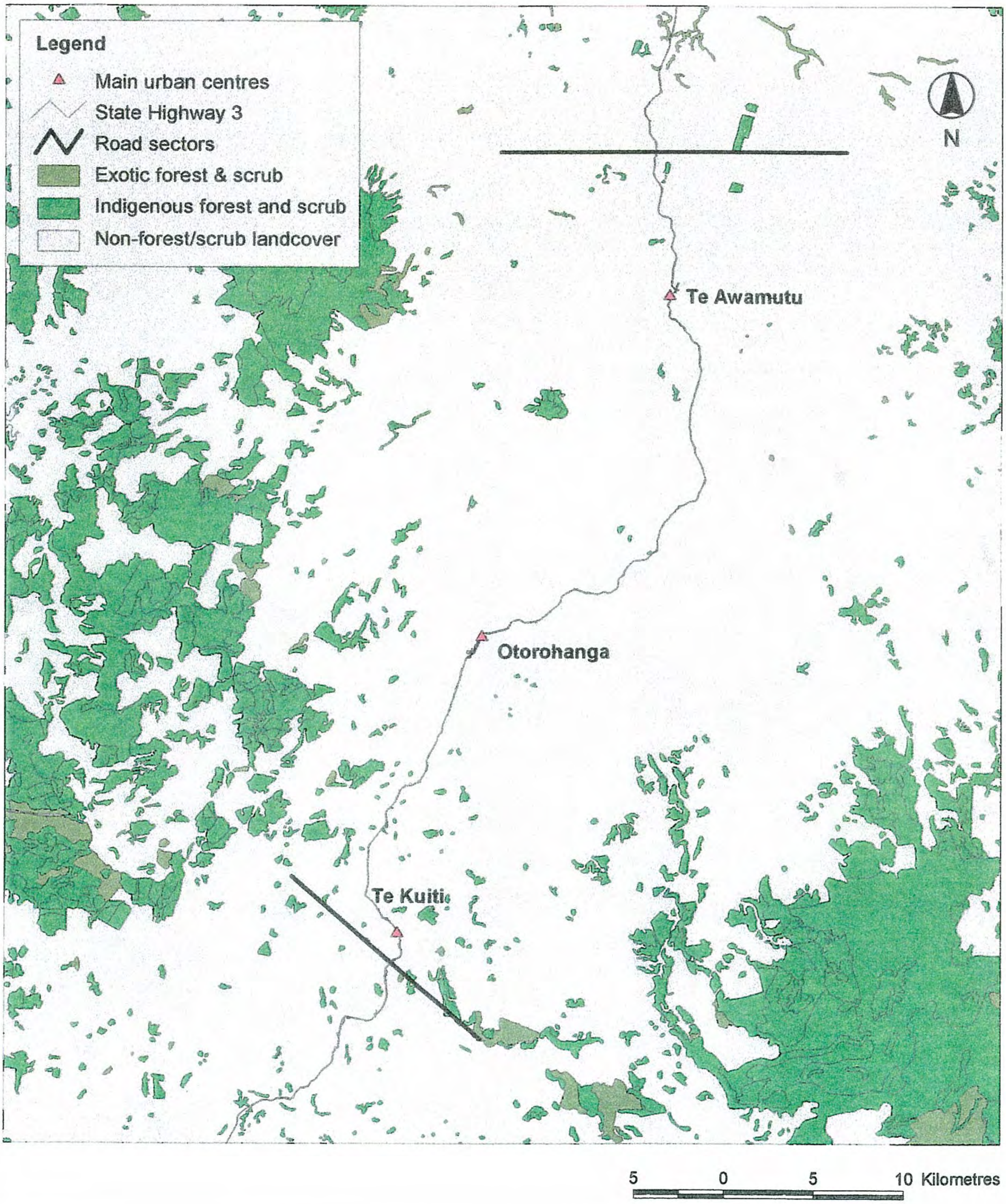
***Direct seeding***

This technique involves the broadcasting or placing of seed directly onto a prepared site. The most critical factors that determine its success are the elimination of competing plants (especially grasses, e.g., kikuyu, via spraying with a knockdown herbicide) and the maintenance of a microclimate suitable for seed germination and seedling growth. A suitable microclimate can be created by rotary hoeing, ripping, discing or ploughing (see below). Large quantities of seed are required, as a number may fall into unsuitable sites or be damaged/eaten by insects, birds or rodents (Porteous 1993). It is appropriate on sites with a gentler contour, or in steeper areas that have been terraced.

***Hydroseeding of native species***

Hydroseeding is the application of a water-based slurry containing seeds/spores and adhesive (e.g., PVC or latex) with a protective mulch of peat, wood fibre, newspaper, or straw (Simcock & Ross 1995). It is appropriate for steep faces and cuttings, sites where exotic grasses have traditionally been used. There is huge potential for the use of native species in these sites, with appropriate species including kiokio ( fern that is widespread on roadside banks), *Poa anceps* (a native grass also common on banks), toetoe (that naturally colonises disturbed sites like roadsides), and tutu (a nitrogen-fixing shrub also common on disturbed sites). Several factors are critical to the success of native hydroseeding, including the exclusion of fertilisers and legumes that enrich the site and encouraging weed growth. Hydroseeding of exotic grasses may be appropriate in some sites to stabilise the soil initially and allow germination of native spores/seeds.

## Figure 11.
## State Highway 3 Waipa sector - natural areas



Seeding, either directly or via hydroseeding, has the advantage of creating plant populations with random spatial and age distribution, as occurs in the 'real world'.

***Planting***

This is the most common technique used in restoring native ecosystems. In road reserve management, planting is particularly appropriate in areas isolated from native vegetation (e.g., Hamilton and Waipa sectors), on exposed sites where natural regeneration is unlikely or very slow, or in high visibility areas where rapid establishment of native cover is desired. Plants can be either bare-rooted, in root-trainers, or potted. Root-trainers and bare-root transplants are cheaper to produce and transplant than potted plants. Also, root trainers usually have a higher root:shoot ratio which favours establishment (Simcock & Ross 1995).

Many sites require the establishment of a nurse crop: fast growing and hardy species that provide initial cover, e.g., manuka, kanuka, koromiko, tauhinu, taupata, and wineberry. These plants can then be thinned and interplanted with primary forest species that are more shade-tolerant and require greater environmental protection than nurse species.

The best time to plant is usually late autumn→winter, when rainfall is more reliable and plant growth has slowed. Plants in milder climates can establish a root system over the winter, and so are better able to cope with dry spells during the following summer.

Weeds should be removed before planting, with residual herbicide application or pre-emergent granules also desirable. Placement of fertiliser in the planting hole or in a slit beside the plant, rather than broadcasting, will maximise its benefit to the plant, and mean weed regrowth is not encouraged by increased soil fertility.

***Forest translocation***

This method involves removing existing seedlings and stumps from the area to be modified, and transplanting them back onto the site after construction. This is particularly applicable in situations where forest is going to be destroyed in road construction. Most seedlings transplant well if done carefully. Lifting and transplanting is best done in winter, with wrenching of larger plants desirable in autumn when there is little root activity. Seedlings and trees should be transplanted into fertilised, shaded beds and pots and left to grow (Porteous 1993). Failure rates with transplanted plants is quite high, so supplementary seeding may be needed.

### 8.2.1 Other considerations

***Site preparation*** – ripping, contouring, terracing, replacing topsoil

Site preparation is perhaps the most important component of restoring a site. Inadequate site preparation can mean increased maintenance and post-planting costs, for example, through supplementary planting, more frequent weed control, and fertilisation to compensate for slower growth (Simcock & Ross 1995). Where possible topsoil should be conserved, stockpiled, and replaced, including any leaf litter. It is a valuable source of mycorrhizal inoculates, invertebrates, organic carbon and nutrients that will 'kickstart' nutrient cycling (Simcock & Ross 1995).

Soil compaction can be mitigated and a varied microtopography created through ripping, scarifying, and/or the application of debris and leaf litter (i.e. salvaged stumps, logs, and branches removed during construction), enhancing the site for natural regeneration or direct seeding.

Coppicing of trees 1–2 years before construction should be used where road re-alignments cut back into forests, to reduce dieback from sudden exposure of canopy trees and understorey plants along the new margin.

***Weed control***

Weed control before direct seeding, hydroseeding, or planting is needed in most areas, especially where there are dense swards of adventive grasses (e.g., kikuyu) and dicot weeds. Herbicides are quick and efficient, especially in preparing large areas. Adding a residual herbicide to the herbicide mix or broadcasting pre-emergent granules after herbiciding prevents the establishment of new weeds for several months, reducing the amount of follow-up labour required. Follow-up control (after 2–5 years) is needed in some sites, especially where aggressive weeds are present.

***Mulching***

Mulching can greatly increase the survival rate of plantings, especially on dry or open sites. It involves spreading loose, readily permeable material (such as straw, bark or sawdust) around plants to protect their roots and trap moisture. Mulching of problem weed trees in the vicinity of the site to be planted, e.g. Chinese privet or brush wattle, provides a novel and cheap alternative.

## 8.3 Appropriate Species for Revegetation/Enhancement Planting in Each of the Six Sectors ($^{(N)}$ nurse plant)

**Hamilton sector**

- *Alluvium* – kahikatea, harakeke

**Waipa sector**

- *Sandstone* – manuka$^{(N)}$, mahoe$^{(N)}$
- *Alluvium* – tarata$^{(N)}$, kohuhu$^{(N)}$, kahikatea, pukatea, titoki, pokaka, mahoe

**King Country sector**

- *Alluvium* – tarata$^{(N)}$, kohuhu$^{(N)}$, harakeke, kahikatea, titoki
- *Mudstone* – manuka$^{(N)}$, koromiko$^{(N)}$, karamu$^{(N)}$, mahoe, lacebark, totara, kahikatea, rewarewa, pukatea
- *Sandstone* – manuka$^{(N)}$
- *Greywacke* – kanuka$^{(N)}$, *Pittosporum colensoi*$^{(N)}$, kahikatea, totara, matai, rewarewa, pukatea, titoki, mahoe
- *Limestone* – manuka$^{(N)}$, lacebark, mahoe, titoki, pukatea, rewarewa, hinau, *Poa anceps*
- *Rhyolitic tephra* – manuka$^{(N)}$, koromiko$^{(N)}$, lacebark, matai, totara, kahikatea, rewarewa

**Awakino Gorge sector**

- *Alluvium* – alluvial terraces above and beside the Awakino River – pukatea, lacebark, ramarama, pigeonwood, titoki, kahikatea
- *Mudstone* – cuttings and lower slopes – manuka(N), karamu(N), koromiko(N), *Pittosporum colensoi*(N)
- *Sandstone* – manuka(N), *Olearia townsonii*(N), karamu(N), kohuhu(N), wharariki(N), *Poa anceps*, rewarewa, pukatea, hinau, titoki, mahoe
- *Greywacke* – tutu(N), rangiora, titoki, mahoe
- *Limestone* – wharariki(N), kiokio, tuhara, *Poa anceps*

**North Taranaki Sector**

- *Andesitic tephra* – inland – rewarewa, mahoe
  – coastal – karamu(N), tauhinu(N), harakeke(N), karaka
- *Rhyolitic tephra* – manuka(N), karamu(N), tauhinu(N), coastal koromiko(N), mahoe
- *Alluvium* – wineberry(N), lacebark, pukatea, kowhai, rewarewa, titoki, mahoe, ramarama
- *Windblown sand* – pohutukawa(N), coastal koromiko(N), karamu(N), harakeke(N), taupata(N), tauhinu(N), toetoe, *Poa anceps*
- *Mudstone* – manuka(N), tutu(N), rewarewa, mahoe
- *Sandstone* – inland – manuka(N), karamu(N), *Pittosporum colensoi*(N), *Olearia townsonii*(N), wharariki(N), kiokio, tuhara, *Poa anceps*, rewarewa, pukatea, mahoe, hinau, pigeonwood
  – coastal – manuka(N), karaka, titoki, mahoe, kowhai, kohekohe, puriri

**Egmont Sector**

- *Andesitic tephra* – ngaio(N), puka(N), rewarewa, titoki, puriri, mahoe, kohekohe, karaka
- *Alluvium* – harakeke, rewarewa, karaka, pukatea, kowhai
- *Sandstone* – rewarewa, karaka, pukatea

## 8.4 Changes to Management Practices

A number of road management and works practices are not conducive to maintaining the native biodiversity of the road reserve in perpetuity. For example, one practice threatening the long-term viability of some natural areas that abut or lie in the road reserve is the disposal of slip debris, e.g. on Mt Messenger and in the Awakino Gorge. During the survey many sites were noted where slip debris had been pushed over the opposite bank. In some areas individual trees had been killed by the dumped spoil, while in others whole tracts of forest or shrubland had been killed by complete burial. Where possible, in areas of high conservation value, slip debris should be removed and dumped offsite (*see below*).

Natural areas have also been and are being adversely affected by the offsite dumping of material produced either by slips, re-alignments or widening of existing roads. An example of this is at the southern end of Mt Messenger, where dumping has destroyed part of a rare stand of kahikatea/swamp maire forest. Wetlands along SH3 have also been lost due to infilling during road widening and re-alignment.

A number of actions could also be carried out before any major road works are undertaken, in areas of higher biodiversity value, that would enhance and protect those values while not significantly adding to the cost of construction. For example, in areas where removal of indigenous forest is required, coppicing of the trees that will become the new forest edge would reduce dieback along that edge and in the understorey.

If restoration of a site is intended, following road works, then topsoil and plant debris from the site could be removed, stored, and re-applied following construction. This would enhance natural regeneration, the success of direct seeding, and/or the survival of planted individuals. Topsoil contains native propagules, micro-organisms, and mycorrhizal fungi that all help – and in the case of mycorrhizal fungi may be vital to – successful restoration of a site. This practice has the added benefit of reducing the amount of material that needs to be dumped offsite.

Hydroseeding with a mix of native and adventive species, instead of the solely exotic mixes currently used on bare areas following road works, would also be beneficial. The adventive grasses would provide initial cover, while the natives grasses or shrubs became established. Natural regeneration of native species from surrounding areas could then occur, or interplanting of natives could be carried out.

Changes could also be made to regular road management, that would enhance the biodiversity values of the road reserve, for example, changing the angle of flail mowing along berms, from following the contours to mowing vertically or on a slight angle. In areas with some indigenous woody or fern cover, this would create denser, copiced vegetation, that could reduce the invasion of weed species.

Many of these changes would not mean increases in the cost of works or maintenance, and could actually provide cost savings in the long term, e.g., by reducing the cost of disposing of material, speeding up rehabilitation/restoration of sites, and decreasing the erosion of cuttings/road works.

## 9 FUTURE DIRECTIONS

The methods developed here have wide applications beyond the characterization of biodiversity along a road reserve segment. The probability sampling techniques used can be applied to a wide variety of important road attributes such as production of pollutants, traffic safety, highway use, and highway maintenance. This could be accomplished by a similar method as was employed in this project, but with the different attributes measured at the sample locations. For instance, if done for traffic use, then traffic counters could be placed along highways at randomly chosen locations. Traffic use could then be related to important factors such as the time of day, day of the week, the size and type of road, and the distance to major urban centres. Applying the methods used in this report, estimates of traffic use could be made for the entire highway, or for particular segments. From these, estimates of pollution or noise production or intervals between maintenance might be made.

These methods can also be applied to entire road networks, rather than simply to road segments. While entirely feasible, this would entail considerable work to generalize the methods from segments to networks. Again, this could be done either for biodiversity or for other road attributes. A fundamental requirement for work on a road network would be the development of a basic road network "skeleton" that would consist of a digital copy of the road network and its cadastral boundaries, and basic information about segments of each road in the network. The basic information could include such information as the type of road (e.g., main highway versus secondary road), the surface type (seal vs metal), or the distance to major urban centres. This could be combined with environmental information about the road, such as the climate, underlying geology, or surrounding land cover. A simple representation of how this might look is given for the Waikato region in Figure 12. Then attributes of the road could be overlaid onto this skeleton, using methods similar to those used for road segments. This digital network skeleton would also serve as a very useful way to organize information about the road, that might be collected by such diverse groups as road contractors, Transit NZ, regional or city councils, or the Department of Conservation.

This research also uncovered some intriguing results that bear further investigation. In particular, there is the paradoxical result that where the road reserve is the greatest biodiversity asset, it is also the greatest biodivesity liability. In the stretch of highway investigated, road reserves surrounded by indigenous forest are wider and have more native species than road reserves in pasture, leading reserves in forest to be larger biodiversity assets (Figure 5). However, road reserves in indigenous forest also have many more exotic species than the surrounding land cover compared with road reserves in pasture (Figure 9), making them greater biodiversity liabilities. Clearly, the role of road reserves in forests as assets (potential public land for conservation) and as liabilities (sources and corridors for weeds and fragmenting natural reserves) requires further research.

Other areas that also warrant further investigation/research include: a review of current maintenance and road construction practices in regard to their impact on biodiversity and native ecosystems; research into hydroseeding techniques using native species, for stabilisation and encouragement of the development of native dominated communities;

and factors affecting or influencing successful amenity plantings in road reserves and around rest areas, especially in regard to composition and width.

Finally, the information and understanding developed in these projects needs to be translated into new policies that protect and enhance roadside biodiversity. Thus policy changes need to be made at all management levels (Transfund NZ, Transit NZ, other roading authorities) to reflect the importance of roads and road reserves on national and regional biodiversity.

The road reserve may be a liability in that it has reduced biodiversity value in the surrounding forests and can act as corridors for the spread of weeds into agricultural areas or indigenous forests. Effective integration of biodiversity conservation and road management can increase these assets and reduce these liabilities. This can be achieved by changing policy at all levels by increasing awareness of the biodiversity value of road reserves, and by providing specific guidelines for the management and protection of roadside biodiversity.

## ACKNOWLEDGMENTS

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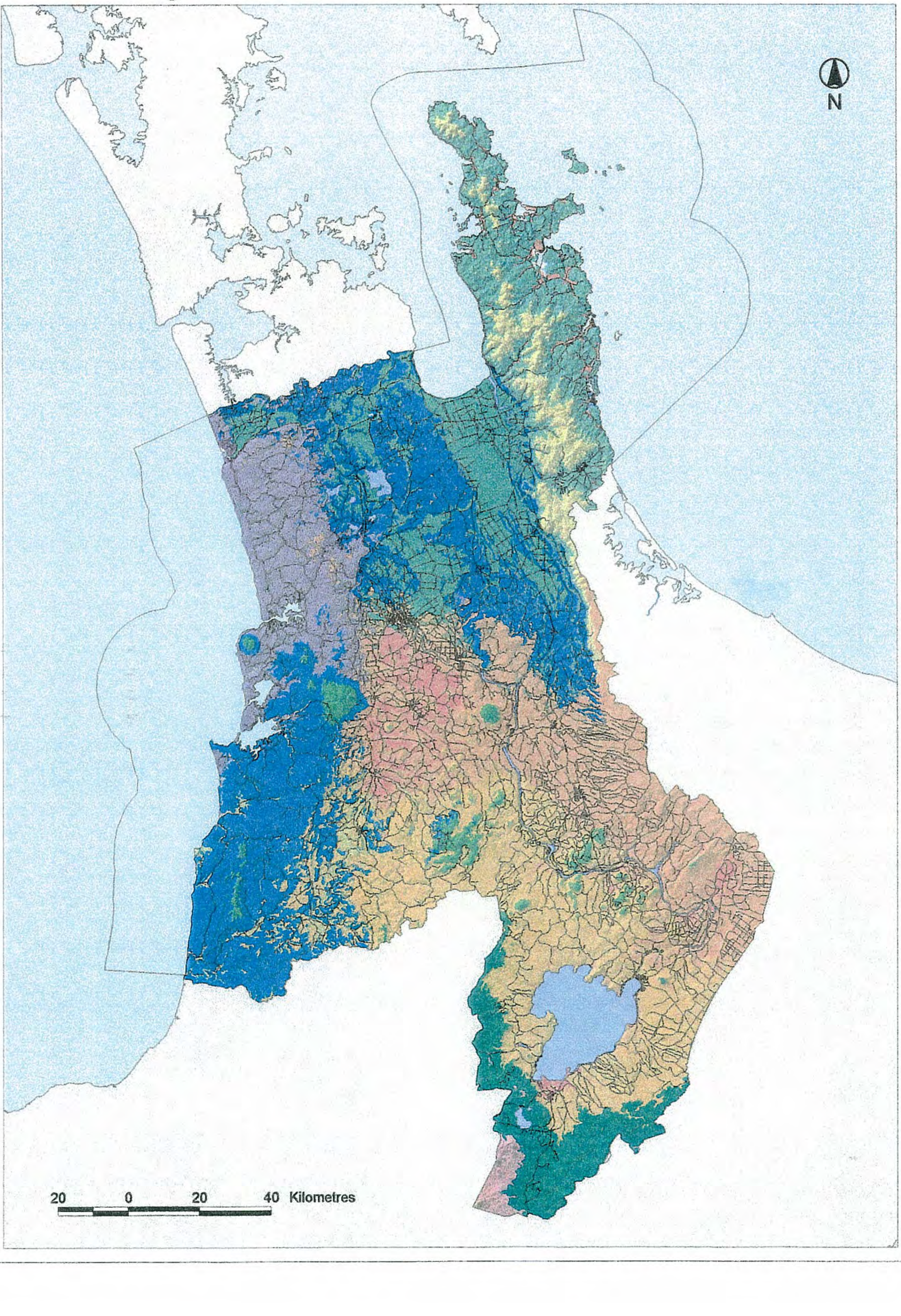
**Figure 12. The road network overlaid on 20 environmental domains of the Waikato region**



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## Appendix 1 Vascular plant species recorded during the SH3 road segment and PNAP surveys

This list includes native and adventive plant species recorded within the road reserve, in the sampled plots and during the PNAP survey, and those encountered in the paired plots. Scientific and common names for adventive species are taken from Webb *et al.* (1988), wetland plants from Johnson & Brooke (1989), trees and shrubs from Poole & Adams (1990), and grasses from Lambrechtsen (1992).

* adventive species, agg. aggregate p planted, not naturally occurring
sp. species (singular), ssp. subspecies, var. variety, x hybrid

| Scientific name | Common name |
|---|---|
| **Ferns and fern allies** | |
| *Adiantum cunninghamii* | common maidenhair |
| *Asplenium bulbiferum* | hen and chicken fern |
| *A. flaccidum* | hanging spleenwort |
| *A. oblongifolium* | shining spleenwort |
| *A. polyodon* | sickle spleenwort |
| *Blechnum chambersii* | |
| *B. discolor* | crown fern |
| *B. filiforme* | thread fern |
| *B. fluviatile* | kiwikiwi |
| *B. novaezelandiae* | kiokio |
| *Cyathea cunninghamii* | gully tree fern |
| *C. dealbata* | silverfern |
| *C. medullaris* | mamaku |
| *C. smithii* | soft treefern |
| **Cyrtomium falcatum* | holly fern |
| *Deparia petersenii* | |
| *Dicksonia fibrosa* | wheki-ponga |
| *D. squarrosa* | wheki |
| *Histiopteris incisa* | water fern |
| *Hymenophyllum rarum* | filmy fern |
| *H. sanguinolentum* | filmy fern |
| *Lastreopsis glabella* | |
| *L. hispida* | |

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|---|---|
| *L. microsora* | |
| *Leptopteris hymenophylloides* | crepe fern |
| *Lycopodium volubile* | climbing clubmoss |
| *Marratia salicina* | king fern |
| *Paesia scaberula* | hard fern |
| *Pellaea rotundifolia* | |
| *Pneumatopteris pennigera* | |
| *Phymatosorus pustulatus* | hound's tongue |
| *P. scandens* | fragrant fern |
| *Polystichum richardii* | |
| *Pteridium esculentum* | bracken |
| *Pteris macilenta* | |
| *P. tremula* | |
| *Pyrrosia eleagnifolia* | |
| **Selaginella kraussiana* | African clubmoss |
| *Tmesipteris elongata* | |
| *T. tannensis* | |
| **Gymnosperms** | |
| **Cupressus lawsoniana* | Lawson's cypress |
| *Dacrycarpus dacrydioides* | kahikatea |
| *Phyllocladus trichomanoides* | tanekaha |
| **Pinus radiata* | radiata pine |
| *Podocarpus hallii* | Hall's totara |
| *P. totara* | totara |
| *Prumnopitys ferruginea* | miro |
| *P. taxifolia* | matai |
| **Dicotyledons** | |
| *Acaena anserinifolia* | |
| *A. novae-zelandiae* | |
| **Achillea millefolium* | yarrow |
| **Agapanthus orientalis* | agapanthus |
| *Alectryon excelsus* | titoki |
| *Alseuosmia macrophylla* | |

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|---|---|
| **Amaranthus powellii* | redroot |
| **Anagallis arvensis* | pimpernel |
| **Aphanes arvensis* | parsley piert |
| *Aristotelia serrata* | wineberry |
| **Aster subulatus* | sea aster |
| *Beilschmiedia tawa* | tawa |
| **Bellis perennis* | daisy |
| **Bidens frondosa* | beggar's ticks |
| *Brachyglottis repanda* | rangiora |
| **Buddleia davidii* | buddleia |
| *Calystegia sepium* | pink-flowered bindweed |
| *C. tuguriorum* | powhiwhi |
| *Cardamine debilis* | |
| **C. hirsuta* | bitter cress |
| *Carpodetus serratus* | putaputaweta |
| *Cassinia leptophylla* | tauhinu |
| **Centaurium erthraea* | centaury |
| *Centella uniflora* | marsh pennywort |
| **Cerastium glomeratum* | mouse-ear chickweed |
| **Cirsium arvense* | Californian thistle |
| **C. vulgare* | Scotch thistle |
| *Clematis foetida* | |
| *C. forsteri* | |
| *C. paniculata* | puawhananga |
| **Conyza albida* | broad-leaved fleabane |
| *Coprosma grandifolia* | raurekau |
| *C. lucida* | |
| *C. repens* | taupata |
| *C. robusta* | karamu |
| *C. rotundifolia* | |
| *C. tenuifolia* | |
| *Coriaria arborea* | tutu |
| *Corynocarpus laevigatus* | karaka |

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|---|---|
| *Corybas trilobus* | |
| *C.* 'papa' | |
| **Corynopus didymus* | twin cress |
| **Cotoneaster glaucophyllus* | cotoneaster |
| **Crataegus monogyna* | hawthorn |
| **Crepis capillaris* | hawksbeard |
| *Crocosmia × crocosmiiflora* | montbretia |
| **Daucus carota* | wild carrot |
| *Dendrobium cunninghamii* | |
| *Dianella nigra* | turutu |
| **Dichondra micrantha* | Mercury Bay weed |
| *D. repens* | Mercury Bay weed |
| **Digitalis purpurea* | foxglove |
| **Disphyma australe* | iceplant |
| *Dodonaea viscosa* | akeake |
| *Dracophyllum strictum* | totorowhiti |
| *Dysoxylum spectabile* | kohekohe |
| *Earina mucronata* | |
| *Elaeocarpus dentatus* | hinau |
| *E. hookerianus* | pokaka |
| *Elatostema rugosum* | parataniwha |
| *Entelea arborescens* | whau |
| *Epilobium pedunculare* | |
| *E. rotundifolium* | |
| **Erigeron karvinskianus* | Mexican daisy |
| *Erodium moschatum* | musky storksbill |
| **Euonymus japonicus* | Japanese spindletree |
| **Euphorbia peplus* | milkweed |
| **Foeniculum vulgare* | fennel |
| *Freycinetia baueriana* ssp. *banksii* | kiekie |
| *Fuchsia excorticata* | tree fuchsia |
| **Fumaria muralis* | scrambling fumitory |

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|---|---|
| **Galium aparine* | cleavers |
| **G. palustre* | marsh bedstraw |
| *Gaultheria paniculata* | |
| *Geniostoma rupestre* | hangehange |
| **Geranium dissectum* | cut-leaved cranesbill |
| **G. molle* | dove's foot cranesbill |
| **G. robertianum* | herb robert |
| **Gnaphalium coarctatum* | purple cudweed |
| *Griselinia littoralis*[P] | broadleaf |
| *G. lucida* | puka |
| *Hebe stricta* var. *stricta* | koromiko |
| *H. stricta* var. *macroura* | coastal koromiko |
| *Hedycarya arborea* | pigeonwood |
| *Haloragis erecta* | |
| *Hoheria populnea*[P] | lacebark |
| *H. sexstylosa* | houhere |
| *Hydrocotyle elongata* | |
| *H. heteromeria* | waxweed |
| *H. microphylla* | hydrocotyle |
| *H. moschata* | hydrocotyle |
| **Hypericum androsaemum* | tutsan |
| **Hypochoeris radicata* | catsear |
| **Ilex aquifolium* | holly |
| *Knightia excelsa* | rewarewa |
| *Kunzea ericoides* var. *ericoides* | kanuka |
| **Lapsana communis* | nipplewort |
| *Laurelia novae-zelandiae* | pukatea |
| **Leontodon taraxacoides* | hawkbit |
| *Leptospermum scoparium* | manuka |
| *Leucopogon fasciculatus* | mingimingi |
| **Leucanthemum vulgare* | oxeye daisy |
| **Leycesteria formosa* | Himalayan honeysuckle |
| **Ligustrum sinense* | Chinese privet |

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|---|---|
| *Linum bienne | pale flax |
| Litsea calicaris | mangeao |
| Lobelia anceps | shore lobelia |
| *Lonicera japonica | Japanese honeysuckle |
| Lophomyrtus bullata | ramarama |
| L. obcordata | |
| *Lotus pedunculatus | lotus |
| *L. suaveolens | hairy birdsfoot trefoil |
| *Ludwigia palustris | |
| *Lythrum hyssopifolia | hyssop loosestrife |
| Macropiper excelsum | kawakawa |
| *Matricaria dioscoidea | rayless chamomile |
| *Medicago lupulina | black medick |
| Melicytus ramiflorus | mahoe |
| *Mentha pulegium | pennyroyal |
| *M. suaveolens | apple mint |
| Metrosideros carminea | crimson rata |
| M. diffusa | |
| M. excelsa | pohutukawa |
| M. fulgens | |
| M. perforata | aka |
| *Modiola caroliniana | creeping mallow |
| Muehlenbeckia australis | pohuehue |
| M. complexa | pohuehue |
| *Mycelis muralis | wall lettuce |
| *Myosotis caespitosa | water forget-me-not |
| Myrsine australis | mapou |
| Nertera depressa | |
| Olearia rani | heketara |
| O. traversii[P] | Chatham Island akeake |
| *Orobanche minor | broomrape |
| *Oxalis corniculata | horned oxalis |
| *Paraserianthes lophantha | brush wattle |

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|---|---|
| *Parsonsia capsularis* | native jasmine |
| *P. heterophylla* | native jasmine |
| **Parentucellia viscosa* | tarweed |
| *Passiflora tetrandra* | kohia |
| *Pennantia corymbosa* | kaikomako |
| **Phytolacca octandra* | inkweed |
| **Picris echioides* | oxtongue |
| *Pittosporum colensoi* | |
| *P. crassifolium* | karo |
| *P. eugenioides* | lemonwood, tarata |
| **Plantago australis* | swamp plantain |
| **P. lanceolata* | narrow-leaved plantain |
| **P. major* | broad-leaved plantain |
| **Polycarpon tetraphyllum* | allseed |
| **Polygonum aviculare* | wireweed |
| **P. hydropiper* | water pepper |
| **P. persicaria* | willow weed |
| *Pomaderris apetala* | tainui |
| **Populus nigra* | lombardy poplar |
| **Potentilla anglica* | creeping cinquefoil |
| *Pratia angulata* | panakeake |
| **Prunus serrulata* | Japanese hill cherry |
| **Prunella vulgaris* | selfheal |
| *Pseudopanax arboreus* | five-finger |
| *P. lessonii* | houpara |
| **Quercus robur* | oak |
| *Quintinia serrata* | tawheowheo |
| *Rhabdothamnus solandri* | |
| **Ranunculus repens* | creeping buttercup |
| **R. sceleratus* | celery-leaved buttercup |
| **Raphanus raphanistrum* ssp. *raphanistrum* | wild raddish |
| *Ripogonum scandens* | supplejack |

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|---|---|
| **Rorippa nasturtium-aquaticum* | watercress |
| *Rubus cissoides* | |
| **R. fruticosus* agg. | blackberry |
| **Rumex acetosella* | sheep's sorrel |
| **R. crispus* | curled dock |
| **R. obtusifolius* | broad-leaved dock |
| **R. sagittatus* | climbing dock |
| **Sagina procumbens* | procumbent pearlwort |
| **Salix fragilis* | crack willow |
| *Schefflera digitata* | pate |
| **Senecio jacobaea* | ragwort |
| *S. rufiglandulosus* | |
| **S. vulgaris* | groundsel |
| **Sheradia arvensis* | field madder |
| **Silene gallica* | catchfly |
| **Sison amomum* | stone parsley |
| *Sizygium maire* | swamp maire |
| *Solanum americanum* | small-flowered nightshade |
| **S. nigrum* | black nightshade |
| **Soliva sessilis* | Onehunga weed |
| **Sonchus asper* | prickly sow thistle |
| **S. oleraceus* | sow thistle |
| *Sophora microphylla* | kowhai |
| **Spergula arvensis* | spurrey |
| **Stachys arvensis* | stagger weed |
| **S. sylvatica* | hedge woundwort |
| **Stellaria media* | chickweed |
| *S. parviflora* | |
| **Taraxacum officinale* | dandelion |
| **Tilia* sp. | lime |
| **Tradescantia fluminensis* | wandering Jew |
| **Trifolium dubium* | suckling clover |

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|---|---|
| **T. pratense* | red clover |
| **T. repens* | white clover |
| **T. subterraneum* | subclover |
| **Ulex europaeus* | gorse |
| **Verbascum thapsus* | woolly mullein |
| **Verbena bonariensis* | purple-top |
| **Veronica arvensis* | field speedwell |
| **V. persica* | scrambling speedwell |
| **V. plebeia* | Australian speedwell |
| **V. serpyllifolia* | turf speedwell |
| **Vicia sativa* | vetch |
| **Viola odorata* | violet |
| *Vitex lucens* | puriri |
| **Watsonia bulbifera* | bulbil watsonia |
| *Weinmannia racemosa* | kamahi |
| **Monocotyledons** | |
| **Agrostis capillaris* | browntop |
| **A. stolonifera* | creeping bent |
| **Aira caryophyllea* | silvery hair grass |
| **Allium triquetrum* | three-cornered garlic |
| **A.* sp. | |
| **Anthoxanthum odoratum* | sweet vernal |
| *Astelia solandri* | perching lily |
| **Axonopus affinis* | narrow-leaved carpet grass |
| *Bolboschoenus fluviatilis* | marsh clubrush |
| **Bromus hordeaceus* | soft brome |
| **B. willdenowii* | prairie grass |
| **Carex divisa* | |
| *C. geminata* | |
| *C. inversa* | |
| *C. solandri* | |
| *C.* sp . | |

| | |
|---|---|
| *Collospermum hastatum* | perching lily |
| *Cordyline australis* | cabbage tree |
| *Cortaderia fulvida* | toetoe |
| **C. selloana* | pampas |
| **Cynodon dactylon* | Indian doab |
| **Cynosurus cristatus* | crested dogstail |
| **Cyperus congestus* | purple umbrella-sedge |
| **C. eragrostis* | umbrella sedge |
| **C. rotundatus* | nut grass |
| **Dactylis glomerata* | cocksfoot |
| **Digitaria sanguinalis* | summer grass |
| **Festuca arundinacea* | tall fescue |
| **F. rubra* | Chewing's fescue |
| *Gahnia lacera* | |
| **Holcus lanatus* | Yorkshire fog |
| *Isolepis nodosa* | knobby clubrush |
| *I. reticularis* | |
| **Juncus articulatus* | jointed rush |
| **J. bufonius* | toad rush |
| *J. gregiflorus* | |
| *J. krausii* var. *australiensis* | sea rush |
| **J. tenuis* | slender rush |
| **Lolium multiflorum* | Italian ryegrass |
| **L. perenne* | perennial ryegrass |
| *Machaerina sinclairii* | tuhara |
| *Oplismenus imbecillis* | |
| **Paspalum dilatatum* | paspalum |
| **P. distichum* | Mercer grass |
| **Pennisetum clandestinum* | kikuyu grass |
| *Phormium cookianum* | wharariki |
| *P. tenax* | harakeke |
| *Poa anceps* | |
| **P. annua* | annual poa |

| | |
|---|---|
| **P. pratensis* | Kentucky bluegrass |
| **P. trivialis* | rough-stalked meadow grass |
| *Rhopalostylis sapida* | nikau |
| *Rhytidosperma gracile* | |
| *Schoenoplectus validus* | lake sedge |
| **Sisyrinchium* 'blue' | |
| **Sporobolus africanus* | ratstail |
| *Typha orientalis* | raupo |
| *Uncinia uncinata* | hook grass |
| **Vulpia* sp. | vulpia hair grass |

## Appendix 2 Glossary of plant names used in the text

| | |
|---|---|
| akeake | *Dodonaea viscosa* |
| bracken | *Pteridium esculentum* |
| broadleaf | *Griselinia littoralis* |
| *brush wattle | *Paraserianthes lophantha* |
| *buddleia | *Buddleia davidii* |
| cabbage tree | *Cordyline australis* |
| Chatham Island akeake | *Olearia traversii* |
| *Chinese privet | *Ligustrum sinense* |
| coastal koromiko | *Hebe stricta* var. *macroura* |
| common maidenhair | *Adiantum cunninghamii* |
| *cotoneaster | *Cotoneaster glaucophyllus* |
| cutty grass | *Cyperus ustulatus* |
| *gorse | *Ulex europaeus* |
| *grey willow | *Salix cinerea* |
| gully tree fern | *Cyathea cunninghamii* |
| hangehange | *Geniostoma rupestre* |
| harakeke | *Phormium tenax* |
| hard beech | *Nothofagus truncata* |
| hard fern | *Paesia scaberula* |
| *hawthorn | *Crataegus monogyna* |
| heketara | *Olearia rani* |
| hinau | *Elaeocarpus dentatus* |
| houhere | *Hoheria populnea* |
| houpara | *Pseudopanax lessonii* |
| *Japanese honeysuckle | *Lonicera japonica* |
| kahikatea | *Dacrycarpus dacrydioides* |
| *Kahili ginger | *Hedychium gardnerianum* |
| kamahi | *Weinmannia racemosa* |
| kanuka | *Kunzea ericoides* var. *ericoides* |
| karaka | *Corynocarpus laevigatus* |
| karamu | *Coprosma robusta* |
| kawakawa | *Macropiper excelsum* |
| kiekie | *Freycinetia baueriana* ssp. *banksii* |
| kikuyu | *Pennisetum clandestinum* |
| king fern | *Marratia salicina* |
| kiokio | *Blechnum novaezealandiae* |
| kohekohe | *Dysoxylum spectabile* |
| kohuhu | *Pittosporum tenuifolium* |
| koromiko | *Hebe stricta* var. *stricta* |
| kowhai | *Sophora microphylla* |
| lacebark | *Hoheria sexstylosa* |
| lake sedge | *Schoenoplectus validus* |
| lemonwood | *Pittosporum eugenioides* |
| mahoe | *Melicytus ramiflorus* |
| mamaku | *Cyathea medullaris* |

| | |
|---|---|
| mangeao | *Litsea calicaris* |
| manuka | *Leptospermum scoparium* |
| mapau | *Myrsine australis* |
| marsh clubrush | *Bolboschoenus fluviatilis* |
| matai | *Prumnopitys taxifolia* |
| *Mexican daisy | *Erigeron karvinskianus* |
| mingimingi | *Leucopogon fasciculatus* |
| miro | *Prumnopitys ferruginea* |
| *montbretia | *Crocosmia* × *crocosmiiflora* |
| ngaio | *Myoporum laetum* |
| trunk sedge | *Carex secta* |
| nikau | *Rhopalostylis sapida* |
| onion orchid | *Microtis unifolia* |
| *pampas | *Cortaderia selloana* |
| panakenake | *Pratia angulata* |
| parataniwha | *Elatostema rugosum* |
| pate | *Schefflera digitata* |
| pigeonwood | *Hedycarya arborea* |
| pohutukawa | *Metrosideros excelsa* |
| pokaka | *Elaeocarpus hookerianus* |
| puatea | *Anaphalloides keriensis* |
| puka | *Griselinia lucida* |
| pukatea | *Laurelia novaezealandiae* |
| purei | *Carex secta* |
| puriri | *Vitex lucens* |
| *radiata pine | *Pinus radiata* |
| ramarama | *Lophomyrtus bullata* |
| rangiora | *Brachyglottis repanda* |
| raupo | *Typha orientalis* |
| rewarewa | *Knightia excelsa* |
| rimu | *Dacrydium cupressinum* |
| rushes | *Juncus* spp. |
| saltmarsh ribbonwood | *Plagianthus divaricatus* |
| sea rush | *Juncus krausii* var. *australiensis* |
| shore lobelia | *Lobelia anceps* |
| sun orchid | *Thelymitra* spp. |
| swamp maire | *Sizygium maire* |
| tainui | *Pomaderris apetala* |
| tanekaha | *Phyllocladus trichomanoides* |
| tarata | *Pittosporum eugenioides* |
| *Tasmanian blackwood | *Acacia melanoxylon* |
| tauhinu | *Cassinia leptophylla* |
| tawa | *Beilschmiedia tawa* |
| tawheowheo | *Quintinia serrata* |
| titoki | *Alectryon excelsus* |
| toetoe | *Cortaderia fulvida* |
| totorowhiti | *Dracophyllum strictum* |
| tree fuchsia | *Fuchsia excorticata* |

| | |
|---|---|
| *tree lucerne | *Chamaecytisus palmensis* |
| tuhara | *Machaerina sinclairii* |
| tutu | *Coriaria arborea* |
| wharangi | *Melicope ternata* |
| wharariki | *Phormium cookianum* |
| whau | *Entelea arborescens* |
| wheki | *Dicksonia squarrosa* |
| wineberry | *Aristotelia serrata* |
| *woolly nightshade | *Solanum mauritianum* |

## Appendix 3 Scenic and allied reserves that abut or are adjacent to the SH3 road reserves between Hamilton and New Plymouth

| **Name** | **Size (ha)** | **Grid Ref. (NZMS260 map series)** | **Comments** |
|---|---|---|---|
| **Hamilton sector** | | | |
| Lake Serpentine Wildlife Management Reserve | 30.3 | S15 138587 | A shallow eutrophic lake with important wildlife values. Restoration planting around the wetland margin. |
| | | | |
| **King Country sector** | | | |
| Paemako Scenic Reserve | 27.1 | R17 795991 | The reserve covers moderate to steep slopes on either side of the Pangaki Stream, which has a scenic waterfall along its course. The slopes nearest the road support primary dense conifer forest dominated by matai, kahikatea, totara, and rimu |
| Mangaotaki Gorge Scenic Reserve | 65.6 | R17 765515 | The reserve includes this remnant of forest on the western side of the road. It has tawa forest with a fringe of manuka scrub on gentle slopes above a series of limestone bluffs. The middle slopes are also dominated by primary tawa forest, with rewarewa, pukatea, kahikatea and titoki (lower section) amongst it. The slopes above the road have low secondary broadleaved forest of mahoe, lacebark, putaputaweta, titoki, pate, and treeferns. |
| **Awakino Gorge sector** | | | |
| Arorangi Scenic Reserve | 311.9 | R17 594808 | Includes two areas of steep rugged slopes above the Awakino Gorge. The west-north-west facing slopes (above SH3) are predominantly (rimu-rata)/tawa-kohekohe-kamahi forest. |
| **North Taranaki sector** | | | |
| Tainui Scenic Reserve | 6.7 | R18 510784 | Gentle hillslopes with tainui forest, coastal broadleaved forest, and a small area of pasture. Tainui is classed as 'vulnerable' (Cameron et al. 1995). |
| Tuhingakakapo Conservation Area | 13.6 | R18 514700 | This conservation area includes two strips of north and west-facing coastal forest on steep slopes just south of Mokau. It is a mosaic of primary and secondary coastal forest types with karaka, kohekohe, mahoe, nikau, kowhai, cabbage tree, and rewarewa all variously abundant. |

| | | | |
|---|---|---|---|
| Mohakatino Swamp Conservation Area | 18.41 | R18 504738 | A coastal wetland bounded by sand dunes, the Mohakatino Estuary and SH3 and backed by a steep hillslope of secondary coastal forest. Contains a small stand of tainui. Also home to spotless crake and Australasian bittern. |
| Kawau Pa Historic Reserve | 1.02 | Q18 492697 | This site incorporates the Kawau Historic Reserve (which includes an ancient Maori pa site), and coastal scrub→low forest along the Kuwhatahi Stream (of karaka-(mahoe)-(hangehange)-(karamu)-(kawakawa), with harakeke, mingimingi, wharangi, kohekohe, and mamaku). |
| Tongapurutu Conservation Area | | Q18 487645 | The vegetation within the Conservation Area is a mosaic of primary and secondary coastal forest→scrub. The gullies have primary tawa/kohekohe forest with karaka and nikau, amongst secondary broadleaved scrub. The slopes/ridges have secondary (rewarewa)/mahoe-karamu-(puriri-hinau) scrub-low forest, with manuka-dominated scrub on the steeper slopes. |
| Pou Tehia Historic Reserve | 0.83 | Q18 488642 | The reserve includes an ancestral burial ground and former pa on a sharp sandstone knob rising 46 m from SH3 and the Tongaporutu River. Covered with diverse coastal forest. |
| Mount Messenger Scenic Reserve | 67.52 | Q18 490560 | Two areas of rugged hill country located to the east and south-west of the Mt Messenger summit, on Mt Messenger sandstone. Tawa forest dominates the vegetation with smaller areas of manuka scrub, cliff faces and slips, and pasture |
| Mount Messenger Conservation Area | 2900 | R19 517506 | The bulk of the area is tawa-kamahi forest, with hard beech forest on the ridges, pukatea-rimu/tawa-pukatea-rewarewa forest and variants on the lower slopes and in the gullies, and kahikatea-dominated forest-shrubland on the damper alluvial sites. |
| **Egmont sector** | | | |
| Onaero River Scenic Reserve | 9.443 | Q19 283443 | Coastal forest on steep slopes above and beside the Onaero R. Includes a raupo reedland and an old pa site. Southern limit of Metrosideros carminea. |
| Pukemiro Historic Reserve | 2.295 | Q19 282446 | Includes coastal forest and a ridge Pa, with ditches, terraces, etc. well preserved, on the eastern side of the Onaero R.. Some already lost through a 1962 SH3 re-alignment. |
| Katere Scenic Reserve | 2.24 | P19 069394 | Small steep bank on the eastern side of Mangaone Stream. Has secondary coastal forest, with a small wetland that supports raupo reedland with harakeke. |

## Appendix 4 Descriptions of sites surveyed using PNAP methodology.

The sites are arranged from south to north, as the survey began in New Plymouth. For a map indicating the location of each of the sites refer Figure 10.

| Site No./Name | NZMS map sheet | Easting | Northing | Comments |
|---|---|---|---|---|
| 1. Katere Scenic Reserve | P19 | 69 | 394 | Small steep bank on the eastern side of Mangaone Stream with secondary coastal forest and a small wetland that supports raupo reedland with harakeke. |
| 2. Amenity plantings | Q19 | 114 | 411 | Extensive mixed native amenity plantings c. 1 km north-east of Bellblock between De Havilland Dr. and the Waitaha Stream. Has been successful with good number of seedlings regenerating beneath the c. 6 m canopy. |
| 3. Waingaria Stream | Q19 | 142 | 421 | Small pocket of coastal forest on the true right bank of the Waingaria Stream with karaka, ngaio and mahoe dominant. The true left bank supports mixed native and exotic scrub of karamu, kawakawa, mamaku and woolly nightshade. |
| 4. Cutting/amenity plantings | Q19 | 179 | 435 | A road cutting planted with a band of broadleaf, kohuhu, mamaku, cabbage tree and fivefinger along the top, and harakeke along the bottom. |
| 5. Amenity Plantings | Q19 | 187 | 443 | Mixed native amenity plantings along SH3 between the northern Waitara turn-off and Bayly St. 3–5 m wide on the western side and 15–20 m on the eastern side of the highway. Includes akeake, whau, karaka, lemonwood, kanuka, karamu, and puriri. Successful with much native regeneration noted. Some native species are not indigenous to the district (e.g., *Olearia traversii* from the Chatham Islands), and should not be used in future amenity plantings. |
| 6. Motunui Synthetic Fuel Plant | Q19 | 214 | 448 | Extensive mixed native plantings of coastal and lowland species in the grounds of the fuel plant. |
| 7. Pukemiro Historic Reserve | Q19 | 282 | 446 | Coastal forest with a ridge pa above the eastern banks of the Onaero R. Adjacent to the road, beside a tributary of the Onaero R., is a riparian strip dominated by rewarewa, mamaku, mahoe, and kawakawa. |
| 8. Onaero River Scenic Reserve | Q19 | 283 | 443 | Coastal forest on steep slopes above and beside the Onaero R. Includes a raupo reedland and an old pa site. Southern limit of *Metrosideros carminea.* |

| | | | | |
|---|---|---|---|---|
| 9. Secondary forest | Q19 | 316 | 448 | Secondary forest on both sides of the road: rewarewa/mahoe-karaka-pigeonwood forest with kawakawa, mamaku, tree fuchsia, wharangi, and *Coprosma grandifolia.* Weedy margins with brush wattle, woolly nightshade and montbretia. |
| 10. Waitoetoe River | Q19 | 344 | 458 | Small pocket of coastal forest on the western side of the highway is karaka-puriri-(tawa)/mahoe forest. Canopy intact but margins weedy. On the eastern side of the road is secondary mahoe-mamaku low forest with kamahi and pigeonwood. Both remnants are on slopes above the Waitoetoe R. |
| 11. Mimi River tributary riparian strip | Q19 | 372 | 480 | Riparian strip of advanced secondary forest along a tributary of the Mimi R. Parts are rewarewa/mamaku-mahoe forest, with the northern end a swathe of mamaku treefernland. Other species in the strip include kamahi, pukatea, pigeonwood, karaka, hinau, and wineberry. High scenic value. |
| 12. Cutting | Q19 | 377 | 484 | Mosaic of different aged vegetation along a c. 25 m road cutting, from young slip vegetation of gorse, bracken, tutu, pampas and buddleia to shrubland of (rewarewa)/mamaku-tutu. The slopes are unstable and weedy throughout. |
| 13. Alluvial forest | Q19 | 383 | 485 | Small remnant of alluvial forest with a grazed and very open understorey – rewarewa/pukatea/mahoe forest→treeland. with titoki, mamaku, silverfern, ramarama, and ie. Includes a small purei wetland. |
| 14. Scrub on cutting | Q19 | 386 | 485 | Road cutting on the eastern side of the road with gorse-mahoe-karamu scrub. Other species present include rangiora, koromiko, tutu, lacebark, wineberry, kawakawa, and kiokio. Kahili ginger was noted. |
| 15 Secondary low forest | Q19 | 391 | 480 | Secondary low forest extending c. 50 m along north facing banks above the highway — mamaku/mahoe forest with karamu, hangehange, koromiko and tutu. A tongue of (rewarewa)/tawa-kamahi-mahoe forest is also present. |
| 16. Forest | Q19 | 396 | 477 | This is the best piece of forest that extends down to the road along this stretch of the highway. |
| 17. Scrub on cutting | Q19 | 402 | 477 | The northern side of the cutting has a narrow strip of vegetation, while on the southern side it extends back to the top of the hill. It is predominantly manuka scrub with mahoe, mamaku, bracken, wharariki, cabbage tree, and *Cordyline banksii.* |

| | | | | |
|---|---|---|---|---|
| 18. Scrub→low secondary forest | Q19 | 413 | 480 | An extensive roadside strip, from c. 5–30 m wide. The scrub→low secondary forest canopy is variously dominated by manuka, tutu, mahoe, mamaku, or gorse, with other species present including karamu, koromiko, wineberry, rewarewa, kiokio and tuhara. *Dracophyllum strictum* is abundant in places amongst the scrub on the mid-lower slopes. Pines have been planted along the upper edge and regeneration is occurring in the scrub below. |
| 19. Scrub on cutting | Q19 | 424 | 491 | This site includes the road cutting and a small bank just south of it. The small bank has (manuka)/mahoe-tutu scrub with kiokio, tuhara, mingimingi, koromiko and heketara. The cutting, which is wider on the eastern side, has mamaku/mahoe-tutu scrub with the same species as the bank. Japanese honeysuckle is present in the canopy. |
| 20. Scrub on cutting | Q19 | 425 | 495 | This cutting, just south of Uruti, has a narrow ribbon of manuka/*Dracopyllum strictum* scrub along the upper edge, backed by pine trees and pasture on the western side. The face of the cutting is weedy. On the eastern side karamu-mingimingi-tutu scrub form a narrow upper band with tuhara, kiokio, koromiko, and *Poa anceps*. Gorse and Himalayan honeysuckle are present. |
| 21 Roadside bank | Q18 | 445 | 530 | Gorse-(koromiko)-(*Dracophyllum strictum*)-tutu scrub on the roadside bank, with manuka scrub behind. |
| 22 Roadside bank | Q18 | 471 | 542 | Roadside bank with koromiko-tuhara-(karamu)-(*Populus* sp.) scrub, and manuka along the upper edges. Pate and fivefinger are also present. |
| 23 Roadside bank | Q18 | 475 | 544 | Roadside bank with vegetation very similar to 22. |
| 24. Shrubland (Mt Messenger - southern end) | Q18 | 478 | 546 | Koromiko-karamu shrubland on roadside bank with manuka scrub on the hillslope behind. Tuhara and *Poa anceps* are also present. |
| 25. Mt Messenger - southern side | Q18 | 479 | 546 | Secondary mahoe-(mamaku)-(pate) low forest on the south-facing gentle slopes below the old road opposite 26. Also present are pukatea, puka, pigeonwood, and gully treefern. |
| 26. Mt Messenger - southern side | Q18 | 482 | 546 | Small remnant of kahikatea-swamp maire forest with lacebark, putaputaweta, kaikomako and mahoe in the subcanopy on a swampy terrace below the road (eastern side). A re-alignment of SH3 has reduced the size of this remnant, opening up the understorey on the western side. |

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|---|---|---|---|---|
| Mt Messenger - general | Q18 | 484 | 556 | The general pattern of the vegetation (including that within Mt Messenger Scenic Reserve and Conservation Area) is hard beech and tawa-kamahi forests on the ridges, tawa-dominated forest on the hillslopes (rimu and rewarewa are common emergents throughout, with pukatea on the lower slopes and in the gullies), and kahikatea-dominated forest on damper alluvial sites. The cliffs and banks bordering the road (almost all of which are within the road reserve) have varied assemblages of native species typical of sedimentary substrates, including kiokio, panakeake, *Corybas papa*, *Gunnera monoica*, *Nertera depressa*, onion orchid, puatea, *Epilobium rotundifolium*, toetoe, tuhara, and *Poa anceps*. The cliffs also have scattered adventive grasses and herbs. |
| 27 Scrub→low forest | Q18 | 485 | 574 | West-facing roadside vegetation south of Mangapepeke Stream – (rewarewa)/manuka scrub→low forest with various mixtures of mahoe, rangiora, koromiko, mamaku, karamu, *Cordyline banksii*, kiokio, and mingimingi amongst it. *Dracophyllum strictum* is present. |
| 28. Fern-sedgeland on cutting | Q18 | 489 | 585 | West-facing cutting with koromiko-manuka-tuhara-kiokio fern-sedgeland. |
| 29-32. South of Ahititi→just south of Tongaporutu | | | | The repeating primary forest pattern in this area is hard beech forest on the ridges and upper slopes (with occasional miro and tanekaha), and tawa-dominated forest on hillslopes, with pukatea and nikau in the gullies. Old burnt ridges have rewarewa/kamahi forest. |
| 29. Forest→scrub | Q18 | 491 | 589 | Finger of rewarewa/kamahi forest and manuka scrub extending down to the road, opposite Mangaonga Rd, south of Ahititi. |
| 30. Forest | Q18 | 494 | 593 | Forest on east-facing slopes just south of Ahititi School, hard beech-(miro)-(tanekaha)/*Gahnia setifolia* forest on the ridges, upper slopes and spurs, tawa-dominated forest on the mid slopes and manuka scrub on the lower slopes with *Dracophyllum strictum*, tuhara, *Olearia townsonii*, kiokio, and wharariki amongst it. |
| 31. Forest | Q18 | 495 | 599 | Forest of kamahi-tawa-(hinau)/mahoe-wineberry-(nikau) with tree fuchsia, pate, pigeonwood, kiekie, mamaku, *Cordyline banksii*, and rangiora also present, on east facing hillslopes. |
| 32. Forest | Q18 | 490 | 614 | Similar forest as described above. |

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|---|---|---|---|---|
| 33. Riparian fringe & alluvial forest | Q18 | 493 | 616 | This site includes a fringe of riparian vegetation (with mahoe, wineberry, mamaku, fivefinger, rangiora, kowhai, and lacebark) along the true left banks of the Tongaporutu R., and a small alluvial kahikatea forest remnant that is contiguous with the riparian vegetation at its northern edge. The kahikatea remnant is diverse, with king fern present in the understorey. |
| 34. Riparian fringe & forest | Q18 | 485 | 631 | Riparian forest fringe on the eastern side of the road continuing almost to Tongaporutu along the banks of the Tongaporutu River. The hillslopes on the eastern side of the road have (rewarewa)/kamahi forest on the upper slopes and manuka scrub on the lower slopes. |
| 35a.Tongaporutu Conservation Area | Q18 | 487 | 645 | The vegetation within the Conservation Area is a mosaic of primary and secondary coastal forest→scrub. The gullies have primary tawa/kohekohe forest with karaka and nikau, amongst secondary broadleaved scrub. The slopes/ridges have secondary (rewarewa)/mahoe-karamu-(puriri-hinau) scrub→low forest, with manuka-dominated scrub on steeper slopes. A wetland of predominantly raupo reedland lies in the depression between SH3 and a section of old road, and is continuous with the Conservation Area. |
| 35b. Pou Tehia Historic Reserve | Q18 | 487 | 641 | The reserve, on a sharp sandstone knob beside the Tongaporutu River has diverse coastal forest of (rewarewa)/karaka-kohekohe-kowhai/mahoe, and includes a ridge top pa. The reserve has high conservation and scenic value. Adjacent to the reserve along the road edge is a strip of predominantly native riparian vegetation. |
| 36. Coastal forest | Q18 | 483 | 646 | The eastern side of the road has nikau-puriri-karaka coastal forest that grades into site 35b. The western side of the road has secondary rewarewa/mamaku-mahoe-karaka coastal forest with whau, puriri, karamu, rangiora, kohekohe, kiekie, and wharangi. |
| Tongaporutu→north along dry coastal strip | | | | Pohutukawa is planted and widely naturalised on the road side banks and cuttings from Tongaporutu north along this dry coastal strip, with taupata, bracken, and pohuehue also common. |
| 37. Wetland & coastal scrub | Q18 | 484 | 659 | A raupo-marsh clubrush wetland, at the mouth of the Rapanui Stream occurs on the western side of road, with coastal scrub of hangehange, kawakawa, karaka, mahoe, and harakeke on the banks on the eastern side of the road. |

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| 38. Cutting | Q18 | 486 | 663 | This site includes a small road cutting through old marine terraces (sandy soils) with a sparse cover of tauhinu, manuka, bracken, pohutukawa, *Haloragis erecta*, sun orchids, kiokio, and shore lobelia. |
| 39. Kawau Pa Historic Reserve & coastal scrub→low forest | Q18 | 492 | 697 | This site incorporates the Kawau Historic Reserve (which includes an ancient pa site), and coastal scrub→low forest along the Kuwhatahi Stream (of karaka-(mahoe)-(hangehange)-(karamu)-(kawakawa), with harakeke, mingimingi, wharangi, kohekohe, and mamaku). |
| 40. Cutting | Q18 | 497 | 710 | This cutting supports coastal harakeke flaxland, with karamu, pohutukawa, kawakawa, cabbage tree, hangehange, koromiko, tutu, and bracken amongst it. |
| 41. Mohakatino Swamp Conservation Area | R18 | 504 | 738 | The conservation area includes a coastal wetland dominated by raupo with harakeke and giant umbrella sedge, bounded by sand dunes, the Mohakatino Estuary and SH3, and backed by a steep hillslope of secondary coastal forest. |
| 42. Cutting | R18 | 504 | 758 | This cutting passes through bands of old windblown sand and andesitic tephra. The vegetation on the sands is stunted sparse tauhinu-*Pimelea urvilleana* shrubland. The bands of tephra support harakeke, tauhinu, manuka, and pohutukawa. This was the only site where *P. urvilleana* was noted. |
| 43. Tuhingakakapo Conservation Area | R18 | 514 | 760 | This conservation area includes two strips of north and west-facing coastal forest on steep slopes just south of Mokau. It is a mosaic of primary and secondary coastal forest types with karaka, kohekohe, mahoe, nikau, kowhai, cabbage tree, and rewarewa variously abundant. |
| 44. Coastal scrub | R18 | 516 | 768 | Gorse-mahoe-(mangeao) scrub on west facing slopes at the southern end of the Mokau River bridge. Other species present include kawakawa, karamu, harakeke, cabbage tree, koromiko, and akeake. |
| 45. Coastal scrub→low forest | R18 | 513 | 771 | Face of coastal scrub→low forest on south-facing banks above the Mokau River, (rewarewa)/mangeao-karaka-mahoe scrub→low forest, with areas of primary coastal forest on the slopes near the river mouth (karaka-titoki-kohekohe-mangeao forest). |
| 46. Cutting | R18 | 509 | 781 | East-facing cutting with coastal scrub of koromiko, kawakawa, mahoe, harakeke, bracken, karamu, pohutukawa, and pohuehue. |

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| 47. Tainui Scenic Reserve | R18 | 510 | 784 | A small reserve that includes low coastal broadleaved forest with mahoe, mamaku, kawakawa, gorse, manuka, hangehange, and karamu, and c. 1 ha of tainui forest. |
| 48. Shrub→flaxland | R18 | 509 | 792 | West-facing cutting with taupata-wharariki shrub→flaxland. Other species present include manuka, karamu, tauhinu, kawakawa, puka, pohuehue, toetoe, mapou, and hangehange. |
| 49. Flaxland | R18 | 510 | 795 | Wharariki flaxland with a mixture of gorse, coastal koromiko, kawakawa, karamu, kiokio, pohutukawa, toetoe, hangehange, pohuehue, and mahoe amongst it. Areas of similar vegetation occur on cuttings and banks from here north to Old Mill Rd. |
| 50. Coastal scrub→shrubland | R17 | 511 | 806 | Mixed coastal scrub→shrubland of karamu, wharariki, hangehange, mahoe, bracken, pohuehue, mingimingi, coastal koromiko, tauhinu and manuka on west-facing slopes above baches. |
| 51. Cutting | R17 | 518 | 820 | Mosaic of bracken fernland, tuhara, and coastal scrub (as for 50) on cuttings just south of Awakino. |
| 52. Secondary forest & saline wetland | R17 | 523 | 819 | Secondary mahoe-mapou forest, with *Gahnia lacera*, hangehange, kawakawa, harakeke, silverfern, karamu, and karaka. Extends from the banks opposite the Awakino Hotel north to where the river leaves the road. On the northern side of the road is a saline wetland with raupo reedland, sea rush rushland, marsh clubrush sedgeland and stands of saltmarsh ribbonwood. |
| 53. Forest | R17 | 532 | 105 | Forest remnant on north-facing slopes above the road. Main ridge has hard beech forest with (rewarewa)/tanekaha-(rimu) forest on the spur end. Lower slopes in places have (tawa)-kamahi-mangeao forest with pigeonwood, mahoe, nikau, karaka, kohekohe, fivefinger, and kanuka (on the margins). Manuka scrub occurs in a fringe along the road (with *Olearia townsonii*, mingimingi, hangehange, mamaku, and mahoe amongst it) and in mosaic with the slope forest. Steep bluffs on the upper slopes have wharariki, tutu, tuhara, *Dracophyllum strictum*, and karamu. |
| 54. Start of the Awakino Gorge | R17 | 557 | 801 | (Rewarewa-mangeao)/silverfern-manuka-mapou scrub on a north-east facing cutting and the slopes above it. Other species present include heketara, *Olearia townsonii*, Hall's totara, tanekaha, karamu, and mamaku. Relic stands of hard beech-tanekaha forest remain on the ridges/upper slopes. |

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| 55. Forest | R18 | 564 | 796 | Forest on south-west facing slopes (opposite side of river from SH3) that is a mosaic of primary hard beech-tanekaha forest on the ridges with either advanced secondary low forest (with kamahi, mamaku, fivefinger, mahoe, tutu, kawakawa) or primary tawa-kamahi forest with titoki and pukatea on the mid-lower slopes. |
| Awakino Gorge - alluvial forest→treeland | | | | The condition of the primary alluvial forest remnants on the mostly narrow alluvial terraces through the gorge varies, with most degraded by logging and grazing (which is ongoing in many areas). In some cases it is reduced to treeland. Pukatea is the dominant canopy tree, with kahikatea, titoki, lacebark, mahoe, kohekohe, pigeonwood, ramarama, and karaka all variously present. |
| 56. Forest | R18 | 564 | 795 | North-east facing slopes that have a repeating pattern of tawa and pukatea-dominated vegetation on the lower slopes, secondary (rewarewa)/kamahi-broadleaved forest on the mid-slopes, and kamahi forest on the burnt ridges and spurs that once supported hard beech. |
| 57. Forest | R18 | 574 | 796 | Stretch of primary (rewarewa)/tawa-(hinau)-(puriri) forest, with advanced secondary manuka scrub and (rewarewa)/kamahi low forest on the ridges/spurs. |
| 58. Arorangi Scenic Reserve | R17 | 594 | 808 | Slopes in the reserve support (rimu)-(rewarewa)/tawa-(hinau)-(pukatea) forest with kamahi, mangeao, miro, tree fuchsia, and kahikatea and titoki on the footslopes. Mahoe and pigeonwood dominate the subcanopy in most places. Recent slip faces support sparse shrubland of buddleia, manuka, koromiko, *Poa anceps*, and adventive grasses. Older slip faces have manuka-dominated scrub with toetoe, harakeke, koromiko, and buddleia. The base of the sandstone bluffs on the slopes have manuka scrub with lacebark, lancewood, cabbage tree, mahoe, karamu, koromiko, *Olearia townsonii*, and *Gahnia* sp., and scattered tawa trees. |
| 59. Scrub→low forest | R17 | 606 | 835 | Secondary mosaic of manuka scrub on the ridges and upper slopes, with broadleaved scrub→low forest and kamahi-mangeao low forest on the slopes, and mamaku treefernland with pukatea in the gullies. The steep rocky slope just above the road supports tutu-mahoe-rangiora scrub. |

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| 60. Low forest | R17 | 608 | 843 | Secondary mahoe-pate-karamu-kawakawa-manuka-koromiko low forest that merges into fragments of old secondary kamahi forest, with occasional pukatea on slopes above the Awakino River. |
| 61. Scrub→low forest | R17 | 610 | 852 | Faces on the eastern side of the road that have variable scrub→low forest of manuka, kamahi, karamu, mamaku, kohuhu, rangiora, tutu, and cotoneaster. Mexican daisy is common. |
| 62. Scrub | R17 | 616 | 854 | Limestone ridge above the road tunnel with manuka scrub. Invasive cotoneaster dominates the shrubland on the slopes around the tunnel, with rangiora, mahoe, and tree fuchsia amongst it. The bluffs have wharariki, tuhara, common maidenhair, *Poa anceps*, kiokio, and Mexican daisy. |
| 63. *Dracophyllum* bank | R17 | 628 | 861 | An 'island' of manuka-karamu-mingimingi-*Dracophyllum strictum*-koromiko scrub with an old section of the road running behind it and cutting it off from the surrounding pasture. Other species present include *Olearia townsonii*, kamahi, fivefinger, *Gaultheria antibody*, kiokio, and *Poa anceps*. |
| 64. Scrub→forest | R17 | 635 | 860 | Remnant extending down to the road on north facing slopes. The ridges/upper slopes/spurs support manuka scrub and a small relic stand of hard beech, with pockets of kamahi forest throughout. The mid-lower slopes have pockets of treeferns and pukatea in the gullies, and amongst kamahi forest. There are also scattered pockets of kamahi/mamaku scrub and manuka-broadleaved scrub on the slopes. The bluffs along the upper edges of the slopes have wharariki flaxland. |
| 66. Scrub | R17 | 656 | 872 | Predominantly north-facing slope with even-aged manuka scrub. Other species include silverfern, lancewood, koromiko, *Pittosporum colensoi*, mingimingi, karamu, and fivefinger. |
| 67. Forest | R17 | 682 | 888 | Small remnant of (kahikatea)-titoki treeland beside the Awakino River, with advanced secondary kahikatea/lacebark-pate-putaputaweta treeland interplanted with Tasmanian blackwood (lower slopes and streamside) and radiata pine (upper slopes) on the opposite side of the road. |
| 68. Scrub→forest | R17 | 726 | 918 | This slope has manuka scrub on the margins with dense stands of young totara-dominated forest in the centre. Species present amongst the manuka include lemonwood, kohuhu, gorse, occasional young kahikatea, lancewood, and rangiora. |

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| 69. Forest | R17 | 730 | 927 | Small remnant of primary rewarewa-(kahikatea)/tawa-pukatea forest and advanced secondary broadleaved low forest in a narrow strip along Mangaonga Rd. |
| 70. Scrub→low forest | R17 | 759 | 948 | Mixed manuka-lacebark-broadleaved scrub low-forest on roadside bank. |
| 71. Mangaotaki Scenic Reserve | R17 | 765 | 951 | The reserve occurs on steep broken hill country with high limestone cliffs flanking both sides of the Mangaotaki Gorge. (Rewarewa)-(kahikatea)/tawa forest dominates the hillslopes, and kahikatea/tawa-titoki forest the lower colluvial/alluvial slopes. Limestone bluffs and boulders are a feature of the reserve. |
| 72. Mangaotaki Scenic Reserve | R17 | 760 | 960 | The reserve includes this remnant of forest on the western side of the road. It has tawa forest with a fringe of manuka scrub on gentle slopes above a series of limestone bluffs. The middle slopes are also dominated by primary tawa forest, with rewarewa, pukatea, kahikatea and titoki (lower slopes). The slopes above the road have low secondary broadleaved forest of mahoe, lacebark, putaputaweta, titoki, pate, and treeferns. |
| 73. Low forest | R17 | 765 | 964 | Narrow roadside strip on north-west facing slopes, with kanuka-mahoe low forest. Titoki, cabbage tree, rangiora, karamu, and tree fuchsia are present amongst it. |
| 74a. Slope vegetation | R17 | 774 | 974 | Semi-continuous strip of slope scrub→forest that extends for c. 1.5 km on west-facing slopes and bluffs above the highway. The slope has a mosaic of manuka-kanuka scrub and primary rewarewa-kahikatea/tawa forest with titoki and totara (a ribbon along the base of the bluffs and upper slopes). There are also pockets of tawa-titoki forest, and old slip faces with a sparse cover of toetoe, manuka and kanuka. |
| 74b. Riparian vegetation | R17 | 774 | 973 | A ribbon of alluvial and slope vegetation along the Mangaotaki River. It is a mosaic of secondary scrub and pockets of primary (kahikatea)/tawa forest with pukatea and totara amongst it on the lower slopes and kahikatea-(rimu)-(totara)-(matai)/kamahi-broadleaved forest on the upper slopes. |
| 75. Forest | R17 | 780 | 978 | Remnant of primary (rimu)/tawa-kamahi forest on south-east facing slopes above the road. The cutting above the road supports kiokio, Mexican daisy, cotoneaster, rangiora, koromiko, and toetoe. The opposite side of the road has a smaller area of similar forest that merges into manuka shrubland with pokaka present. |

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| 76. Paemako Scenic Reserve | R17 | 795 | 991 | The reserve covers moderate to steep slopes on either side of the Pangaki Stream, which has a scenic waterfall along its course. The slopes nearest the road support primary dense conifer forest dominated by matai, kahikatea, totara, and rimu The vegetation on the road cutting opposite the reserve has secondary scrub dominated variously by manuka, toetoe, tutu, and karamu. |
| 77. Scrub on cutting | R17 | 808 | 991 | North-facing cutting that supports secondary scrub dominated by karamu, koromiko, manuka, kiokio, and hard fern. Tree lucerne is also present. |
| 78. Scrub on cutting | R17 | 811 | 989 | Vegetation on both sides of the road cutting dominated by manuka, karamu, and *Dracophyllum strictum*. |
| 79. Mangaparo Stream wetland | S17 | 910 | 69 | Raupo-(harakeke) wetland/swamp on the northern side of the highway. Extensive grey willow invasion around the margins. |
| 80. Fernland→low forest→forest | S17 | 932 | 72 | South-facing roadside banks just before Eight Mile Junction. Secondary bracken fernland→secondary lacebark-wineberry-tree fuchsia low forest. Merges into primary (rimu)-tawa-kamahi forest upslope. |
| 81. Vineland→forest | S16 | 993 | 148 | North-west facing slopes with blackberry vineland and secondary kamahi-mangeao-mahoe-mamaku forest. |
| 82. Alluvial forest | S16 | 978 | 182 | Remnant of advanced secondary kahikatea forest with hawthorn and rimu amongst it on the eastern side of the road. The forest remnant on the western side of the road is also dominated by kahikatea, with pukatea, kohuhu, and swamp maire also present. |
| 83. Alluvial forest | S16 | 986 | 221 | Remnant of alluvial kahikatea-dominated forest with matai, lemonwood, mahoe, tawa, titoki, pokaka, and hawthorn amongst it. |
| 84. Lake Serpentine | S15 | 138 | 587 | A shallow eutrophic lake with important wildlife values. Restoration planting around wetland margin. |

## Appendix 5 Glossary of abbreviations and terms used in text

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| *Ecological District* | A local part of New Zealand where geological, topographical, climatic, and biological features and processes, interrelate to produce a characteristic landscape and range of biological communities. It represents the level for assessing the representativeness of major ecosystem types in the national network of Protected Natural Areas. New Zealand has been subdivided into c. 269 such districts. |
| *Ecological Region* | A group of adjacent Ecological Districts with very closely related ecological characteristics, or , in some instances, a single very distinctive Ecological District (e.g., Egmont Ecological Region). New Zealand has been subdivided into 85 such regions (Leathwick et al. 1995). |
| *Nurse plant* | Plants that are generally hardy and planted first at a site to provide a sheltered environment for the establishment later of other plants. Most often they are native species (e.g., manuka), but in some sites fast growing exotic species are chosen (e.g., tree lucerne. |
| *Primary* | Vegetation that is essentially original in composition and structure, i.e. which has escaped obvious human disturbance. |
| *Secondary* | Vegetation that has developed since major disturbance but with the substrate remaining essentially intact. |

## Appendix 6 Birds and mammals recorded during the SH3 road segment and PNAP surveys

This list includes species heard or seen in or nearby the road reserve, during either the PNAP or probability sampling. In some cases (e.g., for possums) tracks or scat were the only evidence of their presence.

| Scientific name | Common name |
|---|---|
| **Native birds** | |
| *Chalcites lucidus* | shining cuckoo |
| *Circus approximans* | Australasian harrier |
| *Gerygone igata* | grey warbler |
| *Halcyon sancta* | New Zealand kingfisher |
| *Hemiphaga novaeseelandiae* | New Zealand pigeon |
| *Prosthemadera novaeseelandiae* | tui |
| *Rhipidura fuliginosa* | North Island fantail |
| *Vanellus miles novaehollandiae* | spur-winged plover |
| *Zosterops lateralis* | silvereye |
| **Introduced birds** | |
| *Acridotheres tristis* | myna |
| *Emberiza citrinella* | yellowhammer |
| *Gymnorhina hypoleuca* | white-backed magpie |
| *Sturnus vulgaris* | starling |
| *Turdus merula* | blackbird |
| *T. philomelos* | song thrush |
| **Introduced mammals** | |
| *Capra hircus* | goat |
| *Lepus europaeus* | hare |
| *Trichosurus vulpecula* | brushtail possum |

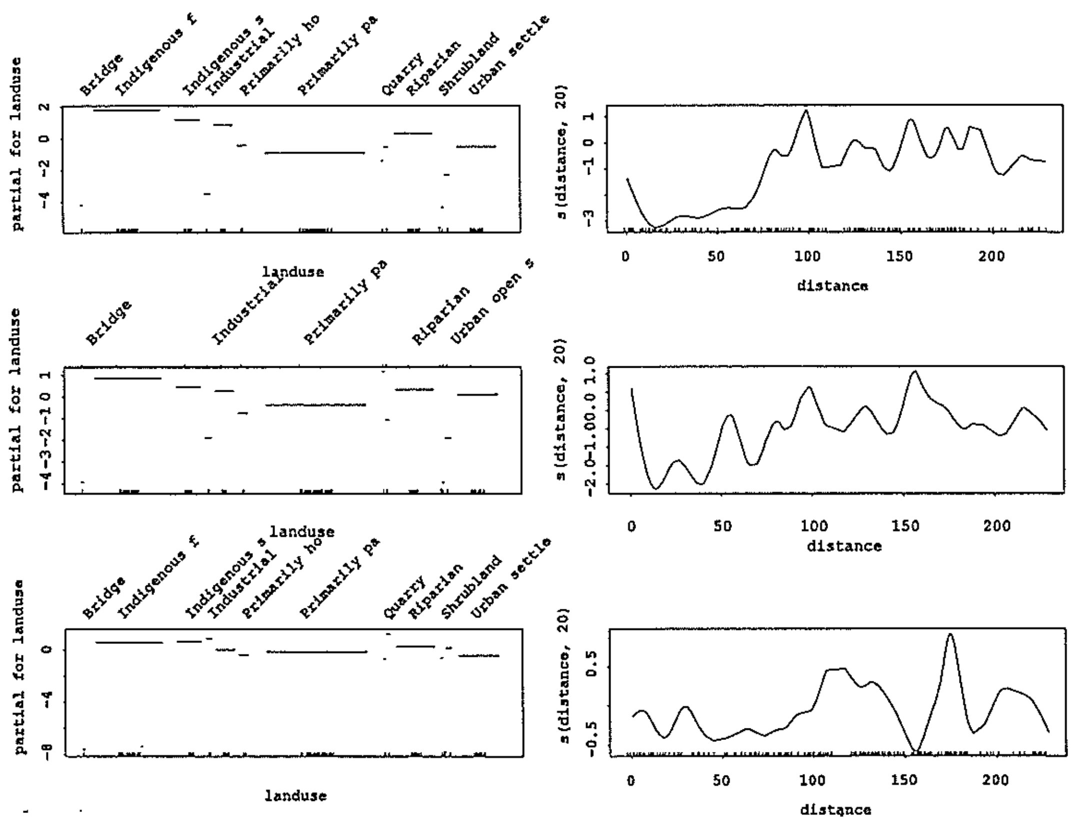
**Species in the vicinity and/or probably present .**

This list includes species known to be present in the road reserve or in land adjacent to it, but that were not recorded during the surveying.

| **Scientific name** | **Common name** |
|---|---|
| **Introduced mammals** | |
| *Erinaceus europaeus* | hedgehog |
| *Mus musculus* | mouse |
| *Mustela* spp. | ferret, stoat and/or weasel |
| *Oryctolagus cuniculus* | rabbit |
| *Rattus norvegicus* | Norway rat |
| *R. rattus* | ship rat |

## Appendix 7 Using Generalised Additive Models (GAMs) to make predictions about the biodiversity along the highway

The strong relationship between surrounding land cover and biodiversity attributes seen in the sampled locations allows the possibility of using this relationship to predict the biodiversity attributes for each 0.5 km-stop, for which only the position on the highway and the surrounding land cover are known. Generalised additive models (GAMs) were used to establish the relationships between three biodiversity attributes— proportion of species native (Propnatc), linear density of native cover (Natcresw), and potential increase in native cover (Potincr) — and surrounding land cover and position along the highway (distance from Hamilton) (below). The distance from Hamilton allows the model to take into account the spatial autocorrelation of the biodiversity attributes, using a smoothing spline with approximately 20 degrees of freedom. While other variables are important in determining the attributes, they were not measured for the 0.5 km-stops, so could not be used for predictions. The relationships in the figure below were then used to predict the biodiversity attributes for each 0.5 km-stop.




Generalised additive models of three biodiversity attributes as functions of land cover and distance from Hamilton. Each row is a biodiversity attribute: Proportion of species native (first row), Linear density of native cover (second row), and Potential increase in native cover (third row). The left column shows the effect of land cover on each attribute, and the right column the spatial autocorrelation accounted for by distance south of Hamilton.