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3. Results

A total of 308 plant species were recorded during the 1986/87 survey, of which 271 were indigenous species. This included a threatened species, scarlet mistletoe (*Peraxilla colensoi*), which has not previously been recorded in WNP.

3.1 FOREST TYPES AND ENVIRONMENTAL DRIVERS

DCA of recce tree cover data collected by the New Zealand Forest Service suggests that Whanganui forests are relatively homogenous and cannot be divided into discrete forest types (Fig. 4). There is some evidence for the separation of plots containing beech, but elsewhere a gradient of dominance by tawa and kamahi exists, with neither species being mutually exclusive. Plots with high DCA axis 1 scores tended to contain seral species such as manuka, wineberry and koromiko, but none of those species had high importance values.

Axis 2 of the DCA resembles the pattern described in earlier accounts (Levy 1923; Nicholls 1956; Baxter 1988), where composition shifted from pukatea, kahikatea and mahoe, through tawa with maire (*Nestegis* spp.) and hinau, to kamahi and black beech with increasing distance upslope from waterways to dry ridges (Fig. 5)—although not all of the species mentioned by those authors had high importance values. However, site factors such as altitude, aspect and slope, which all had regression coefficients < 0.01 (Table 1), had little effect on species composition: although significant, their inclusion in the CCA model explained very little of the variance in composition (Table 2). The two tree fern species suggest a relationship between axis 2 and topography/drainage: wheki (*Cyathea smithii*), which favours damp sites (Brownsey & Smith-Dodsworth 2000), is plotted low on

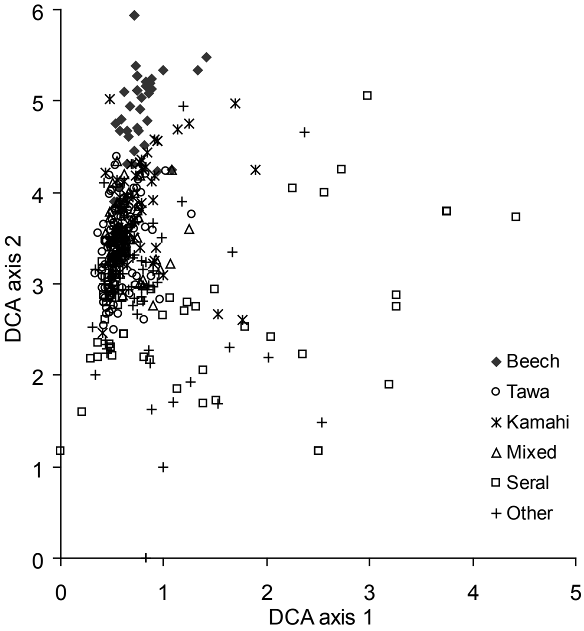


Figure 4. Detrended Correspondence Analysis plot scores from canopy tier cover scores obtained during a variable area recce plot survey in Whanganui National Park in 1986/87.

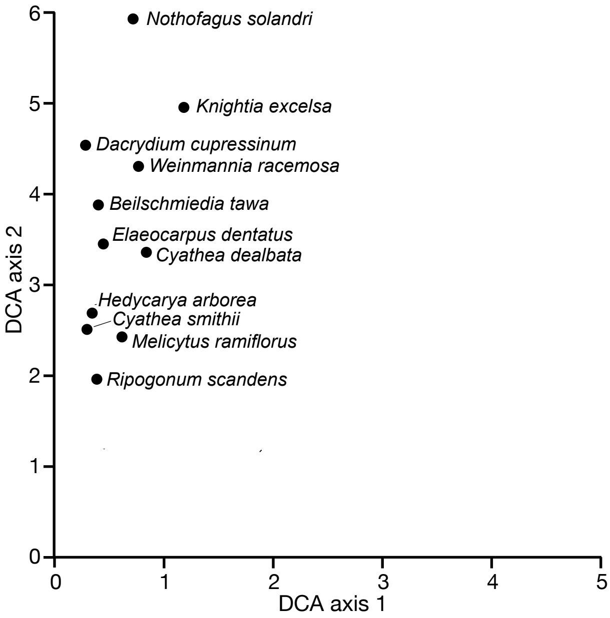


Figure 5. Detrended Correspondence Analysis species scores from tree recce data for species with weights in Detrended Correspondence Analysis > 100.

TABLE 1. STEPWISE MULTIPLE REGRESSIONS OF THE EFFECTS OF DOMINANT SPECIES (> 50 TREE STEMS/ha) AND SITE FACTORS ON RECCE DETRENDED CORRESPONDENCE ANALYSIS AXIS 1 AND 2 SCORES.

EFFECT	REGRESSION COEFFICIENT	SE	*P*
Effects of cover scores on DCA axis 1 scores			
(Rewarewa (*Knightia excelsa*) *P*=0.461 excluded)			
Constant	1.489	0.063	<0.001
Tawa (*Beilschmiedia tawa*)	−0.193	0.020	<0.001
Pigeonwood (*Hedycarya arborea*)	−0.081	0.028	0.004
Mahoe (*Melicytus ramiflorus*)	−0.100	0.023	<0.001
Kamahi (*Weinmannia racemosa*)	−0.077	0.021	<0.001
Black beech (*Nothofagus solandri*)	−0.121	0.032	<0.001
Effects of cover scores on DCA axis 2 scores			
Constant	3.065	0.065	<0.001
Tawa (*Beilschmiedia tawa*)	0.053	0.021	0.011
Pigeonwood (*Hedycarya arborea*)	−0.062	0.029	0.033
Mahoe (*Melicytus ramiflorus*)	−0.183	0.024	<0.001
Kamahi (*Weinmannia racemosa*)	0.194	0.021	<0.001
Black beech (*Nothofagus solandri*)	0.464	0.033	<0.001
Rewarewa (*Knightia excelsa*)	0.152	0.031	<0.001
Effects of altitude and latitude on DCA axis 1 scores			
(Aspect *P*=0.427 and slope *P*= 0.585 excluded)			
Constant	0.801	0.182	<0.001
Altitude	−0.001	<0.001	0.001
Latitude	0.001	<0.001	0.021
Effects of aspect, slope and latitude on DCA axis 2 scores			
(Altitude *P*=0.895 excluded)			
Constant	3.805	0.200	<0.001
Aspect	−0.001	<0.001	0.046
Slope	0.01	0.003	0.003
Latitude	−0.001	<0.001	0.005

TABLE 2. RESULTS OF CANONICAL CORRESPONDENCE ANALYSIS OF RECCE TREE TIER DATA FROM 470 PLOTS MEASURED IN WHANGANUI FORESTS IN 1986/87.

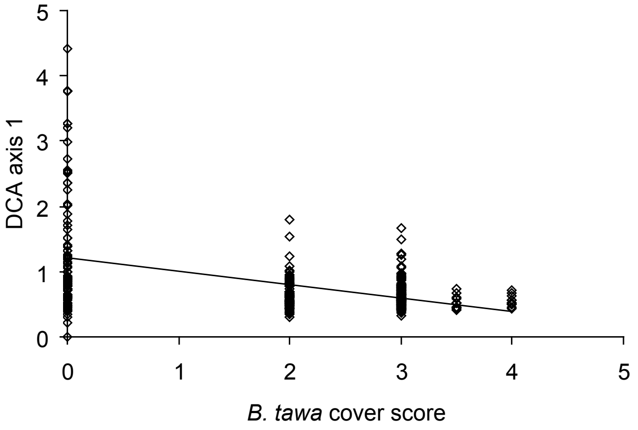
Importance values for each plot were calculated using plot cover scores for the tree tier. Altitude (m a.s.l.), latitude (km), longitude (km), slope (°), physiography and aspect are displayed in order of their inclusion in the forward selection procedure. The variance each factor explains (lambda marginal), additional variance explained at the time each factor was included (lambda conditional) and the significance of the variable at that time (*P*) are shown.

VARIABLE	LAMBDA MARGINAL	LAMBDA CONDITIONAL	*F*	*P*
Altitude	0.08	0.08	3.20	0.005
Latitude	0.06	0.04	1.68	0.060
Physiography	0.06	0.06	2.61	0.005
Longitude	0.05	0.07	2.75	0.005
Slope	0.04	0.05	1.79	0.025
Aspect	0.03	0.02	1.10	0.295

the axis close to mahoe, while silver fern (*C. dealbata*), which occurs on dry, free-draining sites (Brownsey & Smith-Dodsworth 2000), is closer to tawa and hinau.

The occurrence of tawa had an important influence on DCA axis 1 results (Table 1). Linear regression showed that cover scores of tawa predicted 19% of the variation in DCA axis 1 scores (Fig. 6), while cover scores of the next most important species, pigeonwood, mahoe and kamahi, had much less influence on DCA axis 1 scores. Although it had a relatively large regression coefficient and was highly significant in the multiple regression, linear regression found no significant relationship between black beech cover scores and DCA axis 1 scores ($P = 0.736$).

Cover scores of tawa had little influence on DCA axis 2 scores (as shown by the magnitude of the *t*-statistics in Table 1). Similarly, there was no significant difference between DCA axis 2 scores for plots in which tawa was present or absent (Table 3). In contrast, pigeonwood, mahoe and kamahi, which had less effect on DCA axis 1 scores, had much more influence on DCA axis 2 scores, and there were significant differences between DCA axis 2 scores for plots in which these species were present or absent. There were significant relationships between DCA axis 2 scores and cover scores of black beech, mahoe, kamahi and rewarewa (Fig. 7).

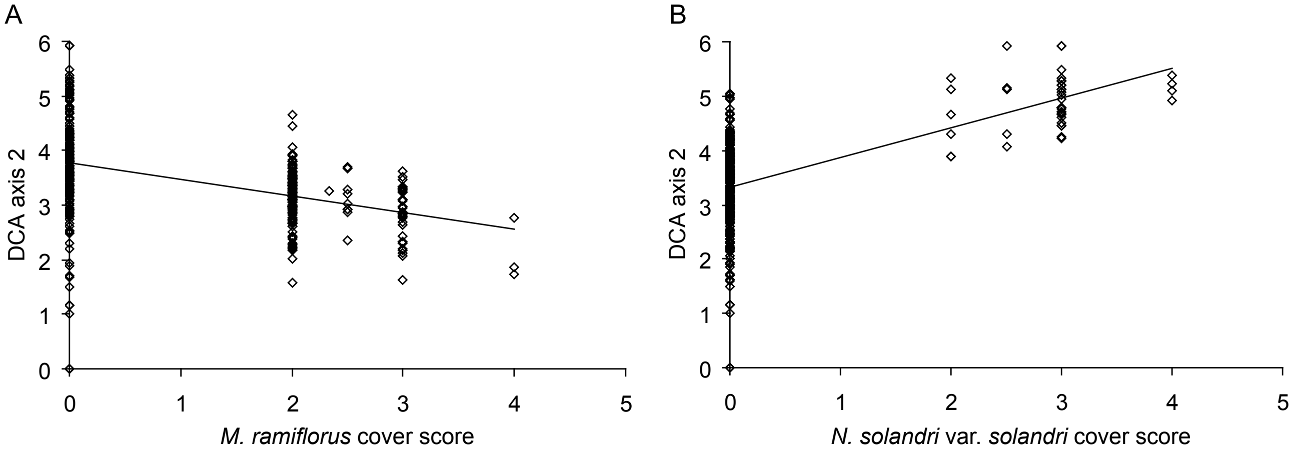


DCA score = 1.212 – cover score × 0.207
($r^2 = 0.191$, $t = -10.19$, d.f. = 438, $P < 0.001$)

Figure 6. The relationship between tawa (*Beilschmiedia tawa*) cover scores and Detrended Correspondence Analysis axis 1 scores. The line of best fit, calculated using linear regression, is shown below the graph.

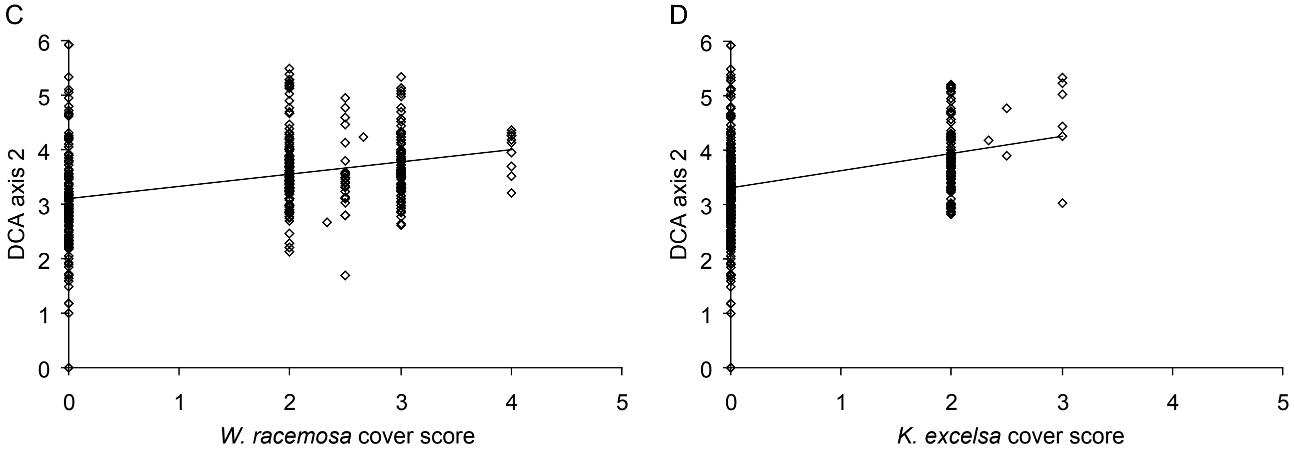
TABLE 3. MEAN (± SEM) TREE RECCE DETRENDED CORRESPONDENCE ANALYSIS AXIS 1 AND 2 SCORES FOR PLOTS IN WHICH THE FOUR MOST IMPORTANT CANOPY SPECIES WERE PRESENT OR ABSENT, AND RESULTS OF *t*-TESTS COMPARING THESE SCORES.

	PRESENT		ABSENT		*t*	*P*
	MEAN ± SEM	*n*	MEAN ± SEM	*n*	(d.f. = 438)	
DCA axis 1						
Tawa (*Beilschmiedia tawa*)	0.624 ± 0.011	314	1.259 ± 0.089	126	7.071	<0.001
Pigeonwood (*Hedycarya arborea*)	0.582 ± 0.014	119	0.888 ± 0.040	321	4.650	<0.001
Mahoe (*Melicytus ramiflorus*)	0.649 ± 0.020	203	0.940 ± 0.051	237	4.978	<0.001
Kamahi (*Weinmannia racemosa*)	0.719 ± 0.017	288	0.970 ± 0.079	152	4.062	<0.001
DCA axis 2						
Tawa (*Beilschmiedia tawa*)	3.430 ± 0.029	314	3.529 ± 0.115	126	1.148	0.252
Pigeonwood (*Hedycarya arborea*)	3.203 ± 0.036	119	3.553 ± 0.051	321	4.046	<0.001
Mahoe (*Melicytus ramiflorus*)	3.106 ± 0.034	203	3.760 ± 0.060	237	9.074	<0.001
Kamahi (*Weinmannia racemosa*)	3.666 ± 0.038	288	3.065 ± 0.079	152	7.785	<0.001



DCA score = 3.766 – cover score × 0.300
($r^2 = 0.176$, $t = -9.7$, d.f. = 438, $P < 0.001$)

DCA score = 3.311 + cover score × 0.548
($r^2 = 0.326$, $t = 14.57$, d.f. = 438, $P < 0.001$)



DCA score = 3.092 + cover score × 0.227
($r^2 = 0.120$, $t = 7.74$, d.f. = 438, $P < 0.001$)

DCA score = 3.306 + cover score × 0.313
($r^2 = 0.115$, $t = 7.53$, d.f. = 438, $P < 0.001$)

Figure 7. Relationships between A. mahoe (*Melicytus ramiflorus*), B. black beech (*Nothofagus solandri*), C. kamahi (*Weinmannia racemosa*) and D. rewarewa (*Knightia excelsa*) cover scores and Detrended Correspondence Analysis axis 2 scores. The lines of best fit, calculated using linear regression, are shown below each graph.

3.2 EVIDENCE OF UNGULATE IMPACT

The density of the sapling tier was generally low, and tree species that are preferentially selected by ungulates, such as mahoe and kamahi, had low sapling densities in comparison to seedling and tree densities (Table 4). Tawa and black beech, which are avoided species, also showed this pattern. The relative scarcity of saplings was evident in both the 1986/87 recce dataset and the 2000–2006 permanent plot dataset, although variance was high in the latter. Rewarewa and tawa, avoided species, and northern rata, which recruits ephiphytically, were the most common saplings in the permanent plots. The seedling tier was also dominated by avoided species (hookgrasses, bush rice grass *Microlaena avenacea* and crown fern *Blechnum discolour*), which become more common when ungulate numbers are high.

TABLE 4. MEAN DENSITIES OF SEEDLINGS, SAPLINGS AND TREES (STEMS/ha ± SEM), RECCE COVER SCORES (0–6 ± SEM) AND BASAL AREAS (m^2/ha ± SEM) FOR SPECIES WITH BASAL AREA ≥ 1 m^2 OR > 500 STEMS/ha AS SEEDLINGS, SAPLINGS OR TREES, OR FOR MEAN RECCE SCORE > 0.25.

Data are from 39 permanent 20 m × 20 m plots (2001–2006) and 470 recce plots (1986/87) established in and near Whanganui National Park. Results of a literature search on the palatability of these species (Nugent et al. 2000; Payton 2000; Forsyth et al. 2002; Husheer et al. 2003) are included. Totals exclude small lianes such as *Metrosideros diffusa*, as individuals of these species are difficult to count. '–' = not recorded.

SPECIES	PERMANENT PLOT SUMMARIES (2001–2006)			RECCE PLOT SUMMARIES (1986/87)			BASAL AREA	PALATABILITY
	SEEDLINGS	SAPLINGS	TREES	SEEDLINGS	SAPLINGS	TREES		
Trees								
Kamahi (*Weinmannia racemosa*)	5275 ± 253	4 ± 4	272 ± 52	< 0.1 ± 0.0	0.3 ± < 0.1	2 ± 1.3	18 ± 3.6	Selected
Mahoe (*Melicytus ramiflorus*)	128 ± 43	1 ± 1	205 ± 48	< 0.1 ± 0.0	0.4 ± < 0.1	1 ± 1.1	5.6 ± 1.5	Selected
Hinau (*Elaeocarpus dentatus*)	43 ± 24	1 ± 1	12 ± 5	< 0.1 ± 0.0	< 0.1 ± 0.0	0 ± 0.8	1.3 ± 0.5	Not selected
Miro (*Prumnopitys ferruginea*)	57 ± 34	2 ± 2	11 ± 4	0.0 ± 0.0	< 0.1 ± 0.0	0 ± 0.4	0.7 ± 0.5	Not selected
Northern rata (*Metrosideros robusta*)	< 1 ± 0	79 ± 38	< 1 ± 0	< 0.1 ± 0.0	< 0.1 ± 0.0	0 ± 0.5	2 ± 1.9	Not selected
Pigeonwood (*Hedycarya arborea*)	299 ± 112	4 ± 2	53 ± 14	< 0.1 ± 0.0	0.3 ± < 0.1	0 ± 0.1	1.6 ± 1.0	Not selected
White maire (*Nestegis lanceolata*)	100 ± 70	8 ± 4	8 ± 6	-	-	-	2.6 ± 2.4	Not selected
Pukatea (*Laurelia novaezelandiae*)	< 1 ± 0	< 1 ± 0	5 ± 3	< 0.1 ± 0.0	< 0.1 ± 0.0	0 ± 0.4	2.7 ± 1.7	Avoided
Rewarewa (*Knightia excelsa*)	584 ± 187	208 ± 105	118 ± 43	0.1 ± 0.0	0.2 ± < 0.1	1 ± 0.9	3.8 ± 1.2	Avoided
Tawa (*Beilschmiedia tawa*)	427 ± 191	62 ± 16	160 ± 39	0.4 ± 0.1	0.5 ± < 0.1	2 ± 1.4	7.6 ± 1.7	Avoided
Lianes								
Supplejack (*Ripogonum scandens*)	456 ± 242	239 ± 77		0.1 ± 0.0	0.2 ± < 0.1			Selected
Groundcover plants								
Hookgrass (*Uncinia* spp.)	2579 ± 679			0.2 ± < 0.1				Avoided
Bush rice grass (*Microlaena avenacea*)	1909 ± 991			0.3 ± < 0.1				Avoided
Crown fern (*Blechnum discolor*)	1595 ± 474			0.6 ± 0.1				Avoided
Kiwakiwa (*Blechnum fluviatile*)	513 ± 234			0.1 ± 0.0				Avoided
All species	**14 918 ± 2348**	**699 ± 168**	**1046 ± 97**			**8.6 ± 4.7**	**51.8 ± 6.0**	

3.3 ADEQUANCY OF THE PERMANENT PLOT NETWORK

Summaries of cover scores from 470 recce plots suggest that tawa is 20% more dominant in Whanganui forests than kamahi, although standard errors of these estimates are high (Table 4). In contrast, basal area summaries from 39 permanent plots suggest that kamahi has twice the dominance of tawa. White maire (*Nestegis lanceolata*) and northern rata are less common in permanent plots than in recce plots, while mahoe and pigeonwood may be over-represented in permanent plots.

Results of power analysis investigating the number of permanent plots needed to accurately identify changes resulting from ungulate control are shown in Table 5. Relatively few plots are needed to detect an increase in the overall density of saplings (e.g. 71 plots to detect a 50% increase), but many more are needed to detect changes in the density of saplings of individual species, especially those which have a lower initial density (e.g. over 1000 plots to detect a 50% increase in kamahi, beech or hinau). Fewer plots are required to detect larger changes (e.g. less than 100 plots are required to detect a 200% increase in most common species).

TABLE 5. NUMBER OF PLOTS REQUIRED TO DETECT VARIOUS MAGNITUDES OF INCREASE IN SAPLING DENSITY USING A ONE-SAMPLE *t*-TEST (TWO-TAILED, ALPHA = 0.05, POWER = 0.8).

SPECIES	50%	75%	100%	125%	150%	200%	300%
Tawa (*Beilschmiedia tawa*)	78	35	20	15			
Hinau (*Elaeocarpus dentatus*)	1396	623	349	226	156	88	39
Pigeonwood (*Hedycarya arborea*)	251	114	63	41	28	16	
Mahoe (*Melicytus ramiflorus*)	583	261	146	96	65	37	19
White maire (*Nestegis lanceolata*)	317	141	80	51	36	20	11
Black beech (*Nothofagus solandri*)	1018	455	255	165	114	64	29
Kamahi (*Weinmannia racemosa*)	1253	555	314	203	140	79	35
All species	**71**	**32**	**18**	**14**	**10**		

4. Discussion

4.1 FOREST CLASSIFICATION IN WHANGANUI NATIONAL PARK

There were only small differences in composition of the tree tier across WNP. Most species were found to be widespread throughout the Park. Although there is some evidence for separation of beech ridges and seral vegetation, the majority of recce plots were dominated by tawa and kamahi.

There were no strong relationships between forest composition and environmental variables. This may reflect limitations of the site description data. Studies that have identified such relationships have used more detailed landform classification systems (Burns & Leathwick 1996) and soil cores (Stewart et al. 1993). Qualitative descriptions of Whanganui forest (e.g. Baxter 1988) refer to hill slope position, drainage and whether soils are eroding or accumulating. These are not captured by the recce measures of slope and altitude. Some patterns may also have been obscured as a result of the plots being unbounded and subjective decisions being made about boundaries of landforms and vegetation types in the field.

Altitude is an important driver of vegetation composition across the New Zealand landscape (Burns & Leathwick 1996; Ogden 1997), and has been closely related to species turnover in time and space at other North Island sites (Husheer 2005, 2006). This was not observed at Whanganui, probably because the overall variation in altitude is low (mean ± SEM = 353 ± 118 m a.s.l., range = 30–525). There was also no relationship between the main DCA axes and latitude, despite some species, such as tawheowheo, being more common to the north. This is probably because these species are never very abundant and so do not greatly influence DCA.

4.2 EFFECTS OF INTRODUCED UNGULATES

The low abundances of seedlings, saplings and trees of common species (each assigned to a palatability class; Table 4) cannot be directly attributed to ungulate impact, but do reflect the anticipated effect of an uncontrolled goat population (as summarised in section 1.1). Findings from early studies (Levy 1923; Nicholls 1956) suggest that those species were more common as seedlings and saplings in the past. Groundcover composition also suggests ungulate impact. However, there is currently little information about the composition of the groundcover in Whanganui forests in the absence of ungulates, which may happen to be naturally dominated by avoided species.

The 'browse tier' in WNP is more open than in other North Island forests. Total sapling density in WNP (699 saplings/ha) is lower than that of karamu, pigeonwood, hangehange or pate alone in Egmont National Park, where there has been effective goat control (Husheer 2006). It is also lower than sapling density in the northern part of Pureora Forest Park in 1985/86 (2560 stems/ha; Clegg 1987). Densities of tawa seedlings and saplings (467 and 62 plants/ha, respectively) were much lower than the 1000/ha that has been suggested as 'probably adequate' for regeneration of that species in Te Urewera National Park (Smale 2006).

4.3 FUTURE VEGETATION MONITORING

The main aim of the WNP monitoring programme is to provide advice to managers about the effects of wild animal control operations. The programme will also provide information about long-term changes to forest structure and composition. Permanent plots are the best tool for long-term forest monitoring (Allen et al. 2003).

The fourth research objective, which aimed to identify which forest types are represented in the permanent plots established from 2001 to 2006, anticipated that different forest communities would be mapped and the plot network then stratified to ensure that all communities were sampled with less variance in each sample. However, the results show that WNP forest is homogenous, providing no justification for stratification.

Comparison of the abundance of common species in the two datasets suggests that the current permanent plot network may not be representative of Whanganui forests, as recce plots provided a much larger sample and were systematically located to give a representative sample (B. Fleury, pers. comm. 2007), whereas permanent plot locations have been biased by their proximity to access points and their avoidance of very steep slopes. Permanent plots also sample a larger area, including the Waitotara Conservation Area (CA) as well as WNP. A random allocation of points is the most reliable way of obtaining a representative sample (Griffiths et al. 1998).

Other plot networks used to measure herbivore impacts in North Island forests have ranged from 12 at Hihitahi Forest Sanctuary near Taihape (Mountier et al. 1984), to 47 in Egmont National Park (Husheer 2006) and 57 in northern Pureora (Clegg 1987), to over 200 in Tararua Forest Park (Husheer 2005).

The number of permanent plots required for vegetation monitoring depends on the magnitude of the change that needs to be detected: the smaller the change, the larger the number required (Griffiths et al. 1998). The magnitude of change that could be detected by a given number of plots depends on the initial density of the species considered. For instance, 40 plots would detect a 75% change in tawa density, but only a 300% increase in kamahi. Thirty plots should be sufficient to detect a doubling of tawa and of total sapling density, but more would be needed to detect a doubling in density of any less common or more variable species. Given the sapling densities that have been recorded in forests with successful ungulate management, changes of this magnitude are possible in the longer term.

When plots are remeasured, the sampling design at WNP will allow comparison of treated and untreated blocks before and after control. This will result in a greater ability to detect differences than the simple comparison simulated in the power analyses allows (Brown & Manly 2001), as will the comparison of repeated measures from the same plots (Legg & Nagy 2006). At present, there are 20 plots and five exclosures in areas receiving goat control, and 18[2] outside it (excluding CMS plots), of which ten are in the Waitotara CA.

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[2] One exclosure and seven unfenced plots were established in summer 2007/08 and were not included in this analysis.

Until 2008, funding has allowed for the measurement of approximately ten permanent plots per year in Whanganui forests. This has resulted in the gradual accumulation of a plot network over nearly 10 years and has provided some useful information. A measurement scenario whereby all new plots are established over one field season, existing plots are remeasured the following season, and the entire sample is remeasured after 10 years would allow more accurate quantification of rates of change over the entire site (J. Hurst, Landcare Research, pers. comm. 2007).

5. Conclusions

The forests of WNP are a homogenous mixture of tawa and kamahi, with occasional distinctive communities dominated by beech or seral species. The scarcity of saplings, particularly of palatable species, suggests that the forest continues to be damaged by ungulates.

There are no grounds for stratified sampling of different forest types. High variance at the local scale means that the permanent plot network should be increased to provide better information about forest structure and composition, and the effects of ungulate management.

6. Recommendations

Based on the findings from this study, the authors make the following recommendations:

- Animal control operations in WNP and adjoining forests should continue. The area under sustained ungulate control should be extended to allow sapling and tree recruitment.
- The sample of permanent plots should be increased to at least 60 plots (including seven exclosures): 20 in the Matemateaonga goat management area (15 plots and five exclosures), ten in the Mangapurua goat management area (eight plots and two exclosures) and 30 outside the goat control areas (spread across WNP and Waitotara CA). If resources permit, the sample should be increased to 70 plots: 30 in the management areas as above, 20 in parts of WNP outside the goat control area and 20 in Waitotara CA. If additional resources are available, priority should first be given to reducing the number of years over which plots are measured, followed by further increasing the sample size.

- Fenced exclosures are the best available tool to measure ungulate impact in the medium term (Coomes et al. 2003). The existing five plots in the Matemateaonga goat management area should be supplemented by two more in the Mangapurua goat management area and, if possible, one in the river trench goat management corridor. Exclosures will continue to be subjectively sited according to access and fencing constraints. A common technique for determining the effects of ungulates is comparison of a small, subjectively sited set of exclosures with a larger, representative set of unfenced plots (Bellingham & Allen 2003). This should be adopted in WNP.
- In the short term, representative information about the outcomes of wild animal control should also be obtained using rapid assessment methods such as the Seedling Ratio Index, a technique developed to provide an efficient measure of ungulate impact on forest (Sweetapple & Nugent 2004), and FBI to quantify possum impact (Payton et al. 1999). These do not have the same location constraints as exclosure plots.

7. Acknowledgements

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