Survey of localised kamahi *(Weinmannia racemosa)* dieback in Tongariro National Park

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Published by
Department of Conservation
Head Office, PO Box 10-420
Wellington, New Zealand

This report was commissioned by Tongariro/Taupo Conservancy.

ISSN 1171-9834

Reference to material in this report should be cited thus:

McBreen, K., 1999.
Survey of localised kamahi *(Weinmannia racemosa)* dieback in Tongariro National Park. *Conservation Advisory Science Notes No. 260,* Department of Conservation, Wellington.

Keywords: kamahi, *Weinmannia racemosa,* tree dieback, Tongariro National Park.

1. Introduction

Health of kamahi (*Weinmannia racemosa*) inTongariro National Park is causing concern especially around Hauhungatahi on the western side of the Park.

This report to the Department of Conservation provides a summary of a survey conducted by the Department of Conservation and Kim McBreen. The survey investigated this area and attempted to determine any causes, using the decline-disease model of forest dieback. The reader is referred for further information to McBreen (1999).

2. Aims and approach

This study focuses on the western side of Hauhungatahi, an area of Tongariro National Park where kamahi dieback is most marked. Transects are randomly located at the forest margin and allocated random orientations into the area to be sampled (Druitt 1985). Although not strictly random, this design allows samples to be treated statistically as if they are random (Hurlbert 1984). All kamahi trees within each quadrat are included in the study, to show the pattern of healthy as well as unhealthy kamahi trees (Acker et al. 1996); details that may affect the level of kamahi regeneration at each quadrat (ground cover and deer browse on kamahi) have also been recorded.

2.1 MEASURES OF HEALTH

Crown density and proportion of dead terminal shoots are recorded as measures of stem health. Crown density is most appropriate for studying changes in health of a stem over time, while proportion of dead terminal shoots is a more direct measure of stem health. The numbers of trees that are dead or very unhealthy in each quadrat, as well as the mean score for dead terminal shoots at that quadrat, have been used to provide measures of stand health. A multitude of dieback variables has been included because little is known of the nature of dieback, or how to measure it; these different ways of measuring dieback should allow every opportunity for meaningful relationships to be detected.

2.2 POSSIBLE CAUSES OF DIEBACK

The decline disease model of forest dieback (Houston 1974; Mueller-Dombois 1988; Manion 1991) categorises factors potentially involved in kamahi dieback as those most likely to predispose certain trees to die, those that may trigger a decline in health that may lead to death, or those that hasten death in trees already declining. By comparing each of the factors studied to a measurement of stem or stand health, it may be possible to determine the role each is playing. If any of the factors suggested to predispose trees to dieback are consistently associated with stands or stems in poor health, and not usually with stands in good health, then those factors are likely to be contributing to the pattern.

Most of the factors suggested as potential 'triggering' or causal factors may instead be hastening factors, which can be confused with the causal factor, or lead investigation away from the proximal cause (Stewart & Veblen 1983). In some cases a particular factor may cause dieback, while in another case it may merely hasten death in an unhealthy tree; whereas it is usually clear that predisposing factors are not causing death, as they have usually been associated with a stand over the whole lifetime of the trees involved. If a factor is consistently associated with dead or dying trees, but not with more healthy trees, it is likely to be a hastening factor. Causal factors are more likely to be associated with stems in declining health. Thus, it is the relationships between each factor studied and measurements of health that are most relevant to this study.

Predisposing factors

Many authors have suggested age affects susceptibility to dieback (for example Stewart & Rose 1988; Payton 1987). Lusk (1989) found a very tight relationship ($y=48.38+5.53x-0.058x^2+0.0004x^3$, $r = 0.87$, $P<0.0001$, $N=200$, $y=\text{age}$, $x=\text{DBH}$) between diameter at breast height (DBH) and age from sections of generally large kamahi taken at approximately 650-700 m a.s.l. on the south-western side of the Park, an area very close to that studied here, but at a slightly lower and more limited altitudinal range. In this study, stem age is measured indirectly by DBH, rather than directly by tree coring, which is more invasive and much more time-consuming. DBH has not been converted to age using the above formula because the relationship is unlikely to be linear over the life of a stem. Also, there will be considerable variation between trees growing under different environmental constraints, for example at different altitudes, on different soil types, or under different light regimes.

Stewart & Rose (1988) comment that young stands are less susceptible to dieback, while stands with a high proportion of old trees are more susceptible. In the present study, quadrats have been put into age categories based on the size distribution of trees within them in order to investigate the effect of stand age.

Stand density can predispose trees to dieback, as competition is higher in denser stands (Peet & Christensen 1987). Conversely, high stem density implies the stand is recently established.

In the southern Ruahine Range, Rogers & Leathwick (1997) found slope, aspect and altitude could predispose forests to poor health. Stands with slopes greater than 20°, and stands with western (and to a lesser extent northern) aspects were more susceptible to dieback, while mid-altitude forests were less susceptible. Each of these factors has been measured directly in the present study.

Cowan's (1997) study of rata dieback in the Orongorongo Valley found exposure and distance from forest edge were important; in the present study, exposure is measured on a subjective scale, while distance from forest edge is measured directly.

Landsberg & Gillieson (1995) comment that soil drainage can affect nutrient levels and tree health, and Akashi & Mueller-Dombois (1995) found drainage to be the key factor in Hawaiian rain-forest dieback; in the present study, a subjective scale is used to compare drainage at each quadrat.

Percentage of kamahi in the canopy is estimated in the present study to determine if more or less monocultural stands are predisposed to dieback.

Whether a stem represents a portion of a multi-stemmed tree or a single-stemmed tree was recorded and is included to determine if either may predispose kamahi trees to dieback.

Triggering factors

In kamahi dieback, possum browse is usually considered to be the trigger factor (e.g. most recently Clarkson & Clarkson 1995; Payton et al. 1997). However, insects can also be trigger factors (Landsberg & Gillieson, 1995). In the present study, to overcome the problem of estimating absolute levels of browse, a scale is used for comparing the relative intensities of possum browse and insect browse in the crown of each stem.

Pathogenic fungi such as *Sporothrix* (Payton 1989) may also trigger dieback. *Sporothrix* presence is here measured indirectly, through presence or absence of its vectors' entry holes on the stem.

Accelerating factors

Accelerating factors can also be very important in dieback; the importance of these secondary factors is highlighted by Rogers & Leathwick (1997) who found that in the southern Ruahine Range, canopy collapses have been due to possum browse, but once started, collapse continues irrespective of levels of possum defoliation. Payton (1988) had previously examined the effect of canopy closure, a measure of stand collapse, in Westland rata-kamahi forest, and found that where possum browsing resulted in canopy opening, exposed leaf bunches continued to deteriorate, even in the absence of further browsing. Rogers & Leathwick (1997) suggest mechanical damage from wind in canopies opened by possums may hasten collapse, while Payton (1988) comments that trees already opened by browse were browsed to much lower levels than intact trees, and suggests the increased light affects palatability of foliage. Payton (1988) also found that level of canopy closure was only important in stands that had already undergone natural thinning (i.e. mature stands). In the present study, quadrats' canopies are classed as either open or closed, and the percentage of canopy cover estimated.

Rogers & Leathwick (1997) suggested outbreaks of defoliating insects attracted by damaged trees (also Agyeman & Safo 1997; Payton 1987) contributed to the canopy collapse; insect browse is measured in the present study as described above. Fungal (Agyeman & Safo 1997) or more specifically *Sporothrix* (Payton 1987) attacks, may hasten dieback; *Sporothrix* presence is assumed from presence of *Platypus*, as described above. Possum browse may also be a hastening factor rather than, or as well as, a trigger factor (Stewart & Veblen 1983); for example, canopy mortality may lead to a 'richer' understorey, which may attract possums; estimation of possum browse in the present study is outlined above.

Statistical approach

In studies of dieback, multiple regression is often considered to be the best way to establish which of a number of variables is most likely to be affecting tree health (for example Manion 1991; Fisher 1997; Rogers & Leathwick 1997). However, multiple regression may be inappropriate if 'independent' variables are highly correlated (Sokal & Rohlf 1995), as they almost certainly are in the present study, and are likely to be in most surveys. For this reason correlations and principal components analysis (PCA) have been used in the present survey.

3. Method

The survey of kamahi in areas of dieback was undertaken during the summer of 1997/1998.

3.1 SITE SELECTION

All 30 quadrats are on the western face of Hauhungatahi, on one of three transects laid by the Department of Conservation (Fig. 1). Transects are numbered from 2 to 4 to coincide with Department of Conservation data. The centre of the first quadrat on each transect is 100 metres from the randomly located transect origin at a randomly allocated direction into the forest. The centres of subsequent quadrats are located at 100 metre intervals (ground distance) on that orientation. Each quadrat is 20 m x 10 m, with the long side perpendicular to the transect.

3.2 SITE CHARACTER

Details of the physiognomy of each quadrat were recorded. Slope and aspect were measured on site; altitude and distance from the nearest forest edge were later determined from topographical maps. Level of exposure is on a scale of 0 to 2, where 0 is not exposed and 2 is very exposed, particularly on ridges. Canopy closure was scored as 0 if open, and 1 if closed. Drainage is on a scale of 1 to 5, with 1 free-draining (usually on a slope) and 5 if water is able to `pond'. Number of kamahi stems and number of stems of all species at each quadrat are from Department of Conservation (unpubl.) data. The height of the canopy was estimated, as were percentage ground cover (vegetation less than 1 metre high), percentage canopy cover, and percentage of kamahi in the canopy. Stand age categories have been established based on frequency distributions of DBH of all trees in each plot.

3.3 TREE HEALTH

Within each quadrat, DBH of each kamahi tree was measured. All stems greater than 3 cm in diameter were included. If two or more stems originated from one root bole, they were scored separately, but were recorded as stems (1), while single-stemmed trees were scored as trees (2). Crown, or foliage, density was measured where possible using the Manaaki Whenua scale. If the canopy was overlapping to an extent that crown limits could not be determined, no score was recorded.

Stems were scored for possum browsed, insect browsed, and deer browsed leaves (where leaves are present at a height accessible to deer, i.e. less than 2 metres) as a proportion of all leaves (Table 1), or in the case of deer browse, as a proportion of all accessible leaves. Distinguishing between possum and insect browse was based on the shape of damage to the leaves (see Meads 1976). Again, for some trees this was not possible, as their leaves could not be distinguished from those of surrounding trees.

Presence or absence of pinhole borer on the trunk was recorded.

The proportion of dead terminal shoots was estimated on a linear scale from 0 to 6 (Table 2). Where the stem being scored was dead, there was a further score for approximate time since death (Table 2).

4. Results and discussion

'Dieback' refers to a multi-factor cause of tree death (Houston 1992). This makes understanding the dieback difficult, as the factor that ultimately causes death may be a long way along a process of decreasing health (Franklin et al. 1987). 'Decline' refers not to individual trees, but is a stand phenomenon, where so many of a species are undergoing dieback that the population is declining locally.

4.1 CHARACTER OF KAMAHI DIEBACK

This survey of kamahi dieback covers 30 quadrats on three transects within this area, amounting to 6000 square metres. Quadrats include a range of altitudes within the limits of kamahi distribution in this area, from near the forest edge to well within the forest, a wide range of slopes, a range of the westerly aspects, medium and low exposure levels, high and low canopy closure and cover as measured in this study, good to poor drainage, a wide range of canopy heights, stand ages and kamahi cover. Mean scores for dieback at each quadrat, and numbers and proportions of dead and dying kamahi stems were assessed in relation to these site factors to determine their effect. In most cases, significant correlations would indicate the more likely predisposing factors, but for some, such as canopy closure, could also indicate a possible hastening factor.

The 800 kamahi stems included in the study ranged widely in DBH (and therefore probably in age), in level of insect or possum predation, and some were attacked by pinhole borer while others were not. Significant correlations between any of these variables and either of the measures of stem health (crown density or dead terminal shoots) would indicate likely triggering or hastening factors.

Results from stem data show that dieback is affecting a considerable proportion of kamahi stems in this study, with approximately 14 % dead, and a further 6.7 % dying. Very few data are available to indicate the proportion of dead and dying trees that would be expected in healthy forests. This proportion of dead and dying trees warrants consideration of the causes.

4.2 PREDISPOSING FACTORS

There were few significant relationships between any of the suggested predisposing factors and any measure of stem or stand health in this investigation (Appendix 1).

There was no correlation between health and DBH (a measure of age), but there was a significant difference in the distributions of DBH for live and dead stems, with dead stems having a significantly larger DBH, and live stems much more likely to be in the smallest size class than dead stems (Fig. 2). Dead stems were over-represented in the second smallest size class compared with live stems. Mortality in stands of the smallest size class (less than 13 cm DBH) may be before competition becomes important in thinning out young stems (Peet & Christensen 1987), while mortality in the second size class (over 13 cm up to and including 23 cm DBH) may represent the age where competition severely thins the cohort.

There is no evidence from this study that stand age plays any role in kamahi dieback, i.e. all measures of health at quadrats varied independently of stand age. Stand density also does not appear to be involved in kamahi mortality in this study. Stand density is largely another measure of stand age.

This study found no effect of slope or altitude. All quadrats in the present study are within a relatively narrow upper lowland-lower montane altitudinal range. Higher levels of dieback were just as likely to occur at the lower limits of this range as they were at the higher limits.

There was a barely significant correlation between the east-west component of aspect and the average kamahi health at a quadrat (Table 3): more westerly sites were found to have better health. In the present study of the western slopes of Hauhungatahi, the least westerly aspect recorded was 210°. On a west-facing hill such as Hauhungatahi, any deviation from west will increase the likelihood of shade during much of the day; therefore stands with more westerly aspects are likely to have a slightly greater photosynthetic potential than stands whose aspects are considerably different. This greater photosynthetic potential may increase a stand's resilience to adversity.

Neither exposure nor distance from forest margin (with nearly all but 2 sites within 1 kilometre, and most less than 500 m, from the edge) had any effect on kamahi health. The site closest to the forest edge (transect 3 quadrat 1, 75 m from edge) has a very high percentage of dead kamahi stems (41.9 %), but the site with the highest level of kamahi mortality (transect 4 quadrat 9) is 1 kilometre from the forest edge. While not highly exposed, many of the plots on transect 4 are a relatively great distance from the edge of the forest, but relatively close to the Makatote Gorge (only a few hundred metres). From the road which runs parallel to the western edge of the forest, it appears that trees within approximately 10 m of the edge are very unhealthy. This study includes no sites this close to the forest edge and our data do not indicate a higher susceptibility to dieback at sites closer to the forest margin.

There was a significant relationship between drainage score and percent of kamahi stems that were dying at each quadrat (Fig. 3a); however this relationship depended on one anomalous site, where kamahi was clearly not at its best (transect 3 quadrat 3, with a single dying kamahi).

Neither percent of the canopy that is composed of kamahi nor whether trees are multi- or single-stemmed affected the health of kamahi in this study.

A strong correlation was found between canopy height and percent of kamahi stems dying (Fig. 3b). Again this relationship was dependent on the one anomalous site, and when this was removed from the analysis, there was no relationship.

A principal component analysis, which summarises the site character data into a few variables explaining most of the variation, offers no further insight (Fig. 4). Quadrats do not cluster according to health when they are mapped on the two longest components. There is a nearly significant relationship between the number of kamahi stems dying at a quadrat and its score on component 2 (Table 4). This relationship is dependent on one quadrat with a much greater density of dying kamahi stems; removing this site from the analysis shows the variation to be entirely random. There is another nearly significant relationship between the percent mortality of kamahi stems and score on component 2 for each quadrat, which is dependent on the quadrat with the highest score for percent dead kamahi, and without which is nowhere near significant.

4.3 TRIGGERING AND ACCELERATING FACTORS

These two classes of dieback factors are discussed together, as most accelerating factors are also capable of triggering dieback in different circumstances, and vice versa. Again, results from the present study offer no clear answers.

There is no relationship between recorded levels of possum browse and either measure of stem health used in this study (crown density: all stems r=-0.02, live stems r=-0.04; dead terminal shoot class: all stems r=0.08, live stems r=0.1). Department of Conservation (unpubl.) data give the trap catch rates for possums on transect 2 as 20.0%, transect 3 as 3.4%, and transect 4 as 11.8%. Transect 2, with the lowest incidence of dead kamahi stems (8.5 %), clearly has the highest recorded rate of possum catch, while transect 3 has the lowest recorded incidence of possums, and the highest rate of dead kamahi stems (22.6 %). While these results can be explained as possums building up in numbers, eating an area to death and moving on to a new healthy patch, and thus having high densities at healthy areas (which they are about to annihilate) and low densities at unhealthy areas (which they have already destroyed), there is no evidence from this study to make such an interpretation anything but speculation. Interestingly, the level of possum browse recorded and trap catch rates for possums on the transects are not related. There are three likely explanations: trap catch rates are a poor estimation of possum density or usage in an area, as suggested by Batcheler et al. (1967); the method used for estimating levels of possum browse in the canopy is poor, as discussed by Leutert (1988; and previously Meads 1976); or possum density is only one factor in the level of possum browse on kamahi in this area, and other factors may be of enough importance to disrupt the relationship. There is no evidence from the present study to suggest that possums are causing kamahi dieback, or accelerating any dieback caused by other factors. Many studies of dieback in other New Zealand forests have found possums are an important factor in mortality of some species, often including kamahi, in those forests. In some of these studies, evidence has been largely circumstantial (as discussed by Leutert 1988) and few have focused on kamahi.

There was no relationship between insect browse and stem health. In New Zealand, insects have generally only been suggested as accelerating factors in tree mortality (e.g. Payton 1987); however, there is no evidence from the present study to suggest them as even having that role for kamahi in Tongariro National Park.

There is clear evidence supporting the hypothesis that *Sporothrix* is not a causal factor, but may be a contributing factor to kamahi mortality. When all stems are included in analysis, pinhole borer, the vector for *Sporothrix* fungus, is significantly more likely to be present when crown density is low, and when level of dead shoots is high. When only live stems are included, these relationships are no longer significant, showing that pinhole borer is not causing a decline in stem health. When only dead stems are looked at, these relationships are again not significant; however, this is because dead stems all have a dead shoot score of 6 (defining them as dead), and have very low crown densities (i.e. only 4% of dead stems have a crown density greater than 1%), while 82% of dead stems contain borer. That this relationship breaks down when dead and live stems are analysed separately, combined with most dead stems containing borer, strongly implies pinhole borer or *Sporothrix* are at most hastening factors rather than actually causing any decline in health. This adds support to those authors who have suggested *Sporothrix* as a symptom rather than a cause of declining health (particularly Hosking 1993a; 1993b).

Canopy closure was not found to be related to kamahi health. Several authors have found that it may play a role in dieback (mainly Payton 1988; Rogers & Leathwick 1997), but with the few quadrats in this study with very high levels of kamahi dieback, it is unlikely if a relationship existed that it would be found.

4.4 SUMMARY

The only factor this study has any evidence to suggest as predisposing kamahi stems to dieback is age, as measured by stem DBH, with older stems more susceptible than younger stems. Even for this factor, the evidence is not compelling, and further investigation would be necessary to confirm its importance. This study provides further support to the hypothesis that *Platypus* tend to invade trees that are in poor health, and any *Sporothrix* infestation only serves to amplify the decline in health. It fails to find any link between site factors and tree health. It also fails to find any 'triggering' or causal factor of kamahi dieback. There is no evidence to suggest possums are having an impact on the health of kamahi in this study area. The initiating cause of the dieback remains unknown.

4.5 RELATIONSHIP TO 1997 SURVEY

This survey is consistent with the findings of McBreen's 1997 thesis draft, which found that kamahi dieback was occurring at a localised level; however, on a larger scale, including all the National Park and surrounding forests where dieback had been reported, it was only affecting a small proportion of kamahi trees (ca. 4%). Age of trees was implicated more strongly as a predisposing factor in the localised areas of high dieback, than on a broad scale.

One reason for the different levels of dieback recorded in the 1997 draft (McBreen 1999: chapter 2) and the present survey is the difference in the way death was recorded in each of the surveys. The present study scored and recorded each stem of multi-stemmed kamahi individually, whereas the earlier survey scored all stems of a tree together as a single tree. If one or more stems of a multi-stemmed tree were alive, that tree would be scored as living in the earlier survey (regardless of how many stems were dead); while in the present study, dead stems would be recorded as dead, and live as alive. Unfortunately, from the data that were (or were not) collected in each of these surveys, there is no way to correct for this difference, or to predict the severity of its effect, except that sites with few multi-stemmed trees or with a lower stem frequency of dieback should be less affected by this methodological difference than sites with many multi-stemmed trees or higher levels of dieback.

Another possible explanation for the difference in rates of dieback recorded in each survey is the patchiness of that dieback. For example, transects 2 and 3 of the present survey recorded very different rates of dieback (8.5% and 23% respectively) despite being located only approximately 1000 m from each other. Even within transects dieback was extremely variable: on transect 4, quadrat 8 recorded 3% of stems dead, whereas quadrat 9 (100 m from quadrat 8) recorded 58% of stems dead. With this degree of variability in mortality levels, it is possible that one survey has missed healthy patches, or 'hit' a disproportionate number of unhealthy patches, or that the other survey struck a disproportionate number of healthy patches and missed unhealthy ones.

Therefore the different levels of dieback reflect the different methodology used in each survey, with the method used in the present study *guaranteed* to find higher rates of mortality in a large survey, and may also reflect the patchiness of the dieback, with transect 2 (and the first 8 quadrats of transect 4) of the present study and all but one or two sites of the earlier survey missing patches of heavy mortality (or transect 3 of the present study missing the patches of healthy kamahi).

5. Management implications

5.1 TREATMENT OF DIEBACK

Attempts at managing patches of dying kamahi, for example, by banding for possums or fungicide treatment for *Sporothrix*, will be expensive and time-consuming, and are unlikely to be successful.

5.2 MAINTENANCE OF POSSUM DENSITY

Reducing density of possums is unlikely to have much effect on the health of kamahi in the area studied, as they do not appear to be exerting much influence over kamahi health; however, this may be due to currently low densities of possums in the National Park. If possum densities increase, possums may affect the health of kamahi; therefore, it is advisable that possum densities be maintained at (or below) the present densities.

5.3 DISSEMINATION OF INFORMATION TO PUBLIC

The Department of Conservation manages New Zealand's national parks on behalf of the public of New Zealand. When an apparently high density of dead trees is visible from a main highway, as is the case with the western side of Tongariro National Park, members of the public are bound to become concerned (see also Mueller-Dombois 1983). Information regarding the nature of kamahi dieback and the scale of its occurrence should be made available to the public, in order to assuage these concerns.

5.4 RESEARCH

When visible dieback of the dominant canopy species of an area occurs, there is a tendency to assume, first, that there is a problem, and second, that there is a simple solution. It is important to first identify whether this dieback is likely to be abnormal or problematic, before trying to isolate possible causes. This will involve research and, ideally, long-term monitoring. Monitoring is the key to increasing our understanding of forest processes, and without an understanding of these, it is very difficult to make appropriate management decisions regarding our forests. Health of trees and forests needs to be tracked over time along with any factors considered to affect health. The difference in results between the present survey and the earlier survey (McBreen 1999: chapter 2) highlights the importance of where and how research is conducted: if results are to be compared to previous work, it is necessary to ensure data of a similar type are collected. Experimentation is the key to determining the causal factors in any forest dieback.

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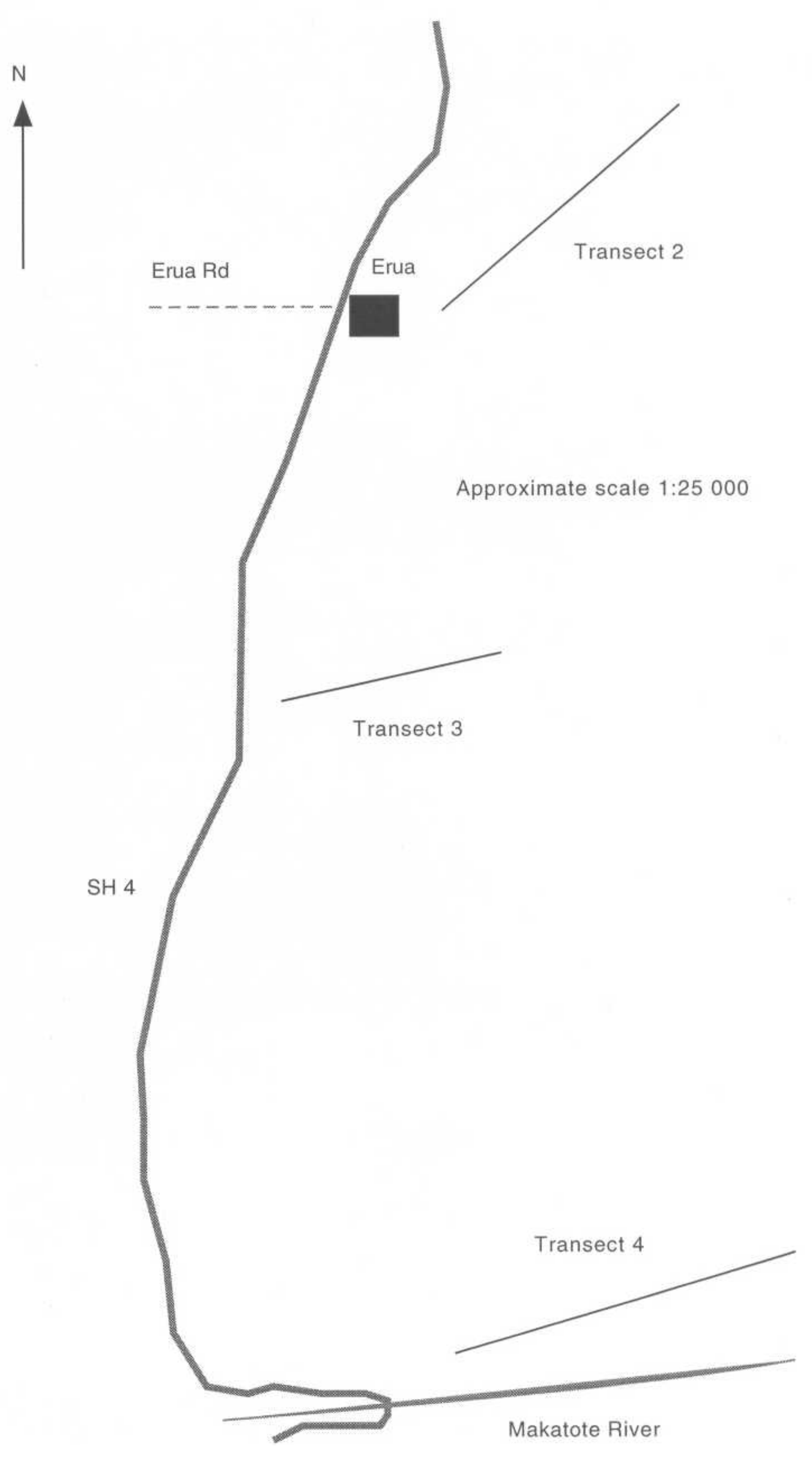

Figure 1. Approximate location of transects on western side of Tongariro National Park

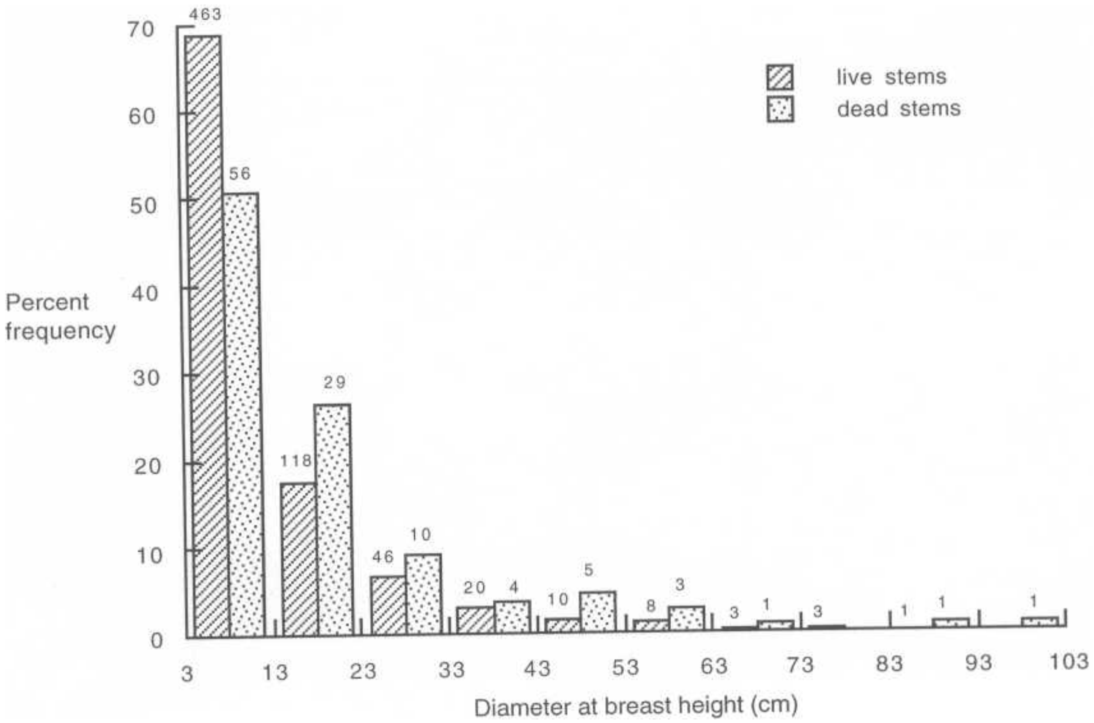

Figure 2. Frequency by percentage of diameter at breast height for live and dead stems of all quadrats. Actual numbers of stems in each size class are given above bars; total number of trees included is 782, with 672 live and 110 dead.

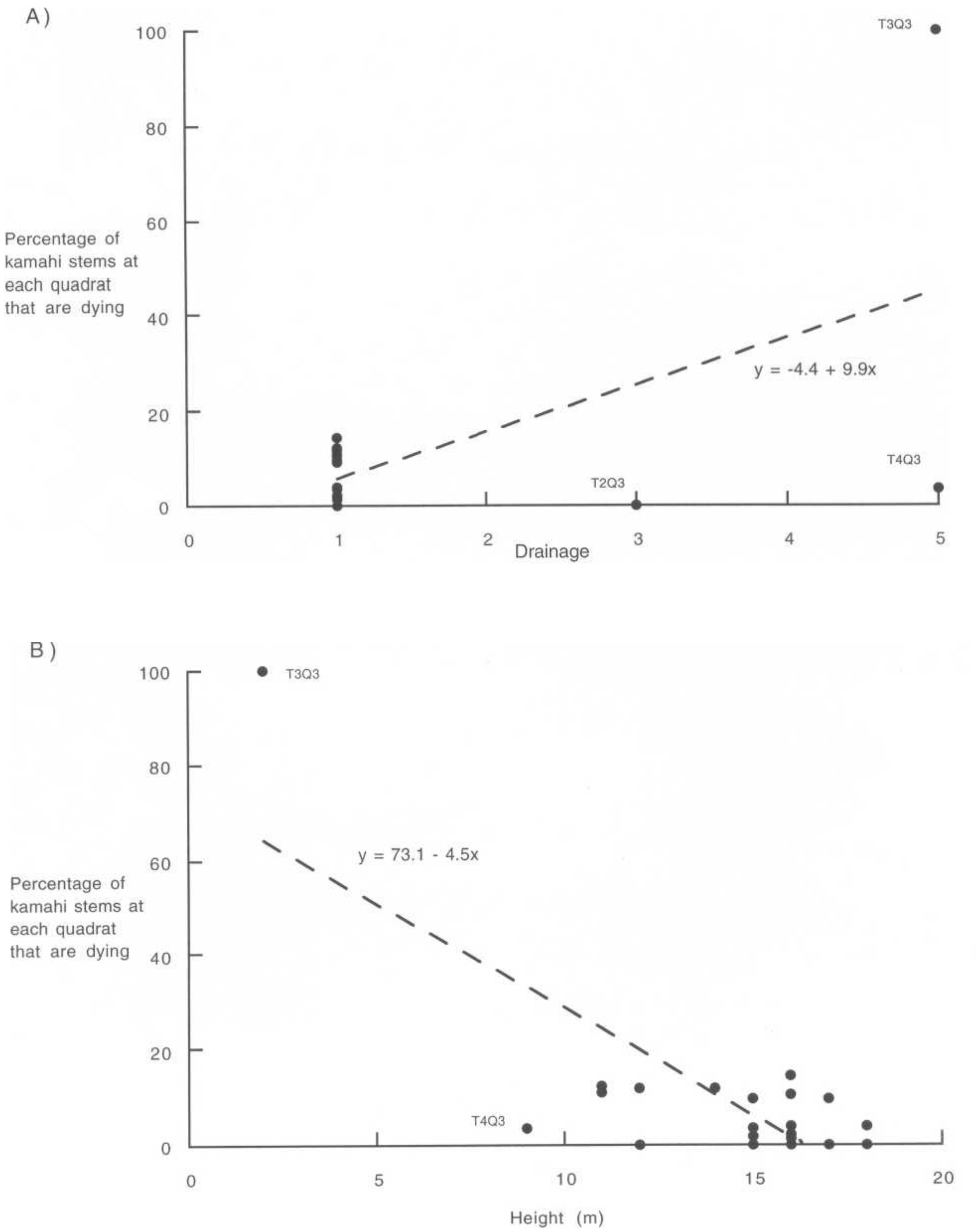

Figure 3. A) Relationship between the percentage of kamahi stems dying and drainage score for each quadrat. r=0.59. B) Relationship between the percentage of kamahi stems dying and canopy height at each quadrat. r=0.78. Outliers for each are labelled with transect (T) and quadrat (Q) number; dashed lines indicate linear regression.

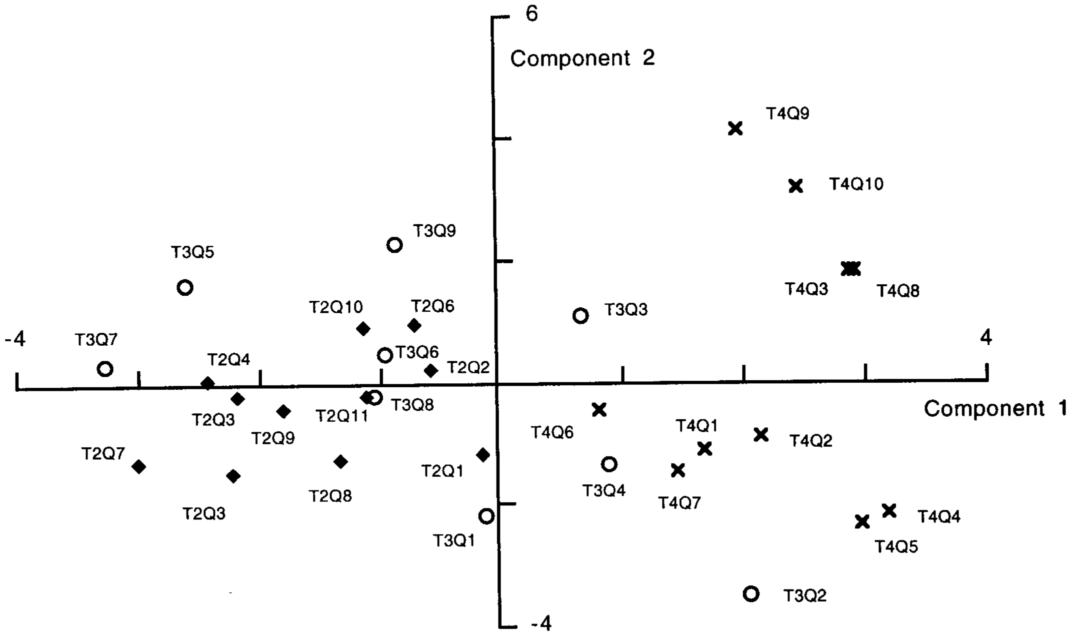

Figure 4. Location of quadrats on first two principal components of site character data. Diamonds are quadrats on transect 2, open circles on transect 3, and crosses on transect 4; quadrats are labelled with transect (T) and quadrat (Q) number. Component 1 explains 28.3% of variance, component 2 a further 20.9%.

Table 1. Scale used for scoring possum-, insect- and deer-browse in stems. Where there were no live leaves, or leaves from the stem to be scored could not be distinguished from those of other stems, the stems were scored as x.

Score	Level of damage	Proportion of leaves browsed
0	nil	0
1	light	1-25
2	moderate	26-50
3	heavy	51-75
4	severe	76-100%
x	unable to estimate	

Table 2. Scoring of stem health. All stems were scored for dead terminal shoots; dead stems were also scored for time since death. Where the crown from the stem to be scored could not be distinguished from other stems it was not scored.

Score	**Proportion of dead terminal shoots**	
0	0	
1	1-19	
2	20-39	
3	40-59	
4	60-79	
5	80-99	
6	100 % stem appears dead	
	Time since death	**State of stem**
1	very recent	very fine twigs present, still has dead leaves
2	recent	fine twigs
3	dead	main branches, some twigs
4	long dead	large branches only, stem may be broken
5	very long dead	rotten stem

Table 3. Significant correlations between site variables and dieback variables (where 1 r 1 >0.5, and P<0.005). Correlations with P>0.005 but 1 r 1 >0.5 are included in italics.

Relationship	**d.f.**	***r*-value**	***P*-value**
Kamahi average x EW	*21*	*-0.59*	*0.0207*
% dead kamahi x Ground cover	29	0.50	0.0045
% dying kamahi x Drainage	21	0.59	0.0040
% dying kamahi x Canopy height	20	-0.78	<0.0001

Table 4. Component loadings on first three principal components of site data and relaionship to measures of stem mortality.

Variable	**Component 1**	**Component 2**	**Component 3**
Altitude	-0.08	0.38	0.85
Slope	-0.80	0.09	0.40
NS	0.60	-0.16	0.12
EW	0.63	0.31	-0.20
Exposure	-0.69	-0.05	0.08
Closure	0.04	-0.72	0.38
Drainage	0.37	0.73	-0.03
Distance	0.28	0.58	0.62
Ground cover	-0.05	0.65	0.02
Canopy cover	-0.13	-0.81	0.35
Kamahi cover	0.51	-0.07	0.74
Stand age	-0.65	0.17	0.11
Density	0.82	-0.13	-0.04
Kamahi density	0.71	-0.37	0.12
Dead stems (all species)	0.57	0.12	0.12
Density dead kamahi	0.35	0.14	-0.01
Dnesity dying kamahi	0.30	-0.44	-0.03
Average kamahi health	-0.09	-0.17	-0.07
Dead stems (%)	0.23	0.31	0.31
Dead kamahi (%)	0.17	0.45	0.08
Dying kamahi (%)	0.09	0.24	-0.39

Appendix 1.

Correlations between all site variables to 2 decimal places. Correlations where 1 r 1 >0.5 are in bold. Variable names are listed in full down the side and abbreviated across the top.

Variable	Alt	Slp	NS	EW	Exp	Cls	Drg	Hgt	Dst	Gd%	Cc%	Kc%	Age	Dty	Kdy
Altitude		.46	-.05	.23	.11	.02	.19	.27	**.70**	.22	.02	.49	.12	-.14	-.08
Slope	.46		-.50	.06	.65	.01	-.24	.39	-.01	.16	.11	-.11	.39	**-.55**	-.46
Aspect - NS	-.05	**-.50**		.02	-.14	.26	-.12	-.37	.24	-.16	.10	.45	-.28	.32	.48
Aspect - EW	.23	.06	.02		.15	-.30	-.16	.19	**.54**	-.41	.10	-.16	-.13	-.27	-.11
Exposure	.11	**.65**	-.14	.15		-.12	-.32	.14	-.12	-.18	.08	-.31	.31	-.41	-.38
Closure	.02	.01	.26	-.30	-.12		-.41	.25	-.24	-.29	**.70**	.32	.02	.02	.26
Drainage	.19	-.24	-.12	-.16	-.32	-.41		**-.58**	**.50**	.29	**-.54**	.10	-.10	.23	-.15
Height	.27	.39	-.37	.19	.14	.25	**-.58**		-.01	-.03	.35	.13	.22	-.21	.14
Distance	**.70**	-.01	.24	**.54**	-.12	-.24	**.50**	-.01		.20	-.21	.48	.00	.07	.00
Ground cover %	.22	.16	-.16	-.41	-.18	-.29	.29	-.03	.20		**-.64**	-.00	.17	-.08	-.10
Canopy cover %	.02	.11	.10	.10	.08	.70	**-.54**	.35	-.21	**-.64**		.19	-.04	-.04	.09
Kamahi cover %	.49	-.11	.45	-.16	-.31	.32	.10	.13	.48	-.00	.19		-.21	.42	.47
Stand age	.12	.39	-.28	-.13	.31	.02	-.10	.22	.00	.17	-.04	-.21		**-.58**	-.48
Density (all species)	-.14	**-.55**	.32	-.27	-.41	.02	.23	-.21	.07	-.08	-.04	.42	**-.58**		**.75**
Kamahi density	-.08	-.46	.48	-.11	-.38	.26	-.15	.14	.00	-.10	.09	.47	-.48	**.75**	