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MAGNITUDE OF CANOPY DIEBACK AND IMPLICATIONS FOR CONSERVATION OF SOUTHERN RATA-KAMAHI *(METROSIDEROS UMBELLATA - WEINMANNIA RACEMOSA)* FORESTS, CENTRAL WESTLAND, NEW ZEALAND

Summary: The amount of conspicuous canopy dieback in all central Westland southern rata-kamahi forests east of the Alpine Fault, between 500 m altitude and treeline, was assessed and mapped from aerial photographs taken in 1984-85 and verified by aerial reconnaissance of selected areas in 1988. At least 20% of all canopy trees, predominantly southern rata *(Metrosideros umbellata)* and Hall's totara *(Podocarpus hallii),* were dead in 1984-85. Major catchments with their headwaters east of the Alpine Fault comprised 78% of the study area and were worst affected (5%-44% canopy mortality). Because affected trees decay and eventually disappear from the canopy, the extent of visible dieback underestimated total canopy depletion, particularly where mortality occurred more than *c.* 15 years ago. Geographical variation in canopy dieback reflected the intensity and duration of browsing by the introduced brush-tailed possum (inferred from patterns of invasion from their liberation sites) and the influences of forest composition and timing of dieback. Although 29% of the forests showed light dieback (<10% mortality), only 11% had not experienced heavier past dieback and could be classified as having canopies largely unmodified by possums. Such widespread and continuing forest depletion, and declining possum control effort over the last decade, indicate the urgent need for a coordinated rata-kamahi forest conservation strategy, involving long-term possum control and monitoring in representative tracts.

Keywords: Brushtail possums; canopy die back; rata-kamahi forests; Westland; mapping; surveys.

Introduction

For over 40 years, progressive canopy mortality in the southern rata *(Metrosideros umbellata* Cav.) - kamahi *(Weinmannia racemosa* Linn. f.) forests of central Westland has concerned researchers and land managers. Such mortality affects mainly southern rata, but also kamahi and the associated conifers Hall's totara *(Podocarpus hallii* Kirk) and kaikawaka *(Libocedrus bidwillii* Hook. f.) In severely affected areas, southern rata fails to regenerate after canopy mortality, so that it will be virtually absent from the canopy for at least a forest generation (Allen and Rose, 1983).

An interdepartmental investigation in 1955 concluded that browsing by the introduced brushtail possum *(Trichosurus vulpecula* Kerr) was the primary cause of southern rata-kamahi canopy mortality (Chavasse, 1955). This conclusion has been widely supported by subsequent studies. Southern rata, kamahi, and Hall's totara are preferred foods of the possum (Fitzgerald and Wardle, 1979; Coleman, Gillman and Green, 1980; Coleman, Green and Polson, 1985). Simulated browsing experiments on southern rata mirror typical canopy 'dieback' (defoliation and mortality) patterns, showing that first the large, old trees and then younger, more vigorous ones are affected (Payton, 1985). Canopy mortality progresses as possums invade an area (e.g., Pekelharing, 1979; Pekelharing and Reynolds, 1983; Leutert, 1988), and where possums are already established, the amount of dieback reflects possum densities and the abundance of preferred foods (Coleman *et al.,* 1980; Pekelharing and Batcheler, 1990; Rose, Pekelharing and Hall, 1988). Interactions between natural stand dynamics and disturbances such as drought and landsliding may also cause natural dieback in rata-kamahi and similar forest types (e.g., Stewart and Yeblen, 1982; Yeblen and Stewart, 1982; lane and Green, 1983). However, because of the over-riding impact of the possum, the role of such factors in recent dieback remains largely undetermined.

Not all forest stands are equally susceptible. Dieback patterns indicate that abiotic factors, such as surface stability of different landforms and rock types, exert a major influence on forest composition and structure, differentially predisposing rata-kamahi stands to possum-triggered dieback. Stands containing abundant possum-preferred subcanopy hardwoods, such as *Fuchsia excorticata* (J.R. et G. Forst.) Linn. f. and *Aristotelia serrata* (J.R. et G. Forst.) W.R.B. Oliver, and a high proportion of old canopy trees are the most susceptible (Chavasse, 1955; Payton, 1987; Reif and Allen, 1988; Stewart and Rose, 1988).

Southern rata-kamahi dieback has prompted extensive State control operations against the possum since the mid-1950s, mainly involving aerially-distributed toxic baits. However, by the late 1970s the prohibitive cost of attempting overall control became apparent. In the South Island alone, the canopy of more than a quarter of the indigenous forest is vulnerable to possum damage (Batcheler and Cowan, 1988). To maintain possum numbers at sufficiently low levels to contain canopy damage it is necessary to mount control operations at less than to-year intervals (Spurr, 1981; Pekelharing and Batcheler, 1990). Such factors led to a decline in the frequency of large-scale operations (Batcheler and Cowan, 1988).

Because of the expense of widespread control, there is a need to select representative rata-kamahi tracts
to target for protection. Optimally, selection should be based on overall knowledge of canopy condition and changes in composition along dominant environmental gradients. Models of compositional change are relatively well developed (e.g., Wardle, 1977; Stewart and Harrison, 1987; Reif and Allen, 1988). However, a systematic inventory of canopy condition is lacking, although Pracy (1974) based his wide-ranging surveys of possum density partly on canopy damage. The lack of an overall inventory of present southern rata-kamahi canopy condition in central Westland prompted the present study. We selected the southern rata-kamahi zone most susceptible to conspicuous canopy dieback (Pekelharing, 1979; Pekelharing and Reynolds, 1983), i.e., all forests east of the Alpine Fault between 500 m a.s.l. and timberline (about 900 m) from the Haupiri River in the north to the Mahitahi River, 220 kill further south (Fig. 1). Specific objectives were to: map the amount of present canopy dieback; infer past canopy mortality; estimate the impact of browsing by the brushtail possum; identify areas of forest relatively unmodified by possums; and comment on likely future trends in canopy mortality and the consequences for forest composition.

Methods

Aerial photograph analysis and mapping

Six New Zealand Aerial Mapping Ltd aerial photographic surveys were assessed for the amount of visibly conspicuous dieback by scoring the proportion of grey or white tree crowns. Combined aerial photograph analysis and vegetation survey in part of the study area (Otira, Deception, and Taramakau catchments; Rose *et al.,* 1988) had previously shown that the amount of dieback visible on monochrome aerial photographs is strongly correlated with mean defoliation and abundance (basal area, density) of the main species affected (for southern rata and Hall's totara; $r^2 = 0.99$).

The six surveys were the most recent photographs available at the time of analysis (February 1988) and were all monochrome or monochrome versions of natural colour photographs taken in November-March 1984 or 1985 at scales of 1:17000 or 1:25000.

Conspicuous dieback was mapped in units defined from the aerial photographs as tracts of southern rata-kamahi forest between 500 m a.s.l. elevation and timberline (about 900 m), of at least 1.6 km (1 mile) in horizontal dimension and bounded by distinct topographic features such as creeks, ridges, or bluff systems. In total, 82 819 ha of mid and upper elevation forest, involving 153 map units, were assessed and mapped on NZMS1 maps (1:63 360). Subsequent analyses and maps were produced using TERRASOFT Geographical Information System (Digital Resource Systems Ltd, Canada).

Preliminary examination of the aerial photographs indicated the range of visible dieback was represented by four broad dieback classes:

1. Light: No defoliated crowns visible, or if present, only isolated and apparently involving individual trees.
2. Moderate: Defoliated crowns present at low densities over most of the map unit, mainly involving individual trees, or small groups.
3. Heavy: Defoliated crowns present at high densities over most of the map unit. Usually involving large groups of trees. Groups often coalescing.
4. Severe: Most of the canopy consisting of defoliated, apparently dead crowns.

For consistency, reference aerial photographs of each dieback class were regularly consulted (Avery, 1966). Copies are held by the authors. We each independently assessed each map unit under 1.5 X magnification, then assigned it to one of the four dieback classes after consensus was reached.

Aerial verification and estimation of canopy mortality

We systematically inspected 16 selected areas or map units from helicopter or fixed-wing aircraft in February 1988 after mapping of dieback from the aerial photographs was completed. Inspections were made by flying at about 1000 m altitude and 500 m from the hillslope (Pekelharing and Reynolds, 1983).

For each area and map unit inspected, we each independently estimated percent dead crowns in the canopy to the nearest 10%. (This would also include some severely defoliated, dying trees.) Where possible, percent cover of live canopy southern rata and percent

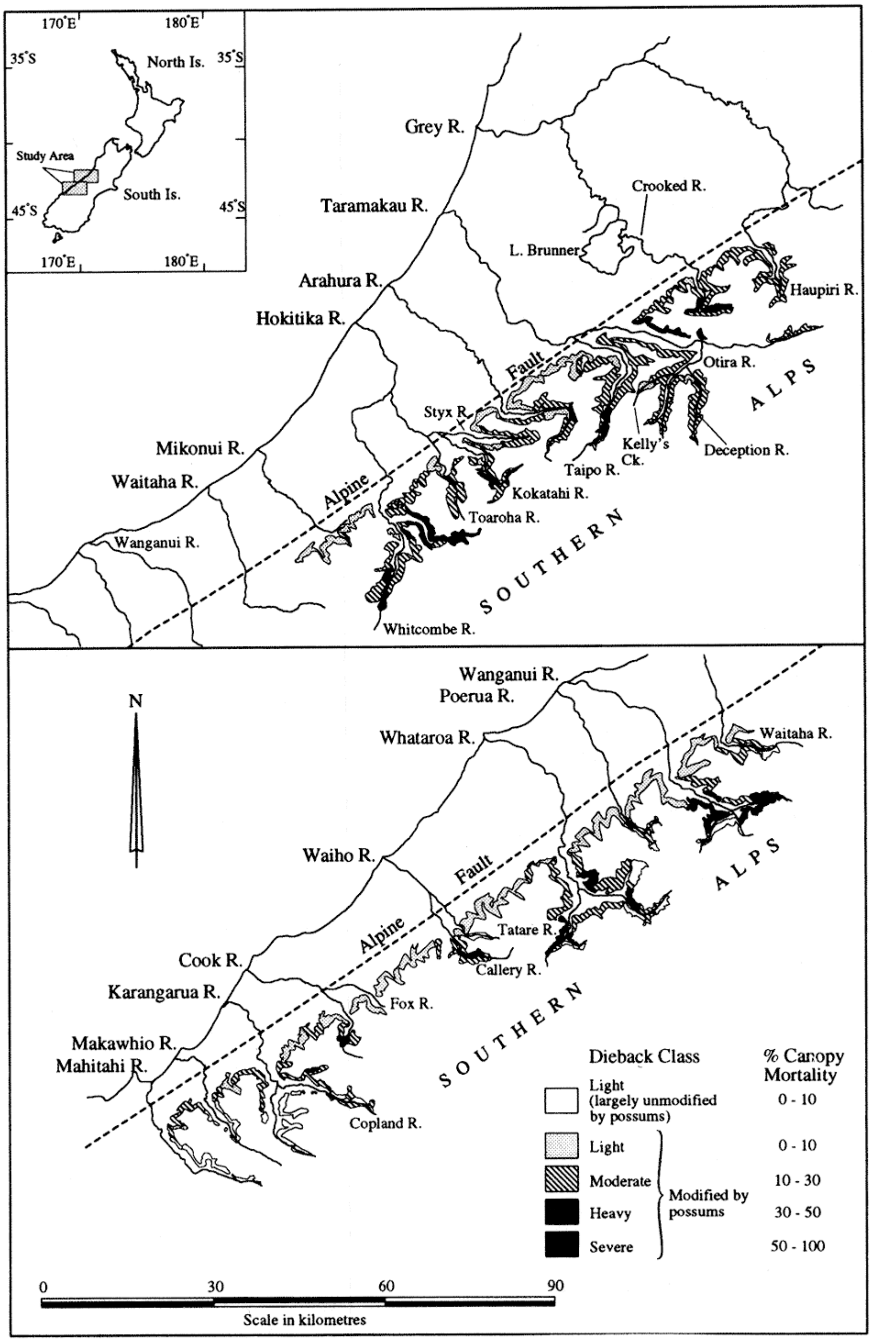

Figure 1: *Canopy dieback in central Westland southern rata-kamahi forests. The study area includes only those forests above 500 m altitude, east of the Alpine Fault. Surrounding unshaded areas are non-forested or below 500 m. Dieback classes were determined from 1984-1985 aerial photographs (see Methods). Possible areas of unmodified forest in western front catchments (Table 7) have not been mapped because of difficulties of assessment.*

seral forest were similarly estimated. Possible bias in percent mortality estimates resulting from a *priori* knowledge of dieback classes for inspected areas/units was reduced by ensuring that such information was not on the map used for navigation and that only one observer had access to this map. Average values obtained were then used to estimate: (1) whether map units that had been placed in similar dieback classes had similar proportions of dead canopy trees; (2) whether there were distinct differences in the proportion of dead canopy trees for each dieback class; (3) percent canopy mortality for each dieback class; (4) the contribution of southern rata and other species to the dead canopy component; and (5) the contribution of major canopy species, especially southern rata, to forest cover.

Results

Aerial verification

Aerial inspection confirmed that differences in the amount of canopy mortality between dieback classes were visually distinguishable. Estimates of percent canopy mortality were highly consistent among observers (Spearman correlation = 0.89-0.96, $P<0.01$; Wilcoxon sign rank tests, $P>0.55$ for all observer pairs). For each observer the estimated proportion of dead trees in each dieback class increased significantly from class 1 to class 4 (Spearman correlation = 0.94-0.96, $P<0.01$; Kruskal-Wallis analysis of variance by ranks, $0.003<P<0.03$). Although estimates of percent mortality became more difficult with increasing dieback, the four predetermined dieback classes closely reflected aerially assessed percent canopy mortality (Table 1).

Estimates of percent southern rata cover were not possible for all areas in the time available, but those made were consistent between observers. For all map units scored, southern rata made up greater than 40%, and usually greater than 70% of canopy cover, indicating broad similarity of forest canopy composition.

Table 1: *Estimated proportions of dead canopy trees present in four dieback classes. Dieback classes were determined from analysis of* 1984-1985 *aerial photographs. The proportions of dead trees were estimated from aerial inspection of 16 areas (see Methods).*

	Estimated % dead trees			
Dieback class	0-10	10-30	30 - 50	>50
Light	13	1	-	-
Moderate	-	9	-	-
Heavy	-	1	9	2
Severe	-	-	3	5

Overall canopy dieback

For the 82 819 ha of forest mapped from aerial photographs, an estimated 19% of all canopy trees were dead in 1984-85 (based on the proportions of dead trees in each dieback class; see Tables 2 and 3). Only 29% of the forests showed light dieback (<10% canopy mortality). Most forests (59%) showed moderate dieback (10-30% mortality), 10% showed heavy dieback (30-50% mortality) and the remaining 2% showed severe dieback (>50% mortality). Most canopy mortality involved southern rata and Hall's totara. Kamahi, and kaikawaka were also affected.

Geographical variation in canopy dieback

Three gradients in canopy dieback were recognised:

1. Canopy dieback was less severe overall in the small western front catchments adjacent to and immediately east of the Alpine Fault than in the larger catchments that have headwaters further east in the Southern Alps (Fig. 1). Overall canopy mortality in the western front catchments was 9%, and 73% of these forests showed only light dieback (< 10% mortality), with no areas of heavy or severe dieback (>30% mortality; Table 2). Further east, overall canopy mortality in the major catchments was 22%, and more than 80% of these forests showed moderate to severe dieback (Table 3).
2. In the western front catchments, canopy dieback was most evident in the north and south. In the north, between the Haupiri and Taramakau Rivers, 97% of the forests showed moderate canopy dieback (10-30% mortality). In the south, between the Karangarua and Mahitahi Rivers, 72% of the forests showed moderate dieback. In contrast, light canopy dieback (<10% mortality) was recorded in 89% of the forests of the front catchments between the Taramakau and Karangarua Rivers (Fig. 1; Table 2).
3. In the major catchments, canopy dieback decreased from north to south (Table 3). Mortality was lowest (8%) in southern catchments (Karangarua-Mahitahi), but these totalled only 4.3% of the study area. In the north, 22% of the forests showed heavy or severe dieback (Table 3; Fig. 1). This declined to 6% in central catchments, and there were no areas of heavy or severe dieback in the south. In southern catchments, 80% of the forests had only light canopy dieback compared to 12-14% of the forests further north.

Variation in canopy dieback in major catchments

In 1984-85, five major catchments showing heaviest dieback comprised c. 20% of the study area (Hokitika, Taramakau, Wanganui, Whitcombe, Cook; Fig. 1; Table 4). Dieback was most severe in the Hokitika and Taramakau catchments, where an estimated 44% and 31 % of canopy trees were dead, respectively (Table 4). In the Hokitika, 80% of the forests showed heavy to severe dieback (25% severe). In the Taramakau, about 33% showed heavy to severe dieback (15% severe). In both catchments, there were no areas of light dieback.

In contrast, all forests of the Fox and Makawhio catchments showed only light canopy dieback (Fig. 1; Table 4). Other catchments showing relatively little dieback included the north bank of the Mahitahi (78% light), the Karangarua (76%), and the Tatare (76%).

There was considerable variation among catchments showing mostly moderate amounts of canopy dieback (Fig. 1; Table 4). For example, all forests of the Haupiri, Deception, and Waiho catchments showed moderate dieback. In the Otira-Kelly's catchment, 82% showed moderate dieback, and 18% light. In the Kokatahi, 73% showed moderate dieback while 20% showed heavy dieback. The Whataroa was the largest catchment, occupying about 20% of the study area. Canopy mortality was about 20% in this catchment, with 86% of its forests showing moderate dieback.

Table 2: *Canopy dieback in western front catchments, central Westland. Dieback classes were determined from analysis of* 1984-1985 *aerial photographs. No areas of heavy or severe dieback were present. The approximate % canopy mortality (D) was calculated from the proportions of dead canopy trees in each dieback class (Table 1). D = 0.01 (5L + 20M + 40H + 70S)%, where L = % of the area showing light dieback, M = % showing moderate dieback, H = % showing heavy dieback. and* S = *% showing severe dieback.*

Block	Area (ha)	Area in each dieback class (%)		Approx. canopy mortality (%)
		Light	Moderate	
Northern (Haupiri-Taramakau)	2097	3	97	20
Central (Taramakau-Karangarua)	14379	89	11	7
Southern (Karangarua-Mahitahi)	1728	28	72	16
All front catchments	18204	73	27	9

Discussion

Factors influencing visible dieback patterns

Much of the geographic variation in the dieback now visible reflects patterns of possum invasion and build-up. However, forest composition and the timing of dieback also influence this pattern.

With increasing time since dieback, the amount that is visibly conspicuous declines as dead or defoliated crowns with attached fine twigs decay and eventually disappear from the canopy. About 30 years after tree death, southern rata crowns will have disintegrated and many spars will no longer remain in the canopy. Dead conifers such as Hall's totara appear to decay at a similar or slower rate, but kamahi decays in about half this time (e.g., Coleman *et al.,* 1980; Allen and Rose, 1983; Pekelharing and Batcheler, 1990). In areas where dieback began less than c. 15 years ago (e.g., Deception and parts of the Taramakau), our dieback classes closely reflected the amount of mortality measured on vegetation plots in other studies (Table 5). In areas where dieback occurred more than 30 years ago (e.g., parts of the Fox and Kokatahi), forests that had suffered heavy or severe dieback now showed only light or moderate dieback because most affected trees had collapsed (Table 5).

The amount of visible dieback is also influenced by the relative abundance of affected species. Although southern rata and Hall's totara are typically dominant in the mid-upper elevation forests selected for this study, forest composition varies along environmental gradients associated with elevation and soil factors (Wardle, 1977; Stewart and Harrison, 1987; Reif and Allen, 1988). If affected canopy species are abundant, defoliation is highly conspicuous; if they are less frequent, even heavy defoliation may be inconspicuous (Coleman *et al.,* 1980; Allen and Rose, 1983; Leutert, 1988; Rose *et al.,* 1988).

The greater amount of dieback in northern than in southern major catchments east of the Alpine Fault (78% of the study area; Table 3; Fig. 1 reflected a gradient of decreasing possum browsing intensity and duration, assessed from liberation records (Pracy, 1974). For the worst-affected northern block (Haupiri-Wanganui Rivers), the frequency of liberations was approximately two to three times as high as for the central and southern blocks (Poerua-Copland and Karangarua-Mahitahi, respectively). Liberations in the northern block were also earlier than those further south; 58% of known-date liberations in the north were before 1920; further south, 92% were after 1920 (Table 6).

In 1984-85, lesser amounts of dieback in the western front catchments than in major catchments east of the Alpine Fault reflected both possum invasion

Table 3: *Canopy dieback in major catchments, central Westland. Dieback classes were determined from* 1984-1985 *aerial photographs. The approximate % canopy mortality was calculated from the proportions of dead trees in each dieback class (see Table* 2 *for detail).*

Block	Area (ha)	Area in each dieback class (%)				Approx. canopy
		Light	Moderate	Heavy	Severe	mortality (%)
Northern (Haupiri-Wanganui)	38807	14	64	17	5	24
Central (Poerua-Copland)	22226	12	82	6	-	19
Southern (Karangarua-Mahitahi)	3577	80	20	-	-	8
All major catchments	64615	17	67	13	3	22

Table 4: *Canopy dieback in the* 26 *major catchments, central Westland. Catchments are arranged in order of increasing overall canopy mortality. Dieback classes were determined from* 1984-1985 *aerial photographs. The approximate % canopy mortality was calculatedfrom the proportions of dead trees in each dieback class (see Table* 2 *for detail).*
[1]*Excludes Copland;* [2]*Excludes Tatare, Callery;* [3]*Excludes Otira-Kelly's, Deception. Taipo;* [4]*Excludes Whitcombe. Kokatahi, Toaroha, Styx.*

Catchment	Area	Area in each dieback class (%)				Approx. canopy
	(ha)	Light	Moderate	Heavy	Severe	mortality (%)
Fox	347	100	-	-	-	5
Makawhio	468	100	-	-	-	5
Mahitahi (north)	1033	78	22	-	-	8
Karangarua[1]	2076	76	24	-	-	9
Tatare	343	76	24	-	-	9
Mikonui	413	67	33	-	-	10
Arahura	3083	30	65	5	-	17
Styx	1581	23	77	-	-	17
Otira-Kelly's	2712	18	82	-	-	17
Waitaha	1335	18	82	-	-	17
Poerua	886	12	88	-	-	18
Copland	1807	18	77	5	-	18
Toaroha	1318	8	92	-	-	19
Deception	1714	-	100	-	-	20
Haupiri	2231	-	100	-	-	20
Waiho[2]	105	-	100	-	-	20
Whataroa	16809	9	86	6	-	20
Taipo	4217	6	86	8	-	21
Kokatahi	1697	7	73	20	-	23
Callery	1127	-	84	16	-	23
Crooked	2052	5	66	29		25
Cook	802	-	70	30	-	26
Whitcombe	4533	3	64	33	-	26
Wanganui	5825	36	22	26	15	27
Tararnakau[3]	2391	-	67	18	15	31
Hokitika[4]	3167	-	20	55	25	44

patterns and differences in forest composition. Nearly all liberations of possums in the study area were west of the Alpine Fault, from where they invaded eastward towards the heads of the main valleys (e.g., Pracy, 1974; Pekelharing, 1979; Pekelharing and Reynolds, 1983). In general, therefore, the western front catchments were subjected to the effects of high possum populations earlier than the main valleys further east. Several lines of evidence, including early ground photographs (e.g., L.T. Pracy, in Chavasse, 1955), anecdotes (e.g., M. O'Reilly, *pers. comm.),* the many canopy gaps or old spars presently visible, and early aerial photographs, all indicate that dieback in most of the front catchments was greate{ in the 1950s-1970s than at present. We therefore conclude that most of the front catchments are in a 'post dieback' phase so that canopy dieback is less conspicuous now than 20-40 years ago.

Table 5: *Effect of timing of dieback on the amount of canopy dieback scored on 1984-1985 aerial photographs, showing the decrease in visibly conspicuous dieback with increasing time since dieback. % mortality is density-based.*
Sources: [1]Allen and Rose (1983); [2]Rose et al. *(1988); [3]Pekelharing and Batcheler (1990).*

Area	Approx. time since dieback (yrs)	Mortality (%) Southern rata	Hall's totara	Dieback class in 1984-85
Fox[1]	35	90-100	50-100	Light (<10% mortality)
Deception[2]	15	9	23	Moderate (10-30%)
Kokatahi[1]	35	90-100	NA	Moderate (10-30%)
Taramakau (part)[3]	15	24	29	Heavy (30-50%)
Taramakau (part)[3]	15	65	75	Severe (>50%)

Table 6: *Possum liberation history and frequency (after Pracy 1974) for three blocks of major catchments presented in order of increasing canopy dieback (refer Table 4). Liberation frequency is calculated from the length of each block as measured along the axis of the Alpine Fault.*

Block	Year of liberation				Unknown date	Total liberations	Liberation frequency
	1900-10	1911-20	1921-30	1931-40			(km^{-1})
Northern (l15km) (Haupiri- Wanganui)	8	6	9	1	11	35	0.30
Central (75km) (Poerua-Copland)	-	-	10	1	1	12	0.16
Southern (20km) (Karangarua-Mahitahi)	-	1	1	-	2	4	0.10

Nevertheless, our impression from aerial reconnaissance was that dieback had removed less than *c*. 30% of southern rata from affected front catchments, considerably less than in the headwaters of most major catchments. West-east gradients in forest composition may predispose the major-catchment forests to heavier dieback. For example, the higher mean elevation of the major-catchment forests would result in greater predominance of highly susceptible southern rata and Hall's totara above *c*. 600 m with corresponding reductions in less preferred canopy species such as *Quintinia acutifolia* Kirk that dominate at lower elevation (e.g., Wardle and Hayward, 1970; Coleman *et al.,* 1980; Rose *et al.,* 1988). Perhaps high proportions of highly-preferred seral forest in the headwaters also predispose these forests to heavier dieback (c.f., Payton, 1987; Reif and Allen, 1988; Stewart and Rose, 1988).

Greater visible canopy dieback in southern front catchments (Karangarua-Mahitahi) than in central front catchments (Taramakau-Karangarua; Tables 2, 3) reflected highly conspicuous dieback resulting from more recent invasion by possums. Reasons for the greater dieback in the northern front catchments (Haupiri-Taramakau) than in the central front catchments were less clear, but we observed a higher proportion of seral forest highly-preferred by possums in the northern than in the central block *(c*. 30-60% and 20-30%, respectively).

Dieback patterns in individual major catchments in 1984-85 often reflected invasion by possums towards the headwaters and the protective influence of topographical barriers to dispersal such as large rivers and side-creeks (Fig. 1). For example, in the Wanganui, post-dieback forests in the lower reaches now show only light or moderate dieback (<10% and 10-30% mortality, respectively), but in the headwaters more recent dieback is heavy (30-50%) or severe (>50%), and some areas of forest are largely unmodified *(pers. obs.)*. On the north bank of the Mahitahi, recent moderate dieback in the lower reaches gives way to largely unmodified forests in the mid and upper valley *(pers. obs.)*. In the Copland, invasion up the north bank has resulted in relatively recent moderate or heavy dieback in the lower-mid reaches and a mosaic of moderate dieback and largely unmodified forests in the headwaters. Possums later invaded down the south bank from the headwaters, but have not yet seriously modified these forests (Pracy, 1974; Fraser, 1979; Pekelharing and Reynolds, 1983; Leutert, 1988).

Proportion and location of unmodified forests

Not all 24 000 ha (29%) of forests showing light canopy dieback could be visited to determine which areas had previously undergone extensive dieback that is now inconspicuous. Our best estimate is that, at most, about 9000 ha (11 % of all forests) had canopies that were largely unmodified by possums in 1984-85 (Table 7; Fig. 1). This estimate is based on our own observations, distances from possum liberation sites (Pracy, 1974) and typical invasion patterns (e.g., Pekelharing, 1979; Pekelharing and Reynolds, 1983), and possum and vegetation surveys and reports of canopy damage (e.g., Coleman *et al.,* 1980; Allen and Rose, 1983; Pekelharing and Reynolds, 1983; Reif and Allen, 1988; Leutert, 1988; Pekelharing and Batcheler, 1990; unpublished N.Z. Forest Service reports and data stored in the National Indigenous Vegetation Survey database).

We consider only 9% (5894 ha) of the forest canopy of the 26 major catchments is largely unmodified by possums. Areas of unmodified forest remain in nine catchments only; they are small (typically <1000 ha) and lie adjacent to more modified forests, indicating that dieback will occur as possum populations invade and build up. At most, 19% (3377 ha) of the front catchment forests appear unmodified (Table 7). However, this figure could be considerably lower as information for these forests is scant.

Table 7: *Location and area of rata/kamahi forest tracts with canopies largely unmodified by possums* in *central Westland, determined from 1984-1985 aerial photographs and aerial inspections of selected areas in 1988.*

	Area (ha)
(a) In major catchments	
Waitaha	245
Wanganui (Adams)	581
Poerua	108
Whataroa	1505
Tatare	261
Copland	335
Karangarua	1586
Makawhio	468
Mahitahi	805
Total	5894
All major catchments (%)	9
Study area (%)	7
(b) In western front catchments	
Doctors - Mikonui	704
Mikonui - Kakapotahi	109
Whataroa - Tatare	2082
Karangarua - Makawhio	365
Makawhio - Mahitahi	117
Total	3377
All western front catchments (%)	19
Study area (%)	4

Extent of past depletion and likely future trends

Our conservative estimate based on present canopy mortality indicates at least 20% of canopy trees, predominantly southern rata and Hall's totara, have died over the last *c.* 40 years in the study area. However, many central Westland rata-kamahi forests now showing light or moderate dieback have already experienced peak possum population densities and are now in a 'post-dieback' phase, so extensive ground-based surveys would be needed to estimate more accurately the extent of depletion since possum-induced dieback first became evident.

Near-complete destruction of the former canopy has already resulted in shifts to forest types dominated by species that are not preferred by possums (notably *Quintinia acutifolia)* over tens to hundreds of hectares in the Kokatahi and the Fox, two of the earliest-affected catchments (c.f., Allen and Rose, 1983). Similar shifts are occurring in at least the 12% of forests in 12 major catchments that showed heavy to severe dieback on 1984-85 aerial photographs (Fig. 1; Table 4; see also Coleman *et al.,* 1980; Pekelharing and Batcheler, 1990).

Because their status varies widely, past depletion and future trends are difficult to assess for the 60% of forests now showing moderate dieback. Those in which possum populations are increasing towards peak levels, will probably experience heavier dieback.

Spread of possum-triggered dieback to the remaining *c.* 11 % of largely unmodified forest may be rapid. We revisited two such areas in April 1990. On the east bank of the Adams River (Wanganui catchment, Fig. 1), *c.* 50% of southern rata had died or had been severely defoliated since 1988. On the north bank of the Mahitahi, moderate dieback had spread further up-valley into previously unmodified forests. For the Adams, this rapid deterioration coincided with a marked reduction in commercial trapping intensity because of low fur prices (J. Scott, helicopter pilot, *pers. comm.).*

Implications for conservation

Early possum control operations were usually initiated after the onset of conspicuous dieback and were rarely followed by repeated monitoring and control. Subsequent studies, including our survey, indicate that such control was often too late and too infrequent to prevent substantial mortality (Batcheler and Cowan, 1988; Pekelharing and Batcheler, 1990). Although commercial possum trapping has been encouraged by successive government departments, its efficacy for forest protection has not been adequately assessed, and its intensity fluctuates with fur prices. Official possum control operations in the most susceptible rata-kamahi forests of the major catchments have virtually ceased since 1980 (Batcheler and Cowan, 1988). Less than

10% of all presently unmodified forests, in the Copland (335 ha) and part of the Karangarua (*c*. 500 ha), have ever been poisoned (in 1986) by aerial sowing *of* 1080-impregnated carrot to control possum populations. In the Deception and Otira-Kelly's catchments, earlier official control operations (1971 and 1975, respectively) reduced possum browsing pressure and prevented heavy canopy mortality. These were followed up in 1988 by contracted commercial trapping and aerially sown 1080 poison baits, in response to evidence that possum populations were again approaching peak levels and that further canopy mortality was imminent (W.P. Chisholm, 1986, unpublished data; Rose *et al.,* 1988).

Our survey highlights the urgent need to develop and implement a coordinated conservation strategy for the central Westland rata-kamahi forests. Ironically, lack of such a strategy over the last decade has coincided with significant advances in possum control technology (e.g., Morgan, Batcheler and Peters, 1986; Warburton, 1982; Green, 1984), understanding of possum population dynamics (e.g., Pekelharing, 1979; Green and Coleman, 1984; Clout and Efford, 1984), and development of models of forest susceptibility to possum-triggered dieback (Payton, 1987; Reif and Allen, 1988; Stewart and Rose, 1988).

Because of the high cost of possum control and the ability of possum populations to increase to high levels *c*. 10 years after control, a conservation strategy should be based on repeated control in areas of relatively unmodified forests selected to represent the range of rata-kamahi forest composition. This is particularly urgent for the highly susceptible forests in the headwaters of the major catchments and the few remaining areas of largely unmodified forest. As most of the Westland rata-kamahi resource now shows moderate dieback, it is essential to determine accurately which of these areas are least modified, i.e., have not experienced heavier past mortality. A conservation strategy should also take into account other ecosystem values such as habitat requirements for the kaka *(Nestor meridionalis* Gmelin), a threatened bird species adversely affected by possum-triggered dieback (O'Donnell and Dilks, 1986; Rose *et al.,* 1990). Long-term possum control strategies should include long-term monitoring of possum densities and vegetation condition, without which the success of control cannot be accurately gauged and tolerable densities in different forest types cannot be assessed.

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