DYNAMICS OF SMALL MOUNTAIN BEECH STANDS IN AN EXPOSED ENVIRONMENT

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ABSTRACT

In four small isolated stands of *Nothofagus solandri* var. *cliffortioides* (Hook. f. Poole (mountain beech), ranging in size from 70 to 140 m^2, exposure was the dominant influence on stand architecture. The most exposed stand exhibited progressive canopy collapse which may eventually lead to its extinction. As shelter increased, stands showed a rapid transition to an intact protective canopy. Dramatic differences in environmental conditions were evident between sheltered and exposed stand edges. Seedlings established in the lee of existing stands while collapse occurred at the exposed edge, leading to stand mobility over time.

Keywords: stand dynamics; *Nothofagus solandri.*

INTRODUCTION

Much of the New Zealand's mountain beech forest occupies high-altitude sites, commonly extending to the tree line. A number of studies have suggested that young even-aged stands are resistant to damage and decline caused by both biotic and abiotic agents and that a closed protective canopy provides a survival strategy in the face of harsh environmental conditions (Grant 1984; Wardle & Allen 1983; Hosking & Hutcheson 1988). Synchronous collapse, often initiated by snow and wind damage, is well documented (Grant 1984; Wardle & Allen 1983; Hosking & Hutcheson 1988; Shaw 1983) and is commonly followed by the rapid growth of dense, even-aged, pre-established seedlings. The present study focuses on the influence of exposure on the development and structure of small isolated stands, and compares these strategies with those of very small forest communities.

METHODS

The study was carried out in two stages: an initial visit to the study site in the Ruahine Range in the spring of 1986 to characterise the stands and obtain preliminary stand age and environmental data, and two visits in the winter of 1992 to collect detailed climatological data.

All four stands were located on a broad north-running ridge just outside the western boundary of the Ruahine Forest Park (39° 35'S, 176° 15'E, 1250 m a.s.l.) (Fig. 1), and were in red tussock grassland (*Chionochloa rubra* Zotov) at least 100 m from adjacent areas of continuous forest. It is likely the stands represent remnants of continuous forest subjected to Maori fires (Elder 1965). Isolated groups of stumps, some appearing as live belts of trees in early photographs (Elder 1965), suggest similar isolated mountain beech stands have failed to survive. The stands were subjectively classified along a gradient from most exposed to most sheltered, based on predicted winter wind frequency and vegetation age and condition.

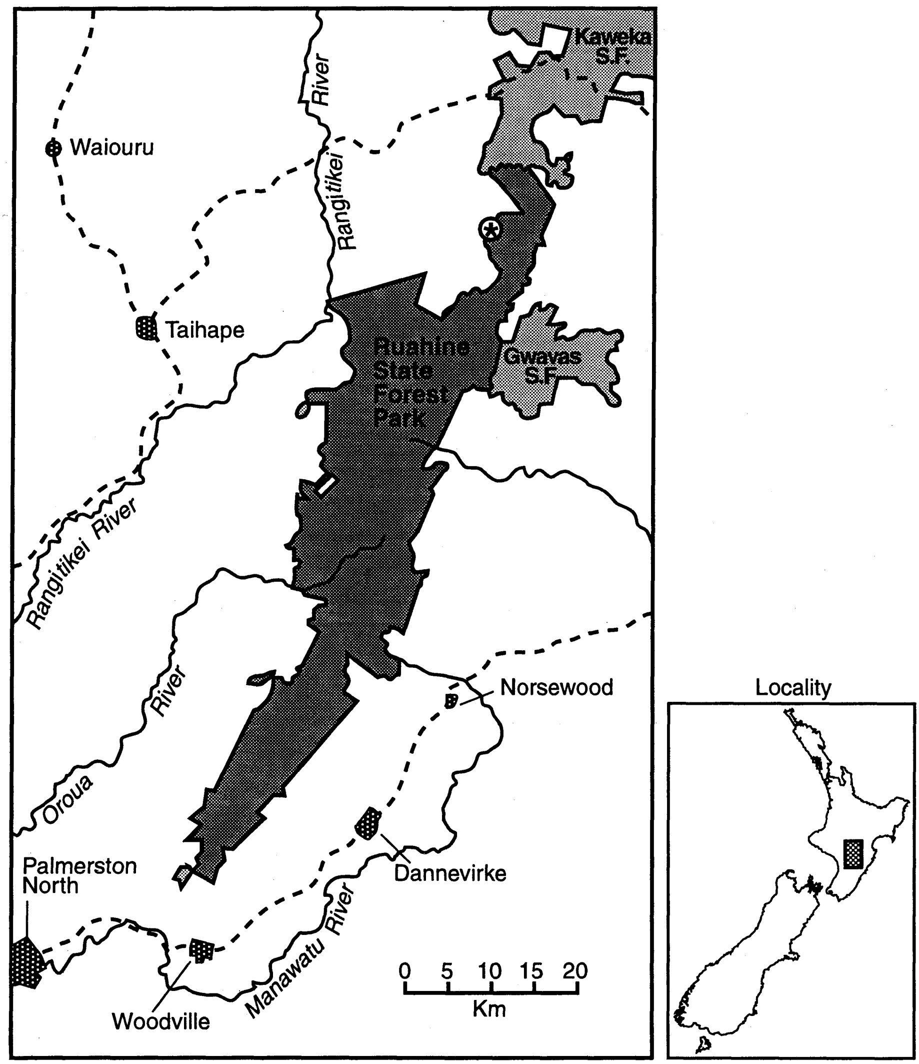

FIG. 1–Location ⊛ of the study site.

Stand Characterisation

Each stand was mapped for all woody vegetation, with mountain beech classified as seedlings (<1 m tall), saplings (<5 cm dbh), poles (5–20 cm dbh), mature (>20 cm dbh), or dead. Two vegetation types were rarely coincident, e.g., seedlings under pole or mature beech, so that the woody plant cover indicated in Fig. 2 includes only marginal overlap. A

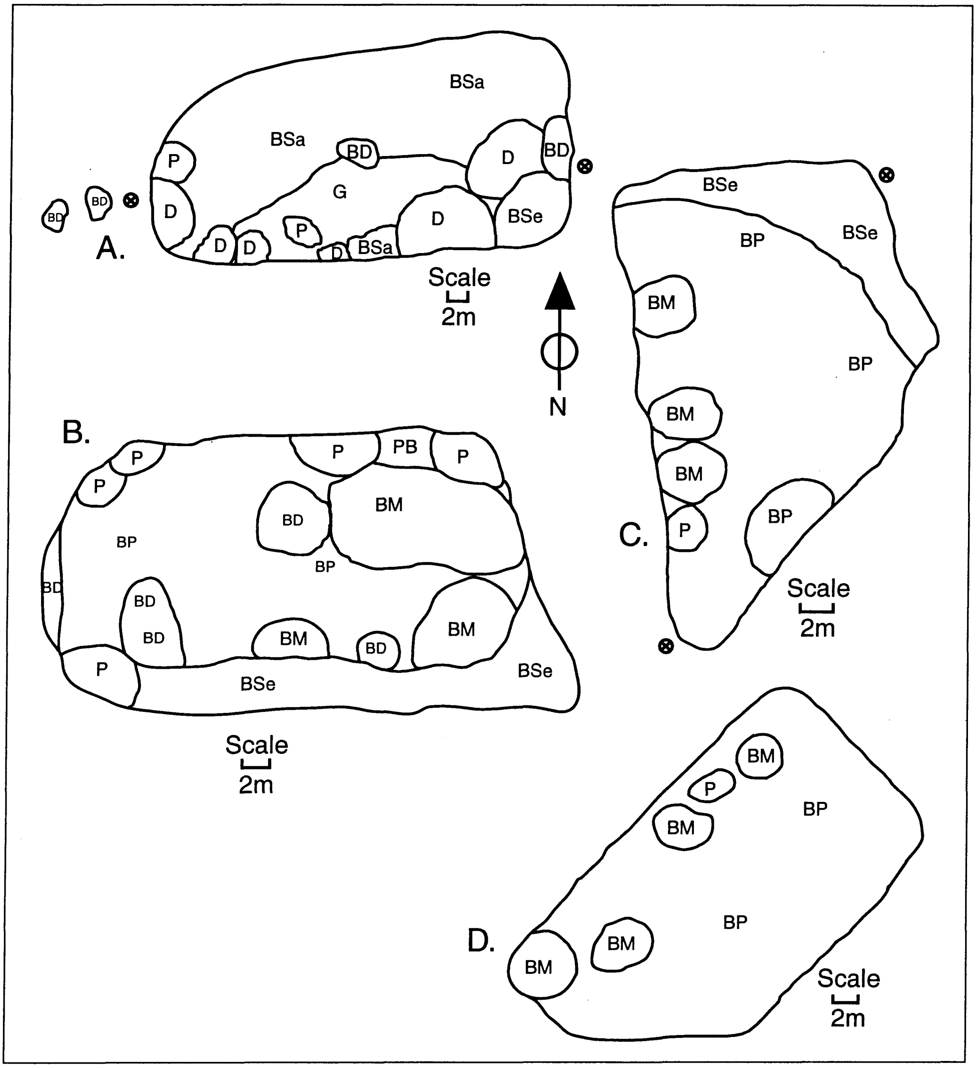

FIG. 2–Distribution of woody plants in the four stands and location of climate stations. A = ridge-top stand; B = ridge-slope stand; C = below-ridge stand; D = sheltered stand.

Key:
BSe = beech seedlings
BSa = beech saplings
BP = beech poles
BM = mature beech
BD = dead beech
P = *Phyllocladus alpinus*
D = *Dracophyllum* sp.
G = grass
⊗ = climate station

total of 50 increment cores were taken from representative saplings (14), poles (30), and mature trees (6) to measure growth rate and determine tree age by growth ring analysis. Because of the errors inherent in tree age estimation based on growth ring counts (Norton *et al.* 1987) the ages derived from cores in this study were used primarily to identify cohorts rather than absolute age. The orientation of what appeared the oldest edge of each stand (based on tree maturity, canopy collapse, or remnant dead trees) was recorded and a narrative description of the stand was compiled.

Climatological Data

The relative exposure of each of the four stands, and the most exposed edge of individual stands, were determined initially from historical climatic data (Elder 1965; Thompson 1987), and from an assessment of present stand structure. It was hypothesised that stand edges with dead and dying trees of older cohorts and lack of seedlings indicated exposure, while edges showing vigorous growth and an abundance of seedlings indicated a more sheltered environment. This hypothesis was tested by measuring climatic variables at what were judged to be the most sheltered and exposed edges of the ridge-top stand and the below-ridge stand over 24 days in the mid-winter of 1992.

Four climate stations were established on 30 June 1992, one each at the exposed and sheltered edges of the ridge-top and below-ridge stands (Fig. 2a, c). Each station consisted of a Vector Instruments pulse output anemometer model A101M measuring wind speed, and two Campbell Scientific temperature probes model 107 measuring air and soil temperatures. Temperature and wind readings were taken every 10 seconds and averaged hourly, while wind measurements also generated hourly average, standard deviation, and maximum gust records. All data were recorded and stored in Campbell Scientific dataloggers, measurement and control model CR10, and downloaded into a laptop computer on the twenty-third day after recording began. All data sets were complete and recording covered a wide range of climatic conditions including high winds, snow, and calm clear weather.

RESULTS

Individual Stand Descriptions

Ridge-top stand A

This, the most exposed of the four stands (Fig. 2a, 3), was only 70 m^2 in area and occupied almost level ground on the crest of the ridge. Four dead trees extending west into the tussock grassland were the only evidence of an old canopy, while its replacement, composed of saplings up to 2 m high, was incomplete. Seedlings were present in localised patches in the south-eastern corner. Much of the interior of the stand was occupied by grasses while *Dracophyllum longifolium* (J.R. et G. Forst.) R.Br., *D. recurvum* Hook.f., and *Phyllocladus alpinus* Hook.f. formed much of the western and southern margins.

Ridge-slope stand B

Similar to the ridge-top stand but sloping away from the ridge line at its eastern end, this stand covered an area of 140 m^2 (Fig. 2b, 4). The open canopy varied between 3 and 5 m

FIG. 3–Stand A, looking south.

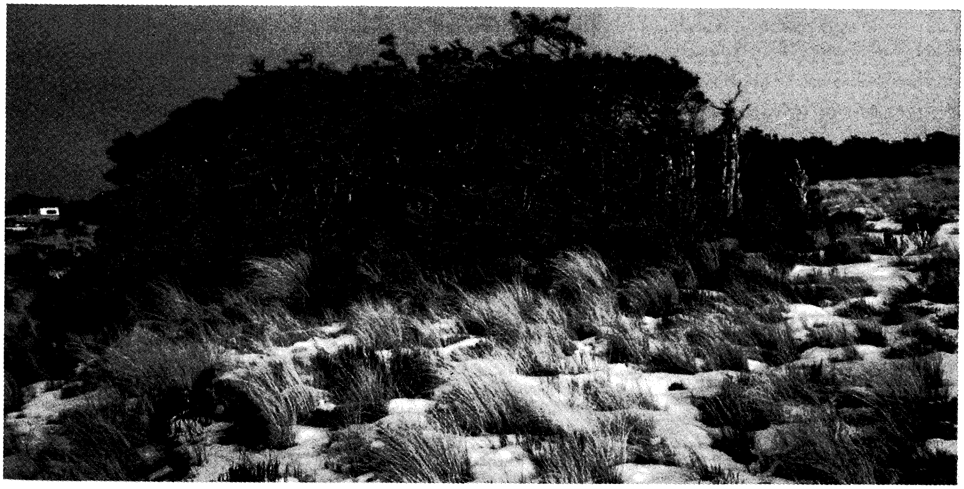

FIG. 4–Stand B, looking south.

above ground level and had collapsed at its western end, where dead trees were all that remained. There was evidence of deterioration of the exposed inner part of the stand from the western edge where young pole trees had dead buds and twigs and reduced foliage. Young vigorous trees were present in the eastern part of the stand and saplings and seedlings formed a dense border along the southern and south-eastern edges. A large, recently dead, beech tree extended above the existing canopy on the southern side. Several *P. alpinus* shrubs up to 2 m tall formed a discontinuous border along the northern and western edges.

Below-ridge stand C

Below the ridge line on the eastern slope about 50 m from and less exposed than the ridge-slope stand, this stand covered 80 m^2 and had an almost complete canopy 5 to 6 m above ground level (Fig. 2c, 5). Four mature beech were concentrated along the exposed western edge, with a pole stand in their lee. A dense border of saplings and seedlings clothed the northern edge. There was little undergrowth within the stand and only a single *P. alpinus* on the western edge.

Sheltered stand D

The most sheltered of the four stands, it was almost at the base of the east-facing slope, and covered an area of 100 m^2 (Fig. 2d, 6). It had a complete canopy rising from ground level to 7 m. A large mature beech occupied the western corner with similar mature trees forming the north-west edge. Pole beech down-slope formed the balance of the stand.

FIG. 5–Stand C, looking south-east.

FIG. 6–Stand D, looking north-west.

Stand Exposure

Strongest winds blew consistently from the south-west and west, as predicted from historical climatic data (Thompson 1987). During the 24-day recording period the wind was from the south-west on 18 days, the south-east on 4 days, and the north on 2 days. Wind speed at the nominal exposed face of both the ridge-top and below-ridge stands was commonly four times that at the nominal sheltered face when flow exceeded 3 m/sec. (Fig. 7a, b). A notable exception was on 22 July when a moderate northerly wind prevailed. Wind speed at the exposed face of the ridge-top stand was consistently twice that recorded at the exposed face of the below-ridge stand, supporting the contention that the former was the more exposed of the two studied.

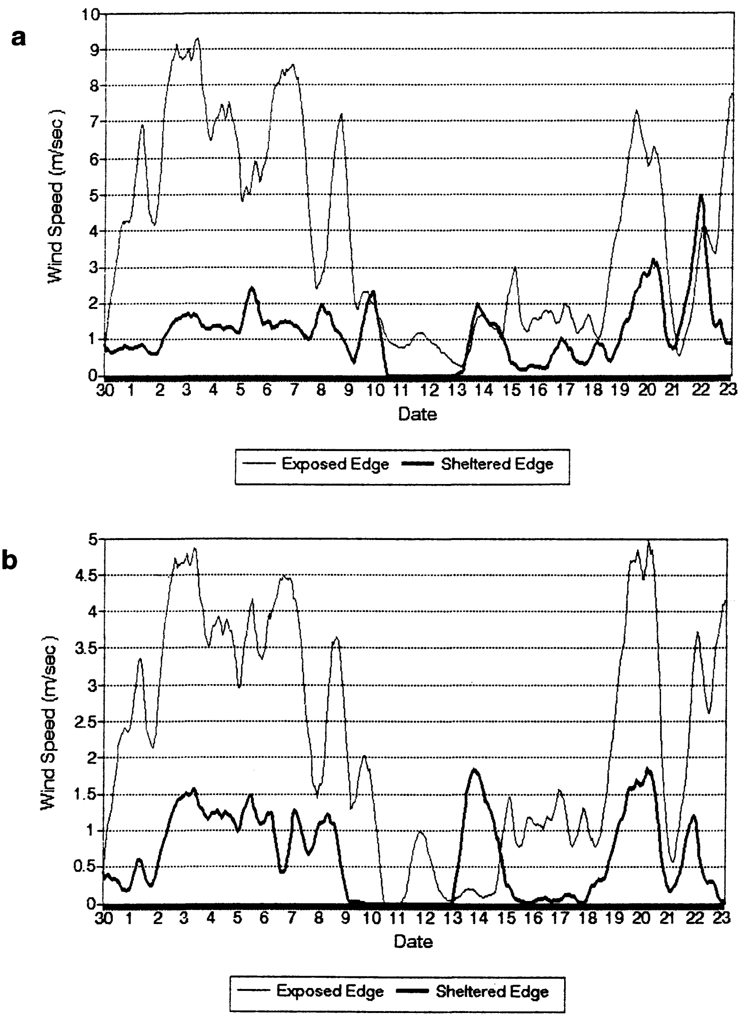

FIG. 7–a: Average hourly wind speed for exposed and sheltered edges of ridge-top stand.
b: Average hourly wind speed for exposed and sheltered edges of below-ridge stand.

During the windiest 48 hours recorded over the 24-day monitoring period, the average hourly wind speed at the sheltered edges of both the ridge-top and below-ridge stands did not exceed 2 m/sec (gusts to 6 m/sec), while the average hourly wind speed at the exposed edge of the ridge-top stand was commonly around 9 m/sec (gusts to 17 m/sec) (Fig. 8).

Variation in air temperature between the four stations was low (Fig. 9) but ranged within stations from –6.3° to 15.1°C over the 24 days. The combined effect of wind and low temperatures generated very large cumulative differences in wind chill between sites (Fig. 10). Soil temperatures were very similar for all four recording stations.

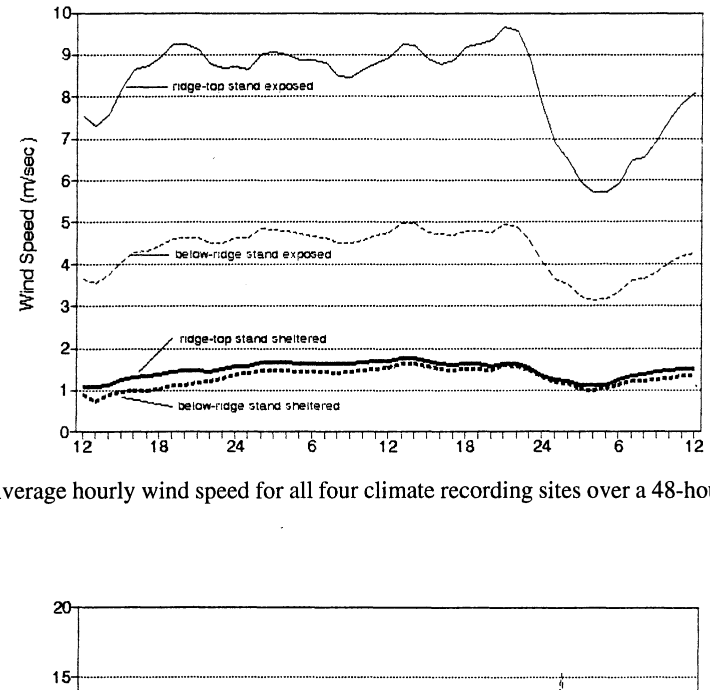

FIG. 8–Average hourly wind speed for all four climate recording sites over a 48-hour period.

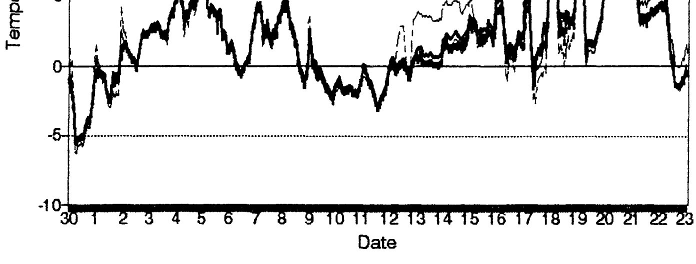

FIG. 9–Average hourly air temperature for all four climate recording sites.

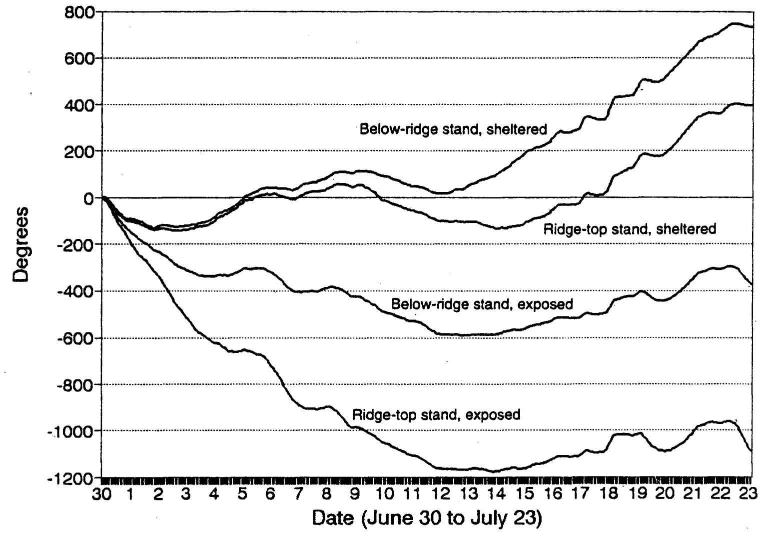

FIG. 10–Cumulative wind chill for each of the four climate recording sites.

Tree Age and Growth Rate

The age-class distribution (Fig. 11), based on increment core growth ring counts, suggests three cohorts in addition to seedlings (<50 cm tall) which were not sampled. These consisted of a sapling cohort (50 to 1500 cm tall and <5 cm diameter at 30 cm stem height) aged between 30 and 50 years, an immature pole cohort (>1500 cm tall and 5 to 10 cm dbh) aged between 60 and 100 years, and a more poorly defined mature cohort (>15 cm dbh) over 110 years of age. The correlation between age and dbh produced an r^2 value of 0.57. The

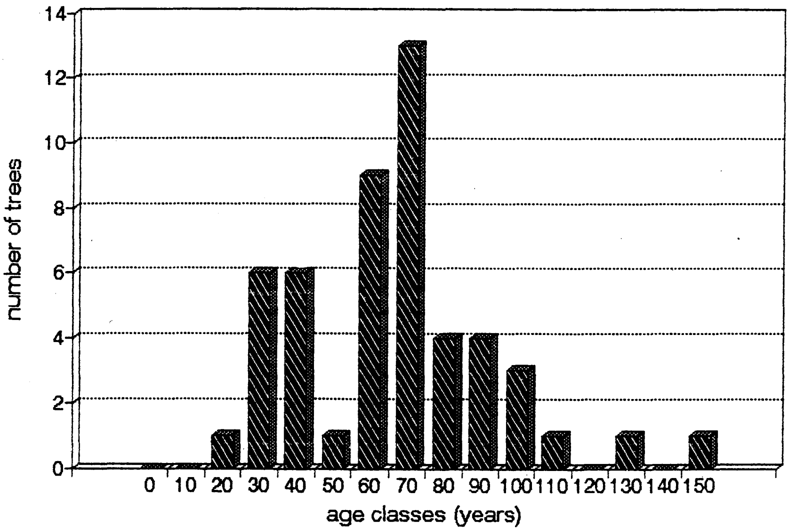

FIG. 11–Age distribution of 50 trees from all stands, derived from growth ring analysis.

annual growth rate over the past 20 years was not significantly different between cohorts and averaged 0.98 mm per year for all trees (SD = 0.36 mm), although the trend from 1930 to 1991 was generally downward albeit with high variability.

In general, stand maturity increased with decreasing exposure: the ridge-top stand had no pole or mature trees, the ridge-slope and below-ridge stands had all four cohorts, while the sheltered stand had no seedlings and was dominated by immature and mature trees. In all four stands tree maturity decreased from the exposed to the sheltered face (Fig. 2) with the ridge-slope and below-ridge stands supporting a seedling zone exceeding 4 m in width along the most sheltered edge.

DISCUSSION

Wardle's (1985b) detailed studies on the environmental constraints on timberline formation by mountain beech focused primarily on temperature effects, and in particular the incidence of frost and freezing conditions causing winter dieback. He clearly established tissue dieback and bud death resulting from low temperature desiccation as an important factor in limiting the advance of timber lines and the establishment of isolated seedlings (Wardle 1985a). The establishment of outlier stands was also discussed by Rogers (1989), who in particular identified the importance of microsite in seedling establishment and survival, and Haase (1989) who made an intensive study of a single stand of *N. menziesii* (Hook.f.) Oerst. (silver beech) examining rate of spread. None of these studies, nor those of Holloway (1954), Wardle (1980), or Allen (1987), which also discussed beech forest boundaries and outlier stands, examined the fate of residual stands isolated from the continuous forest margin by such events as fire or windthrow. The influences described by both Wardle (1985b) and Rogers (1989), in relation to stand establishment, are strongly evident in the dynamics of stand survival examined in the present study; however, exposure to wind, in association with low temperatures, is seen as the dominant influence on the Ruahine stands.

A study by Marr (1977) of tree islands of spruce and fir in tundra vegetation in the Southern Rocky Mountains more closely parallels our findings for the Ruahine stands. He described stand movements of up to 15 m over an unspecified time period, from windward to leeward, largely by vegetative extension and occasional seedling establishment. A similar relationship between dieback along exposed edges and advance along sheltered edges appears to be the key to the dynamics of the stands in the present study. Residual stumps to the west of the ridge-top stand, and tree death and canopy dieback on the exposed western edge of the ridge-slope stand, strongly suggest progressive collapse of these exposed edges, probably as a result of winter dieback. The higher wind speed on exposed edges associated with low temperatures suggests wind chill effect as the primary cause of tissue and bud death leading to the canopy collapse seen in the ridge-top and ridge-slope stands. The rate of stand collapse could not be determined; however, the rate of seedling advance is estimated to be in the region of 2 m (average seedling zone width for ridge-slope stand and below-ridge stand) every 30 to 40 years (average cohort interval for all stands) or about 6 m/century, very similar to that found by Rogers (1989) for mountain beech boundary expansion and not very different from that found by Haase (1989) for silver beech of 9.2 m/century. Stand collapse along exposed edges, combined with seedling advance to leeward, effectively means the stands move across the landscape. Such wind-induced movement may direct the stand up-slope into a more exposed environment, in which situation the collapsing edge may overtake the advancing one leading to stand death. This process may be occurring in a stand which featured in Elder's paper (1965, Plate 5B) and is not far from the present study site. The stand, quite well developed in 1964, had deteriorated to a scattered line of stumps, dead trees, and a few living remnants by 1986. If the movement, as in the stands in the present study, is towards a more sheltered environment, dieback and decline should become less evident and the stand may become stable and perhaps expand. However, the sheltered stand had no seedling zone, suggesting it is presently advancing very slowly or not at all. Unlike the other three stands, it was surrounded by dense vegetation cover. The lack of bare disturbed sites may be the reason for the lack of seedling establishment (Rogers 1989; Wardle 1985a, b). The ultimate fate of stands, such as the ridge-top and ridge-slope ones in the present study, depends upon their reaching a more favourable site before exposed edge dieback overtakes the sheltered edge advance.

Hosking & Hutcheson (1988) have suggested a closed intact canopy is an important factor in the survival of mountain beech at high altitudes where openings through tree death or climate damage lead to ongoing stand collapse (Allen & Wardle 1985). At the timber line a dense closed canopy is also likely to reduce winter dieback affecting exposed individual trees (Wardle 1985a). In the present study the below-ridge stand, which has retained a closed canopy and is advancing down-slope to a more sheltered environment, is young and vigorous and appears assured of survival. The ridge-slope stand occupies an exposed site but has retained a largely intact canopy and is advancing vigorously towards a more sheltered area. Despite dieback along its exposed edge, there seems every chance the stand will survive. The ridge-top stand, the most exposed in the study, has suffered protracted and continuing dieback, the canopy has largely collapsed, and only limited seedling advance is evident. It is possible that this stand will continue to deteriorate to extinction.

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REFERENCES

ALLEN, R.B. 1987: Ecology of *Nothofagus menziesii* in the Catlins Ecological Region, south-east Otago, New Zealand. II. Seedling establishment. *New Zealand Journal of Botany 25*: 11–16.

ALLEN, R.B.; WARDLE, J.A. 1985: Role of disturbance in New Zealand montane and subalpine forests. Proceedings of Third IUFRO Workshop p.1.07-00 1984. *Eidgenossischen Anstalt fur das Forstliche Versuchswesen Berichte 270*: 151–7.

ELDER, N.L. 1965: Vegetation of the Ruahine Range: An introduction. *Transactions of the Royal Society of New Zealand, Botany 3*: 13–66.

GRANT, P.J. 1984: Drought effect on high altitude forests, Ruahine Range, North Island, New Zealand. *New Zealand Journal of Botany* 22: 15–27.

HAASE, P. 1989: A population study of an isolated stand of *Nothofagus menziesii* near Otira, South Island. *New Zealand Journal of Botany 27(1)*: 49–57.

HOLLOWAY, J.T. 1954: Forests and climate in the South Island of New Zealand. *Transactions of the Royal Society of New Zealand 82*: 329–410.

HOSKING, G.P.; HUTCHESON, J.A. 1988: Mountain beech (*Nothofagus solandri* var. *cliffortioides*) decline in the Kaweka Range, North Island, New Zealand. *New Zealand Journal of Botany 26*: 393–400.

MARR, J.W. 1977: The development and movement of tree islands near the upper limit of tree growth in the Southern Rocky Mountains. *Ecology 58*: 1159–64.

NORTON, D.A.; PALMER, J.G.; OGDEN, J. 1987: Dendroecological studies in New Zealand. 1. An evaluation of tree age estimates based on increment cores. *New Zealand Journal of Botany 25*: 373–83.

ROGERS, G. 1989: Beech and conifer community interactions in Moawhango Ecological Region, North Island, New Zealand. *New Zealand Journal of Ecology 12*: 47–61.

SHAW, W.B. 1983: Tropical cyclones: Determinants of pattern and structure in New Zealand's indigenous forests. *Pacific Science 37*: 391–5.

THOMPSON, C.S. 1987: The climate and weather of Hawkes Bay. *New Zealand Meteorological Service Miscellaneous Publication 115(5).*

WARDLE, J.A. 1980: Distribution and dynamics of the indigenous forests in New Zealand with major emphasis on the beeches. Pp. 13–9 *in* Benecke, U.; Davis, M.R. (Ed.) Mountain environments and subalpine tree growth. *New Zealand Forest Service Technical paper No.70.*

WARDLE, J.A.; ALLEN, R.B. 1983: Dieback in New Zealand *Nothofagus* forests. *Pacific Science 37*: 397–404.

WARDLE, P. 1985a: New Zealand timberlines. 1. Growth and survival of native and introduced tree species in the Craigieburn Range, Canterbury. *New Zealand Journal of Botany 23*: 219–34.

———1985b: New Zealand timberlines. 2. A study of forest limits in the Crow Valley near Arthur's Pass, Canterbury. *New Zealand Journal of Botany 23*: 235–61.