CLIMATIC WARMING AND THE UPPER FOREST LIMIT

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INTRODUCTION

Climatic warming is a hotly debated subject these days, with people holding views ranging from the convinced (mainly scientists and 'greenies') to the sceptical (other scientists and those allied to the petroleum industry), with politicians waiting to see which way public opinion swings. Militating against consensus are the swings in climate that occur from year to year, or over a few years, that may or may not have bearing on long-term trends.

As a contribution towards providing objective information about long-term climatic trends, we carried out a study during summer 1989-90 at the upper forest limit, to see whether patterns of seedling establishment provided any evidence that limits were rising (Wardle & Coleman 1992). We restricted ourselves to the limits of mountain (*Nothofagus solandri* var. *cliffortioides*) and silver beech (*N. menziesii*) because these are more sharply defined than forest limits formed by other species, the beeches occur at greater densities than other trees at the forest limit, and their ages are more easily determined. We sampled 18 sites on both sides of the Main Divide from Nelson to Southland, situated as far as possible, on relatively uniform slopes uninterrupted by bluffs and not influenced by fire or destructive avalanches. We searched for the highest elevation seedlings, and measured their distances above the edge of the forest canopy, measured their diameters and heights, and sampled representative plants in order to relate number of growth rings to size.

We found that there was indeed a zone in which young beech plants occur above the limits of mature trees. However, this 'advance zone' was only 5 m and 8 m respectively for mountain and silver beech. The density of young plants was generally low, and most young plants had established within the 60 years before 1989-90. In order to find whether the apparent trend was temporary or continuing, we set up permanent transects at six localities, which were Mt Faust south-east of Lewis Pass, Mt Haast south of the Rahu Saddle, near Craigieburn ski field, the western side of the Mataketake Range near Haast, and in Takahe Valley, Fiordland.

METHODS

We set up the transects during the summers of 1990/91, 1991/92 and 1992/93. Transects ranged from 277 m to 541 m in length (total length 1695 m), though at Mt Haast and Takahe Valley we had to divide the transects into eastern and western portions to obtain sufficient length of suitable slope. The transects consisted of successive sections, each beginning at a high point of the forest edge and permanently marked by waratah standards. The tape was stretched between standards and then allowed to rest on the vegetation between.

Coordinates of all beech plants above the forest edge and of representative points of the forest canopy margin were recorded as the shortest distance from the plant to the tape, and the intersect on (i.e. distance along) the tape (Fig. 1).

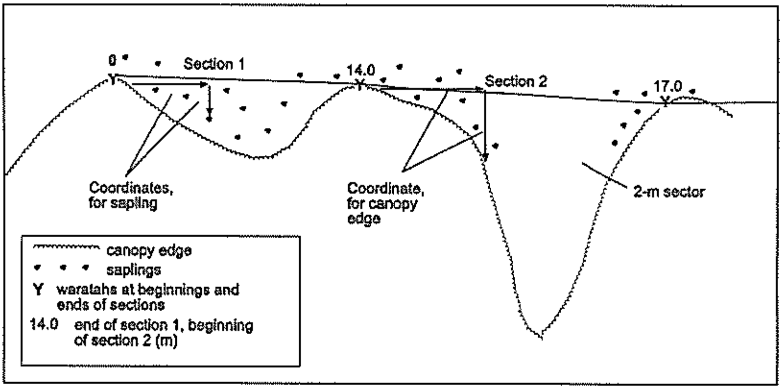


Fig 1. Layout of transects (schematic).

Heights, diameters, and shoot growth increments over the last two years were measured, the number of stems in multi-stemmed plants counted, and evidence for browsing, frost damage, breakage by snow, etc., was noted.

After 11-12 years the measurements were repeated. Only two of the 65 waratahs had become dislodged, because rock prevented them being driven deep enough to withstand sliding snow. Re-measuring the coordinates allowed nearly all of the plants to be confidently identified. Even though it was not always initially possible to re-lay the tapes in exactly the same position as originally, well-established plants provided further reference points that allowed the tape to be adjusted to its original position. Occasional uncertainties arose where young seedlings occurred in great density, or where soil slumping had moved plants downhill, sometimes as much as 2 m. Young plants were numbered and tagged during the 2002-04 measurements to avoid any future ambiguities.

Our data are now being statistically analysed, but we provide this preview, in which we have pooled results from the transects. For present purposes we consider only young beech plants that are at least 5 cm tall, which for convenience we shall refer to as 'saplings'. Results for smaller seedlings are more difficult to interpret, because these appear in large numbers after mast years, have high mortality, and are easy to overlook where they occur sparsely.

RESULTS

Position of the upper forest margin

The position of the forest canopy edge was compared at 647 points in total. At 77% of points it was higher in the second year of measurement (Y2) than in the first year (Y1), at 17% it was lower, and at 6% there was no change. The largest rises (up by 23.5 m) occurred where tall saplings that were outlying in Y1 became merged with an advancing forest canopy by Y2, and the largest falls (down by 15 m) resulted from death of canopy-edge trees. The average rise, however, was only 1.6 m

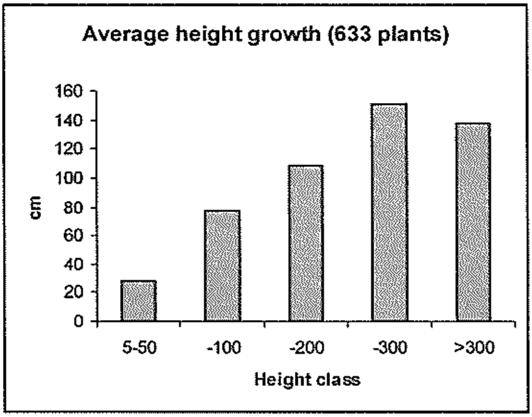
Recruitment and loss of saplings

Numbers of saplings beyond the canopy edge were 779 in Y1, and 950 in Y2, an increase of 71 or 9%. The actual number of new plants found in Y2 was 294 but this was offset by 123 plants that had become suppressed beneath the advancing canopy, uprooted by snow movement or soil erosion, grown to become merged with their neighbour, or were simply missing.

Growth

Surviving saplings show positive height growth between the Y1 and Y2 periods, even though damage, chiefly die-back during and after winter, was noted on 30% of the plants measured (Fig 2). Once plants reached the 300 cm height class the rate of height growth appears to decrease, though in these tallest plants the average was mainly derived through estimation rather than measurement. Diameter increment measured at the base of the stem averaged 2.4 cm over the period, but this is an underestimate because the position measured at Y1 was often buried by Y2, so a higher, thinner part of the stem had to be measured. Height and diameter growth of silver beech averaged half and a third respectively of that of mountain beech.

Fig 2: average height growth of saplings between years 1 and 2



Height of saplings in relation to year of establishment

Age estimates indicate that of the 734 plants recorded in Y1, the 42% that were more than 1 m tall were likely to have been at least 11 years old, and that the 21% exceeding 2m were likely to have been at least 20 years old. Even among plants that were 50 cm or less tall, one third of the 235 present in Y2 were already present in Y1, which suggests that a similar proportion of this height class in Y1 would also have become established at least 11 years previously. Of the 294 plants that were first recorded in Y2, 12% seemed too tall (>80-100 cm) for plants that were only 11 years old, and may have been missed in Y1.

Frequency of saplings

An approximation to frequency (i.e. numbers of plants in a sample area) for Y2 was provided by the numbers present in 2m-wide sectors, that ran upwards from the forest edge to and beyond the base tape. Of the 849 sectors, 53% contained no saplings at all, 24% contained only one, and only 1% contained more than 10. While these frequencies may seem very low, it should be realized that one sapling growing to tree size in a sector is more than sufficient to result in an altitudinal rise of the forest limit. The empty sectors were more or less clustered to form gaps without seedlings. These range from gaps that were only 2 m wide (i.e. a single sector), through to gaps more than 10 m wide, that coincide with deep dips in the forest margin, where little colonisation by young beech is foreseeable. The widest, 82 m, was a scree-filled, avalanche-swept gully.

The sectors containing most saplings (up to 14) occurred on the more eastern transects where patches of bare or mossy ground among short vegetation provide many preferred sites for seedling establishment, in contrast to sectors in western localities that have denser cover of grass and shrubs.

Altitudinal positions of saplings in Y1 and Y2

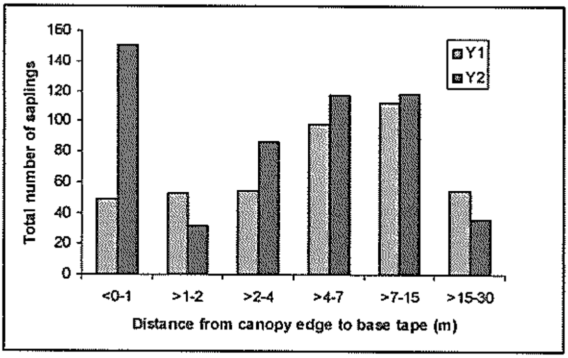
Altitudinal positions of saplings on the slope were determined as the highest sapling in each consecutive 2 m-sector. For 339 sectors that contained saplings in both Y1 and Y2, 17% had a sapling further upslope in Y2 than in Y1, and 4% had a sapling at a higher point in Y1 than in Y2, giving an average movement upslope of only 46 cm, though individual sectors ranged from decreases of 3.75 m to gains of 13.1 m. In 79% of these sectors, there was no change.

There were 68 sectors where we found saplings only in one measurement year, with 76% of these sectors having gained saplings by Y2, compared with 24% that had lost them.

Distance of Saplings from the Forest Margin

To gain an indication of distances of saplings from the forest margin, we selected sections of the transects where the base tape ran more or less horizontally, as these provided a truer picture of the rises and dips in the forest margin than sections where the base tape was inclined up- and down-slope. Along these horizontal sections, we sorted distances of the canopy edge from the base tape into six distance classes (Fig. 3a). Although this figure suggests that there are similar numbers of saplings in each distance class, in Fig. 3b where we make allowance for the different depths of our distance classes, we can see that saplings occur most densely and more closely to the forest edge where the altitude of the forest edge is highest, whereas the saplings establishing in deep dips in the forest edge are spread more sparsely over greater distances.

However, a better impression of the width of the 'advance zone' may be given by the mean distances of the four saplings furthest from the canopy edge in each distance class. These means range from 3-6 m where the forest margin is highest, to 9-14 m where it is lowest. Overall there were more saplings in Y2 than in Y1.



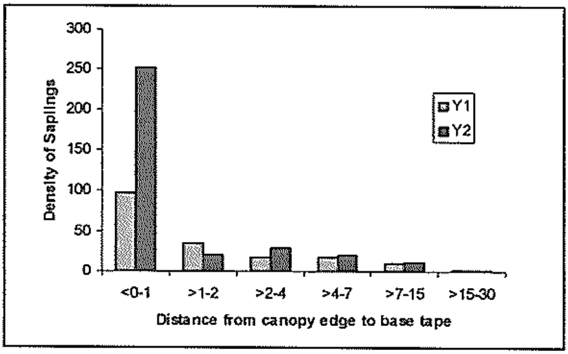


Fig 3. Distance (a) and relative density (b) of saplings in relation to position of the forest canopy margin (all distances in m).

CONCLUSIONS

Our results show, on the one hand, extension upslope of the forest canopy margin and establishment of seedlings beyond it, together with growth of those seedlings into saplings and trees, that would be expected to lead to rises of the forest limit. On the other hand, opposing processes of die-back and death also occur. However, the balance lies on the positive side, and this situation has prevailed over the measurement period of 11 years, almost certainly over a similar period preceding the initial measurement, and perhaps as long as 60 years (Wardle & Coleman 1992).

A natural boundary such as the forest limit can be expected to fluctuate as plants die and new plants become established. Where death and recruitment balance each other, a stable position for the forest limit can be expected. However, this equilibrium may only prevail in the long term; in the short term there may be rises and falls, depending on events that happen with some regularity, such as mast years, or great irregularity such as extreme weather events. Cullen et al. (2001) suggested that the gains that Wardle and Coleman reported may simply represent short-term cycles of recruitment and loss, a possibility that we also raised as the justification for setting up long-term monitoring. The results of 11 years of monitoring totally support conclusions from our initial study, i.e. that the forest margin is expanding upslope. Yet, it must be said that these conclusions are only valid for what has occurred up to the present; hypothetically at least, reversal could commence any time in the future.

Of immediate interest, however, is the small size of the gains that we have measured, other than the quite impressive persistence and growth of established saplings over the 11 years. The average gain upslope was less than 0.5 m for saplings and 1.6 m for the forest canopy margin, which translates to only about half of this in terms of altitudinal gain. However, average values provide a conservative estimate of the gains; outlying saplings also contribute and their visual impact increases as they grow larger. The density of saplings overall is also low, but this too has to be considered in the contexts that low densities can still lead to advance of the forest limit, and that the longest sectors of transect without saplings cross deep depressions in the forest limit caused by environmental factors different from those that set the higher points of the forest limit.

Feasible explanations for the present small but measurable rise in the forest limit include recovery from fire, reduced grazing, or global warming. Occurrence of fire should be evident as charred wood, which we were unable to find. Only at Craigieburn and Faust is there a possibility of sheep having been grazed, and that possibility is very low for Faust, where, however, there is clear evidence of browsing by saplings by hares, which would be expected to counter rather than promote a rising forest limit. Red deer are present at all localities, and because their numbers were reduced after the 1960s, a coincidence with the rise of the forest limit is evident. However, according to Wardle (1984) 'the beeches... are not usually preferred as food plants by red deer; neither are they particularly susceptible to being browsed'; also, beech seedlings under the forest canopy appear more susceptible than those growing vigorously beyond the margin, among more palatable forbs and grasses.

On balance, we prefer global warming as an explanation, but in New Zealand this is believed to have been about 0.5° since the beginning of the 20th century. This might be expected to lead to a rise of some 100 m in altitudinal limits of trees, which is far greater than that indicated even by the most distant outliers that we recorded. The lag in the rise in the forest limit may be due to an environmental hurdle at the transition between forest and the terrain above, involving factors such as the greater frequency and severity of frosts in the open, for which beech seedlings have limited tolerance, and presence or absence of the mycorrhizal fungi that beech depends on (though this has not prevented hardy exotic trees that are equally mycorrhiza-dependent from establishing well above the native forest limit (Wardle 2002).

At their upper limit, our high-altitude beech forests usually contain a high proportion of apparently mature trees (pers. obs.; Cullen et al. 2001). Life spans are up to 360 years for mountain beech and 600 years for silver beech (Wardle 1984), and can be prolonged through layering of lower branches (Norton & Schoenenberger 1984; Wardle 1963). It is therefore possible that present forest limits were set during an earlier period of warmer temperatures, and maintained through an unfavourable period through retaining a forest micro-environment. If so, temperature increases so far may have only allowed beeches to establish a short distance above the present forest limits.

In the context of likely biological effects of global warming, our results suggest that as far as replacement of cold-tolerant biomes, such as grassland and shrubland, by biomes with higher warmth demands, such as forest, is concerned, responses of vegetation may be slower and initially at least, of lower magnitude than climatic changes.

ACKNOWLEDGEMENTS

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