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Forests and Recent Climatic History of the Huiarau Range, Urewera Region, North Island

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Summary

THE forests and their present physical environment are broadly described. Three major forest zones—viz., podocarp, red beech and silver beech, are discussed. Mountain beech communities are briefly outlined.

Within the temperature tolerances of each species, it appears that the vigour and frequency of podocarps and of red and silver beech are primarily related to the moisture factor of the growing season.

At the present each major forest type, indeed each forest zone as a whole, is unstable; and marked changes in forest composition and condition have taken place during the last 300 to 400 years. Many forest changes can only be related to climate.

It is postulated that precipitation effectiveness (P.E.) has decreased significantly, probably on a more or less progressive scale, and this change overtook forests on the moister sites around 1750–1800 A.D., while some time before this the forests on relatively drier sites were affected. There are good indications that, in relation to forest condition, reduced P.E. during the growing season is an effective factor at the present time.

The hypothesis is proposed that a general increase in temperature has taken place, at least since C.1700 A.D. However this change was accompanied by an overall increase in temperature variability which produced a lowering of temperature minima. Furthermore an increase in general windiness has taken place during recent centuries.

Changes in climatic factors must be related, and it is likely that the recent general rise in temperature has induced increased atmospheric turbulence, or windiness, with a consequent change in the rainfall regime—an increased tendency for rather longer periods without effective precipitation to occur. Both increased temperature and windiness have served to further reduce the level of P.E.

Many forest features can only be understood in terms of a hypothesis which proposes that the forests were severely damaged on an extensive scale, probably by winds of exceptional force. This catastrophic phenomenon took place around 1650 A.D. Only the products of this phenomenon and climatic change, in their numerous combinations, can satisfactorily shed light on the history and status of each forest unit. On its own, neither phenomenon can elucidate the forest tangle.

A brief review of the findings of others in this field of work is presented.

An endeavour is made to stress that a thorough understanding of the forests is impossible without sufficient climatological information.

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INTRODUCTION

THE author's close association with the forests of the Huiarau Range and its environs, as a member of the Forest Research Institute, New Zealand Forest Service, terminated at the end of 1951.

Since then, more detailed information relating to species distribution may have been collected; but it is prudently considered that additional data of this kind would not materially alter the major deductions and hypotheses presented.

Detailed forest descriptions are not generally attempted, except where thought desirable in relation to an important deduction or hypothesis.

While varying amounts of evidence are presented for the hypotheses proposed it is extremely important that others set out to test the strength of each hypothesis and leading deduction. It is true that some deductions and ideas are extrapolated beyond the safe limits of the available data; but this is intentional. By such provocative means it is hoped, firstly, to bring to wider notice ideas upon which others may already hold useful information. In the second place it is intended to stimulate greater activity and thought, particularly among foresters, for many have the means at their disposal for the confirmation or modification of the main ideas put forward.

The writer's only apology lies in the thought that if foresters, and others, are able to derive any practical benefit from these contents, then it is unfortunate that circumstances did not permit their presentation at an earlier date.

SECTION 1—ENVIRONMENT

The Huiarau Range is a complicated mountain mass of the North Island. It lies to the east of Lake Taupo and extends north-eastwards from the Taupo–Napier State Highway (No. 5) for about 45 miles (Fig. 1). The eastern portion is traversed by the Rotorua–Lake House State Highway (No. 38) which crosses the divide at the Taupuke Saddle, 3,015ft above sea level. A low saddle, about 1,950ft between the heads of the Whakatane and Waiau rivers, separates the regions referred to as the East and West Huiaraus (Fig. 3). Several peaks ascend to over 4,000ft in elevation, the greatest recorded height being 4,602ft on Mt Manuoha in the East Huiaraus. With the exception of a few agricultural clearings and the tops of some mountains, the range is forested.

Its geology is made complex by the occurrence of Triassic-Jurassic greywacke and argillite, Cretaceous sandstones and mudstones, and at least two groups of Tertiary sandstones and mudstones. The West Huiaraus consist largely of greywacke and argillite, while the eastern region is largely composed of sandstones and mudstones. These younger rocks are block-faulted, and steeply tilted and over a wide area dip to the south-east, forming a more or less parallel series of ridges which trend north-east and have very steep escarpments. A conspicuous fault-line, more or less parallelled by the Whirinaki River, marks the western extent of the Range.

As would be expected the soils are extremely variable. On more stable slopes they are derived wholly or in part from pumiceous deposits; the uppermost being chiefly from the Taupo Shower dated around 200 A.D. (Fergusson and Rafter, 1959). Elsewhere on slopes skeletal soils predominate. Volcanic ash particles become finer and the deposits more shallow towards the east.

Prevailing winds are from westerly quarters with the accent on north-west. These supply moisture, but chiefly to the north and west faces of the range. Much of the region is affected by cool winds from southerly and easterly quarters. These cool winds attain high velocities and distribute moisture over the greater portion of the mountain system but chiefly over areas to the south and east of the divide. These latter localities are generally moister than those on opposing faces.

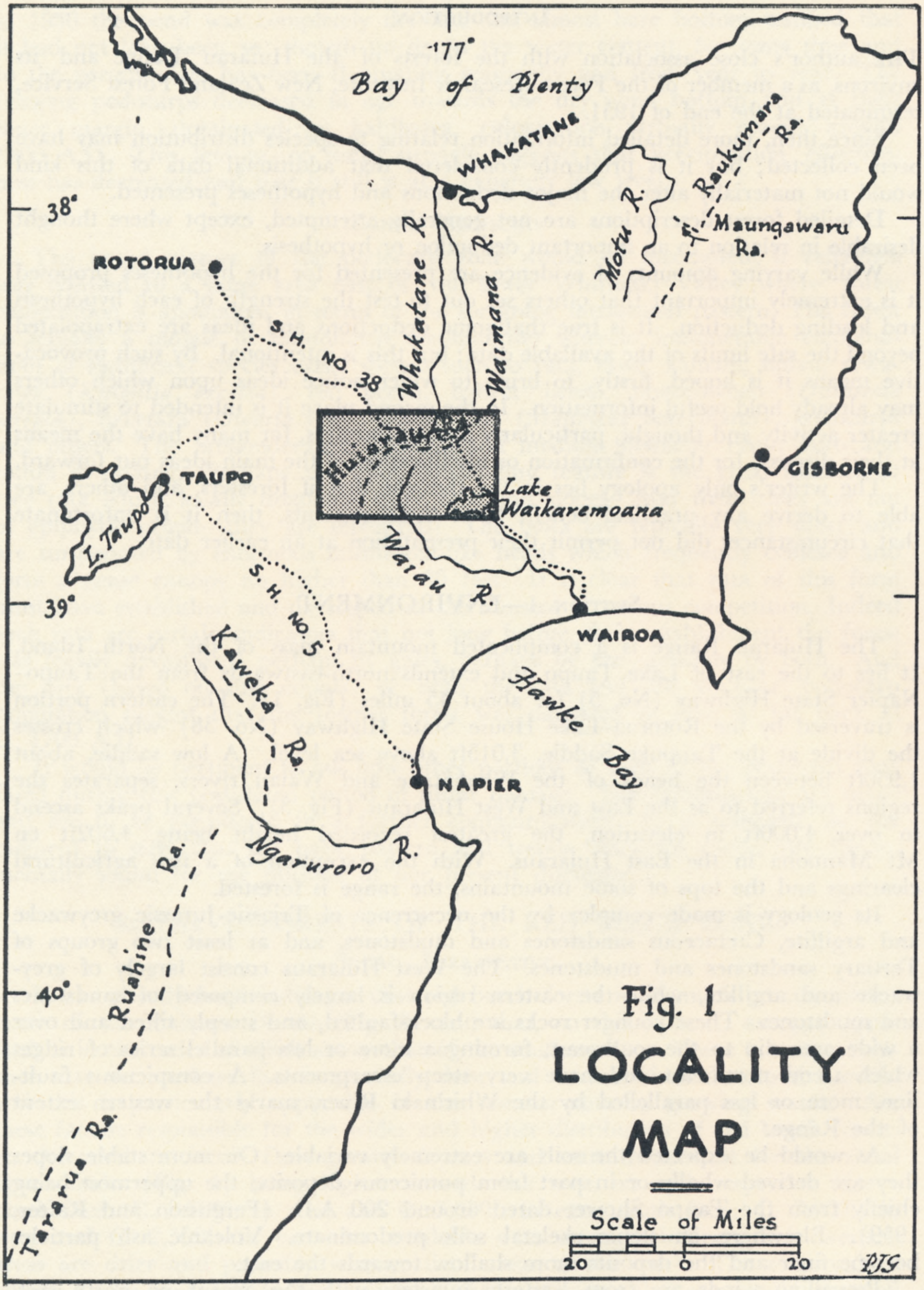


Fig. 1.—Locality Map.

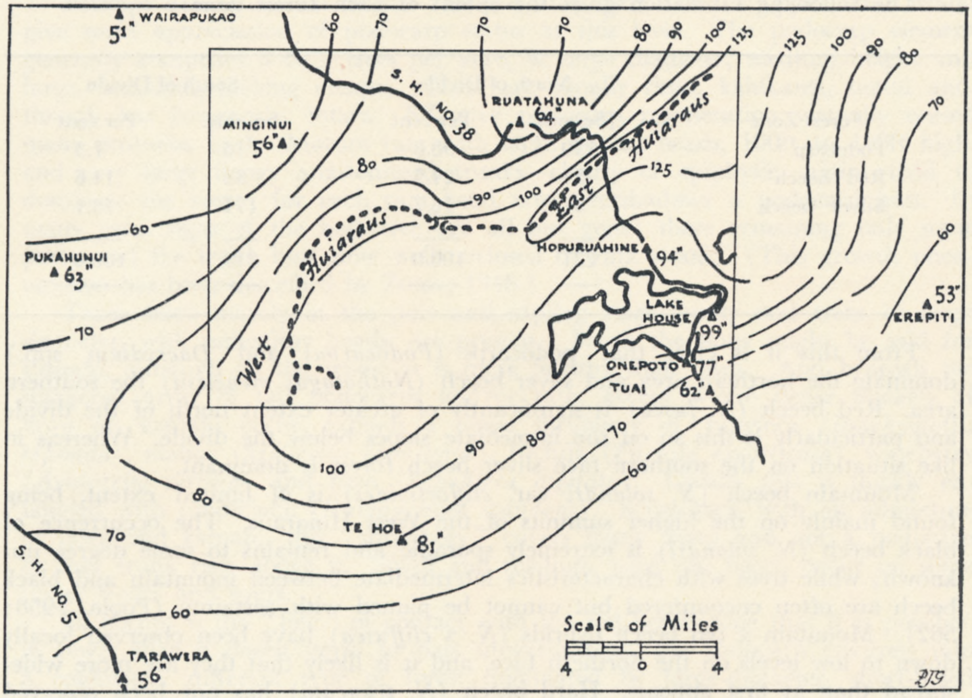


FIG. 2.—Generalised pattern of average annual rainfall for the period 1921–1950.

Average annual rainfall values (Fig. 2) are adopted from a provisional rainfall map (1961) of Meteorological Service, except for Te Hoe, which was calculated by the author. These values and the isohyetal pattern indicate markedly higher rainfalls on the southern face of the divide. And the tendency is strong for eastern areas to be considerably moister than areas farther west. Even if considerable latitude is allowed, and it must be, in the location of some of the isohyets, there is sufficient justification for the broad pattern presented.

Taken overall, areas north of the divide are warmer than their southerly counterparts. This difference is marked and appears to be largely due, first, to the more effective reception of solar heat north of the divide and, secondly, to the greater exposure to cool southerly winds south of the divide.

Frosts, frequently severe, occur during autumn, winter and spring. Snowfalls at upper levels average about 10 to 15 days per annum; the fall varying greatly from year to year. Only infrequently does snow fall below around 2,000ft.

SECTION 2—THE BROAD FOREST PATTERN

The accompanying map (Fig. 3) though excluding a north-eastern and a southern portion of the Huiarau Range environs, presents a picture which, by area, is fairly well balanced. Discounting lake areas the map embraces 440 square miles which are divided by the Huiarau Divide into a northern area of 221 square miles and a southern area of 219 square miles. Three major forest zones have been recognised and broadly delineated; the podocarp, the red beech and the silver beech zones. Within the podocarp zone sizeable clearings exist, but for this introductory bird's-eye panorama of the forests the area of cleared country (about 28 square miles) is incorporated in the total podocarp zone area.

The following tabulation gives the extent of each forest zone:

	North of Divide		South of Divide	
Forest Zone	Sq. mls.	Per cent	Sq. mls.	Per cent
Podocarp	130	58.8	16	7.3
Red beech	54	24.5	32	14.6
Silver beech	37	16.7	171	78.1
	221	100.0	219	100.0

From this it is clear that podocarps (*Podocarpus* and *Dacrydium* spp.) dominate the northern area and silver beech (*Nothofagus menziesii*) the southern area. Red beech (*N. fusca*) is significantly of greater extent north of the divide and particularly is this so on the immediate slopes below the divide. Whereas in like situation on the southern face silver beech forest is dominant.

Mountain beech (*N. solandri* var. *cliffortioides*) is of limited extent, being found mainly on the higher summits of the West Huiaraus. The occurrence of black beech (*N. solandri*) is extremely sporadic and remains to some degree unknown; while trees with characteristics intermediate between mountain and black beech are often encountered but cannot be named with certainty (Poole, 1958: 562). Mountain x red beech hybrids (*N.* x *cliffusca*) have been observed locally down to low levels on the northern face, and it is likely that they are more widespread than at first appears. Hard beech (*N. truncata*) has not been observed in the area by the writer, but it might well be present.

In the podocarp zone the chief species are rimu (*Dacrydium cupressinum*), matai (*Podocarpus spicatus*), kahikatea (*P. dacrydioides*) and miro (*P. ferrugineus*). The high-volume rimu, matai–totara (*P. totara*) and related stands of the Whirinaki Valley are really beyond the scope of this survey but they receive mention in ensuing discussion.

Altitudinal zonation differs markedly between north and south faces and also from east to west (Fig. 4). On the northern face the podocarp zone passes, fairly abruptly, to the red beech zone around 2,400ft, while scattered podocarps chiefly rimu, ascend within the red beech zone to about 2,600ft on the West Huiarau face and to nearer 2,900ft on the East Huiarau face. South of the divide the podocarp zone ascends little above 2,200ft except towards the head of the Waiau River, where the upper zonal limit harmonises more closely, around 2,400ft, with that of the northern face.

The red beech zone of the northern face seems to have its upper limit around 3,300ft in the west and about 3,000ft in the east. On the southern face its upper limit seems to be around 2,900ft to 3,000ft in the west but little above 2,300ft to 2,500ft in the east.

On the East Huiaruas the silver beech zone ascends to the tree-line which on Mt Manuoha is little under 4,600ft. In the west it appears to find its upper limit around 3,800ft.

At this stage it is apparent that the major forest zones comprise a mosaic which alters markedly from north to south and, though rather less so, from east to west as a consequence of variation in both areal extent and vertical distribution of the component zones. To understand the full significance of this pattern we must seek to ascertain the controlling factors of both horizontal and vertical distribution—one is not necessarily a function of the other. And in this quest our first thoughts should turn to the existing factors of the environment.

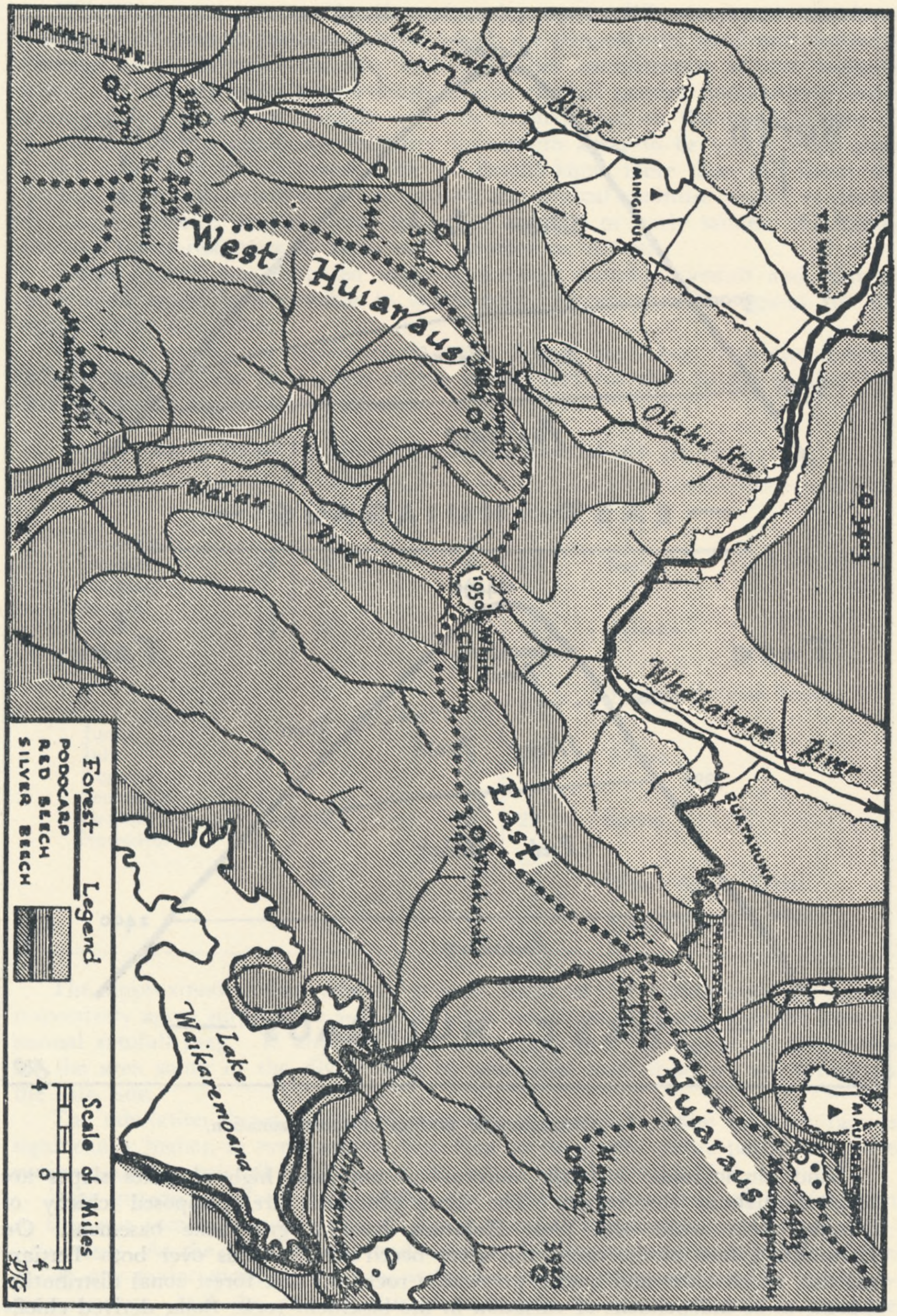


Fig. 3.—Broad pattern of forest zones.

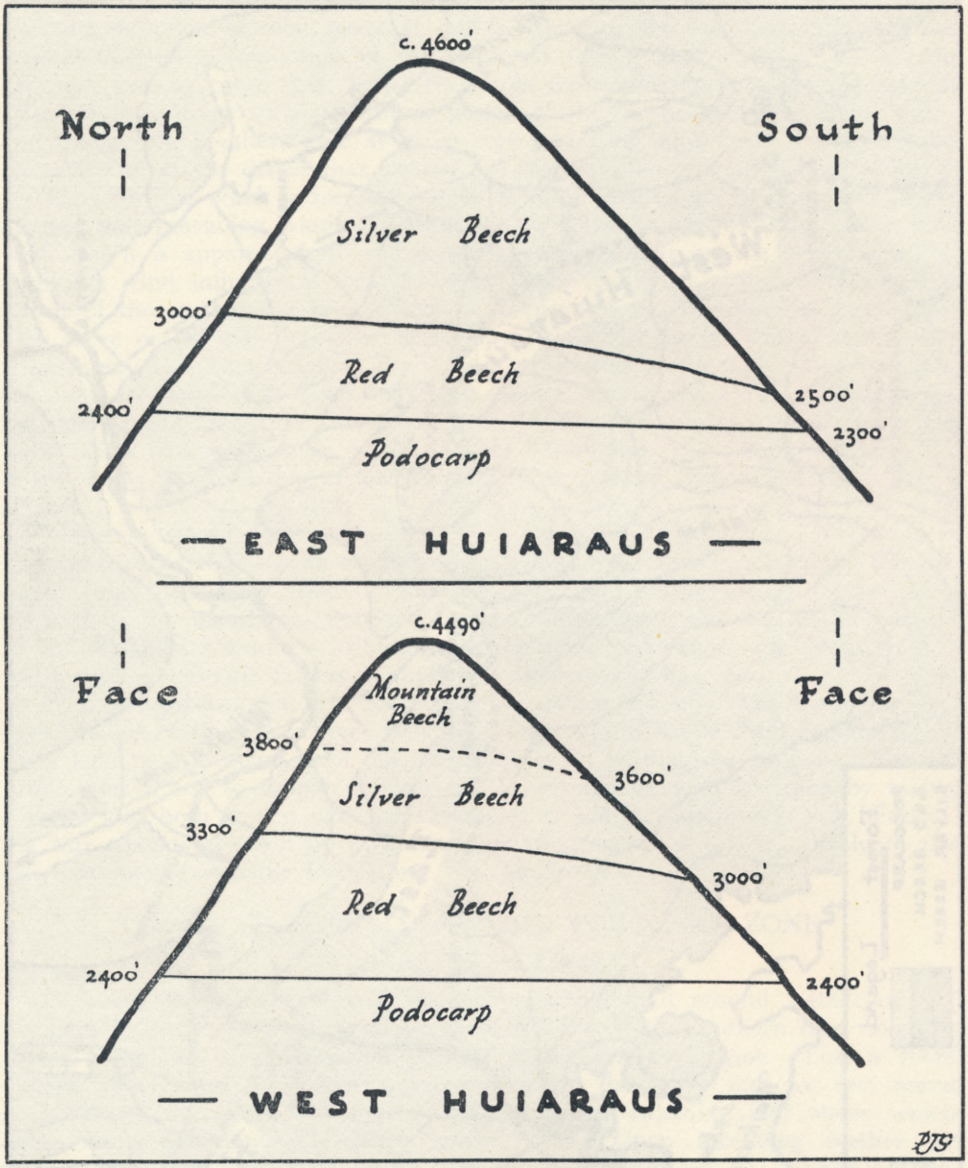
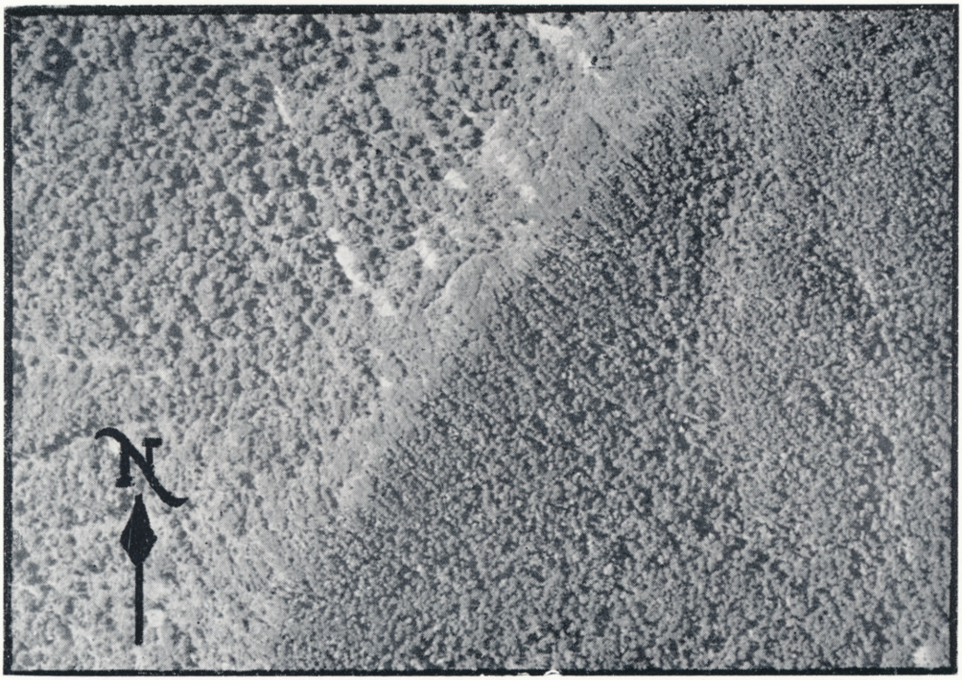


FIG. 4.—Diagrammatic profiles of forest zonation.

Land physiography is fairly uniform—at mid and high altitudes slopes are steep throughout the region. The East Huiaraus are composed chiefly of Tertiary rocks while the West Huiaraus have a greywacke basement. On the southern face of the range the silver beech zone extends over both Tertiary and the much older and harder greywacke rocks, so that forest zonal distribution appears to be independent of variation in the basement rock. Soils, derived chiefly from deep deposits of volcanic ash which become finer towards the east, cannot exercise any significant degree of control because the most marked forest zonal differences are between the northern and the southern areas.



Canopy striations due to south-east winds on the south-east face (back slope) of the East Huiarau divide, about 1 mile south-west of Maungapohatu Trig, 4,483ft. Note the marked difference in tree-head diameters each side of the divide. On much of the very steep escarpment slope, immediately below the divide to the north-west, occurs a very young, seemingly induced, vegetation.

—Photo No. 1645/26: Lands & Survey Copyright.

This leads us to a consideration of major aspect differences and introduces a complex of climatic features chief of which are temperature, wind and moisture. Perhaps we could open the way with a further consideration of the moisture factor. As already stated, the average annual rainfall pattern demonstrates fairly convincingly that annual rainfalls are very much higher on the southern face of the divide, with a significant tendency for eastern areas to be wetter than areas to the west. But in any forest study we should know more than this about the rainfall factor. In relation to tree growth the critical moisture period is during the active growing season—from spring to autumn or early winter. At higher altitudes the period may be from early summer to autumn.

Seelye (1945) has prepared maps of average monthly rainfall and, though on a small scale, it is possible to satisfactorily extract monthly figures for the region under discussion.

For each month an approximate mean figure was taken from the average isohyets both for the area north of the divide and for that to the south. The derived rainfall figures are as follows:

APPROXIMATE MEAN AVERAGE RAINFALLS (in inches)

	North of Divide		South of Divide		
December	5½	15	6	20	Summer
January	4½		6		
February	5		8		
March	5½	19	7½	26	Autumn
April	5½		7½		
May	8		11		
		34		46	Summer–Autumn Totals
June	8	24	11	32	Winter
July	8		10		
August	8		11		
September	5	16	7½	23	Spring
October	6		8		
November	5		7½		
		40		55	Winter–Spring Totals
		74		101	Annual Totals

The approximate mean average annual totals of 74 inches and 101 inches respectively agree surprisingly well with what would be obtained from the average annual rainfall map. If anything, Fig. 2 suggests that the figure of 101 inches for the area south of the divide may be somewhat low—if so we are erring on the safe side.

The tabulation shows that on the average the rainfall of the southern face is significantly higher, in every season, than that to the north. More particularly, the summer-autumn rainfall is higher on the south face by about 35%.

Tree growth is related to available soil moisture rather than to precipitation so that our summer-autumn rainfall figures require adjustment in terms of moisture losses. As the physiography and soils are fairly comparable each side of the divide any major moisture losses must be due to the composite process of evapo-transpiration. And the rate of this phenomenon is closely related to sunshine duration and air temperature. In the absence of comparative temperature and sunshine data for the northern and southern areas we can do no better at present than accept a generalisation to the effect that evapo-transpiration losses are probably greater overall on the northern face, chiefly as a consequence of the more effective reception of solar heat. If this is true then the mean average effective summer-autumn precipitation of the southern face is higher than that of the northern face by more than 35%. In simple terms, therefore, it appears safe to refer to the average summer-autumn period of the northern face as being moist and that of the southern face as being very moist, recognising at the same time on each side of the divide that eastern are moister than western areas.

Thus far the wind factor has not been fully considered. It has been noted already that prevailing winds are from the west with a strong accent on north-west, but it is apparent from the forests themselves that on the south face the dominant wind influence is from the south-east. At higher altitudes the physical effects of the south-easter on the forest canopies are clearly visible in aerial view as a more or less parallel series of canopy striations. These parallel the causal wind directions which, south of the divide, range from south to south-east; south-south-east to south-east being the more general directional range. The canopy striation pattern comprises alternating irregular strips of canopy, one or more tree heads wide, and strips more or less lacking a complete upper canopy (Plate 1). At the same time dwarfing of the forest structure is more pronounced on southerly aspects.

Returning to the forest zones and their distribution we are now in a position to state broadly that forests of the southern face exist under moister, cooler and more windy conditions than do the forests of the northern face. So we may deduce, in the meantime, that the marked differences each side of the divide in vertical and horizontal distribution of the major forest zones are closely related to these three climatic factors of moisture, temperature and wind.

Were we satisfied that this existing forest pattern is fixed—that it has persisted over periods of time to be reckoned in millennia, and that it will remain stable for a long time to come, then our diagnosis would be almost complete. That the proposition is not so simple or clear-cut, however, can be ascertained by taking a closer look both at and under the canopies of the various forest zones. Following this scrutiny we will be in a better position to more correctly evaluate the relationships between the forests and their environments.

SECTION 3—FORESTS OF THE PODOCARP ZONE

BROAD DESCRIPTION

Podocarp forests, which have their upper zonal limit around 2,400ft on the northern face and only locally above about 2,200ft on the southern face, conform to the same vertical distribution pattern throughout the region. This is more clearly depicted on the northern face. Here on the lower sites we find matai or kahikatea dominant stands of mixed podocarps adjoining and above which dense rimu dominant stands frequently occur. Upon ascending further we traverse in turn forest belts which may be labelled loosely as: podocarp-tawa, tawa-podocarp, tawa-kamahi-podocarp and rata-podocarp. (Tawa: *Beilschmiedia tawa*; kamahi: *Weinmannia racemosa*; rata: *Metrosideros robusta*.)

Each belt or discontinuous stand usually grades insensibly into its upper or lower neighbour except where an abrupt physiographic change occurs as between alluvial valley bottom and steep slopes.

Particularly in the western portion north of the divide the rata-podocarp and red beech " line " of contact, which closely follow the 2,400ft contour, appears to be a no-man's land—a belt of stagnation along which conditions are distinctly unfavourable to podocarp, and for that matter tawa, kamahi and rata, perpetuation and are little less unfavourable over much of its length for the invasion of red beech forest.

Perhaps a brief sketch of the rata-podocarp belt near its upper limit would give some appreciation of podocarp status at this level. The podocarp element generally comprises 3 to 5 trees per acre, of large diameter, medium height and large, unhealthy-looking crowns. These are usually rimu, kahikatea, matai and, though less frequently, totara. Effective podocarp regeneration virtually ceased many centuries back. Mature rata with large domed heads, 100ft to 120ft high, and very large flangy anastomosed trunks—clearly of epiphytic origin—tend to dominate the scene; for each rata head now overshadows a podocarp host. In many cases signs of the host tree are all but gone; there remaining only some portion of the trunk butt now well enclosed by rata wood. (This growth phenomenon has been described by Zotov, 1948.)

Tawa exists mainly in the pole and sapling stages—only odd trees of large diameter, with unhealthy heads, are present. Much the same might be said for kamahi, although on the whole it is more healthy than tawa. And beneath the staggered array of tall podocarps and/or rata, except where dense thickets of tawa or kamahi occur, extends a dense shrubbery of rangiora (*Brachyglottis repanda*), mahoe (*Melicytus ramiflorus*), fuchsia (*Fuchsia excorticata*), wineberry (*Aristotelia serrata*) and pate (*Schefflera digitata*). Locally this is thickly entangled with supplejack (*Rhipogonum scandens*). Sometimes, with an admixture of tawa and kamahi, this " shrubbery " covers many acres and not a podocarp or rata trunk rises above it. Small and medium sized red beech occur on some upper slopes and spurs.

So abrupt is the " line " of contact with the red beech zone that it is possible, in fewer than a dozen steps, to pass upwards from the podocarp environs into a completely different type of forest dominated by large-diameter, short-boled red beech.

In the eastern area north of the divide isolated groups or pockets comprising rimu and miro, matai or kahikatea with odd rata and tawa occur up to around 2,700ft. Seldom, however, can these be regarded as " pure " podocarp communities for red beech and some of its associates are usually present. It is significant that podocarp and rata in such groups are considerably smaller and, by random increment borer assessments, younger than trees of the rata-podocarp belt proper.

In general, in the north-eastern area just referred to and on the southern slopes of the divide there is in the rata-podocarp belt a greater loss of type individuality than is found in the north-western area. This is due to more effective infiltration and colonisation by red beech and some of its associates and even by silver beech.

It has already been indicated that the north-western area has the lowest precipitation effectiveness rating during the vital summer-autumn period; in other words it is the driest area and possibly the warmest. For the time being therefore we may be excused for attempting to relate the occurrence of podocarp groups in the north-eastern area at least 200ft (to be on the safe side) above the north-western podocarp zone limit with greater precipitation effectiveness in the east: and the less effective down slope penetration of the rata-podocarp belt by red beech in the north-west to the drier conditions there during the growing season.

At this stage it would be as well to consider how the various podocarp belts, mentioned earlier, differ from each other. Upwards from the dense low-level rimu dominant stands, rimu remains the most frequent podocarp, accompanied by matai, miro and kahikatea, while totara is the least frequent. The following table is based on average numbers per acre of the physiognomic tree dominants.

The figures listed are based on National Forest Survey plot sampling (Thomson, 1946, 1949) of the north-western face, so that for broad application they

Broad Forest Type or Belt	Average No. of Trees (12″ d.b.h.+) Per Acre				Incidence of Rata
	Podocarps	Tawa	Kamahi	Total	
1. Matai dominant	51	6	2	59	Generally absent
2. Rimu dominant	47	10	2	59	Odd juvenile combines
3. Podocarp-tawa (A)	24	16	2	42	Odd juvenile to medium age combines
4. Podocarp-tawa (B)	16	16	3	35	
5. Tawa-podocarp	6	25	3	34	Odd medium to old combines.
6. Tawa-kamahi-podocarp	6	11	5	22	Odd medium to old combines
7. Rata-podocarp	3–5	6*	8*	18*	3–4 old combines per acre

* Figures are rather approximate.

must be interpreted on a relative basis; for though the same major differences and trends are everywhere evident, the stand densities vary according to locality. As a generalisation, podocarp frequency in a given belt tends to increase with increasing available moisture in the growing season. Perhaps the most outstanding trends, upon ascending the hill slopes, are firstly, the decrease in podocarp numbers and the decrease in total tree numbers notwithstanding that both tawa and kamahi have tended to increase, and secondly, the increase in rata numbers. In themselves these trends could be accepted as quite normal were it not for the fact that paralleling the trend for podocarps to decrease numerically upon ascending there is strong evidence that maximum tree ages increase significantly. And this applies to podocarps, tawa, kamahi and rata.

A series of 80 stump ring-counts (38 by C. R. Crutwell, 42 by this writer) and about 100 increment borer age assessments by this writer indicate this to be the situation. On upper sites large trees and decaying remnants suggest maximum ages for podocarps of at least 800 to 900 years—i.e., established C. 1050 A.D.; while few podocarps became established after around 1500 A.D. In the rimu dominant stands of lower slopes maximum tree ages do not appear to exceed 700 years (established C. 1250 A.D.); the chief establishment period having been 300 to 500 years back (C. 1450 A.D. to 1650 A.D.) while significant podocarp establishment virtually ceased around 1750 A.D. The matai dominant stands have maximum tree ages in the order of 460 years (estab. C. 1500 A.D.); the chief period of establishment was 200 to 350 years back (C. 1600 A.D. to 1750 A.D.) and by about 1800 A.D. significant podocarp establishment had come to a standstill.

Towards the upper limits of the zone tawa is generally unthrifty, scattered older trees being about 400 years old. On mid-slopes tawa is rather more thrifty in general and the increased stocking of larger trees (refer table) seems to have established between 200 and 400 years back (1500 A.D. to 1750 A.D.). At lower levels, in both the rimu dominant and matai dominant stands, though a marked difference exists in the frequency of larger tawa in the two stands, older tawa do not appear to exceed around 250 years (estab. C. 1700 A.D.). Though, in the matai dominant stands of lower levels, tawa stocking is lowest, and youngest, the species seems to exhibit the greatest vigour and the highest potential; as long as sufficient protection is afforded from frost. And this overall picture generally applies to other significant, though less frequent hardwoods, such as hinau (*Elaeocarpus dentatus*) and maire (*Gymnelaea cunninghamii*). We might well ask why the above situation should be.

It could be suggested that these outstanding vertical differences and trends are related to variation in available soil moisture on the basis that soil moisture increases generally upon descending. Some confirmation of this relationship is to be found at lower levels for where a gradual slope change exists the transition from one forest type, or belt, to another is correspondingly gradual; whereas when the ground slope changes abruptly there is also a fairly abrupt break between the forest types. Furthermore it has already been indicated that the higher altitudes of podocarp groups in the north-eastern area is possibly related to increased moisture; while, as stated earlier, podocarp frequency in a given belt or comparable type is higher in the moister areas. There are then strong indications, with increasing available moisture in the growing season either from better soil storage or from more effective precipitation, that podocarp frequency increases. Conversely, above the rimu dominant stands, with decreasing available moisture in the growing season podocarp frequency decreases while tawa increases, but this latter only up to the tawa-podocarp belt on the mid-slopes. Above this tawa decreases rapidly and exhibits a marked decline in form and vigour. This feature, coupled with the fact that the upper podocarp zone limit closely follows the 2,400ft contour, except on the more exposed parts south of the divide, strongly suggests that above a certain limit, some aspect of temperature has, or had, a strong controlling influence.

DECREASE IN PRECIPITATION EFFECTIVENESS

It is abundantly clear that all podocarp stands, irrespective of age, are in a state of change. Podocarps throughout are stagnating. And this process commenced earlier and has proceeded farther at upper levels of the zone. That failure of podocarp re-establishment in low level stands commenced around 1750 to 1800 A.D., and the situation seems little changed at the present, indicates that the causal factor(s) is still operative. In the wake of the failure of podocarps to re-establish, and the overall decline in vigour of the podocarp element of each stand, has followed invasion by hardwood species such as tawa, kamahi and hinau. In turn the development of the hardwoods appears to reach a peak and then declines, as has happened at upper levels. On the lowest sites the peak of hardwood establishment is not yet attained.

The overall picture is of a mass down-slope movement staggered in time between the podocarps and the major hardwoods. Such a wholesale movement could only have been initiated by a change in one or more climatic factors.

To say the least observable facts indicate that a significant reduction in precipitation effectiveness has taken place probably on a more or less progressive scale over many centuries. And this progressive change must have passed the threshhold level for effective podocarp re-establishment on the moister forest sites around 1750 A.D. to 1800 A.D.

This situation clearly persisted and was operative at the advent of exotic feral animals to the forests around the year 1900 A.D. (Wodzicki, 1950: 181) as evidenced by the continued failure of satisfactory podocarp re-establishment. During the last 60 years or so animal damage to the lower forest tiers has proceeded so that now the extent of general depletion is both widespread and severe (McKelvey, 1959). However, the writer has noted that podocarp seedlings and saplings are seldom browsed or otherwise damaged by animals. This observation receives confirmation from Holloway (1950). And as little serious damage to podocarps can be attributed to animals at the present time—for dense podocarp regeneration on many widespread sites on Maori clearings and such-like, established since C. 1870 A.D., has developed exceptionally well (Cameron, 1960)—it would appear that the climatic swing towards reduced precipitation effectiveness has remained in operation to the present day.

Backing for this conclusion was gained from the ages of podocarps, chiefly kahikatea, which fringed a small basin pond north of the divide. When visited in 1950 the pond was completely dry and the almost bare bottom testified that it had not long been so; though no doubt the water content, for some time and to the present day, has been fluctuating seasonally and from year to year. The fringing podocarps decreased in age towards the dry pond bottom and at their inner margin, dominated by kahikatea, colonisation virtually ceased around 1800 A.D. This feature, of itself, strongly suggests that precipitation effectiveness has decreased and that it still is at a generally low level.

ZONAL ANOMALY

The broad picture of the podocarp zone would be incomplete if reference was omitted to a large area east of the lower Whirinaki Valley where forest composition is anomalous in terms of the foregoing intra-zonal pattern. The forest is actually a mosaic of randomised communities wherein innumerable combinations of significant species exist; species such as rata, tawa, kamahi, hinau, rewarewa (*Knightia excelsa*), red beech, hybrid beech, tawheowheo (*Quintinia serrata*), heketara (*Olearia rani*), mahoe-wao (*Melicytus lanceolatus*), podocarps and others. The preponderance of small and medium diameter rimu, miro and totara is striking. Perhaps the most outstanding feature is the great number of tree rata which locally dominate ridge tops and slopes. And these trees are not of epiphytic origin—they are terrestrial! The boles are typically very short and are surmounted by enormous mushroom-like heads which frequently coalesce and form a dense canopy no higher than 80 feet. It is clear that rata of this form must have established and developed in the absence of serious competition. Indeed such rata are certain indicators that not long before their establishment the forest was locally devastated; perhaps by gales, perhaps by fire—possibly by both. And the ages (based on ring counts) of both the rata and the younger podocarp population suggest that the former forest was damaged at least as far back as C. 1700 A.D.

It would be pertinent to ask how other portions or belts of the podocarp zone fared during this postulated period of forest damage. The ramifications are many and are to be considered in a further communication. It is sufficient at the moment to state that the basic pattern and trends described earlier are fundamentally sound for the purpose of our present discussion.

SECTION 4—FORESTS OF THE RED BEECH ZONE

BROAD PERSPECTIVE

It has already been indicated that red beech forest is of much greater extent north of the Huiarau Divide (Fig. 3) and that, on this face, its average upper limit is in the order of 400ft above that of the southern face. There is strong evidence that the northern face is generally drier and warmer than that to the south; and this is particularly applicable to the summer-autumn growing season. Are these factors responsible for the wider and higher distribution of red beech forests on the northern face? Does greater dryness and warmth account for the zonal upper limits (Fig. 4) being higher towards the west on each respective face—north face: C. 3,300ft in west and C. 3,000ft in east; south face: C. 3,000ft in west and C. 2,500ft in east—for available data strongly indicate that western areas are drier and probably warmer than areas to the east? The relationships appear to be real, but before accepting them at face value we would do well to look more closely at the structure and condition of the red beech forests.

Silver beech is sprinkled throughout portions of the zone, but extensive areas of pure red beech are the rule. It is an observable fact almost everywhere that the red beech forest canopy is unthrifty. The heads of living trees have sparse and unhealthy foliage and contain many dead limbs; while the upper forest canopy, about 80 to 100 feet high, is pock-marked with gaps where red beech have died or fallen. Almost invariably these breaches in the beech ranks are occupied by secondary broadleaved species such as kamahi and tawari (*Ixerba brexioides*) which form a broken second tier 25 to 40 feet high. Red beech diameters, over large flanges in the larger groups, range chiefly between 24 and 54 inches d.b.h. (diameter breast high). It is noticeable where silver beech occur that they are smaller, therefore probably younger, than the larger red beech nearby. Even so they not infrequently have decadent heads with dead or dying limbs.

Almost everywhere there is a marked shortage of red beech stems in the younger age groups—even under old canopy gaps. Fringing the track from Papatotara to Maungapohatu Pa, where it traverses the red beech zone for several miles, dense stands of chiefly sapling and pole silver beech have developed following clearance. It seems paradoxical that within its own zone red beech has there been outdone by silver beech. Yet almost wherever the two species occur together the same anomalous situation arises for silver beech regeneration is relatively more frequent. The outstanding exception to this is in the Aniwaniwa Stream valley south of the divide where red beech is healthier than elsewhere and regeneration is more prolific and virile.

Within the red beech zone occur scattered miro, rimu and totara with matai and kahikatea more sparingly distributed. Toatoa (*Phyllocladus glaucus*) is scattered throughout though the majority of trees seen were dead or dying as a result of barking by deer. Tanekaha (*Ph. trichomanoides*) has not been observed within the study region though it is known to occur farther south. Podocarp groups including matai, occur on the north face of the East Huiaraus to about 2,700ft while to the west on this face only scattered podocarps, rarely matai, extend to a comparable altitude. In the red beech zone west of Kakanui Trig, podocarp frequency increases significantly towards the south; at the same time there is a marked increase in the frequency of tawheowheo, broadleaf (*Griselinia littoralis*), pokaka (*Elaeocarpus hookerianus*), mountain toatoa (*Phyllocladus alpinus*), toi (*Cordyline indivisa*) and heruheru (*Todea* spp.). As isohyets indicate increasing precipitation in this direction this gives further evidence that podocarp frequency is closely related to the moisture factor. And in this case notwithstanding that increasing moisture is accompanied by increasing altitude.

Observation indicates that red beech stands are more viable, more vigorous and of better form, both south of the divide on sheltered sites such as the Aniwaniwa Valley and on moist lowland sites, usually bordering waterways, to the north of the divide. It is impossible to reconcile this situation with the wider and higher extent of red beech forest in the drier northern regions unless, after considering forest structure and condition, it is postulated that as a unit the red beech zone is highly unstable. Furthermore, as the more stable facies are related to increased moisture it is reasonable to postulate that the general instability and deterioration is related to a critical decrease in available moisture. But south of the divide the moisture factor is generally more favourable than on the northern face, and yet we find that red beech here is very much more restricted! However, the fact that forest canopies on the southern face clearly exhibit deformation from the southerly winds and the added fact that more stable red beech stands on this face are usually on sites fairly well sheltered from the cool southerlies, leads us to believe that wind exposure, with moisture, is a factor controlling the extent of the red beech zone. But once again there is an anomaly to explain in the fact that even on very exposed mid slopes of the southern face there exist, amid the silver beech, random groups or individual trees of red beech. Admittedly these trees usually have decadent heads, but so too have a large number of neighbouring silver beech. This situation is not wholly in keeping with the proposition that the limited extent of red beech on the southern face is due to the long continued influence of the strong cool southerly winds.

CATASTROPHIC FOREST DAMAGE

It is considered that the problem can only be satisfactorily resolved by postulating—and there is evidence for so doing—that at some time, or times, in the past the forests of the Huiarau Range were extensively damaged or laid low, possibly by gale force winds. Though this phenomenon appears to have affected both faces of the divide, even to fairly low levels, its effect over large expanses south of the divide was catastrophic. The causal gales would seem, therefore, to have come from a southerly direction. The likelihood of serious forest damage taking place on leeward slopes and on the lee side of the divide may be debated, but it is distinctly a high probability. First, many forest stands and random groups on the north face suggest a period of induction which agrees closely with that postulated (see later) for the south face, and secondly, the phenomenon of windthrow on leeward slopes has been recorded at least once in recent years (Hocking, 1947).

Prior to this cataclysmal event red beech forest was very much more widespread on the southern face than is the case today; though the forests were nevertheless declining and slowly giving ground to silver beech. Following this cataclysm, which also affected the podocarp stands of the south face except on very sheltered sites, silver beech colonisation of the devastated red beech areas proceeded rapidly and only here and there did red beech reassert itself to any extent. Many sites formerly occupied by podocarps were reclaimed by either silver or red beech or an admixture of the two. At higher levels, in the silver beech forest, a vigorous re-growth of silver beech took place in moister regions, particularly towards the east, while farther west where upper level silver beech tended to be rather more unstable an extension of mountain beech took place. All these replacement changes are marked by a general lowering of the canopy height.

It is considered that this hypothesis, simple in its proposition, adequately explains the broad anomalies of species distribution and age grouping in the red and silver beech zones, for it proposes widespread forest destruction which permits of a complex mosaic of recolonisation patterns and at the same time allows on the more exposed sites that random trees or groups survived the catastrophe. As a result it explains the marked age differences both between red and silver beech in the same stand and between adjoining stands. From limited age structure studies on the south face the postulated catastrophe is considered to have taken place in the order of 250 to 300 years ago (C. 1650–1700 A.D.). This date, derived independently, agrees closely with that suggested for forest damage in the podocarp zone east of the Whirinaki Valley (Section 3).

Confirmatory evidence that some form of widespread and severe forest damage took place not long back is afforded by the existence in waterways throughout the region of low, recent-looking depositional terraces. These can only have been formed during an interval of erosion such as could be expected to occur immediately following widespread severe forest damage. And in a few cases where podocarp stands on such deposits have been examined and maximum tree ages determined it is definite that maximum stand age is in the order of 300 years (estab. C. 1650 A.D.); while the immature nature of the forest floor proclaims these to be the primary colonising stands. This evidence strengthens the case for widespread forest damage, as postulated, and supplies added weight to the period already suggested. However it should be recognised that a dating of C. 1650 to

1700 A.D. must be read as the latest possible dating. It is likely that the catastrophe which marked the time of the erosion interval took place a few decades before 1650 A.D.

In connection with this matter a valid query could be raised. It is this: could fire have been the major agent of widespread forest damage? It has been suggested (Sec. 3: A Zonal Anomaly) that fire may have been partially responsible for damage to podocarp stands east of the lower Whirinaki Valley. Indeed, there is evidence of early fires, around 1650 to 1700 A.D., on a number of sites fringing the scrub and tussock covered valley from Te Whaiti to south of Minginui (Fig. 3). But clear evidence of forest damage by fire as far back as this seems to be restricted to stands abutting scrubland of long standing. Furthermore it is certain that the scrubland itself was formerly forested. However, at higher altitudes there is no convincing evidence of extensive fire damage about the period concerned. All features point to wind as the most probable agent of forest damage.

CLIMATIC INFERENCES

The outstanding puzzle of the red beech zone is its "line" of contact with the podocarp zone around 2,400ft. This has received mention in the preceding section on the podocarp zone. The most that can be said here about this zonal phenomenon is that it is more pronounced in the drier regions; owing its partial breakdown in moister regions to the more effective infiltration and colonisation by beech species and to the fact that podocarp replacement has continued into a later period. Essentially, however, it seems to be related in some way to temperature; probably not to existing conditions, but to a state of affairs which was operative some time not long back.

To crystallise the reply to the opening queries of this section it can be stated that the present extent of the red beech zone firstly, is related in part to catastrophic forest destruction considered to have taken place about three hundred years back. Secondly, the variable upper limits of the zone are not related to the existing moisture regime for the drier the situation the more unstable are the red beech forests—they are possibly the result of an earlier moisture regime or of some aspect of temperature not yet clearly understood. They may even be related to the wind factor. And as the present degree of instability has obviously reached a critical stage during the life span of existing mature red beech, there is a first class case for significant climatic change during the last few centuries. To say the least, the red beech zone affords confirmatory evidence of a recent decrease in precipitation effectiveness.

SECTION 5—FORESTS OF THE SILVER BEECH ZONE

GENERAL

Forests designated on the accompanying map as silver beech forests are extremely heterogeneous in composition. At upper levels they are truly silver beech dominant forests; at intermediate levels over wide areas they constitute admixtures of silver and red beech where the proportions of each species vary, often rather abruptly, between true silver beech dominant stands and stands where red beech is the physiognomic and numerical dominant. The many stand composition anomalies encountered in this heterogeneous zone are more readily understandable in terms of the hypothesis that widespread catastrophic damage to the former forests took place, possibly by winds of exceptional force. Certainly on its own any hypothesis of recent climatic change is unable to adequately explain many aspects of species distribution and stand composition. However it must be recognised that the cataclysmal destruction of wide areas of forest took place at a time when the climate had already changed significantly. Indeed it must have been these combined circumstances which permitted silver beech to descend so rapidly, so widely, and yet so erratically, into the red beech zone.

In the east silver beech forest ascends to the tree-line which is little under 4,600ft. In the western area silver beech dominant forest does not exceed about 3,800ft above which only scattered silver beech ascend to around 4,300ft. This marked difference in upper limits harmonises with the climatological evidence that eastern areas are moister than western ones so that it may be safe to assume that moisture is the chief controlling factor.

At uppermost levels silver beech are stunted to 10 or 20 feet and wind-deformed, and many trees bear dead or dying limbs. Locally dead standing trees are common. Seedlings and saplings are usually present but not in abundance. On more exposed faces the forest canopy clearly exhibits a striated pattern resulting from the blast of the south-easter (Plate 1). Common associates include pink pine (*Dacrydium biforme*), mountain toatoa, hupiro (*Coprosma foetidissima*), orihou (*Neopanax colensoi*) and broadleaf while, about Mt Maungapohatu in the east, leatherwood (*Olearia colensoi*) is also common. Red beech is absent.

At higher levels the forest floor and the tree limbs are heavily encrusted with mosses. This phenomenon though existing in western areas, is certainly more pronounced in the east.

Upon descending there is a general improvement in tree form and size until on lower sheltered sites silver beech attain 100 feet and more. Below about 3,100 feet on the East Huiaraus and 3,300ft in the west red beech becomes a conspicuous component of the stands. Almost wherever the two species occur together the larger silver beech are exceeded in size by the larger red beech; though both species exhibit various signs of decline and decay. The chief understorey associates are kamahi, tawari, tawheowheo and broadleaf. Below about 3,300ft thin-barked totara (*Podocarpus hallii*?) to 50ft tall occur at random; many trees being either dead or dying, while only scattered regeneration exists. Particularly on the East Huiaraus occasional rimu, with deep crowns and chlorotic foliage, occur to around 3,000ft.

A FOREST PHENOMENON AND DROUGHT

It is remarkable, even as low as 2,800ft to 3,000ft on the East Huiaraus, that silver beech crowns are decadent and many trees are dead. As this phenomenon is also widespread on sites as low as 3,300ft on the north-west face of the divide it seems unlikely that it is related to the effects of the cool south-easterlies. Were the phenomenon significantly more marked on red beech in the silver beech zone it would suggest merely that ruling conditions favour silver beech. But on the contrary, an inference to be drawn is that present conditions in some way are unfavourable to both red and silver beech. And the same factor is likely to be responsible for the decadence and death of many thin-barked totara.

A. Cunningham has expressed the view (*pers. comm.*) that at the upper altitudinal limits of a forest there is an apparent decadence due to a higher-than-normal percentage of standing dead trees which are simply due to lower than average decay rates. However, this view does not seem to completely explain the phenomenon, and in the light of the deductions already made in this paper it is reasonable to look to the factors of the environment, in particular to the moisture factor.

Thus far only average moisture conditions have been treated, though it has become clear that the broad forest pattern is closely related to them. At this point, however, the variability of the moisture factors should be considered. In particular, do physiological droughts occur?

The 1945-46 dry period constituted a physiological drought on many sites in the central portion, at least, of the North Island. Hocking (1946) commented on this in the Hawke's Bay area and recorded occasional mortality among rimu, browning-off of totara and some permanent damage to black (?) beech. Elder (1956) related large numbers of dead mountain beech on pumice soils in a wide area west of the upper Ngaruroro River (Fig. 1) to the 1946 drought. To determine whether this drought was physiologically severe on the Huiarau Range a simple analysis was made using rainfall records for Onepoto which is considered to be a reliable index for the southern face of the Range. Monthly potential evapotranspiration figures were derived on the basis of Thornthwaite's formula (Palmer and Havens, 1958). Unfortunately soil moisture storage data is lacking. However, the accumulated difference, between rainfall and potential evapotranspiration becomes so pronounced that no doubt could arise as to the existence on many sites, of physiological drought or near-drought over an extended period—from January to early March.

1945-46	Rainfall Inches	Pot. Evap. Inches	Difference	Accumulated Difference	Comments
Sept.	7.43	1.3	+ 6.1	Omitted	Soil close to Field Capacity about end of September following high run-off.
Oct.	3.78	1.7	+ 2.1	+ 2.1	Run-off diminishing rapidly and ground water depletion commencing in November.
Nov.	0.83	2.9	− 2.1	Nil	
Dec.	4.12	3.0	+ 1.1	+ 1.1	
Jan.	1.67	3.6	− 1.9	− 0.8	Soil moisture and ground water becoming progressively depleted. Severe drought conditions by February and continuing into March.
Feb.	0.23	3.3	− 3.1	− 3.9	
Mar.	5.78	2.8	+ 3.0	− 0.9	
April	9.31	1.8	+ 7.5	+ 6.6	Field Capacity regained followed by run-off.

The above evidence that a prolonged period of severe moisture deficiency occurred at Onepoto between January and March, 1946 can safely be applied to the south face of the divide. A perusal of rainfall records for several stations north of the divide indicates that similar conditions must have enveloped the Huiarau Range region. At medium to high altitudes, dead beech trunks usually decay and fall inside 50 years and frequently within 30 years after death (N. L. Elder, *pers. comm.*). This observation from the Ruahine Range, which can safely be applied to the Huiarau Range, substantiates the view that the decadence, or death, of a large number of beech has come about very recently. In the light of the above analysis for the 1946 drought and the comments of Hocking and Elder it would be unreasonable to overlook the likely effects of this phenomenon on the forests of the Huiarau Range. In fact it must be concluded that some damage must have resulted and it is suggested that this included the death or present decadent condition of many red and silver beech everywhere, of many podocarps on mid and upper slopes and probably of thin-barked totara. But, of course, the 1946 drought was simply the last severe one on record.

SECTION 6—THE MOUNTAIN BEECH COMMUNITIES

In the East Huiaraus mountain beech is very limited in distribution. Small, seemingly induced groups have been observed on slopes; and it occurs also on some boggy sites (McKelvey, P. J., *pers. comm.*). However, forests containing mountain beech seem to occur chiefly in the high southern portion of the West Huiaraus where the species is usually found from about 3,800ft upwards. Many of these sites are exposed to the cold blasts of the south-easter, which has left its mark on the vegetation. Extensive pure stands of mountain beech are rare for silver beech commonly exists with it to at least 4,300ft. Around this altitude mountain beech and pink pine often form a fairly dense canopy about 25ft high—but dwarfed to several feet on very exposed sites. Silver pine (*Dacrydium colensoi*) occurs locally.

Upon descending there is a progressive increase both in number and size of silver beech. However, mountain beech is usually more frequent and aggressive, although silver beech tend to be larger trees—sometimes to 30 inches d.b.h., or over. Common associate species include: mountain toatoa, hupiro and broadleaf. These, plus others, usually comprise a fairly dense shrubbery, while mosses and lichens are plentiful on trees and rocks.

It must be pointed out that while mountain beech is well established in some localities down to around 3,800ft, there remain many West Huiarau sites above this level dominated by silver beech. This situation is rather analogous to that already referred to in the silver beech zone. And it is considered equally likely that the widespread, though rather haphazard, forest catastrophe considered to have taken place about three centuries ago offers a reasonable explanation for many such anomalies. But it is not suggested that all anomalous situations are directly related to this catastrophic event, for many stands suggest a very much later period for induction which may have resulted from either fire, landslide or localised blow-down.

Suffice it to state that though mountain beech is far more extensive in the drier western region its vertical and horizontal distribution are not altogether in harmony with climatic influences.

SECTION 7—FURTHER COMMENTS ON THE NATURE OF FOREST AND CLIMATE CHANGES

SPECIES MIGRATION

Some evidence has been presented which strongly indicates that the vigour and frequency of podocarps, and also of red and silver beech, within the temperature tolerances of each species, is primarily related to the moisture factor of the growing season. All forest zones are unstable and there is good evidence of a mass down-slope migration which has been active for several centuries and which is still in progress. Within each zone this downward movement, or retreat, of the major species is thought to be primarily related to decreased precipitation effectiveness during the growing season. But it cannot be assumed that this factor can account also for the downward shift, which is taking place, of the red beech and silver beech zonal limits. It is true that certain features are indicative of a temperature change but the direction of this is considered, during recent centuries, to have been generally towards warmer conditions. This feature, alone, therefore does not assist in a better appreciation of the process of downward movement of species and zones. But if increased warmth is assessed in conjunction with decreased P.E. (due primarily to changes in the nature of the rainfall) then it is readily appreciated that the former serves to aggravate the latter. This combination might well underlie the phenomenon of downward zonal shift. However, a few simple considerations are worthy of notice.

When all forest zones are reasonably in equilibrium with the environment and self-perpetuating forests form closed communities, infiltration of species " foreign " to a forest is very little. But the infiltration potential could be classed as high because gravity, wind, water, birds, etc., must often distribute seed beyond the bounds of its mother forest type. Under the same conditions of equilibrium, moreover, if open spaces become available due to fire, wind damage, etc., the infiltration potential of " foreign " species may become reality. And under conditions of great instability, which exist today, when tree vigour is reduced and the defence mechanism of self-perpetuation becomes a negligible factor in the re-establishment of open spaces, the incidence of invasion and establishment by foreign species must increase markedly. In general it is true that montane species are more likely to find a satisfactory niche at low levels than are low level species likely to become established and survive at high levels. To find beech or mountain toatoa or alpine herbs in the Whirinaki River valley is of some interest, whereas the sight of one well grown kahikatea at 4,500ft would demand much thoughtful explanation. And as beech seed is winged a strong down-slope and down-wind migration bias is a natural consequence of the present unstable forest regime. Of course this process is likely to be a very slow one unless widespread open sites become available. This, as postulated, has taken place so that forest patterns now present a rather confused picture—one which conveys the impression that species infiltration into other types, and zonal migration, takes place very rapidly. In fact it might well be that this " confused picture ", which has arisen from the forest catastrophe, actually over-emphasizes the amount of true climatically controlled zonal movement that has taken place in recent centuries. For much apparent migration of the beech zones is clearly explicable in terms of the above comments and previous statements about the catastrophic forest damage.

WINDINESS

Maximum canopy height for the same species and altitude, but on different aspects, differs widely. It is clearly related to the degree of exposure to the southerly winds, the physical effects of which have already received mention in this paper (Plate 1). The observation was made that on any particular site, particularly on the southern face of the divide, a marked decrease in maximum canopy height was discernible in the red beech zone. Actually, this phenomenon is not restricted to the red beech zone for it is also plainly discernible both above this zone and in parts of the podocarp zone. In all cases a wide age range, of two or more centuries, is required either between adjoining similar stands or between trees on the same site. The younger generation stands and exposed trees plainly exhibit greater physical deformation and dwarfing—consistent with the known effects of the southerly winds. The analogy can be made between stands, at the present time, which differ in physiognomy according to the degree of wind exposure, and stands on the same site which indicate that the physiognomic potential has diminished over a span of time. From this it is reasonable to deduce that within the last few centuries an increase in general windiness has taken place.

CLIMATIC FACTORS RELATED

Statements concerning the change in climatic factors are largely deduced from the vegetation itself. We are, therefore, left to ponder somewhat as to the proper connections between cause and effect (on the vegetation).

Of course we cannot speak about change in one facet of climate without automatically inferring change in other facets. The close inter-relationship of all components of the climatic complex demands this. But, on observational grounds, while it may be possible to reasonably assess change and its direction in some factors, it is seldom possible to adopt the same standard of assurance with other factors. At best we are left to generalisations.

It was established (Section 5) that physiological droughts do occur on the Huiarau Range. The query arises, then: how frequently have they occurred and during what span of time? With regard to the time-span it has been shown for the podocarp zone that the level of precipitation effectiveness passed into a critical stage about 1750 A.D. on the moister sites and some time before this on drier sites. It is logical to assume that the intensity rating of physiological drought followed a similar, more or less progressive, trend. Indeed it would be surprising if it did not; for it is more than likely that periodical physiological drought is the master process in the overall phenomenon of reduced precipitation effectiveness.

Thinking in broad terms makes it difficult to imagine that forests in a region with an average annual rainfall of 100–120 inches could be subject to deficiencies of available moisture. But analysis on a monthly basis can show that this does occur; and soil moisture storage studies on a daily basis would almost certainly confirm and emphasise the monthly analysis. When it is stated that precipitation effectiveness (P.E.) has decreased, perhaps progressively, it is not implied that there has been a more or less linear trend in any one factor concerned, for this is hardly necessary. First, however, as stressed in this paper elsewhere, we must centre on the growing season—the large amounts of rain that fall when temperatures are too low for active plant growth are of little consequence. Progressive reduction in P.E. may result either from a decrease in the drought recurrence interval or from a marked increase in the severity of an occasional drought. A combination of the two drought variables is also possible.

A drought recurrence interval measured by many decades is sufficient to either seriously impair the vigour, or cause mortality, of older trees; and would be effective in retarding the satisfactory development of the replacement phases. An extremely severe physiological drought once in 50 years, or even 100 years, would seriously impair forest health and nullify much of the growth of the preceding interval. Moreover, on a physiological basis the more favourable to forest development is the intervening period, the more drastic will be the effects of drought when it occurs. Likewise, forests of wetter regions may be more adversely affected by periodic drought than forests of relatively drier regions. And it has been shown that the forests of the Huiarau Range have been subject to at least one severe physiological drought in recent years. It can also be shown that during the period of climatological records, these forests have been subject to several droughts or near-droughts; but this is a matter for further discussion (refer Postscript).

There are strong suggestions of change in the temperature factor during recent centuries and, from an overall consideration of related aspects, this is thought to have been in the general direction of increasing warmth. From podocarp wood growth comes some evidence to support this postulate; for, during growth-ring studies, a marked increase in the incidence of abnormal growth-rings ("split" rings, etc.) was observed to take place during the last 250 years or so (i.e.) since C. 1700 A.D. This phenomenon indicates that the previous nearer-normal alternation of growth and dormancy has been disturbed since C. 1700 A.D.; and it strongly suggests that during the present period the temperature factor is more variable and probably warmer.

It is conceivable during the previous climatic regime, while mean temperatures, for some or all seasons, were somewhat lower than at the present, that temperature minima and maxima were confined to a narrower range. That is to say that even though it may be generally warmer today, it might also at times become cooler, season for season, than previously. This is a possible explanation of the observed anomaly that while some features appear to indicate increased warmth, others, such as severe frost damage to tawa, indicate increased coolness—in this case a marked lowering of temperature minima.

We are now in a better position to elaborate upon the relationships between reduced precipitation effectiveness, increased windiness and a general rise in temperature. Accordingly, it is postulated that a recent general rise in temperature has induced increased atmospheric turbulence, or windiness, and both factors have been active in further reducing the general level of P.E. It is to be remembered, at this point, that physiological drought has been suggested as the master process governing the recent trend of decreased P.E. It is to be expected, however, that some close link exists between drought (rainfall deficiency) and the other factors of temperature and windiness. We cannot overlook that changes in temperature and windiness must initiate a complex chain-reaction and a series of feed-back mechanisms—and amid all this the precipitation factor itself is likely to be altered. In fact, it can hardly escape modification.

Following the increase in windiness, which may or may not have been accompanied by a directional change, it can be reasonably expected, while total precipitation amounts may have altered little, that the nature of their fall may have altered greatly. In particular, prior to the onset of the present climatic regime, in which rather long periods without effective precipitation occur periodically, it is probable that during the growing season, rainfall was more evenly distributed in time and hence more effective. With respect to this the writer believes that the not infrequent high-intensity and short-duration rainfalls which produce serious flooding and, at times, forest damage, constitute a feature which has increased both in magnitude and frequency in very recent times. And this feature has probably developed hand in hand with the drought factor—both rainfall facets being a consequence of change in temperature and atmospheric turbulence.

What then of changes in the spatial distribution of precipitation?

The likelihood is very real that spatial alterations to the rainfall regime have taken place, but as any discussion of this aspect can only be based on theoretical considerations of atmospheric physics it is not likely to assist materially in the present analysis. It is sufficient here to recognise that increased atmospheric turbulence is likely to result in both wind directional changes and in alteration of the spatial distribution pattern of precipitation.

SOME SPECIAL FOREST FEATURES

Several features, of widespread occurrence on the Huiarau Range and environs, are worthy of mention. The first is the presence of beech species, chiefly red and hybrid mountain x red beech, either singly or in groups, in isolated locations amid many lowland podocarp stands. General opinion has favoured the view that such beech have a relict status. From field studies this writer is convinced that such beech groups are induced; that they became established in damaged areas of podocarp forest and that the older trees (about 300 years) established soon after the postulated widespread forest catastrophe (C. 1650 A.D.). Some beech groups established around 1700–1750 A.D. The mechanism of beech seed dispersal is a matter for conjecture. It could have been by man, animals or birds; or under the extreme conditions which must have prevailed at the time of the major catastrophe some seed dispersal could well have been directly by wind. The location of most of the beech groups excludes the possibility of seed dispersal by water. In the same period, and in like manner, terrestrial rata became established over wide areas.

But we should not dismiss rata so peremptorily for its epiphytic growth habit can tell us something. When it is remembered that in its early years as an epiphyte it depends on the moisture store of niches above the ground level it is a simple step to deduce that the satisfactory establishment of epiphytic rata is dependent upon the level of precipitation effectiveness (P.E.). The lower is the P.E. during the growing season the less chance has rata to survive the epiphytic growth phase and hence the lower is likely to be the frequency of well-grown rata. The converse would be equally true. At higher levels of the podocarp zone the establishment potential of rata, based on present frequencies, was once high. The same could not be said today as there is a dearth of rata in the younger age groups. And this same observation applies in podocarp stands of lower levels. Yet widespread seed dispersal must take place for wind and birds (Zotov, 1948) are the chief agents. In concluding that this reduction in the establishment of epiphytic rata is attributable to a decrease in P.E. during the growing season we are further confirming foregoing deductions along the same lines.

Another feature of interest concerns the lack of establishment of podocarp and beech regeneration on the forest floor except on very wet sites or sites devoid of mature tree root competition such as Maori clearings, recent alluvial deposits, erosion scars and roadsides. Also, beech regeneration is frequently abundant on decayed logs and stumps, even under a canopy, whereas nearby it is sparse or absent on the forest floor. Both features are more pronounced in the drier areas, and it is considered that this phenomenon is related to the moisture factor, in particular to the P.E. rating of the growing season. Carrying this a step further, it becomes clear, due to the variable nature of the moisture factor from year to year, that in competition with mature tree root systems, seedlings may establish at irregular intervals, only to perish at some early stage in development due to physiological drought. This phenomenon should be carefully studied and clearly understood before making an assessment of animal damage.

There is another forest feature worthy of mention, one that when fully understood may contribute much to our understanding of present forest condition and may even give a reliable indication of forest development in the near future. It is this: during growth ring studies on podocarps it was recorded time and time again that about 40–55 years back (i.e., 1905–1920 A.D.) diameter growth rates, on normally drained sites, diminished markedly, and the diminished lateral growth rates have persisted to the present. On mature trees this could be read as being quite normal, but the phenomenon exists on well-grown trees of all ages. In other words the suggestion is strong that the causal factor is all-embracing and therefore is probably one of climate. This feature is to receive further consideration (refer Postscript).

FOREST CATASTROPHE AND CLIMATE

Quite apart from the influences of secular change in the climatic regime and the increased variability of the present climate it has been postulated that the forests of the Huiarau Range have been greatly modified; in all probability by gale force winds. This was initiated, seemingly cataclysmally, around 1650 A.D. when it was accompanied, or immediately followed, by a short erosion interval. However, since this catastrophe there have been a number of similar though milder occurrences, which have affected only limited areas. More convincing evidence for the occurrence of this catastrophe, around 1650 A.D., is to be presented in a further communication, when it will be shown that the phenomenon was not restricted to the Huiarau Range, but had a very much wider coverage. Furthermore the sequence of events which probably took place about this time comprise a rather more complicated picture than is here presented.

The occurrence of some such event about the time postulated accounts for the widespread, rapid distribution changes that have taken place and the complicated state of affairs found somewhere in every forest zone. These forest changes which have occurred in the last three centuries or so—even within the life span of many existing trees—could not be the direct outcome of secular climatic change. But nonetheless, these same rapid changes serve to confirm that even at the time of the postulated forest catastrophe (C. 1650 A.D.), and probably earlier, the forests were under the influence of a significantly changed, and changing, climatic regime. On its own, neither changed climate nor extensive forest damage can elucidate the forest tangle. Only the products of the two phenomena, in their numerous combinations, can satisfactorily shed light on the history and status of each forest unit.

SECTION 8—FINAL DISCUSSION AND SOME IMPLICATIONS

REVIEW OF PAST AND PRESENT FINDINGS

This paper deals primarily with forest history and climatic variations during the last 300–400 years (i.e., since C. 1600 A.D.). Of prime importance is the realisation that these findings substantiate J. T. Holloway's overall hypothesis of recent climatic change (Holloway, 1954). Though he considered that a progressive climatic trend may have been, and may still be in operation, he was chiefly concerned with a significant climatic change set at about the year 1200 A.D. (1954: 373). These present findings do not disagree with this contention but rather strengthen it, for if the age structure of the Huiarau Range podocarp forests be carefully considered it becomes evident that climatic change was effective, on the forests, around 1500 A.D. and possibly as far back as around 1250 A.D. But no real attempt is here made either to date or analyse this change.

Age structures of podocarp types indicate that, about the Huiarau Range there was a brief interlude about 300–400 years ago (C. 1550–1650 A.D.) when conditions were reasonably satisfactory for forest regrowth on mid and lower slopes. However it is clear since that interlude—which did not favour podocarp re-growth on upper slopes—that climatic conditions have become more unfavourable, probably on a progressive scale. And in the foregoing pages it is postulated for the last 300 years, or thereabouts, that a general rise in temperature—with lowering of temperature minima—has induced increased windiness. As a consequence of these alterations the nature of the rainfall has changed to produce longer and more intense periods without effective rain during the growing season. And changes in all three factors have been such that in combination they have produced a very marked decrease in precipitation effectiveness.

Let us turn again to Holloway's (1954) hypothesis based on an examination of South Island forests—for his is the outstanding work in relation to forests and recent climatic change in New Zealand. From the hill podocarp stands of Westland "where rainfall totals remain fully sufficient for all forest growth" he concludes that "there must have been a substantial temperature drop"; though, in the east, "there was an undoubted fall in effective regional rainfall" (p. 380). He qualifies these hypotheses (p. 403) by stating: "the initial change, the fall in mean or effective temperature, must have been common to all regions, but the consequential changes, particularly in respect to wind frequencies, force and direction, and therefore in respect to regional precipitation effectiveness, varied greatly in degree and possibly also in direction . . ." No forthright evidence for these consequential changes was presented though one can read passages that strongly indicate change in the wind factor; such as (p. 400) where the comparison is made between old very large single-trunked rata and younger trees which are multi-leadered and on which growth appears to stop when individuals are little more than large shrubs. This can be read as a close analogy to phenomena on the Huiarau Range which are considered to be related to an increase in windiness. But this is intended as a brief review, not an analysis, of the findings of others.

P. J. McKelvey (1953), having sighted Holloway's unpublished manuscript, assumed that a climatic change towards colder and drier conditions could explain many of the anomalies and special phenomena of West Taupo podocarp forests (Fig. 1). He states that after C. 1600 A.D. the influence of climatic change began to be felt in the North Island and the podocarps became a little maladjusted. No clear-cut evidence for climatic change is presented as such.

R. J. Cameron (1954) applied the concept of cyclical succession of dominants to the Whirinaki River basin podocarp forests (Fig. 3) for which he proposed a successional cycle. He gave no satisfactory evidence in support of the hypothesis and stated, among other things, that the causes of a cyclical succession are not well understood. The present writer believes that much of the mosaic pattern that Cameron attempted to interpret by cyclical succession is explicable in terms of adjustments to changed, and changing climate, and the effects of periodic episodes of severe forest damage.

Cameron dismissed the probability of recent climatic change and stated: ". . . . it might well be that had the podocarp forests (including those of the Whirinaki River valley) remained undisturbed they might still be perpetuating themselves successfully and keep on doing so for centuries to come." He would now, however, admit (*pers. comm.*) of recent climatic variation if further evidence were produced.

In his study of the Taranaki podocarp forests J. L. Nicholls (1956), after taking the story back about 15,000 years (there seems to be no material gain from this) considered that if recent climatic change be accepted as a fact, the ecological problems could be resolved fairly simply. Nicholls writes that by about A.D. 1650 the cumulative effects (of climatic change) were sufficient to suppress advance growth of rimu, kahikatea and matai everywhere in the region; the first and hardest hit area being the forest over 2,000ft. Here again no first-hand evidence was presented to substantiate the hypothesis of recent climatic change. A feature of considerable interest, however, in the papers of both McKelvey and Nicholls is the definition (means not stated) of the time, C. 1600–1650 A.D., which marked the onset of the present unsatisfactory conditions in podocarp forests.

N. L. Elder (1956) states that retreat of the timber line is evident in mountain beech along the axis ranges from as far north as Maungawaru Range to as far south as the species extends on the Ruahines (Fig. 1). He further states that on the Ruahines there are indications that change (in vegetation) has been continuing within the last 200 years. Photographic comparisons of silver beech forest, over a 20-year period, on the Tararua Range, show that changes are taking place, "probably in the same direction as in mountain beech forest".

More recently the same author (Elder, 1959) attributed the discontinuous forest pattern on the Ruahine Range "to the drowning out of forest by the formation of peat, presumably marking a recent climatic change to cooler, wetter, and/or cloudier conditions . . ." He states also: "As far as the Kaweka Range is concerned there is no evidence supporting the hypothesis of a climatic change towards cooler, wetter conditions" (Fig. 1). Details of the process of forest replacement by peat were not given but are highly desirable.

Elder's observations concerning very recent changes in forest status are valuable and receive confirmation in the present paper. Once again, however, a generalised hypothesis relating to climatic change has been proposed without the foundation of substantial evidence and without the necessary integration with forest mechanisms. It is clear, however, that Elder is not satisfied with the present state of his own findings.

Since Holloway (1954: 408) opened the debate on forest problems and climatic variation it is plain that little has been forthcoming either to substantiate the overall hypothesis or to confirm or clarify the nature of the postulated changes. It has usually been deemed sufficient merely to refer back to the original generalised postulate of a substantial drop in temperature and a fall in effective rainfall. Consequently many issues have become clouded and very little real progress in forest understanding has been achieved. It is necessary to know more of the nature of the climatic changes involved, and these must be placed in a proper chronological setting before the real relationships between climates and forests can be ascertained.

It might well be, even in the South Island, that the same forest phenomena, ascribed in the main to decreased temperature, are more nearly the outcome of a combination of: increased windiness, periodical physiological drought, a rise in the overall temperature regime, a general increase in temperature variability and a marked decrease in temperature minima. Even at and above the high timber line, vegetation instability, rather than be related to a general lowering of temperature, might well be the result of a similar environmental complex but one in which increased windiness plus the features of the new temperature regime (as postulated herein) play leading roles. It is very clear, either if the normal period of plant dormancy is interrupted by short periods of physiological activity stimulated by unusually high temperatures, or if the warmer growing season is beset by periodic frosts and cold winds, that plant growth is thereby made very susceptible to damage. And quite apart from serious damage to vegetative structures is the strong possibility that the reproductive capacity of many plants, including podocarps and beech species, could be severely impaired under such circumstances. The present work indicates that just these conditions, far less marked in earlier times, characterise the present climatic regime of the Huiarau Range; and probably apply to a much vaster area.

With respect to an increase in windiness, as postulated, it should be added that a proportional increase in the adverse effects on the vegetation with increasing altitude, is not to be expected for general indications suggest that above a certain altitudinal belt, somewhere in the range of 3,000–3,500ft on the Huiarau Range, there has been a disproportionate step-up in the wind factor. This simply means that if, up to say 2,000ft, the wind factor has increased twofold, above say 4,000ft, it is likely to have increased four or five fold—or thereabouts. Such a disproportionate change in the wind factor, though difficult to substantiate, should not be overlooked in any analysis of high-altitude forests. At the same time, of course, forest stands on some low-level valley or gully sites may be little affected by change in the wind factor.

UNDERSTANDING THE FORESTS BETTER

In the Huiarau Range, the need is very real, and pressing, to understand the forests as completely as possible, for in this region rise several large rivers (Fig. 1), each of which in its lower reaches constantly threatens and damages lowland settlements. Wise catchment control is the aim and this hinges primarily on vegetation conservation. Added to the complex situation already described is the impact of exotic feral animals. When this study was commenced (1950) forest condition was by no means satisfactory while the ensuing decade has seen further deterioration.

In relation to this problem it can be stated in general terms that the lower is the precipitation effectiveness, the more vulnerable to damage is the forest. Stated in another way, the drier is the forest climate during the growing season the less is the vigour and regrowth of forest species and consequently the greater is the apparent damage even from a smaller number of animals. The determination of growing season moisture ratings, on a year to year basis, thus affords a sound foundation for the proper assessment and planning of animal control. But reliable moisture ratings can only be based on sufficient climatological data; there is not sufficient at present.

This leads to a consideration of some importance. " If we are to seek a full understanding of the interactions of the indigenous forests and exotic animal invaders, we must first of all seek an understanding of the forests themselves."

This truth, propounded by J. T. Holloway (1951) is unassailable. However, to it the present writer would add the axiom: if we are to obtain an understanding of the forests, we must study the climates in which they grow. It is certain that a better knowledge of the present climates of forest regions would lead to a more accurate assessment of both present forest status and of former climates.

CLOSING COMMENTS

This writer has not wished to impart any thought that the final solutions have been found. Rather, it has been the intention to try to bring a clearer focus to many concepts, processes and related physical phenomena. In so doing the complexity of the situation has become even more apparent to the writer, if not to the reader, and it is certain that a great deal more research is required to clarify the changes of the past centuries.

It is essential that the nature of the earlier climatic changes be determined more precisely and it will not be possible to achieve this until we can more precisely define present climates in forested regions. The next step should be to examine more closely the chronology of the changes, or trends, for this aspect alone is responsible for much present-day confusion. And sufficient of this information is contained in the forests and their present environments if we would care to search.

POSTSCRIPT

It was the intention to bring this study up to date by incorporating an analysis of pertinent climatological records and a discussion of these in relation to current forest condition and likely trends. However, it was soon realised that to do so would make this communication too cumbersome so that it has been omitted. Instead, this work will be communicated in a follow-up paper in the near future.

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GLOSSARY OF PLANT NAMES USED

PODOCARPS AND RELATED SPECIES

Kahikatea	*Podocarpus dacrydioides* A. Rich.
Matai	*Podocarpus spicatus* R. Br. ex Mirbel
Miro	*Podocarpus ferrugineus* G. Benn. ex D. Don.
Mountain toatoa	*Phyllocladus alpinus* Hook. f.
Pink pine	*Dacrydium biforme* (Hook.) Pilger
Rimu	*Dacrydium cupressinum* Lamb.
Silver Pine	*Dacrydium colensoi* Hook.
Tanekaha	*Phyllocladus trichomanoides* D. Don.
Toatoa	*Phyllocladus glaucus* Carr.
Totara	*Podocarpus totara* G. Benn. ex D. Don.
Totara (thin-barked)	*Podocarpus hallii* T. Kirk

BEECH SPECIES

Black Beech	*Nothofagus solandri* (Hook. F.) Oerst.
Hard beech	*Nothofagus truncata* (Col.) Ckn.
Mountain beech	*Nothofagus solandri* var. *cliffortioides* (Hook. f.) Poole
Red beech	*Nothofagus fusca* (Hook. f.) Oerst.
Silver beech	*Nothofagus menziesii* (Hook. f.) Oerst.

OTHER SPECIES

Broadleaf	*Griselinia littoralis* Raoul
Fuchsia	*Fuchsia excorticata* (J. R. et G. Forst.) Linn. f.
Heketara	*Olearia rani* (A. Cunn.) Druce
Heruheru	*Todea hymenophylloides* A. Rich.
Heruheru	*Todea superba* Col.
Hinau	*Elaeocarpus dentatus* (J. R. et G. Forst.) Vahl.
Hupiro	*Coprosma foetidissima* J. R. et G. Forst.
Kamahi	*Weinmannia racemosa* Linn. f.
Leatherwood	*Olearia colensoi* Hook. f.
Mahoe	*Melicytus ramiflorus* J. R. et G. Forst.
Mahoe wao	*Melicytus lanceolatus* Hook. f.
Maire	*Gymnelaea cunninghamii* (Hook. f.) L. Johnson
Orihou	*Neopanax colensoi* (Hook. f.) Allan
Pate	*Schefflera digitata* J. R. et G. Forst.
Pokaka	*Elaeocarpus hookerianus* Raoul
Rangiora	*Brachyglottis repanda* J. R. et G. Forst.
Rata	*Metrosideros robusta* A. Cunn.
Rewarewa	*Knightia excelsa* R. Br.
Supplejack	*Rhipogonum scandens* Forst. Char. Gen.
Tawa	*Beilschmiedia tawa* (A. Cunn.) Benth. et. Hook. f. ex Kirk
Tawari	*Ixerba brexioides* A. Cunn.
Tawheowheo	*Quintinia serrata* A. Cunn.
Toi	*Cordyline indivisa* Steud.
Wineberry	*Aristotelia serrata* (J. R. et G. Forst.) W. R. B. Oliver