This work of restoration will, in view of the density of the scrub hardwood growth now on the ground, be both difficult and costly; it probably could not, or need not, be undertaken for many years to come. But an early and wide attack on the many problems involved, on an experimental scale, is recommended.

REFERENCES

(1) Holloway, J. T.—1946—Forest Associations of the Longwood Range, Southland. N.Z. Journal of Forestry, Vol. V, No. 3, pp. 199-209.

(2) Thomson, A. P.—1946—Design for a Forest Survey. Ibid. Vol. V, No. 3, pp. 191-199.

FOREST COLONISATION AFTER RECENT VOLCANICITY AT WEST TAUPO

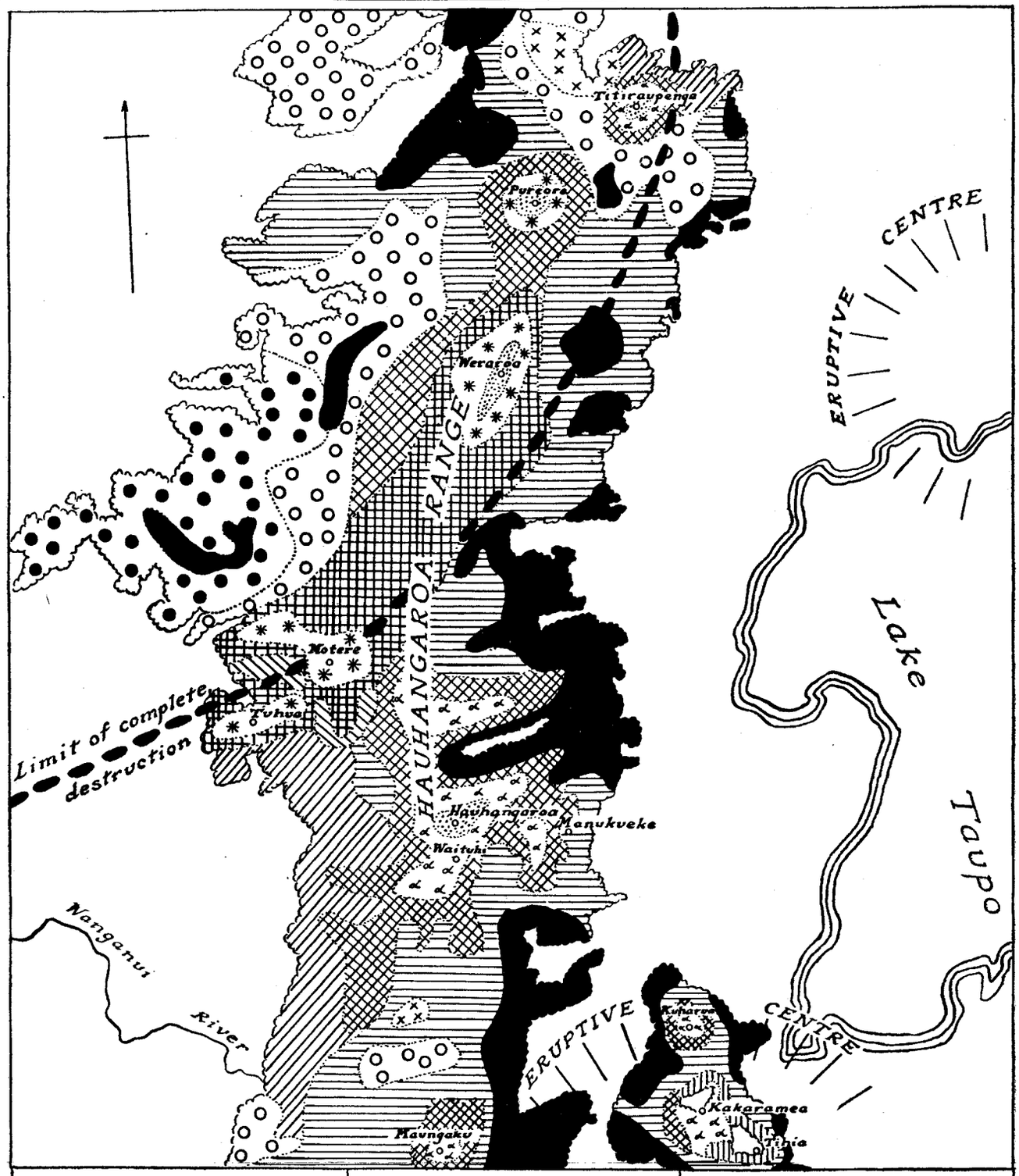
By P. J. McKELVEY

1. INTRODUCTION

Between Lake Taupo and the Main Trunk Railway is the extensive forest tract of West Taupo. The area selected for study here extends from near Titiraupenga Mountain in the north to the Wanganui River and Kakaramea and Tihia Mountains in the south (see accompanying map), approximately 300,000 acres. Forest colonisation following extensive volcanic eruption 1,700 years ago has produced a zoning of distinctive forest associations around eruptive centres.

Topographically and geologically the area is rather complex. In the north is the andesitic spine of Titiraupenga (3383 ft.) and the symmetrical cone of Pureora (3793 ft.), greywacke capped with andesite. Around the bases of these two mountains and in the saddle between them is a dissected, gently sloping ignimbrite sheet. The Hauhungaroa Range (3000 ft—3600 ft.), a tilted dissected greywacke fault block with scarp face to the east, forms a north-south axis to the West Taupo area. The southern end of the range, the andesitic block of Waituhi and Hauhungaroa (3541 ft.), is separated from the main salient by a low lying saddle on which is the extensive forest surrounded clearing, the Whenuakura Plain. North-west of the plain are the high ignimbrite escarpments of Motere (3248 ft.) and Tuhua (3425 ft.). Flanking both sides of the north part of the Hauhungaroa Range, like sea around a rocky prominence, are moderately to deeply dissected gently tilted ignimbrite sheets. Ignimbrite

FOREST ASSOCIATIONS
WEST TAUPO



Lower Altitude

- Dense podocarp-kamahi-maire
- Scattered podocarp-kamahi-maire-hinau
- Scattered podocarp-hinau-tawa
- Scattered podocarp-hinau-quintinia
- Scattered podocarp-hinau-rewarewa
- Scattered podocarp-rata-hinau-tawa
- Scattered podocarp-rata-maire-hinau

Sub-montane

- Sparse podocarp-kamahi-maire-scrub hardwood
- Sparse podocarp-maire-quintinia

Montane

- Scattered H. totara-kamahi-maire-scrub hardwood
- Scattered H. totara-maire-quintinia
- Beech-podocarp
- Mountain toatoa-H. totara

extends all the way along the eastern forest margin, sloping down to Lake Taupo, and forms the extensive flat Moerangi Clearing which separates the main forest mass from the forested andesitic outlier of Kuharua (3707 ft.), Kakaramea (4269 ft.), and Tihia (3824 ft.). Indeed most of the merchantable associations are on ignimbrite country. From Waituhi the land falls away south to the Wanganui River, moderately to deeply dissected mudstones, sandstones, occasional sandy limestones and minor conglomerates. An extrusion of basalt occurs near Maungaku (3213 ft.). Overlying the ignimbrite in the east are thick deposits of pumice breccia. (1)

Over all these basement rocks is a mantle of volcanic ash varying in thickness from 4 to 8 feet. Accumulations of water-washed volcanic material may greatly exceed these depths. This mantle is made up of five groups of showers, Ngauruhoe, Taupo, Tongariro, Tirau and Mairoa. The first is the most recent but only forms thin deposits confined to the south-east corner of the area. It is in the Taupo sandy silts, sands and gravels that the forests are rooted. North of Weraroa trig the Taupo pumice lies on the buried top-soils of the Tirau and Mairoa showers. South of here the Taupo pumice lies on the rather more basic brown sandy loam of the Tongariro shower. On some steep slopes, especially to the south, the Taupo ash has been washed away and the Ngauruhoe material lies directly on the Tongariro deposits. The weakly weathered nature of the soils permits the different types of forest cover to have rapid effect on the soil profiles. Under a podocarp canopy the soils become moderately to strongly podsolized. The mull forming hardwoods do not induce podsolization and generally remove the podsol profile if they replace a podocarp crop. However some hardwoods, especially tawa (*Beilschmiedia tawa*), are slow to do this. Apparently the cold climate minimises the ameliorating hardwood effect. Where the podocarp stocking is scattered or sparse a "mosaic" of podsolization results. It is very noticeable in the field that podsol profiles are more easily induced in the Taupo pumice than in the more basic Tongariro material.

The climate is cool and wet. Seelye's map shows an annual rainfall of 60-80 inches on 150-170 rainy days. In winter snow falls at the higher altitudes. Westerly winds may reach gale force for short periods. Podocarp rooting systems are shallow and many large diameter and overmature podocarps suffer windfall. The frequent low forking of podocarps may be due to wind damage. Heavy frosts occur intermittently through the winter; they are usually followed by fine clear days. Fog is not common.

2. FOREST ASSOCIATIONS

Podocarp-hardwood associations make up these West Taupo forests. Rimu (*Dacrydium cupressinum*) and matai (*Podocarpus spicatus*) are the principal podocarps. Other podocarp species

occurring are miro (*Podocarpus ferrugineus*), kahikatea (*Podocarpus dacrydioides*), totara (*Podocarpus totara*), Hall's totara (*Podocarpus hallii*), tanekaha (*Phyllocladus trichomanoides*), toatoa (*Phyllocladus glaucus*), and mountain toatoa (*Phyllocladus alpinus*). The principal hardwood species are tawa (*Beilschmiedia tawa*), hinau (*Elaeocarpus dentatus*), pokaka (*Elacocarpus hookerianus*), kamahi (*Weinmannia racemosa*), white maire (*Olea lanceolata*), black maire (*Olea cunninghamii*), northern rata (*Metrosideros robusta*), rewarewa (*Knightia excelsa*), and Westland Quintinia (*Quintinia acutifolia*). Of considerable physiognomic importance is an aggregate of minor hardwood species that form a hardwood scrub complex (*Nothopanax spp., Coprosma spp., Pseudowintera colorata, Melicytus ramiflorus, Suttonia spp., Schefflera digitata, Pseudopanax crassifolium, Pittosporum spp., Pennantia corymbosa, Carpodetus serratus, Olearia spp., Hoheria spp., Griselinia littoralis, Fuchsia excorticata, Brachyglottis repanda, Aristotelia serrata*). Beech does occur at the upper forest limit on Kakaramea and Tihia mountains, mainly *Nothofagus fusca*, with a small admixture of *N. cliffortioides* and hybrids. A small riparian consociation of *N. menziesii* exists at the eastern forest edge.

The forests can be divided into broad associations on recognition of differences in altitude, podocarp stocking, and the presence or absence of significant hardwood elements.

3. LOWER ALTITUDE FORESTS

The altitudinal range of these forests is from the natural and cultural forest edges at 1,000-1,500 feet up to 2,500 feet. On flat and moderately dissected country, mainly at and near the eastern forest edge occurs the DENSE PODOCARP-KAMAHI-MAIRE ASSOCIATION. This is made up of dense stands of tall (90-130 feet) podocarps. Diameters range from small to large but medium diameters are predominant. Tree form is good although many trees are low forked, especially matai. Rimu is dominant on undulating and dissected country and matai on level areas where the soils have been water-lain (stream terraces, basins). Other podocarps present are miro, totara, Hall's totara, kahikatea, and tanekaha, the latter only near the forest edge in the north-east of the area. Podocarp stocking per acre ranges from 25 to 60. Under the fairly dense podocarp canopy is a sparse hardwood undertier (40-60 feet); small diameter kamahi are dominant in this tier and small to large diameter black maire and white maire occur frequently. Hinau and *Quintinia* occur sparingly and sporadically. The sparse to moderately dense lower tiers are dominated by treeferns and scrub hardwoods. There is some scanty podocarp advance growth, a few poles and poor stocking of saplings and seedlings. Small dense stands of tawa poles and thickets of tawa saplings and seedlings occur sporadically.

West of the dense podocarps and forming the bulk of the lower altitude forests are scattered podocarp-hardwood associations. The

podocarp stocking per acre ranges from 8 to 20. The podocarps are predominately large diameter and often overmature. Boles are short to medium and tree form is often poor, many being forked with large spreading heads. Podocarp height ranges from 80-100 feet. In moderately and deeply dissected country the podocarp and upper hardwood tiers are concentrated on ridges and upper valley sides. On lower valley sites and in gullies hardwood scrub is dominant. On knolls and ridges small and medium diameter podocarps often occur. Here there is also sporadic, often dense, podocarp advance growth (miro, rimu, totara, Hall's totara, tanekaha, toatoa). It is significant that on these sites the lower scrub hardwood and treefern tiers are absent or less dense.

Immediately west of the dense podocarps is the extensive SCATTERED PODOCARP-KAMAHI-MAIRE-HINAU-ASSOCIATION. Here rimu and matai are dominant; other podocarp species present are totara, Hall's totara, miro and kahikatea. There is a scattered hardwood undertier (50-70 feet) composed mainly of small to medium diameter kamahi and hinau and small to large diameter maire; in this tier are also occasional small diameter Hall's totara. In the scrub hardwood dominated lower tiers are poles of kamahi and *Quintinia*. Under the podocarp canopy on ridges and upper valley sides are sporadic areas of dense tawa poles, saplings and seedlings.

Further to the west, mainly in the northern half of the area, is the SCATTERED PODOCARP-HINAU-TAWA ASSOCIATION. Here rimu is dominant; matai, totara, Hall's totara, kahikatea, miro also occur. The 50-70 feet hardwood tier is dominated by small to medium diameter tawa. Hinau is predominately large diameter and maire has virtually disappeared. Away from gullies and valley sides the lower tiers are dominated by tawa with the consequent reduction of podocarp advance growth. In the dense tawa tier are found occasional small to medium diameter miro.

In the SCATTERED PODOCARP-HINAU-QUINTINIA-ASSOCIATION, the latter species instead of tawa dominates the 50-70 feet hardwood undertier. A small admixture of Hall's totara and miro is also found in this tier. The lower tiers under the dense *Quintinia* canopy are dominated by pole and sapling kamahi.

In the SCATTERED PODOCARP-HINAU-REWAREWA ASSOCIATION there is a moderately dense 50-70 feet tier of small to medium diameter rewarewa and a little small to large diameter hinau. Tawa does occur but it is always of smaller diameter than the rewarewa and is subdominant to it.

In the extreme west is the SCATTERED PODOCARP-RATA-HINAU-TAWA ASSOCIATION. The salient features of this association are the large podocarp-rata combines, the dense tawa undertier which has a larger proportion of medium diameter trees than the non rata association, and the scattered small to large diameter

hinau. Rimu is the dominant podocarp, all the podocarps common to the other scattered podocarp-hardwood associations are present. The lower tiers are dominated by tawa and treeferns. Rata combines are also seen on hinau and maire.

4. SUBMONTANE FORESTS

Between 2,500 and 3,000 feet the podocarp stocking decreases to 2-8 per acre. The height of the podocarps is between 50 and 90 feet; tree form is poor. Boles are short and many trees are forked, most have large spreading heads. Diameters are predominately large although many medium diameter trees occur. Rimu, matai, totara, Hall's totara are the dominant podocarps. Other species occurring are miro and kahikatea, the latter is rare and usually of massive proportions. Where the country is dissected the podocarps are concentrated on ridges and upper valley sides; scrub hardwoods dominate lower valley sides and gullies.

In the southern half of the area a sparse stocking of podocarps and a sparse undertier of small to large diameter maire and small to medium diameter kamahi stand above dense scrub hardwoods, forming a SPARSE PODOCARP-KAMAHI-MAIRE-SCRUB HARD WOOD ASSOCIATION. An occasional Hall's totara pole is emerging from the dense lower tier. Cattle and deer have reduced the undergrowth and unpalatable species such as *Pseudo-wintera colorata* have become relatively abundant. Treeferns are common and there are many Hall's totara seedlings. Amongst the scrub hardwoods are higher altitude species such as *Olearia ilicifolia* and *Coprosma foetidissima.*

On the main part of the Hauhungaroa Range the upper hardwood tier is denser and is dominated by *Quintinia,* giving a SPARSE PODOCARP-MAIRE-QUINTINIA ASSOCIATION. With this increase in density of the upper hardwood tier there is consequent reduction in the scrub hardwoods. Kamahi saplings and poles are numerous under the *Quintinia* canopy.

5. MONTANE FORESTS.

From 3,000 to 3,500 feet, excluding the beech associations, Hall's totara is the physiognomic dominant. Podocarp height has fallen to between 30 and 70 feet but the stocking has increased, 5 to 20 per acre. Most extensive is the SCATTERED HALL'S TOTARA-KAMAHI-MAIRE-SCRUB HARDWOODS ASSOCIATION. Small to large diameter Hall's totara with a few small to medium diameter miro stand above small to medium diameter kamahi and small to large diameter maire; the latter species is absent at the upper altitudinal limit of the association. The two upper tiers are emergent from dense pole kamahi and scrub hardwoods. Species common in the latter complex are *Nothopanax colensoi, N. sinclairii, Griselinia*

littoralis, Suttonia salicina and *Olearia ilicifolia.* Occasional sapling and pole mountain toatoa and Hall's totara are emerging from the hardwood scrub.

On Weraroa, Pureora, Motere and Tuhua mountains *Quintinia* occurs, making up a SCATTERED HALL'S TOTARA-MAIRE-QUINTINIA ASSOCIATION.

On Kakaramea and Tihia mountains (and also on Pihanga to the south) BEECH-PODOCARP ASSOCIATIONS form "collars" at the upper forest limit. Dense small to large diameter *Nothofagus fusca,* with an occasional *N. cliffortioides* and rare hybrids form a dense canopy at 40 to 70 feet. Under the beech is a sparse tier of suppressed Hall's totara and mountain toatoa and a little kamahi. There is thick advance growth of beech in canopy gaps. Beech stands often occur as small islands surrounded by Hall's totara and scrub hardwoods. The beech islands are expanding as sapling and pole beech encroach on the surrounding association. There is not extensive riparian migration of beech to lower altitudes.

At the upper forest margin (3,600 feet) is a scrub MOUNTAIN TOATOA-HALL'S TOTARA ASSOCIATION. Windshorn mountain toatoa and Hall's totara, up to 20 feet, are emergent from dense *Nothopanax colensoi, N. sinclairii, Griselinia littoralis, Pseudowintera colorata, Olearia ilicifolia* and *Coprosma* spp. There are occasional Hall's totara saplings and seedlings.

6. SWAMPY CLEARINGS

Swampy clearings are a feature of West Taupo topography; the most extensive is the Whenuakura Plain lying north of Hauhungaroa mountain. Drainage systems have been upset by volcanic ash deposition and the subsequent washing of pumice material into valleys and depressions. Waterwashed pumice sands form compacted impervious layers with the result that soils are shallow and the water table is kept permanently high inducing swampy conditions. Often a weakly cemented pan is found 6-9 inches below the surface. All these swampy clearings are being drained by incising streams.

These swampy sites and difficult soils prohibit hardwoods and as drainage slowly lowers the water table the shallow-rooted podocarps pioneer. At high and low altitudes the present main pioneering species on such sites is mountain toatoa, and to a lesser extent Hall's totara. At lower altitudes stands of small and medium diameter matai, miro, Hall's totara and occasionally rimu on low-lying slow-draining areas indicate that these species have been swamp colonisers.

Around the peripheries of these swampy clearings occur narrow ecotone fringes, seedlings and sapling mountain toatoa and a little Hall's totara (*Dracophyllum subulatum*). Around the ecotone fringe is usually a belt of dense pole mountain toatoa (up to 2,000 per acre).

Around the pole toatoa and on a similar site is often a zone of dense small to medium Hall's totara. This is anomalous because there is no evidence of the mountain toatoa association being replaced by dense Hall's totara. These concentric zones around slowly draining swamps appear to be finite and not seral stages.

7. THE FOREST EDGE

There is little natural forest edge in the west ; the present forest edge there is the ragged limit of burning, land clearing and timber exploitation. In the east there is a semi-natural forest edge, fire having swept up against most of the forest at some time or other during the last century. In the east the forest, if not arrested by burning, is encroaching on the adjacent manuka and monoao with mountain toatoa and tanekaha as pioneers ; the latter species seems to be restricted to the northern half of the eastern forest edge. Hall's totara is a minor pioneer and effective seedling, sapling and pole growth of other podocarps may be present in a few localities. Dense sapling and pole stands of tanekaha and mountain toatoa form a narrow broken fringe along the eastern forest edge. However nowhere is there a gradual transition to mature *Phyllocladus* forest, there is usually a "step" junction between the dense small *Phyllocladus* and the mature dense podocarp-kamahi-maire association. Occasional medium to large diameter tanekaha do occur up to a mile from the forest edge in the north of the area. There is no evidence to show that rimu, matai and totara follow the *Phyllocladus* spp. so as to form a dense mixed podocarp association.

8. RECENT VOLCANICITY.

The Central North Island has had a long and varied volcanic history. However only the last extensive outburst (Taupo) need be considered here in order to lead to an understanding of the distribution of West Taupo forest associations. Study of radio-active carbon in recent volcanic ash deposits shows that the last eruption covering the West Taupo area took place only 1,700 years ago ($\pm$150)[2]. Investigations have indicated that these showers came from at least two sources, one at the north end of Lake Taupo and the other south of Kakaramea mountain. Volcanic debirs was thrown radially from these two areas. I. L. Baumgart considers that the volcanic bombardment was severe enough to cause complete forest destruction at least as far west as the line shown on the accompanying map.

The zoning of forest associations agrees with this except at one place in the north. There the gap in the Hauhungaroa Range between Weraroa and Pureora and also the gap between Pureora and Titiraupenga mountains seem to have enabled forest destruction to extend further west than elsewhere. Probably the Hauhungaroa Range acted as a barrier to the volcanic bombardment and protected much of the forest in its lee. Thus it seems reasonable to assume

that about 300 A.D. all the lower altitude forest to the east and south of the Hauhungaroa Range and also much of the submontane and montane forest was completely destroyed. It also seems likely that scattered areas of forest further west were destroyed, especially areas west of gaps in the mountain barrier.

9. POST ERUPTION COLONISATION.

There are two salient facts. Firstly the area of forest destroyed was large, secondly the subsequent forest colonisation must have been swift and extensive to have covered such a large area in 1,700 years. As a corollary it can be pointed out that the diameter size (age) relationships between the same species in different associations and between different species in the same association will often indicate seral positions.

Ring counts in mature podocarps have shown that large diameter trees vary in age from 400-700 years. Massive totara are probably older but they are usually hollow and their age cannot be assessed. Therefore on those areas that were colonised first the present podocarp crop will be the third or fourth. If it is assumed that forest colonisation proceeded from the undamaged forests in the west to the east, and it seems hardly likely that the few surviving trees (if any) could have colonised such a large area so quickly, then much of the forest crop in the extreme east must be the original colonising one. In other words the dense podocarp association is a first crop and the scattered podocarp associations further west are an older first crop or subsequent crops. The writer does not envisage a single colonising wave with an ecotone fringe at the foot. Such a mechanism would hardly have produced such large areas of even-aged forest. It seems likely that a scrub association, probably *Leptospermum* spp., would pioneer on the skeletal pumice and provide a nurse for the podocarps. Podocarp seed would be largely bird distributed and the pattern of colonisation irregular but with a general west to east direction. It seems reasonable to suppose that the amount of podocarp seed dropped by birds would vary inversely as the distance away from mature podocarp forest, in this case in the west. The supposition that the dense podocarp association concentrated at the eastern forest edge is younger than the scattered podocarp associations further west is supported by a study of the tree diameters in the two. In the scattered podocarp associations the average diameters are appreciably larger than the average diameters, species for species, in the dense podocarp association. It would appear then that the former have developed from the latter.

The presence or absence of certain hardwood species in the different lower altitude associations is dependent on the distance from the eruptive sources and thus on the relative age of the association. Here it may be explained that, in this study, for a hardwood species to be significant in an association it must occur frequently and be of

tree size (diameter of 12 inches and over). Under the fairly close canopy of the dense podocarps kamahi and maire form a sparse tier; they evidently followed closely the invading podocarps. In the scattered podocarp-kamahi-maire-hinau association, that association immediately to the west of the dense podocarps, hinau has become established. Further west still in the scattered podocarp-hinau-tawa association maire has virtually disappeared and tawa is the dominant hardwood. It is significant that in this association the predominant hinau diameter is large and the predominant tawa diameter is small—too large a difference to be accounted for by differential growth rate. A similar diameter relationship is seen between hinau and *Quintinia* and bewteen hinau and rewarewa in the other scattered podocarp associations. The tawa, rewarewa and *Quintinia* associations are approximately equidistant from the eruptive centres. Furthest from the ash shower centres is the scattered podocarp-rata-hinau-tawa association. The tawa here is of larger diameter than in the non rata association. Around the margins of the rata association forest with large rata combines passes abruptly into forest with no rata. There are very few small rata vines at the ecotone. A coherent hardwood sere then can be discerned in the lower altitude forests, firstly maire and kamahi, secondly hinau, thirdly tawa or rewarewa or *Quintinia* and fourthly rata. The striking constant relationships of diameter sizes of the different hardwood species, indicative of their seral positions, would seem to show a rapid and recent hardwood migration. Seed distribution would be by wind and birds. Field observations indicate that *Quintinia* seed is often water borne. The presence or absence of tawa, rewarewa and *Quintinia* is probably a matter of proximity of the scattered podocarp associations to seed source. Once tawa becomes established its dense canopy excludes the light demanding *Quintinia* and rewarewa. The shade tolerant tawa is able to become established under rewarewa and to a lesser extent under *Quintinia*. The Hauhungaroa Range is an altitudinal barrier to the eastern migration of tawa. It is spilling over the low saddle between Pureora and Titiraupenga mountains. This less hardy species apparently needs partial overhead protection to develop; in dissected country it is confined under podocarps, to upper valley sides and ridges. The ubiquitous hardwood scrub complex, present as a sparse lower tier in the dense podocarp association, forms a dense matrix in all the scattered podocarp associations except those contaning tawa. The dense shade cast by this species reduces the hardwood scrub to something approximating the lower tier under dense podocarps.

Evidently colonisation of the sub-montane areas at first was similar to that at lower altitudes. The same podocarp species are found, even kahikatea. Hall's totara is more plentiful. Large diameter maire occur frequently. Hinau is present but is not so plentiful as at lower altitudes. Tawa is absent, obviously these

forests are beyond its altitudinal range. The two major hardwood elements are *Quintinia* and scrub hardwoods. At these altitudes the form of kamahi enables it to be included in the latter group.

The montane areas were probably colonised by Hall's totara and perhaps miro ; mountain toatoa would have been most aggressive at the upper forest limit. Maire is present and probably filled the same role as at lower altitudes. *Quintinia* and scrub hardwoods are the major hardwood elements. The distribution of *Quintinia* is interesting. It apparently became established in the montane and sub-montane forests on the Hauhungaroa Range and at the present time is invading the lower altitude forests by riparian migration. The presence of beech at the upper forest limit on Kakaramea and Tihia mountains (and also on Pihanga to the south) is hard to explain. Being high above the adjacent eruptive centre it may have survived the volcanic bombardment. The beech, mainly *N. fusca*, is very aggressive and eventually will dominate the montane forests of Kakaramea and Tihia.

The relative proximity of the different lower altitude associations to the eruptive sources enables a colonising sequence to be recognised : podocarps, kamahi and maire, hinau and scrub hardwoods, tawa or rewarewa or *Quintinia*, rata. In the sub-montane forests the sequence appears to be : podocarps, maire, scrub hardwoods or *Quintinia* and in the montane forests : Hall's totara with miro and mountain toatoa, maire, scrub hardwoods or *Quintinia*. The scrub hardwood complex is represented in early colonising phases but it is only later in the sere that it assumes physiognomic importance. In the scattered and sparse podocarp associations there is pedological evidence that the areas carried denser podocarp stands : typical podocarp podsol profiles, now being obliterated, are often found under hardwood canopies.

10. ANOMALIES

Inspection of the accompanying map will show some anomalies in this account of colonisation after volcanic eruption. Why should there be extensive areas of dense podocarp forest in the west, furthest away from the volcanic sources ? These areas occur between Pureora and Titiraupenga mountains, north-west of Pureora mountain and west of Weraroa and Motere trigs. They all have a common edaphic feature ; all the areas are level and relatively low lying and were formerly swampy or semi-swampy. As the water table was lowered by dissecting streams podocarps invaded. The resultant forests are of comparable age to the main zone of dense podocarps along the eastern forest edge.

The intermittent nature of these dense podocarps along the eastern edge is in itself anomalous, one would expect a broad continuous zone. Undoubtedly the eastern spread of the forest has been retarded and even reversed by burning in both post-european

and pre-european times. Haphazard agriculture has been carried out between Lake Taupo and the forests for the last century and before the coming of the pakeha there was a fairly high Maori population on the west side of the lake. There is pedological evidence of forest retreat as soils outside the forest show traces of forest profiles.(3)

North-west of Titiraupenga mountain and also south of Hauhungaroa mountain there are areas of rata forest without tawa (SCATTERED PODOCARP-RATA-MAIRE-HINAU ASSOCIATION). This can only be explained by postulating that occasional rata combines survived the volcanic bombardment in these areas. Rata would spread from these areas in the new colonising forest before tawa had arrived from the west.

The forest associations on Kuharua, Tihia and Kakaramea are puzzling. It would be logical to suppose that this area would be colonised last of all as it is adjacent to one of the eruptive sources. Then it would be expected that the area be covered with dense mixed podocarps and Hall's totara at low and high altitudes respectively. This is not so at all. At the lower forest edge are extensive areas of dense podocarp forest on low lying terrain, some of which was formerly swampy. In the west the dense podocarps fringe the extensive Moerangi Clearing. The bulk of the area is made up of scattered podocarp forests with scattered Hall's totara and beech at higher altitudes. It is significant that there are no tawa, *Quixtinia*, rewarewa or rata associations. Rewarewa does occur at the forest edge but only marginally and then induced by fire. Perhaps the low-lying volcanic source south of Kakaramea erupted laterally and forest high up on Kakaramea and Tihia escaped heavy ash deposition ; forest colonisation would then proceed from high to low altitudes.

Then there are two major anomalies which, although they are diverse in nature, can be explained in the terms of one hypothesis. For the large devastated area to have been colonised so quickly all podocarps must have been very aggressive. However the present colonising podocarps are those species which normally belong to the montane forests and the narrow ecotone fringe formed by these species is incapable of swift extensive colonisation. Again if the general forest progression is from west to east, hardwoods replacing podocarps, then the forests in the west should have a smaller podocarp component than those in the east. With the exception of the dense podocarps at the eastern forest margin the podocarp stocking is similar for all the lower altitude forests. That is the podocarp stocking in the third or fourth crop scattered podocarp-rata-hinau-tawa association is similar to that in the first or second crop scattered podocarp-kamahi-maire-hinau association. It would seem that some major external factor has influenced all the podocarps at the same

time, rendering their advance growth less aggressive and unable to compete with the hardwoods. When the hypothesis of regional climatic change as put forward by J. T. Holloway is applied many anomalies and phenomena become intelligible.

11. CLIMATIC CHANGE

The essence of Holloway's postulate is that for the last 800 years a general regional climatic change causing colder and drier conditions has rendered many New Zealand forest associations less well adjusted to their habitats. In many places in the South Island podocarp forests have or are being replaced by *Nothofagus* forests or tussock grassland.(4)

In the North Island because of its mean warmer climate, the effect of climatic change would not be so marked but would be appreciable. It follows that comparable climatic change effects in the North Island will occur after those in the South Island. If it is assumed that climatic change has had an effect on West Taupo podocarp forests causing some mal-adjustment then many of the anomalies and phenomena outlined above can be explained. What is written below is, of course, pure conjecture but conjecture that accounts fairly satisfactorily for observed phenomena and also is in line with Holloway's recent advances in New Zealand forest ecology. It is emphasised that the bulk of West Taupo forests are over 2,000 feet in altitude, an equivalent climate at sea level would occur much further south. From 200 A.D. (approximate date of eruption) until about 1600 A.D. colonisation by podocarps of the devastated areas proceeded apace. Below 3,000 feet the colonising species were rimu, matai, totara and kahikatea and a dense mixed podocarp association developed, probably with kamahi, maire and scrub hardwoods as minor associates. Above 3,000 feet developed dense forests of Hall's totara with miro, maire, *Quintinia* and scrub hardwoods as subsidiary species, mountain toatoa would be present at the upper forest edge. After c. 1600 A.D. the influence of climatic change began to be felt in the North Island and the podocarps became a little mal-adjusted. It would be at the upper altitudinal limit of the dense mixed podocarps (2,500-3,000 feet) that the effect of climatic change would be first apparent. Podocarp advance growth would gradually become less aggressive and less able to compete with the hardwoods, the stockings of the subsequent podocarp crops would be much reduced. The hardwood elements, maire, kamahi, *Quintinia* and scrub hardwoods would increase in physiognomic importance. Scrub hardwoods seem to have "run riot" in filling the partial vacuum ; species like *Pseudopanax crassifolium*, *Coprosma* spp., *Pseudo-wintera colorata* are of very large size, occasionally over 12 inches in diameter. *Fuchsia excorticata* frequently occurs on such unusual sites as high broad ridges. In this manner have developed the sub-montane sparse podocarp associations. Above 3,000 feet the hardier Hall's totara would be better

suited to resist the change and the podocarp stocking of subsequent crops would be higher (scattered Hall's totara associations). At lower altitudes the podocarp advance growth would be affected but to a lesser degree. Here would develop the scattered podocarp associations with kamahi, maire, hinau, tawa, rewarewa, *Quintinia*, and scrub hardwood associates. Climatic change would have an accelerating effect on the west to east invasion by these hardwood species; with the decreasing aggressiveness of the podocarps they would become established with greater facility. It has been pointed out in section 9 that study of hardwood diameter sizes indicated a rapid and recent hardwood invasion. On sites that were inimical to hardwoods, dry ridges and knolls, shallow water-washed slow-draining pumice soils and areas not yet colonised by forest, dense mixed podocarp forest would be established or re-established. Scrub hardwoods and treeferns are mainly responsible for the inhibition of podocarp advance growth. This explains the concentration of podocarps and podocarp advance growth on narrow ridges in dissected country. It is significant that on these sites scrub hardwoods and treeferns are absent or less dense. As the climatic change progressed species migrated to lower altitudes. The frequent occurrence of Hall's totara at lower altitudes, often forming dense stands, can be explained in this way. More recently mountain toatoa "migrated downhill" and a narrow ecotone fringe of this species at the eastern bush edge replaced the "blanket" colonising of rimu, totara, hakikatea and matai. Around many swampy clearings that are now being drained a narrow belt of pole mountain toatoa passes abruptly into dense to medium diameter Hall's totara with no evidence of the *Phyllocladus* association changing to dense Hall's totara, indicative of colonisation under different climatic conditions. Probably the static and relict condition of rata can too be ascribed to climatic change.

12. CONCLUSION

The present distribution of West Taupo forest associations appears to be the product of post eruption colonisation modified latterly by regional climatic change. This account of forest development is conjectural, all that can be said of it is that it fits the observed facts fairly well. Possibly other ecological mechanisms could produce the observed end product. What is required is more investigation conjecture and criticism and also investigation in other Central North Island forests. Future forest management and land utilisation in the forested areas of the Central North Island must take cognizance of present major ecological trends.

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