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# Drought effect on high-altitude forests, Ruahine Range, North Island, New Zealand

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**Abstract** Shortly before 1917 abnormally high mortality of canopy trees occurred up to the timberline, c. 1470 m, in the central Ruahine Range. Rainfall records and historical observations indicate that this resulted from intense drought during 1914–15. Despite the drought damage and the impact of deer, the forest regenerated and after 1915 no major source area of coarse sediment developed in Centre Branch of the Waipawa Basin. Forest recovery at the head of the upper Waipawa Basin has produced a timberline which is c. 90 m lower than it was before 1915. On most of the Ruahine Range there is evidence of a recent lowering of timberline which probably also resulted from the 1914–15 drought and which is not associated with decrease of temperature.

**Keywords** drought; wind; temperature; erosion; timberline; browsing animals; *Nothofagus*; Ruahine Range, New Zealand

## INTRODUCTION

Cunningham & Stribling (1978) postulate that many factors have contributed to erosion in the Ruahine Range and that "... introduced animals by modifying the vegetation have played a most important part in initiating erosion". They state (1978, p. 21): "The evidence suggests that deterioration (of Ruahine Range vegetation) has occurred particularly during the past 50 years". Cunningham (1979) outlined the trips into the Ruahines in 1913 and January 1914 by the botanists B. C. Aston and F. Hutchinson (Aston 1914) and commented that they made no mention of any vegetation damage, saying "... it is difficult to believe that such forest debility as was later described could have escaped notice or gone unrecorded. It must be concluded that before 1920 the Ruahine Range forests were generally in a healthy condition". He continues that by the mid 1920s there was a high deer population in the northern Ruahines and that at that time the forest floor was bared. By the 1930s deer were frequent throughout the upper Tukituki and Waipawa basins.

The aims of this paper are to: present evidence that c. 1914–15 large areas of high-altitude forest in the upper Waipawa Basin (Fig. 1) suffered extensive mortality of canopy trees; show that this severe forest damage almost certainly resulted from drought; demonstrate that in the presence of dense deer populations a new beech forest canopy re-established widely; show that severe damage to high-altitude forests does not necessarily produce a marked increase in the extent of severely eroding bedrock areas; and discuss certain aspects of forest ecology in the light of this new and important aspect of Ruahine forest history.

## FOREST MORTALITY

In 1913, two botanists, B. C. Aston and F. Hutchinson, spent three days in the Makaretu headwaters, 16 km south of Middle Stream and in January 1914 they crossed the Ruahine Range, 8 km north of the upper Waipawa (Aston 1914) but made no mention of any damage.

The late Mrs A. A. Hutt clearly recalled (pers. comm. 1976) that in 1915 there were few dead trees in the forest visible from the house where she lived at that time compared with the number a few years later.

In 1919, at the head of the upper Waipawa River (Fig. 2 and 3), there were numerous dead, standing tree trunks and heads. Fig. 4 also shows many dead standing trunks of former canopy trees in the Middle Stream basin from at least c. 750 m to c. 1150 m a.s.l. As in the upper Waipawa River area the forest is dominated by red beech (*Nothofagus fusca*) at lower altitudes and mountain beech (*N. solandri* var. *cliffortioides*) at higher altitudes.

Research in the upper Waipawa Basin, partly reported by Grant (1977), has prompted the production of 1:2000 scale maps with contours at a vertical interval of 5 m. Using these maps, areal

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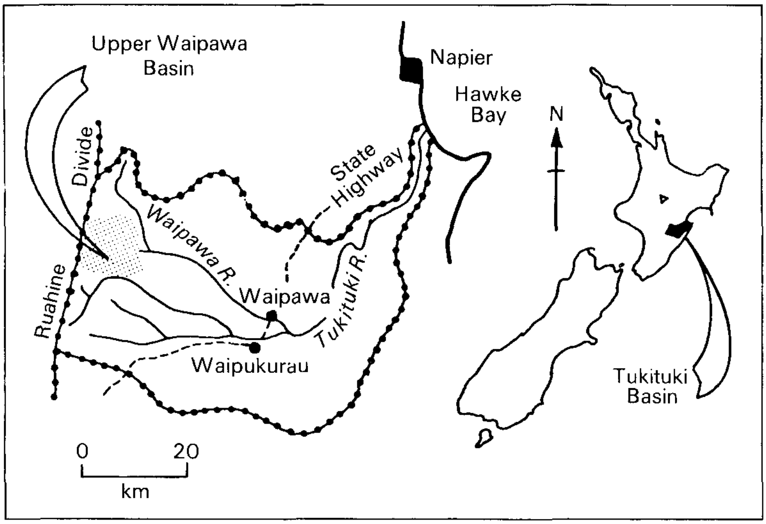


**Fig. 1** Location of the Tukituki and upper Waipawa basins, North Island, New Zealand.

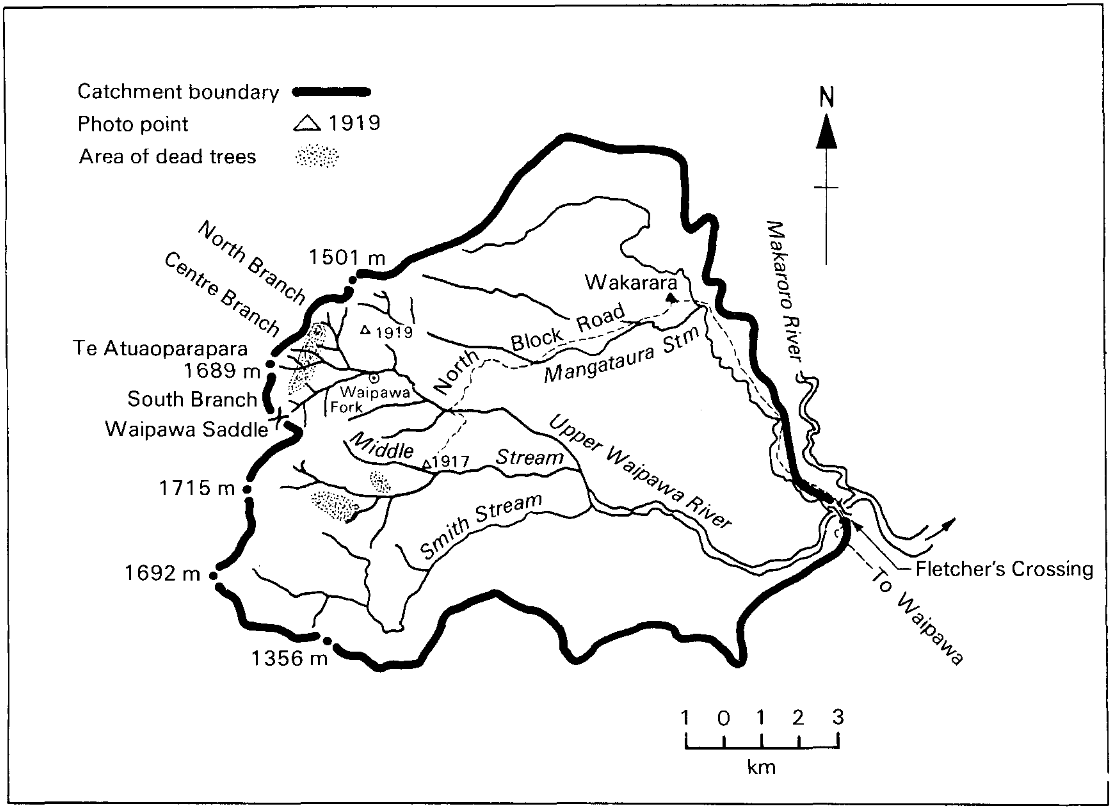


**Fig. 2** Upper Waipawa Basin comprising the headwaters of Mangataura Stream, upper Waipawa River, Middle Stream and Smith Stream. The upper Waipawa River area consists mainly of the drainages of North, Centre, and South branches.

**Fig. 3** Taken in 1919 from near Buttercup Hollow (NZMS1, N140: 627037), showing abnormally high numbers of standing dead tree trunks and heads (in white or grey). Te Atuaoparapara, 1689 m, the highest point at the left, is to the WSW of the photo point (N140: 603028) and is at the head of Centre Branch of the upper Waipawa River.
Photo: Mr B Bibby

and altitudinal values have been derived from Fig. 3 in which dead trees are visible from a former timberline* at c. 1470 m down to c. 950 m. Within a triangular area of 4 ha in the right half of Fig. 3, c. 300 dead, standing tree trunks were counted — an average density of 75/ha. This estimate must be conservative because of the difficulty of defining short dead trunks and the impossibility of determining the number of dead trunks hidden by others. The altitudinal range of c. 950–1470 m includes Austin's (1975) mid-upper red beech — mountain beech forest type and his upper mountain beech — scrub type.

The writer is satisfied that the dates of photography of Fig. 3 and 4 are correct because in each instance the date can be related to the photographer's personal history in relation to World War I (1914–18).

In February 1982, the area of Fig. 3 was photographed in colour and reproduced as Fig. 5. Comparison with Fig. 3 highlights the fact that today there are few dead standing tree trunks. Instead the forest canopy appears healthy, although certain distributional changes have occurred. Similarly the forest area of Fig. 4 today presents a more healthy canopy than in 1917. It is not possible to rephotograph the area shown in Fig. 4 from the same point because of the growth of exotic trees.

The comparison between the present forest canopy appearance and that of 1917–19 is sufficient to show that before 1917 the forests in the area had suffered a major disaster which had killed a very high proportion of canopy trees.

## Possible causes of forest mortality

There had been no fire. There were no animals in the forest capable of such widespread and severe damage in such a short space of time. It was not the type of damage that resulted from gales, heavy snow or rainfall, or even earthquake.

The late Mr R. D. Yeoman, Wakarara (pers. comm. 1973) commented that in early 1973 the streams from the Ruahines were the lowest since 1914 (Grant 1973). This suggested the occurrence of a major drought about 1914. Bondy (1950) noted that the 1914 winter-spring was "very dry over the greater part of the Dominion".

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**Timberline* is defined as the upper limit of tall, erect "timber-sized" trees (Wardle 1965).

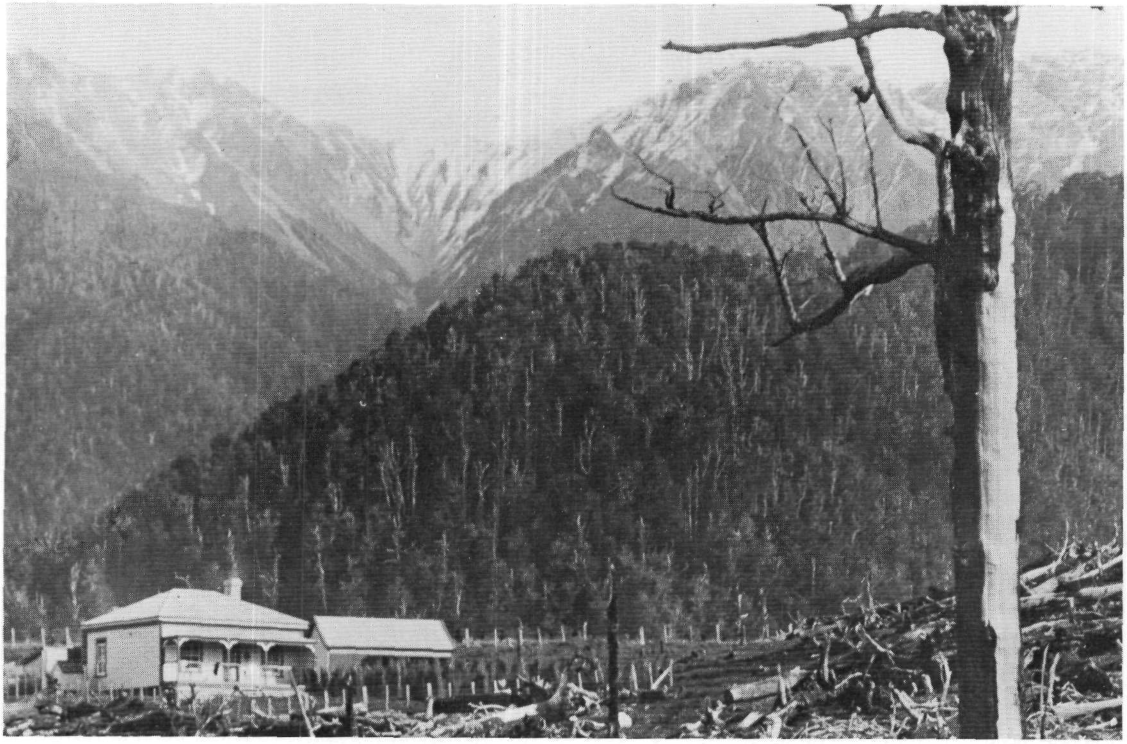

**Fig. 4** Taken in 1917 (N140: 643001), showing abnormally high numbers of standing dead tree trunks and heads in Middle Stream basin. The house was occupied by Mr and Mrs A. A. Hutt during 1915–20.
Photo: Mr A. A. Hutt

## DROUGHT

### Rainfall records

As no long-term rainfall stations existed on the Ruahine Range for about 1914–17, records from Gwavas (D96741) 24 km to the east and Taihape (E95681) 32 km to the WNW which are the closest long-record stations on each side of the range, were examined. Records for the two stations commenced in 1890 and 1906 respectively (Fig. 7).

Monthly rainfalls for Gwavas and Taihape during January 1974 to July 1981 ($n = 81$) were separately correlated with monthly values from Waipawa Fork by the upper Waipawa River (Fig. 2). Between Waipawa Fork and Gwavas: $r = 0.76$, $r^2 \times 100 = 58\%$, and $P < 0.001$; whereas with Taihape $r = 0.48$, $r^2 \times 100 = 23\%$, and $P < 0.001$. The Waipawa Fork-Gwavas relation is about 2.5 times stronger than that with Taihape therefore drought patterns based on monthly rainfalls at Gwavas should be better indicators of drought in the upper Waipawa Basin. The occurrence of a major dry period at both Gwavas and Taihape, at the same time, may be interpreted as a near certainty that the Ruahine Range between the two stations was similarly affected. Gwavas and Taihape are positively but weakly correlated: $r = 0.36$, $r^2 \times 100 = 13\%$, $P = 0.001$.

### 1914–15

The driest periods since 1906 for durations of 3–12 consecutive months were extracted from the Gwavas and Taihape records (Table 1). The most severe drought for each duration is ranked first. Ranking is based on the value of the average daily rainfall for the period. For 12 months, only the two driest periods are listed and for 3 months the six driest.

At Gwavas the 1945–46 dry period was the most severe recorded for durations of 3–5 months and it maintains a very high ranking for 6–9 months. The 1914–15 dry period ranked second up to 5 months but for 6–12 months it was clearly the driest recorded. The 12-month rainfall for June 1914–May 1915 of 459 mm was only 43% of the Gwavas normal (1941–70) annual amount of 1069 mm. It is pertinent that at Gwavas 1907–08, merely 6–7 years before 1914–15, was very dry for 3–5 months and 1912–13 was very dry for 3 months. Furthermore

**Table 1** The driest periods since 1906, for durations of 3 to 12 consecutive months, at Gwavas and Taihape rainfall stations.

| | Gwavas | | Taihape | | |
|---|---|---|---|---|---|
| Duration (months) | Dry period | Average rainfall (mm/day) | Dry period | Average rainfall (mm/day) | Common periods |
| 3 | Nov 1945–Jan 1946 | 0.34 | Feb–Apr 1919 | 0.89 | |
| | Dec 1914–Feb 1915 | 0.46 | Jan–Mar 1939 | 0.92 | |
| | Dec 1907–Feb 1908 | 0.56 | Aug–Oct 1914 | 0.97 | 1907–08 |
| | Dec 1912–Feb 1913 | 0.56 | Dec 1907–Feb 1908 | 1.01 | 1945–46 |
| | Dec 1930–Feb 1931 | 0.60 | Jan–Mar 1911 | 1.01 | |
| | Oct–Dec 1914 | 0.73 | Dec 1945–Feb 1946 | 1.04 | |
| 4 | Nov 1945–Feb 1946 | 0.28 | Nov 1945–Feb 1946 | 0.86 | |
| | Nov 1914–Feb 1915 | 0.65 | Feb–May 1919 | 0.98 | |
| | Sep–Dec 1914 | 0.69 | Nov 1947–Feb 1948 | 1.00 | 1907–08 |
| | Nov 1907–Feb 1908 | 0.71 | Jan–Apr 1939 | 1.06 | 1914 |
| | Dec 1930–Mar 1931 | 0.91 | Aug–Nov 1914 | 1.25 | 1945–46 |
| | Jan–Apr 1964 | 0.96 | Nov 1907–Feb 1908 | 1.28 | |
| 5 | Oct 1945–Feb 1946 | 0.52 | Nov 1947–Mar 1948 | 0.89 | |
| | Oct 1914–Feb 1915 | 0.64 | Jan–May 1939 | 0.97 | |
| | Oct 1907–Feb 1908 | 0.93 | Jan–May 1919 | 1.11 | 1914 |
| | Dec 1920–Apr 1921 | 1.13 | Jul–Nov 1932 | 1.39 | |
| | Nov 1930–Mar 1931 | 1.14 | Jul–Nov 1914 | 1.45 | |
| 6 | Sep 1914–Feb 1915 | 0.63 | Nov 1947–Apr 1948 | 1.17 | |
| | Sep 1945–Feb 1946 | 0.91 | Jan–Jun 1939 | 1.31 | |
| | Nov 1920–Apr 1921 | 1.16 | Jan–Jun 1919 | 1.38 | 1914–15 |
| | Oct 1930–Mar 1931 | 1.32 | Jul–Dec 1932 | 1.39 | |
| | Dec 1963–May 1964 | 1.42 | Sep 1914–Feb 1915 | 1.45 | |
| 7 | Aug 1914–Feb 1915 | 0.77 | Aug 1914–Feb 1915 | 1.35 | |
| | Nov 1920–May 1921 | 1.23 | Jan–Jul 1919 | 1.44 | |
| | Aug 1945–Feb 1946 | 1.33 | Jul 1932–Jan 1933 | 1.54 | 1914–15 |
| | Aug 1972–Feb 1973 | 1.42 | Jun–Dec 1959 | 1.64 | |
| | Nov 1963–May 1964 | 1.55 | Jan–Jul 1939 | 1.78 | |
| 8 | Jul 1914–Feb 1915 | 0.76 | Jul 1914–Feb 1915 | 1.46 | |
| | Jul 1945–Feb 1946 | 1.38 | Jan–Aug 1919 | 1.69 | 1914–15 |
| | Jul 1972–Feb 1973 | 1.43 | May–Dec 1932 | 1.73 | |
| 9 | Jun 1914–Feb 1915 | 0.79 | Jun 1914–Feb 1915 | 1.54 | |
| | Jun 1945–Feb 1946 | 1.39 | Apr–Dec 1932 | 1.79 | 1914–15 |
| | Jul 1972–Mar 1973 | 1.48 | Jan–Sep 1919 | 1.87 | |
| 10 | Jun 1914–Mar 1915 | 1.26 | Jun 1914–Mar 1915 | 1.64 | |
| | Jul 1972–Apr 1973 | 1.52 | Mar–Dec 1932 | 1.65 | 1914–15 |
| | Aug 1963–May 1964 | 1.53 | Jan–Oct 1919 | 1.82 | |
| 11 | Jun 1914–Apr 1915 | 1.24 | Jan 1914–Apr 1915 | 1.63 | 1914–15 |
| | Jul 1972–May 1973 | 1.59 | Feb–Dec 1932 | 1.79 | |
| 12 | Jun 1914–May 1915 | 1.26 | Jun 1914–May 1915 | 1.65 | 1914–15 |
| | Jun 1972–May 1973 | 1.69 | Jan–Dec 1932 | 1.73 | |

the Gwavas annual rainfalls for 1910, 1911, 1912, and 1913 were all below normal, being 91, 85, 85, and 76% respectively — a total deficit below normal of 63% at the end of 1913. This pattern, climaxed by the sustained dry conditions of June 1914–May 1915, is likely to have produced, by 1915, the most intense physiological drought conditions at Gwavas of this century.

At Taihape for durations of 3–6 months several different years rank the most intense in dryness but 1914–15 ranks in the top five. For 7–12 months, 1914–15 was the driest period at Taihape and for

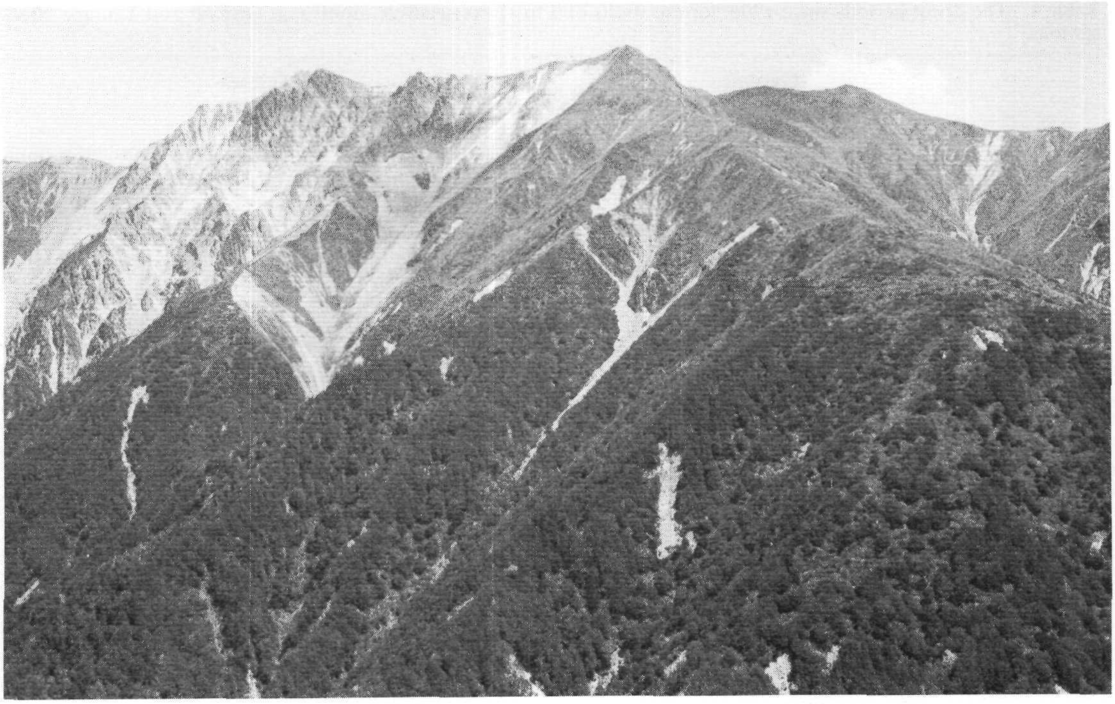

**Fig. 5** Taken in 1982, showing the area photographed in 1919 (Fig. 3). Note the absence of large numbers of dead trees and the bushy, healthy appearance of the beech forest canopy.

each duration the period of extreme dryness at Taihape agreed in time with that at Gwavas. The 12-month rainfall at Taihape for June 1914–May 1915 of 632 mm was 67% of the normal annual value of 949 mm.

The average daily rainfall values (Table 1) are lower at Gwavas for the 1914–15 dry period and they represent a smaller percentage of the annual normal value than at Taihape, therefore the 1914–15 drought period was relatively more intense at Gwavas. The fact that both at Gwavas and Taihape, each side of the Ruahine Range, the 1914–15 dry period was clearly the most intense drought of this century and that there was chronological agreement in the month of onset and closure suggests that the phenomenon was extremely widespread and must have affected the Ruahine Range itself. This hypothesis is strengthened by the comments of Bondy (1950), Coulter (1965), and Jane & Green (1983) indicating how widespread the 1914–15 drought was in New Zealand. The absence of comment on any vegetation damage in 1913 and January 1914 by the botanists Aston and Hutchinson, the observation of the late Mrs Hutt that in 1915 there were few dead trees visible compared with those in 1917 (Fig. 4), the back-up evidence in 1919 of recent widespread canopy mortality (Fig. 3), and the fact, from personal observations, that beech trees often die within a few years of a major setback also support one logical conclusion: the widespread disastrous death of forest canopy trees in the upper Waipawa Basin (shown in Fig. 3 and 4) and neighbouring basins were subjected to extremely severe drought conditions for an extended period culminating during June 1914–May 1915. It is probable from the widespread extent of this drought in the North Island that the entire northern and central areas of the Ruahine Range, and possibly also the southern areas, were similarly affected (Fig. 7).

### Other dry periods

The 1945–46 dry period ranked highly for 3 and 4 months at both Gwavas and Taihape (Table 1) which is an indication of its widespread occurrence and hence its probable impact on the Ruahine Range vegetation. At Gwavas, and probably in the central and northern areas of the Ruahine Range, the 1945–46 dry period was more intense than that of 1914–15 for durations of 3–5 months, but for longer durations 1914–15 was the most severe dry period since 1906. The 1945–46 drought had a noticeable effect on mountain forests. Some of this

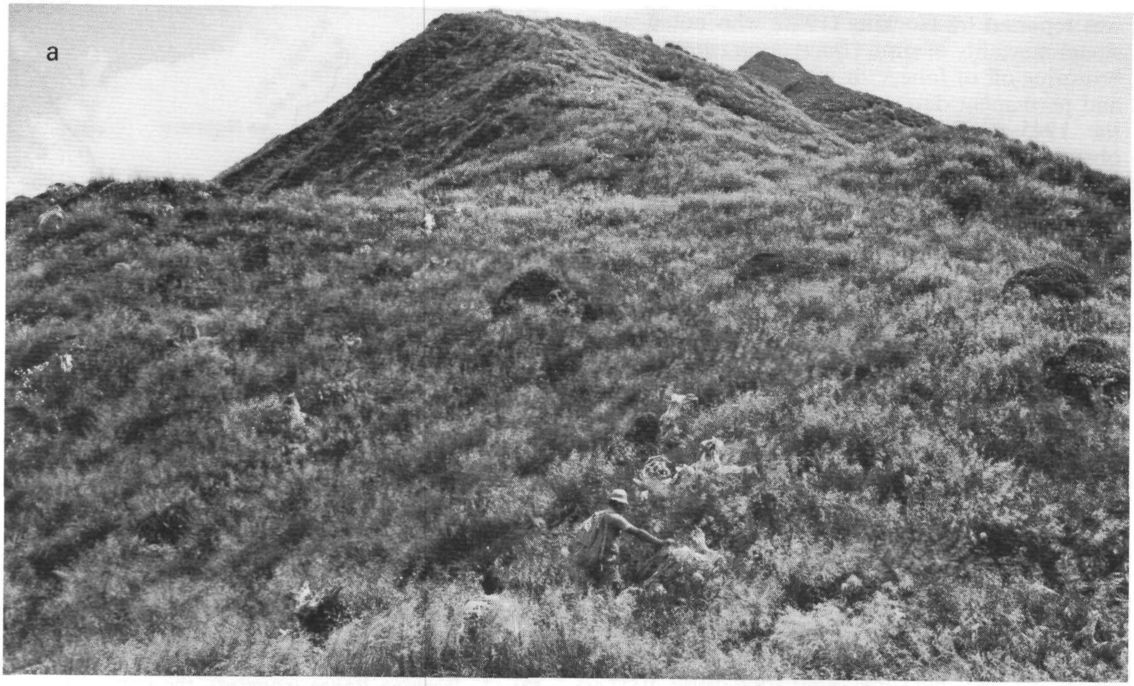



**Fig. 6** At the head of North and Centre branches of the upper Waipawa River, between the pre-1915 timberline of c. 1470 m and the present level, c. 1380 m. Photographed in 1982.

**Fig. 6a** Dead prostrate beech trunks are visible, close to the old timberline c. 1470 m, where snowgrass now dominates. Note that a few small rounded leatherwood bushes are established. — Difficult to see.

**Fig. 6b** Close to the present general timberline c. 1380 m, dead prostrate beech trunks (pre-1915) are scattered throughout a mixture of snowgrass, young leatherwood bushes, and young mountain beech. Note the ill thrift and low windswept heads of the beech. (detail difficult to see) was reported by Hocking (1946) who noted occasional mortality of rimu (*Dacrydium cupressinum*), browning-off of foliage of totara (*Podocarpus* sp.), and permanent damage to "black beech". During the 1945–46 drought Mr A. Reeves, Hinerua, observed in Middle and Smith Stream basins (Fig. 2) that the shrub tier in the forest was severely affected by drought and much rangiora (*Brachyglottis repanda*) had died (pers. comm.). In pastoral areas adjoining the range large rimu died. Elder (1962) described the widespread death of mountain beech 55–60 km north of the Waipawa Basin, in a belt at 900–1200 m altitude, extending from the Kaweka Range (Fig. 7) westwards across the southern Kaimanawa Range. He observed this phenomenon in 1947 "when evidence of the 1945–46 drought was still evident in shrubland as well as forest, and was then assumed to be the result of it. Regeneration has since become typical in these areas, some, though not all of this, dating from 1947". For the Ruahines he referred to the 1945–46 drought (Elder 1965) and considering the southern area of the Ruahine Range he stated (1958): "The recent large scale changes in the vegetation of the area appear to have occurred so nearly simultaneously that some originating cause, 10 years or so prior to 1957, seemed probable". He deduced that the changes possibly resulted from the 1945–46 drought, "...but the evidence is inconclusive". The few recorded observations which exist of the damaging impact on forests of the Ruahine, Kaweka, and Kaimanawa ranges of the 1945–46 drought constitute an ample basis for postulating that during the later stages of the more prolonged and intense 1914–15 drought its impact on mountain forests must have been even more drastic.

Other sustained dry periods at Gwavas (Table 1) which could have extended to the Ruahine Range and affected its vegetation occurred during 1907–08 (3–5 months), 1920–21 (5–7 months), 1930–31 (3–6 months), 1963–64 (6–10 months), and 1972–73 (7–12 months).

Mr E. S. Bibby of Blackburn (pers. comm. 1982) considered that 1907–08 was the first very dry period to affect the Ruahine Range since forest was felled about Blackburn (Fig. 7) in the 1870s. Bondy (1950) stated that the 1907–08 summer was "especially severe in parts of Hawkes Bay". At Taihape, 1907–08 was also a severe dry period for 3–4 months which indicates, as for the 1914–15 drought, that the 1907–08 dry period affected the central and northern areas of the Ruahine Range. The 1907–08 dry period was followed, as already outlined, by the relatively low-rainfall years of 1910 to 1913 at Gwavas. However, up to January 1914 the extended dry period evidently had not resulted in outstanding forest damage (Aston 1914). Nevertheless there is little doubt that the prolonged relatively low-rainfall period from 1907 to 1913 must have contributed to the final disastrous effects of the 1914–15 drought on the Ruahine Range vegetation.

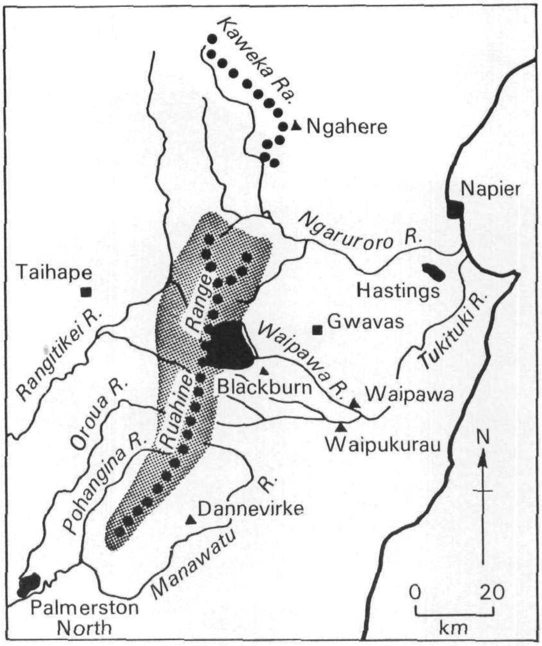


**Fig. 7** Ruahine Range (stippled), the upper Waipawa Basin (shaded), Gwavas and Taihape rainfall stations and other locations.

In 1937, Kean and Newcombe crossed the divide via Waipawa Saddle (Fig. 2) and noted the prevalence of dead timber in the beech forests of the Waikamaka and Kawhatau valleys (Kean & Newcombe 1937) . In the Waipawa valley also dead trees were widespread and many "were alive, but slowly dying". Their description implies that mortality had been induced not long before 1937, perhaps as a consequence of the drought of 1930–31 or earlier droughts. However their comment on the dead trees in the Kawhatau suggests that these died earlier, probably following the great drought of 1914–15.

The 1963–64 and 1972–73 dry periods at Gwavas did not affect Taihape therefore there is no firm basis for believing that they severely affected the vegetation of the Ruahine Range. However, the relatively low rainfall on the central and northern areas of the range in 1972–73 resulted in depletion of basin groundwater reserves which produced the extremely low streamflows recorded (Grant 1973). This situation is not necessarily accompanied by drought conditions for vegetation, but probably on some sites physiological drought did adversely affect the forests.

In summary, the droughts for which there is evidence of their effect, or probable effect, on Ruahine Range vegetation are:

1907–08 common to Gwavas and Taihape; contention of E. S. Bibby (pers. comm.).
1914–15 common to Gwavas, Taihape, and elsewhere; observations (Mrs Hutt pers. comm., Aston 1914).
1945–46 common to Gwavas and Taihape; extensive observations (Hocking 1946; Elder 1958, 1962, 1965; Reeves pers. comm.).

Of the above three droughts the dry period culminating in 1914–15 was undoubtedly the greatest drought at Gwavas since 1890 and at Taihape since 1906. It appears to have been the greatest drought to affect the vegetation of the Ruahine Range since at least 1906. If E. S. Bibby's contention that the much less severe 1907–08 drought was the first major drought since the 1870s to affect the Ruahine Range, then the great drought of 1914–15 must have had a more severe impact on Ruahine forests than any other drought since the 1870s.

## FALL OF TIMBERLINE

From photographic evidence (Fig. 3 and 4) and field observation, the timberline at the head of the upper Waipawa Basin dropped about 1917, from c. 1470 m to c. 1380 m. It is concluded here that this resulted from the great 1914–15 drought.

Most of the area between the two timberlines is now densely covered with snowgrass (*Chionochloa pallens*) amid which still exist numerous fallen tree trunks to c. 6 m long and 0.6 m diam. (Fig. 6a), three of which were identified from samples as beech (Mr L. Donaldson, Forest Research Institute, pers. comm.). Much of the lower portion of the area is dominated by leatherwood (*Olearia colensoi*), and even where snowgrass now dominates, leatherwood is establishing on some small exposed soil surfaces. Where scattered mountain beech have established since 1917–19 above c. 1380 m it appears that they are not likely to attain the dimensions of the prostrate relics in the snowgrass (Fig. 6b). However their presence suggests that the fall of the beech timberline may be only a relatively short-term change.

Fig. 5 shows that the present forest canopy in the upper Waipawa is more healthy than in 1919 but it also clearly shows, below present timberline, that extensive formerly forested areas have been revegetated by a paler and lower canopied vegetation which is dominated by leatherwood. This scrub type descends into the beech zone to c. 1150 m on the bottom right of Fig. 5.

Elder (1956) summarised his wealth of observations: "Stumps and logs under snowgrass ... are exposed at numerous points in the Ruahines above the present forest limits, and the existing timberline is dying back and being replaced by scrub and tussock, indicating that change has been continuing within the last 200 years". In the north-western area of the range Elder (1957) found it noteworthy that "...dead *Dacrydium* (*biforme*) branches project from individual *Olearia* bushes which appear to have supplanted it comparatively recently". In the central area he described (1957) comparable timberline situations where beech regeneration dated back to at least 1921. And in the southern Ruahines he (Elder 1958) describes "...mainly dead and moribund *Dacrydium* with a proportion of taller *Olearia* projecting above the present *Olearia* windroof. It appears fairly certain here that a *Dacrydium* — scrub forest some 12–15 ft (3.7–4.6 m) high is in the last stages of being replaced by 6–8 ft (1.8–2.4 m) high *Olearia* scrub ..."

Ogden (1976) discusses the influence of drought on lowland forest and points out that vegetation change associated with drought occurs because certain species are more susceptible to drought than others. He notes "...species with annual seed production and abundant seedlings will have a higher probability of long-term survival than species with few seeds or seedlings which require conditions for germination or establishment that are not fulfilled annually, despite the much greater *apparent* damage to the former species, ..." Later he says: "... one has to remember that the present distribution of a species may be in part determined by the history of earlier droughts". These principles apply also to mountain vegetation and especially to timberline environments.

The timberline changes in evidence today, and described above, appear to be ecologically comparable and chronologically in agreement with the changes presented here for the head of the Waipawa Basin. Therefore it is possible that most, if not all, of the recent timberline changes on the Ruahine Range are also primarily the consequence of the great drought of 1914–15. This does not negate the probability that other climatic factors are also contributing to long-term vegetation change. However, it does not agree with the contention that this latest fall of the timberline, or a fall of timberline anywhere, is necessarily related to decrease of a temperature parameter (Raeside 1948, Elder 1955). Actually, results of Grant (1983) agree with those of Salinger (1979, 1982) and show that since around 1915 there has been general *warming*, in all seasons, throughout the North

Island; the Ruahine Range would not be an exception. It is extremely dangerous to blindly deduce climatic changes of the recent past from our limited understanding of past and present vegetation changes.

## DEER AND EROSION

About 1917 Mr A. A. Hutt saw "the first mob of about six red deer" in the Waipawa area (pers. comm. 1976). In the 1920s deer were frequent in Smith and Middle streams and the upper Waipawa River areas, and it was common to see 20 stags feeding in a mob and large mobs of hinds (Hutt pers. comm.). Around 1928 the lower forest tiers were heavily browsed and tracks were well-developed (Mr A. Reeves, Hinerua, pers. comm. 1975). By 1935 exposure of the forest floor by trampling had become noticeable in the head of the Waipawa (Elder 1965). Peak populations of deer, from the Waipawa northwards, are likely to have been around 1938-40 (Jackson 1966).

Despite the increasing impact of deer on the lower forest tiers soon after the 1914–15 drought (the effects of which may have facilitated, or induced, the rapid spread of deer), the forest did recover. Today, particularly at higher altitudes the forest canopy is more healthy (Fig. 5) than it was in 1917–19 (Fig. 3 and 4). This is a remarkable phenomenon which demonstrates the tremendous resilience of the mountain vegetation.

The major eroded areas on the slopes of Te Atuaoparapara (Fig. 2) are essentially the same in location and extent in Fig. 3 and 5, but locally in the areas of Fig. 5 there is some small areal enlargement. Fig. 3 shows several long eroded gully surfaces on the left lower slopes which, in Fig. 5, are largely revegetated in grasses and shrub species. However, Fig. 5, at the left, shows a marked downslope enlargement of the 'hook' eroded surface which from photo records occurred during 1919–50. At a similar level, to the right of photo centre (Fig. 5), exists a large vertically oblong erosion scar which from aerial photos occurred during 1967–74. However, the most important point is that all the extensive major areas of severe erosion, which are known today to be major supply areas of coarse sediment to the Waipawa River (Grant 1983), appeared in 1919 essentially as they are today. On the very steep slopes of the upper Waipawa River Basin there is no evidence that the frequency of debris avalanches increased as a result of animal impact. No major coarse sediment supply area was initiated as a consequence of the combined impacts of the 1914–15 drought and of deer. Since 1919, some minor eroded areas have revegetated; and some old ones have enlarged a little and an odd new minor one has developed —the result I believe of heavy storm rainfalls such as the effects of cyclone Alison documented by Grant et al. (1978) and Grant (1982). This overall outcome is remarkable also because the areas shown in Fig. 3 and 5 include the highest and some of the steepest land in the upper Waipawa River headwaters, which has the largest eroded-surface to basin-area ratio in the entire upper Tukituki River drainage system (Austin 1975), and probably has the greatest average annual yield of coarse sediment (Grant 1982).

Rates of coarse sediment yield and river transport have continued to increase only since the late 1940s (Grant 1977, 1983) before when no marked trend of change has been determined in the channel of the upper Waipawa River. By the late 1930s when deer numbers peaked, and the influence of the drought was waning, the current unstable channel regime trend had not commenced. By the 1950s and 1960s when increased sediment transport had altered the channel regime greatly, and continues to do so, the influence of the 1914–15 drought had waned still more, deer numbers had declined markedly, and old entrenched deer tracks had widely become overgrown. Clearly, the current regime in the Waipawa Basin of increased erosion and increased sediment transport from the range is inexplicable in terms of the supposed effects of introduced browsing animals.

The effect of the 1914–15 drought, on canopy trees, was a more abrupt change than any possible there by animals. It damaged forest structure more drastically and in a shorter period of time. The drought damage to canopy trees resulted in extreme exposure of sub-canopy plants to heavy rainfalls, wind, solar heat, snowfall, and frost. The 1914–15 drought damage, which appears to have been very widespread, must have had a greater negative influence on the water cycle (probably by reduction of interception loss) and in a shorter time than would animal browsing. The great overall impact of the 1914–15 drought did not result in an increase in the extent of major erosion. On each point mentioned by Cunningham & Stribling (1978) as a means by which animals "... have contributed to the process of deterioration" there is little doubt that the impact of such an intense drought as that of 1914–15 must have far outweighed that of animals. Yet increased erosion and sediment yields did not follow closely in the wake of the great drought.

## DISCUSSION AND CONCLUSIONS

The preceding exposé centres on the photographic evidence of widespread mortality of forest trees up to timberline which must have occurred not long before 1917 on evidence that in 1914–15 the Ruahine Range was probably affected by an extremely severe drought; and on the logical deduction, from available information, that the 1914–15 drought was the cause of the forest mortality. This dieback phenomenon at the head of the upper Waipawa Basin resulted in a lowering of timberline of c. 90 m.

A recent retreat of the timberline is widespread on the Ruahines (Elder 1955, 1956, 1957, 1958) and this appears to be ecologically comparable and chronologically in agreement with the timberline changes documented here. Therefore the severe impact of the 1914–15 drought probably widely resulted in a very high frequency of tree mortality. This conflicts with the statement of Cunningham & Stribling (1978) that deterioration of forests "... has occurred particularly during the past 50 years". It also disagrees with Cunningham (1979): "Apart from the changes caused by fires and localised storms there is no evidence that the Ruahine forests were seriously damaged or unhealthy before 1920". In the upper Waipawa River and Middle Stream basins in particular (Fig. 3 and 4) the evidence is undeniable that during or after 1914–15, but before 1920, the forest canopies up to timberline were severely damaged. The date, 1917, of Fig. 4 indicates that the causal factor was effective before 1917. Yet it was about this same time that deer were first sighted in the area by the resident, Mr A. Hutt. Opossums were reported (Grant 1956) to cause some damage to canopy species in a nearby area. Elder (1965) says that opossums probably did not enter the Waipawa Basin until a little before 1937. Therefore it is concluded that neither deer nor opossums caused, or contributed to, the forest mortality shown in Fig. 3 and 4.

The increase in deer numbers in the Waipawa Basin after c. 1917 added to the severe damage resulting from the 1914–15 drought, did not prevent the forests from regenerating over the greater portion of the affected slopes (Fig. 3). However, on large areas down to c. 1150 m which are now dominated by scrub (Fig. 5), beech did not regenerate. This may have been the consequence of the presence of deer but it could have resulted from other factors.

Comparison of Fig. 3 and 5 shows that no major eroded area, constituting a major sediment supply area to the drainage system, resulted from either the impact of the 1914–15 drought on the forests or the subsequent effect of deer and opossums. This supports my contention that in the upper Waipawa, and in some other basins of the central and northern Ruahine Range, the major areas supplying coarse sediment to channels today originated before animals were introduced and before any impact of European settlement on the range. Their origin undoubtedly preceded AD 1845 (Colenso 1884, quoted in Grant 1965). When their great denudation depths are considered it is probable that the major coarse sediment supply areas of today (Grant 1982, 1983) have existed for many centuries, or even millenia.

Evidence indicates that since the great drought of 1914–15 and its disastrous damage to Ruahine forests, and since the advent of deer, the forests have been affected by at least one other effective drought in 1945–46. It is noteworthy that Jane & Green (1983) defined two forest mortality episodes in the Kaimai Range "closely linked with severe droughts which occurred in 1914 and 1946." Since 1915 changes have taken place not only in forest canopy composition and form but also in the vegetation tiers within browsing reach. In the browse zone, changes of density and of species composition are usually assumed to be the effects of animals. In some situations this may not be so; it may be the result of drought (Atkinson & Greenwood 1972). Ogden (1976) states: "Vegetation change associated with drought occurs because certain species are more susceptible to drought than others, just as changes in composition resulting from browsing by introduced mammals occurs through differential palatability. (Footnote: In practice, of course, these two causes of change are often confounded). Depletion or extinction of certain susceptible species may be followed in subsequent non-drought years by expansion or invasion of more tolerant species." Perhaps since the great drought of 1914–15 physiological drought has been more influential on the vegetation of the Ruahine Range than we realise. It is certain that before 1914–15 the Ruahine forests must have been affected by drought at some time.

It is pertinent to note Moar's conclusion (1956) on Mokai Patea, c. 6 km north-west of the head of the Waipawa Basin, at altitudes between 1200 and 1520 m, that "...peat formation and the extent of peat were greater at some time in the past, for peat formation is not now active and there is no widespread accumulation of peat. Stagnation and erosion are now the characteristic features of these peats. It is evident that the two mires that are still accumulating peat depend mainly on the reserves of water in the tarns, for apart from these two there is no active peat formation in the locality". His final statement is: "Available data indicate that the mires have been formed under wetter conditions than at present, ..." The present drier conditions which are adversely affecting peat accumulation could be explained by a recent increase in drought frequency or even by an increase in the severity of an occasional drought, such as that of 1914–15.

Grant (1963) showed that forests of the Huiarau Range, about 140 km to the north-east, were almost certainly adversely affected by the 1945–46 drought. He postulated that precipitation effectiveness has decreased significantly and that drought is probably the master process — which agrees with the information and deductions of this study. However, it is considered that the postulated increase in the severity of drought, probably this century, is only part of the total climatic regime change which has taken place and which widely appears to be effecting change in the indigenous vegetation.

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