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ECOLOGICAL ASPECTS OF CLIMATE PATTERNS WITHIN THE KAIMAI RANGES, NORTH ISLAND, NEW ZEALAND

Summary: Meteorological data from stations around and within the Kaimai Ranges and data from temporary sites are used to characterise the climate of the ranges. Lowland climate is warm temperate with ample rainfall but the upland region is cooler, wetter and frequently enveloped in fog. Frequent fog plays an important part in the climate of upland regions. By modifying light, moisture and temperature regimes fog may be a significant determinant of plant associations and may severely restrict growth. The absence of fog during prolonged drought may accentuate plant water stresses and appears to playa significant role in the occurrence and location of forest mortality.

Keywords: Climate; rainfall, temperature; fog; drought; forest ecology; Kaimai Ranges; New Zealand.

Introduction

Recent studies of vegetation mortality in the Kaimai Ranges have suggested that climatic factors, especially waterlogging and drought, play a significant role in the initiation of periods of mortality (Green and Jane, 1984; Jane and Green, 1983a). It has also been suggested that, as a result of vegetation mortality, reduced forest cover and weakened root systems, there has been increased susceptibility to landslides in severe storms (Jane and Green, 1983b).

Drought stress is known to cause localised mortality on sensitive sites (Coulter, 1966; Finkelstein, 1971; Atkinson and Greenwood, 1972; Ashton, 1976) and may place a wide range of species at risk to disease (Peace, 1960; Schoenewiss, 1975; Tobiessen and Buchsbaum, 1976). Yet it is difficult to envisage drought damage initiating the mortality in the Kaimai Ranges, an area of high rainfall. Soils, however, are shallow and frequently saturated, thus restricting root systems. Consequently factors such as soil flooding, waterlogging and gleying play an important part in plant development and the onset of disease symptoms through modifying the physiological responses of the plants (Green and Jane, 1983a, b). The end result is that dry spells readily place the plants under water stress and initiate the periods of mortality (Jane and Green, 1983a).

The spatial distribution of vegetation mortality appears to be related to climatic discontinuity produced by the prevalent fog and low cloud on the ranges and through effects on the hydrological regime (Jane and Green, 1983b). The persistent fog, through effects on soil and air temperatures and light regimes may also have a significant impact on plant growth under normal conditions.

Accordingly, climate studies in the Kaimai Ranges and analyses of data from local stations were initiated to clarify these points. The two main uses for the data were to provide environmental data for plant physiological studies and to identify major climatic events which could have disrupted plant growth and hence induced the reported incidents of plant mortality.

Data Sources and Collection

The location of the main meteorological stations around the Kaimai Ranges and periods of record are noted on Figure 1. Rainfall records at T e Aroha began in 1889 and temperature records began on the same site in 1907. Between 1896 and 1907 records are fragmentary but from 1908 they can be regarded as continuous. The continuity of the record was not significantly affected when the station was shifted a few metres in 1954 (Hessell, 1980). Site modification due to local clearance of forest and development of the town is regarded as insignificant compared with changes at urban meteorological stations such as Auckland and Christchurch (Tomlinson, 1976).

Devereux (1910) began rainfall records at Waihi in 1899. Temperature records began in 1907 but many discontinuities and shifts in station location limit the value of the data. From 1960 a number of climate stations were established on the fringes of the forest, at altitudes of up to 300 m (Fig. 1). These recently-established meteorological stations provide useful detail for establishing climatic patterns but are of limited value for determining long-term trends. In 1967 a meteorological station was established within the forest at the summit of Mt Te Aroha. For 1968, 1969 and 1971 the instruments were read daily but in other years instruments were only read when clerical staff were present, five days a week or less. As a result, Monday readings are the accumulated values for the previous three days and there may be breaks in the record extending over several weeks during holidays.

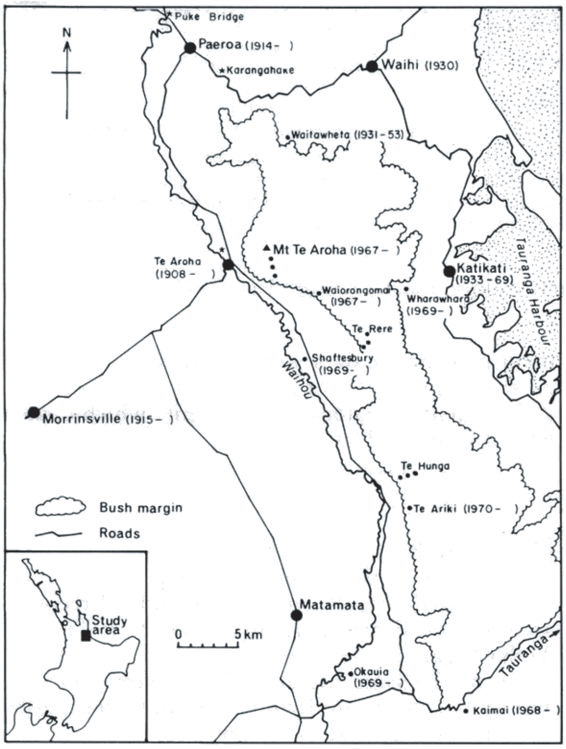


Figure 1: *Location of meteorological stations around the Kaimai Ranges; * indicates the approximate location of gauging stations. Dates are the establishment and closing dates for rainfall records.*

These inconsistencies place limitations on the use of the data, particularly the interpretation of daily records.

River gauging stations were established within the Waihou River system at Karangahake in 1956, at the mouth of the Waiorongomai hydrological representative basin in 1967, at T e Aroha in 1969, and Shaftesbury in 1969 (Fig. 1). The base flows from these stations provide a useful indication of the long term effects of rainfall trends on soil moisture storage levels.

Supplementary local data

Study ridges were selected at three localities; Te Aroha, Te Rere and Te Hunga, and instruments placed at a range of altitudes (Table 1). The Te Rere and Te Hunga ridges were traversed weekly from September 1980 to April 1981, and fortnightly for the next year. Te Aroha sites were visited monthly from October to April each year.

Table 1: *Location of recording stations on the three study ridges. Instruments used were: T, min-max thermometers; P, Piche evaporimeter; R, rain gauges;* S, *soil temperatures; M, soil moisture samples. Summit height at Te Hunga was 850m; Te Rere 750m (bush line 700m); and Te Aroha 950m.*

	Study Area		
Altitude	Te Hunga	T e Rere	Te Aroha
300	TSMPR	TSMR	TSM
400	TSM	TSM	
500	TSMP	TSMR	TSM
550		T	
600	TSMP	TSM	TSM
650	TSMP	TS	
700		TSM	TSM
750	TSMP	R	
800	TSM		TSM
850	TSMPR		
900			SM

As far as was practical, instruments were placed adjacent to one another and successive measurements were made in the same place.

In three study areas simple maximum-minimum thermometers were set out without screens although each thermometer was nailed to the south side of large trees at 1.5 m height in permanent deep shade. These were read at each visit. Continuous records were made, at selected thermometer stations in rotation, using screened thermocouple probes attached to Grant thermographs to calibrate and supplement data from the simple thermometers. Soil samples were collected with a Dutch clay auger from 20 cm and 50 cm depth at monthly intervals from September to April for gravimetric soil moisture determination. Soil temperature at 20 cm depth was recorded at each thermometer station at each visit. Rain gauges were placed in suitable open areas and read at each visit. Piche evaporimeters were placed at a number of thermometer stations on Te Hunga from November 1981 to April 1982 and read at irregular intervals.

Synoptic Situations

New Zealand weather is largely influenced by the easterly movement of frontal systems (De Lisle, 1967; Maunder, 1970). In summer the weather of the Kaimai Ranges is dominated by southeasterly movement of anticyclones from the north Tasman Sea (tropical influences) and in winter by the northeasterly movement of troughs to the south of New Zealand (Garnier, 1958). Much of the local rain comes from a westerly quarter (Maunder, 1973) with the result that the east of the ranges are in a minor rain shadow. Less common extreme events are also significant.

The study areas are affected by two storm patterns. Summer tropical cyclones, originating to the north of New Zealand, characteristically sweep southwards following the east coast of North Island to Coromandel Peninsula, just north of the study areas, and then veer eastward out through East Cape bringing intense storms to the ranges (Devereux, 1909; Barnett, 1938). Winter storm fronts arising from the southeasterly movement of low pressure troughs sweep northeastwards along the central mountain chain of North Island to Mt Ruapehu and then swing eastward to East Cape and only occasionally continue northward to give cold rains or snow to the Kaimai Ranges (Burrows and Greenland, 1979; De Lisle and Kerr, 1963). The relative importance of these patterns is determined by the location of stable sub-tropical blocking anticyclones situated to the north of the Bay of Plenty and can give long dry or wet periods (De Lisle and Kerr, 1963; Maunder, 1973; Tomlinson, 1980a). General changes in the circulation patterns appear to be related to the quasi-biennial oscillation (Tomlinson, 1976) and, to a lesser extent, to sunspot activity (Seelye, 1950; Salinger, 1979; Tomlinson, 1980b). The former produces short term changes and the latter long period oscillations in weather patterns (Burrows and Greenland, 1979; De Lisle, 1961; De Lisle and Kerr, 1963; Tomlinson, 1980b).

The effect of the winter and summer storm patterns is to produce different weather patterns in the Waikato River basin, to the west of the ranges, and in Bay of Plenty, to the east (De Lisle, 1967). For instance, coastal sea breezes may moderate the climate of Bay of Plenty at times when the barrier of the ranges leads to either calm warm or frosty conditions in Waikato. As a result, the region is usually considered as part of two weather districts (Maunder, 1970; Salinger, 1979; Tomlinson, 1981) and correlations between climatic parameters for T e Aroha and Waihi are poor (Table 2).

Fog and Low Cloud

Low cloud or fog along the crest of the Kaimai Ranges is very frequent (Martin, 1889; Clay ton

Table 2: *Correlations between climatic parameters portrayed as a diagonal matrix. Codes are in two parts: area and climate parameter. Areas are: T, TEA = Te Aroha; W, WAIHI = Waihi. Climate parameters are: TOT = total rainfall; JAN, FEB, MAR = monthly rainfalls; MAX = maximum temperature; SCR = screen frosts; GRN = ground frosts. Significance levels are 0.21 for 95% probability and 0.28 for 99% probability.*

	T TOT	W TOT	T DEC	T JAN	T FEB	T MAR	T MAX	T SCRF	W JAN	W DEC	W FEB	W MAR	W MAX	W SCR	W GRN
TEA TOT	1.00														
WAIHI TOT	−0.23	1.00													
TEA DEC	0.13	0.21	1.00												
TEA JAN	0.30	−0.01	0.01	1.00											
TEA FEB	−0.05	0.03	0.13	−0.03	1.00										
TEA MAR	−0.28	0.20	0.02	0.09	−0.02	1.00									
TEA MAX	−0.16	0.32	0.15	−0.15	−0.31	0.10	1.00								
TEA SCRF	0.07	−0.23	0.07	0.42	0.08	−0.03	−0.08	1.00							
WAIHI JAN	0.07	−0.22	−0.00	−0.02	0.03	0.23	−0.19	0.16	1.00						
WAIHI DEC	0.32	−0.16	0.14	0.01	0.15	−0.15	−0.08	−0.11	0.04	1.00					
WAIHI FEB	0.02	0.32	0.18	0.18	0.07	0.10	0.05	−0.02	0.03	−0.11	1.00				
WAIHI MAR	0.12	−0.04	0.31	−0.06	0.23	−0.05	0.01	0.08	−0.01	0.12	−0.11	1.00			
WAIHI MAX	−0.27	0.22	0.03	−0.04	−0.08	0.08	0.23	−0.17	−0.21	−0.27	0.11	−0.10	1.00		
WAIHI SCR	0.05	−0.17	−0.10	−0.19	−0.08	−0.25	0.06	−0.11	−0.04	−0.08	−0.12	−0.03	0.10	1.00	
WAIHI GRN	0.01	−0.13	−0.02	0.12	−0.01	0.06	−0.10	0.26	0.10	0.08	0.14	−0.12	−0.06	0.06	1.00
	T TOT	W TOT	T DEC	T JAN	T FEB	T MAR	T MAX	T SCRF	W JAN	W DEC	W FEB	W MAR	W MAX	W SCR	W GRN

Table 3: *Percentage of days clear,* or *with cloud cover on the summit in each of the three study areas. Based on 2-hourly observations from September 1981 to April 1982.*

Te Hunga	Full day	Half day	4 hours	2 hours	Clear day
Te Hunga	28.6	57.6	73.3	79.0	21.0
T e Rere	26.6	55.3	65.3	73.3	26.7
Te Aroha	25.3	51.0	58.6	70.0	30.0

Greene, 1976). Records kept at Mt Te Arohoa during 1969-72 indicate an average of 200 fog days per year at 9 am. Observations made during the wet summer, 1980-1981, showed that fog commonly persisted for much of the day (Table 3). Average figures indicate that the cloud base was at a differing altitude but at about 150 m below the summit in each of the study areas (Jane and Green, 1983b). There was considerable variation in the cloud base with season, weather conditions, time of the day, and the mechanism of fog formation.

Mechanisms of fog formation

Fog formation on the Kaimai Ranges normally occurs through thermal inversions or air pressure anomalies similar to those described by Coulter (1967). The exact mechanism depends on weather conditions, and the fog duration is of ecological significance:

1. air ponding under calm conditions can produce lowland fogs in winter: At Te Aroha town, over the period 1926-1978, there was an average of 7.7 fog days per month during winter (June-August), and 2.1, 1.6 and 7.2 days per month during spring, summer and autumn respectively. Such fog rarely extends above 300 m altitude although on several frosty occasions in winter the Waikato basin filled to the height of the lowest points on the range (550 m). These fogs rise slowly and, if strong thermal inversions are present, may leave the crest of the range in calm, clear, warm conditions possibly placing plants there under extreme water stress (Green and Jane, 1983b).

   High soil moisture content, producing high local humidities, may also favour this form of fog formation particularly in calm conditions following rain but the fog is usually transient. During the early part of the dry 1981/82 summer, fog was often present in the lowlands in the morning, rose to arrive at the range crest in the late morning and clear about three hours later thus blocking the full heat of the midday sun. After six weeks with little rain, in January 1981, the fog became restricted to only a few hours in the morning or was absent altogether as lowland soils dried out.
2. Trapped adiabatic air flows, resulting from normal air flows over mountains, causing eddy currents in the lee of the ranges (Tricker, 1970), produce a uniform cloud base particularly after rain. These fogs are of short duration and have little ecological impact.
3. Pressure reductions arising from the flow of high speed winds over the mountains produce capping fogs of variable height usually accompanied by strong winds (Grace, 1977). The barrier of the ranges is known to modify the dominant westerly surface air tides (Trenberth, 1977a) and fog in these conditions appears to be related to incoming low pressure or frontal systems when rain is imminent. Cloud base levels are highest on Mt Te Aroha, often capping only the summit, and lowest at T e Rere. When this form of fog occurs the cloud level rises rapidly to cap only the top 100 m of the range by mid-morning and may clear briefly in mid-afternoon. The high winds that frequently accompany the fog are a well-known local phenomenon and were observed by the authors to cause down-draughting easterly winds that reached gale force in a standing wave 0.5-3 km from the western foot of the ranges. Temperatures are often low and since the fog may persist for several days conditions may be very unfavourable for plant growth.
4. Orographic cloud, directly associated with frontal rain, that results from the normal rain cloud conditions. At times of heavy rain the cloud base is as low as 300 m altitude along the whole western side of the range but with light rain the cloud base may form a line at 800 m. These fogs are of short duration and little adverse ecological impact.

Precipitation

Mean annual rainfall increases eastward from 1500 mm at Te Aroha to 2000 mm at Waihi and southwards from 1500 mm at Te Aroha to 2500 mm at Shaftesbury at the base of the Te Rere study area (Coulter and Hessell, 1980). It also increases with altitude from 1500 mm at Te

Aroha town to 2000 mm at the summit of Mt T e Aroha and field observations suggest an increase of 60% at other points to give about 3000 mm per annum at Te Rere and Te Hunga summits.

During periods in which tropical influences predominate the effects of the quasi-biennial oscillation may be strengthened and very high rainfalls occurring in one year may be followed by a year of very low summer rainfall (Burrows and Greenland, 1979; Maunder, 1969; Seelye, 1950; Tomlinson, 1976, 1980). Summer rainfall for Waihi (Fig. 2) shows this strongly oscillating pattern. Similar fluctuations are absent at Te Aroha possibly because that side of the ranges receives more rain from predominant stable westerly conditions (De Lisle, 1967). Rainfall records from Te Aroha show a long term trend of increasing rainfall and decreasing annual variability (Fig. 3), similar to that generally noted for northern regions of New Zealand (Trenberth, 1977b; Vines and Tomlinson, 1980) and resulting from changes in circulation pattern about 1954 as noted by Trenberth (1976). These changes appear to have resulted in a lower occurrence of tropical storms and a predominence of less severe storms of southern origins in more recent years (Burrows and Greenland, 1979; Trenberth, 1976).

Snowfalls occur about every second year but

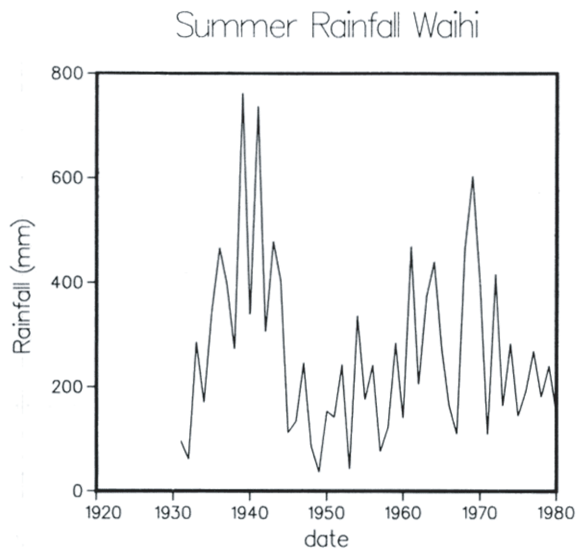


Figure 2: *Trends in summer (January and February) rainfall at Waihi: A strong oscillating quasi-biennual trend suggesting influences of summer storms and a long period oscillation peaking in 1939 and 1969.*

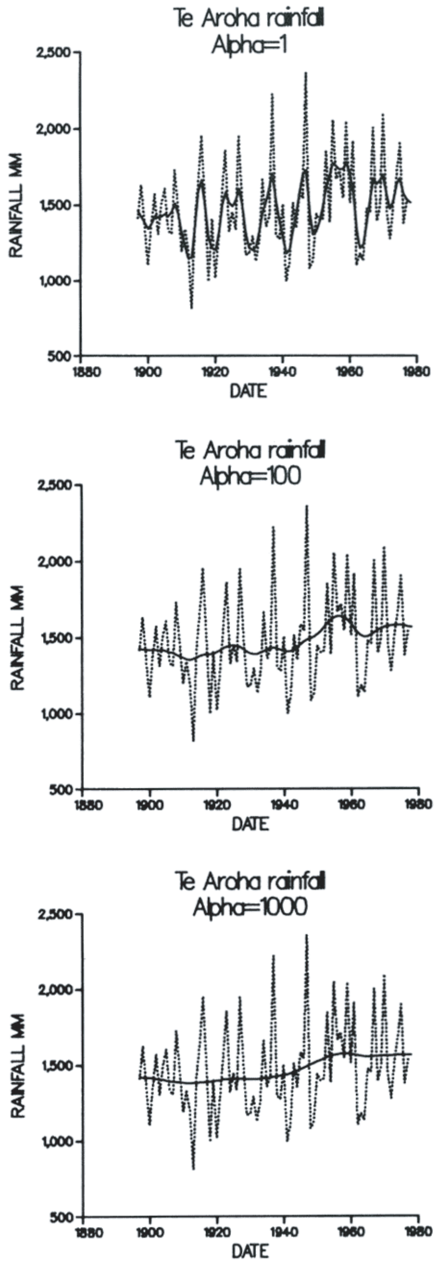


Figure 3: *Trends in Te Aroha total rainfall shown by smoothing splines (Schlicht, 1981), with alpha* = 1, *alpha = 100 and alpha = 1000. Trends indicate a general increase in rainfall to about 1960 and a subsequent decline. The period of higher average rainfall (1950-60) is characterised by lower variability.*

melt rapidly and contribute little to total precipitation. The heaviest known falls occurred in 1918 and 1980 and extended down to Waihi and Te Aroha. These falls lay for several days at upper altitudes.

Fog and accompanying light drizzle probably add considerably to annual precipitation at altitudes above 500 m. Overseas studies have indicated that fog in forested areas can contribute over 300 mm to annual precipitation (Kerfoot, 1967; Chaney, 1981) and examination of the rainfall records for days on which the fog persisted at Te Aroha summit indicate up to 2 mm per day are trapped in a normal rain gauge. Evapotranspiration is also affected by fog occurrence. Piche evaporimeters placed at Te Hunga show little difference in evaporation with altitude over periods of wet weather but a marked reduction in evaporation is apparent above 650 m during extended periods of foggy weather (Jane and Green, 1984). Similarly soil moisture contents show a distinctive discontinuity above the cloud base (Green and Jane, 1983a) reflecting the decreased evapotranspiration and increased precipitation resulting from the persistent fog.

Drought

Drought intensity can be measured in a number of ways. A commonly used measure of drought intensity is the number of days without rain or length of period with less than 5 mm precipitation (Coulter, 1966; Kidson, 1930; Maunder, 1973). Waihi recorded 38 days without rain in 1908 and 31 days in 1928 (Table 4) and the longest period without rain at Te Aroha was 27 days in 1957 (Maunder, 1973). None of these periods were regarded as significant or severe droughts in the Kaimai Ranges (Bondy, 1950). There were a number of other periods of below normal rainfall throughout New Zealand but their effects appear to have been localised. Finkelstein (1971) compared the severity of the 1969/70 drought with that of 1908 and noted the localised character of these and the 1928 and 1946 droughts. Droughts reported for Waikato or Bay of Plenty, in decreasing order of severity, occurred in 1913/14, 1918/9, 1945/46, 1953/4, 1908,1927/8,1969/70, and 1957 (Bondy, 1950; Kidson, 1930; Finkelstein, 1971; Coulter, 1969).

'Days without rain' may not be a reliable indicator of drought severity because the dry periods may not occur at times of high evaporative losses or high levels of soil water depletion. Values of tank evaporation for Ruakura (in central Waikato) are probably applicable to the local lowland area, and indicate

Table 4: *Major droughts and dry years at Te Aroha and Waihi. The figures are the recorded rainfall for January and February combined, and the total recorded for the year*. (1. December 1927 was also dry with 26.9mm; 2. Drought extended 38 days into March (30.5mm))

	Rainfall (mm)			
	Te Aroha		Waihi	
Drought year	January / February	Total	January/February	Total
1889	no data	1,413	no data	no data
1890	81.5	1,628	no data	no data
1900	64.0	not avail.	90.7	2,418
1908	2.0	2,248	45.7	2,248
1914	66.3	812	no data	no data
1915	92.7	1,428	no data	no data
1919	69.3	917	no data	no data
1925	89.9	1,320	no data	no data
1928'	56.9	1,956	96.3	3,234
1939'	37.1	1,300	126.2	2,184
1946	29.0	1,582	27.3	2,358
1950	46.5	1,128	43.2	1,793
1954	39.6	1,844	76.2	2,031
1970	63.8	1,432	95.0	2,083
1982	235.7	1,089		
Normals	192.7	1,498	246.9	2,163

that net losses are about 1100 mm per annum (Maunder, 1973). Rainfall fell below tank evaporation in only four years, 1914, 1919, 1942 and 1982, when rainfalls were 891 mm, 994 mm, 993 mm, and 1089 mm respectively. The period 1913-15, as well as containing the summer drought of 1913/14, had less than 50% of the normal rainfall. Then 1917, a wet year, was followed by 1919 again containing low rainfalls and summer drought. Between 1940 and 1950 there were several years of low rainfall and in a four-month period from December 1945 only 82 mm rain was recorded. This resulted in severe drought conditions on local farms *(Te Aroha News* 2/3/46). Bondy (1950) and Maunder (1973) do not mention the area specifically but the Kaimai Ranges could be included in the parts of Auckland province affected by the 1939 and 1946 droughts. Between 1928 and 1934 there were several dry years but rainfall average for the period was near normal and as a result these years were possibly of minor ecological significance.

Lowland information is difficult to apply to the upland forests because of limited data, the impact of fog on evaporative losses, lower temperatures, higher rainfall and greater wind runs. However, the same extreme years are likely to have significant effects on plant growth. Some indication of the importance of these dry years can be seen in the marked decline in soil moisture content noted within the Kaimai Ranges during 1980-82, a period of very low rainfall and decline in the extent of waterlogging between 1980 and 1983 in the absence of a recognised drought (Jane and Green, 1983b). The dry year obviously had a severe impact on aquifer storage within the ranges which was sustained over more than the one year.

Some assessment of the significance of these long term deficits on soil water storage levels can be obtained from examining the flow data for the Waihou River system. There is a linear relationship between summer rainfall and minimum flows in successive years (Fig. 4) but at two points, 1969 and 1976, it is displaced to give a rhomboid shape (for the years 1969-75 correlations and regression coefficients are: r=0.75, a=237, b=0.21 and for other years r = 0.86, a = 153, b = 0.35) implying that the displacement may result from changes in aquifer storage. One interpretation of the diagram is that winter rainfall following the 1969/70 drought was insufficient to recharge the aquifer, a

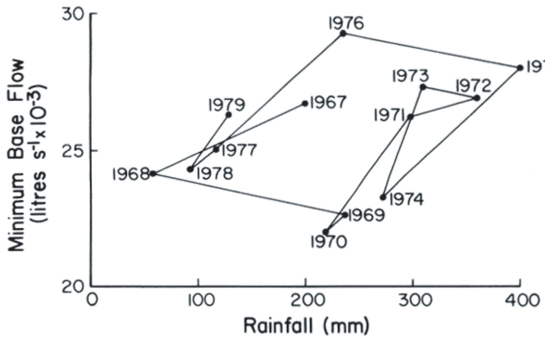


Figure 4: *Trends in river summer base flow at Te Aroha Bridge in relation to summer rainfall (January, February and March) at Te Aroha. Discontinuities in the relationship follow the dry 1969/70 summer and the wet* 1975 *and* 1976 *winter*.

situation which persisted until 1975 when two wet years may have resulted in full recharge. Obviously, a mild drought occurring when the aquifers were depleted could have a more severe impact on river flows than a longer drought occurring when soil recharge levels were high.

No similar data are available for the earlier droughts but it is evident that those of 1914, 1919 and 1946 occurring during or at the end of a series of dry years will be more damaging to plant growth than others in periods of normal rainfall such as 1928 and 1969/70.

Lowland Temperatures

Mean annual temperature at Te Aroha is 14.5 ºC but on the coastal side of the range at Waihi it is 13.7 ºC. At both stations the diurnal range is approximately 9 ºC, typical of most coastal areas of New Zealand (Coulter, 1973; Cox, 1968). There are no general trends in the recorded mean temperatures but maximum and minimum temperatures are now less. extreme (Hessell, 1980). Such changes could have been brought about as a consequence of the extensive forest clearance and swamp drainage in the area, in a reverse manner to that suggested by Hessell (1980) for urban areas; however, it appears more likely to be linked with changes in annual rainfall (Goulter and Hurnard,.1980).

Ground frosts occur principally between April and September although there is a large year to year variability (Fig. 5). Ground frosts at Te Aroha have declined from over 30 per annum to only 10 per annum over the last 70 years with a similar decline since records began at Waihi, in 1930 (Fig. 5). Unseasonal frosts are rare but summer frosts were recorded in 1913 and 1914. The cold winters at Te Aroha, with monthly average temperatures below 2 ºC, occurred in 1914, 1918, 1942 and 1945. The period 1914 to 1919 was marked by particularly low winter temperatures and the periods 1942-45 and 1969-72 contained a series of cold winters. High maximum temperatures often occurred in the same years. It is striking that these years coincide with the years of extended rainfall deficit and suggests that clear skies were then more prevalent. On the other hand, the significant correlation between maximum temperatures and total rainfall reflects a more general trend for warm years at Te Aroha to occur in years dominated by tropical influences in which one or two severe storms occurred (Table 2).

Upland Temperatures

Between 1967 and 1977 Mt Te Aroha station recorded extreme maximum daily temperatures of up to 17.6 ºC and similar values were found at the uppermost study sites (Fig. 6). Lack of continuous recent data at Mt T e Aroha does not permit direct comparison. Diurnal temperature range at the summit is lower than at Te Aroha town because of cloud influences. This was particularly well demonstrated by a thermograph record at 600 m altitude on T e Hunga during one extended fog period of 17 days. A mean diurnal variation of only 2.5 ºC was recorded and values for individual days were as low as 1.25 ºC. The temperature range over the 17 days was 6.0 ºC. In this period temperatures were governed by incoming frontal systems rather than diurnal variations in incident radiation (Fig. 7). Brief sunshine periods of less than half an hour record on the 6th, 17th and 21st days resulted in transient temperature peaks and an arithmetic mean temperature which lay below the median of daily values. The transient values indicated the extent of depression of temperatures below the values expected in the absence of fog (Fig. 7). On occasion, during a series of physiological experiments, clearance of fog from Te Hunga was observed to result in a rise in temperature from 11 ºC to 19º C and a decline in relative humidity from 89% to 50% in less than an hour. Winter temperatures at Mt Te Aroha averaged 4.2 ºC but screen frosts were not common. In 1968 there were just over three times as many frosts as at the

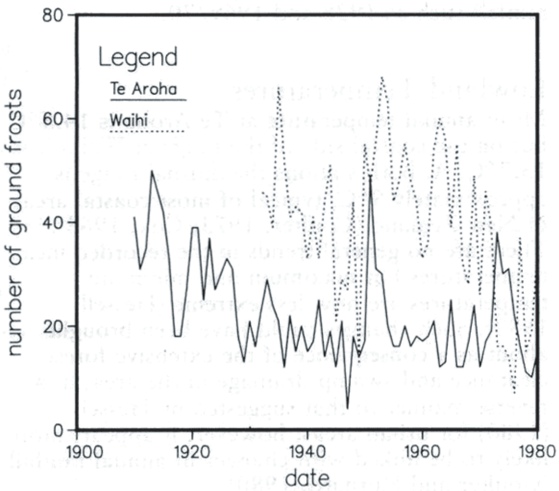


Figure 5: *Annual ground frost numbers at Te Aroha and Waihi. A marked long-term decline in number is evident although numbers are high at Te Aroha in the dry 1943-1946 and 1970-1972 periods.*

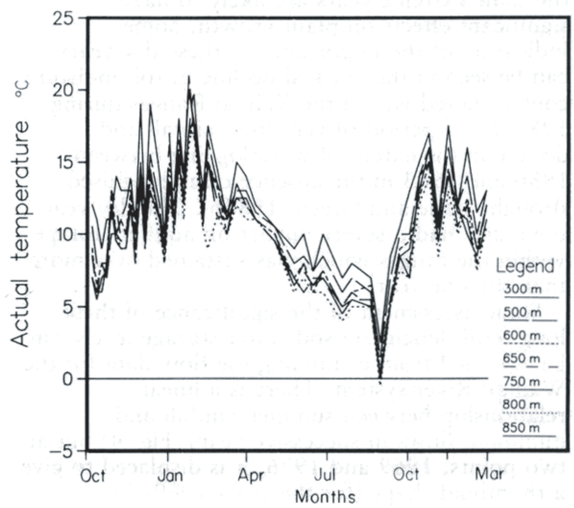


Figure 6: *Seasonal variation in actual air temperatures at Te Hunga measured between* 8 *am and* 10 *am, ascending by altitude. Almost identical values were obtained at Te Rere. Records began in October 1980 and terminated in March 1982. Observations were made at weekly intervals from October 1980 to April 1981 and fortnightly thereafter.*

town (37 cf. 11) but in wet years, such as 1968, numbers were similar between base and summit of the mountain.

Lapse Rates

A uniform lapse rate is often assumed for estimating temperatures at altitudes different from a recording station. In the study areas this assumption was not valid because the lapse rate varied with season, altitude and presence of fog. On Mt Te Aroha lapse rate of the mean daily maximum temperature between the town and summit is uniform through the season whereas that for mean daily minimum temperatures is lowest in winter, down to 0.4 ºC/100 m (Fig. 8) perhaps resulting from more intense air ponding and still air at lower altitudes as opposed to winds at the range crest. Similar values and seasonal variability were noted by Coulter (1967) for the Black Birch Range.

At Te Hunga lapse rates show a small depression just below the fog zone, at between 500 m and 700 m from 1 ºC/100 m to less than 0.3ºC/100 m altitude and there is an accompanying depression in the diurnal range (Fig. 8). Temperatures below 500 m often differ considerably from those at higher altitudes where they are frequently uniform. The difference is greater in winter from the 35th to 60th visits (June to September, Fig. 9). On a number of occasions a thermal inversion was present at 600 m resulting in temperatures of 1-2 ºC higher on the summit plateau. These could be

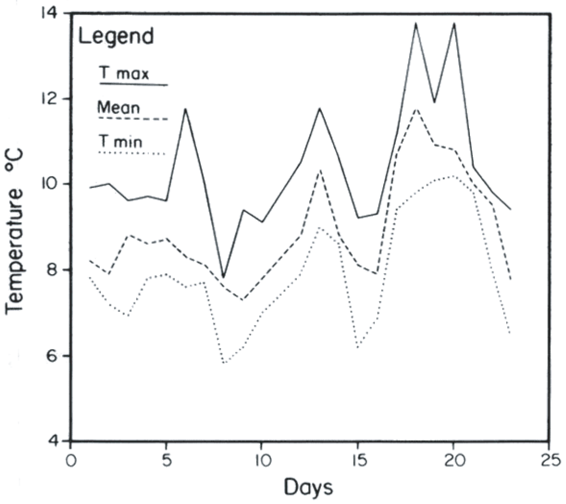
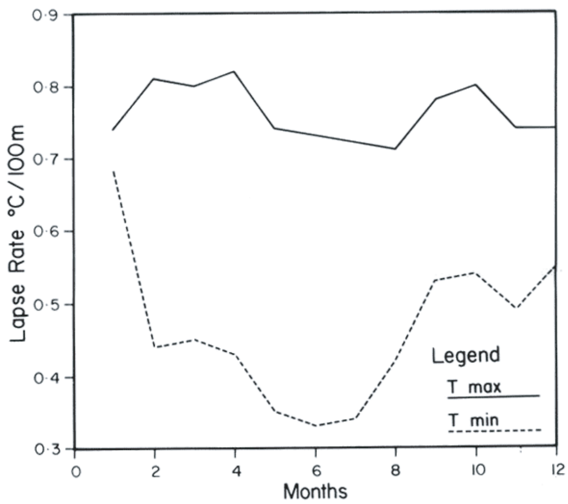


Figure 7: *Daily mean temperatures calculated from half hourly temperature records on a Grant Thermograph made at 600 m on Te Hunga during a period of cloudy weather from 15th November to 16th December 1980.*



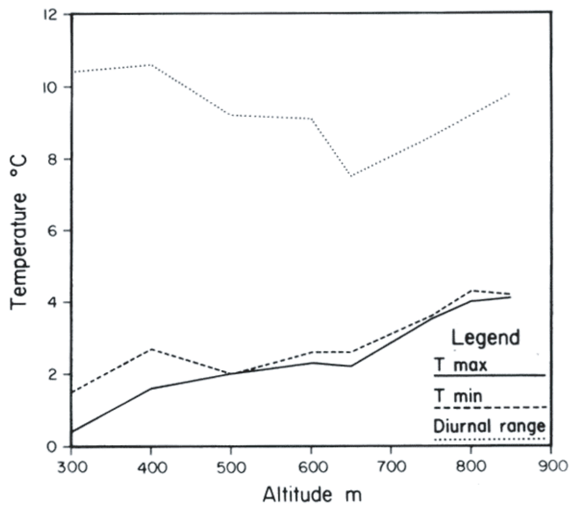


Figure 8: *Lapse rates. (a) Seasonal varition in lapse rates in minimum and maximum temperatures between Te Aroha Town (30 m) and the Mountain summit (950 m) for 1967-1977. (b) Air temperatures by altitude at Te Hunga calculated by subtracting temperatures at 500 m from the respective temperatures at other altitudes and adding* 2. *This shows the small difference in temperature at middle altitudes about the cloud base and the depressed diurnal range.*

responsible for the observed zonation of the vegetation (Jane and Green, 1984).

Lapse rates for mountain areas often differ considerably from free air values above a recording station. Garnier (1958) gives values ranging from 0.27 to 0.80 ºC/100 m altitude with values of about 0.6ºC/l00 m generally applying to upland mountain area above 700 m. Values for specific studies range 0.4-0.6ºC/100 m (Coulter, 1967) and many studies of mountain areas have shown a similar thermal belt or zone of low lapse rates extending over several hundred metres altitude (Geiger, 1965; Hayes, 1941; Morris, 1965). Examination of lapse rates for several paired stations in mountain areas suggests that thermal belts are of common occurrence in New Zealand and related to areas of high fog incidence. Sites such as Wharakite peak and Te Aroha with high fog frequencies have low lapse rates and a small dirunal temperature range while stations such as Egmont Mountain House, with fewer fog days, have a higher lapse rate and diurnal temperature range close to that at adjacent lowland stations (Table 5). In drier areas such as the Old Man Range a steep lapse rate has been recorded (Mark, 1965). Mean temperatures and diurnal range at Mt Egmont, a fog free area, is comparable to Invercargill and other coastal stations in the south of South Island, but because of fog and inhomogeneity in lapse rates, comparisons for foggy areas such as between T e Aroha town and summit or Ohakea/Wharakite can be misleading.

Growing Season

The growing season at Te Aroha town extends from September to May and there are 1727 degree days above 10 ºC (New Zealand Meteorological Service, 1978). For Te Aroha summit insufficient temperature data and incomplete records do not permit reliable calculation of degree day totals but the observed growing season extends from December to March (Jane, 1983). Taking Invercargill, a station with similar mean monthly temperatures and diurnal temperature range as a guide, there are only 514 degree days at the summit. Similar values are found in dry mountain areas such as Mt St John (438 degree-days) or the Heritage (507 degree-days). These figures are liable to be reduced considerably by the effects of fog, as indicated by the Chateau which has only 250 degree-days. Data for the wet 1968/69 summer suggests that in this summer there were less than 120 degree-

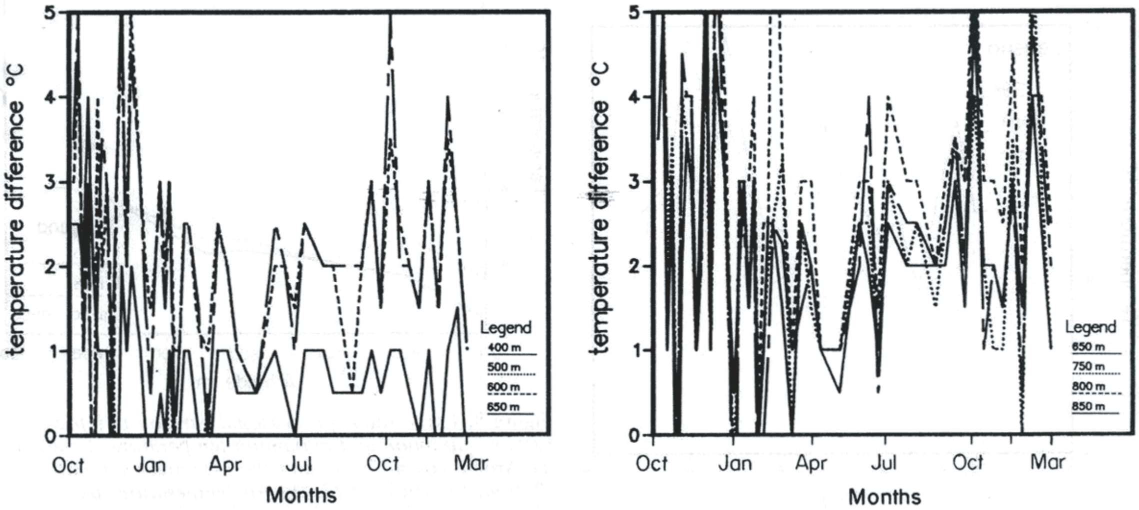


Figure 9: *Seasonal* air *temperatures differences at Te Hunga calculated by subtracting temperatures at 300 m from the respective temperatures at higher altitudes. Left hand side: below 650 m Right hand side: above 650 m. Temperatures above 500 m were usually closely similar whilst 400 m and 300 m temperatures were one and two degrees lower respectively.*

Table 5: *Mean temperature, mean daily range, and lapse rates for selected pairs of adjacent uplands and lowlands meteorological stations in coastal situations and data for two other comparable meteorological stations.*

		Temperature			
Station	Altitude (m)	Mean daily ºC	Mean daily range ºC	Lapse rate ºC/100m	Days of fog
Te Aroha	30	15.4	8.7	0.60	20
Mt. Te Aroha	950	9.3	5.3		200
Ohakea	48	13.2	8.7	0.66	
Wharakite	914	7.3	5.9		173
New Plymouth	97	13.6	9.3	1.0	
Mt. Egmont Mountain house	846	8.9	8.7		51
Invercargill	20	9.6	9.4		
Milford	0	10.3	8.0		

days. Data from O'Rourke and Terjung (1981) indicates that fog reduces net photosynthesis by 75% without taking into account temperature effects. Hence the fog zone is liable to be a very difficult climate for plant growth.

Soil Temperatures
Soil temperatures at 850 m altitude ranged between 4.8 ºC and 14.6 ºC and followed a similar annual pattern at 300 m and intermediate altitudes (Fig. 10). Summer temperatures rose abruptly in December during two weeks of fine weather and fell similarly in April with the onset of frosts. Apart from very dry periods, temperature lapse rate with altitude was very uniform and at each visit soil temperatures at 850 m could usually be predicted within 0.2 ºC from one measurement at 300 m by adding 3 ºC (Fig. 10). This contrasts markedly with the low lapse rate at mid-altitudes noted in air temperatures.

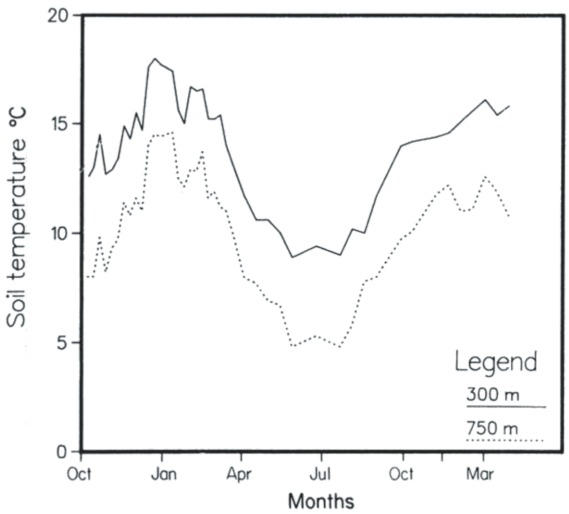


Figure 10: *Seasonal pattern of soil temperatures at 300 m and 850 m on Te Hunga.* A *very consistent lapse rate was maintained.*

Discussion

Extreme events affecting plant growth in the Kaimai Ranges are likely to be drought, snowfalls, frost and wind damage from tropical cyclones. Of these frost and snow do not appear to be any more significant in the recent past and there is little direct field evidence of damage from severe storms (Jane and Green, 1983b). However there appears to be good evidence for drought damage and an influence of fog in triggering the mortality .

Droughts conditions
The periodic dominance of blocking high pressure systems to the north, related to long term shifts in the circulation patterns, appear to result in periods of highly variable weather conditions in which droughts, severe storms and temperature extremes are likely (Tomlinson, 1980a). The most severe droughts in the Kaimai Ranges appear to occur in periods of high rainfall variability suggesting some intensification of the quasi-biennial oscillation (Tomlinson, 1976). These may be periods when the region is most strongly influenced by tropical storms. High maximum temperatures are related to warm tropical

conditions bringing rain to Te Aroha from intense cyclonic storms in January or February but the winters may be dry. This is reflected in the significant positive correlation between January rainfall and frost days at Te Aroha (Table 2). In other years the storms may be less frequent, or absent, and severe droughts may occur. This appears to have happened in the period 1913-20. The dry period appears to have terminated with a change in circulation pattern about 1918, as noted by Burrows and Greenland (1979).

Reports written at the time of the 1914-20 droughts were not readily able to assess severity since the prior climatic records were short (Bates, 1915, De Lisle, 1967) and population density was light especially in the Waikato and Hauraki Plains (Tye, 1974; Vennel, Fitzgerald and Gordon, 1951). In retrospect, these were the most severe ever recorded in the area. Kidson (1930) stated "for the Auckland Province, 1914 was undoubtedly the driest year hitherto recorded" and indicated that, in 1919, deficits of up to 30 inches (760 mm) may have been present in the Kaimai Ranges. The 1914 drought occurred in the middle of a series of dry years a situation repeated in 1919 suggesting tht the impact of these droughts must have been severe. In contrast, the 1928 drought occurred in a period of above normal rainfall and the 1939 and 1946 droughts at the beginning and end, respectively, of the same series of dry years. Of the last three droughts only the one in 1946 was significant for agricultural crops. The 1969/70 drought occurred in a period of near normal rainfall and provoked no local comment. Neither was 1972 regarded as a severe drought.

Other factors also permit an assessment of the nature of the droughts. In 1908 day temperatures over 27 °C, and night temperatures of 14 °C for January and 12 °C for February indicate humid weather, described as sultry *(Te Aroha News, Bay of Plenty Times),* with frequent cloud. In contrast, the summer of 1913-14 was characterised by both very hot days, over 27 °C, and very cool nights. The maxima and minima for January are the most extreme on record and those for December 1913 and February 1914 are also unusually extreme. This extreme weather suggests exceptionally dry soils and clear skies with little fog. This situation appears to have continued for much of the year since the winter is the coldest on record. Extreme conditions continued for the next five years with low rainfall and cold winters in 1915, 1916 and 1918. Similar conditions appeared in 1928 but did not persist.

From the various viewpoints expounded above it should be clear that the period 1913-1920 contained the most severe droughts recorded in the region. A similar but far less severe period occurred between 1939 and 1948 and other droughts in 1928/30, 1934/5, 1956/7, and 1969/70, although severe by some measures, were relatively unimportant. These dates correspond well with suggested dates for recent mortality episodes within the ranges (Jane and Green, 1983b).

Significance of fog

Fog has wide-ranging effects on climate and consequently on plant growth. The fog types of longest duration and most ecological significance are related to prolonged periods of wetter weather resulting in high soil moisture contents or frontal systems associated with rain. As a result a very considerable reduction in fog frequencies occurs during drought periods.

Fog modifies the hydrological regimes by increasing precipitation and reducing evapotranspiration, leading to long-term soil flooding in the Kaimai Ranges. This results in a severely restricted rooting zone for trees and shrubs and in some of the species to adaptation to permanent waterlogging (Jane, 1983). Fog also lowers mean temperatures, delaying the spring flush (Jane, 1983) and lowering potential carbon fixation. Reduced light exacerbates the growth deficiencies and not only reduces the ability of plants to respond to stresses but also results in a number of shade tolerant shrubs assuming dominance (Jane, 1983).

On the other hand, in the prolonged absence of fog, the shade-tolerant species are placed under severe stress (Green and Jane, 1983a) and many other plants with restricted root systems have a limited ability to respond to water stress (Green and Jane, 1983b).

Summary of climatic conditions within the ranges

The lowland areas can be very adequately described from the current meteorological data base as having a warm temperate climate, usually of adequate rainfall, but agricultural droughts may occur every 10-15 years. The climate of upland areas, in which much of the current ecological investigations were carried out, cannot be as well described. Extrapolation of lowland values suffer from many difficulties. Rainfall is clearly much higher and evapotranspiration can be considerably lower due to fog and lower temperatures. The climatic gradient is not even and there appears to be a sharp change at the cloud base at which there is a lowering of the temperature gradient and an increase in soil moisture to waterlogging levels (Jane and Green, 1983b). There is considerable difficulty in extrapolating lowland drought severity to the upland areas and the higher rainfall suggests that drought impact would be slight. However, reduced fog incidence during drought may well accentuate soil water deficits and there is a strong probability that plants in the cloud forests may be slow growing and unusually sensitive to small climatic perturbations (Jane and Green, 1983b). The high cloud frequencies markedly reduce light levels and consequently photosynthesis. Cooler temperatures will affect growth and frequent leaf werting may impede stomatal gas exchange. It is also known that soil waterlogging, by restricting root systems to the upper soil horizons, places the plants at a higher risk during drought (Jane and Green, 1983c; Kozlowski, 1982).

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