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STUDIES IN CATCHMENT HYDROLOGY IN THE AUSTRALIAN ALPS

I. TRENDS IN SOILS AND VEGETATION

By A. B. Costin,* D. J. Wimbush,* D. Kerr,* and L. W. Gay†

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Summary

It is now accepted that the stability of the high mountain soils and vegetation of the Australian mainland has been impaired by the various forms of land use which have been carried out in the past (grazing, and in places engineering, tourist, and forestry activities). The present trend of soil and vegetation development, however, whether up, down, or stable, is not so clear. This problem of soil and vegetation *trend* as distinct from *condition* is examined by using a variety of methods, some interpretative and some experimental, with respect to each of the land units wet sclerophyll forest, subalpine woodland, sod tussock grassland, tall alpine herbfields, short alpine herbfield, fjaeldmark, heaths, bogs, and fen. The situation is a complex one in which certain units or parts of them are tending to stabilize whilst others are continuing to get worse; the nature of the trend in each case depends on the severity of the natural environment, the nature of land use both past and present, and the extent to which a particular unit is affected by changes induced in other units with which it is associated hydrologically.

Examination of typical sequences of undamaged and damaged land units in the alpine, subalpine, and upper montane tracts emphasizes (i) the mutual dependence of one unit on another, (ii) the existence of the trend towards more rapid run-off of precipitation and depletion of available soil moisture, with (iii) accelerated soil movement downslope towards the smaller and eventually the larger streams. The direction of most of these changes can be altered by changes in land use alone, but others, particularly the lateral and vertical erosion of streams with its subsidiary effects, are largely irreversible unless artificial soil conservation measures are also employed.

The nature of these soil and vegetation trends has a bearing on several general principles in ecology and soil conservation. In the first place, soil and vegetation trends, whilst usually proceeding in the same direction, may exhibit non-parallelism both between different areas and on one and the same area. Secondly, trends in a particular land unit may be reversed by the impact of trends in another with which it is associated hydrologically. Thirdly, whilst downgrade trends can usually be reversed either immediately or after some lag following removal of the disturbing agent, severely or badly damaged environments sometimes fail to respond and in these cases the downgrade trends, once started, may be irreversible. In some instances disharmony between existing climaxes and the macroclimate is inferred.

The application of these principles can be used to evaluate the significance of various kinds of catchment damage, and in particular to recognize often small but critically situated "flood-source areas" in which the direct and indirect effects of damage may be more serious than widespread slight to moderate damage spread

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over the catchment as a whole. It is therefore necessary in economically successful catchment management programmes to distinguish between those areas which can be expected to recover by changes in land use alone and those for which additional conservation measures are also needed.

I. Introduction

It has been well established that the high mountain soils and vegetation of the Australian mainland* are in a damaged condition (e.g. Australian Academy of Science 1957). However, it is being realized increasingly by workers in range management problems that the present *condition* of the soils and vegetation may be less important in decisions affecting land use than the direction of change or trend (cf. Ellison, Croft, and Bailey 1951).

In this paper the question of trend as distinct from condition is examined in the light of experience gained throughout the Australian Alps during the last 12 years. Five main methods of study are employed:

(i) Repeated observations or measurements on permanent quadrats and enclosures;

(ii) observed changes at or around fixed points;

(iii) deduced changes from the present condition of the soils and vegetation;

(iv) growth ring and fire-scar interpretation;

(v) evaluation of experience of local residents.

These methods are combined in an examination of trends in each of the main types of country, at first individually, then in combination to give a picture of high mountain conditions as a whole. In the first instance, a certain amount of published information is re-presented (cf. Costin 1954, 1957*a*, 1957*b*), but it is much supplemented by fresh quantitative and historical data. The resultant picture, now clearer and more complete than before, provides the basis in terms of which the hydrological aspects of this and subsequent papers in this series are considered.

II. Trends in Individual Land Units†

(*a*) *Wet Sclerophyll Forest:* Eucalyptus delegatensis–E. dalrympleana *Alliance*

Although not truly high mountain in character (i.e. alpine or subalpine), the wet sclerophyll forests just below the winter snow-line are also included in this study, as they are subject to much the same land use practices as the subalpine and alpine communities proper which they adjoin.

In their natural condition, these forests show a tall, interlacing stratum of usually uneven-aged trees below which a discontinuous layer of smaller trees may or may not be present, a fairly sparse shrub stratum, and a dense stratum of grasses and other herbs. Such natural stands, although now in the minority, are still preserved in several places including the Mt. Stirling and Mt. Pinnibar areas of Victoria, the Pilot and Mt. Clear areas of New South Wales, and parts of the Cotter Catchment in the Australian Capital Territory. That fires were less frequent before white occupation is shown by observations on fire-scar frequencies on tree trunks as far afield as the Baw Baw Plateau, the Bogong High Plains, and the Snowy Mountains. As the practice of burning became more common, owing to its effects in producing temporarily more palatable feed, the character of the natural forest vegetation altered. Locally severe fires which developed into crown fires frequently killed the dominants, especially the fire-sensitive species *Eucalyptus delegatensis* Baker. In these areas dense regeneration usually followed rapidly with the development of fairly close-spaced even-aged stands instead of the more open, uneven-aged natural ones.

* For locality details, see Appendix I.

† The condition of the various land units is described in other publications (Costin 1954, 1957*a*).

More usually, however, the main effects of the fire were largely confined to the lower strata. Under the mildest conditions when only the shrubs and tops of the grasses were burnt, the open character of the forest was accentuated for some time owing to the relative elimination of shrubs. In general, however, the fires were more severe and exposed part of the underlying soil. This condition of soil exposure facilitates the rapid development of many native shrubs of the forest as well as the dominant trees themselves, so that within a few years after the fire dense pyric scrub begins to take the place of the original herbaceous sward. The actual constituents of the shrub community also changed towards dominance by certain species possessing hard, fire-resistant seeds or the capacity to regenerate from underground stems or rootstocks, such as *Acacia dealbata* Link., *A. penninervis* Sieb. ex DC., *Bossiaea foliosa* A. Cunn., *Daviesia corymbosa* Sm., *D. latifolia* R. Br., *D. ulicina* Sm., *Oxylobium alpestre* F. Muell., *O. ellipticum*, and *Veronica derwentia* Andt. Many of these shrubs are also inflammable, even in the green condition, so the inflammability of the forest also increased both by the dense growth of woody vegetation and the fuel characteristics of some of the major components. Under these conditions bushfire danger and the occurrence of major conflagrations increased. Meanwhile, useful burns (from the graziers' viewpoint) continued to expose the surface soil where locally heavy grazing occurred following the transitory growth of palatable herbs on the bare areas. Accelerated soil movement commenced, and is now evident in the widespread occurrence of severely truncated soil profiles with little or no surface litter.

These changed conditions in the forests have also been accompanied by changes in the associated natural tall-grass meadows of tussocky poa (a form of *Poa caespitosa*), in many of which repeated burning and grazing have produced a short, closely grazed turf containing naturalized grasses and white clover. Local gullying leading to the development of creeks in these modified meadows is also common.

Measurements in the Kosciusko area based on growth ring counts and fire history in relation to the condition of the vegetation show that fire-induced development of scrub does not continue indefinitely. Dense undergrowth can be expected to persist for as long as about 20 years after a fire, but thereafter, as the shrubs increasingly compete with each other and the dominant trees regain their former dominance, the shrubs are gradually eliminated until after about 30–40 years without fires a fairly grassy floor approaching the original condition is restored. Similar changes appear to be occurring on the experimental forest plots in the Cotter

Catchment being studied by Dr. M. Jacobs of the Australian Forestry School. It has been mentioned before that a continuous sward does not favour vigorous shrub and tree regeneration so that this return to a grassy floor can be regarded as a fairly stable condition in the absence of further fires or other disturbance of the continuity of the sward. This will be the main trend if fire protection can be achieved. The initiation of creeks, on the other hand, is virtually irreversible except with human aid.

(*b*) *Subalpine Woodland:* Eucalyptus niphophila *Alliance*

Snow gum country (subalpine woodland) in its natural condition is park-like in character with spreading, single-boled snow gums underlain by a dense herbaceous stratum (including numerous forbs as well as snow grass) with relatively few shrubs; in the more rocky situations the shrubs become more common. Seedling (and lignotuber) snow gums are present below the tree canopy, but are permanently suppressed until released from competition by the death of a dominant tree. This natural condition, now rare in the mountains, is ideally shown in the 150–200-year-old stand of largely unburnt and ungrazed snow gum above the Mt. Kosciusko "Chalet", and in the snow gum country between Mt. Franklin and Mt. Ginini in the Australian Capital Territory (Plate 1, Fig. 1).

As in the adjacent forests, this original structure has been much modified in most areas. Bushfires and intentional burning aimed at improving the palatability of the native snow grass pastures have modified both the dominant and subordinate strata. The snow gum itself, a fire-sensitive species, is easily killed even by a hot ground fire. It is usually able to commence vigorous vegetative regeneration from the lignotuber, however, with the result that most burnt areas soon develop into dense coppice. If bare soil is exposed by the fire this coppice also includes a large number of subordinate pyric shrubs including *Bossiaea foliosa*, *Drimys vickeriana* A. C. Sm., *Hovea longifolia* auctt. (non R. Br.), *Phebalium ovatifolium*, and *Prostanthera cuneata* Benth.; if the soil is not exposed the herbaceous sward usually recovers without an increase in shrubs. This dense coppice-shrub regrowth now covers large areas of subalpine woodland country in the Australian Alps, but the trend is towards the original climax. Growth ring studies and observations on areas known to have been burnt at certain times (e.g. at Kosciusko in 1919, 1926, and 1939) show that the density of the snow gum coppice and shrubs increases up to about 20 years. After this, natural thinning of the snow gum and shrubs produce a gradually more open woodland with an increasing proportion of herbs to shrubs, until at about 40 years after the fire the coppice growth has been reduced to only a few stems per original tree and an almost continuous herbaceous stratum has reappeared. For practical purposes this can be regarded as the climax since the few remaining stems of the coppice will never thin themselves to one as in the original woodland.

The addition of grazing influences complicates the picture further. The continual browsing by sheep of snow gum shoots results in the death of the tree seedling or lignotuber. In this way large areas of snow gum country in the Snowy Mountains have been made treeless. A typical example is the Daner's Gap area at Kosciusko, where grazing by sheep following the 1939 fires has virtually eliminated the trees; in the adjacent Hotel Kosciusko Water Reserve, which was also burnt but which was not subsequently grazed, good regeneration has occurred. The extent of these differences is shown in Table 1.

The relative importance of shrubs and herbs in disclimax treeless areas depends on how much the soil is exposed during and following the fires. If the herbaceous sward is broken and bare soil is exposed, shrubs usually make a rapid appearance. If, on the other hand, fires are mild and do not create bare spaces between the tussocks, a disclimax herbaceous community develops, which at first contains snow grass. In most instances the vegetation is a mosaic of these secondary heath and snow grass communities. The snow grass communities are liable to undergo still further changes with grazing practices, with the elimination of palatable co-dominant and subdominant herbs and the development of intertussock spaces consisting of various minor herbs, bare ground, and litter. These changes are considered more fully in connexion with the *Poa caespitosa–Danthonia nudiflora* sod tussock grassland alliance (cf. Tables 2 and 3).

TABLE 1

EFFECT OF SHEEP GRAZING ON REGENERATION OF SNOW GUM AFTER FIRE IN DANER'S GAP AREA*

Cover Type	Ungrazed Reserve (%)	Grazed Lease (%)
Snow gum	39	2
Snow grass	34	42
Shrubs	15	20
Bare spaces and inter-tussock areas	12	36

* Based on approximately 6 miles of line transect measurements, 1 chain inside and 1 chain outside the boundary fences, carried out in summer 1955–56.

That many treeless areas can be reforested by seedling regeneration following removal of grazing is shown by the strong recovery which has commenced during the last few years in the enclosure of the Soil Conservation Service at Long Plain, near the headwaters of the Murrumbidgee River (Plate 1, Fig. 2). Once snow gums in an area have been killed and the seed reserves exhausted, however, this recovery takes place slowly and with difficulty. In initially difficult snow gum environments, furthermore, as near the tree-line and next to frost hollows, it is problematical if natural regeneration can be achieved, as the removal of the woodland *en masse* creates more extreme climatic conditions as regards exposure to wind and frost which regenerating snow gums seem unable to tolerate (e.g. the Blue Cow area at Kosciusko). In these cases, therefore, the disclimax grasslands and heaths must now be accepted as relatively permanent, even if grazing were eliminated.

Under existing land use, many of these disclimax areas are deteriorating; the area of bare soil is extending and erosion is continiung sometimes despite an apparent recovery of shrubs. This apparent non-parellelism of soil and vegetation development requires explanation and further comment, as it is generally accepted that soil and vegetation trends are parallel—either both on the upgrade or both downwards. Many areas of disclimax heath (e.g. the "Hump" and "Cathedral" on the Buffalo Plateau, and the Blue Cow at Kosciusko) give the impression, based on the condition of the vegetation, that an upward trend is in progress and that stability will be regained. Examination of the soil surface, however, shows that accelerated erosion is active, despite the presence of the shrubs, to a degree that surface-binding herbaceous vegetation cannot re-establish and maintain itself; this is shown by the pronounced pedestalling and death even of short-lived plants, and by the development of gravelly erosion pavements. Thus the vegetation trend may at first be upward despite a downward soil trend. Ultimately, however, the cumulative effects of soil loss must predominate. Evaluation of catchment trend in these circumstances must be done carefully, giving greater weight to the soil than to the vegetation.

When the vegetative cover opens up to the extent that the bare areas exceed the area protected by the remaining groups of plants, deterioration becomes more rapid, with coalescence of formerly separate bare spaces to form large and actively extending bare expanses. This situation has been reached in badly damaged sections of many high mountain areas of the Australian Alps, as on the Perisher Range at Kosciusko, on Mt. Hotham, and on the Feathertop Razorback. Here the downward trend is now irreversible, even in the absence of further fires and grazing, unless active reclamation measures are instituted.

(c) *Sod Tussock Grassland:* Poa caespitosa–Danthonia nudiflora *Alliance*

The sod tussock grasslands* are naturally closed communities dominated by one or more of the various forms of snow grass (*Poa caespitosa*) and other perennial herbs. Bare ground is rarely exposed and when it is, the bare area is usually small enough to be protected by the leaves and litter of adjacent tussocks. Grazing use has resulted in the progressive elimination of the palatable major herbs, accompanied in most areas by a general opening up of the snow grass sward with the development on the intertussock spaces and more extensive bare areas of various minor herbs (e.g. sorrel, *Asperula* spp., *Plantago tasmanica* Hook. f., *Brachycome* spp., *Lagenophora stipitata* Druce, *Leptorhynchus squamatus*, and *Festuca asperula*). Invasion by shrubs, chiefly *Kunzea muelleri* Benth., has also occurred in some cases.

The first stage of modification—the elimination of the major forbs—was apparently a fairly rapid process. This is seen in Table 2 which gives the percentage composition of a forb-rich snow grass pasture in the Hotel Kosciusko Water Reserve before and after one season's grazing in 1957–58. This area had not been grazed previously for at least 20 years, and probably longer.

* Disclimax grasslands produced by deforestation of subalpine woodlands are also considered here.

Current utilization of the modified grasslands differs according to the local cover type (Costin 1958). The limited areas of grassland from which only the major forbs have been eliminated without disruption of the snow grass sward are not being subjected to much further modification by light grazing where this is unaccompanied by fires, owing to the fact that the mature snow grass is not palatable. This is also apparent from Table 2. Shrub-invaded areas are likewise only slightly grazed. In the absence of soil-exposing influences such as fires, these secondary shrubberies would gradually disappear, since shrub regeneration becomes increasingly difficult as the herbaceous sward is gradually restored, and the life-span of most of the shrubs does not seem to be more than about 20–30 years.

TABLE 2

EFFECT OF GRAZING ON COMPOSITION OF NATURAL SNOW GRASS PASTURE IN HOTEL KOSCIUSKO WATER RESERVE*

Period	Composition (%)				
	Snow Grass	Herbs	Shrubs	Litter†	Bare Ground
Before grazing	67	16	3	13	1
After grazing	71	7	3	18	1

* Determined by measurements along permanent line transects before and after grazing season of 1957–58.

† The apparent increase in litter was due mainly to its exposure following removal of the herbs by grazing.

The areas of partly bare ground and minor herbs present a different picture. These areas afford most of the palatable grazing in the form of intertussock plants such as sorrel, *Geranium* spp., *Leptorhynchus squamatus*, and other composites, which represent an intermediate stage in the secondary succession, occasionally with *Themeda australis* Stapf., *Danthonia* spp., and naturalized white clover at the lower levels. Irrespective of low overall stocking rates (from half to one sheep per acre over a snow lease as a whole), effective stocking rates are very high (locally approaching 5–10 sheep per acre; cf. Costin 1958). The continual grazing of these poorly covered areas also means that the soil remains exposed to the erosive action of frost, wind, and water. The extent of the soil movement is shown by the pronounced pedestalling of even short-lived plants and the development of gravelly erosion pavements. Owing to the usually considerable depth of the soil, however, and the capacity of some of the minor herbs (particularly sorrel) for vigorous re-establishment until erosion has proceeded almost to the underlying rock, the significance of these soil losses is easily underestimated. Once the size of the intertussock space increases beyond the protective influence of adjacent overhanging tussocks, however, larger bare areas begin to develop through the erosion of tussock margins and the heaving of regenerating seedlings due to increased frost action.

Protection from grazing is usually followed by an increase in minor herbs within a few years, although the regeneration of snow grass and major herbs is a much slower process. Detailed line transect measurements in the Daner's Gap area in 1957–58, which was a particularly favourable season, showed a 2·6 per cent. increase in the minor herb component of ungrazed areas compared with a decrease of 2·6 per cent. in contiguous areas which were grazed. Other measurements on intertussock areas in and adjacent to the soil conservation enclosures at Daner's Gap and the Plains of Heaven (protected since 1951) and the Hotel Kosciusko Water Reserve (protected at least since 1939) are summarized in Table 3.

TABLE 3

EFFECT OF PROTECTION FROM GRAZING ON COMPOSITION OF INTERTUSSOCK SPACES IN GRASSLAND*

Cover Type	Plains of Heaven		Daner's Gap		Water Reserve	
	Grazed (%)	Ungrazed (%)	Grazed (%)	Ungrazed (%)	Grazed (%)	Ungrazed (%)
Minor herbs	47	61	27	39	20	26
Litter	39	28	28	33	19	44
Shrubs	—	—	—	—	4	7
Bare ground	14	11	45	28	57	23

* Determined by quadrat measurements of percentage cover, carried out in Plains of Heaven, summer 1957–58; Daner's Gap, summer 1955–56; Water Reserve, summer 1955–56.

The deleterious effects of grazing damaged areas are accentuated by the selective utilization of inflorescences and seed heads. This is evident from Table 4 which gives details of seed production in the Daner's Gap area in 1957–58 under grazing intensities of zero, one, and two sheep per acre for the grazing season. It is noteworthy that very light overall grazing is sufficient to produce a large reduction in seed supply.

(d) *Tall Alpine Herbfield:* Celmisia longifolia–Poa caespitosa *Alliance*

Communities of the *Celmisia longifolia–Poa caespitosa* alliance, the most extensive herbfield community, are naturally closed, with *Celmisia*, *Poa*, and associated herbs as dominants. As in the sod tussock grasslands, much of this herbfield vegetation has been modified by grazing and fires. There is strong evidence (Costin 1958) that these herbfields used to be richer in several palatable co-dominant or subdominant species which have now either become less common (e.g. the various forms of *Craspedia uniflora*) or have virtually disappeared (e.g. *Danthonia frigida* Vickery), leaving relatively greater amounts of *Poa* in the present vegetation. Where the herbfield stratum has been broken, several minor herbs, notably sorrel and small composites, have also become more conspicuous. Even more than in the

TABLE 4

EFFECT OF GRAZING ON SEED PRODUCTION IN DANER'S GAP AREA*

Species	No Grazing			One Sheep per Acre			Two Sheep per Acre		
	Heads per Acre	No. of Seeds per Acre	Seed Wt. (lb/acre)	Heads per Acre	No. of Seeds per Acre	Seed Wt. (lb/acre)	Heads per Acre	No. of Seeds per Acre	Seed Wt. (lb/acre)
Poa caespitosa Forst. f.	133,800	10,704,000	3·20	47,600	3,332,000	0·93	15,100	377,000	0·10
Festuca asperula J. Vickery	11,370	852,000	0·23	—	—	—	—	—	—
Aira caryophyllea L.	1,200	24,000	0·01	—	—	—	—	—	—
Asperula spp.	4,730	9,930	0·07	—	—	—	—	—	—
Carex hebes Nelmes	2,390	11,950	0·04	—	—	—	—	—	—
Danthonia pilosa R.Br.	7,170	28,680	0·96	—	—	—	—	—	—
Helichrysum scorpioides Labill.	600	192,000	0·14	—	—	—	530	53,000	0·10
Rumex acetosella L.	68,200	634,000	4·56	33,700	303,300	0·39	7,540	67,860	0·09
Stellaria media Vill.	—	—	—	1,470	7,350	0·01	—	—	—
Viola betonicifolia Sm.	—	—	—	—	—	—	1,100	27,500	0·06
Totals	229,460	12,456,560	9·21	82,770	3,642,650	1·33	24,270	525,360	0·35

* Based on counting and harvesting seed heads in ¼ metre square quadrats along fixed transect lines in summer 1957–58, followed by separation, counting, and weighing of the seeds.

sod tussock grasslands; the more severely damaged herbfield areas have extended into adjacent undamaged areas and are continuing to do so even though the initial disturbing agent has in some cases been removed.

The present distribution of herbfield types on certain mountains (e.g. Carruther's Peak, Mt. Northcote, and Mt. Clarke in the Koscuisko area) is at first glance puzzling; extensive pure communities of *Celmisia* are found in patchwork fashion under a fairly wide range of ecological conditions apart from the relatively snowy situations known to favour this species. Closer analysis of the problem in the light of the very heavy stock concentrations during earlier years indicates that many of the *Celmisia* patches of today occur on areas damaged by grazing, and local experience strongly supports this view.

Not all damaged areas on which grazing pressure has been relaxed have responded in this manner. Only the fairly favourable situations show this improvement. The unfavourably situated and badly damaged places have continued to get worse, and the damage is extending rapidly year by year (e.g. on Mts. Bogong, Loch, Hotham, and Feathertop in the Bogong High Plains area, and in the Kosciusko and Gungartan areas of the Snowy Mountains). In other places, as on Mt. Northcote at Kosciusko, the balance appears to have been very delicate and wavering for some time, as the rapid enlargement and coalescence of bare areas has become noticeable only during the last few years although there has been virtually no grazing since 1944. The present situation is a complex one, as many of the down-grade areas are extending as a face under wind and frost action into adjacent areas which were formerly undamaged or which had even been restabilized by *Celmisia*. In the more exposed parts the end point to this situation (unless active conservation measures are undertaken) is the removal of most of the soil mantle from whole mountain slopes, as on parts of Carruther's Peak, the Mt. Twynam area, the Granite Peaks, Gungartan, and the Kerries, and Mts. Loch and Bogong in Victoria. Occasionally, if the solum is very stony, a stone erosion pavement may form before the soil mantle is all removed, and this tends to reduce the rate of soil loss.

It has been claimed that this large-scale erosion along the Main Range north of Mt. Kosciusko is a natural phenomenon which has been in progress since pre-settlement times (e.g. Doyle 1956). A recent origin, however, is indicated by the ecological evidence; this includes islands and abrupt exposed faces of soil and herb-field vegetation in otherwise denuded areas, soil and lichen lines on rocks, and freshly buried soils on adjacent lower slopes (cf. Plates 4–7). On historical grounds, furthermore, most if not all of this catastrophic erosion appears to have occurred during the present century, since it is not recorded in the writings of the early explorer botanists and geologists. Helms (1893, 1896) in particular, who was very conservation-minded for his day, would almost certainly have recorded such large-scale deterioration if it had been there. In this regard, his peak-by-peak description of the Kosciusko area is enlightening (Helms 1896). That he clearly distinguished between the extensive alpine herbfields and the restricted, naturally bare snow patch areas is shown by the statement (p. 77): "At the highest elevations an almost alpine vegetation covers every available spot between the rocks. A few narrow stretches only do not produce the faintest particle of vegetation. This occurs in places where the snow accumulates in masses on the eastern slopes of the Snowy Mountains, drifting before a western gale from off and over the ridges." Helms's description of Carruther's Peak ("Slate Peak", p. 82), "with the exception of a few protruding masses of barren rock, it is covered with vegetation", is now quite out of date. If Helms were to return to Carruther's Peak today, he would have to describe it thus: "Except for a few pieces of vegetation, it is covered with bare soil and stones" (Plate 4, Figs. 1, 2). The first indication of extensive deterioration of the top country was in the reports of Byles (1932), whilst Dr. W. R. Browne, with long experience of the summit country, thinks it was noticeable as early as the 1920's. It would appear that the damage developed within the first 20 years of this century, probably as the direct result of the periods of very heavy grazing known to have occurred during this time (as many as 30,000 sheep in the summit area alone).*

The nature of the final eroded surface in these areas is instructive as regards the time that would be needed for secondary successions to restore the original climax. Dry erosion surfaces—consisting of scattered stones and rotten rock—are becoming occupied very sparsely by species of the *Epacris petrophila–Veronica densifolia* and *Coprosma pumila–Colobanthus benthamianus* fjaeldmark alliances, typically *Kelleria tasmanica* Domke. and *Colobanthus benthamianus*. These fjaeldmark alliances occur naturally in the most wind-exposed and cold situations respectively, such as exist in association with permanent or near-permanent ice and snow, and which were probably more extensive in the higher parts of the Australian Alps about 20,000 years ago. Thus, soil succession and plant succession have probably been put back in the eroded areas by a very long period of time. Wet, stony erosion surfaces are also of interest from the successional viewpoint. These support a very open vegetation of species of the *Plantago muelleri–Montia australasica* short alpine herbfield alliance, including *Oreobolus* spp., *Montia australasica*, *Caltha introloba* F. Muell., and *Dioschiadium ranunculaceum* Domin, which are restricted naturally

* The analysis by Foley (1957) of droughts in Australia provides indirect evidence that much of this deterioration was probably initiated about the turn of the century. The drought period of 1895–1903 is stated to have been far worse and more far-reaching in its effects than any before or since. "Never before has the drought been so extensive. On previous occasions stock were removed to mountain country to the east but even the mountains have felt the effects of the dry season". The latter part of this remark is significant, since it is generally taken for granted that the mountains never experience drought conditions. Drought is a relative term, and a dry summer in the mountains, which is accompanied by an unusually high number of frosts, imposes a severe set-back to much of the vegetation. The effect of heavy stocking under these conditions, and the subsequent autumn burn which would have been carried out, would have been still more damaging.

Some idea of the vast numbers of livestock which must have been removed to the higher levels during these dry years can be judged from a Narrandera press report during the previous drought. It stated that since August 500,000 sheep had gone through Narrandera towards the mountains and one million sheep were said to have passed through the Wagga district within a month (Foley 1957). The Narrandera–Wagga route is only one of many leading to the mountains.

The period 1904–1910 also continued dry, particularly in southern areas. By 1908 Nimmitabel reported one of the driest periods on the Monaro for 50 years.

For the 15 years between 1895 and 1910, therefore, the demand for relief grazing on the mountains is likely to have been consistently very heavy.

to moist, snow patch situations. In this case also, advanced deterioration of the tall alpine herbfield vegetation and soils has led to the spread of comparatively rare species which hitherto were restricted to very special habitats.

In addition to the areas considered above, other damaged herbfield areas show extensive invasion by shrubs, especially *Hovea longifolia*, *Oxylobium ellipticum*, *Prostanthera cuneata* Benth., *Phebalium ovatifolium*, and *Orites lancifolia* F. Muell. (e.g. on Mt. Stirling and the Feathertop Razorback in Victoria). As in the subalpine woodland and sod tussock grassland areas dealt with earlier, this invasion is favoured by exposed soil; in the case of fire-favoured species such as *Hovea longifolia* fires have probably assisted this invasion. The trend in these shrub-invaded areas depends on the type of situation, the intensity of grazing, and whether or not there are fires. Favourable situations, especially those which have been free from fires and heavy grazing for some years, are slowly returning to tall alpine herbfield, as on Mts. Howitt, Gibbo, and Pinnibar. Unfavourable situations, however, are continuing to deteriorate, as on the Feathertop Razorback, in some cases even in the absence of fires and without much further disturbance from grazing.

Although of great importance from the catchment point of view, the badly damaged herbfield areas considered so far constitute the minority of herbfield country. The Kosciusko area as a whole does show definite improvement since most of the livestock were removed in 1944. Local mountain people, particularly those living at the Mt. Kosciusko "Chalet", were soon impressed by the increased flowering both of forbs and snow grass which commenced in the summit area (Plate 2, Figs. 1, 2). This was partly an expression of the recolonization of the bare spaces between the tussocks of snow grass by various forbs, mainly conspicuous composites and species of *Euphrasia*. It is noteworthy that several of these forbs (e.g. *Brachycome* spp. and *Craspedia uniflora*) are very palatable, and the inflorescences in particular are eagerly eaten so that during grazing extensive recolonization is checked. The massed flowering of snow daisy (*Celmisia longifolia*) also became more noticeable, and, as discussed previously, the field evidence for this is still apparent. Thus, recovery of the tall alpine herbfield areas in the closed portion of the summit area (apart from the very vulnerable places) is still strikingly in progress.

Further evidence that protection from grazing, even at the present lower rates, is beneficial to herbfield vegetation, is shown by the condition of grazed areas such as Gungartan and Jagungal, a few miles north of Kosciusko. These tall alpine herbfields contain abundant and extending intertussock spaces in which sorrel is one of the main species, not the recolonizing forbs (especially *Craspedia uniflora*) as around Kosciusko, and snow daisy is markedly less conspicuous (Plate 3, Fig. 2). This shows that recent grazing pressure in these areas has still been too heavy to permit the same large-scale recolonization as has occurred around Kosciusko. Furthermore, the species *Danthonia frigida*, *Ranunculus anemoneus* F. Muell., and *Aciphylla glacialis* are virtually absent, whereas in the Kosciusko area they have steadily become more common since 1944 (Plate 3, Fig. 1; cf. Costin 1958). In the Victorian Alps, the eroding condition of mountain tops which are still grazed (e.g. Mts. Bogong, Hotham, and Feathertop, and Mt. Stirling and The Bluff) contrasts strongly with those which are grazed only lightly or not at all (e.g. Mts. Howitt and Pinnibar). These Victorian herbfields are also much poorer in the alpine forbs found at Kosciusko.

The extent of the differences in the floristic composition, flowering, and seed production of the tall alpine herbfields of the Kosciusko and Gungartan areas is shown in Tables 5, 6, and 7. From Table 5, it will be noted that 51 per cent. of the Kosciusko herbfields is dominated or co-dominated by snow daisy and major herbs other than snow grass, compared with only 12 per cent. at Gungartan. Table 6, showing the relative abundance of species other than snow grass, further emphasizes the richness of the Kosciusko communities (41 species recorded compared with 26 at Gungartan), and the preponderance of major herbs (e.g. *Celmisia*, *Craspedia*, *Euphrasia*, *Microseris*, and *Oreomyrrhis*) instead of the minor species which are so common at Gungartan (e.g. *Rumex*, *Asperula*, *Cotula*, *Ewartia*, *Scleranthus*, and mosses).

TABLE 5

COMPARISON OF TALL ALPINE HERBFIELDS IN KOSCIUSKO AND GUNGARTAN AREAS*

Cover Type	Kosciusko (%)	Gungartan (%)	Cover Type	Kosciusko (%)	Gungartan (%)
Snow grass	42	74	Snow grass–herbs	5	3
Snow grass–snow daisy	37	7	Intertussock spaces	6	12
Snow daisy	8	1	Bare ground	1	3
Other herbs	1	1			

* Based on approximately 8½ miles of line transect measurements, summer 1957–58.

The differences in flowering and seed production summarized in Table 7 are equally striking, the ratio of seed weights at Kosciusko and Gungartan being approximately 14 : 1 and of numbers of seeds about 12 : 1. These differences reflect both the selective grazing of inflorescences and seed heads at Gungartan (particularly with respect to snow grass) and differences in floristic composition as such (particularly as regards other major herbs). On Mt. Bogong, in the Bogong Creek Catchment which has been closed to grazing for about two years, snow grass seed heads were approximately seven times more numerous* at the end of the 1957–58 grazing season, than in the adjacent areas which are still grazed. It will probably be several years before similar effects are apparent with respect to the forbs, however, owing to the virtual elimination of many of them by grazing.

(e) *Tall Alpine Herbfield:* Brachycome nivalis–Danthonia alpicola *Alliance*

The tall alpine herbfields of the *Brachycome nivalis–Danthonia alpicola* alliance, although nowhere extensive, are of some significance as regards current trends.

* Determined by quadrat measurements carried out in 1958.

TABLE 6

RELATIVE ABUNDANCE OF SPECIES OTHER THAN SNOW GRASS IN TALL ALPINE HERBFIELDS AT KOSCIUSKO AND GUNGARTAN*

Species	Kosciusko (%)	Gungartan (%)	Species	Kosciusko (%)	Gungartan (%)
Acaena ovina A. Cunn.	0·10	1·24	*Hymenanthera dentata* R.Br. ex DC.	0·63	0·50
Aciphylla glacialis F. Muell. ex Benth.	0·31	—	*Leptorhynchus squamatus* Less.	0·21	—
Asperula spp.	1·56	6·41	*Luzula campestris* DC.	4·16	8·16
Baeckea gunniana Schau.	0·31	—	*Microseris scapigera* Schulz.-Bip.	5·42	1·48
Brachycome decipiens Hook. f.	4·27	2·62	*Montia australasica* Pax. & K. Hoffm.	2·82	3·47
Calostrophus lateriflorus F. Muell.	1·26	—	Mosses	1·47	5·00
Carex hebes	11·59	15·79	*Olearia* sp.	1·15	—
Celmisia longifolia Cass.	17·03	4·45	*Oreomyrrhis andicola* Endl. ex Hook f.	2·09	—
Colobanthus benthamianus Fenzl.	0·21	—	*Prasophyllum* sp.	0·61	—
Cotula alpina Hook. f.	—	2·72	*Oxylobium ellipticum* R.Br.	—	0·50
Craspedia uniflora Forst. f.	8·99	—	*Phebalium ovatifolium* F. Muell.	0·84	0·25
Danthonia sp.	1·15	—	*Pimelia alpina* F. Muell. ex Meissn.	5·14	8·16
Epacris microphila R.Br.	0·52	0·50	*Plantago muelleri* Pilger	0·10	—
E. paludosa R.Br.	0·31	—	*Ranunculus* spp.	0·94	—
Epilobium confertifolium Hook. f.	0·94	1·48	*Richea continentis* B. L. Burtt.	0·21	—
Erigeron pappocromus Labill.	0·10	—	*Rumex acetosella*	2·71	20·03
Euphrasia sp.	4·50	—	*Scleranthus biflorus* Hook. f.	0·31	1·24
Ewartia nubigena Beauv.	0·73	2·47	*Senecio lautus* Willd.	4·27	—
Geranium sp.	0·10	—	*Stackhousia* sp.	0·42	—
Gnaphalium collinum Labill.	3·66	2·97	*Stellaria pungens* Brongn.	—	0·40
Helichrysum bracteatum Andr.	—	0·74	*Taraxacum officinale* Weber.	—	0·25
H. scorpiodes	0·52	3·44	*Trisetum subspicatum* Beauv.	3·12	1·24
Hydrocotyle hirta R.Br.	1·04	—	*Viola bentonicifolia* Sm.	4·16	4·45

* Based on percentage presence in ¼ metre square quadrats thrown along transect lines, in summer 1957–58. Percentage presence figures reduced to common base of 100.

TABLE 7

COMPARISON OF SEED HEAD AND SEED PRODUCTION AT KOSCIUSKO AND GUNGARTAN*

Species	Kosciusko			Gungartan		
	Heads per Acre	No. of Seeds per Acre	Seed Wt. (lb/acre)	Heads per Acre	No. of Seeds per Acre	Seed Wt. (lb/acre)
Aira caryophyllea	6,560	120,000	0·04	5,550	117,660	0·02
Brachycome decipiens	3,440	183,350	0·19	—	—	—
Carex hebes	9,570	122,500	0·45	6,220	23,010	0·09
Celmisia longifolia	1,640	180,070	0·75	—	—	—
Craspedia uniflora	1,290	303,150	0·86	—	—	—
Danthonia nivicola J. Vickery	—	—	—	1,680	1,680	0·03
D. nudiflora P. F. Morris	2,730	71,250	0·18	—	—	—
Euphrasia sp.	23,000	1,150,000	4·60	—	—	—
Ewartia nubigena	—	—	—	3,700	44,400	0·10
Gentiana diemensis Griseb.	10,970	109,700	1·69	—	—	—
Gnaphalium collinum	16,800	840,000	1·11	1,520	18,240	0·04
Luzula campestris	3,000	150,000	0·24	1,510	100,700	0·06
Microseris scapigera	1,640	164,000	0·35	—	—	—
Montia australasica	220,800	662,400	1·41	—	—	—
Oreomyrrhis andicola	1,640	27,390	0·18	—	—	—
Poa caespitosa	621,700	50,979,400	42·70	78,200	4,301,000	3·41
Poranthera microphylla Brongn.	2,460	13,300	0·04	—	—	—
Prasophyllum sp.	1,090	2,180	0·02	—	—	—
Rumex acetosella	16,800	1,087,000	1·62	26,500	300,000	0·44
Senecio lautus	21,900	876,000	1·06	—	—	—
Trisetum subspicatum	8,470	1,694,000	1·10	1,680	62,500	0·09
Viola bentonicifolia	860	21,500	0·06	—	—	—
Totals	976,360	58,757,190	58·64	126,560	4,969,190	4·28

* Based on counting and harvesting of seed heads in ¼ metre square quadrats thrown along transect lines in summer 1957–58, followed by separation, counting, and weighing of the seeds. The results probably give an underestimate, as a small amount of seed had already fallen and 1957–58 was a poor flowering year for *Celmisia*. They should be regarded as approximate only.

These chomophyte communities mostly occupy relatively inaccessible habitats such as cliff faces, rock ledges, and crevices, and are thus little affected by land use. However, it would appear that at least one of the dominants, *Alchemilla novae-hollandiae* Rothm., was once more widespread in moist places, since it now exists mainly where grazing animals cannot reach it (cf. Costin 1958). On the other hand, another dominant, *Brachycome nivalis* F. Muell., has invaded eroding *Celmisia longifolia–Poa caespitosa* habitats, as on Mt. Hotham, and to this extent these chomophyte communities are extending slightly.

(*f*) *Short Alpine Herbfield:* Plantago muelleri–Montia australasica *Alliance*

The short alpine herbfields of the *Plantago muelleri–Montia australasica* alliance (snow patch communities) are undergoing marked and rapid changes as a result of grazing. These communities are both attractive and accessible, which means that overgrazing is unavoidable even with very low overall stock numbers.

These communities are subject to heavy pressure under natural conditions, by virtue of the fact that they act as stabilizing outwash aprons for the melt-waters from snow patches. They perform this function successfully because of their closely appressed, carpet-like growth, and that they have continued to do so for many hundreds and in some cases thousands of years is shown by the depth of the underlying snow patch peats. Once the surface mat is broken by trampling, however, and the evenly distributed surface flow from the snow patch is channellized, gully erosion and drying out of the snow patch vegetation advance rapidly. This removal can now be seen in progress all over the higher parts of the Alps (Plate 6, Fig. 1; Plate 7, Fig. 1). In many places—e.g. Perisher Range, Gungartan–Kerries area, Carruther's Peak—the stripping has been so complete that the resultant bare areas are easily taken to be natural. The true origin of these areas is usually apparent, however, from the small islands of old soil in protected places, from "soil-lines" on exposed rocks, and from the nature of the exposed rocks themselves (Plate 7, Figs. 1, 2). Unlike naturally exposed rocks which are rounded by prolonged weathering and largely covered by lichens, the rocks exposed by recent erosion are angular and generally clean and fresh-looking owing to the fact that little weathering or lichen growth has had time to take place.

As observed earlier, certain snow patch plants have also extended their range on to wet, rocky, eroded surfaces in tall alpine herbfield, but in these cases the plants are mostly scattered and do not form the continuous, mat-like communities typical of undamaged areas.

(*g*) *Fjaeldmark Alliances*

The two fjaeldmark alliances—*Epacris petrophila–Veronica densifolia* alliance in the most wind-exposed situations and *Coprosma pumila–Colobanthus benthamianus* alliance in cold, exposed upper snow patch areas—have not been affected much by land use. As mentioned in connexion with the *Celmisia longifolia–Poa caespitosa* alliance, however, certain fjaeldmark species are now establishing themselves on almost completely eroded herbfield areas, and to this extent these alliances are extending.

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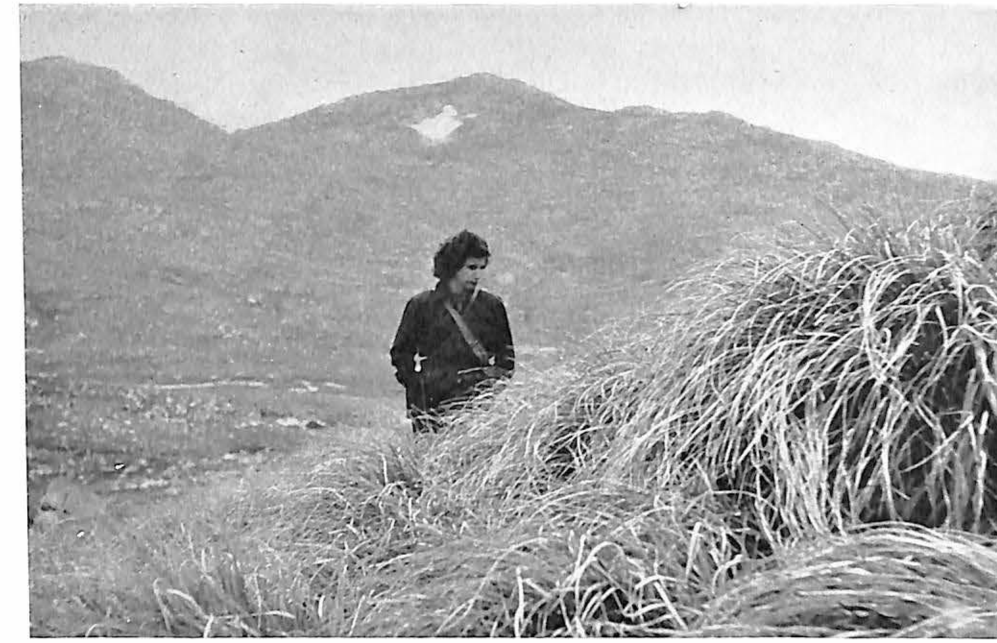

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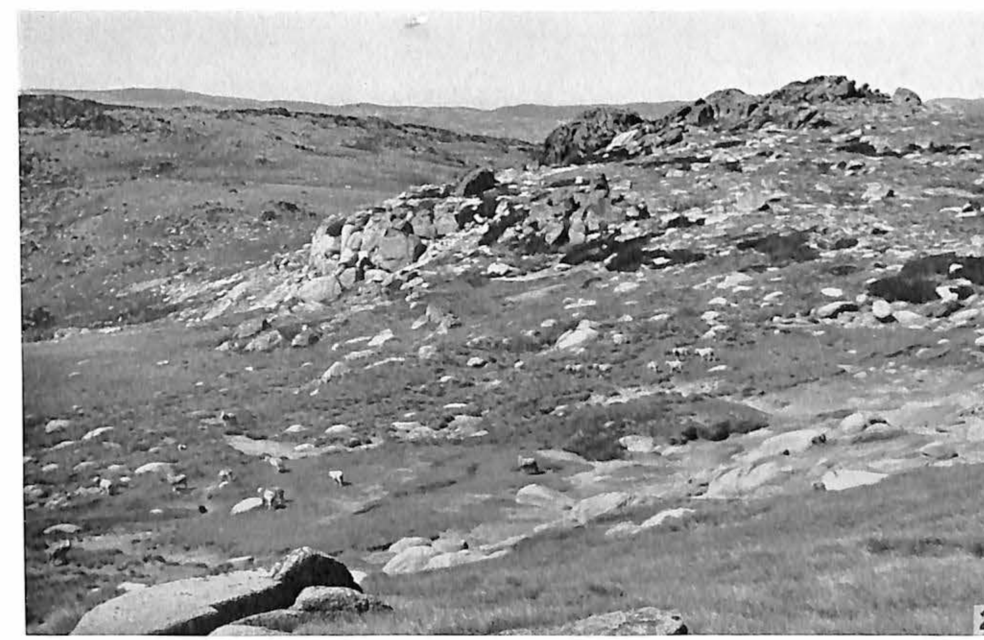

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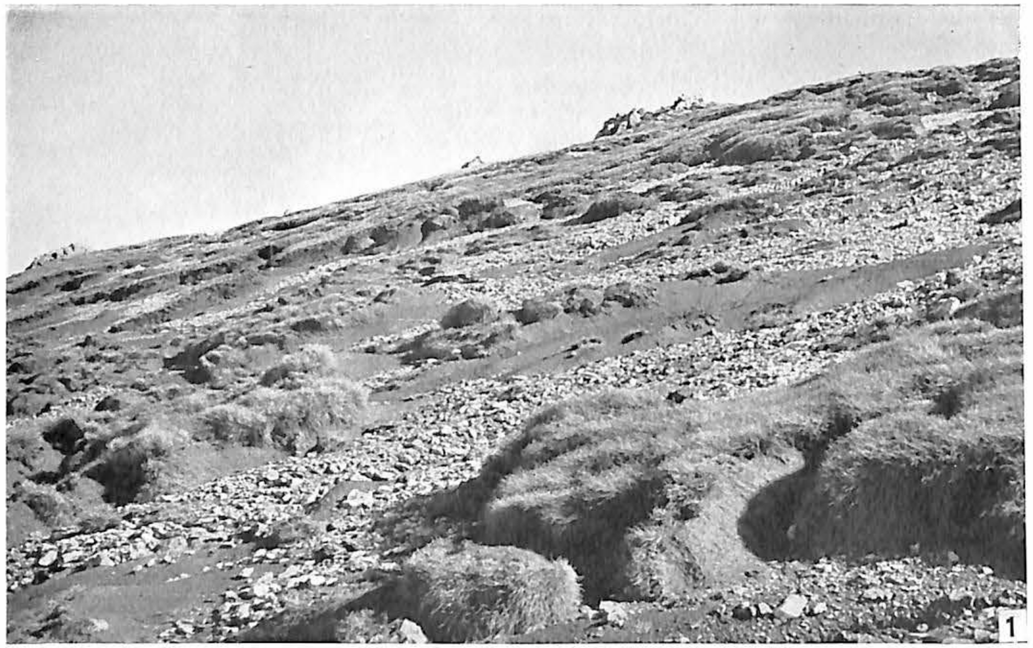

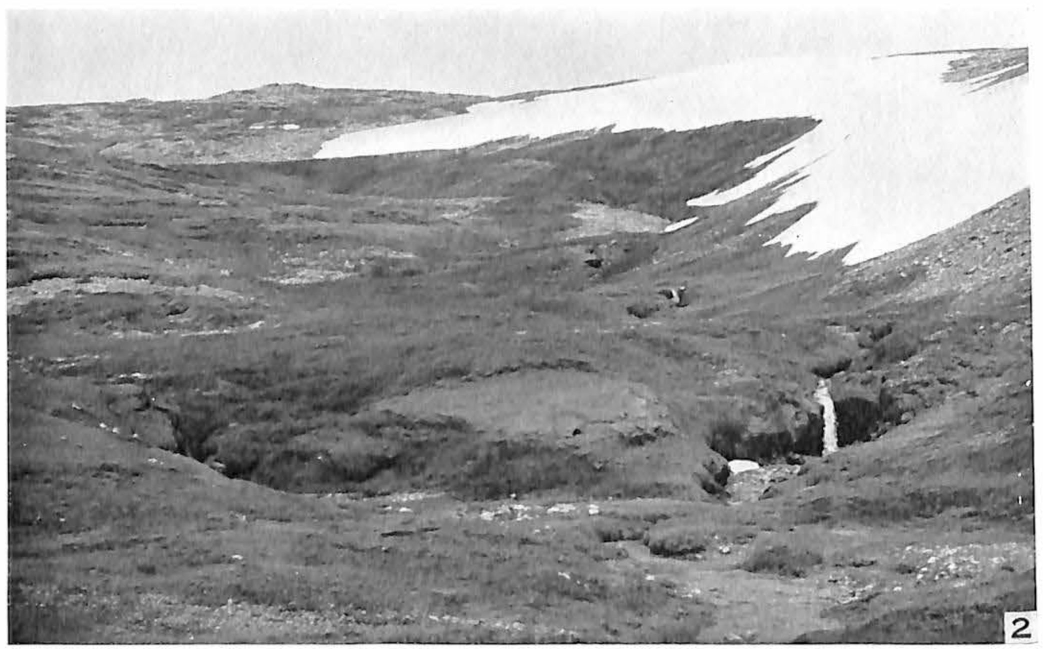

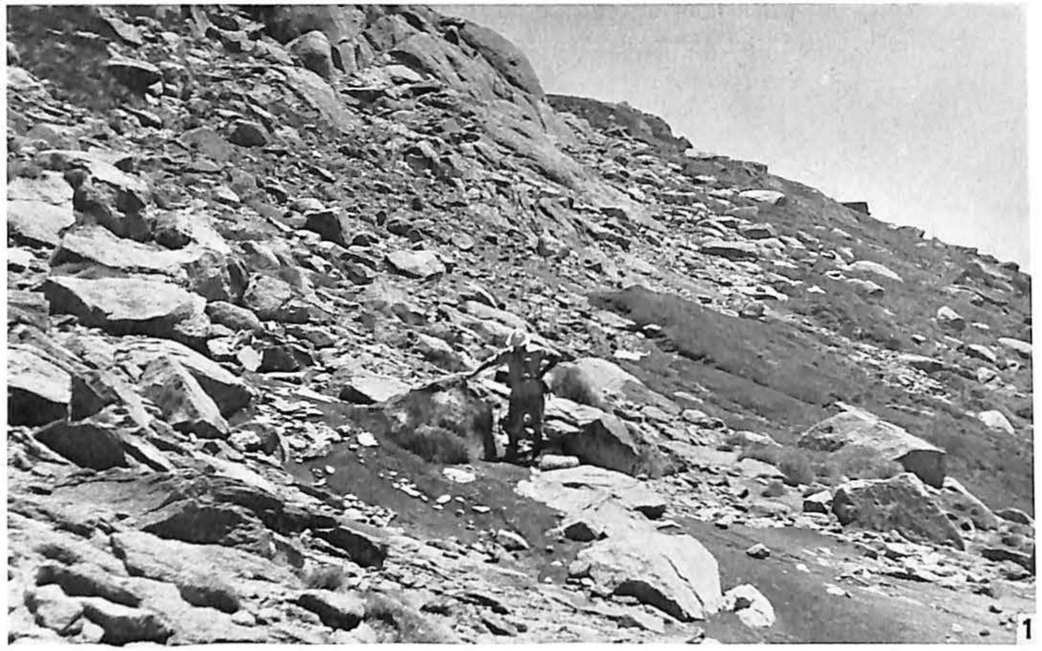

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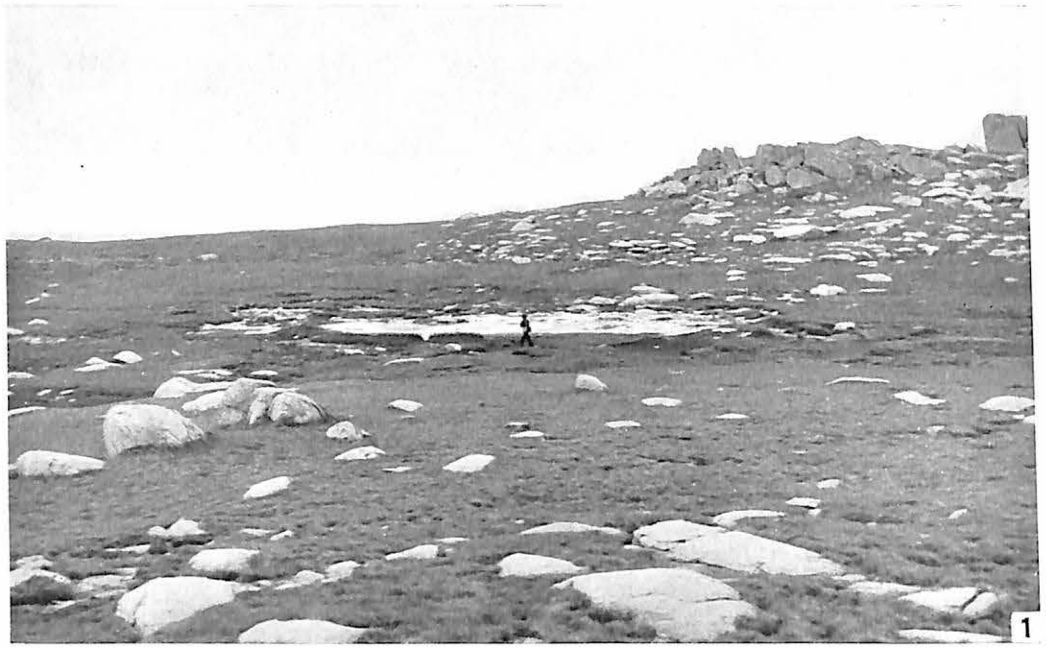

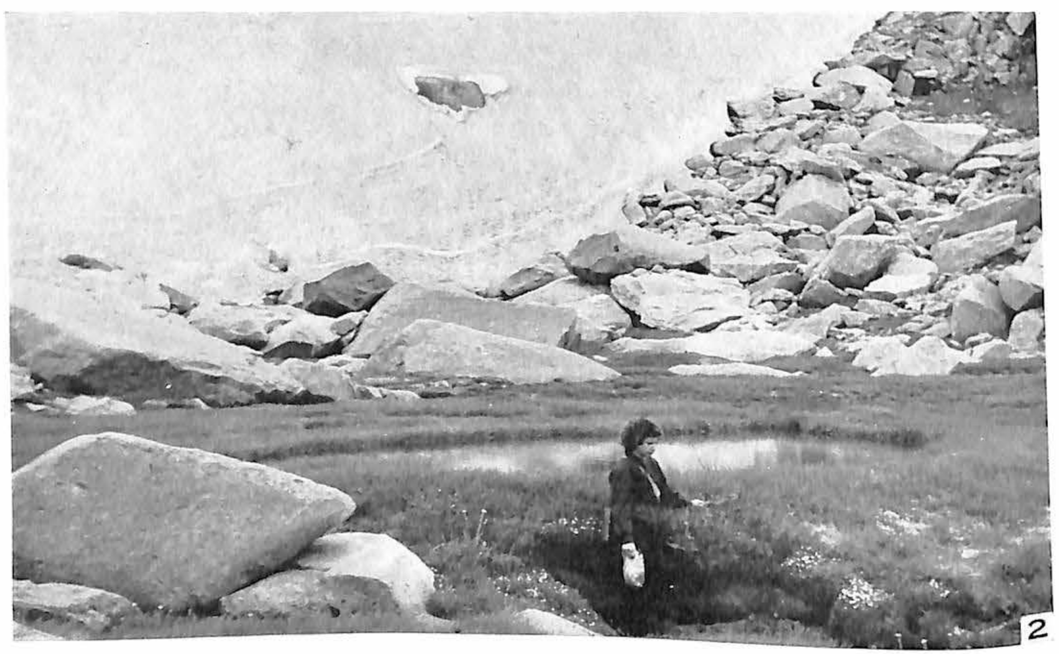

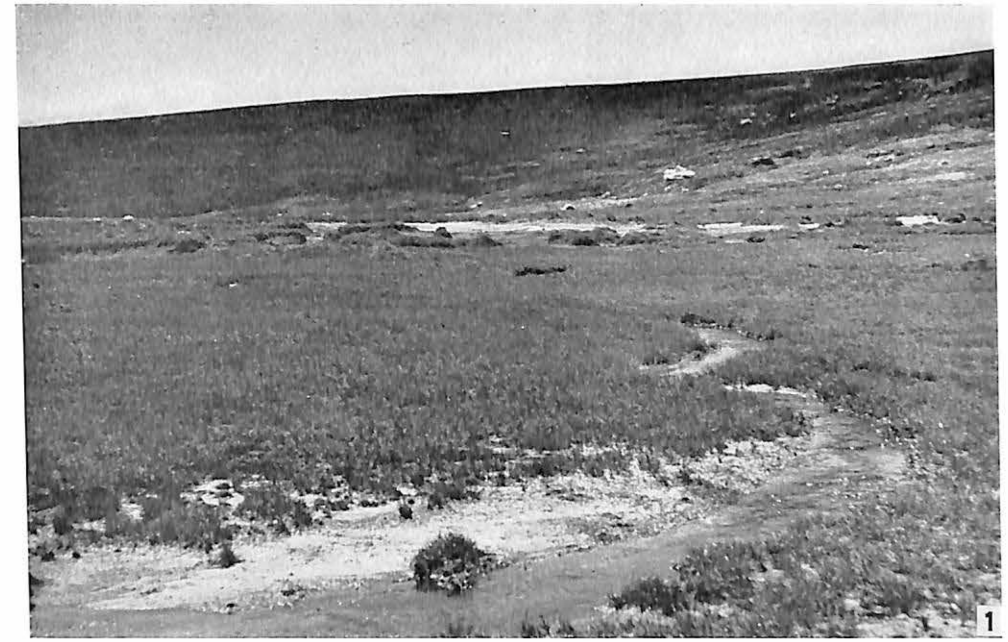

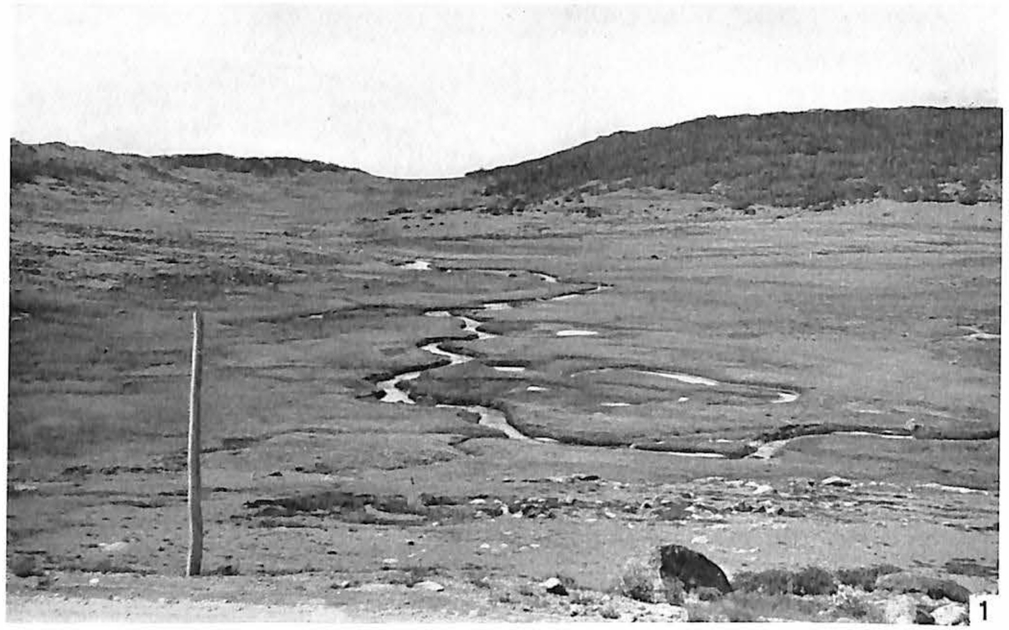

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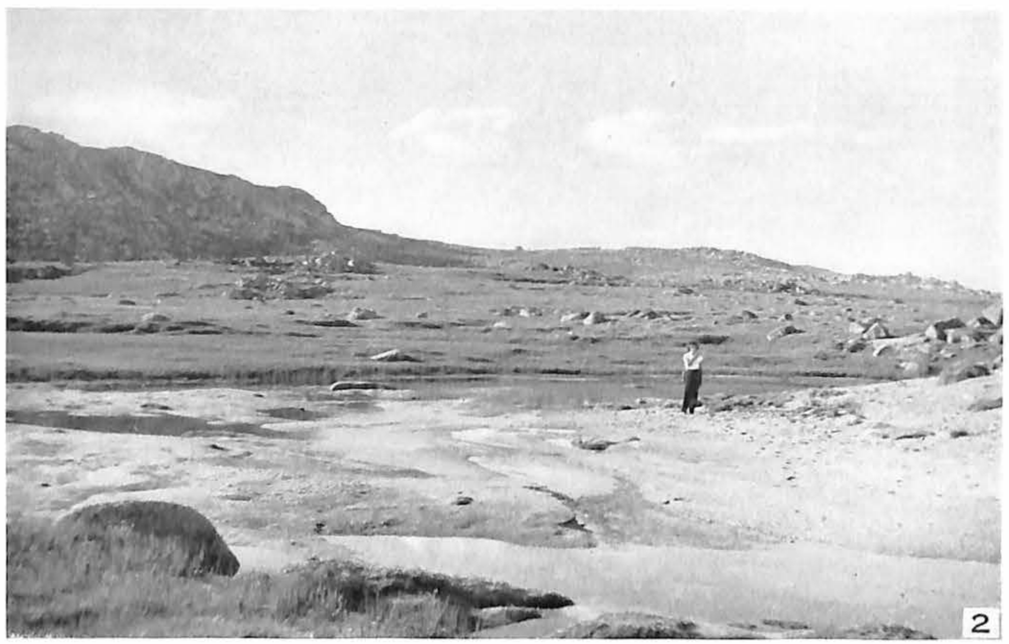
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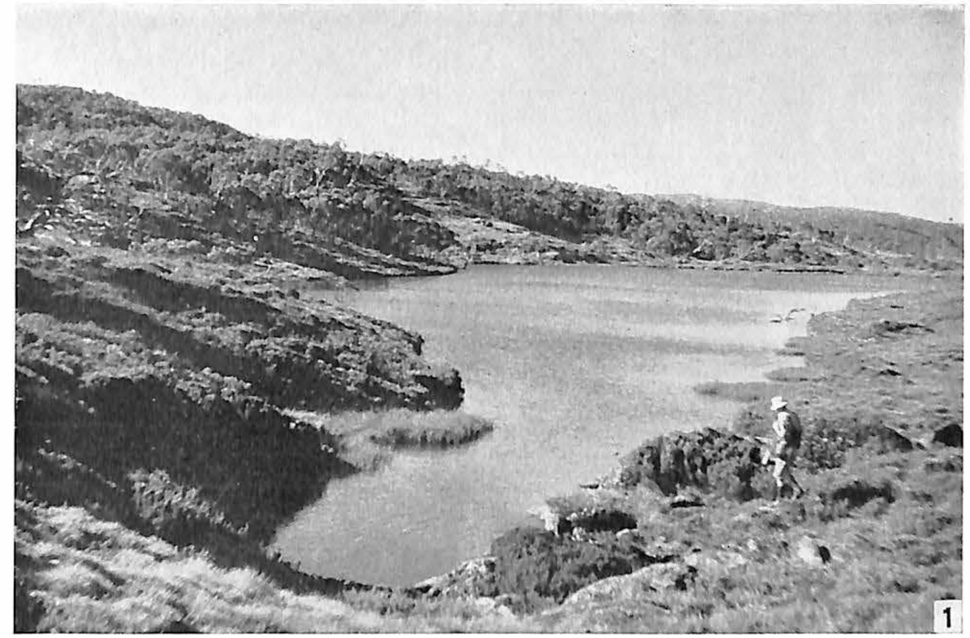

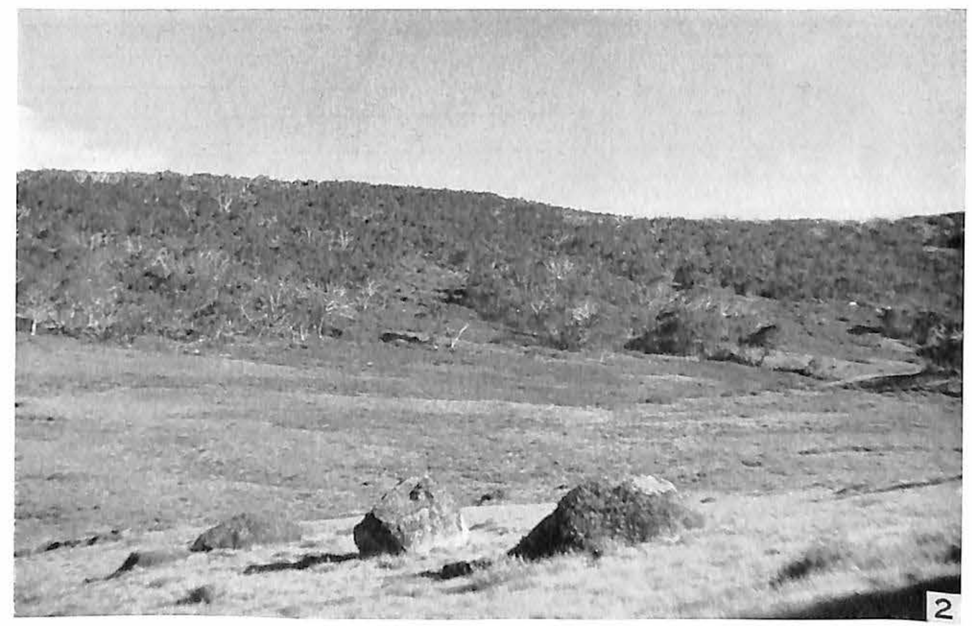


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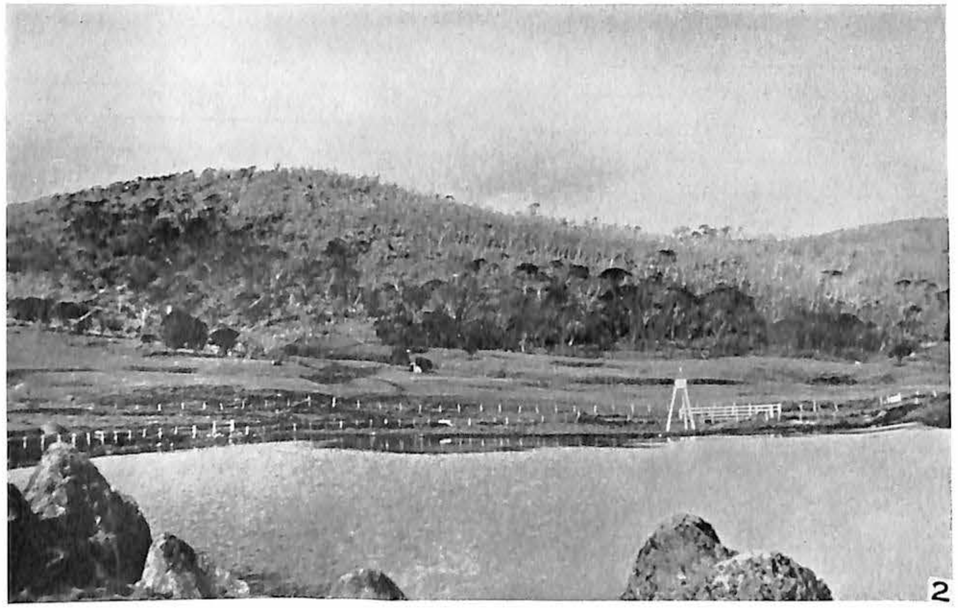
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(*h*) *Heath Alliances*

Both of the heath alliances—*Podocarpus alpinus–Oxylobium ellipticum* and *Epacris serpyllifolia–Kunzea muelleri*—have been affected by land use, especially by fire. In their natural shrubby condition they are of little grazing value and are not much affected by stock; large areas of both types of heath still exist as fairly stable entities (e.g. on the Bluff, Mt. Tingiringi, and Yaouk Bill Range). However, the unpalatibility of these communities has encouraged periodic burning and definite changes are evident on the burnt areas, differing somewhat according to the character of the heath vegetation.

In the *Podocarpus alpinus–Oxylobium ellipticum* alliance, which contains several relatively fire-hardy species, there is usually rapid regeneration after fire. Only in a minority of cases have these heaths been replaced by secondary grasslands or herbfields. More commonly the reverse has occurred, when exposure of forest, snow gum, and alpine herbfield soils has produced favourable conditions for shrub invasion.

The shrubs of the *Epacris serpyllifolia–Kunzea muelleri* alliance are more fire-sensitive and susceptible to replacement by disclimax grasslands when subject to periodic fires and grazing. On the other hand, damaged areas of sod tussock grassland and dried-out bogs (see below) have become covered by heath communities of this alliance, and this replacement is still in progress.

(*i*) *Bog Alliances*

The two bog alliances recognized in the Australian Alps—*Carex gaudichaudiana–Sphagnum cristatum* and *Epacris paludosa–Sphagnum cristatum*—can be treated together for the purpose of this discussion. The various types of evidence bearing on this particular problem are so consistent as to leave no doubt that the bogs in general have undergone widespread drying out and that this trend is still in progress.

Early recollections of the Australian Alps are that they were far boggier than today, and the existence of this condition can easily be proved, in many places up to the time of the 1939 fires. Old graziers remember well areas that were once too boggy to ride over or to drive livestock across, which now are almost dry underfoot in summer and completely safe to traverse. Writing of the Mount Kosciusko area last century, Maiden (1899) warns that "in daylight one has to proceed carefully, as one's horse (unless he be left to himself) may sink to his belly, while riding in such country after sundown is very dangerous". Petersen (1957), drawing on almost 40 years' experience of the mountains, describes some of the changes he himself recollects.

"In the year 1920, just after my return from the First World War, I paid my first visit to the Kosciusko Plateau. On the first afternoon, when I rode from Hotel Kosciusko on to Crackenback Range and down to Boggy Plain, my horse became restless when I endeavoured to force him to cross the valley. Suddenly he sank to his belly in a soak, or peat bed. After we had extricated ourselves from the black peat, a horseman rode up, an old shepherd who had spent most of his lifetime on the ranges. He had been gathering sheep which had been missed in the general round-up before departure to the lowlands for winter. The old stockman gave me a hand to clean my horse and told me that when he was a lad, Boggy Plain was one huge bog, covered with *Sphagnum* moss three and four feet deep, beneath which lay deep peat beds. He said it was rubbish and the locals burnt it to improve the country, to make grass. He also said the only place affording a crossing was at the later roadway—even the old road along the Crackenback swung round to this crossing . . . I mention this as an illustration and example of the change that has taken place, not only here, but all over the ranges. Over the years by gradual burning, and finally during the devasting bushfires of 1939, great areas of moss and peat have been destroyed. I remember when I rode again over this area after the fire, the peat bogs were burning for weeks; and now it can be crossed anywhere along the valley."

The field evidence in the form of partly humified and humifying peat, relic bog vegetation, and contraction of the remaining communities, supports this completely. Another telling piece of evidence is the course followed by the snow pole lines on the Bogong High Plains, which in terms of existing conditions makes long and unnecessary detours to the heads of valleys to avoid bogs which are now no more. At the time when these snow poles were put in it can be assumed that the valleys which can now be crossed so easily were too wet and boggy to be safe.

Present-day bog trends can now be examined in greater detail in the light of the above information.

Relatively few undamaged bogs, characterized by discontinuous *Carex* hollows separated by *Sphagnum*-shrub hummocks, remain today. The best remaining examples are the Ginini bogs in the Cotter Catchment of the Australian Capital Territory, where there has been little grazing and few fires. These bogs, which consist of a large proportion of active *Sphagnum* moss showing hollow-hummock development, extend right across the valley floor. Although the valleys have a considerable gradient, the streams are small and almost completely stable over most of their course, as shown by the riparian vegetation along their banks and the aquatic vegetation including algae along the stream bed. Along considerable stretches the stream disappears altogether beneath a continuous cover of bog vegetation and peat. Near the knick points on Ginini and Stockyard Creeks, where the valleys change from a broad to a narrow rocky condition, the rate and volume of stream flow increases suddenly. This closely approaches the natural stream conditions, described in Section III(*a*). The Snowy Flats bogs, a few miles south of Ginini, are also in a more stable and active condition than most of those in the Australian Alps. Elsewhere in the high country of New South Wales and Victoria as a whole, the few undamaged bogs are largely restricted to wet rocky places or other situations of difficult access, or where the bog is so large that extensive bogginess has prevented livestock from entering far into it.

Slight to complete bog deterioration is now the general condition. Under existing land use, furthermore, this deterioration is continuing, since even with low overall stock numbers selective grazing results in overstocking of the bogs, and soil infiltration capacity remains impaired on a catchment scale (cf. Australian Academy of Science 1957, p. 49). The breakdown of the internal bog drainage system means that more water is able to flow over the bog surface. This produces drainage channels which on the steeper slopes develop into gullies. The consequent lowering of the water-table causes the peat to dry out and commence to humify. Once the surface peat begins to dry out, a partly irreversible stage has been reached, since dried-out peat is difficult to rewet and the bog surface either erodes, if the changes are rapid, or commences to humify. The humification is accompanied by considerable shrinkage and cracking, and the original bog surface subsides.

When these changes occur fairly slowly (as over an estimated period of about 20 years) the vegetation appears to be able to make a fairly stable adjustment. If the drying out is not accompanied by fires, the *Sphagnum* moss and associated helophytes are increasingly replaced by shrubs leading gradually to dominance by *Epacris serpyllifolia* auctt. (non R. Br.) in communities referable to the *Epacris serpyllifolia–Kunzea muelleri* heath alliance. If, however, fires also occur—and this means that selective grazing is heavier—the shrubs are usually replaced by the rigid-leaved swamp form of snow grass to form communities referable to the *Poa caespitosa–Danthonia nudiflora* sod tussock grassland alliance. If, on the other hand, the drying out, humification, and shrinkage of the bog are rapid, subsequent stability may not be achieved. As before, there is development of heath and grassland vegetation, but the strong development of shrinkage cracks within the peat leads to tunnelling erosion followed by a very rapid breakdown of the bog into actively entrenching gullies (e.g. in the valley of Little Digger's Creek near the Kosciusko Hotel, Teddy's Creek near Snowy Plains, and the head of Bennison Creek in Victoria). This is the mode of development of many of the fast-flowing peaty streams now accepted as natural in the Australian Alps (see Section III(*a*)). Rapid erosion finally results in the stripping off of the peat to wet rock or gravel and colonization by various naturally restricted plants including the snow patch species mentioned earlier.

To what extent recovery could now be achieved is an important question for catchment interests. That mere protection from trampling and similar mechanical disturbance can reverse the downward trend on bogs in more favourably situated places (e.g. wet, almost level situations) is apparent in many areas. Thus, on the moist Baw Baw Plateau, which is now only lightly grazed, many bogs which were badly fire damaged in 1939 have since made active regrowth. On the Bogong High Plains, a bog fenced off by the State Electricity Commission of Victoria in 1945 at the request of the Melbourne University Botany Department has started to recover over the last few years. Many of the bogs of the Kosciusko Hotel Water Reserve, which is stock free, have also made noticeable recovery since the 1939 fires, in contrast to the bogs outside the enclosure where grazing has continued (Plate 15, Fig. 2).

On the other hand, where deterioration is advanced, or where conditions of slope or exposure are almost critical, protection alone is insufficient. In some of these instances, however, artificial assistance in the form of check dams and water spreading structures can could swing the balance, as on Mt. Buller in Victoria (Costin 1957*a*, p. 66).

(j) Carex gaudichaudiana *Alliance*

Like the *Sphagnum* bogs, the fens of the *Carex gaudichaudiana* alliance have been much modified by land use. In their natural condition these communities have a rather sparse cover of *C. gaudichaudiana* Kunth sometimes with associated helophytes, and are underlain by compact deposits of acid peat or by organo-mineral acid marsh soils. Typically, the fens occupy permanently wet basin situations, but they can also develop on gentle slopes. The compactness of the peat enables the water-table to be raised locally several feet above the general level of the water-table, and there is convincing evidence in the form of deep deposits of peat, that this has been happening in many places for thousands of years (e.g. near the Kosciusko lakes and in the Upper Snowy Valley).

Once the surface drainage of the fen is disturbed, however, enabling water which was formerly pooled on the broadly concave surface to run off, the building-up process can be stopped. The fen may then be eroded down to the underlying gravel or rock, as in the snow patch areas between Carruther's Peak and Mt. Twynam, in the arm of Geehi Creek west of Kosciusko, near Mt. Townsend, and in numerous places along the Upper Snowy Valley. One of the reasons for the rapidity of this peat erosion is the fact that dried-out peat is difficult to rewet. Under these conditions revegetation is difficult and wind and water erosion follow. In places, the field evidence can again be checked against historical evidence. In the Mt. Townsend area, a small fen-lake called Russell Tarn existed at least up to the close of last century (Helms 1896). The tarn subsequently disappeared (cf. Browne and Vallance 1957) until by 1946 (at the very latest) only remnants of the much-eroded fen peat remained (Plate 8, Figs. 1, 2).

The high palatability of the sedge *Carex gaudichaudiana* results in overgrazing of the fens regardless of the overall stocking rate. The result is that very few undamaged fens remain in the Australian Alps today; many have disappeared entirely and most of the rest are deteriorating under grazing pressure. The removal of grazing influences could be expected to start recovery in those fens on which the internal surface drainage pattern had not been broken down, but where this breakdown has occurred already fen deterioration can be expected to continue. In these instances the vegetation often changes to grassland communities of the *Poa caespitosa–Danthonia nudiflora* alliance.

(k) Effects of Other Activities

The changes described so far have been those initiated by fires and grazing, both of which have been of general occurrence throughout the Australian Alps. More recently, engineering, and to a less extent tourist and forestry activities have caused more restricted but locally serious damage.

Prior to the construction activities of the Snowy Mountains Hydro-Electric Authority in the Snowy Mountains and the State Electricity Commission of Victoria on the Bogong High Plains, the adjacent major rivers did not discolour after heavy rains to the extent that they discolour now. In the Snowy Mountains in particular Clayton (1956) emphasizes the seriousness of roadside erosion damage along the Snowy Valley and in the Cabramurra area, not to mention extensive access tracks and transmission line roads. The proximity of many of the roads to the rivers means that the eroded soil is discharged almost directly into them, and that some slopes, barely stable under natural conditions, are undercut and rendered liable to landslide damage (Plate 18, Figs. 1, 2). Extensive clearing in the Cabramurra fire-break area resulted in the loss of approximately 75,000 cu. yd. of soil during heavy rains in 1954. Despite the relatively small areas directly affected by these activities, therefore, the seriousness of construction damage should not be underestimated, especially as many of the vulnerable subalpine and alpine areas have continued to deteriorate after the road- and track-making operations have ceased. Large sums of money are now being spent on remedial measures.

Similarly, access tracks associated with tourist development in the Kosciusko summit area, on the Perisher Range and on Mt. Buller and the Buffalo Plateau in Victoria, have initiated downgrade trends which are rapidly accelerating. To a less extent, forestry operations have produced similar problems, as in the Tolbar State Forest in the Snowy Mountains and in the Mt. Stirling area of Victoria.

(l) Summary of Trends in Individual Land Units

Before proceeding to discuss the interactions and significance of the various trends in the main communities, the discussion to date can be summarized as follows:

Certain types of areas have been little affected by fires or grazing or both, and can be expected to remain stable, provided they continue to escape these influences. These areas include the few remaining stands of more or less natural forest, subalpine woodland, sod tussock grassland, and tall alpine herbfield; the fjaeldmark and heath alliances (which are not particularly palatable); and the largely inaccessible communities such as the chomophyte herbfields.

Mostly, however, the communities have been damaged by fires and grazing and are unstable. Most areas of forest, subalpine woodland, heath, sod tussock grassland, and to a less extent alpine herbfield and bogs should regain a stable condition similar to the original climax, if given the chance to do so. In certain instances—e.g. in some of the forests, subalpine woodlands, and heaths—protection from fire alone would be sufficient; mostly, however, protection both from fires and grazing would be required.

A minor but important number of communities have been damaged so badly, or are so susceptible to disturbance, that they will continue to deteriorate even if completely protected both from grazing and fires. These communities include badly damaged tall and short alpine herbfields, sod tussock grassland and upper subalpine woodland areas, and bogs and fens. In these cases irreversible changes have been initiated which can now continue and accelerate under the impact of natural forces alone.

More locally, engineering, tourist, and forestry activities have caused rapid downgrade trends. In the more favourable situations, these trends can be expected to revert towards stability following the removal of the disturbing agent, but in the more difficult environments supplementary conservation measures are also required.

In contrast to this general picture of instability and change, the situation before human disturbance was one of stability and active up-building. In the forests and subalpine woodlands the presence of old, uneven-aged stands of trees with a comparative lack of fire scars in their early history indicates conditions of natural replacement without or with only occasional major disturbances by bushfires. Similarly, the shrub, grassland, and tall alpine herbfield communities were stable and in places were extending the soil-plant mantle over steeply sloping surfaces; this is obvious from the ubiquitous "vegetation lines" which have been only recently exposed by the removal of soil and vegetation from rock surfaces. The long stability of the bogs and fens and of the still more difficult snow patch environment is evident from the depth of the underlying peats, representing accumulations of several thousand years. The most wind- and cold-exposed situations also carried stable fjaeldmark vegetation.

III. Trends in Land Systems and Hydrological Implications

It is now possible to examine the hydrology of undisturbed environments, in terms of typical vegetation sequences in the alpine, subalpine, and upper montane tracts, then to examine the hydrology of disturbed areas at the present time.

(a) *Alpine Tract*

Figure 1 shows a typical topographic sequence of vegetation in the alpine tract; locally, the tall alpine herbfields are replaced by the wind-exposed type of fjaeldmark in very exposed places, by chomophyte herbfields on cliffs and steep rock faces, and by heaths in rocky and relatively snow-free situations. This hydrological pattern is more complex than the simpler drainage systems of steeper mountains such as the Alps of Europe and New Zealand, where bedrock is close to the surface and bogs and fens are relatively unimportant. Similar complexity is also found in the subalps.

Water received as rain or snow on the summit herbfields rarely flows over the surface.* In Figure 1 water is pictured as entering the soil and moving downwards, mostly into the deeply weathered substrate to reappear in the valley below or in a lower catchment area; some of the water, however, reappears as hillside springs, usually marked by the presence of bogs. The cold-type fjaeldmark vegetation of the upper snow patch areas, although largely bare, produces little overland flow, owing to the very rocky and porous nature of the soils (lithosols). Part of the water derived from the late-lying snow patches passes over the carpet of short alpine herbfield vegetation, but it is soon absorbed into the substrate or by adjacent bogs. Most of the snow-water and rainwater derived from the hillside herbfields also moves into the substrate; the small part of it which appears as hillside springs is taken up and subsequently released by bogs. Towards the base of the slope where a continuous water-table appears in the soils for the first time, more extensive bogs

* The main exception is in spring and early summer if the snow slimes have not been washed off the leaves by spring rains; under these conditions slime-encrusted vegetation hardened by exposure to sun may produce considerable surface flows. After heavy rain and periods of rapid snow melt, detention-storage flow sometimes occurs through the herbaceous layer, but this is not to be confused with actual overland flow.

and fens are found. Water movement from these areas under natural conditions is by oozing rather than flowing. Helms (1896) noted that these valleys "have no surface outlets for water, or only to a limited extent".

On this general pattern is superimposed the sequence down a hillside watercourse, consisting for the most part of bogs, broken by heaths in the rockier places. Each bog acts as a tiny check dam, reducing the velocity of flow, so that the water discharged to the main valley reaches it gradually with minimal scouring of the main bogs and fens.

Under natural conditions in the alpine tract, the well-defined, permanent creeks are largely restricted to the narrower, rocky valleys, and to steep watercourses joining hanging valleys to the main valley below.

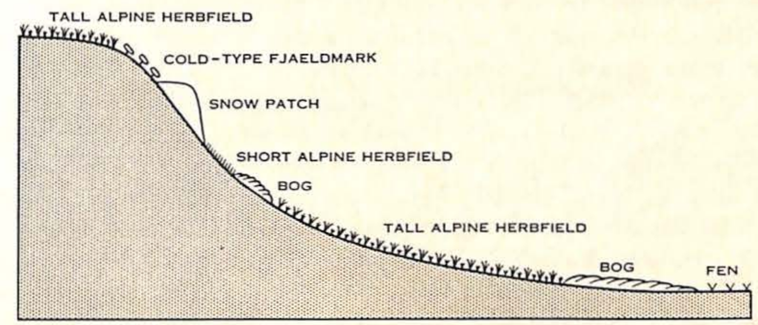

Fig. 1.—Topographic sequence of vegetation in the alpine tract.

Hydrological conditions on damaged alpine slopes present a marked contrast. Locally severe damage on the summit herbfields exposes bare soil which extends under the erosive action of wind, water, and frost, producing a "flood-source area" large enough to produce overland flow (Plate 4, Figs. 1, 2). If this overland flow occurs over the "well-drained" herbfield form of snow grass during the growing season, it can kill the grass and subsequently gulles may develop (Plate 5, Figs. 1, 2). Such overland flow continues over and beneath the snow patch, producing rills and gullies through the short alpine herbfields at the base (Plate 6, Figs. 1, 2). These gullies deepen and cause drying out of the snow patch peats, often followed by erosion, down to gravel or rock (Plate 7, Figs. 1, 2). Similarly, if entrenchment develops in the hillside bogs, the resultant overland flow on to adjacent tall alpine herbfields can lead to the death of the snow grass, with subsequent gullying; in this way hitherto unrelated bog communities on different parts of a slope separated by healthy herbfield areas become united in drainage by the development of gullies between them.

The result of increasingly channelized flow* towards the main valleys is that the extensive bogs and fens which occur there, themselves often damaged by grazing and fire (Plate 8, Figs. 1, 2), are no longer able to absorb all of the water received, and they too become entrenched (Plate 9, Figs. 1, 2). This entrenchment also taps

* This discussion of stream entrenchment and sedimentation is also relevant to the lower tracts.

large reserves of water in the adjacent bogs and fens, resulting in a permanent creek where formerly none existed. The flows of these unnatural creeks (Plate 10, Fig. 1) differ from the flows of natural watercourses (Plate 10, Fig. 2). The creek at first develops pronounced meanders, as the soft peat into which it cuts vertically is equally susceptible to lateral erosion. In time, the stream may scour through the peat until rock bars are exposed; these reduce the rate of vertical erosion. Lateral stream bank erosion continues, however, with the cutting off of existing bends, the formation of new ones, and the continual widening of the creek, which discharges water with increasing rapidity. Once this entrenchment has become well established it is irreversible except by human assistance in the form of water spreading and check dams.

These conditions are now so widespread that most people accept them as natural, although the contrast to natural streams is usually fairly clear-cut. A natural mountain stream (e.g. Blue Lake Creek, below Hedley Tarn) usually flows through a narrow or steep-sided valley, whereas the induced streams occupy a wide and flat valley floor. Both types of stream are fast-flowing but the natural stream is comparatively straight while the induced stream meanders. The natural stream has rocky sides (or is stabilized by vegetation to the water's edge) and flows over rock (or stable aquatic vegetation); this constitutes a stable watercourse and there is negligible stream bank erosion. The unnatural stream has bare peat sides, usually flows over peat, is actively eroding both laterally and vertically, and lacks stable stream bank and stream bed vegetation. The vegetation of the natural streams is typically a riparian heath referable to the *Podocarpus alpinus–Oxylobium ellipticum*, or tall alpine herbfield communities of *Danthonia frigida*, whereas the vegetation of the unnatural streams is typically transitional from bog or fen towards sod tussock grassland with relic stands of the original hygrophilous vegetation, notably those dominated by *Richea continentis*, *Restio australis* R. Br., *Calostrophus lateriflorus*, and *Epacris serpyllifolia*.

From these descriptions of natural and induced streams it should not be assumed that free-flowing creeks did not exist naturally in some of the broad, boggy, or swampy mountain valleys referred to. In large catchments of high precipitation the point must come where the slope either down or across the valley produces stream flow. Such natural streams, however, conform to the description given above. Thus, although in these instances the streams flow through and over peat, both the stream banks and its bed are stabilized by riparian (often *Sphagnum* moss) and aquatic (usually *Carex* spp.) communities, which, furthermore, offer considerable frictional resistance to flow. Stream behaviour in these valleys is instructive. The low-stage, non-scouring flows are carried in the stream channel itself. In view of its small volume, tortuous course, and obstruction by riparian and aquatic vegetation, the channel readily overflows, spreading water over the boggy or swampy valley floor. At such critical periods, the actual stream channel carries only a small fraction of the total flow. Peak flows at the end of the valley are correspondingly subdued. On the other hand, these peaty streams are obviously susceptible to disturbance, which initiates the lateral and vertical scouring described above. As this scouring increases, the capacity of the stream channel also increases, so that an ever-increasing

proportion of flood flows is carried in the stream channel itself, virtually without overflow on to the valley as a whole. In this way stream erosion and peak flows become increasingly self-accelerating and irreversible processes.

These processes of catchment deterioration are accompanied by considerable soil movement, although the fate of this soil is not always apparent. Large quantities of soil have definitely been removed from many areas, especially the higher summits such as Mts. Loch, Hotham, Feathertop, and Bogong in Victoria, and the Gungartan and Kosciusko areas in New South Wales. During the last 50 years more than one million tons of soil have been eroded from about 3 sq. miles of the Carruthers–Twynam area alone, about half the capacity of Guthega Pond a few miles downstream. Inspection of the many hillside bogs which naturally play the part of small check dams shows that these areas are receiving large amounts of soil material, as are natural depressions (Plate 11, Fig. 1). The best example on a large scale is the swampy cirque between the eroded slopes of Mt. Twynam and Blue Lake, which until a short time ago was peaty to the surface and now contains up to a foot of eroded soil (Plate 11, Fig. 2). However, this siltation process cannot go on indefinitely. The natural storages have so far been able to absorb much of the eroded material but in many areas "soil-saturation" point has almost been reached. The removal of the arrested silt appears to be catastrophic in nature, inasmuch as a deposit built up over several years can be partly destroyed during a single very heavy rainstorm. The recent accumulations of large bars of sand and gravel in creeks where they were inconspicuous even 10 years ago (e.g. Carruther's Creek, Spencer's Creek, Bett's Creek, Upper Perisher Creek, and Dicky Cooper Creek) can be interpreted as evidence that some silt traps are now starting to break down (Plate 12, Figs. 1, 2). There is field evidence that the sediment in these bars moves largely as bed-load; therefore, it is not detected in the standard sediment surveys which measure only suspended material and are based on the assumption that there is turbulent flow.

The fate of the peat eroded from entrenched hillside and valley bogs and fens is also interesting. The extent of recent lateral and vertical stream erosion shows that large quantities of peat have been removed, but owing to the fact that it goes rapidly into a finely suspended or colloidal condition, it is not detected in usual silt surveys. Even during periods of normal flow, however, many streams now have a perceptibly brownish tinge, indicating that peat erosion is occurring higher up, and if inspected during low flows they are found to contain murky patches of temporarily deposited peat.

(*b*) *Subalpine Tract*

In subalpine areas the hydrology is similar to that described for the alps. A typical vegetation pattern from near tree-line to a lower subalpine valley floor is shown in Figure 2; heath vegetation may be superimposed locally in rocky places and, as in the alps, steep downslope watercourses consist of many boggy sections interspersed with riparian heaths.

Under natural conditions, overland flow is uncommon, although detention-storage flow through the herbaceous sward is sometimes considerable. This detention storage is well shown in the broad subalpine valleys of the north-western Monaro

(Tantangara etc.) where heavy rains produce several inches of water *between* and *among* tussocks over most of the valley floor. The replacement of such a coarse, tussocky surface by a smooth one in the form of a closely grazed pasture, reduces detention-storage capacity and thus produces surface run-off with the danger of channellized flow through the valley.

Damaged snow gum areas commonly develop into "flood-source areas" (Plate 13, Fig. 1), as do the summit alpine herbfields. Where deforestation occurs *en masse*, the resultant extremes of wind and low temperature may exceed the capacity of the tree seedlings to re-establish themselves. One of the most strikingly hydrological effects of this treeless condition is that less snow is accumulated, often exposing the soil to frost action when normally it is protected by a mantle of winter and

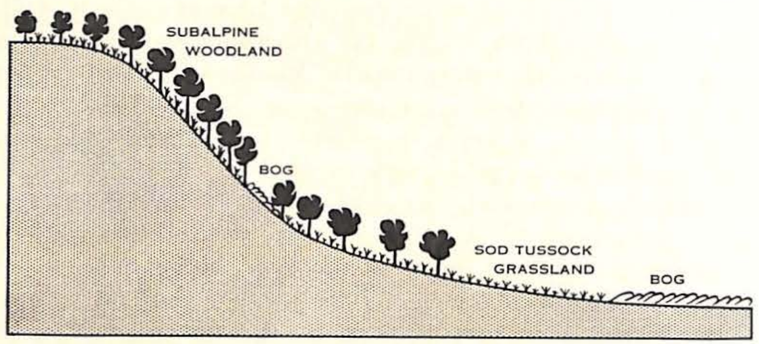

Fig. 2.—Topographic sequence of vegetation in the subalpine tract.

early spring snow. This is seen along parts of Disappointment Spur above the Munyang River and the watershed between the Crackenback and Snowy Rivers in the Kosciusko area. The exposed soils sometimes remain frozen for extended periods in which condition they are largely impervious to moisture and can produce overland flows. As far as actual water yield is concerned, the loss of snow from the higher deforested areas, especially those situated along the watersheds themselves, means that less water is available to the higher streams, and that some of the snow blown over into the lower catchments melts sooner, thus increasing the intensity of the spring thaw floods at the expense of more sustained water yield. The duration of the melt period, and hence the usability of the water, is also reduced by as much as one month, in the absence of trees. Surface run-off during the growing season can kill the "well-drained" form of snow grass of lower slopes and initiate gully formation. The hillside bogs, damaged by siltation and overland flow, also discharge water rapidly towards the sod tussock grasslands and bogs of the lower slopes and valley floor (Plate 13, Fig. 2), where entrenchment occurs (Plate 14, Figs. 1, 2). Examples of recent creek formation with vertical and lateral erosion are so numerous as to constitute the general condition throughout most of the Australian Alps. In the Snowy Mountains area the Big Bogong Swamp, Finns Swamp, Boggy Plain, and Snowy Plains are typical examples.

The Hotel Kosciusko area provides an example of the relation between catchment condition and rate of erosion both from the catchment as a whole and from

the stream banks. The upper catchment area of Digger's Creek supplies water to a reservoir for use by the Hotel. The catchment was fenced off from grazing immediately after the 1939 fires. Excellent regeneration of snow gum has since occurred, and most of the bogs are in an active condition. Snow surveys have shown that the spring thaw is more prolonged in this catchment than on adjacent unforested land. The reservoir in the protected catchment shows only minor siltation and the valley floor leading into it is covered by a large active bog in which there is little scouring of watercourses (Plate 15, Figs. 1, 2). The adjacent catchments which have continued to be grazed show less regeneration of snow gum and bogs, and the valley of Little Diggers' Creek above the Hotel Kosciusko Lake is actively scouring. Since 1939 the Hotel Lake, into which the grazed catchments drain, has developed a silt bar about 40 yd long and 60 yd at its longest point (Plate 16, Figs. 1, 2).

(c) *Montane Tract*

A more or less natural upper montane environment consists mainly of well-grassed, uneven-aged sclerophyll forest, broken by tall natural meadows of tussocky *Poa*. Steep hillside gullies contain *Sphagnum* bogs. As at the higher elevations, these natural conditions produce little overland flow, and when in the meadows surface flow occasionally occurs, the tall tussocks spread the water and reduce flow velocities to a minimum.

In damaged forests, the development of partly bare soils is usually accompanied by the replacement of the tall tussocks of the meadows by a short, closely grazed sward of naturalized clovers and fine grasses on which detention-storage capacity is comparatively small. The overall result is that increased flows from the forests reach the short-grazed meadows which become channellized to form gullies and creeks. This further hastens the movement of water down to lower levels. These contrasting conditions are seen side-by-side in the Upper Cotter River area above the Old Cotter Homestead, and along Old Yaouk Creek and adjacent tributaries of the Murrumbidgee, a few miles to the south. In the Upper Cotter area, where there has been virtually no grazing for about 40 years and few fires, the sclerophyll forests are well grassed and the flats are covered by tall tussocky *Poa* up to 3 ft high, virtually without continuous surface drainage lines (Plate 17, Fig. 1). In the heavily grazed and frequently burnt Yaouk area, on the other hand, the forest floor is poorly grassed and the *Poa* flats have been largely converted to a smooth, short sward in which small creeks are actively forming (Plate 17, Fig. 2).

Since it is the alpine, subalpine, and upper montane country which supplies most of the water to the mountain-fed streams of south-eastern Australia, the changed hydrological conditions in this higher country must be producing corresponding changes in the lower reaches of these streams.

IV. Ecological Principles in Relation to Conservation and Land Use

Notable features emerging from earlier work (Costin 1954, 1957*a*) and from the present study are the variation in trends in one and the same mountain area, and the variation between different areas.

Each area, except the largely stable and up-trending Cotter Catchment, shows a complex of conditions, with well-marked downward trends in one or more land units or parts of them and stable or uptrending conditions in others. These differences result from the wide variation in grazing intensities within an area and from varying susceptibilities to disturbance.

The variations shown between different areas—for instance the Baw Baws and Echo Flat with a large measure of recovery, the Buffalo Plateau and Kosciusko area with widespread deterioration, and the mountains of the Cotter Catchment in a generally stable or upgrade condition—are related to differences in the natural environment and in the intensity of past and present use. The relatively oceanic climate of the Baw Baws and Echo Flat has favoured greater recovery than the more continental conditions of the Snowy Mountains and the Buffalo Plateau. On the other hand, the mountains of the Cotter Catchment, which also experience continental summers, are more stable than the adjacent Snowy Mountains area, on account of their comparative freedom from recent grazing and fires. In most cases there is sufficient evidence that protection from fires and grazing will check deterioration and encourage upward trends, although this recovery is to be reckoned in terms of decades rather than years. The main exceptions to this generalization are severely damaged areas in difficult environments, where stability has never been restored despite many years' protection from grazing and fires. In such cases supplementary conservation measures are also required.

A number of principles emerge from this study, which have application to problems of land use and resources conservation in general. These are the non-parallelism of soil and vegetation trends, both between different areas and on the same area; the irreversibility of trends; and the significance of flood-source areas.

That there may be non-parallelism of trends between different areas is obvious enough when they differ appreciably in their reactions to the same combinations of influences. This requires little comment, except to say that it is still largely ignored in land use.

The second case of non-parallelism of soil and vegetation trends—on the same area—is rather less obvious. Most ecologists and conservationists favour the view that soil and vegetation change in the same direction, whether it be up or down. In most cases this is true, and, if the time interval is long enough, it is always so. However, there are cases when soil and vegetation trends may move in opposing directions for considerable periods. In unfavourable environments, initially severe disturbance of the soil sets downward trends in progress. Because of the depth of the solum, however, some of the surviving plants may continue to grow for the rest of their life-span, which in the case of shrubs may be as long as about 20–30 years. Vigorous annual and short-lived perennial herbs (e.g. sorrel) may also reproduce themselves, particularly if soil erosion is largely confined to short periods of the year, and this may continue until the soil mantle has been reduced almost to the underlying rock. An important implication of this non-parallelism of soil and vegetation trends on the same area is the relative weights which should be given to soil and vegetation condition.

It has been seen that a relatively large area of stable or upward-trending country can be changed in a downgrade direction by the impact of damage from an adjacent downgrade area. In the Australian Alps the best examples of this interaction of trends are in the summit areas around Mt. Twynam and Carruther's Peak, where damage initiated near the tops has spread not only sidewards and downwards but also upwards (by wind and frost action) into larger areas of hitherto undamaged or recovered land. The accelerated run-off from the damaged sections has also destroyed hillside snow-patch areas and bogs, finally resulting in entrenchment and erosion of valley-bottom bogs and fens removed from the original source of damage. In many parts of the Australian Alps (e.g. Kosciusko, Mts. Bogong, Loch, Hotham, and Feathertop) this interaction of trends with resultant extension of downgrade areas has reached irreversible proportions, and is producing large areas of bare rock and rubble which from the successional viewpoint are a return to the early post-glacial conditions of thousands of years ago. Land use planning should give consideration to all areas which directly or indirectly influence a particular piece of land, and all areas which are affected by it.

Most damaged areas are usually capable of recovery following the removal of the disturbing agent. In very unfavourable situations, on the other hand, slight damage can initiate downgrade trends which continue and even accelerate, after the disturbing agent is removed. This suggests that, although the pre-grazing period was one of stability and upward-trending (cf. Section II(*l*)), all of the high mountain land units were not necessarily in harmony with the macroenvironment in all areas. Climax vegetation may continue to maintain itself and spread slowly by virtue of a favourable microclimate partly of its own making, under macro-climatic conditions which are unfavourable for the revegetation of extensively eroded areas or the colonization of new ones. This situation obtains in the badly damaged alpine herbfields and subalpine woodlands in exposed situations on the Alps. In these cases it seems necessary to postulate more favourable post-glacial conditions (milder and moister summers, with fewer frosts and strong winds) to account for the development of these communities to the limits to which they now extend. Other vegetational evidence from the Monaro region (Costin 1954) also indicates that these more favourable post-glacial conditions prevailed. In these instances, the requirements of successful land use are clearly more stringent and precise than for most types of land, since management practices, besides conforming to conventional needs, must also preserve the microenvironment if long-term stability of the soil-vegetation system is to be safeguarded.

The preceding discussion points to the importance of flood-source areas. Many examples have been given, ranging in size from a few square yards to whole watersheds and adjacent slopes. At the one extreme are damaged patches near the top of steep slopes from which overland flow on snow grass during the growing season can kill the grass and initiate gullying. At the other extreme are more extensive plateau areas situated at the watershed from which overland flow not only causes gullying on adjacent slopes but also causes entrenchment of extensive bogs along the valleys, producing permanent creeks where they hardly existed before. Because of the variable significance of damage in different areas, ranging from the most critical summit flood-source areas to those which can recover even from severe damage, information commonly presented in standard erosion surveys can be misinterpreted. For example, up to about 50 per cent. of a certain catchment may be moderately damaged, with the damage spread uniformly as numerous small, discrete openings over the whole of the catchment area, but there may be few damaging overland flows. On the other hand, if about 20 per cent. of a similar catchment is damaged but this damage is more concentrated as larger openings permitting greater opportunities for overland flow, quite serious flooding and soil losses may result. Finally, if only 10 per cent. of an otherwise similar catchment is damaged, but this damage is concentrated on the watershed itself (which usually receives the heaviest precipitations and on which the opportunities for overland flow are greatest), overland flows from the damaged watershed section can cause serious floods and erosion on adjacent undamaged land.

A recent example was the behaviour of the Snowy River following the rain of December 29, 1957, when 5 in. were recorded at Spencer's Creek and probably about 8 in. fell along the Main Range itself. Although the rain fell steadily, it was not exceptionally heavy (about 1 in. an hour maximum intensity at Spencer's Creek), nor were there many late-lying snow patches from which much snow-melt run-off could be produced. However, the flow of the Snowy River at Guthega exceeded 14,000 cusecs (average late December flow about 200 cusecs), and produced unexpected flooding at Waste Point and Jindabyne downstream. Subsequent inspection of most of the flood-source areas (including vehicle tracks) showed they had been the origin of high and apparently violent flooding in the streams below them, and the source of locally very heavy soil loss (on bare areas of Carruther's Peak an average of about 1 in. of soil).

The significance of flood-source areas is now becoming recognized in the United States where it is accepted that unless repairs are effected immediately when the damage is small the expense of tackling the work at a later stage may be prohibitive. On the Wasatch Plateau in Utah, for example, reclamation costs on 1300 acres of flood-source areas amounted to 300,000 dollars, representing an investment of 230 dollars per acre (Bailey, Craddock, and Croft 1947). At Carruther's Peak near Mt. Kosciusko a reclamation trial by the Soil Conservation Service of New South Wales on about 2 acres of flood-source area amounted to several hundred pounds per acre, and this does not include a considerable amount of maintenance and follow-up work which will be needed in future years.

V. Acknowledgments

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Appendix I

Detailed Maps

The distribution of the high mountain areas referred to in this paper is shown in a preceding publication (Costin 1957*b*, Fig. 1). More detailed information can be obtained from the maps listed below.

Victoria:

Baw Baw Plateau (Victorian Mountain Tramping Club).

Macalister River Watershed (Victorian Mountain Tramping Club).

Dargo High Plains (Forests Commission of Victoria, Dwg. No. 55–G/111).

Tourist Map of Mt. Buffalo National Park (Victorian Railways).

General Plan of Kiewa Scheme (Dwg. No. O.E. 49/16/8B, State Electricity Commission, Victoria).

New South Wales:

S.M.A. 1 in. series (2nd Ed.), covering Snowy Mountains Area (Snowy Mountains Hydro-Electric Authority, Cooma).

Australian Capital Territory:

Topographical Map of Australian Capital Territory and Environs (Department of Interior, Canberra).

Explanation of Plates 1–18

Plate 1

Fig. 1.—Natural stand of subalpine woodland near the Ginini Flats in the Australian Capital Territory, showing the mature, widely spaced trees, and the forb-rich herbaceous stratum containing suppressed snow gum seedlings.

Fig. 2.—Soil conservation enclosure at Long Plain near the head of Murrumbidgee River, showing regeneration of snow gum following protection from grazing.

Plate 2

Fig. 1.—Tall alpine herbfield near Mt. Townsend in the Kosciusko area, showing abundance of *Celmisia longifolia*, *Craspedia uniflora*, and *Euphrasia glacialis* Wettst., as well as snow grass. Since this particular area has been under observation (from 1946 onwards, two years after removal of grazing), the increase in forbs has been spectacular (cf. Gungartan area; Plate 3, Fig. 2).

Fig. 2.—Tall alpine herbfield in Kosciusko area showing prolific seeding of *Celmisia* and snow grass (cf. Gungartan area; Plate 3, Fig. 2).

Plate 3

Fig. 1.—*Danthonia frigida* on western slopes of Mt. Kosciusko, one of the several conspicuous herbs which has been increasing since grazing ceased in 1944. This and other species are virtually absent in the grazed Gungartan area.

Fig. 2.—Tall alpine herbfield, Gungartan, showing preponderance of snow grass, widespread development of intertussock spaces and bare areas, and relative lack of forbs and of flowering and seed production.

Plate 4

Fig. 1.—Eroding tall alpine herbfield, Carruther's Peak. In 1896 this area was described by Helms as being covered with vegetation. Damage was probably initiated by very heavy grazing during the 1895–1910 droughts. Although there has been little grazing since 1944, active erosion still continues. An irreversible trend has been set in progress which, in the absence of soil conservation works, will lead to the complete removal of the herbfield vegetation and soils.

Fig. 2.—This stripping of the plant-soil mantle from Carruther's Peak has produced extensive flood-source areas from which surface run-off is scouring through ground-water areas downslope.

Plate 5

Fig. 1.—Close-up view of eroding alpine herbfield in the Carruther's Peak area showing removal of plant-soil mantle as a face. The remaining rubble is being colonized sparsely by fjaeldmark species which were probably more common at the end of the last ice age.

Fig. 2.—Overland flow from flood-source areas onto undamaged herbfield during the growing season can kill the snow grass. Gullies may then develop.

Plate 6

Fig. 1.—Erosion of short alpine herbfield, Perisher Range. Although grazing has now ceased, the plant-soil mantle continues to be stripped off down to the underlying rock. Lower slopes are being adversely affected by the resultant overland flows.

Fig. 2.—Stable short alpine herbfield, near the Ramshead, showing the spreading of snow-melt water over the whole of the surface. There is no channelized flow, as in the damaged snow-patch area shown in Figure 1.

Plate 7

Fig. 1.—Large areas of bare rock are being exposed along the higher ranges. Many of these are accepted as natural, but closer inspection often reveals a recent origin. In this example, a few fragments of short alpine herbfield still remain.

Fig. 2.—The recently exposed rocks are fresh-looking without lichen growth. The original level of soil and vegetation is usually marked by a distinct rock line. Many flood-source areas commence in this way.

Plate 8

Fig. 1.—Erosion of fen down to the underlying gravel (centre of photograph). The detention-storage capacity of this area is correspondingly reduced. The bare area marks the position of Russell Tarn, described by Helms in 1896; the original peat bank of the lake is still partly visible.

Fig. 2.—Small fen tarn, near Mt. Townsend, of the type described by Helms.

Plate 9

Fig. 1.—Initiation of small creek in a fen below Seamen's Hut; channellized flow is now well established. The origin of this damage is the eroded bog visible above the centre of the photograph.

Fig. 2.—A similar area showing the natural type of flow during the spring thaw. The water is spread evenly over most of the valley, without scouring.

Plate 10

Fig. 1.—An unstable stream, Upper Spencer's Creek. The creek has formed in peat, in which there is very active stream bank erosion, resulting in the widening and deepening of the channel. Large sand and gravel bars have formed, from which there is appreciable transport of sediment downstream as bed-load.

Fig. 2.—A stable stream, below Mt. Townsend. The creek has stable banks and bed and is stabilized by vegetation to the water's edge. Sand and gravel bars are virtually lacking.

Plate 11

Fig. 1.—*Sphagnum* bog, acting as a small silt trap to an eroding flood-source area, near Gungartan.

Fig. 2.—Cirque above Blue Lake, acting as a large silt trap to the extensive flood-source areas near Mt. Twynam. The peaty surface of the floor of the cirque is abruptly overlain by sediment; the white areas are recently eroded stones and gravel.

Plate 12

Fig. 1.—Accumulation of sand and gravel bars in creek below the Carruther's flood-source areas. This material is moving downstream as bed-load.

Fig. 2.—Accumulation of sand and gravel bars in the Upper Snowy River.

Plate 13

Fig. 1.—Flood-source areas in the subalpine tract above Daner's Gap. The original tree cover has been destroyed by fires and grazing, and the herbaceous sward and soil are now being stripped off. In this exposed locality, these are probably irreversible changes.

Fig. 2.—Opening up of snow grass on lower subalpine slopes, near Happy Jacks. The resultant loss of detention-storage and infiltration capacity in the catchment has contributed to accelerated scouring and stream erosion along the once-boggy valley floor.

PLATE 14

Fig. 1.—Active stream scouring and erosion along Little Digger's Creek. The catchment has been badly damaged by grazing after fires.

Fig. 2.—An adjacent valley in the ungrazed Treffle Park area where there has been good regeneration. At high flows the water is spread right across the valley, with minimal scouring.

PLATE 15

Fig. 1.—Reservoir in protected catchment of Upper Digger's Creek. There is only minor siltation.

Fig. 2.—The broad boggy valley above the Reservoir. Active *Sphagnum* hummocks are in abundance and there is very little scouring and creek formation.

PLATE 16

Fig. 1.—Hotel Kosciusko Lake, which receives water from a large area of damaged catchment. The silt bar has advanced about 40 yd since 1939; the remains of an old pigeon loft mark the original edge of the lake.

Fig. 2.—An old photograph taken by the late George Petersen, formerly Manager of the Hotel, showing the original margin of the lake.

PLATE 17

Fig. 1.—The Upper Cotter Valley above the Old Cotter Homestead, showing the natural condition of the forest meadows. Entrenched drainage lines are virtually lacking. This area has been comparatively free from grazing and fires for a long time.

Fig. 2.—The Old Yaouk Creek area a few miles south. Burning and grazing have led to the replacement of the original tussocks by a short, palatable sward. This surface has a lower detention-storage and infiltration capacity, and recently formed creeks are actively cutting through it.

PLATE 18

Fig. 1.—An example of flood-source areas due to engineering activities along the Snowy Valley and Perisher Creek. Although occupying a relatively small area of the catchment, the proximity of the roads and tracks to major streams means that their contribution of sediment may be considerable.

Fig. 2.—Sediment deposited in the aqueduct intake on Perisher Creek.