THE CHANGING WEED FLORA OF AUSTRALIA

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Summary. Changes in the botanical composition and other characteristics of the naturalised alien flora are discussed. It is suggested that they arise from a) biological factors inherent in the plants, b) historical factors such as settlers' origins, external and internal lines of communication and the patterns of settlement, c) environmental factors such as the similarities between the sites from which weeds originate and those to which they are introduced and changes in the locations of various activities which influences the weeds that will be associated with the activity, and d) managerial factors including changes in soil fertility, grazing intensity and general farming technology and practices. A generalised sequence of weed types is suggested.

The composition of the weed flora is continually changing. In the short-term its composition varies amongst a suite of species within and between seasons; over longer periods the spectrum of species itself changes. Species formerly present disappear and new ones appear. As the actual composition of the alien flora at any time is undoubtedly the result of a combination of historical, environmental and managerial factors then the changes that occur in the alien flora must necessarily be regulated by the same forces. The alien flora can be reviewed on a species by species basis and changes recorded in the spectrum of species present either absolutely or in terms of relative abundance. Alternatively the flora may be considered collectively by examining various characteristics and monitoring changes in their relative importance.

In this paper some examples of changes in the characteristics of the naturalised alien flora are presented. I then discuss some of the forces responsible for these changes, focussing on the cropping systems of south-eastern Australia to which my own experience is largely confined and for which much detail is now available (1, 2, 3, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 43, 44). The reader is referred to these papers for the details of the alien flora of various periods and situations as reconstructed by the respective authors. The statistical data are derived from a major investigation of the alien flora of S.A. (24) and perforce are restricted to that State. It is believed that they are indicative of the situation prevailing throughout the mediterranean portions of Australia.

The word "weed" in the title will be defined very broadly as a plant interfering with human activity in one way or another and thus has come to be regarded negatively by at least part of society. The term "alien plant" refers to any established plant that has reached these shores in active or passive association with Man, regardless of its effects.

SOME CHANGES IN CHARACTERISTICS OF THE ALIEN FLORA

Taxonomy. There has been a remarkable consistency in the relative frequency of plant families through time but there is a decided trend in the ranking of genera in the naturalised flora of S.A. (28). By 1855 the best-represented families were:

(1) Poaceae, (2) Asteraceae, (3) Caryophyllaceae, (4) Brassicaceae, and (5) Fabaceae.

In 1984 the best represented families were:

(1) Poaceae, (2) Asteraceae, (3) Fabaceae, (4) Brassicaceae, (5) Iridaceae, and (6) Caryophyllaceae.

The first four families occupied identical rankings in the alien flora of Victoria and New South Wales (28).

In 1855 the numbers of species were too low for generic differences to be obvious but by 1909 the best represented genera were:

(1) *Trifolium*, (2) *Medicago*, (3) *Euphorbia* and *Bromus*, and (4) *Vicia*.

In 1984 the ranking was:

(1) *Trifolium*, (2) *Medicago*, (3) *Solanum*, (4) *Oxalis* and *Opuntia*, and (5) *Euphorbia*.

Geographical origin. The changes in the origin of the naturalised flora of S.A. between 1855 and 1984 may be seen in Table 1. At first a much higher proportion of plants originated from Europe/Eurasia but now the majority of naturalised plants are derived from other mediterranean areas.

Table 1. The origins of the South Australian naturalised flora in 1855 and 1984 (after ref. 29).

Origin	1855		1984	
	Number	Proportion	Number	Proportion
Mediterranean	25 spp.	25%	284 spp.	31%
Europe[a]	50	49	232	26
Eurasia[a]	9	9	41	5
Asia	–	–	11	1
Eastern Asia	–	–	11	1
Old World tropics	–	–	8	+
California	2	2	8	+
North America[a]	2	2	51	6
Central America	1	1	19	2
South America	4	4	63	7
South Africa	8	8	132	15
East Africa	–	–	9	1
Western Australia	–	–	5	+
South Australia	–	–	5	+
Eastern Australia & N.Z.	–	–	15	2
Garden origin	–	–	10	1
Total	101 spp.	100%	904 spp.	100%

[a]Excluding that area immediately preceding in the list.
+Less than 1% of total.

Growth forms. There has been a substantial fall in the proportion of annual plants and a consistent increase in other growth forms between 1855 and 1984 (Table 2).

Table 2. The growth forms of the South Australian naturalised flora in 1855 and 1984

	1855		1984	
	Number	Proportion	Number	Proportion
Annuals	74	73.2%	454	50.2%
Herbaceous perennials	21	20.8	298	33.0
Shrubs	1	1.0	76	8.4
Trees	1	1.0	36	4.0
Climbers	1	1.0	24	2.7
Aquatics	3	3.0	14	1.5
Parasites	-	-	2	0.2
	101	100%	904	100%

Mode of Introduction. There has been only a slight increase in the proportion of the naturalised flora that was introduced intentionally from 54% in 1855 (21) to 57% in 1984 (29). However, if we examine lists of introduced plants at Sydney in 1802-4 and Melbourne in 1856 (23), there are 45 species found in S.A. and at least one of the other colonies. These plants are assumed to have been the most "successful" being relatively widespread and are likely to have been particularly early colonisers. Of this group, only 24% were introduced intentionally. This would appear to support the intuitive conclusion that the earliest established weeds were those that were introduced accidentally.

BIOLOGICAL FACTORS

The stability of the relative frequencies of plant families and, to a lesser extent, genera, militates against change in the weed flora. It is beyond the scope of this paper to canvass the reasons, but the best-represented families as noted above are those generally regarded as "weedy" and in fact, on a world basis the same families are the largest in terms of numbers of species (12).

The generic rankings are remarkable for the fact that the best-represented are those whose species were largely introduced on purpose. It seems to be significant that the two most numerous genera in S.A. since at least 1909 are *Trifolium* and *Medicago*. Both these genera are regarded as desirable and consequently their introduction, establishment and spread are generally encouraged. Predictably therefore, they are equally prominent in the naturalised flora of Victoria (37), N.S.W. (18) and W.A. (13).

The first species to become successfully naturalised in southern Australia (29) were largely those that possess a "general purpose" genotype (5) because southern Australia was settled from northern Europe and for a long time its main cultural and trading links were with that region. Consequently, this facilitated the movement of species originating from a different environment from that of southern Australia so that only those with a "general-purpose" genotype were likely to thrive. Species originating elsewhere that had been brought to northern Europe previously, either intentionally or accidentally, also were brought here (29). Some of these were far better suited to southern Australian conditions than they were to northern Europe e.g. *Oxalis pes-caprae*, *Medicago* spp.

Such plants are characteristically annuals (5) and consequently that growth

form predominated in early weed populations (Table 2). Later the proportion of perennials rose substantially with the establishment of better-adapted species from more similar environments.

HISTORICAL FACTORS

Settlers' origins. Because of the relationship between weeds and Man their arrival at a new location is, by necessity, coincidental. It follows therefore that the weeds that colonise a location reflect the origin of the human settlers and the nature of their pursuits rather that the environmental characteristics of the new location itself (11). Thus because Australia and South Africa were settled largely from northern Europe, the first weeds of mediterranean South Africa (45) and South Australia (29) were those of northern Europe rather than other mediterranean environments. Conversely, California and Chile were both initially settled by the Spanish and their respective weed floras have always had a high proportion of Mediterranean species (16) which for California at least, were specifically noted to be of Spanish origin (35).

In time, the numbers and proportions of naturalised aliens originating from other mediterranean areas rose, and presently about half of the naturalised alien species of South Australia originated from such regions (Table 1). However, the mediterranean areas of the west coasts of the Americas are still under-represented and a gradual accretion of species from there may be predicted. In spite of the influx of species from the Mediterranean basin, there are still many species there which might successfully establish in southern Australia. Indeed, current fodder plant introduction procedures are designed to find, in a somewhat haphazard way, such plants having desirable characteristics. Consequently plant collecting trips are largely confined to the eastern and southern portions of the Mediterranean basin.

Therefore it may be concluded that, if southern Australia had been colonized by a Mediterranean nation, it is likely that the number and proportion of Mediterranean species would have been considerably higher, both initially and subsequently, as is the case in California (29). It may be argued therefore that the historical fact of northern European settlement of southern Australia had an inhibiting effect on the naturalisation of alien plants.

Lines of communication. The lines of communication which the settlers established between their countries of origin and Australia, and within Australia, are also relevant. It appears that most of the naturalised plants of South Australia reached there via Great Britain (29); of the 904 naturalised species at least 765 were native to Britain or had been introduced and grown there by the 1830s. The ornamental bulbs from South Africa and even the Australian species such as *Sollya heterophylla*, *Pittosporum undulatum* and *Albizia lophantha* which had been introduced to British horticulture before the colonization of South Australia (32), were almost certainly introduced to South Australia via Great Britain.

Patterns of settlement. Within the colony, settlement proceeded inland largely from Adelaide but also from outports such as Port Lincoln and Robe. The lines of communication tended to follow the same paths although the development of the grain trade led to the rise of many small outports served by coastal ketches. In a number of cases the port was the terminus of a railway serving the hinterland. The present railway and highway networks developed somewhat later. Although there is only limited documentation available, it is highly likely that the spread of weeds followed the lines of communications (29).

Additionally the movement of settlers from old areas that were overexploited to new areas as they were opened up would have been responsible for the spread of weeds. Settlers moving from the Adelaide Hills to take up cropping land in the north were probably responsible for the introduction of *Dittrichia graveolens* to that area. The migration of settlers from South Australia to the Riverina has been held responsible for the introduction of *Echium plantagineum* to the Albury area from where it eventually escaped (20).

The initial wave of settlement to the country as a whole, and to areas within it, established a weed population that seems to have been fairly similar in the various Australian colonies (23). The subsequent divergence in their composition resulted from differences in the environment and management of where the weeds were growing.

ENVIRONMENTAL FACTORS

Environmental factors such as rainfall and soil type exert a sorting effect on the alien species. Woody plants tend to be confined to higher rainfall areas or where runoff augments the natural rainfall. Soil type as characterised by pH, fertility level and physical composition, has a very marked differentiating effect on the naturalised alien flora. These effects are apparent in spite of levelling of the environment by the use of fertilizers and herbicides, the widespread sowing of similar species and cultivars and the use of the same general cultivation practices over wide areas.

Environmental similarities. It is a remarkable fact that weeds are highly likely to be moved from one particular environment to another very similar one. Consequently, if the weed thrived in the first, it was likely to succeed in the second, as the following examples illustrate. Ballast excavated from near a coastal wharf was likely to be dumped on the beach or nearby, at a new location. Strand plants contaminating the ballast were cast into a very similar environment to that in which they orginated. Ruderal plants growing on the dockside and adjacent city streets etc. attached to footwear, clothing and other paraphernalia as migrants gathered to board their vessels. When the passengers disembarked they moved into a similar environment of docks and streets and, although most of the propagules would have been dislodged during the voyage, those remaining could be introduced to a similar environment from whence they came. Contaminated seeds intended for sowing in gardens or field, were eventually planted in a cultivated seedbed approximating that in which the crop and weed seeds' progenitors had grown. Fragments of aquatic plants picked up in water barrels as they were being filled in freshwater sources could have been introducted to other similar water bodies when the barrels were being rinsed and refilled subsequently. Weeds adhering to animals' fleeces and coats from a pastoral environment had the opportunity to colonise a similar environment when the animals were eventually unloaded and put to graze at their destination.

Changes in location of an activity. For various reasons that will not be canvassed here, the location of land use activities may change with time. This was the case with cereal growing in South Australia, which originated in the Adelaide area where the annual rainfall is relatively high and reliable and the soils are around neutral. Subsequently, cereal growing spread through the southern Mt Lofty Ranges where the rainfall, in places, was even higher and the soils generally neutral to acidic. By the last decades of last century, cereal production moved from the hills to become centred in the lower rainfall, neutral to alkaline soils. With the clearing of mallee scrub, areas even more extreme with respect to aridity and alkalinity were farmed (14). The changes in the weed flora of South Australian cereal crops during the 150

years since settlement may be explained to a large extent by differences in the climatic and edaphic characteristics of the locations in which the crops were grown.

MANAGERIAL FACTORS

Long-term land managment decisions such as whether cereals in rotation, "natural" (i.e. unimproved, permanent, annual) pastures, shelter belts or reserves are maintained will affect the composition of the naturalised alien flora. In general, perennials are rare in rotations but as the frequency of disturbance decreases they become more common and herbaceous types will be joined by woody forms, if sufficient moisture is available.

Species respond differentially to seasonal conditions and to temporary managerial factors, such as phase of the rotation, and obviously there is an interaction between environmental and managerial factors. Changes in the weed flora caused by a number of factors amenable to influence by the land manager will be reviewed briefly.

Changes in soil fertility. Because of the overriding need for phosphate fertilisers in Australian agriculture, there is considerable information on the effects of increasing fertility on the sown and volunteer species of farming systems. In Western Australian pastures, as shown in Table 3, the sward components were found to respond differentially to the soil phosphate supply (38).

Table 3. The effect of phosphate supply on the composition of the flora of Western Australian pastures (after ref. 38)

Phosphate supply	Dominants	Sub-dominants
Low (as applied phosphate)	*Erodium* spp.	*Vulpia* spp.
	Hypochoeris glabra	*Trifolium subterraneum*
Intermediate	*Trifolium subterraneum*	*Vulpia* spp.
	Erodium spp.	*Arcthotheca calendula*
High	*Bromus* spp.or	*Erodium* spp.
	Hordeum spp.	*Trifolium subterraneum*
	Arctotheca calendula	

In the south-east of South Australia, it had been recognised as early as 1924 that there was a sequential change in pasture composition in response to superphosphate applications (4). A sequence of legumes was identified on the alkaline soils adjoining the lakes of the Lower Murray (15). At low soil phosphate levels, *Trifolium arvense*, *T. tomentosum* and *Medicago minima* were common. With increased phosphate applications, *T. glomeratum* and *M. polymorpha* appeared. *M. truncatula* only thrived at the highest levels of phosphate. Griffiths did not mention any other volunteer species. Tiver and Crocker (41) elucidated a succession in pasture composition under grazing and superphosphate application. This is presented in Table 4 in a modified form to allow for nomenclatural changes and to include more information than in their original representation. (The changes which are supported by other information (10) are discussed in detail elsewhere (25)).

Moore (33 *et seq.*) examined the interaction between environmental and managerial factors in pastures over a wide part of southern Australia and *inter alia* formulated a succession in the vegetation in response to grazing and superphosphate applications. The changes in the grazed flora were peculiar to the native plant formations originally found in the particular regions. In turn, these were dependent on environmental factors such as rainfall and soil pH, and Moore (34) developed his scheme to show the changes caused by grazing and fertilizer usage to the alien flora on acid, neutral and alkaline soils (Tables 5, 6, and 7 respectively).

Changes in grazing intensity. In general, low stocking rates encourage the growth of tall species particularly grasses, whereas at high stocking rates the low-growing legumes are favoured (e.g. 6). However, if soil fertility levels are not sufficiently high to sustain legumes, there will be a swing towards prostrate broad-leaved weeds such as *Hypochoeris* spp. *Erodium* spp. and *Arctotheca calendula* (42) and *Crassula* spp., *Lythrum* spp. and *Poa annua* (39). At high stocking rates *Trifolium subterraneum* pastures at Turretfield, South Australia were dominated by *Poa annua*, *Trifolium glomeratum*, *Vulpia myuros*, *Bromus diandrus*, *B. hordeaceus*, *Hordeum leporinum* and *Arctotheca calendula* (8). At high stocking rates, the *Medicago* and *Trifolium* burrs and seeds will be eaten and they will disappear from the sward as seed reserves fall below the levels necessary to ensure sufficient numbers germinating to compete successfully with other species (7, 36). Haycutting which requires the pasture to be ungrazed, also leads to changes in composition, as the taller species will shade out the prostrate plants (17,40).

Changes in water regime. In agriculture, the installation of irrigation will have a profound effect on the weed population. Sealed road surfaces and associated drainage works, by altering the water availability to small adjoining areas, with alter the flora to a lesser extent. Where irrigation is established perennials and summer-frowing annuals not previously present may appear. The latter are more likely when the irrigated areas are regularly cropped. In many cases they are introduced as contaminants of seed of the summer crops. Typical examples include *Chenopodium album*, *C. murale*, *Polygonum aviculare*, *Cenchrus longispinus* and *Tribulus terrestris*. In the south-east of South Australia where land previously used solely for grazing was developed for vineyards and irrigated cropland during the last twenty years, there has been a rapid swing from pastoral weeds to those species enumerated.

Along roadsides, where the runoff enhances the natural water supply of the immediate area, the change in the weed flora is not as marked. Nevertheless, weeds from more-favoured areas will appear along such roads, eventually forming a narrow ribbon similar to that along creeklines. Examples include *Rubus* spp. and *Rosa* spp. which are found along roadsides and watercourses far from the high rainfall areas where they are a problem. Similarly a number of weeds of the agricultural areas are found along roadsides into the interior. If for some reason the augmented water supply becomes unavailable, these types of weeds usually disappear.

Other changes in technology and farming practices. Other major changes in technology and farming practices will influence the weed flora. A number of these will be mentioned. There has been a general improvement in the cleanliness of seed saved for sowing. The original weeds of Australian cereal crops were themselves introduced as seed contaminants (3). The most extreme change resulting from increasing seed cleanliness was the disappearance of *Lolium temulentum*, an obligate crop weed that was very prominent in early Colonial days, through the adoption of "drake sieves" designed especially to remove the weed seeds from the crop sample.

Table 4. Alien plants invading herbaceous communities of *Eucalyptus camaldulensis* - *Danthonia* savannah woodland in the south-east of South Australia as a result of grazing and superphosphate application (after ref. 41).

The sites were located on meadow podsols of pH 5.0 - 6.8 where the effective rainfall is less than nine months. The following table is based on Figure 5 in the cited paper supplemented by data from elsewhere in that paper.

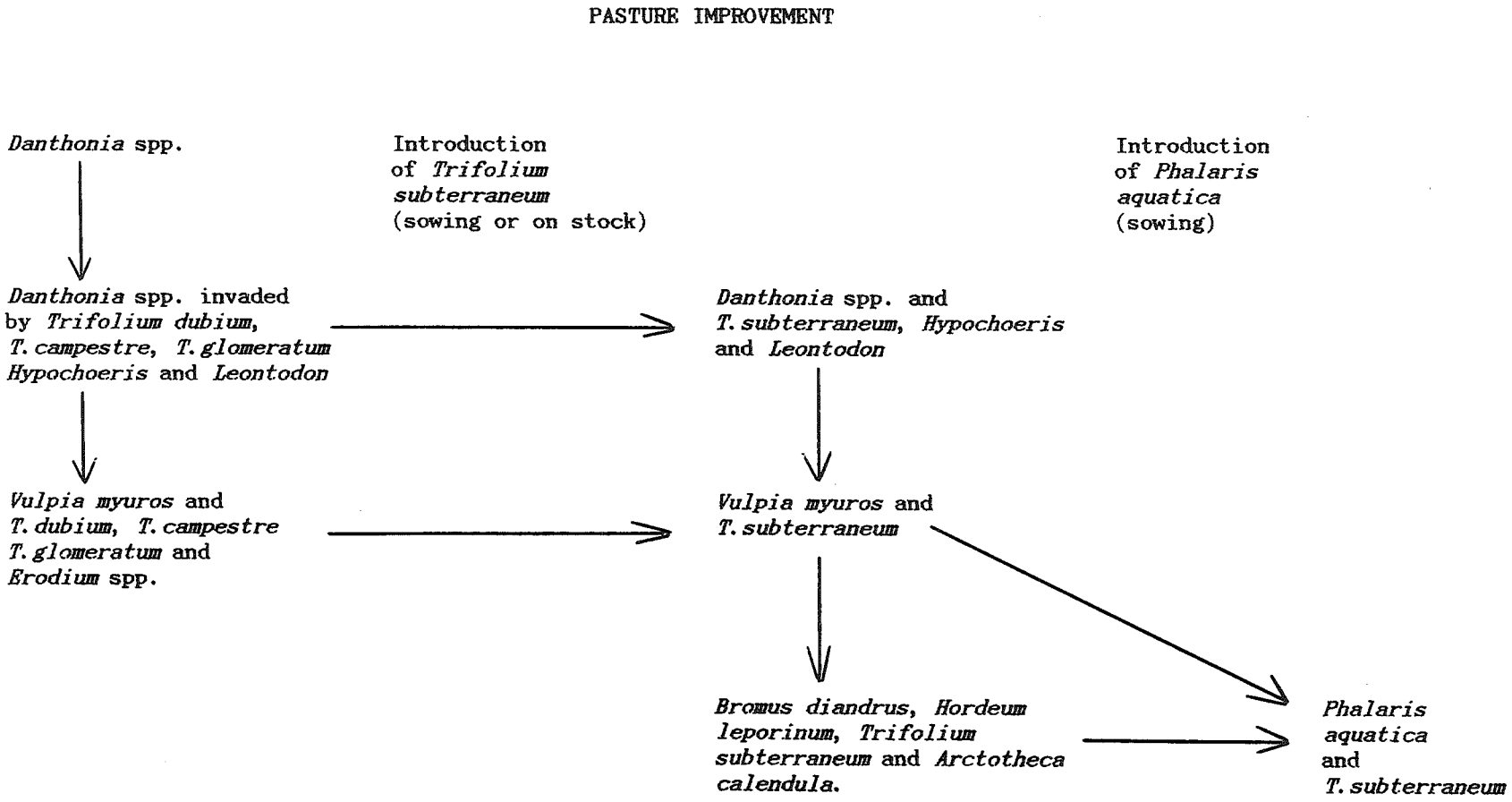

Table 5. Alien plants invading herbaceous communities of *Eucalyptus melliodora - E. blakelyi* woodlands in the Southern Tablelands, N.S.W. as a result of grazing (after ref. 34. p. 178).

The sites were solodized solonetzic soils of pH 5.9, having a uniformly - distributed average annual rainfall of 585 mm. The species shown are those with presence values greater than 50 per cent.

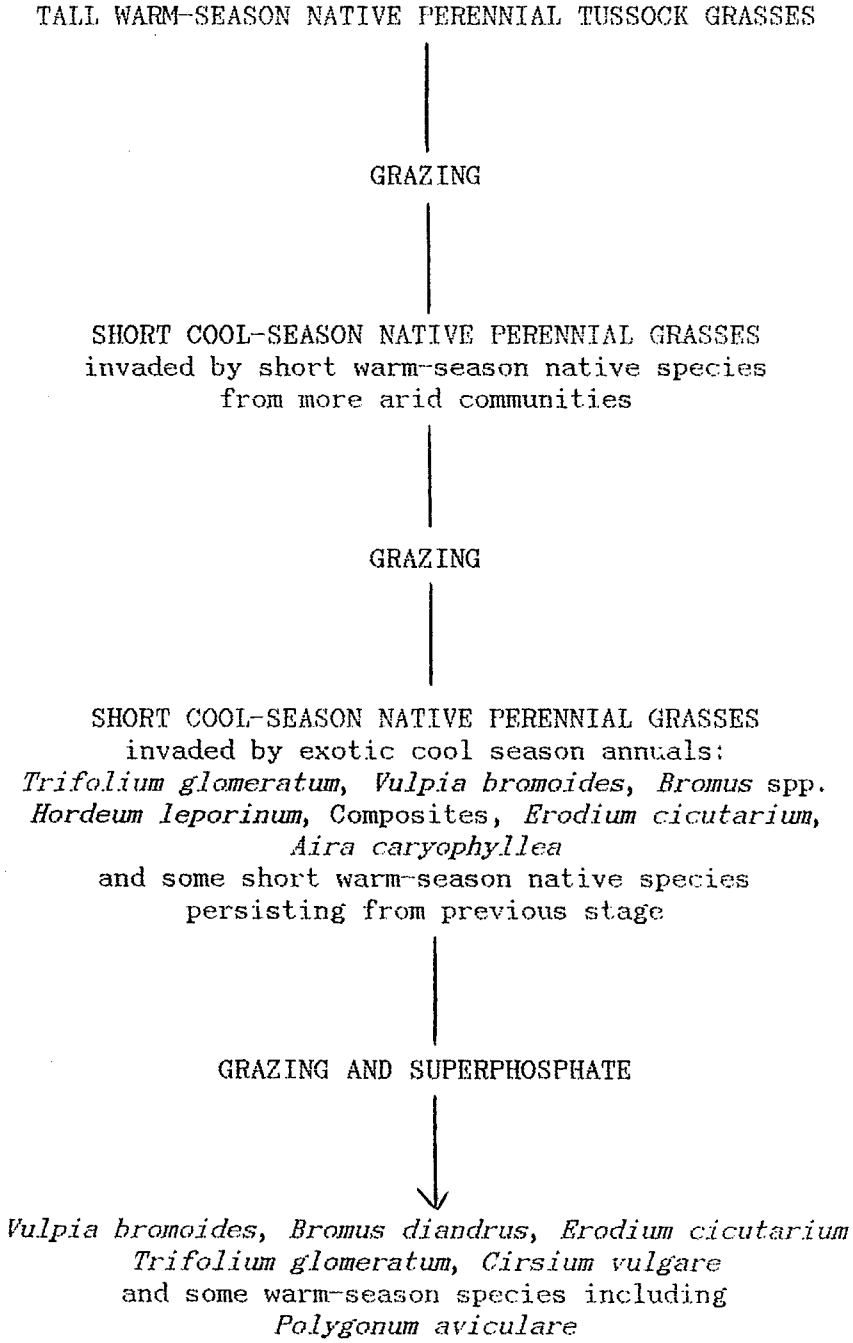

Table 6. Alien plants invading herbaceous communities of *Eucalpytus woollsiana* woodlands on the South-western Slopes of N.S.W. as a result of grazing (after ref. 34, p. 180)

The sites were red-brown earths of pH 6.9, having a uniformly-distributed average annual rainfall of 508 mm. The species shown are those with presence values greater than 50 per cent.

TALL WARM SEASON NATIVE PERENNIAL TUSSOCK GRASSES

↓

GRAZING

↓

MID COOL-SEASON NATIVE PERENNIAL GRASSES
invaded by short warm-season native perennial species
and mainly exotic cool-season annuals:
Hordeum leporinum, *Medicago minima*, *M. polymorpha*,
Trifolium glomeratum, *Vulpia bromoides*, *Aira caryophyllea*,
Moenchia erecta, *Carthamus lanatus*, *Arctotheca*
calendula, *Erodium cygnorum*

↓

GRAZING

↓

MAINLY EXOTIC COOL-SEASON ANNUALS:
Hordeum leporinum, *Medicago minima*, *M. polymorpha*,
Erodium cygnorum, *Vulpia bromoides*, *Carthamus lanatus*,
Aira caryophyllea, *Salvia verbanaca*, *Arctotheca calendula*,
and some mainly native warm-seaon species but including
Xanthium spinosum

Table 7. Alien plants invading herbaceous communities of *Eucalyptus hemiphloia* - *Casuarina lehmanii* woodlands in the Wimmera, Victoria as a result of grazing (after ref. 34, p. 181)

The sites were on grey and brown cracking clays of pH 8.1, and having a predominantly winter rainfall averaging 457 mm per annum. The species shown are those with presence values greater than 40 per cent.

TALL WARM-SEASON NATIVE PERENNIAL TUSSOCK GRASSES

GRAZING

SHORT COOL-SEASON NATIVE PERENNIAL GRASSES
invaded by cool-season annuals:
Medicago minima, *M. polymorpha*, *Erodium cygnorum*, *Crassula* spp.

Cool season, mainly-exotic annuals
Medicago minima, *M. polymorpha*, *Hordeum leporinum*, *Lolium rigidum*, *Erodium cygnorum*, *Carthamus lanatus*, *Euphorbia drummondii*, *Lamium amplexicaule*, *Vulpia bromoides*, *Scleropoa rigida*, *Crassula* spp.

The sowing of *Lolium rigidum* in pastures and even under crops, which persisted until the 1950s, is largely responsible for the current widespread ryegrass problem. Because it was regarded as a pasture grass it was believed that it could not be a problem in crops.

The current trend to minmum tillage is causing an upsurge in *Bromus*, *Hordeum* and *Vulpia*. Having awned seeds they are favoured by minimal disturbance at the expense of *L. rigidum* which prefers regular disturbance (31).

Changes in rotations will affect the weed flora. The previously widespread fallow-wheat rotation had a number of disadvantages but one benefit was that it kept *Oxalis pes-caprae* under control. The move to include pasture phases in the rotation or even to continuous cropping favoured that weed (24).

The sequential changes in the weed flora resulting from the successive introduction of new herbicides from the 1940s to the present have been documented elsewhere (3, 25). Suffice to say here that the poppies, crucifers and other weeds susceptible to the phenoxy herbicides have decreased in prominence and have been replaced by many others as indicated earlier. The successful removal of many weeds has enabled others, resistant to the herbicides used, to move in and occupy the vacant places. Therefore I draw attention to the five weeds, *Bifora testiculata*, *Myagrum perfoliatum*, *Silene apetala*, *Vulpia fasciculata* and *Juncus bufonius*, that within six seasons from 1980 to 1985 became sufficiently important in South Australian cereals to warrant inclusion in the standard recommendations (9) in spite of being virtual rarities a few years earlier.

CONCLUSION

The general pattern of land settlement over much of southen Australia was of extensive pastoralism followed by subdivision and closer settlement leading to the cultivation of crops, irrigated where possible, or intensive stock production, generally dairying. This sequence affected the weed flora and led to the following long-term trends:

1. The establishment of those species unintentionally introduced by Europeans throughout the world wherever they went (23). Some resulted from the earliest contact but others came later being associated with contaminated ballast, fodder and packing, and propagules caught in mud attached to footwear, implements and other materials.

2. The establishment of plants introduced by propagules attached to animal coats and fleeces, during the earliest period of settlement when the land was used mainly for extensive grazing.

3. The establishment of seed contaminants following the subdivision of grazing properties for cereal growing.

4. The escape and spread of garden plants which in later years was facilitated by the abandonment of old gardens and their amalgamation with adjoining paddocks.

5. The establishment of intentionally-introduced fodder plants.

At any one location these processes overlapped and they were not synchronous between locations. Furthermore, as the time taken for individual species to become naturalised varies greatly, plants introduced at later historical stages may become naturalised before another species introduced earlier.

Therefore it is impossible to forecast the individual species that will become established and perhaps troublesome in the future. However in southern Australia, it could be predicted that, as a group, more perennials originating from mediterranean areas will appear. In cropping systems those species adapted for high fertility soils and possessing an innate tolerance of currently used herbicides will become more significant. Where reduced cultivation techniques have been adopted there will be an upsurge in weeds preferring consolidated seedbeds with a corresponding reduction in those requiring fine seedbeds. I feel that, unless there is some catastrophic breakdown in quarantine, the weeds of the future will come from the large number of alien species that are already in Australia which have yet to find a niche where they can thrive unaided. But my most certain prediction is that the weed flora of Australia will continue to change.

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