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The Evaluation and Exploitation of Semi-Arid Lands: Australian Experience [and Discussion]

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The evaluation and exploitation of semi-arid lands: Australian experience

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Arid and semi-arid lands are areas where rainfall is too low or too unreliable for cropping or sown pastures. Australian arid and semi-arid lands comprise a single vast area extending to the 250 mm mean annual rainfall isohyet in the south and the 750 mm isohyet in the north. The grazeable areas are used for grazing of sheep or cattle under very extensive management, producing wool and meat for export. The industries have a low production per unit area, but are very efficient in terms of production per unit of labour.

Graziers and administrators have had an overoptimistic perception of the land and climate which has led to varying degrees of resource degradation. Applied research into resource inventory, range condition and trend, stock carrying capacities, and droughts is described.

The land and climate of arid and semi-arid Australia are comparable with those of other parts of the world, but socio-economic factors are very different.

Definition

In Australia, arid and semi-arid lands are together synonymous with the 'pastoral zone', and comprise that part of the continent where rainfall is too low or too unreliable for cropping or sown pastures to be economic. This definition is similar to that of Meigs (1953) for arid land and has two important connotations. First, the emphasis is on inadequacy of rainfall for cropping, that is the biological or agricultural effectiveness of rainfall, rather than on an absolute amount of rainfall (Perry 1968, 1970*b*). It therefore includes a whole complex of factors such as seasonality, reliability, rate of evaporation during the rainy season, and soil aspects concerned with the size and duration of the soil water store. The essential feature for cropping is a reliable, unbroken period of available soil water which is long enough to allow the crop to complete its life cycle. In southwestern Australia where rain falls in winter, when evaporation is low, and from a fairly regular progression of low pressure systems at approximately weekly intervals, wheat can be grown economically under a mean annual rainfall as low as 250 mm even on sandy soils with a low water holding capacity. The situation is quite different in tropical Australia where dryland cropping is possible only where mean annual rainfall exceeds 750 mm. This is because the rain falls in summer when evaporation is high and the rain-bearing influences (convectional thunderstorms and tropical cyclones) are erratic. Below 750 mm mean annual rainfall in these areas, there is a high frequency of dry periods of several weeks duration within the rainy season. During such dry periods the soil water store is depleted completely, thus breaking the continuous period of available soil water required for cropping. A similar situation applies in North Africa where the mean annual rainfall at the boundary between arid and non-arid (or cropping and non-cropping) is much lower under the Mediterranean winter rainfall areas north of the Sahara than in summer rainfall areas south of the Sahara. This is a very important aspect; the lack of recognition by people of European origin of the low biological or agricultural effectiveness of rainfall in summer rainfall areas has been the cause of the failure of many developmental schemes in those parts of the world, including tropical Australia.

The second connotation in the definition used in Australia of arid and semi-arid lands stems from the word economic. Although in the definition it qualifies cropping and sown pastures in higher rainfall areas, it is equally applicable to any industries in arid Australia. The implication is of a monetary, market-oriented cultural system which contrasts markedly with the subsistence systems of many of the world's arid lands.

Rainfall in the area is highly variable and droughts of one to several years duration are a normal feature. Management for both financial and biological performance must be in the context of droughts being a normal feature of the environment.

Description

The Australian arid or pastoral zone is a vast continuous area of 5.7×10^6 km^2, over 70 % of the total area of Australia (figure 1). It extends from latitude 16° S to 35° S and longitude 113° E to 148° E and stretches for over 3200 km east to west and for more than 2000 km north to south. It is second only in size to the arid area stretching across North Africa to the Indian subcontinent (Perry 1970*b*).

Topographically it is flat and low, a vast gently undulating plain broken only by isolated low mountain ranges. The lowest point, Lake Eyre, is about 10 m below sea level and the highest, Mt Zeil in central Australia, is 1500 m above sea level. No large rivers, like the Nile, Indus or Colorado, with headwaters in higher rainfall areas, cross it. It contains no perennial rivers, the water courses being dry except after rain. Most of the area either drains through an ephemeral internal drainage system towards Lake Eyre or has only disorganized drainage with short streams petering out on plains not far from their source.

Much of the area is, or is derived from, an ancient Tertiary land surface with consequent highly leached, infertile soils.

Most of the area receives more than half its rainfall in summer but in the south, winter rainfall is more reliable and effective (Perry 1970*a*). Rainfall variability from year to year is high with consequent high variability in plant growth and forage availability. The lowest mean annual rainfall is 125 mm in the Lake Eyre region. From Lake Eyre, mean annual rainfall increases outwards towards the zone boundary which corresponds to the 250 mm isohyet in the south, the 750 mm isohyet in the north, and intermediate isohyets in the east.

At the level of detail required for management purposes the arid and semi-arid part of Australia contains a great diversity of land types varying in climate, slope, soil and vegetation. However, for broad general purposes most of the area consists of the following few types (Christian & Perry 1969; Leigh & Noble 1969; Perry 1970*a*).

Mitchell grass plains

These are treeless, or almost treeless, plains with cracking heavy clay soils. They are characterized by perennial *Astrebla* spp. (Mitchell grasses). Their main occurrence is in a broad arc around the northern and north eastern summer rainfall part of the zone. The dominant grasses are discrete tussocks 0.5 to 1 m high and 10 to 30 cm in diameter. Other perennial

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grasses include *Eragrostis* spp., *Aristida* spp., and *Dichanthium* spp. Following rain, annual grasses and forbs grow in the interspaces between the perennial tussocks.

Livestock preferentially graze the short annual plants, but within a few months after the end of the wet season they are forced to rely on the less palatable and less nutritious perennial grasses. Despite the inhospitable nature of these hot, shadeless plains with forage of low nutritive value for a good part of each year this country supports several times the intensity of stocking of any adjacent land types. It carries a substantial proportion of Australia's arid land flocks and herds. With continuous heavy stocking the perennial grasses are reduced or eliminated and the pasture becomes an annual grassland lacking the reserve forage provided by perennial grasses in the late dry season. Even when devoid of vegetation the flat topography and fine-textured soils are resistant to erosion.

Chenopod shrublands

These occur in the southern half of the zone where, on the average, summer and winter rain are about equal. The most common dominant plant species are *Atriplex vesicaria* (bladder saltbush) on cracking clay or texture-contrast soils and *Maireana sedifolia* and *M. pyramidata* (bluebushes) on calcareous soils. These perennial bushes are low (< 1 m) and spreading. Annual grasses and forbs grow in the interspaces in favourable periods.

These lands are mostly used for grazing by sheep which concentrate on the short annual vegetation when it is present, but rely on browsing the shrubs in other periods. Under heavy grazing the shrubs decrease and are replaced by shorter, less useful plants, particularly *Bassia* spp. The vegetation has been depleted over a considerable proportion of these lands, and much has suffered erosion of varying degrees.

Low woodlands

These occur on medium to fine-textured soils throughout most of the zone except the far north. Characteristically they are dominated by tall shrubs or low trees (2–10 m high), mostly various *Acacia* spp., of which *A. aneura* (mulga) is the most widespread and best known. The understorey varies greatly from place to place, even over short distances. In places it is dominated by perennial grasses such as *Eragrostis* spp. and *Monochather paradoxa*, in others by short annual (or short-lived perennial) grasses such as *Aristida* spp. and *Enneapogon* spp., and in the south by perennial or annual chenopodiaceous plants.

Low woodland country is used for grazing by sheep or cattle, both of which preferentially graze the short grasses and forbs when they are present. Most of the dominant tall shrubs and low trees are browsed by livestock in unfavourable periods. The effect of past grazing on the perennial shrubs varies in different regions. In the arid winter rainfall areas shrubs have decreased, in arid summer rainfall areas shrub populations appear little affected. In higher rainfall parts, particularly in the east of the zone, grazing has caused such an increase in shrubs, mostly unpalatable to livestock, as to render the land almost useless for grazing.

Spinifex grasslands

Vast areas of sandplain and dunefields are characterized by *Triodia* spp. or *Plectrachne* spp. (collectively called spinifex) which are large evergreen perennial tussock grasses with rigid, spiny, unpalatable foliage of low nutritive value.

Most spinifex areas are not used for livestock but small parts, with 'softer' species, are grazed at low intensities particularly in conjunction with other, better types of country.

Floodplains and alluvial fans

Floodplains and alluvial fans occur as small discontinuous areas adjacent to and at the end of rivers and creeks and at the foot of mountains and hills. Their total area is small compared with the previous four land types, but with their favourable water régime and commonly fertile soils they are very productive. Their soils and vegetation are very diverse, but they are preferentially grazed by livestock to the extent that they support grazing intensities possibly 100-fold greater than adjacent lands. It is not surprising that many are severely degraded and eroded.

Mountains and hills

Much of the relatively small areas of mountains and hills is too steep and rugged to be used for livestock, but the lower and gentler slopes are grazed at similar intensities to adjacent land types.

Exploration and settlement

The first Europeans to see any part of arid Australia were Dutch traders who happened to sail too far east on their journey to Indonesia. Their accounts emphasize the desolate nature of the western coast. The first British visitor was William Dampier in the late 17th century. His description of the land and its inhabitants was depressing.

In 1788 the first European settlement in Australia was established at Sydney, but it was three decades later before the first explorers from the settlement crossed into the arid lands. With the establishment of a colony at Adelaide in 1836 the tempo of exploration increased. New land was required for the colonies' increasing flocks and much of the exploration, both official and private, was inspired by pastoralists. The evaluations in this period were over-optimistic. First, it is likely that these early explorers, and those to follow in the next few decades, were only able to penetrate the inland areas during favourable years. Abortive expeditions were probably not recorded, thus biasing evaluations towards favourable years. Secondly, there were undoubted exaggerations; from reading some of the journals in the light of present-day knowledge, expressions such as 'passed through grass up to the horse's belly' should be interpreted as 'crossed a creek line today.'

Thirdly, the population and colonial administrators selectively interpreted the journals; they made much of the favourable parts, but neglected the descriptions of the poorer parts even when explorers suffered incredible hardships in traversing them. For example, despite the fact that Stuart had to make three attempts before successfully crossing Australia from Adelaide to the north coast and that he reported difficulties in finding water for his lightly equipped, mobile, horse-mounted expedition, the Governor of South Australia reported to the Colonial Office that cattle and sheep could easily be driven over the whole route (Duncan 1967).

By the early 1860s most of the grazeable land in arid Australia had been located and described by explorers and settlement began in earnest. Most of the whole vast area of grazeable land was occupied within the next three decades. The new settlers moved out from higher rainfall areas into areas with lower and less reliable rainfall, which perhaps partly explains their overestimation of the stock carrying capacity of the new lands and their underestimation of droughts.

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Initially, crown land was occupied by the simple process of 'squatting' without legal sanction, but the situation was soon legalized by granting leasehold. The initial settlement and subsequent development of a region astride the New South Wales–Queensland border has been described well by Heathcote (1965); other regions differ only in degree. The crown lands were vested in the various Australian State Governments, who were anxious to avoid nomadism on the one hand, and the development of vast land monopolies, on the other. A compromise was developed; the governments leased the land to individuals and companies on a long term basis. The original leases were as short as eight years, but they are now much longer, mostly 30 to 50 years (Heathcote 1969). Thus the real owners of the arid grazing lands in Australia are the State Governments who administer them through their various Departments of Lands.

Within three decades the grazing industry in the earliest settled parts (western New South Wales) was in difficulty (Barnard 1969). The sheep population had increased rapidly to a high level as had the rabbit population. Undoubtedly the high grazing pressure had caused the land and vegetation resources to degenerate. With the onset of drought the sheep population in part of western New South Wales crashed dramatically from 13.6 to 3.6 million (Butlin 1962; Perry 1967*a*). Since that time stock numbers have increased, probably in response to additional stock watering points bringing more land within grazing range, but they have never reached the early high level. Stock populations in other arid regions have followed a similar pattern; an initial rapid increase to high levels, a sudden crash, and then a slight recovery (Perry 1968).

A broad general view of the present condition of Australia's rangelands (Newman & Condon 1969) reveals that the more sensitive land and vegetation types have degenerated to poor condition, the more robust types remain in good condition and intermediate types are in moderate condition. It is likely that the high stocking rates following shortly after settlement caused the major degeneration and that resource condition has changed little since then. If this is so, the heavy stocking for a few years caused a long-lasting deterioration in the resources; with consequent lower safe stocking capacity. Had the early stock populations not been so high, present resource condition and safe stocking capacity probably would be higher.

In evaluating Australia's arid grazing lands the explorers, administrators and pastoralists overestimated their potential. These overoptimistic attitudes have been, at least partly, responsible for resource degeneration. The main reason for overoptimistic evaluations is a set of perceptions some of which still persist today.

(i) The land and vegetation was perceived as being able to support more stock than it could.

(ii) The normal climate was perceived as being that of good years as expressed by 'We haven't had a normal rainfall for 25 years'.

(iii) The degeneration caused by heavy stocking was perceived as being less than actual and was commonly blamed on other factors, such as rabbits and droughts.

(iv) Land and vegetation were perceived as being more resilient and recovery more rapid than actual as expressed by 'It always comes back after a good rain'.

Present grazing industries

Nearly half of arid and semi-arid Australia (mainly the spinifex sandplains and dunefields) is unoccupied by European man and his livestock. Most of the remainder was settled for livestock grazing between 80 and 120 years ago, which is about the same time that western U.S.A. was opened up for the same purpose. In Australia the gold won from the goldfields of Victoria and New South Wales in the few decades after 1851 provided much of the development capital for extension of settlement into the pastoral areas.

The arid and semi-arid area supports about 5 million cattle, mostly in the north, and 30 million sheep, mostly in the south (between 20 and 30 % of Australia's total sheep and beef cattle population) (figure 1). The livestock population of arid Australia has remained relatively constant since 1910, but its proportion of the total Australian population has fallen as livestock populations have increased in the higher rainfall areas due to the development of sown and fertilized pastures (Barnard 1969). To some extent the demand for livestock caused by improved pastures in the higher rainfall areas has been supplied from the arid areas.

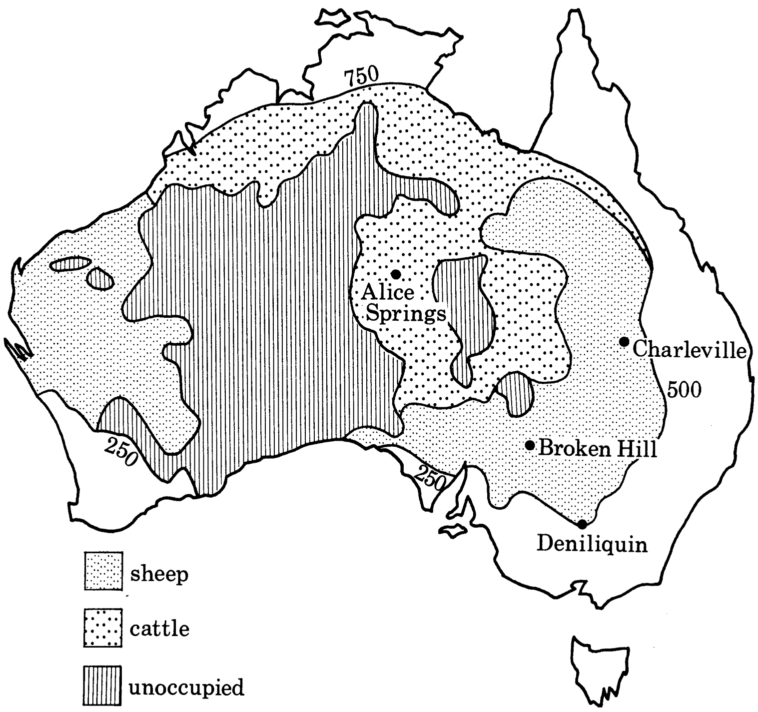

FIGURE 1. Map of Australia showing land use in the arid and semi-arid areas. The figures on the boundary of the arid and semi-arid area are mean annual rainfall in millimetres.

The livestock industries in arid Australia have always been oriented to export markets (Perry 1970*b*). In the past, annual variations in production from these areas had a very considerable influence on Australia's export income, but the upsurge of mineral exports has reduced the effect in recent years. Even today, with mineral exports accounting for about half of Australia's export income, the pastoral areas contribute about one quarter, and thus remain an important factor in the affluence of all Australians. Because of the export orientation, profitability is determined by international markets, and thus is affected by political and economic conditions in other countries. Profitability of Australian arid land grazing industries is affected by factors such as Britain joining the European Economic Community, the state of the Japanese economy, and the activities of the beef lobby in U.S.A.

By world standards, individual properties are very large. Sizes vary greatly, but 200 000 ha is about average for cattle, and sheep properties are 25 000–50 000 ha in New South Wales and larger in other states. It is generally considered that herds of 2000 breeding cattle or flocks of over 5000 sheep are needed for economic viability. Profitability per unit area is very low (of the order of 1 to 3 cents (Aust.) per ha) and productivity per animal is low compared with higher rainfall areas but not with other arid lands.

Management is very extensive (as opposed to intensive); the relative absence of animal pests and diseases assists in this regard, as does the yearlong continuous grazing system. Apart from regular inspection to ensure that water supplies are adequate, the sheep and cattle are left to fend for themselves for most of the year, their distribution being controlled by fences and watering points. Cattle are mustered once or twice per year to brand calves and draft off beasts for market, bulls remain in the herd yearlong. Sheep are mustered for shearing and crutching and lamb marking, breeding is controlled by putting rams into the flocks for only a few months. This extensive management enables the industries to be very efficient in terms of labour – each man is able to manage about 1000 cattle or 5000 sheep, the use of fences instead of herders to control distribution being an important factor.

This efficiency in terms of labour can be illustrated further by considering total figures. In the 1966 census the total human population of pastoral Australia was 323000 (including 35000 aborigines). Of the total about 200000 live in mining and tourist centres, leaving only about 100000 concerned with livestock industries (this includes services to the industries as well as pastoralists themselves). As this 100000 earns about one quarter of Australia's export income, they are 40 to 50 times more productive (in terms of export income) than the average Australian.

In recent years rising costs of labour and the squeeze between costs and prices have caused a reduction in labour in the pastoral area. Migration to the coastal cities and towns has resulted in a steady decline in the rural population in the pastoral zone, and this decline is predicted to continue. Although the population is declining the efficiency per unit of labour is increasing.

The most important differences in the exploitation of Australia's arid and semi-arid lands in comparison with developing countries are socio-economic. The Australian grazier manages a highly capitalized, highly mechanized business reasonably well integrated with higher rainfall areas through a well organized communication, distribution and marketing infrastructure. Success or failure in Australian grazing industries depends on profits which is very different from the subsistence (or near-subsistence) industries of many other arid areas where failure means starvation for operator and family. Unlike his counterpart in most other countries, the Australian grazier enjoys a high status in the community. It is not long ago that the highest status in Australia was accorded to the owners of sheep stations; Australia 'rode on the sheep's back'. The situation has changed, but the Australian pastoralists remain a well-respected, well-educated, technologically advanced, and a relatively well organized, politically active group.

Scientific evaluation

Little applied research, with the objective of developing management strategies to maintain or improve the productivity of arid Australia, was done before the end of the Second World War. A considerable number of scientific papers had accumulated, but the literature was fragmentary, mostly reporting on short-term, isolated investigations in specific fields. This, and similar literature produced more recently, reveals that scientists, particularly the more

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academic of them, have different perceptions from graziers of the land and industries. Some of their perceptions which deserve questioning are:

(i) *Graziers are avaricious exploiters of the land and vegetation, mining the resources in chasing profits.* This is doubtful; certainly graziers have been the agents of resource degeneration, but more through their overoptimistic perceptions of the land and climate and an ignorance, shared by administrators and scientists, of good management principles.

(ii) *The resource degradation caused by past grazing is continuing at the same rate and will ultimately result in a vast dustbowl.* It is more likely that degeneration has been caused by one or more relatively short periods of over-use in the past and that the lands are now in a new equilibrium, albeit with many areas in poor condition and all areas subject to further degradation if subjected to future periods of misuse.

(iii) *Arid ecosystems are fragile.* An alternative suggestion is that many arid ecosystems are quite robust, the fact that they have degenerated being due to severe misuse rather than inherent fragility.

Within the last two decades applied research has increased and, for the first time, small research centres have been established at various locations within the arid and semi-arid zone. Scientists at these centres, and many others from institutions located in the higher rainfall areas, are doing research on biological and physical aspects of rangeland ecosystems (Christian & Perry 1969). In addition the Bureau of Agricultural Economics and economists in various universities have increased economic research on arid lands. Better definition of practical objectives for research has led to better integration, and investigations have begun on aspects such as resource inventory, resource condition and trend, safe stocking capacities and drought management strategies. The need for associating social, economic, and technological research has been recognized.

(*a*) *Resource inventory*

Shortly after the end of the Second World War, C.S.I.R.O. began a series of broad scale integrated land surveys in northern Australia. With the large areas to be covered speed was essential. A technique was devised of using interdisciplinary teams (geologist, geomorphologist, pedologist, plant ecologist), relying heavily on aerial photograph interpretation. These teams surveyed about 125000 km^2 each year mapping (generally at 1:1000000) and describing land systems defined as recurring patterns of topography, soils and vegetation (Christian & Stewart 1964). Within 15 years the nature and distribution of land types were described in much of the northern part of arid Australia (Christian *et al.* 1954; Mabbutt *et al.* 1963; Perry 1960; Perry *et al.* 1962; Perry *et al.* 1964; Speck *et al.* 1964; Stewart *et al.* 1970.) The broad scale was reasonably appropriate to the extensive nature of the pastoral industries (Perry 1967*b*).

More recently Queensland, Western Australia and New South Wales have adopted and modified the approach and are steadily completing an inventory of their arid grazing lands (Payne, Kubichi & Wilcox 1974; Wilcox & McKinnon 1974; Queensland Department of Primary Industry 1974). Some of these more recent surveys go further than inventory and include assessments of land condition and recommendations for administrative and legislative action.

(*b*) *Range condition and trend*

Since its inception in the late 1960s the C.S.I.R.O. Rangeland Research Unit (now part of the Division of Land Resources Management) has been concerned with establishing the concepts of range condition and trend in Australia and developing or adapting methods for assessing them. The rationale is that successful management of rangelands for long term productivity must be based on the condition and trend of the land resources rather than on short term profits or stock condition (Perry 1974, 1967*a*).

These concepts are new to Australia, but were developed in U.S.A. over 50 years ago and have been used there ever since. The reasons why they have been used for so long in U.S.A., but have only recently been introduced into Australia, are probably associated with differences in land tenure, responsibilities of Agencies, and population distribution. They were first developed in U.S.A. for Federal lands by Agencies charged with administering the lands in the public interest. Considerable centres of population near the lands and interested in uses other than grazing created pressure for maintenance of the lands in good condition. This urban public had a different perception of the effect of grazing on the lands than the ranchers. In Australia the lands are owned by State Governments, are administered by Agencies with charters not so specifically defining public interest, and are remote from any large and interested public. The reasons are social rather than technological.

The concepts of range condition and trend as important or essential rangeland management tools have already gained considerable acceptance by scientists in Australia and there are signs of interest among some of the administering agencies.

The common, but not the only, concept of range condition is analogous to health of an individual. Like health, condition involves many factors and is therefore difficult to assess absolutely. After some years of experimentation and experience Australian scientists are beginning to accept the American conclusion that the most appropriate single index to condition is change from original botanical composition. It is likely that future methods for assessing range condition in Australia will be based, as they are in U.S.A., on this single index.

Essentially range condition is the result of past management treatment and is therefore not a sensitive indicator of present or recent past management. The real indicator of recent management is range trend (current change in range condition). Range trend is more difficult to evaluate than range condition, but the development of suitable methods for assessing it, and their application in the management of Australia's arid grazing lands is probably the most important challenge to Australian range scientists in the near future.

(*c*) *Stock carrying capacity*

Ideally, in arid grazing lands, stock numbers should be flexible and managed according to observed range trend. From this point of view the idea of determining stock carrying capacities for various types of country has the inherent danger that the numbers so determined become a fixed right irrespective of climatic variations and of the effects on the resources. However, the practical situation is that administering agencies desire carrying capacity estimates for various purposes. The inherent danger is low if they are regarded as guidelines to be adjusted according to climatic and resource changes and not as long term absolute figures.

The New South Wales Soil Conservation Service devised a simple method for use in central Australia (Condon 1968; Condon, Newman & Cunningham 1969*a*, *b*, *c*, *d*). The principles of the method have since been applied to other regions. An inventory of land types (in Australia the land system surveys are used) and the location of stock watering points (to determine areas of land types within grazing range of water) are prerequisites for using the method.

Basically the method consists of:

(i) The best known land type under a particular mean annual rainfall and in good condition is chosen as a standard and allocated a stock carrying capacity, from experience.

(ii) For this standard land type, the factors which influence stock carrying capacity (topography, soil, hilliness and salt lakes, tree density) are all given a rating of 1.0.

(iii) For other land types a relative rating is estimated, from experience, for each of the factors. The product of these factor ratings provides a relative index for each land type in comparison with the standard.

(iv) Stock carrying capacities for each land type under standard rainfall are determined by multiplying the appropriate index by the carrying capacity of the standard.

(v) Stock carrying capacities for parts of land types under different rainfalls are adjusted by multiplying by a rainfall factor.

(vi) The condition of each occurrence of a land type (e.g. on particular properties or in particular paddocks) is allowed for by multiplying the carrying capacity by a condition rating factor.

The method provides a simple, practical way to determine stock carrying capacities. It uses only experience and the best estimates available, but is easily upgraded with increasing knowledge. Despite its simplicity and subjectivity I think the estimates obtained are probably as accurate as more complex methods requiring more sophisticated information.

In practice in Australia a stock carrying capacity in drought periods is also determined in a similar way but considering only drought reserve forage (mostly browse shrubs) and the factors influencing it. Using the 'normal' and 'drought' stock carrying capacities estimates of carrying capacities for the first, second, third and fourth years of a drought are recommended. Generally these are determined as follows:

(i) first year of drought – reduce stock by one quarter of the difference between 'normal' and 'drought' carrying capacities; (ii) second year of drought – reduce stocking by one-half the difference between 'normal' and 'drought' carrying capacities; (iii) third year of drought – reduce stocking to 'drought' carrying capacity; (iv) fourth year of drought – reduce stocking to one-half of 'drought' carrying capacity.

(*d*) *Droughts*

In most of arid Australia droughts are periods of forage shortage, water shortage only being a problem in areas where underground water is not available. Non-droughts are periods of adequate forage. It follows that management, and particularly stocking intensity, between droughts affect the duration and severity of drought periods.

In the Alice Springs district (central Australia) forage production depends on summer rains and non-drought years are those which follow summers during which the growing season is long enough to produce enough forage to last until the following summer.

The length of a growing season can be estimated from daily rainfall records with a simple soil water balance model (McAlpine 1970). By comparing estimates of growing season so calculated with 20 years of records of forage availability at five locations in central Australia I (unpublished data) was able to show that summers with a growing period of four weeks duration or more were followed by non-drought years and that summers with growing periods of less than four weeks duration were followed by drought years. Applying this criterion to the 92 years of rainfall records then available for Alice Springs, the probability of any year being a drought was estimated as 0.27. By using this figure and the Poisson distribution, droughts of one year duration can be expected in Alice Springs 14 times in 100 years, droughts of two years duration four times in 100 years, droughts of three years duration once in 100 years, droughts of four years duration once in 360 years, and droughts of five years duration once in 1250 years.

(*e*) *An economic computer model*

The Australian Bureau of Agricultural Economics (1974), in conjunction with officers of C.S.I.R.O., has developed and tested a computer model simulating the physical and financial functioning over time of beef production properties in the Alice Springs region. The model avoids the problem of the effects of different grazing intensities on the degradation of land resources by assuming that the 'normal' and 'drought' grazing capacities calculated by the method described above and the recommended drought destocking policy constitute conservative management and thus are compatible with long term resource stability.

The model is designed to investigate the effects on economic viability of such aspects as herd size, age of turnoff, beef price, availability of credit, borrowing rates, and levels of fixed and variable costs. It can be used to evaluate 'trade-offs' between variability in income and absolute size of income for particular properties and the probability of a property exceeding certain thresholds of income over a series of years with a normal sequence of drought and non-drought years. One result indicated by the model is that the minimum herd for long term financial viability is about 2500 breeding cows in the Alice Springs district.

Conclusions

For the last 100 years the grazeable part of arid and semi-arid Australia has been used for grazing sheep and cattle under a very extensively managed, market-oriented system, producing wool and meat mostly for export. Characteristically the industries have a very low productivity per unit area, a low productivity per animal, a high return to capital, and a very high production per unit labour.

The development and consolidation of the industries has been a trial and error procedure with overoptimistic perceptions of the productivity and resilience of the land resources. In the process resources have degenerated, some land types have been severely degraded, but others are little affected. The present rate of degradation is debatable. It is only in the last 20 years that integrated research with long term objectives has started.

Apart from the economic aspects of costs and market prices, the future viability of the grazing industries depends on maintaining the basic resources in a healthy state. Management practices based on the condition and trend of the land and vegetation resources need to be developed and applied. If safe management practices are developed and applied there are no technical reasons why the existing industries should not continue in the long term. Economic aspects may dictate some changes, and possibly some diversification of products.

Biologically and physically Australia's arid and semi-arid lands are comparable with those of other parts of the world, but there are tremendous social and economic differences. Technically, there is little problem in adapting successful management practices developed in Australia and U.S.A. to developing countries; the knowledge and experience are available. It is the large social and economic differences which appear to pose the major problems to their application.

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Discussion

S. Sandford (*Overseas Development Institute*, 10–11 *Percy Street*, *London W*1). Dr Perry has described how, in Australia, the beginnings of a probabilistic approach to estimation of stock carrying capacity had been made, with different estimates for 'normal' years and for successive years of drought. Unfortunately in most estimates of stock carrying capacity in developing countries a single figure is still being used. A move towards a more probabilistic approach is overdue, with estimates being made in the form of x hectares per livestock unit in y years in every 10, but $x \times z$ hectares in $(10-y)$ years in every 10.

Dr Perry claimed that enough scientific and technical knowledge existed already to improve productivity in the semi-arid areas, and that the remaining obstacles are socio-economic. But if one used Dr Perry's own figures for changes in livestock populations in the pastoral zones of Australia over the last 60 years, and assuming that figures for population are a reasonable proxy for figures for output, then the evidence appears to suggest that not even in Australia, where socio-economic problems are less serious than in developing countries, are increases in productivity being achieved; and this must cast doubt on whether adequate scientific and technical knowledge does really exist.

R. A. Perry. Climatic factors limit productivity of arid land grazing industries to relatively low values per unit area. In the developed countries technical knowledge has been used mainly in:

(i) establishing standards for safe resource management;

(ii) substituting capital for labour.

The available technical knowledge could be adapted easily for the same purposes in underdeveloped countries but social and economic factors are very different.

Sir Joseph Hutchinson, F.R.S. (*St John's College*, *Cambridge*). Mr Perry has told us that the only real insurance the Australian grazier has against drought is money in the bank. The subsistence herdsman in the semi-arid areas of the Third World seeks insurance by maintaining the maximum number of animals on the hoof. Though he may argue that banknotes do not produce calves and his stock do, nevertheless in the long term his extra stock are a liability rather than an asset. In times of drought they aggravate the situation against which they are supposed to insure. This is the real argument for bringing subsistence herdsmen at least to some extent into the market economy. The offtake of meat or of milk products from grazing lands can be used to provide a real insurance against drought, in that the returns from it are earned in sectors of the economy not directly dependent on the vicissitudes of the climate.

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