The Australian Ecosystem

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Old, weathered soils and variable climate have shaped the productivity, reliability and stability of Australia's environments. Such environments can support a great diversity of plants, invertebrates and cold-blooded vertebrates, but a relatively impoverished assemblage of larger mammals compared with other continents. Humans are large warm-blooded omnivores with high energy demands which makes them potentially vulnerable in Australian environments. Pre-European human populations in Australia were small and dispersed, and an order of magnitude or more smaller than the average density found on other continents. The level of population that can be supported by Australian ecosystems is dependent on how well modern agriculture works within the boundaries set by soil productivity and climate variability.

1 INTRODUCTION

Economists, politicians and scientists have long debated what the optimum population size for Australia might be. One of the earliest and most perspicacious of musings on this subject is that of a young Charles Darwin in 1835:

> *The rapid prosperity and future prospects of this colony are to me, not understanding these subjects, very puzzling. The two main exports are wool and whale oil, and to both of these productions there is a limit. Pasture everywhere is so thin that settlers have already pushed far into the interior: moreover the country further inland becomes extremely poor. Agriculture, on account of the droughts, can never succeed on an extended scale: therefore, so far as I can see, Australia must ultimately depend upon being the centre of commerce for the southern hemisphere, and perhaps on her future manufactories. Possessing coal, she always has the moving power at hand. From the habitable country extending along the coast, and from her English extraction, she is sure to be a maritime nation. I formerly imagined that Australia would rise to be as grand and powerful a country as North America, but now it appears to me that such future grandeur is rather problematical* (Darwin 1845).

Darwin's analysis is extremely perceptive, for he saw both Australia's 'poor country' (poor soils) and droughts (resulting from the El Niño Southern Oscillation, ENSO) as being fundamental determinants of life on the continent.

This paper re-examines the issues raised by Darwin. It is divided into two sections. The first is devoted to a brief review of the continent's physical conditions and how they have shaped the Australian biota. The second addresses the question of how these factors affect humans and their population size. Humans are large warm-blooded omnivores. They have high energy demands. This makes them potentially vulnerable in Australian environments. Human populations in Australia have always been small and dispersed, being an order of magnitude or more smaller than the average density found on other continents (Birdsell 1953).

2 DEVELOPMENT OF THE AUSTRALIAN BIOTA

The geological, climatic and ecological history of a continent shapes the productivity, reliability and stability of its environments. These in turn shape the ecology of its flora and fauna.

Over the Cenozoic Era (65 million years ago to present), Australia has experienced extraordinary geological stability and low topography. Mountain building and its associated erosion have been extremely minor. Features such as the Great Dividing Range, once thought to be late Cenozoic in age, are now known to be some 80 million years old (Veevers 1986). Indeed, there has been no significant folding of rocks (which leads to mountain building) within Australia for the past 100 million years (Veevers *et al.* 1991). The geological quiescence of

Australia over this period is well illustrated by the great age of Australian drainage patterns. Even on the east coast, which is relatively active geologically, most drainages pre-date the tectonic rifting of Tasmantis (for a definition of Tasmantis see Flannery 1994) from Australia 80 million years ago. Indeed, this rifting beheaded many catchments, resulting in the reversal of drainages lying to the east of the divide (Ollier and Pain 1994).

Volcanoes have been periodically active on the eastern margin of the continent throughout the Cenozoic. Moderately extensive Neogene basalt flows have resulted in western Victoria, north-eastern and south-eastern Queensland (Sutherland 1991). Erosion of these basalts has resulted in 'islands' of relatively fertile soils in an otherwise infertile region.

The reasons for Australia's remarkable geological stability are not entirely clear. But many geologists suspect that it is due to the enormous depth of ancient continental crust under Australia. The crust, they argue, is so old and thick that magma (which forms volcanoes) cannot easily penetrate it and, likewise, its thickness and strength prevent it from being easily folded and uplifted into mountain ranges.

Furthermore, Australia's low topography and temperate location have determined that the extent of glaciation, even during the Pleistocene glacial maxima, has been small. At the height of the last glacial maximum (25 000–15 000 years ago), glaciers covered a mere 6000 km^2 in Tasmania and 50 km^2 in south-eastern Australia (Peterson 1971). Their effect on soil production was minimal.

The absence of recent tectonism, widespread glaciation or volcanic activity in Australia has resulted in old, often skeletal soils which are also frequently deeply leached (Hubble *et al.* 1983). In addition, Australian soils generally have low organic matter content, low soil water storage capacities and high soil temperatures (Hubble *et al.* 1983). They are also notoriously deficient in plant nutrients. On average, phosphorus levels are 300 ppm in Australian soils, compared with 550 ppm and 650 ppm for American and English soils respectively (Williams and Raupach 1983). Levels of nitrogen are likewise low (0.01–0.05% in the drier regions), as are levels of soil sulfur (Hurditch *et al.* 1980; Williams and Raupach 1983). Levels of trace elements are also very low, deficiences of manganese, copper, zinc, cobalt, boron and molybdenum having all been identified. As a result, approximately 33% of agricultural land in Australia has been treated with trace element supplements (Williams and Raupach 1983).

Altogether, these various attributes of Australian soils have limited biological productivity in Australia. Perhaps the most important factor concerning the evolution of plants is the low level of phosphorus, for it may have been the main determining factor in the evolution of scleromorphy and the zoogeographic patterning of various native plant communities (Beadle 1966).

A second major determinant of productivity is climate. Australia is unique among the continents in the extent that it is affected by ENSO (Nicholls 1991). ENSO brings a very large inter-annual variability in rainfall to Australia and this, along with the effects of scleromorph vegetation, makes variability in surface water runoff far greater in Australia than on other continents (Finlayson and McMahon 1991).

The El Niño phase of the ENSO cycle bring drought to Australia. It begins with a change in sea-surface temperature in the eastern Pacific ocean. Off the coast of Peru the temperature at the surface of the normally cold sea begins to rise. Eventually it can rise to 4°C more than normal. Over the course of a year this warm water can spread into a huge tongue extending over 120 m deep and 8000 km eastwards across the Pacific at the equator. The warm water comes from the western Pacific, in the vicinity of Australia. The warmer waters of the Pacific are normally kept in this region by the prevailing westerly winds. When the winds weaken, the warm water flows back east (Burroughs 1991).

Around Australia the situation is reversed. There, the coastal water is colder than normal and thus evaporation and cloud formation are decreased. Droughts, sometimes of years duration, occur. Bushfires are prevalent and wind erosion is increased. Effects of ENSO are felt as far away as India, where the monsoon is delayed. Brazil, central America and southern Africa can also experience drought. It is only in Australia, however, that almost the entire continent is affected.

Eventually, the El Niño phase weakens. Westerly Pacific winds re-establish themselves and warm water once again accumulates around Australia. In Australia the drought is broken, often with widespread flooding which promotes further erosion in the denuded landscape.

The length of the ENSO cycle is remarkably variable, ranging from two to eight years (Burroughs 1991). It is this variability as much as anything else that makes it so difficult for living things to cope. For example, food storage strategies (such as is seen in small overwintering boreal mammals) are inadequate, for the periods between productive episodes are so long and unpredictable.

From a biological viewpoint, one of the most interesting questions relating to ENSO involves how long the cycle has been in existence. By examining old weather records, climatologists have established that it has been operating since at least the late 18th Century (Nicholls 1988), but judging by the way the Australian flora and fauna are adapted to it, researchers suspect that it has been in operation for very much longer, perhaps for millions of years (Nicholls 1991).

The impact of impoverished soils and extreme climatic variability on the Australian biota has been profound. They have limited biological productivity, resulting in extraordinary adaptations and ecological assemblages. They have, paradoxically, resulted in great biological diversity, particularly in scleromorph plant communities and cold-blooded vertebrates. This extraordinary biodiversity accounts for Australia's listing as one of eight 'megadiverse' regions on Earth. The maintenance of high biodiversity in low productivity environments is an apparent paradox explained by Tilman (1982). He theorises that such environments can have higher diversity than more fertile regions because 'superspecies' (highly efficient, high energy consuming species) are excluded. Where such 'super-species' exist, they exclude many other taxa through competition.

Whereas low fertility environments can promote great diversity among plants, invertebrates and cold-blooded vertebrates, species with high energy demands such as warm-blooded organisms and particularly large carnivorous ones, are greatly disadvantaged. This has resulted in an impoverished assemblage of larger mammals in Australia relative to other continents (Flannery 1994). One result is that the larger Australian mammals weigh approximately a third as much as their ecological counterparts on other continents (Murray 1991).

The number of species in each of the mammalian carnivore guilds is also limited, each major guild in Australia being occupied by a single, small to medium-sized species. This stands in contrast with the seven or more species, including some very large ones, that comprise the more diverse of such guilds overseas (Flannery 1989). For example, Europe has 27 species of extant carnivorous mammals, including five canids and three felids (McDonald and Barrett 1993). The largest carnivores are the two species of bear, which can weigh between 100 and 300 kg. Even during the Pleistocene, Australia had only seven carnivore species weighing more than a kilogram. The largest weighed only 60 kg. In addition, Europe supports a human population of 660 million, Australia only 17 million.

Another phenomenon which is unique to Australia during the Cenozoic is that the largest Australian carnivores were all cold-blooded (Flannery 1989). At least three large reptilian carnivores, including a 3-metre-long land crocodile, a 7-metre-long varanid, and a 6-metre-long constricting snake, were widespread.

It has been argued that these unusual features of Australia's carnivore assemblage result from Australia's small size relative to other continents. The size argument alone seems inadequate, however, to explain these factors fully. Much smaller Madagascar, for example, has seven carnivorous mammal species in the 500 g–4 kg size range (Nowak and Paradiso 1993). Australia has only five.

Returning to Australia's flora, many other features are attributable to poor soils and variable climate. The large number of carnivorous plant species present in Australia is one. Approximately 130 of the 160 known *Drosera* species (sundews) are indigenous to the south-west of Western Australia, as is the monotypic family Cephalotidae (WA pitcher plant) and the genus *Polypompholyx* (bladder worts). All of these plants appear to have turned to carnivory in order to obtain nitrates, phosphates and other plant nutrients.

But without doubt the most pervasive and influential of all adaptations in the Australian flora is scleromorphy. The botanist B.A. Barlow (1981) called it 'an expression of uniqueness' and describes it thus: 'Many… major [plant] groups are characterised by relatively small, rigid leaves, by short internodes, and small plant size.'

Most eucalypts, banksias, bottlebrushes, ti-trees and a vast number of other non-rainforest Australian plant species exhibit scleromorphy to some extent. It is, according to Barlow, 'the most striking aspect of the autocthonous [Gondwanan] element' of Australia's flora. There is palaeontological evidence that scleromorphy began to develop at least 50 million years ago in Australia (White 1994).

The fact that scleromorphy has developed in many unrelated plant families suggests that it is a response to some pervasive force in the Australian environment. But what that force might be has until recently remained unclear. Earlier researchers suggested that it might be a response to aridity and in particular to the Mediterranean climate that dominates southern Australia. This view is no longer widely held and it is now believed that scleromorphy is a response to the very low levels of phosphates present in Australian soils (Beadle 1966). Its manifestations, such as small leaves and small distances between leaves, are the result of limitations on plant growth which probably result from the small number of new cells that can be sustained at the plant's growing tip.

Perhaps the most striking effects of scleromorphy are seen among the few mammal species that feed upon the leaves of scleromorph trees. The most well-known of all such species is the koala (*Phascolarctos cinereus*). Its diet consists entirely of eucalypt leaves, but it is extremely selective as to which leaves it eats, preferring those with the fewest tannins and phenolics and the highest levels of nutrients. The koala really lives on the edge, for its food source is so full of dangerous chemicals and so low in nutrients that it has evolved to restrict its energy needs. It thus needs to eat relatively little. In fact, it is possibly the greatest energy miser of all mammals. Its slow movements and low rate of reproduction are obvious results of this, but less known is the extraordinary koala brain.

The brain is one of the greatest energy users of all the organs. In humans the brain weighs a mere 2% of total bodymass, yet it uses approximately 17% of the body's energy while not exercising. Because of its high metabolism, it is no surprise that the koala has made some major reductions in brain volume in order to save energy. The strange thing is that the koala brain is much smaller than the cranial vault that houses it. Its hemispheres sit like a pair of shrivelled walnut halves on top of the brain stem, in contact neither with each other nor the bones of the skull. It is the only mammal on Earth with such a brain (Haight and Nelson 1987). In the past the koala's major predators were reptiles and other marsupials. Great intelligence may not have been necessary to outwit them.

The koala is clearly an extreme, but marsupials in general are not known for their large brains nor outstanding intelligence. In Australia, marsupials survived while condylarth-like placental mammals apparently became extinct (Godthelp *et al.* 1992). Precisely the reverse occurred on the other continents (except South America), where productivity is not so limited. These patterns of differential survival may relate to relative energy requirements.

Wombats, the closest living relatives of the koala, also have an extremely unusual lifestyle which may have been dictated by the limited resources of the Australian environment. The three extant wombat species are the only large herbivorous mammals anywhere on earth that live in burrows (Barboza *et al.* 1993). Normally, herbivores need to range over a wide area to meet their energy demands and spend large amounts of time feeding. This means that they cannot derive much benefit from burrowing. Wombats are able to benefit from living in burrows by keeping their energy requirements extremely low. They require only a third as much energy and nitrogen as a similar-sized kangaroo and spend long hours in their burrows, where they experience near constant temperature and humidity. Thus they use as little energy as possible. It may be that wombats have been able to evolve such a unique lifestyle by virtue of long evolutionary selection for low energy requirements.

The kangaroos themselves have also been shaped by selection for low energy requirements. Their most distinctive feature, hopping, is an energy efficient means of getting about. At low speeds, running and hopping use about the same amount of energy, but at higher speeds hopping is more efficient (Dawson 1977). This is because the energy of each bound is re-captured in the tendons of the legs when the kangaroo lands, rather like in a pogo stick, and is used to power the next leap. Likewise, the force of each leap pushes the gut downwards, creating a vacuum which pulls air into the lungs. Upon landing, the force is reversed, emptying the lungs. This saves the kangaroo from having to use the chest muscles to breathe.

Given the efficiency of hopping and its success in Australian environments, it is remarkable that hopping has not evolved in large animals elsewhere. Kangaroos may well owe their ability to hop in part to the marsupial mode of reproduction. The young are born at the size of a bean and therefore the pelvis can be built solidly enough to withstand the enormous pressures that hopping places upon it. It simply may not have been possible for placental mammals, which give birth to much larger young, to evolve such a rigid pelvis, for the birth canal must be large and the pelvis flexible for the large young to pass through at birth.

Another of the effects of scleromorphy on the shaping of the Australian fauna has only recently been discovered. The Australian zoologist Steve Morton was long puzzled by the great diversity of reptiles, particularly lizards, in central Australia. In some parts of the arid zone up to 47 lizard species can inhabit a sand dune complex of 1 km^2. This is a far higher number of lizard species than is found living together anywhere else on Earth (Pianka 1986). Morton became even more puzzled when he found that many of the species ate just one food resource, termites (Morton and James 1992). He suggests that the scleromorphic vegetation of Australia is simply too poor a food resource to be utilised by large herbivores and that termites play a particularly important role in breaking down plant matter and returning nutrients to the soil in Australian ecosystems. The abundance of termites in Australia, he argues, has led to unequalled opportunities for termite eaters. Lizards, by virtue of their body form and small size, have been able to specialise variously upon this resource, foraging within subterranean tunnels, in tree limbs, in the bases of grass tussocks and in the open.

Perhaps the most characteristic feature of the Australian fauna is a low rate of reproduction. Reproduction is also often opportunistic, rather than seasonal in nature. An account of what is known regarding mammal reproduction can be found in Strahan (1983). Our native rats and mice (Family Muridae) usually have extremely small litters (often one or two) when compared with rats and mice elsewhere. Many native birds also have small clutches compared with similar species elsewhere. Remarkably, there is also some evidence that the average clutch size of some introduced bird species is declining as they adapt to Australian conditions (C. Dickman, pers. comm.).

Other reproductive strategies which are unusual elsewhere are widespread among Australian species. Many Australian birds have a social structure where one or more young stay with their parents into adulthood, or relatives help feed another's young (Ford 1989). These individuals forego the chance to raise young themselves, in order to help their parents feed their younger brothers and sisters. Kookaburras, Noisy Miners and Fairy Wrens all exhibit this behaviour. Indeed, it is extremely widespread, almost characteristic of many Australian birds of Gondwanan origin. About 85% of all species world-wide which exhibit it are Australian (Allen Keast, pers. comm.). The strategy is clearly beneficial for species living in low productivity environments.

An even more extreme reproductive adaptation, possibly related to nutritional requirements of the young, is seen in the carnivorous marsupials of the genera *Antechinus* and *Phascogale* (Tyndale-Biscoe and Renfree 1987). Each year, after a frenzied bout of mating-related activity (which lasts about 2 weeks in *A. stuartii*), all males die. For a time, the population is composed solely of pregnant females or females with very small young. The lack of males during this time may be critical to the success of reproduction, for the females do not have to compete with males for food when they face the great energy demands of lactation. Likewise, when the young are weaned they do not need to compete with males for resources. That this adaptation occurs among the carnivores, some of which are very small (30–50 g), may relate to their higher trophic level.

Remarkably, a small lizard, the Mallee Dragon (*Amphibolurus fordi*), has developed a similar strategy (Cogger 1978). Most adults live for less than a year. They are dead by the time the new season's eggs hatch. This means that the young do not face competition for resources with older individuals of the same species. This strategy may have developed in this species because of its unique ecology. Both adults and young exploit the same food source, and the difference in size between adults and young is relatively small.

Yet other small marsupials have developed an opposite, yet equally effective strategy, that of extremely long life for females at least. Researchers have recently discovered that female Mountain Pygmy Possums (*Burramys parvus*) live up to 11 years in the wild (Mansergh and Scotts 1990). This makes them the longest-lived small ground mammals in the world. They may need to live that long in order to successfully raise a few litters in Australia's erratic environment.

Where Australian species do produce lots of young, they are often tied to an erratic cycle of reproduction. Perhaps the best example of this is the Banded Stilt (*Cladorhynchus leucocephalus*). Until recently its breeding habits remained largely mysterious, the only occurrence recorded before 1989 was the discovery of breeding colonies on Lake Grace (WA) and Lake Callabonna (SA) in 1930.

In March 1989 the Banded Stilts disappeared from their usual haunts. They were finally located nesting on three small islands on Lake Torrens (SA). Remarkably, they had left the coast within days of rain falling in the inland thousands of kilometres away, even before the inland lakes had filled. About 100 000 birds were nesting and the whole region was throbbing with life, for rains had filled Lake Eyre and other lakes to a 15-year high.

The reproductive cycle is very rapid, the three or four young growing rapidly upon a diet of brine shrimp. Soon after hatching, the young form up into creches, which are tended by the males. The creches leave the breeding area to roam over the shallow lakes, in one case swimming 130 km in six days. A mere three weeks after hatching, the young are ready to fly. Just two weeks after the first clutches of eggs hatch, the females nest again at another location. They presumably mate with the males while the latter are tending the creches. In all, the reproductive cycle of the Banded Stilt can be completed in just seven weeks, but even this can be cut down as one nesting cycle overlaps another (Phillips 1990).

This remarkable reproductive cycle is necessary because the salt lakes upon which the birds depend can support brine shrimp for only a short time. The shorter their breeding cycle, the more young can be raised. It is important for a pair to raise as many young as possible during a good season, for it may be a decade or more before conditions are right for the stilts to breed again. Although the lifespan of the Banded Stilt is undocumented, it is certain to be a long-lived species, for adults must often go a decade or more without breeding.

Yet another feature of Australian ecosystems which results directly from their inherent constraints is nomadism. Nearly a third of Australia's bird species are truly nomadic (Keast 1961), which is an extraordinarily high percentage in world terms. The Red Kangaroo (*Macropus rufus*) is also partly nomadic, following the rains that produce the short green pick that it prefers. Of course, Australia's first human settlers remained nomadic.

A possibly related phenomenon is the success of birds in Australia relative to mammals. When the area of Australia is compared with that of other landmasses and the number of bird species calculated on an area basis, we find that Australia has a fauna roughly equivalent, or a little more rich, than is found on the other continents. Its mammal fauna, when viewed on the same basis, is very small. For example, Australia's 250 species (Strahan 1983) compares unfavourably with the 850 recorded from the admittedly larger North America (Hall and Kelson 1959). It may be that Australia's very large size, erratic climate and poor resource base make it beneficial to be able to fly to reach resources, as quickly as possible after they become available.

Although few of these features are uniquely Australian, the abundance of adaptations serving the one end is quite remarkable. This is eloquent evidence of the forces shaping the Australian ecosystem.

The effects of infertile soils and ENSO are very far reaching, for not only do they shape life on land, but they help shape life in the sea as well. This is because there are few nutrients flowing into Australian marine environments from Australia's small and highly variable (in terms of flow) rivers. With a conspicuous lack of cold-water upwellings around the continent, this has produced some of the least fertile seas on Earth. Australia's oceans are a watery mirror of its land; both are largely infertile deserts.

These factors are reflected in Australian fisheries. Despite an enormous fishing zone (about the same size as that of the United States), Australia rates 55th in size among the world's fisheries. Despite the small catches, fisheries officials were warning as early as 1985 of a crisis in Australian fisheries (Bain 1985). This crisis is well under way today, with most fish stocks continuing to decline through overexploitation.

3 THE HUMAN 'CARRYING CAPACITY' OF AUSTRALIA AND AUSTRALIAN LAND AND WATER RESOURCES

Humans are large warm-blooded omnivores. They have high energy demands. This makes them potentially vulnerable in Australian environments. Human populations in Australia have always been small and dispersed, being an order of magnitude or more smaller than the average density found on other continents (Birdsell 1953). They have occupied a particularly wide ecological niche, and have been densest (approximately 40 times the average density) only where rivers have concentrated nutrients (Birdsell 1953).

The existing human population of Australia is, in world terms on a per area basis, tiny. It is also highly urbanised and affluent with great technological know-how. Yet environmental degradation resulting from overexploitation of natural resources suggests that limits have been exceeded in some areas.

Until the early 1980s, agricultural products were the single most important income earners for Australia. Since then, a rapid growth in mineral exports has superseded agriculture, so that today mining earns Australia some $29 billion, and agriculture $16 billion. All our other exports (including all manufacturing) earn around $11 billion. Because both mining and agriculture are highly mechanised industries which require small workforces, Australia can manipulate population size without compromising earnings.

This means that if Australia's population were smaller, we could afford to do many things differently. The argument over logging of old growth forest, for example, would be less intense, for the housing construction industry, which uses much of the hardwood timber produced, would be scaled down. Likewise, increased levels of affluence would mean that the dollars earned through woodchip exports would not be so vital. It would also give us much more choice when it came to the preservation of other areas, for the cash earned through their exploitation would not be as vital as it is now.

I think that a number of social and economic indicators suggest that Australia has a population problem. High levels of chronic unemployment suggest a population level which has exceeded the society's capacity to provide useful work. Persistent difficulties with balance of payments deficits indicate a level of population generating demands for imports which cannot be met through the earnings of its workforce. Finally, increasing reliance on non-renewable mineral wealth suggests that the demands of a large population have exceeded the resources available from renewable sources.

What then is a desirable population size for Australia? Estimates have varied widely over the years. One of the earliest scientists to concern himself with this problem, Professor Griffith Taylor of Sydney University, produced a number of estimates in the early part of the century (Powell 1993). Whereas he predicted that Australia would have a population of 19 million by the year 2000, he also suggested that the maximum population for a people living at US or European living standards lay between 20 and 65 million. Less scientific estimates of the maximum population have also varied widely, from 480 million to 10–15 million. The most recent and carefully thought out estimates are those of Professor Henry Nix of the Australian National University. He has based his estimates on the amount and quality of arable land available in Australia. His earlier computer-based estimates, made in the 1960s, suggested that Australia had just under 125 million hectares of arable land. When he revised his estimate in 1976, taking into account better knowledge about soil types and climate, he came up with an estimate of only 77 million hectares (Nix 1990). He predicts that, when the data are examined again in the light of new satellite information, the estimate will be again lower (Nix, pers. comm.).

Currently, 22 million hectares of arable land are being used in Australia (Nix 1990). Much of this land would be considered to be marginal agricultural land on other continents. Yet it is by far the best of Australia's arable land. The rest is decidedly marginal even by Australian standards, and is largely untested in terms of its agricultural potential. Already, after less than 200 years of use, much of our agricultural land is degraded and in need of soil restoration programs. For example, salination affected 427 000 hectares in 1982, but had increased to 790 800 hectares by 1991 (ABS Environment Report 1992). Water and wind erosion, soil acidification and soil structure decline are also having a significant effect. There are no cost-effective remedies for much degraded land. As the ABS Environmental Report (1992) says, 'The emphasis today is on prevention rather than reclamation'. Even if degraded agricultural land could be restored, and national parks, forest and urban sprawl abolished from potentially arable land, the output of Australia's agriculture would always remain relatively small.

Nix estimates that Australia is currently capable of feeding around 50 million people. Much of this food is exported. Given current technology and investment, we can take this figure to be a carefully estimated, if perhaps a trifle optimistic, maximum population for Australia, unless we, currently one of the world's half dozen or so reliable food exporting regions, decide to start importing food.

But what of an optimum population? This is much harder to estimate, for much depends upon non-biological factors such as mineral resources and commodity prices. But from a purely biological perspective a few comments can be made. Given the desire of Australians to reserve some potentially arable land for purposes other than agriculture, particularly national parks and forests, and given the enormous challenge presented by soil degradation, a more realistic maximum population for Australia may be 20–30 million. A population of this size would also give Australians a chance to earn some money from food exports.

This, however, is not the whole story. By examining those societies which live in a sustainable manner, a few important principles of sustainability for humanity can be discerned. Most hunter-gatherer societies are ecologically sustainable, the basic lifestyle having been in existence for 100 000 years or more. Virtually all hunter-gatherer societies seem to possess a 'golden rule' of population. This is, that in 'normal' times, the human population of a given area rarely exceeds 20–30% of the carrying capacity of the land (Sahlins 1968). This occurs because people are long-lived and usually reproduce slowly. Their population takes a long time to recover from disasters such as droughts, but their food species recover much more quickly. This means that, for most of the time, hunter-gatherers lead a leisurely lifestyle. They spend a relatively few hours each day finding their food, and use the rest in recreation or ritual.

Australia's high rainfall variability and fragile natural environment mean that special care should be taken. It would appear to make good sense to observe the 'golden rule' of population in determining Australia's 'carrying capacity'.

In late 1994 The Australian Parliament House of Representatives Standing Committee on Long Term Strategies delivered a report entitled *Australia's Population 'Carrying Capacity'. One Nation — Two Ecologies*. This report argued that Australia should adopt a population policy. The first and most crucial step in formulating such a policy is the estimation by Australian scientists of an optimum human population size for Australia based upon current technology, affluence and social organisation. Previously, estimates of an optimum population for Australia (including my own) have been relatively poorly supported. A well-funded national effort to determine this figure is now imperative. A particularly important component of the determination of this figure will be knowledge of how sustainable is our food production capacity. The following chapters of this volume consider most of the factors that contribute to degradation of our agricultural resources and how we might go about saving what remains.

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