CHAPTER 23

Reconciling agriculture and nature conservation: toward a restoration strategy for the Western Australian wheatbelt

E. C. Lefroy[1], R. J. Hobbs[2] and M. Scheltema[3]

In this chapter we suggest that a description of the basic nature and extent of revegetation necessary to overcome land degradation in the wheatbelt of Western Australia can be arrived at systematically. In doing so we attempt to focus attention away from a perceived conflict between production and conservation and towards the common ground shared by both i.e., the restoration of basic ecosystem functions. Rather than asking how to protect the existing production system, this approach asks firstly: what form does the vegetative cover of this region need to take to best ensure its long-term health? And secondly: what are the potential economic values of such vegetation that might motivate its establishment? This analysis suggests that in the order of 500 million to one billion trees and shrubs are required over the 15 million hectares of cleared land. It is also suggested that if the revegetation is concentrated into belts and planted with attention to landform and aspect, the production of crops and pastures could be enhanced while simultaneously providing wildlife habitat and permanent protection against land degradation as well as providing some commercial products from indigenous woody plants. Actual and potential economic and nature conservation values of such a vegetation network are discussed, as well as the practicality of revegetation at this scale.

INTRODUCTION

THE range of opinions concerning the extent to which a productive but degrading landscape requires rehabilitation can be thought of as lying on a continuum. This continuum stretches from a purely productive, "business-as-usual" approach that sees no justification for revegetation or restoration, through a reluctant acceptance that there is a need for defensive revegetation to patch up and maintain the present productive system, to a view that supports the exclusive use of indigenous species and the primacy of nature conservation values.

In this chapter we put a case for a function based approach which is seen as offering resolution to the conflict that inevitably arises in the debate between production and conservation (Fig. 1). We argue that restoration of the basic ecosystem processes of water cycling, nutrient cycling and energy flow and their maintainance through biodiversity is essential to any form of land management, and that an analysis of the state of these processes will suggest the form that the vegetative cover need take. In this sense the economic potential of a region will be suggested by a description of its desired vegetative cover, rather than as a non-negotiable given at the commencement of any debate on sustainable land use.

Rather than revegetation being seen as peripheral to mainstream agriculture, or as an expensive defensive strategy to shore-up an ailing production system, it is seen as a means of driving the restoration process through the economic value of a proportion of the replanting.

In essence this view holds that ecological considerations need to be taken into account prior to economic and social issues. Far from denying the importance of social or economic factors, it suggests that they be examined within an ecological

[1]Department of Agriculture, Baron Hay Court, South Perth, Western Australia, Australia 6151.
[2]CSIRO Division of Wildlife and Ecology, LMB No. 4, PO Midland, Western Australia, Australia 6056.
[3]Greening Australia, 1118 Hay Street, West Perth, Western Australia, Australia 6005.

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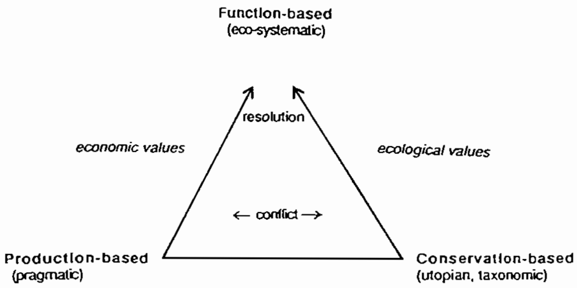

Fig. 1. A simplistic representation of attitudes to land management suggesting that an approach based on restoring ecosystem function could resolve the conflict that often exists between production-based and conservation-based approaches.

context. We develop this idea through an examination of the Western Australian wheatbelt, an area that has been rapidly developed for agriculture over the last century and which is now experiencing severe land degradation and loss of nature conservation values (Hobbs and Saunders 1991).

BACKGROUND

"The hinterland is now becoming a vast cornfield, interlaced with railways and studded with bustling towns" Grasby (1913).

For the purposes of this discussion the wheatbelt of Western Australia is defined as that part of south-western Australia receiving between 600 and 275 mm of rainfall per year (Fig. 2). The 600 mm rainfall isohyet has been regarded as the outer limit for conventional forestry due to growth rates and transport distances. It also represents the inner or western limit of wheat growing.

Some 75 per cent of the annual rainfall of this region occurs during the six cool winter months from April to September when low pressure systems, originating in the Indian Ocean, move past the south-west corner of the State. At the end of this period, a belt of high pressure lying across the continent moves south, and centred over the Southern Ocean produces an easterly wind pattern and high temperatures. A characteristic of the region is that the dry season from November to April is occasionally interrupted by the southerly movement of decaying tropical cyclonic storms. These bring high winds and occasionally intense rainfall at a time when annual crops and pastures have died and offer least protective cover. The long hot summers mean that vegetation is highly combustible and fire has long been a characteristic of the region and important in the evolution of its flora.

Much of the region's vegetation has evolved from tropical species and exhibits a summer active growth pattern. Although the original plant cover existed as a mosaic of communities closely associated with soil types, broad vegetation types can be described and are shown in Figure 2.

Of a total 19 million ha in the region, some 15 million ha (80%) has been cleared for agriculture (Carder and Grasby 1986; Australian Bureau of Statistics 1990). Some 2.3 million ha of the remainder (12%) exists as national parks, major reserves and vacant Crown land with three large reserves accounting for most of this. A further 1.5 million ha (8%) exists as mainly small scattered remnants on private land (Hamilton *et al.* 1991). In the centre of the region, which is the heart of the wheat growing area, 93 per cent of the land has been cleared with the majority of the remaining vegetation being in unfenced patches on private land (Hobbs and Saunders 1991).

Economic value

The region has produced between four and five million tonnes of wheat per year, or about one-third of Australia's total production, since the mid 1970s. In 1988/89, wheat represented just under half the value of total agricultural production in the State and 12 per cent of the value of the State's exports. In terms of world trade, five million tonnes represented less than 1 per cent of world wheat production in 1989/90, reflecting the sensitivity of the State's economy to world prices in relation to the small influence it exerts on world production.

Adding the value of wool and livestock from the region brings its contribution to the State's export earnings to just over 20 per cent (Australian Bureau of Statistics 1990). This significant contribution has

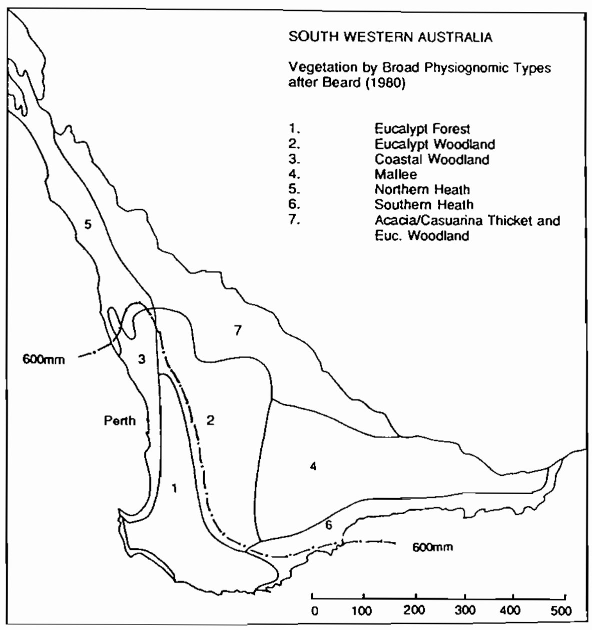

Fig. 2. Southwestern Australia showing the broad vegetation types of the agricultural area and the 600 mm isohyet which approximates the western and southern limits of the wheatbelt. Vegetation types are 1. Eucalypt forest 2. Eucalypt woodland 3. Coastal woodland 4. Mallee 5. Northern heath 6. Southern heath 7. Acacia/allocasuarina thicket and eucalypt woodland (adapted from Beard 1980).

been maintained by a decreasing number of farmers. Farm businesses have amalgamated in the face of declining terms of trade as the costs of inputs have continued to rise faster than world prices for wheat and wool. As a result, the number of farms in the region has decreased by 18 per cent between 1980 and 1990, from 12 000 to 10 000 (Australian Bureau of Statistics 1990). Meanwhile, the level of production of wheat has been maintained while that of wool has increased. The area sown to wheat peaked in 1983 and has declined since.

Natural capital cost

On the other side of the ledger are the unintended side effects of agriculture: the depletion of the natural capital stock in the form of soil fertility, fresh water and biodiversity; the social cost of farm businesses and small towns folding and the economic cost in the form of the level of debt that may have to be written off. To date these externalities have not been expressed through the traditional economic measures of well being (Eckersley 1991). Although depreciation of most capital items is well recognized by farm businesses, depreciation of natural capital is not.

A summary of the type and extent of the depreciation of the natural capital base of agriculture is shown in Table 1. This table shows that the estimated annual cost of land degradation, in terms of lost production, amounted to 17 per cent of the gross value of agricultural production in 1988/89. This amount is not yet recognized as a legitimate cost of agricultural production in the national accounts. In fact the Gross National Product registers the money spent on land conservation, which is going some way to meeting this cost, as *income* (Eckersley 1991). The Select Committee into Land Conservation in Western Australia (House 1991) considered that the costs shown in Table 1 are under-estimates. Some other costs more external to the agricultural environment, such as eutrophication of rivers and estuaries, are either being passed on now to the wider community (Peel-Harvey catchment) or exist as potential costs (Swan-Avon catchment).

In addition to these land and water conservation issues are more general nature conservation issues that cannot be accurately expressed solely in terms of their value to the human population. The extinction of species through the fragmentation of this landscape may well be undermining the life supporting capacity of the region but we cannot put a dollar value on each species, especially the ones we cannot see such as soil organisms. The "vast cornfield" is now studded with dying towns and small islands of bush that have similarly lost their inhabitants. Of the 10 000 species of plants found in Western Australia, 238 are classified as rare and endangered and most of these are woody perennials from the agricultural region (Hopper *et al.* 1990), of these one-third are found only outside nature reserves (Saunders and Hobbs 1989) and are therefore more vulnerable.

Of 46 species of native mammals that occurred in the region, 13 are extinct and only 12 remain common. Of 192 species of birds, 50 per cent have decreased in abundance and three have disappeared (Saunders and Hobbs 1989; Hobbs *et al.* 1992). Added to this, the last 150 years has seen the almost complete displacement of the Aboriginal occupants. With them has gone a profound knowledge of the region's biota, both in terms of its utility to humans and an appreciation of its interdependence.

Table 1. The nature, extent and cost of land degradation in the agricultural area of Western Australia (Department of Agriculture 1991).

Form of land degradation	Estimated area affected (ha)	As a % of cleared land	Estimated cost ($M/YR)
Salinity — Land	433 090 (1989)	3%	61
— Major public water resources			41
— Private on farm water			3
Waterlogging	500 000 (Crop, av. year)	3%	90
	1 300 000 (Pasture, av. year)	8%	
Water Erosion	750 000	5%	21
Wind Erosion	50 000 (variable)	0.3%	21
Soil Structure Decline	3 500 000	22%	70
Subsoil Compaction	8 500 000	54%	153
Water Repellence	5 000 000	32%	150
Soil Acidification	375 000	2%	5
		TOTAL ANNUAL COST:	$615
As a % of Total Agricultural Production 1988/89:			17%

The landcare movement

Seen over more than 40 000 years of Aboriginal occupation the changes described above have occurred extremely rapidly; in the relative equivalent of one and a half days out of a year. By comparison, the human modification of the Mediterranean ecosystems of Southern Europe and North Africa have occurred over 8 000 years (the relative equivalent of three months out of a year). It has been argued that the gradual development of agriculture and civilization results in a more symbiotic relationship between man and nature through which the landscape alters the occupants as much as the reverse (Dubos 1976). However, the end result in these two cases have been the same; soil erosion, extinctions and near complete removal of permanent vegetation cover to produce the Mediterranean "goatscape" and the southern Australian "wheatscape".

The rapidity of landscape changes in Australia's case may however be a distinct advantage. Much of this change has occurred within the memory of existing generations. Personal memory combined with anecdotes of parents and grandparents may prove to be a strong motivating factor in reversing trends such as vegetation decline, soil erosion and the waning fortunes of country towns. Also, Australia has not developed the complex social and political customs and land use patterns typical of the Mediterranean basin. These may prove more resistant to change than the strongly developed materialism of Australian society which Roberts (1984) argues is the most significant barrier to the development of sustainable land use.

In this regard, the most encouraging phase of the short dramatic history of the region may be the growth of the Landcare movement (Goss and Chatfield, this volume). The passing of the Soil and Land Conservation Act in 1982 precipitated the formation of Land Conservation District Committees and there are now some 90 within the wheatbelt region. While 75 per cent of these are based on Local Government boundaries, which have no particular ecological significance, much of the action of these committees is taking place within catchment groups defined by watershed boundaries. This division of the landscape is increasingly being seen as the most relevant in which to address problems of land conservation and pursue the development of sustainable land use patterns. In fact Crombie (1991) suggests that in the Landcare movement, specifically in the case of catchment groups, we may be witnessing the emergence of the fourth tier of government. He sees it as having the potential to become the first form of government based on ecological boundaries; as he terms it "watershed governance". The suggestion here is that there is the need for change in social structures and laws so that they are compatible with watershed "laws" or ecological processes, rather than being loosely based on statistical and electoral boundaries that have no biological basis (see also Curry 1977, 1981; Emery 1989).

In this sense the Landcare movement could be seen to have two potential roles in the future; to be a defensive movement aimed at patching up the existing production system, where conservation gains are the legacy of good years only, or to become the focus for the development of bioregional solutions and, as such, the voice of the land.

THE ECOLOGICAL IMPERATIVE

As humanity is a product of nature, and can only exist within nature, the patterns of human land use must ultimately respect the tolerances within which natural physical, chemical and biological processes operate. Ecological values must ultimately take precedence over other values. The boundary conditions or tolerances within which natural processes operate will always be outside human influence and cannot be compromised without compromising human existence. This is where the concept of the rate-limiting step is important. Forms of land use that accelerate erosion are ultimately limited by the rate of soil formation. Forms of land use that are energy intensive are ultimately limited by the rate of fixation of solar energy (until nuclear fusion becomes a realistic proposition).

Overcoming the problems facing the wheatbelt, as described in the previous section, can be seen as attempting to satisfy the objectives of land and nature conservation, while at the same time continuing to support the region's population and maintaining its contribution to the State's economy. This is represented in Figure 3 as attempting to satisfy both the ecological imperative and the economic imperative.

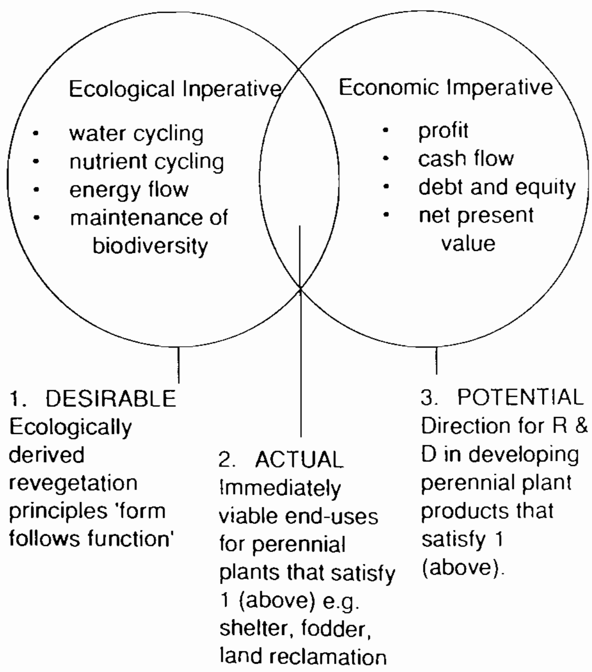

Fig. 3. Schematic framework for a productively driven revegetation strategy.

The process should occur in three stages (Fig. 3). The first stage is to describe the necessary form or structure that the vegetative cover of a region would need to take to ensure restoration of basic ecosystem functions. The second is to determine which aspects of this broad description are economically and practically feasible today in order to become the focus of immediate action. Thirdly, that part of the desired outcome that is not viable or practical today suggests potential areas of research into the economic values of perennial plants. The long-term aim is to increase the degree of overlap between the two circles in Figure 3. This approach of working *backward* from a desired or utopian outcome, (that of ecological sustainability) as well as *forward* from the pragmatic starting conditions of today has several advantages over solutions that are purely agricultural or production oriented.

Firstly, solutions that only work outwards from the starting conditions and assume that agriculture in its present form will always be the dominant productive system are limited in their effectiveness because there is no attempt to define the goal of sustainability. Consequently there is no way of knowing if the steps being made today towards sustainability are all in the same desired direction. This has been described as "disjointed incrementalism" by Braybrooke and Lindblom (quoted in Crombie 1991), and more memorably by Mark Twain who said "If you don't know where you're going, any road will get you there". In some cases the only change that has happened to existing agricultural practice has been to re-name it "sustainable". Attempts to change outwardly from the current state may be limiting themselves by only looking for agricultural solutions. The more likely outcome is some combination of agriculture, horticulture, forestry and floriculture, with a common emphasis on the productive use of a combination of perennial and annual plants.

Analog forestry

An approach to the design and management of agricultural systems that is based on the observation of the ecosystem functions in the wild was articulated by Howard (1979). This has been extended by the work of Jackson (1987) and Savory (1988) in particular. Senanayake (1984) has referred to this approach as "analog forestry". In the application of this approach given below we look at four basic ecosystem functions (the cycling of water, the cycling of nutrients, the flow of energy and the role of biodiversity) as they occur in the remnants of native bush and ask the question "how can these conditions be approximated in a managed productive landscape where vegetation replacement must be primarily economically driven?".

In contrast, work by ecologists in the wheatbelt to date has focused largely on studying remnants of native vegetation in isolation rather than to derive analogs or principles for managing the surrounding matrix. In this sense, these scattered remnants have become refuges for ecologists as much as for the native biota. There is a great need for ecologists to venture out of these remnants and to turn their attention to improving the health of the agricultural matrix.

Use of the word forestry does not imply that "analog forestry" is only relevant where the original vegetation was forest. In the case of the wheatbelt the same principles are applied to an area formerly covered by open woodland, shrublands and heath.

Each of the following four sections are dealt with in more detail in Lefroy *et al.* (1992) including suggested indicators for sustainable land use.

Water cycling

Many of the land degradation problems shown in Table 1 are a direct result of excess water accumulating in parts of the landscape following replacement of the original perennial vegetation by annual crops and pastures. Meanwhile water remains the limiting factor in the present agricultural system for at least six months of the year. The challenge is to use the excess water that results in waterlogging, salinity and soil erosion as productively as possible. The first question is how much water is there to be used now that we have a landscape dominated by annual plants and consequently a less buffered hydrologic system?

Peck and Hurle (1973) estimated that between 5–10 per cent of rainfall is currently unused on cleared land in southwestern Australia and contributes to problems of salinity and waterlogging. Taking an annual rainfall of 350 mm per annum, this amounts to an average of 1 000L ha^{-1} of excess water per day assuming 10 per cent of the rainfall is not intercepted by crops and pastures. By comparison Nulsen *et al.* (1986) in a study of a mallee catchment, showed that virtually all the rainfall was accounted for by redistribution within the catchment. Rain intercepted by the canopy flowed down the mallee stems and along root channels to be later transpired by vegetation. Run off was almost negligible at 0.025 mm yr^{-1}.

The limited information on the rate at which trees and shrubs use water in the wheatbelt environment suggests a need to replace on average 30–40 stems per ha. This is based on water use of 25–30 litres per day for four-year-old *Eucalyptus* spp. (Greenwood and Beresford 1979). This figure is of course dependant on age, health, species and competition but as a crude estimate, it serves as a starting point until better information comes to hand. Using these admittedly rough assumptions gives us a conservative revegetation target of 525 million trees and shrubs for the 15 million hectares of cleared land in the region.

The next question is the pattern in which this revegetation could be laid down to best intercept water and also contribute to the protection of remnants, the provision of corridors, improved nutrient cycling and energy use efficiency.

If this planting is concentrated into belts 15 m wide with a density of 400 stems ha^{-1} and spaced 200 m apart, this desired overall population can be achieved while occupying less than 10 per cent of the area. If these belts are aligned on the contour and located along banks to effectively bring the water to the trees, a form of alley farming can be practised that is similar to the keyline system (Yeomans 1958, 1964; Watkins 1990). On sandplain soils, orientation of the tree and shrub belts is more logically based on wind direction (Melvin, D. Elderts Weekly Jan. 16, 1992), (see Fig. 5). Using these belts to reunite patches of remnant vegetation would satisfy some conservation objectives, providing they had a suitable layered structure with provision for shelter, year round food supply and nesting sites for a wide range of species.

Two important questions remain. Will this basic pattern of vegetation belts intercept sufficient water to correct localized hydrologic imbalance and what economic incentives exist for its implementation?

Nutrient cycling

When considering nutrient cycling in agricultural and natural ecosystems with the aim of achieving ecologically sustainable land use, the desired outcome is to close the nutrient cycle as much as possible by matching inputs to the losses due to harvest, by fostering biological recycling and by minimizing losses due to leaching and erosion. Lipsett and Dann (1983) and Williams (1991) have demonstrated the extent to which Australian agriculture is running down its soil resource through the net export of nutrients in grain, wool and meat. Russel (1980) has estimated that the best soil nutrient level that can be maintained with a cereal crop/annual legume pasture rotation is about 60 per cent of that in the natural ecosystem. An analog forestry approach would suggest several possible avenues for improvement. One is to increase the proportion of deep-rooted perennial species, particularly nitrogen fixers. The other is to increase the proportion of indigenous species that are known to be well adapted to low soil nutrients particularly phosphorous (Bowen 1981; Bettenay 1984; Lamont 1984).

The analog forestry approach has been adopted by the Land Institute in Kansas which has set itself the task of answering four questions in developing perennial based agriculture: can perennialism and high yield go together? Can a polyculture of perennials outyield a monoculture of perennials? Can we manage such complexity and avoid the problem of pests outcompeting us? Can such an ecosystem sponsor its own fertility (Jackson 1987)? To this end the Land Institute has developed a perennial grain crop from the grass *Thinopyron intermedium* (Wagoner 1990). Herbaceous perennial forage species, (grasses, herbs and legumes) presently under trial in the wheatbelt could possibly be used on a four to five year rotation with conventional grain crops and so introduce improved nutrient cycling and water use to some of the region's soils (Parker 1989) (See Table 2).

The development of perennial crops and pastures would also contribute to overcoming the problems Parker (1989) identified as leading to a decline in biological activity in wheatbelt soils, namely the loss of plant residues as soil cover, regular shallow soil disturbance through cultivation and the absence of deep-rooted plants. Inclusion of perennial legumes, through inter-cropping or rotations at four to five year intervals may be sufficient to keep old root channels and other preferred pathways open for both water movement and increased soil biological activity. The use of no-till drills with annual cropping also has a great contribution to make in this regard.

The tree and shrub belts for increased water use could have an important role in limiting losses of applied nutrients. For this to be effective, any layout would need to include revegetation of drainage lines as well as alignment along the contour. The contribution of wheatbelt agriculture to eutrophication of the Swan-Avon River system in particular is likely to bring increasing pressure from urban areas for this aspect of revegetation.

While greater water use may be achieved by judicious revegetation of as little as 10–20 per cent of cleared land, putting nutrient cycling on a sustainable footing involves the whole landscape and focuses attention on the strategic use of perennial plants between the tree and shrub belts as well as changes in tillage practice

Energy flow

No system of land use can be considered sustainable while it is reliant on inputs of energy that are being consumed at a faster rate than they are being produced. Dryland cereal production in Australia is often quoted as being more energy efficient than in most countries, having a ratio of energy output to energy input of 4:1 compared to 0.7:1 for dryland corn in North America (Watt 1982). However, both systems are ultimately dependant on supplies of liquid fossil fuels which, as stocks inevitably run down, become increasingly expensive and contribute further to the cost-price squeeze. Two studies in Australia to date (Wynen 1988; Derrick 1990) have suggested that farmers adopting low input systems have, to some extent, substituted more intensive management for high energy inputs of diesel, fertilizer and pesticides. In many cases yields were lower, but costs were proportionally lower still, resulting in higher net returns.

Table 2. The potential role of perennial plants in the wheatbelt.

Component	Structure	Function	Economic value
Permanent Vegetation Belts			
— on the contour	Indigenous trees, shrubs, perennial and annual grasses and herbs.	Water use, erosion control, wild life habitat, corridors.	Shelter effects
— along drainage lines	Indigenous trees, shrubs, perennial and annual grasses and herbs.	Water use, erosion control, nutrient, interception, wild life habitat, corridors.	Shelter effects
— on salt land	Trees.	Water use.	Land rehabilitation
Harvested Vegetation Belts			
— on the contour or against prevailing winds	Various indigenous spp. *(Eucalyptus, Acacia)*	Water use, erosion control, seasonal habitat.	Shelter effects, biomass, essential oils, tannins, solvents, seeds etc.
— on sandplain	*Chamaecytisus, Acacia* sp.	Water use, erosion control.	Forage
— on salt land	atriplex, *Agropyron* sp.	Water use.	Forage, land rehabilitation.
Perennial Pasture	Grasses, legumes (e.g., *Chloris* sp., *Medicago* sp.)	Water use, nutrient cycling, erosion control.	Forage
Perennial Grain Crops	Perennial grass, and legume spp. (cf. *Thinopyron* sp.)	Water use, nutrient cycling, erosion control.	Grain

Finding a substitute for liquid fossil fuels remains the big challenge. An exciting development in this regard is the technology that enables the production of ethanol from cellulosic raw materials rather than the more conventional cane sugar or grain starch (Lynd *et al.* 1991). Combining the abilities of fungi and yeasts to break down and ferment cellulosic biomass means that a wide range of woody material is now potential feedstock for ethanol production, including tree and shrub biomass. Estimated costs of production in Australia are in line with current crude oil prices at US$21.50/barrel or $0.24/litre (Reeves 1991). The most likely use initially is as a 15 per cent additive to diesel fuel. With annual consumption at 10 000 ML Australia wide this would involve 1 500 ML yr^{-1} of ethanol, in turn consuming 5 million t yr^{-1} of feedstock.

Here it is possible to see a direct commercial end use for some of the tree and shrub belts, harvested on a three or four year rotation. According to Lynd *et al.* (1991) these would produce a higher net energy yield in the long term than harvesting conventional annual ethanol feedstocks. This product would also have an immediate local market and not suffer, like many other industrial products of indigenous plants, small and often volatile niches on world markets.

In addition to using biomass, Newman (1990) suggests that we could see wheatbelt farmers generating energy from sun and wind and selling electrical power from these sources into the regional grid as is happening in the southwestern United States.

Biodiversity

Of all the conditions we are striving for in developing sustainable land use systems, biodiversity remains the most difficult to specify because its role in natural systems is so poorly understood. Adding, almost as an extra condition to those of water cycling, nutrient cycling and energy, the need to have a system based on as wide a range of species, and variation within species, as possible does not necessarily ensure that nature conservation objectives will be met. It is true, however, that by simultaneously meeting the first three objectives, a greater diversity will inevitably result than is found in conventional agriculture.

Design and location of revegetation

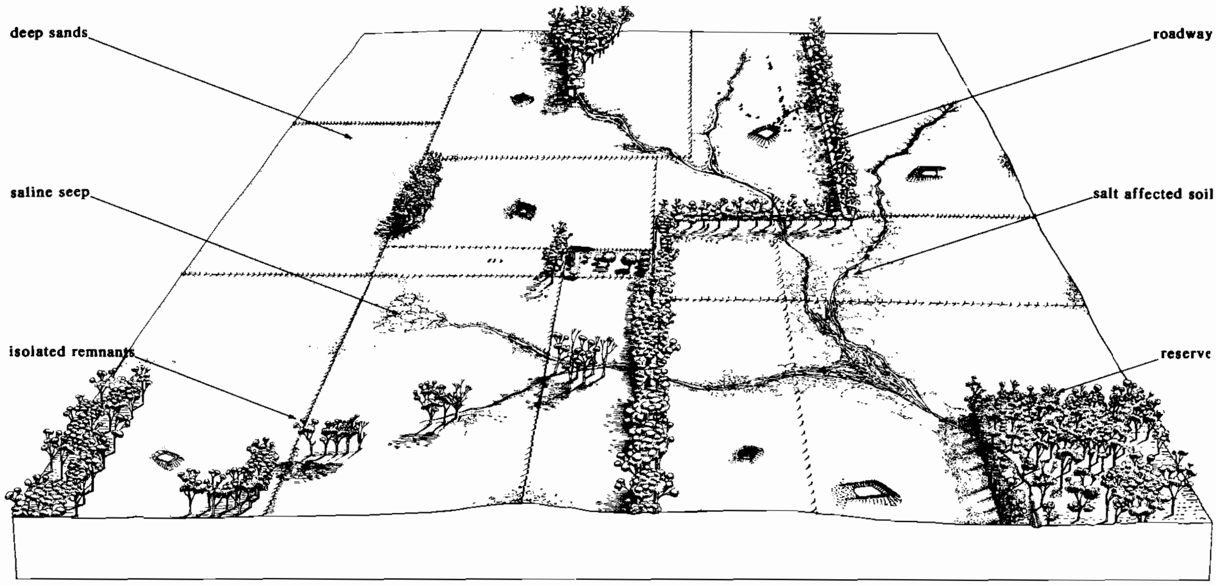

Fig. 4. A stylized view of the present state of the wheatbelt landscape showing the grid of human activity in relation to the drainage pattern, land degradation problems and the isolated nature of remnants of native vegetation.

The fact that we are unaware of the number of extinctions amongst the soil micro fauna and flora of the wheatbelt, or their role in resource recycling, illustrates the danger of taking a purely taxonomic view of biodiversity with its inevitable bias toward the species we can see and whose roles we appreciate. For this reason Main (1982, 1984, 1987) in discussing the role of biodiversity in the wheatbelt pursues a "functional substitutability" approach: that is, an approach that attempts to identify the range of species that are capable of substituting for others in carrying out critical ecosystem functions. For example, with respect to nitrogen retention in wheatbelt soils, Main argues that the important factor is the variety of indigenous species that are capable of performing this function (insect larvae, nematodes, fungi, protozoa and bacteria) under a wide range of environmental conditions. He argues diversity provides a pool of organisms from which functional substitutes can be found following the loss of one that formerly filled that role. A purely taxonomic view of diversity that attempts to preserve every species because we may fail to appreciate their role, or because of belief in the intrinsic value of every species is unlikely to succeed. As a guide to this approach of functional subsitutability, Main (1992) lists the important functions as he sees them, which could serve as a useful addition to the analog forestry approach for assessing diversity. These are: to fix carbon and nitrogen; to provide architectural structure or habitat; to interact with other species so that one or several do not dominate the use of resources; and to recycle resources so that net loss from the system is minimized.

ECONOMIC IMPERATIVE

The combinations of various types of perennial plants that might satisfy the ecological conditions suggested by the analog forestry approach are summarized in Table 2.

To put this into context it is worth considering the *extent* as well as the *nature* of revegetation required. With some 15 million ha of cleared land, the target of 30–40 stems per ha (derived from approximations of water use) would mean 525 million trees and shrubs in total. Assuming that these plants could have the desired effect when concentrated into strategically placed permanent and rotationally harvested belts, these belts could then become the backbone of a long-term revegetation plan (see Figs 4 and 5). An estimation of requirements for a complete shelterbelt network over the entire 15 million hectares also suggests in the order of 600 million trees (8–10% of the land planted at 400 stems per ha). While some of these may perform the dual role of intercepting water, some will not, thus putting the total revegetation target at between 500 million to one billion trees and shrubs.

Assuming that 50 per cent of trees and shrubs planted won't survive due to drought or pests, the establishment of such a network over 10 years would require 100 to 200 million plants per year. Assuming a life span of 30 years in these narrow belts, there would also be a requirement for replacement at the rate of some 30 to 60 million *per year* after 30 years, although it is likely that revegetation on this scale using mainly indigenous species will be self regenerating and hence develop a self sustaining system.

A long term revegetation plan

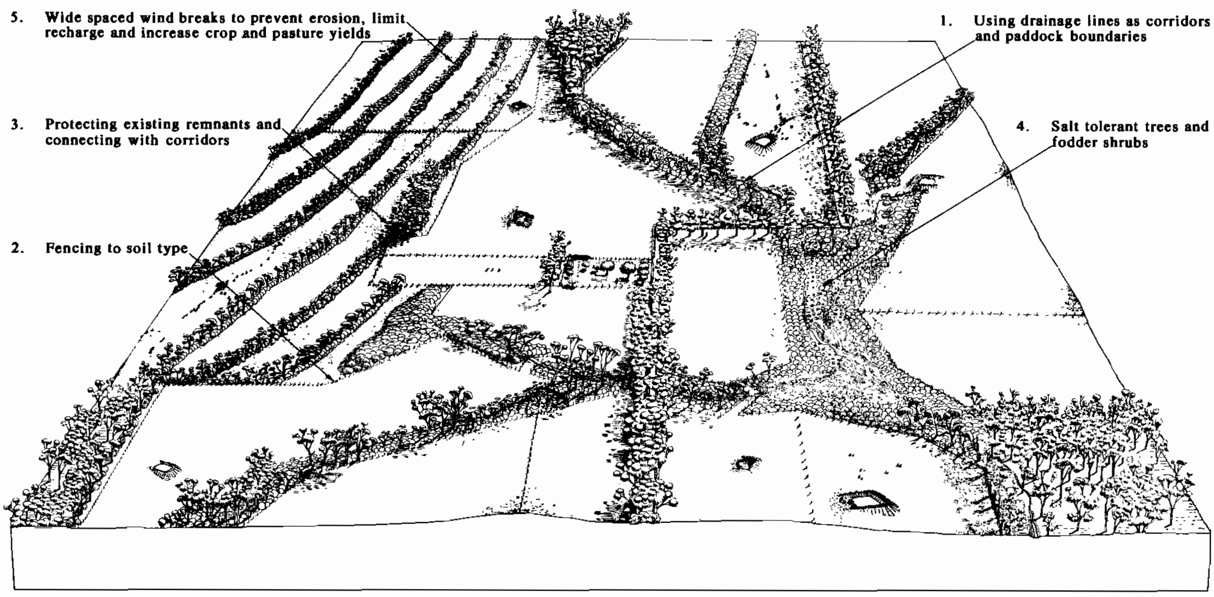

Fig. 5. A stage in transition towards restoration of the wheatbelt landscape showing fencing aligned to soil type and drainage patterns, revegetation of drainage lines and alley farming between shelterbelts.

Within this backbone of tree and shrub belts, it is suggested that there is need for the development of perennial species for forage, grain and possibly industrial uses, particularly in the two landscape extremes of coarse structured, high recharge soils and finer textured waterlogged valley soils.

The major question then becomes, what economic incentives exists for revegetation on this scale? Tables 2 and 3 summarize the immediate and potential plant products or values that could provide this incentive.

Shelterbelts and alley farming

The damage caused by wind erosion shown in Table 1 is likely to be a gross underestimate, due mainly to the lack of documented evidence. The few isolated studies point to a much larger problem and a much higher cost. In one study a single storm in summer, while a paddock was being grazed by sheep, removed 18 per cent of the topsoil. The loss of "fines" or dust from the top 8 mm of soil reduced yield in the subsequent crop by 12–25 per cent, and it was estimated that continued summer grazing in the same paddock would reduce productivity by 50 per cent within seven years (Marsh and Carter 1983). The damage caused by wind erosion is also likely to be greater than that measured in terms of production loss. Removal of organic matter and consequent reduction in the populations of soil micro-organisms put nutrient fixing, nutrient cycling and maintenance of soil structure at risk.

The Department of Agriculture (1991) acknowledges that the entire 15 million ha of cleared land in the region is susceptible to wind erosion under certain conditions. Such conditions include lack of protection of the soil surface (<750 kg ha^{-1} cereal stubble or <500 kg ha^{-1} pasture), grazing by sheep over summer and autumn (which can loosen in the order of 40 t ha^{-1} of topsoil (Marsh and Carter 1983)) and tropical cyclonic storms or early winter low pressure systems moving over the area between January and May. Even if there was adequate retention of stubble on cropped areas, the remaining 50 per cent of cleared land that is under pasture each year remains at risk. Sandy surfaced soils of the lateritic uplands and sand-plains which make up almost half of the regions agricultural soils (Carder and Grasby 1986) are the major hazard.

Reliable protection will only come from a reduction of windspeed across paddocks. This indicates a valuable role for the vegetation belts described above for water use. An incentive to establish such a network of tree belts, either along the contour or at 90° to prevailing winds, exists in the form of increases in crop and pasture production. This incentive has not been significant to date due to the lack of data quantifying the gains. However, work carried out in eastern Australia (Bourke, quoted in Bird 1991) has shown increases in wheat yield of 25 per cent from *Eucalyptus* shelterbelts, while Bicknell (1991) has shown a net increase across the paddock of 20 per cent in grain lupin yield between shelterbelts in the southern wheat-belt. In reviewing the effectiveness of windbreaks in Australia, Bird (1991) suggests that for best economic response, shelterbelts should be spaced at about 12 times the tree height apart which provides an average 50 per cent reduction in windspeed. At a spacing of 20 times the tree height apart, wind speed reductions are in the order of 30 per cent.

Table 3. An analysis of the potential products from woody plants growing in a semi-arid climatic zone. Notes (a) numbers shown for costs, values, market potential and spin-offs indicate a relative scale from 1 (small) to 5 (large). (b) transport radius is distance for which transport cost exceeds value of load. (c) location symbols are L (local), S (state), N (national) and I (international).

Woody Plant Part	Product		Production System			Raw Value $		Transport Radius	Processing			Market			Spin Offs	
	Type	Example	Cycle yrs	Costs	Labour Input	Per Tonne	m^3	km	Product	Value	Infrastructure Cost	Location	Scale	Growth	Water use	Shelter
Flower	cut	Banksia	1	4	5		10	open	Flowers	4	2	1	1	3	2	1
Fruits	fresh	Olive	1	4	5	10^3		10^2	Olive oil	4	3	S,N,I	1	1	2	2
	fodder	Oak	1	3	2	(fodder for conventional wool and meat production)									4	4
	nuts	Pistachio	1	4	4	10^4		open	Bulk nuts	4	2	S,N,I	1	1	3	4
	seeds	Eucalypt	1–5	3	4	10^5		open	Seed	4	2	S,N,I	1	2	4	5
Leaf	oil	Eucalypt oil	2	3	2	10^4		open	Cineole	4		1	2	4	3	2
	fodder	Tagasaste	1	2	2	(fodder for conventional wool and meat production)									3	2
	foliage	Eucalypt	1	3	5		10	open	foliage	4	2	S	1	3	3	4
Bark	tannin	Acacia	10	3	2	10^3		open	Tanning agents	3	3	S,N,I	1–2	3	4	5
	cork	Oak	30	3	3	10^4		open	Cork	5	3	S,N,I	1	3	4	5
Wood	aromatic	Sandalwood	75	3	2		10	open	Joss sticks	5	3	I	1	4	3	4
	specialty	Craftwood	50	4	3		30	300	Tool handles	3	3	S,N,I	1	3	5	5
	reconst	VALWOOD®	20	3	2		30	300	Furniture	4	3	S,N,I	2	4	5	5
	residue	Chip	10	3	2		20	200	Chip/pulp	2	5	I	5	4	5	5
		Liquid Fuel	10	3	2		20	200	Ethanol	2	3	L,S	5	5	5	5
		Solid Fuel	10	3	2		20	200	Firewood	1	1	L,S	1	3	5	5

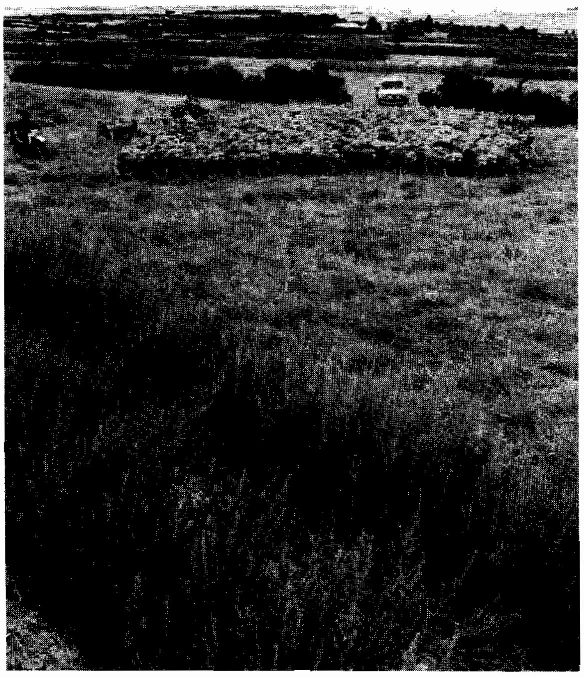

Fig. 6. Alley farming in practice in the Western Australian wheatbelt. Brothers Dean and Craig Melvin mustering sheep in an alley paddock on their farm at Dowerin. The shelterbelts are composed of a mixture of tagassaste *(Chamaecytisus palmensis)* acacia *(Acacia saligna)* and various *Eucalyptus* spp. The shelterbelts are spaced to allow crop or pasture production in the alleys.

The likely mechanism for yield improvement is through raising the canopy temperature in winter, reducing physical damage to leaves and reducing flower abortion and other consequences of heat stress in spring. Apart from the two cases cited, most work on potential economic benefits has been based on models of farm scale or regional wind break networks (Bird 1988; Bulman 1991; Kubicki *et al.* 1992). These suggest that such a network would be profitable *if* yield improvement, salinity control and absence of wind erosion were all considered over the long term. In the case of Kubicki *et al.* (1992) annual profit on a central wheat belt farm increased after eight years as a result of establishing a shelterbelt network when the benefits of avoiding wind erosion damage were considered. In addition land degradation is halted. The challenge is to reduce the costs of establishing and protecting shelterbelts and so increase their impact on farm profit.

Evidence of improvement in crop pasture and animal performance over a range of sites in the wheatbelt is required to act as an incentive to landholders to establish shelterbelt networks across their farms and practice what has become known as alley-farming (Fig. 6).

Forage shrubs

A characteristic of agriculture in this region is a shortage of feed for sheep over late autumn and early winter. Between the crop residues and dry annual pastures of summer and the first growth of new pastures in May or June, there is commonly a two month period during which juvenile and female sheep are fed on grain. This costs roughly $2 per head for some half of the region's 30 million sheep, or about $30 million annually.

In addition to feeding costs, holding sheep in paddocks low in feed increases the likelihood of wind erosion and slows the establishment of new pastures following winter rain. An alternative to this practice is to plant shrub species as a source of browse. As perennial plants, they provide green feed during the autumn/winter feed gap and can be grown on land unsuitable for crops and pastures. Two distinctly different shrubs have been used to date: species of *Atriplex* or saltbush on saline soils of the valley floors (Malcolm 1986) and *Chamaecytisus palmensis* or tagasaste, a leguminous shrub from the Mediterranean that is suited to deep infertile sands (Oldham *et al.* 1991; Lefroy 1991).

To date some 20 000 ha of these shrubs have been planted in the wheatbelt; saltbush mainly in the saline valleys of the centre of the region and tagasaste on the sandplain of the western and southern margins. However, the potential area of these shrubs is limited to that area necessary to provide feed for a one to two month period only. At other times of the year annual sources of feed are readily available and are less expensive to establish and maintain.

Land rehabilitation

Planting trees and shrubs on salt affected land has the value of returning that land to productive use regardless of any commercial value derived from the plants themselves. At densities as low as 80 stems per ha, *Eucalyptus occidentalis*, a native tree of saline and brackish swamps, has been shown to lower saline water tables sufficiently to return land to productive use within six years (Engel 1988).

Similarly, saline seeps on hillsides where saline ground water comes to the surface can be reclaimed by tree planting (George 1991). In both these cases, dramatic forms of land degradation can be stopped and in many cases reversed. As indicated in Table 2, these are concerned with small obvious parts of the landscape, whereas commercial incentives are required to bring about protection of the majority of this landscape against more gradual forms of degradation.

Other incentives

A target of 100 million trees planted each year for ten years, and 30 million per year thereafter was arrived at in the discussion on restoring localized hydrologic imbalance. To put that into perspective, some nine million trees were planted on farms in the region in 1989/90 (Scheltema 1990). Of these, seven million were planted by farmers and two million by a combination of city based volunteer conservation groups, rural landscape groups and country shire councils. During this period $465 000 was made available in government grants and 300 000 seedlings were provided by industry as incentives to plant and protect vegetation. In addition, expenditure on trees planted on farms for land and nature conservation is tax deductible. The latter, however, is no incentive to farmers who have low incomes.

Will the native biota benefit?

The problems faced by those trying to conserve the native biota of the wheatbelt are caused mainly by the fragmentation of the native vegetation into mainly small, often isolated patches, together with the introduction of weeds and domestic and feral animals (Saunders *et al.* 1991; Hobbs *et al.* 1992). It is clear that the current nature conservation system will not retain adequate representation of the remaining native biota (Hobbs and Saunders 1991), and hence some mitigating action is required to maintain nature conservation values. This involves retention and protection of remaining patches of bush, and rehabilitation of degraded areas. This in itself is a large task, especially compared to the resources available to achieve it (Wallace and Moore 1987), but is probably not sufficient. Indeed to reverse current trends of declining populations of many species, increased areas of native vegetation are required. Given the lack of resources available to do this purely on a nature conservation basis, extension of reserve areas by restoration efforts seems unlikely.

However, revegetation for agricultural reasons is imperative and is increasingly being carried out by private land-holders. In the scheme we propose, significant increases in perennial cover will occur over the wheatbelt region and it is possible that, with some co-ordination, this revegetation could enhance the current conservation network (Hobbs and Saunders 1992). The question remains to what extent this revegetation will be beneficial to the native biota. There is little evidence on which to base an argument that revegetation will aid nature conservation, and studies of formal use of restored areas are urgently required. However, if native species of plant are used in revegetation and the various canopy layers are returned (Lefroy *et al.* 1991), it is possible that this will provide habitat or movement corridors for components of the biota. The revegetated areas will not be "natural" and the extent to which they aid conservation will depend on how successfully ecosystem processes are restored within them.

Even if the revegetated areas fail to act as simplified analogs of the natural systems in the first instance, much can be learned in the process of whether remnant vegetation can be protected by buffer strips and if the nature conservation system will benefit from reduced degradation of the surrounding agricultural system.

Future directions

"The future is not some place we are going to but one we are creating. The paths to it are made, not found..."

Phillip Adams, quoted by Hay (1992)

To achieve revegetation at the scale suggested, direct and immediate incentives to private land-holders are required. Two areas stand out. Firstly, the collection of more evidence of the effects of shelterbelt networks on crop yield and animal performance throughout the region. Secondly, the development of a wide range of commercial products from native perennial plants.

Quantifying the benefits of shelter is important because of its potentially wide application. No other single modification to the present landuse system is likely to have the multiple benefits of water use, wind protection, creation of habitat for the native biota and improvement in agricultural productivity. Research into the impact of shelterbelt networks on crop yield, soil moisture, wind speed, evaporation rates and pest management is imperative in order to establish their potential role on a wide range of soil types. One innovative approach to plant establishment and grazing management has reduced the cost of establishing shelterbelts to $100 per km or less than $20 per ha of paddock and eliminated the need for fencing (Melvin, Elders Weekly, Jan. 16, 1992). This cost is roughly equivalent to half the annual cost of herbicide application in wheat growing.

The second incentive of developing commercial products from native woody plants is important in order to add a direct commercial value for a proportion of the tree and shrub belts. Economic models of shelter effects (Bird 1988; Bulman 1991; Kubicki *et al.* 1992) have suggested only marginal increases in profitability in the long term. This is mainly because they assume high costs of establishment and conservative productivity improvements. While reduced costs due to improved establishment methods will change this, commercial products from native plants would likely tip the balance and give revegetation the impetus it requires.

In this way the region's future may lie as much in industrial crops through semi-arid horticulture and forestry as it does in agriculture. A range of potential products are very dependent for their profitability on the price of crude oil. Ethanol is a derivative of woody plants that represents an alternative to diesel and petrol. Cineole is a solvent derived from eucalyptus oil that could replace petroleum based solvents like acetone. Both are likely to find increasing markets as oil stocks run down and prices rise.

Table 4. Organizations involved in wheatbelt revegetation.

Organization	Role
Land Conservation District Commitees (90)	Land use planning, co-ordinating, tree planting.
Greening Australia	Awareness, education, funding, volunteer tree planting.
Men of the Trees	Volunteer tree planting.
Hunger project	Volunteer tree planting.
Service Clubs (various)	Volunteer tree planting.
Department of Conservation and Land Management	Management of public lands, protection of wildlife, advice on nature conservation.
Department of Agriculture	Research and advice on management of private lands.
CSIRO	Research and advice on nature conservation.
Corporate Sector	Sponsorship.
Department of Main Roads	Revegetation of road reserves.
Shire Councils (various)	Tree planting.

Another potential product group are those that can substitute for synthetic chemicals that are increasingly in disfavour because of the adverse effects on human health. These include food additives such as emulsifiers, flavouring and colouring agents. Similarly tannin, a derivative of wattle bark and the basis of an Australia-wide industry earlier this century, may prove to be a more acceptable and therefore viable alternative to chrome-based chemicals in the tanning industry. These potential products are summarized in Tables 2 and 3.

CONCLUSIONS

The "analog forestry" approach suggests that sustainable land use lies in the direction of a perennial polyculture, where the productive component of the landscape more closely approximates the structure and function of the remaining islands of native vegetation. In this way the resource base of agriculture is protected and the isolated patches of native bush could be united and enhanced.

A stylized view of stages in transition towards such a landscape is shown in Figures 4 and 5. This example is not intended to provide a definitive plan, but rather an example of an approach that in the combined hands of landcare groups, research organizations and conservation bodies could produce a revegetation strategy that would unite their efforts in the region.

The stark contrast between the present management of agricultural land and the management of remnants of native vegetation has been described by Bradby (1989) as ecological apartheid. A consequence of the approach suggested here would be the development of an irregular mosaic of agricultural, natural and semi-natural ecosystems and a blurring of the distinction between productive land and remnant bush.

Just as important is the blurring of the distinctions between the various groups of people working in the region so that there is some unity of purpose. To do this, the debate on the desired characteristics of sustainable land use needs to be broadened to include options other than agriculture. The potential of the region, both in terms of production and nature conservation, is possibly limited at present by the assumption that restorative measures must all be economically driven by the surplus profits of conventional annual agriculture, namely wheat and wool.

All of the groups and organizations listed in Table 4 have a contribution to make to this debate which should aim to bring to the issue as wide a diversity of experience, initiative and resources as possible. A great asset in this regard is the potential of the network of Landcare and catchment groups to act as the catalysts in this process and initate Crombie's (1991) concept of "watershed governance".

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REFERENCES

Agricultural Outlook, 1991. Agricultural Outlook, November 1991, Economic Research Service, United States Department of Agriculture: Washington.

Australian Bureau of Statistics, 1990. Western Australian Yearbook, Perth.

Beard, J. S., 1980. A new phytogeographic map of Western Australia. *W.A. Herb. Res. Notes* 3: 37–58.

Bettenay, E., 1984. Origin and nature of the sandplains. Pp. 57–68 *in* Kwongan: Plant Life of the Sandplain. University of Western Australia Press: Perth.

Bicknell, D. R., 1991. The role of trees in providing shelter and controlling erosion in the dry temperate and semi-arid southern agricultural areas of Western Australia. Pp. 21–34 *in* Proceedings, The Role of Trees in Sustainable Agriculture. Bureau of Resources: Canberra.

Bird, P. R., 1988. Financial gains of trees on farms through shelter. *In* Proceedings, International Forestry Conference for the Australian Bicentenary, Vol. 2. Australian Forest Development Institute.

Bird, P. R., 1991. The role of shelter in Australia in protecting soils, plants and livestock. *In* Proceedings, The Role of Trees in Sustainable Agriculture. Bureau of Rural Resources: Canberra.

Bowen, G. D., 1981. Coping with low nutrients. Pp. 33–64 *in* The Biology of Australian Plants. University of Western Australia Press: Perth.

Bradby, K., 1989. New challenges in the bush. Pp. 61–71 *in* The Bush Comes to the City ed by J. Arnold. Environmental Protection Authority: Perth.

Bulman, P., 1991. Shade shelter and erosion control. *In* Proceedings, The Role of Trees in Sustainable Agriculture. Bureau of Rural Resources: Canberra.

Carder, J. and Grasby, J., 1986. A framework for regional soil conservation treatments in the medium and low rainfall agricultural districts. Department of Agriculture: Western Australia.

Crombie, A., 1991. Ecological sustainability: learning the way ahead. Occasional paper. Centre for Continuing Education. Australian National University: Canberra.

Curry, R. R., 1977. Watershed form and process: the elegant balance. *Geology* **480**: 1–27.

Curry, R. R., 1981. Reinhabiting the Earth: life support and the future primitive. Pp. 1–23 *in* Recovery and Restoration of Damaged Ecosystems ed by J. Cairns. University of Virginia: Charlotesville.

Department of Agriculture, 1991. Situation statement: soil and land conservation programme in Western Australia. Division of Resource Management, Department of Agriculture: Western Australia.

Derrick, J., 1990. Some organic cropping systems for south-eastern Australia. MSc Thesis, Australian National University: Canberra.

Dubos, R., 1967. Symbiosis between earth and humankind. *Science* **193**: 459–62.

Eckersley, R., 1991. Green economics: overcoming the credibility gap. *Habitat Australia,* December 1991, Pp. 29–32.

Emery, R., 1989. Toward Real Democracy. Ontario Ministry of Labour: Toronto.

Engel, R., 1988. Controlling saltland with trees. Farmnote 46/88. Department of Agriculture: Perth, Western Australia.

George, R., 1991. Reclaiming sandplain seeps by planting trees. *West. Aust. J. Agric.* **32**: 18–23.

Grasby, C., 1913. *In* the Cyclopedia of Western Australia, Volume II an Epitome of Progress. The Cyclopedia Company of Perth.

Greenwood, E. A. N. and Beresford, J. D., 1979. Evaporation from vegetation in the development and reclamation of dry-land salinity. Pp. 205–33 *in* The Reconstruction of Disturbed Arid Land ed by E. B. Allen. Wesview: Boulder.

Hamilton, G. J., Hawkins, C., Mlodawski, G. and Wallace, K., 1991. An evaluation of the remnant vegetation protection scheme, 1988–91. Department of Agriculture: Western Australia.

Hay, I., 1992. New world order. *The Australian Way,* January, 1992.

Hobbs, R. J. and Saunders, D. A., 1991. Re-integrating fragmented landscapes — a preliminary framework for the Western Australia wheatbelt. *J. Environ. Manag.* **33**: 161–67.

Hobbs, R. J. and Saunders, D. A., 1992. Conclusions. Can we reintegrate fragmented landscapes? Pp. 299–309 *in* Reintegrating Fragmented Landscapes: Towards Sustainable Production and Nature Conservation ed by R. J. Hobbs and D. A. Saunders. Springer-Verlag: New York.

Hobbs, R. J., Saunders, D. A., Lobry de Bruyn, L. A. and Main, A. R., 1992. Changes in Biota. Pp. 65–105 *in* Reintegrating Fragmented Landscapes: Towards Sustainable Production and Nature Conservation ed by R. J. Hobbs and D. A. Saunders. Springer-Verlag: New York.

Hopper, S., van Leeuwen, S., Brown, A. P. and Patrick, S. J., 1990. Western Australia's Endangered Flora and other Plants under Consideration for Declaration. Department of conservation and Land Management: Perth.

House, M. G., 1991. Select Committee into Land Conservation. Final Report. Parliament of Western Australia.

Howard, A., 1979. An Agricultural Testament. Rodale Press.

Jackson, W., 1987. Altars of Unhewn Stone: Science and Earth. North Point Press: San Fransisco.

Kubicki, A., Denby, C., Stevens, M., Haagensen, A. and Chatfield, J., 1992. Determining the long term costs and benefits of alternative farm plans. Pp. 245–78 *in* Re-integrating Fragmented Landscapes Towards Sustainable Production and Nature Conservation ed by R. J. Hobbs and D. A. Saunders. Springer-Verlag: New York.

Lamont, R. B., 1984. Specialized modes of nutrition. Pp. 126–45 *in* Kwongan: Plant Life of the Sandplain ed by J. S. Pate and J. S. Beard. University of Western Australia Press: Perth.

Lefroy, E. C., 1991. Trees and shrubs as sources of fodder in Australia. *In* Proceedings, The Role of Trees in Sustainable Agriculture. Bureau of Rural Resources: Canberra.

Lefroy, E. C., Hobbs, R. J. and Atkins, L. J., 1991. A Revegetation Guide to the Central Wheatbelt. Western Australian Department of Agriculture, Greening Australia (WA) and CSIRO: Perth.

Lefroy, E. C., Salerian, J. and Hobbs, R. J., 1992. Integrating economic and ecological considerations: a theoretical framework. Pp. 209–44 *in* Re-integrating Fragmented Landscapes: Toward Sustainable Production and Nature Conservation ed by R. J. Hobbs and D. A. Saunders. Springer-Verlag: New York.

Lipsett, J. D. and Dann, P. R., 1983. Wheat, Australia's hidden mineral export. *Aust. Inst. Agric. Sci.* **49**: 81.

Lynd, L. L., Cushman, J. J., Nichols, R. J. and Wyman, C. E., 1991. Fuel ethanol from cellulosic biomass. *Science* **251**: 1318–23.

Main, A. R., 1982. Rare species: precious or dross. Pp. 163–74 *in* Species at Risk: Research in Australia ed by R. H. Groves and W. D. S. Ride. Australian Academy of Science: Canberra.

Main, A. R., 1984. Rare species: problems of conservation. *Search* **15**: 94–97.

Main, A. R., 1987. Management of remnants of native vegetation: a review of the problems and development of an approach with reference to the wheatbelt of Western Australia. Pp. 1–13 *in* Nature Conservation: The Role of Remnants of Native Vegetation ed by D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins. Surrey Beatty & Sons: Chipping Norton, NSW.

Main, A. R., 1992. The role of diversity in ecosystem function: an overview. Pp. 77–93 *in* Biodiversity of Mediterranean Ecosystems in Australia ed by R. J. Hobbs. Surrey Beatty & Sons: Chipping Norton, NSW.

Malcolm, C. V., 1986. Production from salt affected soils. *Reclaim. Reveg. Res.* **5**: 343–61.

Marsh, B. and Carter, D., 1983. Wind erosion. *West. Aust. J. Agric. W.A.* **24**: 54–57.

Newman, P., 1990. Future energy supplies. *In* Sustainable Agriculture for Western Australia — Fact or Fantasy? Symposium proceedings Western Australian Branch of Australian Institute of Agricultural Science: Perth.

Nulsen, R. A., Bligh, K. J., Baxter, I. N., Solin, E. J. and Imrie, D. H., 1986. The fate of rainfall in a mallee and heath vegetated catchment in southern Western Australia. *Aust. J. Ecol.* **11**: 361–71.

Oldham, C. M., Allen, G., Moore. P. M. and Mattinson, B. C., 1991. Animal production from tagasaste. *West. Aust. J. Agric.* **32**: 24–30.

Parker, C. A., 1989. Soil biota and plants in rehabilitation of degraded agricultural soils. Pp. 423–38 *in* Animals in Primary Succession: the Role of Fauna in Reclaimed Lands ed by J. D. Majer. Cambridge University Press: Cambridge.

Peck, A. J. and Hurle, D. H., 1973. Chloride balance of some farmed and forested catchments in southwestern Australia. *Water Resources Res.* **9**: 643–57.

Roberts, B. R., 1984. Land ethics — a necessary addition to Australian values. *In* Proceedings, Land Degradation Conference. Australian National University: Canberra.

Reeves, R., 1991. Research and development on the bioconservation of cellulosic materials to ethanol and by products. APACE research: University of New South Wales, Australia.

Russel, J. S., 1980. Crop sequences, crop pasture rotations and soil fertility. Pp. 15–29 *in* Proceedings Australian Agronomy Conferences, Lawes 1980.

Saunders, D. A., Hobbs, R. J. and Margules, C. R., 1991. The biological consequences of ecosystem fragmentation. A review. *Conserv. Biol.* **5**: 18–32.

Saunders, D. A. and Hobbs, R. J., 1989. Corridors for conservation. *New Scientist* **1649**: 63–69.

Savory, A., 1988. Holistic Resource Management. Island Press: Washington, DC.

Scheltema, M., 1990. How many trees were planted in Western Australia 1989–90? *Land Conservation District Newsletter* **12**: 4–5.

Sennayake, R., 1984. The ecological, energetic and agronomic systems of ancient and modern Sri Lanka. *In* Agricultural Sustainability in a Changing World Order ed by G. K. Douglas. Westview Press: Boulder, Colorado.

Wagoner, P., 1990. Perennial grain: a new use for intermediate wheatgrass. *Soil and Water Conserv.* **45**: 81–82.

Wallace, K. L. and Moore, S. A., 1987. Management of remnant bushland for nature conservation in agricultural areas of southwestern Australia — operational and planning perspectives. Pp. 259–68 *in* Nature Conservation: the Role of Remnants of Native Vegetation ed by D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins. Surrey Beatty & Sons: Chipping Norton, NSW.

Watkins, R., 1990. Directory of innovations and land management practices No. 2, Land Management Society, October 1990: Perth.

Watt, M., 1982. An Energy Analysis of the Australian Food System. Ph.D. Thesis, Murdoch University: Perth.

Williams, J., 1991. Search for sustainability: agriculture and its place in the natural ecosystem. *Agricultural Science,* March 1991. 32–39.

Wynen, E., 1988. An economic comparison of sustainable and conventional farms in southeastern Australia. Pp. 25–35 *in* Sustainable Agriculture: A Viable Alternative. National Association for Sustainable Agriculture: Sydney.

Yeomans, P. A., 1958. The Challenge of Landscape. Keyline: Sydney.

Yeomans, P. A., 1964. Water for Every Farm. Murray: Sydney.