Land use and natural ecosystems: A revolution in land use is the key to a sustainable landscape

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Abstract

While rural production has played a major role in Australia's economic development, it has had a profoundly detrimental impact on biodiversity and the quality of land and water resources. Australia's geological history has created a unique, ancient, biodiverse, very flat continent that has accumulated enormous amounts of salts in the soils, regolith, lakes and groundwater. Most of our rivers and groundwater systems are sluggish, with only a small capacity to move salt from the continent. Unfortunately, most of our European style of agriculture, pastures and annual crops is ill-suited to this landscape. The resulting loss of native species, changes in ecosystem processes and the consequent land and water damage is well documented. Much of the degradation is the consequence of agro-ecosystems that leak carbon, water, nutrients and sediments. The challenge is to build an ecologically sustainable landscape consisting of a mosaic of commercial land uses that can capture this waste and turn it into wealth creating food and fibre products. This needs to be coupled with native ecosystems that provide a suite of ecosystem services that are valued and paid for by stakeholders and beneficiaries. This will require innovative and inclusive approaches that permit fair comparison of market and non-market values. Developing the concept of valuing and marketing ecosystem services as part of this process will be increasingly important.

Challenge facing rural Australia

Australian agriculture has been very successful for over 200 years, producing substantial wealth to support the nation's economic development. However, we are now producing commodities with ever-declining terms of trade and at significant cost to the environment, as evidenced by extensive losses of species and changes in ecosystem processes, resulting in the increasing degradation of our land and water resources. Australia is geologically very old, very flat and has a dry, but highly variable climate. Any mismanagement of natural resources will have significant and long-lasting consequences for society. Management that resulted in permanently degraded land was once accepted by the few who knew of it. Since about 1985, however, Australian society, as reflected in the emergence of Landcare and the conservation movement, has decided it will no longer tolerate the level of managerial inadequacy that resulted in losses of biodiversity and land and water degradation. It now allocates considerable, but inadequate, resources to fixing the problems. In the past 15 years, Landcare and other institutions have produced significant changes in the attitudes and activities of land managers, industries and society as a whole. On increasing numbers of farms and small catchments where the declining condition of the land and water had been acknowledged and identified, there is emerging evidence that these activities have begun to treat the symptoms and are attempting to heal the wounds and stabilise the situation. However, land managers must now shift their focus to treating the cause of the degradation. That will not be easy, as it requires a revolution in land use.

To create and shape the future we will need to move from producing the familiar commodities to new products for new markets that demand goods produced in environmentally benign ways. This will require shifting beyond 'rejigging' old farming systems and 'business as usual,' to developing and designing new farming systems and other commercial land uses that are more compatible with the ecosystem and landscape processes and functions. We need commercial land uses that are 'benign by design'. This means land uses that do not cause further species losses, impacts on ecosystem processes or damage to land and water while they are generating farm and enterprise wealth to support sustainable rural communities. In addition to commercial land use to produce food and fibre, increasingly, enterprise income will be derived from the provision and management of ecosystem services (such as the production of clean water, sequestration of carbon dioxide, and production of oxygen) that are currently not valued, let alone paid for. The challenge then is to build a mosaic of commercial land uses that are ecologically sustainable and to spatially integrate these with land uses that provide a suite of ecosystem services that are valued and paid for by stakeholders and beneficiaries, private and public.

Discovering and building new land use practices that meet these essential criteria will require solutions to scientific and technical problems that are many, complex and difficult. At present, there are few such biophysical solutions. Little work has been done on the use of native plants, their genes and the processes by which they capture water and nutrients. Furthermore, there are serious gaps in our ecological understanding of the rehabilitation process in Australian landscapes.

The solutions to the biophysical problems are scientifically demanding. They also require new ways of doing science within the imperatives of rural communities facing radical environmental, social and economic changes. For these communities in Australia, this is both an opportunity and a challenge. Partnerships between governments, businesses, community sectors and scientists can, we believe, build a better future for regional Australia by developing a mosaic of farming and land uses that do no further harm to the environment. The natural sciences have established the overall strategy to be followed, but can we marshal the investment in human and social capital to create our future?

The unique Australian landscape and its biota

If Australia's geography and climate had been similar to those of North America and Europe, our current agricultural and pastoral systems would not have caused the major problems we now face. But the geography and climate of this continent are very different to those of the Northern Hemisphere landmasses.

Australia's geological history has created an ancient, very flat continent that has accumulated enormous amounts of salts in its soils, regolith, lakes and groundwater. The continent has been geologically stable, with little volcanic or seismic activity. With few mountains, it also lacks deep, rich soil formed via the weathering action of glaciers. The long period of isolation and the extensive period without glaciers have led to the evolution of a rich and diverse biota, much of which is endemic.

Since the continent is flat, and dominated by a gentle fall towards its interior, most rivers and groundwater systems are very sluggish, with little capacity to drain the continent of its salt and water. As a consequence, enormous stores of salt characterise the landscape. They are concentrated in the semi-arid and arid landscapes of Australia.

Across much of the continent, low rainfall compared to potentially high evaporation rates means one of the lowest rates of runoff to rivers and deep drainage to groundwater in the world—all conducive to the accumulation of salt that is not flushed out by water leaching. The saline lakes, streams and land are a natural part of the Australian landscape and native vegetation has adapted to these unusual conditions.

Native vegetation evolved to balance salt and water in the landscape

Trees, woody shrubs and perennial grasses comprise much of Australia's native vegetation. This perennial vegetation, with its relatively deep, dense, root systems, takes full advantage of any available water, thereby minimising recharge, that is, the amount of water that leaks past the root zone to groundwater. Native plants have evolved a fragile balance to manage the low rainfall and large salt stores in subsoils, regolith and groundwater. The evolutionary traits of our native vegetation have meant that the rate of leakage past the plant roots into the landscape's internal drainage systems is approximately equal to the drainage or discharge rates of water from the deeper soils of the landscape. Healthy native ecosystems within catchments were in hydraulic and salt balance. The salt discharged slowly from the catchment balanced the input of salt to the catchment.

Changing native vegetation set water and salt moving—the start of salinisation

European settlers have changed the hydrology of the Australian landscape to a remarkable degree in a relatively short time. Large-scale clearing of native vegetation and its replacement with annual crops and pastures have substantially increased the amount of water leaking beneath the root zone and entering the internal drainage and groundwater systems of the landscape. This has caused water tables to rise—bringing the salt with them into the topsoil.

The amount of water leaking into groundwater systems depends on the climate (particularly the distribution and amount of rainfall); the depth, water storage-capacity and permeability of soils and subsoil; and vegetation characteristics. Not all the water leaking beyond the root zone necessarily ends up in groundwater. It also moves laterally through the soils to drain into surface streams. In other situations, leakage can occur from the base of streams into groundwater systems. Once the leakage beneath the root zone is increased, and this water begins to move through salt stored in the landscape, either to land surfaces and/or to rivers and streams, the dryland salinisation march has begun.

Natural resource degradation: extent and estimates of trends

Australian farmers and scientists face a demanding task in building productive, sustainable farming systems that do not harm the environment in ways such as damaging soil, water and biodiversity resources. If we fail to address this urgent task in an integrated, inclusive and adaptive way, the outcome will be further losses of biodiversity, land degradation, and the cessation of agricultural production in the worst affected areas.

The main forms of degradation are:

- loss and fragmentation of habitat, particularly on the more productive soils;
- decline of remnant vegetation, including riparian vegetation;
- decline of billions of paddock trees;

- loss of native species;
- decline in native pastures and environmental value of rangelands;
- deteriorating soil quality caused by depletion of nutrients, acidification, and structural and biological decline;
- dryland and irrigation salinisation of rivers and land;
- water and wind erosion;
- changes in riverine processes and loss of essential environmental flows;
- movement of nutrients, salts and pollutants to rivers, wetlands and water bodies;
- contamination of groundwater with nutrients, salt and pollutants; and
- contamination of land with residues of agricultural chemicals.

These effects are enduring, not easily reversed, and are becoming increasingly expensive to correct. Such damage has:

- reduced the productive capacity of lands (although in some areas productive capacity has increased);
- adversely impacted on water quality and biological diversity;
- put agricultural trade at risk through contamination and failure to demonstrate production systems that do not damage the environment; and
- threatened health.

Salinity impacts

Land—about 2.5 million ha is affected by dryland salinity, and there is potential for this to increase to more than 12 million ha. The estimated capital value of land lost to dryland salinity already exceeds $700 million.

Water quality—Increasing salt concentrations can be observed in most streams and rivers. For example, salinity levels in the Murrumbidgee River are increasing at between 0.8 per cent and 15 per cent per annum. Stream salinity in the Murray River now exceeds World Health Organization guidelines for about 10 per cent of the year. Recent preliminary work suggests that in the next 50 years, the water will be considered undrinkable for long periods of the year. Increasing salinity in our rivers threatens irrigated agriculture as well as the ecological health of the rivers themselves.

Remnant vegetation and wetlands have been damaged or are at risk from rising water tables and increasing salinity. Remnant native vegetation and its associated fauna are threatened. Riparian vegetation, critical to stream bank stability and wetland areas, is already damaged and under increasing threat. In Western Australia, 80 per cent of the length of rivers and streams is degraded by salinity and half the water bird species have disappeared from the many wetlands that were once fresh or brackish.

Road, bridges and urban infrastructure are at risk or have been damaged. For example, the National Dryland Salinity Program has estimated that high water tables affect about 34 per cent of State roads and 21 per cent of national highways in south-western New South Wales, amounting to damage costs of about $8 million per year.

Soil acidification

Soil acidification is extensive and continues. It is known to occur on more than 90 million hectares, of which 33 million hectares have a pH in water that has fallen below 4.8. This seriously impacts on production.

Wind erosion

Wind erosion is a major problem throughout the margins of the Australian cereal cropping zone and large areas of the southern rangelands. Continuing dust storms are testimony to this. The loss of the most valuable topsoil is largely irreversible. It reduces the nutrient levels of the soil and its ability to retain moisture for plant growth. Wind erosion is a danger wherever plant cover is not protecting the soil because of over-grazing, frequent cultivation or long fallow. In Victoria, an estimated 2.6 million ha of cropland (2.5 per cent of the Murray Darling Basin) is potentially subject to wind erosion. In New South Wales, grazing lands are mainly affected, with a total area of 21.3 million ha at risk. This amounts to 20 per cent of the Murray Darling Basin.

Water-induced erosion

Water-induced erosion from cropland in Victoria is estimated to affect 1 million ha, most of it in the Murray Darling Basin. Another 4.8 million ha (about 0.5 per cent) of grazing land is affected and most of this is also within the Murray Darling Basin. In New South Wales, 15 million ha of cultivation land and 16.3 million ha of grazing land (14 per cent and 15 per cent respectively) are subject to water and wind erosion. The National Land and Water Resources Audit demonstrates that water erosion in southern Australia is dominated by gully erosion; in northern Australia, sheet and hillslope erosion is the dominant process; and central and north Queensland is exposed to a high risk of water erosion.

Water quality and river health

Agricultural land affects water quality and the environment in the following ways:

- the extraction of water from rivers and groundwater is central to irrigated agriculture and therefore has severe impacts on the ecosystems of our rivers, wetlands and estuaries. The drainage water that returns from irrigation may be heavily polluted by high loads of salt and agricultural chemicals;
- irrigation uses rivers and wetlands as storages and conduits, resulting in distortion of the river or wetland flow regime;
- runoff from rural land carries sediment, nutrients, organic matter and agricultural chemicals; and
- land clearing and irrigation activities cause rising water tables and salinisation of rivers and wetlands.

Status of biodiversity

Biodiversity is the variety of all life forms—the different plants, animals and microorganisms, the genes they contain and the ecosystems of which they form part. Importantly, biodiversity includes the interactions between all the life forms and the environment. Thus there are three interactive levels of biodiversity: the genetic, species, and ecosystem levels.

Agriculture is an ecological enterprise that totally depends on ecosystem processes and functions such as soil formation, nutrient cycling, maintenance of hydrological cycles, and pollination of crops. These processes and functions are all driven by interactions between elements of biodiversity.

Unfortunately, biodiversity loss is Australia's most serious environmental problem. The most severe losses are in Australia's agricultural zones. In many areas within these zones, less than 10 per cent of the original vegetation remains, with the cleared areas used for agricultural production. This extensive loss of native vegetation is now resulting in massive changes to ecosystem processes and considerable loss of native species.

Preventing land and water degradation by conserving native vegetation, biodiversity and landscape function

It is a worthwhile working hypothesis that retaining and/or increasing the native vegetation cover in a landscape will help to retain the native biota and control most land and water degradation. To establish the basis for this concept, it is important to define ecosystem goods and services and to understand how these are often lost as degradation takes place.

Ecosystem goods and services

The phrase ‘ecosystem goods and services’ is appearing with increasing frequency in debates about alternative forms of land use. The ‘goods’ are the products we harvest from ecosystems, and include an increasingly wide array, as landowners begin to find value in natural products in addition to the traditional livestock and agricultural crop products. The ‘services’ are more difficult to define, but include such things as regulation of the hydrological cycle, maintenance of nutrient cycling, removal of carbon dioxide, production of oxygen, disposal of wastes, and pollination.

Ecosystem ‘goods’

Pastoralism and forestry depend heavily on ecosystem goods. Pastoralism in the rangelands is based on production of forage by native plants. Forestry, both public and private, depends exclusively on ecosystem goods. Extensive agriculture also depends heavily on ecosystem goods, but in the main, they are goods originally from outside Australia. For example, cereal crops, domestic livestock and fruit are all derived from elements of the biodiversity of areas other than Australia.

Ecosystem ‘services’

The majority of biodiversity in agricultural landscapes occurs in the soil. Farmers know that maintenance of soil fertility is the basis of all agriculture. They also know that it is expensive to keep applying fertiliser, and that problems of soil acidification, salinisation, compaction, loss of structure (and therefore water infiltration) and soil loss (erosion) are serious problems that greatly reduce profitability. A common reason for these various forms of soil degradation is loss of the soil biota (flora, fauna and microorganisms), which means—the loss of ‘free’ ecosystem services that biodiversity provides.

The issue of ecosystem services needs to be borne in mind when making decisions on land use. For example, a patch of remnant vegetation may provide more than aesthetics, shade and shelter. It is removing carbon dioxide, producing oxygen, using water, and may have some role in controlling water tables, and the movement of wind and water over the surface of the land. At present, these services tend not to be included in the cost accounting for agricultural production.

How ecosystems function

The cycles and processes we observe within a natural landscape result from the functions and interactions of the many elements, both living and non-living. These processes, such as the recycling of carbon, nitrogen and phosphorous, the hydrological cycle and the transfer of energy, as well as the slower processes of weathering and erosion, all rely to varying extents on the functional role of plants, animals and microbes. Stable ecosystems show a balance in these cycles according to supply and demand, so that few resources are either lost or accumulate.

Individual organisms, from bacteria to large trees, function for their own survival and reproduction and also play a functional role in wider ecosystems. For example, in performing the functions necessary for its own survival, an annual grass contributes to processes such as soil stabilisation, nutrient and water cycling, providing habitat for ground dwelling animals and food for millions of other living things such as decomposing bacteria or herbivorous insects. The more biodiverse an ecosystem, the more complex the interactions of the functional roles, producing an overall functioning ecosystem much greater than the sum of its constituent parts. Similarly, reduction in biodiversity can safely be assumed to create impairment in the overall functioning of a natural system and on a scale much greater than the sum of parts removed.

Natural systems also show a redundancy of functional components, such as a high diversity of grass species in woodland, when only one or two would be necessary to maintain ground cover. Having five species when two would do the job would be redundancy if environmental conditions did not vary too much. However, natural areas experience a wide range of environmental conditions, requiring species with functions that at first appeared redundant, to fill similar roles under different environmental conditions. For example, some grass species may die off following a drought, leaving areas of bare ground exposed if not for the presence of more drought-tolerant perennial species. Ecosystems that maintain their natural constituent parts (elements of biodiversity) also maintain a high level of resilience to cope with stress and changing conditions, and therefore maintain a balance of resource accumulation against loss.

As biodiversity is lost, ecosystems become less complex. This initiates a cascading sequence of events that result in important and long-lasting changes. Simplified ecosystems become less resilient. They are less able to absorb environmental shocks and disturbances while continuing to maintain their original levels of function, such as rates of growth, transpiration, fixation and uptake of nitrogen. Reducing biodiversity means that there are fewer components to buffer the blows inflicted by drought, fire, exotic species and climate change.

How terrestrial biodiversity relates to water quality and salinity

Deteriorating water quality and dryland salinity are direct consequences of loss in biodiversity and, in turn, impact adversely on biodiversity. The widespread removal of native vegetation has had a dramatic and immediate impact upon ecosystem function, causing major changes in the hydrological cycle as well as changes in surface flow of wind and water. The complex root systems of grasses, shrubs and trees and their symbiotic relationship with soil fungi provide a vast network for recycling and redirecting water and nutrients. With their removal, there may be less buffering and more extreme run-off events. More water flows across the landscape, moving topsoil around, eroding agricultural land and silting watercourses. These have become severe degrading forces.

Landscape redesign: using vegetation cover to enhance biodiversity and reduce land and water degradation

The sacrifice of biodiversity in agricultural landscapes has come at such a high cost in terms of land and water degradation that we need to rethink and redesign our use of these landscapes in ways that maintain their integrity but still provide for their profitable, sustainable use. Part of the solution lies in restoring crucial elements of biodiversity to the landscape and optimising the ecosystem services provided by biodiversity.

The size of native vegetation patches (when isolated from other patches of native vegetation by large areas of agricultural land) and their arrangement on the landscape has a large influence on which species survive and consequently, which ecosystem services are maintained. While there are considerable gaps in the scientific information available to advise on landscape design, the significance of design is being shown to be profound.

The key elements of design as far as terrestrial biodiversity and ecosystem functions are concerned are size, shape, separation/connectivity, species composition, and position in the landscape.

Design elements are most important for landscapes with less than 70 per cent native vegetation cover. Below 30 per cent cover, design is an essential component of revegetation to maximise results for efforts. In landscapes with 30–70 per cent native vegetation cover, design principles can help to avoid thresholds of change that cause rapid loss of species and change in ecosystem functions.

All of these factors need to be considered together.

Patches

The effectiveness of conserving patches of habitat as a way of allowing species to persist in highly cleared areas is frequently debated, mostly because there are few, reliable empirical observations to guide us. A landscape strewn with small patches might be effective in maintaining some elements of biodiversity. However, the cost of maintaining small patches may be much higher than for larger patches, and those organisms with habitat requirements that are met only by large patches will become locally extinct. It would be expedient to design a landscape with an optimum number of small, medium and large patches to maintain species and minimise maintenance costs.

Revegetation design

In landscapes where clearing has reduced native vegetation to less than 30 per cent cover, the emphasis is on revegetation, which is time consuming and expensive. We need to refine our understanding of these landscape design elements so that revegetation can be done efficiently and effectively. At present this involves planting or direct seeding, which are labour intensive and expensive.

Much research is needed in areas such as:

- Where in the landscape should vegetation be placed?
- How should the condition of current vegetation be improved?
- What sort of species and structural complexity is necessary?
- How can regeneration of remnant vegetation be used to enhance revegetation?

These important questions must be resolved if we are to address environmental problems in the landscape.

Landscape design for hydrology and ecosystem function

Clearing or intensification of land use occurs in places usually associated with the most productive soils. This means that patches of remnant vegetation can be more or less aggregated. Native species are lost as habitat is lost or degraded. The outcome for fauna and flora will depend on which habitats are cleared and how different species use the landscape. The effect that the loss of patch connectivity will have on species depends on their life history characteristics and mobility.

As noted, Australian vegetation evolved predominantly as perennial deep-rooted trees, woody shrubs and perennial grasses that can use most of the rainfall in ways that have minimised the amount of water that leaks past the root zone.

Our management options to control salt delivery to land and water include reversing this process by planting perennial deep-rooted trees and shrubs back into the landscape. This will greatly reduce the amounts of water moving beyond the root zone and return recharge rates to levels similar to those that existed before clearing for annual crops and pastures. Successful management of the cause of salinity depends on reducing groundwater recharge.

It follows that there will continue to be a great deal of emphasis on replanting deep-rooted perennial plants to reduce the rate of leakage to water tables and the salinisation of rivers, wetlands and valley bottoms. Planning for terrestrial biodiversity outcomes and recharge control needs to be integrated in order to achieve the best outcome for rural communities and the Australian environment.

A sustainable land use might consist of:

- 30 per cent of the area permanently covered in native vegetation, including trees, shrubs and grasses;
- 20 per cent covered in deep-rooted trees, shrubs and grasses, planted primarily for recharge control and income from grazing and farm forestry;
- 30 per cent intensively used for annual crops; and
- 20 per cent less intensively used for mixed grazing and cropping.

The correct balance between different types of land use will vary for different catchments, size of catchments and position in the landscape.

The amount of native vegetation remaining determines how intact biodiversity and ecosystem functions are. A number of theoretical and empirical studies have analysed the changes in the rate of loss of interconnectivity of patches, rate of species loss, and lag times associated with random and non-random clearing. These thresholds are at:

- 30 per cent cleared, with 70 per cent native cover remaining in which most of the habitat is connected. Thus, for organisms that require large areas of continuous habitat, or need to disperse through particular types of habitat, more than 70 per cent cover of suitable habitat may be necessary. As clearing or degradation reduces the cover of suitable vegetation, a threshold of connectivity is passed.
- 70 per cent cleared.
- More than 90 per cent cleared.

Landscape diagnosis, the focus for targets, and management priorities all depend on the landscape context.

Scale of revegetation and its strategic location

For recharge reduction to be effective, revegetation will need to be strategically located and of sufficient scale to match the particular groundwater system that is controlling the expression of the salinisation process. The geological structures and groundwater systems of catchments determine the scale and relative importance of strategic positioning of revegetation for forestry, agroforestry and native vegetation. The scales required to meet the thresholds and targets set for biodiversity appear to be of the same order as those required for management of dryland salinity and water quality.

Studies show that in some geological settings, the specific location of planting can be critical to providing recharge reduction benefits. Increasingly, salinity management planning is applying such information to ensure plantings are carefully targeted.

Time lag between revegetation and impact on land and water

We are starting to develop an understanding and characterisation of how groundwater flow systems can be applied to catchments and used to inform:

- the extent of land use change and recharge reduction that is required to halt, and maybe reverse, the spread of salinity; and
- the lag times between adoption of recharge reduction or interception of saline groundwater and any evidence of responses in groundwater levels or salt delivery.

The extent of land use change required and the likely lag times involved in achieving an impact on salt discharge to land and water resources are far greater than is widely recognised in either policy strategy or on-ground implementation. The estimates indicate that after recharge reduction measures have been implemented, there will not be evidence of groundwater and therefore salt responses at the discharge end of the system for times ranging from 10 years for local systems to 50–200 years for large regional groundwater systems. This reinforces the urgency of the need to facilitate large-scale revegetation by developing forestry and agroforestry industries to add to the native vegetation in the mosaic, in the knowledge that the response times will be very slow.

Balance between reduction in recharge and in water yield

Recent theoretical work on catchments in mid to low rainfall environments suggests that revegetation for forestry and agroforestry can reduce the amount of water entering rivers and streams. In these environments, a careful analysis is needed of the relative benefits of groundwater recharge management compared to the contribution of low salinity freshwater to stream flow. Specific catchment, climate and groundwater characteristics are important considerations in assessing relative benefits. The amount by which revegetation can reduce river flow is predicted to be much smaller in mid to low rainfall catchments than for high rainfall catchments.

Landscape redesign:—some possibilities for farming without harming

As noted, we need to develop and deploy a suite of novel land uses that are matched to the diverse climate, soils, hydrological conditions and, to some extent, the native biota of the Australian continent. While this is a huge undertaking, it is the challenge ahead if we seek sustainable management of rural landscapes. These land uses, in combination, need to deliver water and nutrient fluxes or leakage rates past the root zone or across the land surface that approach those under natural vegetation. This will require radical change to land use incorporating:

- development of commercially driven tree production systems and/or novel tree species for large areas of the current crop and pasture zones. These would include trees to produce fruits, nuts, oils, pharmaceuticals, bush foods and forestry products such as specialty timbers, charcoal, and biomass energy;

- new farming systems made up of novel mixes of all the best current annual and perennial plants, the best agronomy, companion plantings, rotations and combinations;
- new forms of cereals, pulses, oilseeds and forages selected or bred for characteristics that substantially reduce deep drainage and nitrogen leakage; and
- new land assessment tools that
  - best locate trees, other perennial plants, high-value annuals, and native vegetation to meet water quantity and quality targets, and biodiversity goals, and
  - facilitate identification and re-assignment of land so that on some parts of the landscape, productivity is greatly enhanced (double yield) and other parts are removed from production to provide a range of ecosystem services and protect the native biota.

To realise this vision, we will need to pioneer the development of a new landscape. This will comprise a mosaic of tree crops driven by large-scale industrial markets such as biomass fuels, high-value annual crops, mixed perennial–annual cropping systems, and areas devoted to the maintenance of those elements of the Australian biota dependent on native vegetation. Devising the optimal placement of these land uses in terms of salinity control, productivity and maintenance of native biota will require a robust understanding of landscape processes and functions, good maps of landscape properties, particularly salt storage and groundwater flow, and an understanding of the distribution and abundance of flora and fauna.

Such a mosaic of ecologically sustainable, commercial land uses could be combined with land uses that provide ecosystem services that are valued and paid for by stakeholders and beneficiaries. The consequence would be that rural enterprises might derive their income from sources other than traditional food and fibre production. For example, they might provide services paid for by either private or public stakeholders and beneficiaries, or in some innovative mix. A possible set of diverse sources of income is set out in Table 1.

Table 1: New commodities and markets

Commodity	**Share of business %**	**Client**
Wheat	40	World market
Wool	15	World market
Timber	10	Pulp wood, biomass energy, speciality timber
Carbon credits	7.5	Steel mill
Salinity credits	7.5	Cost sharing for catchment management
Water supply management	15	Water supply company
Biodiversity credits	5	Public/private trusts

However, while visions for sustainable landscapes are emerging, many of the components described above do not yet exist. A substantial new research and development effort is needed that tackles the redesign of farming systems and their integration into the landscape as a whole. This needs to combine biophysical and economic studies that deliver

- novel designs well matched to soil, climate and catchment circumstances including biodiversity;
- on-farm measurement and improved land assessment techniques;
- modern genetic improvement techniques; and

- a participatory process that engages all land managers.

Farm forestry, new agricultural production systems and restoration of native vegetation

As mentioned earlier, much landscape degradation results from reduced water use associated with the replacement of perennial native vegetation with annual crops and pastures. Thus farm forestry, new agricultural production systems, and restoring native vegetation present opportunities to restructure the landscape with vegetation that has a water-use pattern similar to that of the original native vegetation, and the potential to substantially ameliorate existing and impending problems.

The possibility of implementing this type of solution is increasing. The expansion of forestry on cleared agricultural land is becoming more attractive in higher rainfall zones. Commercial prospects for traditional grazing are poor, while market prospects for the expansion of plantation forestry appear to be improving. Added to this is the increasing interest both in Australia and overseas in using the ability of trees to sequester carbon as a means of meeting greenhouse commitments. The opportunity to combine carbon sequestration incentives with reafforestation to control dryland salinity is receiving attention. Farm forestry and agro-forestry for the mid to lower rainfall zones appear to offer attractive options, although a great deal more work in building these new industries is essential. The Joint Venture Agroforestry Program of the Rural Industries Research and Development Corporation and Land and Water Australia is making an important contribution to building these new industries.

The use of native flora and fauna may form an increasing part of rural production. Bush foods, native wildflowers, essential and other oils for pharmaceutical or industrial chemicals are receiving increasing attention. Indigenous people have much to contribute in the use of native plants and animals for food and fibre. This form of diversification in farming enterprises will increase the planting of native vegetation onto the Australian landscape and expand production on those elements of the landscape suited to high-value crops and pastures. Alley farming of native trees, shrubs and leguminous plants with cereal and oilseed production is increasingly adopted in those regions of Western Australia with light textured soils and prone to wind erosion. While many ideas are being considered, it must be emphasised that enormous work lies ahead in finding sustainable solutions.

There is an urgent need for strategic research in farming systems to find solutions to matching these sources and sinks, and then match the residual flows to those in the ecological and landscape functions operating in the Australian environment. The Redesigning Agriculture for Australian Landscapes Research and Development Program is a joint initiative of Land and Water Australia and CSIRO. It is researching how agricultural systems in Australia can be redesigned to address a range of sustainability issues. This design approach has potential to be applied through:

- selection and plant breeding—including molecular genetics—for commercial crops, pastures and native plants to manipulate phenology, canopy development, rooting function, distribution and temperature response; and
- rotating, and mixing in space and time, innovative configurations of plants involving annual and perennial crops, pastures, forest and horticultural trees, native plants, bush foods, etc. in alleys, blocks, windbreaks and clusters, over rotations of months or years.

Recognising the huge task ahead, the Redesigning Agriculture for Australian Landscapes Program actively seeks opportunities to collaborate, focusing on integrating the research and development program with other redesign initiatives and incorporating program outputs into other research and development initiatives.

We need more information on the water using capacity of various types of vegetation and on experimentation with new farming systems that are adapted to the temporal and spatial variability of the Australian climate. Much of this research must be at a larger geographic scale than has characterised much previous research.

Most plant breeding programs generally focus on grain yield and quality, pest control and other limitations. Few, if any, breeding efforts have focused on the role of crop and pasture species in controlling deep drainage and nitrogen leakage. In essence, crop and pasture species have not been designed with the control of natural resource degradation in mind. Studies have highlighted that the breeding, selection and bioengineering of annual crops and pastures have considerable potential to help ameliorate dryland salinity and acidification by designing crops and pastures to minimise the leakage of water and nutrients past the root zone. This contribution is likely to be over and above current agronomic and other management improvements. However, while investments in breeding, selection and biotechnology are likely to reap short-term benefits, most of the opportunities will require a long-term (10–15 year) research and development program.

Development of new farming operations that do not harm the natural resources and environment, while generating enterprise incomes that can support sustainable communities, must be an urgent goal for Australia.

Scientific solutions are many, complex and difficult

To understand how Australia's rural industries might move towards ecological sustainability, we first need to identify the scientific and technological issues that must be solved. Reluctance to recognise, then confront, the demanding scientific and technical challenges in finding sustainable agricultural systems for the Australian environment are barriers to progress. They result in failure to direct research to solve the fundamental scientific and technical issues that are the causes of natural resource degradation. So much policy and so many funding allocations have been flawed by the assumption that solutions to land degradation are readily available that Australia lacks a strategy for seeking solutions to the cause of degradation.

Research and development continues to focus on improving productivity and reducing costs of current commodities such as wool, wheat and beef. We spend little effort on finding farming solutions that do not harm the natural resource base. Further, there is a failure to recognise that the problems Australian scientists and farmers face in finding new solutions are more exacting and difficult than for most other places in the world. This is due to Australia's highly variable climate, coupled with soils that are, in general, old, highly weathered, fragile and of low fertility. The scientific problems to be solved before Australian agricultural systems approach ecological sustainability are many, complex, and difficult. The solutions to the problems confronting rural industries are technically demanding. They require radical changes to government policies, and to the orientation of research institutions, extension and consultancy agencies, and research and development corporations, as well as to the priorities of large sections of our rural community.

The very leaky nature of Australian agro-ecosystems lies at the root of nearly all land and water degradation issues. To match farming and land use pattern to landscape and ecosystem function, we desperately need new biophysical solutions that can plug leaky systems and capture the water and nutrient for productive purposes. The irony of Australian agriculture is that while the shortage of both water and nutrients greatly restricts yield, the fundamental cause of both salinity and acidification is the loss of valuable water and nutrient beneath the crop or pasture. A key strategic focus for science and technology, therefore, is to build productive agro-ecosystems that leak much less water, nutrient and carbon to the landscape in which they are located.

To achieve this goal, the scientific effort must first recognise that the soil/plant/animal agro-ecosystems must be studied in an integrated way and examined as part of the larger-scale ecological and hydrological processes that operate over the landscape. Solutions must incorporate these functions at a range of scales, including paddocks, hillslope, catchment, whole landscapes and regional basins. The landscape designs will need to integrate sustainable production and maintenance of biodiversity for the catchments and regions. Any revegetation program must have multiple objectives and therefore be designed for restoring ecosystem function: hydrology, nutrient cycling, maintenance of habitat, and movement of biota. These will need to be configured with the aid of emerging knowledge of:

- salt storage, groundwater and surface water flows, river form and function;
- biodiversity, including ecosystem function;
- biogeochemical process and water quality; and
- carbon sequestration.

While these are plausible objectives, government planners and the community will have to acknowledge the serious deficiencies and problems with our scientific understanding of the ecology of the rehabilitation process in Australian ecosystems and landscapes. We do not know how to reconstruct them. There is little in the way of tested theory or design rules for rehabilitation, quite apart from a process for communities to set objectives. At present, our approach is *ad hoc*. Not much is gained if dryland salinity is controlled by afforestation that subsequently results in serious decline in river flow or provides little in the way of benefits for biodiversity. We must avoid solving one problem while creating another. The way in which production systems interact with hydrological and nutrient balances and the implications of these interactions for longer-term stability and ecological functionality have been neglected or studied in isolation from the production systems. The first step in our search for an ecologically sustainable agriculture requires that we address agricultural production as an agro-ecosystem that is part of the larger-scale ecosystems and landscape processes. Knowledge of how best to revegetate land and implement land uses that are ecologically sustainable and can support viable rural communities is critical to any regional development plan. At present, we risk creating new problems while attempting to solve current ones.

Sustainable rural landscapes: people and institutions

Solutions to environmental and natural resource issues require institutional, structural and social change as well as new scientific knowledge and strong economic drivers. Therefore it is key requirement that people from all sectors of the community are involved with scientists from the earliest stages of a program involving planning, research implementation, monitoring and evaluation. Scientific and technological innovation both on farms and in laboratories will play a fundamental and increasing role in the development of sustainable farming. However, the impact of such innovation will increase significantly if it becomes a tool for rural society and is not used to set the agenda in isolation of the rural community. This will require a paradigm shift by research institutions, rural communities, funding agencies and governments. A catalyst is required to bring the change required.

The work being done on the new national Natural Resource Management Policy Statement may be a vehicle to bring realignment and focus on development of farming systems that do not harm. Whatever the mechanisms, there will need to be a policy framework for changes in farming so that our landscapes are not further damaged.

The development of farming systems that do not harm the environment will require many things. These are a rationalisation of resources and a refocus on farming system research within an ecological framework, coupled with adoption of participatory methods of on farm research and cooperation between universities, CSIRO and state agencies in research and development that underpins the development of ecologically sustainable agriculture. A significant feature of the future will encompass rural communities working with biophysical scientists, conservation biologists, sociologists and economists to build new systems. The innovative use of on-farm measurement, coupled with simulation models to design and examine alternative operations in terms of both production and impact on the natural resource, will be an increasingly important tool of discovery.

Conclusions

The search for sustainable landscapes will be incremental and based on an adaptive management cycle of research, innovation, monitoring, reporting and revision. It will not be well served by a failure to tackle the problems at their roots—the fundamental leakage or other dysfunctional ecological processes that drive specific degradation processes.

Developing ecologically sustainable landscapes that support robust and resilient communities is a very difficult problem, scientifically and socially. Were this not so, we would not be in our present predicament. It is most misleading to assert or assume that our current knowledge base is sufficient and that ecologically sustainable land use is possible simply by applying existing knowledge. Present-day information must be applied. It must also be recognised that many current management issues are the result of failure to research and develop farming systems and integrate them with other land uses so that the flows of matter and energy are compatible with the ecological, hydrological and biogeochemical processes operating in the landscape. Few commercial farming and other land use systems are able to control the causes of land degradation while generating farm incomes that can sustain rural communities. The search for farming systems and land use patterns that do not harm our environment is urgent. It must form a central plank in any strategy for regional development in Australia.

The sacrifice of biodiversity in agricultural landscapes has come at such a high cost in terms of land and water degradation, that we need to rethink and redesign our use of these landscapes in ways that maintain their biotic integrity but still provides for their profitable, sustainable use. Part of the solution lies in restoring critical elements of biodiversity to the landscape and optimising ecosystem services provided by biodiversity.

We know what factors influence rates of nutrient cycling and availability to plants. We do not yet know what the minimum set of biodiversity requirements are for ecologically sustainable agriculture in different soils under different grazing and cropping systems and in different climatic regimes.

The challenge is to come up with biodiversity-based solutions for reconstructing the Australian landscape and ensuring a sustainable future for rural and urban communities alike.

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