Discussion Paper on Ecosystem Services for the Department of Agriculture, Fisheries and Forestry

Final Report

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SHAPING THE FUTURE

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6 Application of an 'ecosystem services approach'

Key conclusions from this chapter:

- An ecosystem services approach is one that seeks to integrate the ecological, social and economic dimensions of NRM (including conservation as well as production objectives) at ecosystem scales and in language and concepts that engage a wide range of stakeholders
- Ideally, an ecosystem services approach will consider the full range of services strategically as focusing on one or a few services in ignorance of the others creates the risk of generating perverse societal outcome and even reducing human wellbeing
- Two other concepts that appear frequently in the literature and in policy documents are 'ecosystem management' (also called the 'ecosystem approach') and 'ecosystem stewardship'
- The ecosystem approach emphasizes the scale of environmental management (ecosystems rather than individual species) — the concept of ecosystem services is a key component of most ecosystem approaches
- Ecosystem stewardship emphasizes the need to consider social as well as ecological factors that affect the resilience of coupled ecological and social systems and their ability to adapt or transform as a response to change
- For an ecosystem services approach to be relevant and effective in natural resource policy and management, it must include the principles of ecosystem stewardship
- The ways in which an 'ecosystem approach' is described and recommended in the recent review of the *Environment Protection and Biodiversity Conservation Act 1999*[22] is consistent with ecosystem stewardship and is a good model for applying an ecosystem services approach

6.1 The essence of an ecosystem services approach

Seppelt *et al.* (2011)[205] recently reviewed literature on ecosystem services approaches. They concluded that the ecosystem service concept is intended to support the development of policies and instruments that integrate social, economic and ecological perspectives and has become the 'paradigm of ecosystem management'. They also concluded, however, that:

> The prolific use of the term 'ecosystem services' in scientific studies has given rise to concerns about its arbitrary application. A quantitative review of recent literature shows the diversity of approaches and uncovers a lack of consistent methodology.

Seppelt and colleagues distilled four core facets of an ecosystem services approach:

- biophysical realism of ecosystem data and models
- consideration of local trade-offs
- recognition of off-site effects
- comprehensive but critical involvement of stakeholders within assessment studies.

These core facets agree well with the ways in which an ecosystem services approach has been defined in the USA[204] and Australia (Box 1), where Cork *et al.* (1997)[63] suggested that the essential objective of an ecosystem services approach is to facilitate strategic dialogue and planning about multiple ecological processes and benefits.

Box 1: Essential features of an ecosystem services approach.[63]

An ecosystem services approach is one that seeks to integrate the ecological, social and economic dimensions of NRM (including conservation as well as production objectives) by:

- explicitly identifying and classifying the benefits that people derive from ecosystems, including market and non-market, use and non-use, tangible and intangible benefits
- describing and communicating these benefits in concepts and language that stakeholders and the public can understand
- posing and trying to answer a set of critical questions for sustainable management of ecosystems and human welfare, including:
  - Which services are provided by which ecosystems?
  - Who benefits from different services? How? What are the future needs of humans for these services?
  - What are the impacts of humans on different ecosystem services?
  - What is the role of biota and other natural assets?
  - How do different ecosystem services interact with one another?
  - What are the critical levels of ecosystem services for human welfare and survival?
  - What are the possibilities and implications of technological substitution for ecosystem services?

An ecosystem services approach focuses dialogue on a set of key integrative questions (Box 1). This set of questions is similar to those that underpin benefit-cost analyses in economics. The intention of an ecosystem services approach, however, is to engage a wider range of stakeholders in consideration of environmental and social benefits and costs using language and concepts that are more accessible than those of the discipline of economics.

There has been considerable debate over the past decade about whether the language and typologies of ecosystem services do achieve this objective, or whether there is a risk that they might confuse stakeholders if they are inconsistent. In our opinion, the following conclusions can be drawn from this debate:

- Diverse stakeholders react well to processes that allow them to 'discover' the ecosystem services that are important to them [1, 34, 150, 189, 190]
- Imposing a preformed typology too rigorously or early in an engagement process has the potential to inhibit engagement with stakeholders (Simone Maynard personal communication, August 2011)
- On the other hand, too little attention to what has been learned in ecology and economics about the need for clarity of definitions of terms like 'processes', 'functions', 'services', 'benefits' and 'value' can lead to confusion and biased conclusions.

6.2 Considering the full suite of services

The ideal application of an ecosystem services approach is to consider the full suite of services in one strategic analysis. This was the approach pioneered by the Millennium Ecosystem Assessment.[144] It has been described by the Natural Capital Project in the USA as 'Strategic Ecosystem Assessment'.[164-166] The UK National Ecosystem Assessment has applied a further refinement of this strategic approach.[228] These are not the only examples globally, and strategic approach to assessing the full range of services have been trialled in Australia as well.[1, 34, 190]

Although considerable progress has been made through studies focussing on a few ecosystem services — in terms of raising awareness of the benefits from ecosystems — concerns have been raised that such narrow studies might, in some cases, have counter-productive effects.[204] For example, prioritising a single service (e.g., carbon sequestration) or even a bundle of services (e.g., bundles associated with tree planting) can lead to significant trade-offs with other services (e.g., tree planting to manage water tables can affect water yield from a catchment. A recent study found that locations selected for conservation of ecosystem services globally would conserve only 22-35 percent as many species as locations selected for preservation of biodiversity.[162] Another concluded that only 16 percent of World Bank biodiversity-focused development projects resulted in a win-win for biodiversity and human well-being.[213] This is not to say that management for particular ecosystem services should not be done, as in many cases purpose managed ecosystems can produce more of desired services that native ones (e.g., monoclonal forest farms are reported to provide greater carbon sequestration than native forests as they can be maintained in rapid growth states[214]). It is, however, important to make such decisions in full knowledge of the implications for other services.

In relation to this issue of considering multiple services, a debate is emerging about the virtues of 'stacking' ecosystem services. This is the practice of allowing land managers to claim payments for several ecosystem services from the same piece of land.[87] The main benefits from stacking is that the overall payment becomes competitive with land development options. This is essentially the same as the approach to bundling ecosystem services proposed by Binning and others previously in Australia.[33] We mention stacking and bundling, together with other approaches to payments for ecosystem services, again in Section **Error! Reference source not found.**. The mention of them here is to reinforce the message that market-based mechanisms are emerging to deal with suites of ecosystem services but there is an urgent need for ecologists, economists and social scientists to develop the theory and frameworks so that markets can be guided towards suites of services that meet strategic societal objectives.

6.3 When an ecosystem services approach is most useful and the roles of ecological and economic analyses

As the professions of economics and ecology have increasingly interacted in the development of ecosystem services assessments over the past decade, more has been learned about how these disciplines can be integrated most effectively. Early research tended to focus either on ecological or economic approaches with the other as an add-on, but more recently strategic assessment approaches have emerged that start by considering the nature of the challenge and proceed to consider what balance of ecological and economic information and analysis is required.[70, 100, 130, 148, 164, 181, 183, 200, 216, 225, 228] Some of these approaches are discussed further in Chapter 7 of this report. Table 1 illustrates a strategic consideration of whether an ecosystem services approach is likely to be appropriate for a particular challenge and how that approach might be developed. This table outlines the criteria desirable in the best-case but usually not all of these will be achievable or even always desirable. For example, it might not always be possible to achieve a short time from actions to delivery for ecosystem services that rely on ecosystem processes that might take years or decades to improve (e.g., regulation of water tables by deep-rooted vegetation). Similarly, the absence of a well established cause-effect relationship between actions and service delivery should not preclude taking an ecosystem services approach to exploring possible relationships, but it would suggest that research and a feasibility study be conducted before large investments are made.

Table 1: Framework for assessing the viability of an ecosystem services approach for meeting natural resource management (NRM) objectives (adapted from a framework developed specifically for achieving conservation objectives).[165]

Criteria	*Best-case*	*Some questions to consider*
1. Service delivery	• Clear evidence that feasible actions will increase services • Minimum time from actions to delivery • Delivery where demanded • Low variability in delivery	Is there clear evidence of a cause-effect relationship between proposed actions and service delivery? What are the current conditions and trends in service delivery? How long will it take for the intervention to result in service delivery? Will the services be delivered where they are demanded? Are there unacceptable trade-offs within/among services?
2. Measurability of service	• Clear units • Accurate/cost-effective measurement	How accurately and cost effectively can changes in the production of services be measured? Can the measurement be influenced by other factors? Is there a clear unit (e.g., carbon dioxide equivalent, nutrient credit) that adequately captures the attributes of the service delivered? If it is not possible to measure service delivery, can a closely linked activity be easily measured as a proxy?
3. NRM delivery	• Contributes to NRM objectives	Would proposed actions both increase services and advance NRM goals? Does the approach entail proven effective NRM strategies?
4. Scalable and replicable	• Supports NRM at scale	Will the proposed ecosystem services strategy deliver NRM benefits at scale? Is the approach likely to be replicable? If so, within what spatial area (e.g., same basin, region-wide, globally)?

Criteria	Best-case	Some questions to consider
5. Superior to alternatives	• Ecosystem services strategy is best available option compared to both technological substitutes and alternative NRM approaches	What are the possible alternatives to an ecosystem services-based strategy for delivering service benefits (e.g., infrastructure/technology)? Would other approaches (perhaps unrelated to NRM) produce service benefits more cost-effectively with less risk? Would other NRM approaches achieve conservation goals at less cost and risk?
6. Providers and beneficiaries	• Providers and beneficiaries exist that are not widely dispersed • Strong ongoing demand with beneficiaries willing to pay	Is there demand for services? How is it projected to change over time? Are there entities willing to pay for improvements in ecosystem services (public sector programme, institution, or constituency, private sector market or buyer)? Are there many potential providers and beneficiaries? Are they concentrated in a particular area or dispersed?
7. Benefits and costs	• High-value/important benefits with potential to translate into financial support for the project • Costs not prohibitive • Policy cost-effective for society and key stakeholders	Would proposed actions produce meaningful service benefits (that is, significant enough benefits to generate support/buyers for the actions)? What are the likely costs of proposed actions (implementation, monitoring, measurement, enforcement, transaction and opportunity costs)? Are costs potentially prohibitive (compared to the expected benefits)? If so, could they be reduced without compromising the approach? Can ecosystem service benefits be translated into financial returns for providers?
8. Legal context, institutional Enfield capacity	• Strong legal/regulatory framework • Supportive policies • Clear property rights • Strong institutions • Sufficient field capacity to implement project	Are there legal or regulatory drivers that support an ecosystem services approach? Are management and use rights clear for the services? Are property rights clear for the areas where the services are sourced and delivered? Is resource use effectively governed by informal rules (not captured in the current legal and regulatory framework)? Are there strong existing institutions that could support the ecosystem services strategy? Is there sufficient institutional and field capacity to use an ecosystem services approach (funding, technical skills, leadership)? Would an intermediary coordinating mechanism be required to facilitate exchange? Could any existing organisation potentially fill this role? Are there existing ecosystem services projects in the area? How successful have they been?

Criteria	*Best-case*	*Some questions to consider*
9. Stakeholders, equity and political viability	• Stakeholder support with local champion • Participation by and trust among stakeholders • No “big losers"; poor made better off or compensated • Approaches politically feasible; will not be blocked by adversely affected groups or powerful interests • Stakeholders support policies that enable ecosystem services approach	Are key stakeholders likely to be supportive? Are there local champions for taking the ecosystem services approach forward? Is there public understanding and support for ecosystem services provision? Are people concerned about degradation of ecosystem services? Are there existing mechanisms for participation in conflict resolution that would be useful for ecosystem services approach? Are they clear “winners and losers"? Are poor communities likely to be made better/worse off (both providers and non-providers of the service)? Would poor people be able to participate in the ecosystem services scheme? Is there political support/capital for solutions to preserve ecosystem services? Will the project adversely affect the interests of politically influential stakeholders? Are stakeholders sufficiently supportive of current or additional required policies that are needed for a ecosystem services approach?
10. Economic context	• Sufficient budget available • Current incentives favourite ecosystem services approach • Resilient to future changes in markets	Is there sufficient budget available to implementing ecosystem services approach? Are there existing subsidies or taxes that would undermine incentives to provide ecosystem services? Could an ecosystem services approach have secondary effects on prices, creating incentives that could undermine conservation? How would future predicted price changes affect the viability of the ecosystem services approach? Could other land uses soon become more financially attractive?

Several conclusions can be drawn from dialogue about integrating ecology and economics within an ecosystem services framework over the past decade:

- It is vital to be clear about the nature of the issues and the questions that need to be answered
- Often there will be critical gaps in ecological knowledge that need to be filled before accurate assessments of costs and benefits can be performed, but in many cases a coarse assessment of the full range of ecosystem benefits and beneficiaries, will be adequate to support decisions because the likely balance of benefits to costs is clear even when uncertainties in current ecological and economic understanding are considered (e.g., see Table 2 for an example of an analysis of the likely magnitudes of different ecosystem services, which allows additional research to be focussed where it is most critical)
- There is a need to include a much wider range of disciplines than ecology and economics in applying an ecosystem services approach, as issues such as legislative arrangements,

governance, equity and politics need to be taken into account[15, 44, 100, 105, 127, 130, 165, 181, 200, 225, 226, 248]

- When considering payments policies that encourage markets for ecosystem services, it is more important to focus on the mechanisms that allow stakeholders to negotiate market transactions that to attempt to calculate values accurately, as the latter are likely to be influenced by many variable factors. [15, 44, 100, 105, 127, 130, 165, 181, 200, 225, 226, 248]

Table 2: An example of a qualitative expert assessment of ecosystem services from inland wetland ecosystems (from the Millennium Ecosystem Assessment).[152] Increasing size of the filled circles denotes low, medium and high magnitude of services; not known = ?.

Services	*Components and examples*	*Permanent and temporary rivers and streams*	*Permanent Lakes, Reservoirs*	*Seasonal Lakes, Marshes, and Swamps, Including Floodplains*	*Forested Wetlands, Marshes, and Swamps, Including Floodplains*	*Alpine and Tundra Wetlands*	*Springs and Oases*	*Geothermal Wetlands*	*Underground Wetlands, Including Caves and Groundwater Systems*
Provisioning services									
Food	production of fish, wild game, fruits, grains, and so on	⬤	⬤	⬤	⬤	•	•		
Fresh water	storage and retention of water; water for irrigation and for drinking	⬤	⬤	●	•	•	•		⬤
Fiber and fuel	production of timber, fuelwood, peat, fodder, aggregates	●	●	•	⬤	●	•	•	
Bio-chemical products	extraction of materials from biota	•	•	?	?	?	?	?	?
Genetic materials	medicine; genes for resistance to plant pathogens, ornamental species, and so on	•	•	?	•	?	?	?	?
Regulating services									
Climate regulation	regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of the atmosphere	•	⬤	•	⬤	•	•	•	•
Hydrological regimes	groundwater recharge and discharge; storage of water for agriculture or industry	⬤	⬤	●	●	•	•		•
Pollution control	retention, recovery, and removal of excess nutrients and pollutants	⬤	●	•	●	•	•		●
Erosion protection	retention of soils and prevention of structural change (such as coastal erosion, bank slumping, and so on)	●	•	•	●	?	•		•
Natural hazards	flood control; storm protection	●	⬤	⬤	●	●	•		•
Cultural services									
Spiritual & inspirational	personal feelings and well-being; religious significance	⬤	⬤	●	●	•	●	•	•
Recreational	opportunities for tourism and recreational activities	⬤	⬤	●	•	•	•	•	•
Aesthetic	appreciation of natural features	●	●	•	●	•	•	•	•
Educational	opportunities for formal and informal education and training	⬤	⬤	●	●	•	•	•	•
Supporting services									
Biodiversity	habitats for resident or transient species	⬤	⬤	●	●	•	•	•	•
Soil	sediment retention and	⬤		●	⬤	•	?	?	

formation	accumulation of organic matter								
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients	●	●	●	●	▪	▪	?	▪
Pollination	support for pollinators	▪	▪	▪	●	▪	▪		

6.4 ‘Ecosystems approach’ and ‘ecosystem stewardship’

Two other concepts that overlap strongly with an ecosystem services approach are ‘ecosystem management’ (also called ‘the ecosystem approach’) and ‘ecosystem stewardship’. There have been suggestions that some ecosystem approaches retain undesirable elements of past ‘steady state’ approaches to resource management. We explore these suggestions below and conclude that application of an ecosystem services approach in natural resource policy and management in Australia must be embedded in an ecosystem stewardship approach to be relevant and effective in the world of the next few decades and beyond. We further conclude that at least some of the ways in which the Australia Government is proposing to implement ecosystem-scale policy and management recognises and incorporates the essential elements of ecosystem stewardship.

The ecosystem approach focuses on the scale of management (i.e., ecosystems rather than species). Proponents of an ecosystem stewardship approach suggest that an ecosystem focus is not sufficient to prepare coupled ecological and social systems for the sort of change likely in the next few decades and beyond (e.g., climate change and pressures on arable land for urban development, food production, energy production and other uses).[50] They argue that past, steady-state, approaches to resource management frequently failed because they applied limited understanding of how coupled ecological and social systems remain resilient, adapt or transform in the face of pressures and shocks (Table 3). In their view, an ecosystem-scale approach might not perform much better than previous approaches unless specific attention is paid to the interactions between social and ecological systems, including governance and other institutional components.

Table 3: Differences between steady-state resource management and ecosystem stewardship.[50]

Characteristic	*Steady-state management*	*Ecosystem stewardship*
Reference point	Historic condition	Trajectory of change
Central goal	Ecological integrity	Sustain social–ecological systems and delivery of ecosystem services
Predominant approach	Manage resource stocks and condition	Manage stabilising and amplifying feedbacks
Role of uncertainty	Reduce uncertainty before taking action	Embrace uncertainty: maximize flexibility to adapt to an uncertain future
Role of research	Researchers transfer findings to managers who take action	Researchers and managers collaborate through adaptive management to create continuous learning loops
Role of resource manager	Decision-maker who sets course for sustainable management	Facilitator who engages stakeholder groups to respond to, and shape, social–ecological change and nurture

		resilience
Response to disturbance	Minimize disturbance probability and impacts	Disturbance cycles used to provide windows of opportunity
Resources of primary concern	Species composition and ecosystem structure	Biodiversity, well-being and adaptive capacity

Some form of assessment of benefits to humans for ecosystems, who the beneficiaries are and how the dynamics of human-ecosystems are managed is central to an ecosystem stewardship approach. The essential difference between an ecosystem stewardship approach and the sorts of approaches that Chapin and colleagues are critical of is not whether ecosystems services are considered but what processes are used to anticipate and prepare for future needs for services and future ability of ecosystems to meet those needs.

These criticisms of past resource management, and especially ecosystem-scale approaches, are important to consider when thinking about how terms like 'ecosystem approach' and 'ecosystem services' are used and interpreted in policy and management. Governments around the world have been moving towards ecosystem-scale environmental management for much of the past decade,[174, 204] and ecosystem services is an integral component of most approaches to ecosystem management.[205] The recent review of the *Environment Protection and Biodiversity Conservation Act 1999* – one of the main instruments by which the Australian Government can bring about strategic thinking and planning about environmental issues – recommended that:[17]

> The Act should be amended to incorporate these principles of the ecosystems approach.

That review articulated the principles of an ecosystem approach, drawing on the Convention on Biodiversity (Box 2). This approach is far from being a steady-state approach and is consistent with an ecosystem stewardship approach.

Box 2: Principles of an ecosystem approach as articulated in the recent review of the Environment Protection and Biodiversity Conservation Act 1999.[17]

Principle 1: The objectives of management of land, water and living resources are a matter of societal choices

Principle 2: Management should be decentralised to the lowest appropriate level

Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems

Principle 4: Recognising potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should:

- reduce those market distortions that adversely affect biological diversity
- align incentives to promote biodiversity conservation and sustainable use
- internalise costs and benefits in the given ecosystem to the extent feasible.

Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach

Principle 6: Ecosystems must be managed within the limits of their functioning

Principle 7: The ecosystems approach should be undertaken at the appropriate spatial and temporal scales

Principle 8: Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term

Principle 9: Management must recognise the change is inevitable

Principle 10: The ecosystems approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity

Principle 11: The ecosystems approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices

Principle 12: The ecosystems approach should involve all relevant sectors of society and scientific disciplines

Ideally an ecosystem services approach would include both analysis of ecosystem benefits and beneficiaries and consideration of governance and other institutional requirements for achieving strategic objectives that allow for adaptation and transformation of ecological and social systems if necessary. Simply assessing ecosystem services without embedding that assessment within an ecosystem stewardship framework is simply 'ecosystem services evaluation' and not what we term an 'ecosystem services approach'. We argue, therefore, that our concept of an ecosystem services approach is virtually synonymous with ecosystem stewardship and that together they provide frameworks and language that should be an important component of both policy and management approaches. The approach outlined in Box 2 reflects a desirable ecosystem approach, but we have not attempted to analyse application of ecosystem-scale policy and management across other state and federal government areas of interest.

7 Relationships between ecosystem services and biodiversity

7.1 The issues

The ecological underpinnings of most ecosystem services remain poorly understood.[24, 142, 172, 195] A central question is how the mix of species present in an ecosystem affects the nature of ecosystem functions and services at one point in time and through time in the face of environmental change. There has been a long debate about these relationships.[98, 120, 132, 154, 156, 158, 159, 203, 218-221, 245] Experimental work on the relationship between species mixes and ecosystem function has been almost entirely on artificial, simplified communities of organisms because of the difficulty manipulating naturally occurring ecosystems.[134]

An important reference point for this debate was the work of Vitousek & Hooper (1993),[237] who suggested three different possible relationships between plant diversity and ecosystem functions (Figure 1). On the basis of what was known at the time, they concluded that the asymptotic relationship, shown as Type 2 in Figure 1, was the most likely one. This relationship is expected to come about because the essential functions of an ecosystem, including nutrient cycling and decomposition processes, are provided at any point in time by a relatively small number of species and addition of more species primarily replicates these essential functions. In general the research cited above has supported this conclusion. Following sections of this chapter address some of the key questions that follow from this hypothesis, including:

- Do all ecosystems follow the relationship depicted in Type 2 of Figure 1?
- What significance do 'replicate' species have through time and space?
- What happens if ecosystems assemble or disassemble non-randomly?
- How does diversity of species and functions relate to production of ecosystem services?
- Can we identify ecosystem service providers and measure their efficiency?

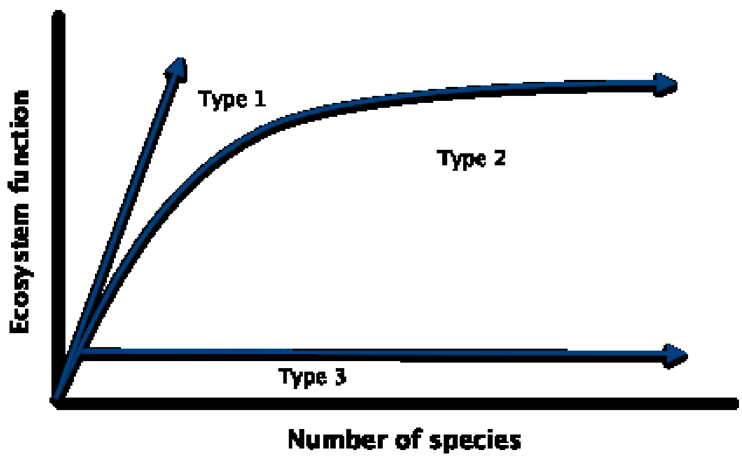

Figure 1: Possible relationships between biological diversity and ecosystem functions for the plant subsystem.[237]

7.2 Relationship between diversity and ecosystem function

The research cited above generally has supported the existence of the Type 2 relationship of Figure 1.[121] Research on agricultural ecosystems has suggested that genetic, species and functional diversity are all important for providing the ecosystem service of natural pest control but that the right combinations of functions are also important.[121] In some cases, natural pest control increases with increasing diversity of plant and insect species[167] but, in other cases where the combinations of functions are not conducive, higher biodiversity appears to encourage greater pest populations through such mechanisms as providing key hosts of high palatability or that allow pests to complete a complex life cycle.[43, 185]

7.3 The significance of "replicate" functions

There are at least three ways in which diversity of species and functions might be important in agricultural landscapes:[234]

- Biodiversity might enhance ecosystem function because different species or genotypes perform slightly different functions (have different niches)
- Biodiversity might be neutral or negative in that there are many more species than there are functions and thus redundancy is built into the system
- Biodiversity might enhance ecosystem function because those components that appear redundant at one point in time become important when some environmental change occurs.

More and more evidence is emerging that the third possibility is most often the reality. Maintaining a diversity of functional types is thought to confer resilience on ecosystems. Resilience is a complicated issue but put simply is the ability of a system to cope with change.[191] Resilience often comes from the presence of rare species that can take on critical functions when conditions previously favouring dominant species change. In other words, maintaining a mix of species that respond differently to different environmental perturbations maintains management options.[121] For the below-ground community, for instance, there is evidence that the same enzymatic function is carried out by different species of bacteria or fungi from the same soil under different, and even fluctuating, conditions of moisture stress or pH.[112]

In the case of plants, different species may play a similar functional role in different seasons, under varying conditions of environmental stress and in different stages of patch-level succession.[212] In savanna rangeland communities in Australia minor species that were functionally similar in trait space (redundant) to the dominant herbaceous species responsible for the majority of ecosystem functions (carbon storage, nitrogen cycling, etc.) were also more resistant to grazing, becoming superior competitors under conditions of high grazing.[239]

These and other arguments and research findings argue that protecting as much biodiversity as possible is a wise strategy for managing risks associated with medium and long term climate and other environmental change and for keeping future management options open. Because lost diversity is difficult or impossible to reconstruct, it would be unwise to sacrifice it simply because of uncertainty about the extent and mechanisms by which it affects ecosystem properties and services.[121]

7.4 How do ecosystems assemble and disassemble?

The number and types of species in an ecosystem are the result of dynamic interactions among many factors, including competition for resources among species, synergies among species, the history of which species arrived first and when other species arrived, local extinctions or adaptation of roles (e.g. competitors, predators, pests or diseases) by new or existing species to changed species composition and/or abiotic environmental conditions and influence of random events.[122, 212] Attempts to assemble combinations of the same number of species under slightly different conditions and in particular without the history of interaction often fail.[96, 97, 212]

In agricultural ecosystems, farmers become part of this dynamic interplay by the selection of which organisms are present, by modifying the abiotic environment and by interventions aimed at regulating the populations of specific organisms. In addition to the biodiversity that farmers manipulate in a planned way, there is *associated biodiversity*.[212] Some species leave and some move into the agricultural system as a result of the planned changes. Some support the agricultural endeavours (e.g. soil organisms that take over essential nutrient cycling functions) while some do not (e.g. pests, weeds and diseases). Conversion to agriculture almost always results in fewer species and fewer functional groups,[212] making it important to consider managing diversity at larger scales than the farm to ensure that sources of functional groups exist to colonies the farms and to continue providing broader ecosystem services as conditions change in the future.

Decline in biodiversity with intensification of land management could follow various paths (Figure 2).

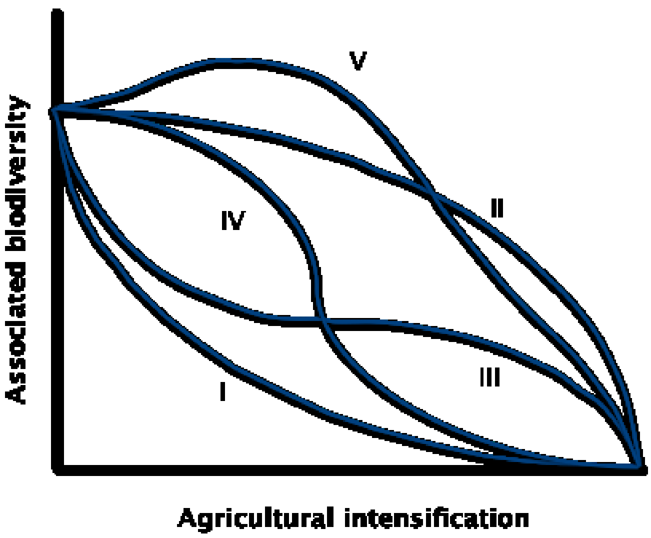

Figure 2: Potential effects of intensification of agriculture on biodiversity.[121]

Letters a–f on the *x*-axis refer to increasing states of management intensity, with ''a'' being an unmanaged ecosystem and ''f'' being intensive, industrialized agriculture. Intensification tends to reduce diversity of associated taxa, although a range of trajectories is possible, including the potential for initial increases in biodiversity as intermediate levels of disturbance create more niches.

Until recently, speculation about the implications of these paths for ecosystem services was limited. A few recent publications have summarized the evidence about decline (disassembly) of ecosystems and concluded that this is rarely, if ever, a random process – in other words some species groups and functions are more likely than others to decline first.[84, 212] Using this knowledge, it is possible to speculate about different rates of loss of different ecosystem services (Figure 3).

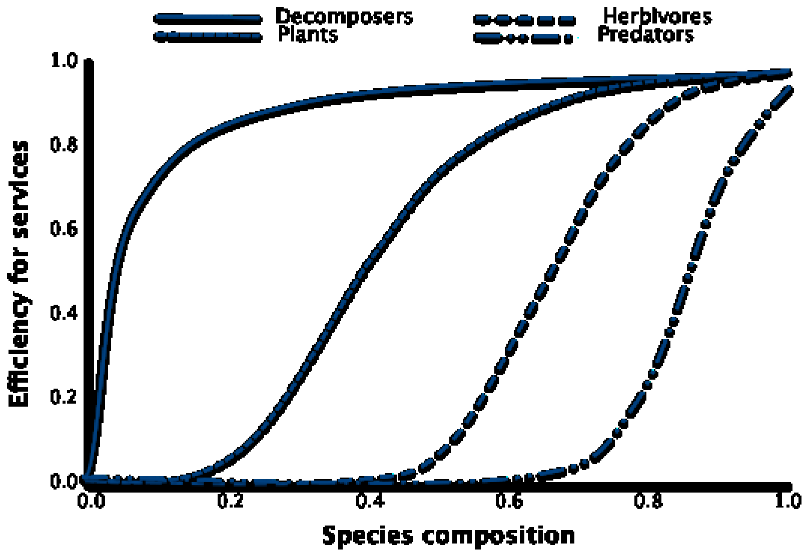

Figure 3: Functional forms for the relationship between loss of biodiversity and loss of function.[84]

Each of the curves represents the decline in both number of species at each trophic level and the ecosystem services undertaken by species on different trophic levels as the total number of species in the community declines. The lowest line (alternating dots and dashes) is for predators and services on the top trophic level, the second lowest line is for herbivores, the dotted line is for plants, and the solid line is for decomposers. The threshold values occur when each trophic level passes through the value of species composition that corresponds to 50% of maximum efficiency for services undertaken at that trophic level.

The scientific community has come to a broad consensus on many aspects of the relationship between biodiversity and ecosystem functioning, including many points relevant to management of ecosystems.[121] Detailed management prescriptions and monitoring are not possible for all ecosystem services, and there are complications because ecosystem processes and services overlap and interact with one another. Understanding is, however, adequate for broad management objectives to be set within a framework relating ecosystem function to human needs and for progress against those objectives to be assessed.

7.5 How much biodiversity is enough?

For over fifty years ecologists have pondered the question 'why are there so many species?'[123] Allied to this question is the one occupying the minds of policy makers and land managers worldwide, i.e. 'how much biodiversity is enough?' An implication from current understanding of the relationship between biodiversity and ecosystem function is that it is not possible to define a level of biodiversity that is ideal for all ecosystems or all purposes. Optimal levels will depend on the ecosystem functions required for specific purposes and needs, what functions are present at a site and in a landscape, the degree of overlap in functions between species, the degree of change possible, the resilience of the ecosystems and the preferences of people who derive value from the ecosystem.[212]

Some generalizations have, however, been offered in the literature. There is substantial experimental evidence that many key functions can be maintained by only small numbers of species within a particular functional in an artificial and space-restricted ecosystem group. For example, single-species plantings of perennial plants can be as effective as a diverse plant community in controlling erosion. In a laboratory, decomposition of organic matter can be achieved by a single species of fungus yet across a landscape there might be thousands of species of fungi, bacteria or invertebrates with different species playing a role in nutrient distribution and decomposition functions at differences places and in different environments.[107, 211, 212]

The role of replicate species in providing resilience over time has been discussed previously. The same argument leads to the hypothesis that the diversity of functional groups and species within functional groups needs to be higher in nature than in laboratories and higher at landscape scales than plot and farm scales because of greater variation in abiotic environments and biotic and abiotic perturbations[212] (Figure 4). Resilience also depends on the degree of connectivity between and among the elements of ecosystems and landscapes.[4, 119, 191] It follows that diversity of land uses within a landscape is likely to be an important strategy for maintaining resilience of both ecosystem services and human welfare in the medium and long terms.[212]

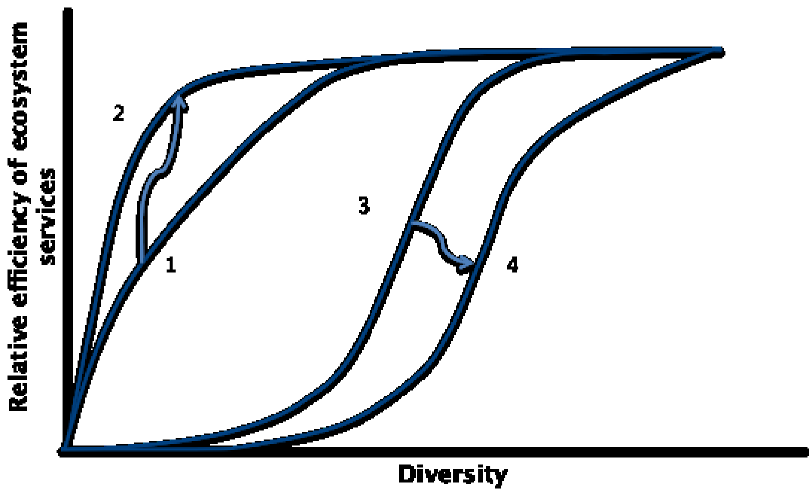

Figure 4: Hypothesised relationships between diversity (as measured by species richness) and the efficiency of ecosystem services at plot to landscape scales.[212]

Curve 1 represents the type of relationship suggested by most current knowledge. Curve 2 depicts how substitution of diversity by inputs derived from human labor and petro-chemical energy in an intensively managed agricultural plot may lead to higher efficiencies. Curve 3 is the equivalent relationship to curve 1 but at a landscape scale. At this scale it is postulated that the threshold of 'essential' diversity is greater because the variation in stresses and disturbances and the likelihood of change due to human or other

impacts is far greater. Curve 4 represents circumstances of high disturbance of the landscape by human intervention. These impacts increase the levels of diversity required to maintain a resilient system.

7.6 Identifying ecosystem service providers and their efficiencies

As a way to advance thinking about the relationships between biodiversity, and ecosystem services, some researchers have attempted to characterize ecosystem services by the component populations, species, functional groups (guilds), food webs or habitat types that collectively produce them. These have been termed 'Ecosystem Service Providers'[134] or 'Service Providing Units'.[142] Ecosystem service providers are defined at different levels within ecological hierarchies depending on the type of service being provided, and the geographic scale over which it operates (Table 4). For example, maintenance of resistance to pests, weeds and diseases in crops is a service provided at the scale of genes and operates at local scales.[142] On the other hand, biological control of crop pests operates at the population and/or food-web level at landscape scales[243] and regulation of water flow by vegetation occurs over landscape and larger (e.g. regional) scales.[113]
A few studies have applied this reasoning to perform Functional Inventories of ecosystems. These studies have identified the component Ecosystem Service Providers and measured or estimated the contribution of each in terms of its abundance and the efficiency with which it performs the service.[26] Examples of the units in which functional efficiencies are measured include pollen grains deposited per bee and dung burial rates by dung beetle.[138] According to Kremen (2005),[135] functional inventories provide a range of insights into ecosystem function that can form the basis for prioritization of research, policy and management. For example:

- Particularly influential Ecosystem Service Providers (ESPs) can be identified by ranking ESPs in terms of their contribution in relation to abundance
- The functional structure of an ecosystem can be explored by ranking species by their functional importance and investigating how equal or unequal the contributions of different ESPs are
- Species traits, such as body size, dispersal distance, and response to disturbance can be correlated with functional efficiency, to characterize the suite of response and effect traits that a community exhibits and predict its resilience to disturbance
- Using functional importance values, predictions can be made about how delivery of ecosystem services might change as the composition of ESPs changes over space or time, along disturbance gradients, or with different management regimes.

Table 4: Ecosystem services and their ecosystem service providers.[134]

'Functional units' refer to the unit of study for assessing functional contributions of ecosystem service providers; spatial scale indicates the scale(s) of operation of the service. The author's (Kremen 2005)[134] assessment of the potential to apply this conceptual framework to the service is purposefully conservative and is based on the degree to which the contributions of individual species or communities can currently be quantified.

Service	*Ecosystem service providers/ trophic level*	*Functional units*	*Spatial scale*
Aesthetic, cultural	All biodiversity	Populations, species, communities, ecosystems	Local–global
Ecosystem goods	Diverse species	Populations, species, communities, ecosystems	Local–global
UV protection	Biogeochemical cycles, micro-organisms, plants	Biogeochemical cycles, functional groups	Global
Purification of air	Micro-organisms, plants	Biogeochemical cycles, populations, species, functional groups	Regional–global
Flood mitigation	Vegetation	Communities, habitats	Local–regional
Drought mitigation	Vegetation	Communities, habitats	Local–regional
Climate stability	Vegetation	Communities, habitats	Local–global
Pollination	Insects, birds, mammals	Populations, species, functional groups	Local
Pest control	Invertebrate parasitoids and predators and vertebrate predators	Populations, species, functional groups	Local
Purification of water	Vegetation, soil micro-organisms, aquatic micro-organisms, aquatic invertebrates	Populations, species, functional groups, communities, habitats	Local–regional
Detoxification and decomposition of wastes	Leaf litter and soil invertebrates; soil micro-organisms; aquatic micro-organisms	Populations, species, functional groups, communities, habitats	Local–regional
Soil generation and soil fertility	Leaf litter and soil invertebrates; soil micro-organisms; nitrogen-fixing plants; plant and animal production of waste products	Populations, species, functional groups	Local
Seed dispersal	Ants, birds, mammals	Populations, species, functional groups	Local