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RESEARCH ARTICLE

Integrated vegetation designs for enhancing water retention and recycling in agroecosystems

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Abstract Long term studies have shown strong links between vegetation clearing and rainfall declines and more intense droughts. Many agroecosystems are exposed to more extreme weather and further declines in rainfall under climate change unless adaptations increase the retention of water in landscapes, and its recycling back to the lower atmosphere. Vegetation systems provide vital feedbacks to mechanisms that underpin water vapour recycling between micro- and meso-scales. Various heterogeneous forms of vegetation can help generate atmospheric conditions conducive to precipitation, and therefore, increase the resilience of agroecosystems to drought and climatic extremes. The aim of this paper is to demonstrate how vegetation can be designed for agroecosystems to enhance recycling of water vapour to the atmosphere through the regulation of surface water and wind, and heat fluxes. The structure of the paper revolves around five functions of integrated vegetation designs that can help underpin the restoration of water recycling through enhanced retention of stormwater, protection from wind, moistening and cooling the landscape, production of plant litter, and contribution toward regional scale climate and catchment functioning. We also present two supplementary functions relevant to land and natural resource managers which may also be integrated using these designs.

Keywords Ecohydrology · Water recycling · Landscape restoration and design · Multifunctional landscapes · Native vegetation · Agroecosystems

Introduction

Across the Earth's biosphere there is an estimated large volume of water stored in vegetation and soil (Kravcík et al. 2007), but storage volumes do not convey the significance of flows. For example, Oki and Kanae (2006) estimate that there is only 2000 km^3 of water stored in Earth's rivers yet annual withdrawal of water from these sources is estimated at 3800 km^3/year. Water vapour flows are clearly important for maintaining water resources. However, as a consequence of the clearance of broad extents of forests and woodlands, significant reductions in water vapour flows have occurred. For example, forest

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clearance across the Earth has reduced water vapour flow by approximately 3000 km^3 (Gordon et al. 2005), while clearing across ~15% of the Australian continent over the past 200 years has caused a 10% (340 km^3) decrease in water vapour flows (Gordon et al. 2003). Attributes of vegetation that link it with the atmosphere and terrestrial hydrological cycle are, therefore, particularly important for restoring flows in the hydrological cycle and for creating resilient agroecosystems. The redesign of agroecosystems must facilitate the 're-saturation of the small water cycle' to mitigate extreme climate change (Easterling et al. 2000; Kravcík et al. 2007), but it also must be integrated with other landscape functions that underpin multiple ecosystem goods and services (Jackson and Hobbs 2009; McAlpine et al. this edition).

Water is a critical limiting resource in regions with a semi-arid climate such as eastern Australia. These regions must find ways to adapt agroecosystems to accommodate the multiple risks that stem from ongoing changes in climate and water availability, and losses of soil fertility and biodiversity. Australia, for one, is already witnessing increasing competition for water between primary industries and other users. Climate changes are placing greater burdens on agroecosystems through increasing aridity and temperature extremes (McKeon et al. 2009; Steffen 2009). There is increasing interest from industry, policy makers and scientists alike towards how agricultural and grazing landscapes (i.e. agroecosystems) will adapt to decreased rainfall and hotter temperatures, as well as ways to potentially offset emissions through bio-sequestration (Garnaut 2008).

Of critical importance to ensure agroecosystems remain productive despite increasing climatic extremes and drought, future changes in ecohydrological functioning and climate should be both incorporated into current land use and natural resource planning efforts (Bathgate et al. 2008; Campbell 2008). If agroecosystems are to produce rather than consume ecosystem services (Boody et al. 2005), designs must integrate landscape functioning by emphasising the role of landscape heterogeneity. In other words, landscapes can support a range of seemingly contradictory uses and functions simultaneously through the careful planning of landscape heterogeneity (Mander et al. 2007).

We support the view that the redesign of agroecosystems should be focussed on achieving multiple functions concurrently, and that planned heterogeneity is a key part of this redesign. Native vegetation offers a robust strategy to create functional and resilient heterogeneous structures within agroecosystems, however, the loss of productive land and competitive effects must be minimised (i.e. economic viability). The focus of this paper is to investigate how native vegetation can be used to integrate multiple production, ecological and ecohydrological objectives through the mutual reinforcement (i.e. feedbacks) of functions across scales. These feedbacks, in turn, may increase the resilience of agroecosystems to variability and change in climate.

This paper aims to demonstrate how heterogeneous bands, belts or blocks of native vegetation can be used to integrate production and conservation functions at the scale of agroecosystems, while providing essential feedbacks to regional scale climatic processes. We highlight how, based on this approach, landscape resilience can translate to sustainable production in agroecosystems. The paper outlines a structured complex adaptive landscapes approach (see Ryan et al. 2007) to the redesign of agroecosystems, based on the links (feedback mechanisms) between five core functions at micro- to meso-scales. We also include two supplementary functions, which largely operate at the micro-scale (listed after the #), that may also be integrated to enhance production and conservation outcomes:

Micro-scale functions

i. Ecohydrological sink (retention of stormwater runoff, reduced soil erosion and improved water quality);
ii. Microclimate buffer (increased soil moisture, reduced evaporative demand);
iii. Soil dynamics (increased soil organic matter, biological activity and carbon levels); and

\# Supplementary functions: biosequestration and biodiversity conservation.

Meso-scale functions

iv. Enhancement of atmospheric-vegetation feedbacks; and
v. Restoring catchment functioning.

Conceptual framework

In a complex adaptive landscape (Ryan et al. 2007), small patches or bands of perennial vegetation promote feedbacks that are conducive to recycling of water vapour, and soil moisture and nutrients (Fig. 1). Numerous small interactions provided by different vegetation species have greater accumulative effects on larger scales than the sum of their individual properties would suggest. A key function is that they enhance the recycling of moisture and precipitation generating processes. When applied to meso-scales, vegetation patches and bands have accumulative effects on radiation and moisture partitioning which influences land surface climate interactions, including wind, temperature, precipitation and severity of drought (Pielke et al. 2007; McAlpine et al. 2009). Importantly, micro-scale structures are limited by how effectively they perform water retention functions in excess of survival; such as through the generation and build up of plant litter and soil organic matter that enhance soil biological activity and moisture. The following discussion will outline the feedbacks that influence water retention and recycling at micro-scales (hillslope to local landscape scale), including supplementary functions which may also be integrated into the same designs.

Micro-scale functions

The regulation of moisture in the hydrological cycle by vegetation (‘green flow’, Fig. 1) forms the basis to integrated designs that aim to enhance the storage and recycling of water vapour between the land surface and lower atmosphere in agroecosystems. When moisture is evaporated direct from soil as a result of short-wave radiation and wind there is a loss of ecosystem production and resilience. Adaptive designs that use integrated vegetation bands to address ecohydrological functioning and land degradation, can also underpin multiple ecosystem services and increase landscape resilience.

i. Ecohydrological sink

A major driver of the erosive potential of water across hillslopes is the removal or reduction of woody

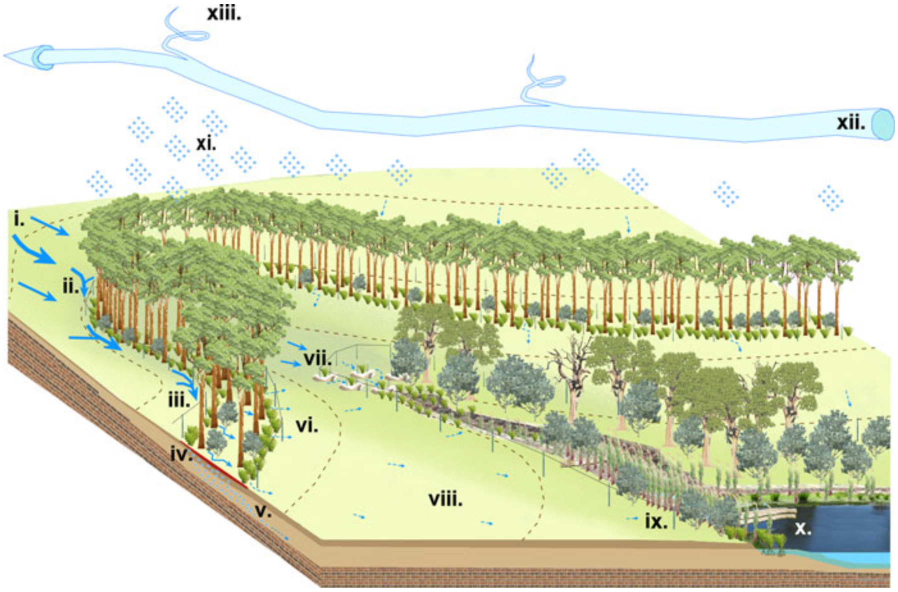

Fig. 1 An adaptive design for enhancing ecohydrological functioning and resilience of currently cleared agroecosystems. To buffer against high volumes and velocities of overland flow (*i*) following heavy precipitation, different vegetation types obstruct and repartition overland flow (*ii*, *iii*), slow velocity (*iv*), increase infiltration (*v*), spread water laterally to drier sections of the ridges (*viii*), arrest the erosion of waterways (*vii*), and improve downstream water quality (*x*). These vegetated bands are offset at −3% to the contour to redirect overland flow, but also to reduce wind speed (*xii*), increase atmospheric humidity (*xi*) and turbulence (*xiii*)

and herbaceous vegetation which increases runoff volumes and velocities (Falkenmark and Rockstrom 2004). Peak flows are larger and arrive sooner after heavy rains (Fohrer et al. 2005), which then cause erosion of soil, failure of stream banks and loss of water quality in fluvial networks (Rutherford 2000). Where stormwater converges its depth or velocity increases (Fig. 1i). The volumes of runoff generated on cleared lands is much greater than under their native cover, often with a concurrent increase in water velocity. Using locally adapted vegetation species, vegetated bands can form a semi-permeable barrier which can help reduce the velocity and increase the retention of stormwater runoff (iii, iv, v).

The degree to which vegetation can enhance soil and ecohydrological functioning depends on soil infiltration rate and saturation capacity, micro-topography, slope length and gradient, vegetation characteristics, organic matter and leaf litter depth (Bonan 2002; Cammeraat 2004; Liu and Singh 2004). Water held in micro-topographic depressions and plant litter is termed detention storage, and it is a variable which can affect the volume, velocity and pathway taken by overland flow (Lane et al. 2006; Paz-Ferreiro et al. 2008). The amount of water held is strongly affected by the type, thickness and moisture content of plant litter and soil organic matter (Paul et al. 2003; Chahinian et al. 2006).

A well developed litter layer represents an abrupt change in surface roughness that causes sediment to flocculate into the 'backwater' that forms behind vegetative barriers (Hussein et al. 2007). Increased surface roughness, organic biomass and soil macropores together help stabilise slopes, prevent sheet erosion, remove nutrients from overland flow and increase infiltration (Eamus et al. 2005; Post et al. 2006). Plant litter also helps cool the soil, stimulates microbial activity, and buffers soil aggregates, biological casts and biopores from rain splash and erosion (Greene and Hairsine 2004). Larger woody debris, leaf, bark and sticks (plant litter) are also necessary to provide strong structures behind which water can form 'micro-terraces' (Geddes and Dunkerley 1999), while the dense stems and fibrous roots of tussock grasses and sedges reduce water velocities and retain sediments (Hook 2003; Rachman et al. 2004).

While vegetation has a significant influence on the dissipation of kinetic energy in flows (Zhang and Su 2008), this depends on the physiology and density of the vegetation. It also depends on the spatial configuration of vegetation. Ryan (2007) highlighted the importance of spatial configuration for reducing the velocity of stormwater runoff in a headwater catchment of southeast Queensland, Australia. On slopes up to 24%, the velocity of overland flow was reduced by 14% under 20-m wide tree belts compared to pasture grasses by themselves, while infiltration increased by 23%. In this case, the creation of backwaters from plant litter beneath vegetation bands caused stormwater runoff to be infiltrate more than for open pastures. Increased retention of water during intense rainfall, in turn, can lower peak boundary outflow (discharge) which can help arrest soil erosion and the head-ward erosion of gullies, and increase the volume and duration over which water is stored within a landscape.

ii. Creating a microclimate effect

Vegetation bands can also provide wind shelterbelt and microclimate functions (Fig. 1). The aerodynamic properties of vegetation directly affect wind speeds, directions and the turbulence of the air flow (Cleugh 1998), such that evaporation of soil–water, wind erosion and heat stress on plants can all be reduced by vegetation bands and patches (Cleugh 2003). The performance of vegetation bands on microclimate, soil moisture and plant growth are primarily a result of tree height, band porosity and upwind turbulence (Cleugh and Hughes 2002). The microclimate effects improve plant water use efficiency by lowering evaporative demand and reducing damage to leaves (Cleugh 1998, Nuberg 1998). The modification of microclimate under tree canopies also modifies soil biological activity and soil health (Hairsine and van Dijk 2006).

Analyses of data collected from three grazing properties in southern Queensland found that vegetation bands resulted in maximum temperatures up to 2.6°C cooler while minimum temperatures were up to 0.95°C warmer (McKeon et al. 2008). While competition resulted in very low pasture growth in the vegetated band itself, microclimatic changes and soil moisture effects resulted in up to 20–30% greater pasture production in zones up to four to six tree heights ($Z \cong 20$ m) on the lee side of band. Similarly in semi-aid Kenya, (Ong et al. 2000) found that *Grevillea robusta* significantly altered understorey microclimatic conditions and water availability, with shading decreasing the mean diurnal temperature range and maximum meristem temperature by up to 7°C relative to mono-crops of maize. Plants develop deeper and more drought tolerant roots due to increased soil moisture from reduced wind speeds and shading (Nuberg 1998).

Reduction of wind speed also protects soil from excessive desiccation and erosion which is costly for landscapes functioning and agroecosystems (Bird et al. 1992). For example, dust generated from eroded soils can have enriched nutrient levels up to 20 times for nitrogen and phosphorous (Leys and McTainsh 1994), and up to ten times the organic matter content than the soils from which it was derived (Nuberg 1998). Vegetation bands can also reduce evaporation from water storages. For stormwater detention and storage dams, a narrow-deep reservoir will have much lower evaporative losses compared to a wide-shallow reservoir with the same storage volume (Wallingford 2004). Tall vegetation can reduce the surface area from which evaporation from wind can occur, and assist the formation of a cold pool of water which mixes with warmer surface water to lower evaporation. Livestock can also benefit from vegetated bands as a result of increased thermal comfort (Bird 1998).

Multiple arrays of vegetation bands are needed to obtain maximum protection and performance as a windbreak (Judd et al. 1996), but existing patches of vegetation and topographic features must also be considered in the design. Vegetation bands and patches on hillcrests and saddles are more likely to be affected by high winds, but provide greater turbulent flow further down the slope (Cleugh and Hughes 2002). Winds flowing down a valley can be funneled into stronger winds that can damage riparian areas (Ruel et al. 1998). Even the differential heating of slopes of different aspects can cause local breezes to form (Cleugh and Hughes 2002). The alignment and placement of vegetation bands should be matched to topography, soil and existing vegetation patches, using monitoring to determine water and wind flows.

iii. Restoring soil dynamics and health

While the restoration of native populations of soil microorganisms is impractical in agroecosystems that are open to continual disturbance, designs that include bands or patches of native vegetation can maintain a high diversity of species to provide soil health benefits. Whereas microbial biomass and activity, macro-aggregates, and concentrations of nitrogen and carbon are all reduced in agroecosystems compared to native ecosystems (Olechowicz 2007; Fabrizzi et al. 2009), vegetation bands have higher levels of biological activity, nutrient cycling, formation of soil aggregates and infiltration rates (Bregman 1993; Abel et al. 1997). Agroecosystems can also use vegetated bands as a source of organic matter to reverse soil structural decline (Thomas et al. 1996). Organic matter also maintains soil water retention capacity, fine clay particles and soil colloids over time (Lal 1993).

Different vegetation species will also alter the composition on soil microbial communities and nutrient through its effects on pH and the types of organic matter recycled within the soil (Balieiro et al. 2008). Earthworms that help create soil biopores, for example, rely on decaying above- and below-ground litter for their food supply (Dlamini and Haynes 2004). This is important for production, as the diversity of soil organisms affects the decomposition of organic matter, nutrient cycling and pathogen suppression (Bardgett 2005; Fitter et al. 2005).

Mycorrhizal relationships between some vegetation species and fungi can also increase access to mineral nutrients for plants, and provide protection from pathogens and drought (Harris 2009). In a field experiment, Li and Wilson (1998) found that mixing forest trees with a shrub in the presence/absence of a grass species could increase soil moisture and nitrogen.

Native vegetation can also be very competitive for soil moisture and nutrients. *Grevillia robusta* trees, for example, have been shown to extract substantial quantities of water over 2-m from their trunk (Lott et al. 1995). Other studies suggest that some tree species such as *Eucalyptus tereticornis* and *E. viminalis* are very competitive for nutrients, while others such as *E. camaldulensis* less competitive (Bird 1998; Nuberg 1998). In some cases *E. camaldulensis* has been suggested to recycle deep nutrients (e.g. N, K, Ca, Mg, Na) back into leaves and eventually to the soil as leaf litter.

Supplementary functions: bio-sequestration and biodiversity

While not directly affecting water recycling, bio-sequestration and biodiversity conservation can be integrated with other ecohydrological functions at micro-scales using vegetated bands or blocks. The level of soil carbon is generally higher in soils under native vegetation compared with other land uses (Young et al. 2005; Wilson et al. 2008). For example, the removal of tree cover across the semi-arid grazing lands of Central and Southern Queensland has been shown to lower soil carbon by 5–8% at depths to up to one metre (Harms et al. 2005). Native regrowth also represents a large carbon sink for many regions, provided drought, wildfires and land use do not reduce the cover as climatic conditions become increasingly harsh.

Designs based on integrated vegetated bands offer a compromise to sequester large amounts of carbon over a relatively small spatial extent (Schoeneberger 2005). A mix of vegetation species in banded form can have greater efficiencies in the capture and utilization of nutrients, light, and water, which may result in greater net carbon sequestration than for single-species systems (Nair et al. 2009). Species need to be selected based on a trade off between survival and growth of a species versus its potential to sequester carbon at a high rate and underpin vital ecosystems services. Some *Eucalyptus* species have shown abilities to sequester carbon at rates of up to 35.2 t ha^{-1} at 10 years of age in plantations (Walsh et al. 2008), although the extent of carbon sequestered will depend on the biological, climatic, soil and management factors at a particular site (Nair et al. 2009).

Planted native perennials can also provide a renewable source of woody biomass for timber, biofuel and biochar products, and offset emissions from agriculture (Vergé et al. 2007). Biochar is produced by pyrolysis of residues from crops, forestry, and animal wastes, and is suggested to store carbon for long periods while helping to restore soil fertility (Lehmann 2007). To minimise the return of carbon to the atmosphere, biochar must be buried in soils used for agricultural production (Millar et al. 2007); however, its longevity before CO_2 is again released to the atmosphere is still debated (Lehmann et al. 2006).

To adequately provide for biodiversity in agroecosystems, large, structurally complex patches of native vegetation are needed to provide core habitat for biodiversity, with corridors and stepping stones linking them (Fischer et al. 2006). The role of vegetation bands to increase connectivity and buffering functions of isolated remnants is gaining attention from ecologists (McNeely and Schroth 2006). Wide tree belts (>50 m) can provide habitat and movement corridors for native birds, reptiles and mammals, especially when they link large patches of native vegetation (McAlpine et al. 2002; Lindenmayer et al. 2003). The vegetated bands must have a structurally complex understorey environment, however, to accommodate greater diversity of vertebrate species (Borsboom et al. 2002).

Mesoscale functions

The accumulative forcings from numerous micro-scale interactions of vegetation patches with the land surface can affect meso-scale atmospheric circulation, turbulence, temperatures, precipitation patterns and drought severity (Pielke et al. 2007; McAlpine et al. 2009). A key question for the redesign of agroecosystems is whether we can use native vegetation to moderate extremes of temperature and severity of droughts, while invigorating convective systems that may generate localised precipitation at meso-scales (Fig. 2). Ecohydrological sinks are vitally important to this process, as they hold more moisture for longer durations compared to extensively cleared agroecosystems.

iv. Enhancement of atmospheric-vegetation feedbacks

The spatial distribution of soil, vegetation and land use significantly influence land surface energy and water dynamics as evident when comparing open agroecosystems (Fig. 2a) with those where vegetation bands have been widely implemented and native vegetation restored on ridgelines and riparian areas (Fig. 2b). These processes in turn, drive heat and moisture fluxes and balances (Stohlgren et al. 1998, Pielke 2001). Many types of sharp discontinuities between soil and vegetation types and moisture contents can create strong feedbacks to landscape to meso-scale atmospheric processes, and may be a critical design factor that can help underpin ‘precipitation recycling’ (Brown and Arnold 1998; Hayden 1998; Pal and Eltahir 2001). Numerous studies have found that rain-bearing cumulus clouds and

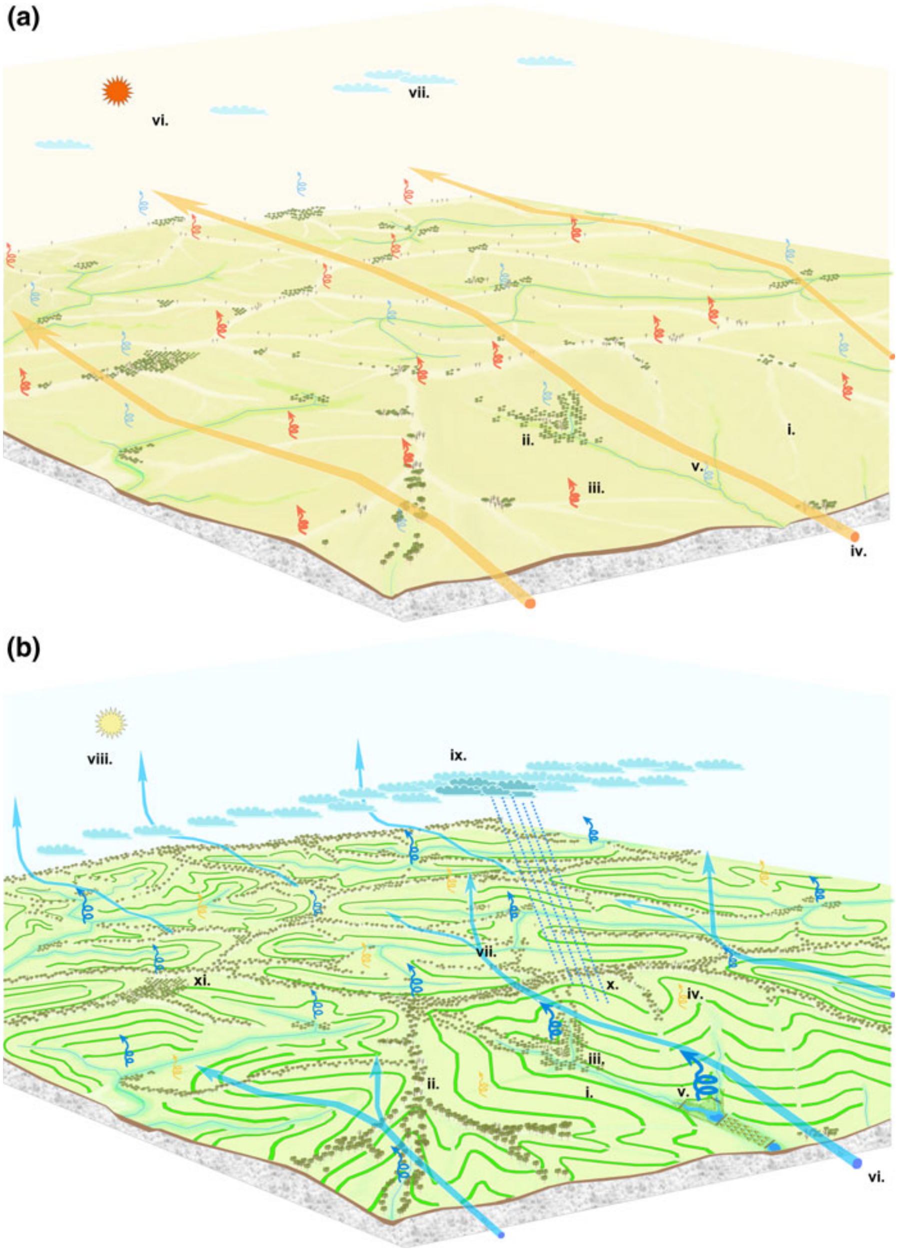

Fig. 2 Conceptual model of meso-scale feedbacks between vegetation and atmospheric processes. **a** Agroecosystems devoid of native forest/woodland cover (*i*, *ii*) has impaired recycling of water, greater sensible heat (*iii*) and lower latent heat (*v*), drier and stronger surface winds (*iv*), lower atmospheric turbulence and convection (*vii*), leading to a hotter/drier landscape (*vi*). **b** Vegetation bands designed to help restore water recycling in agroecosystems. A greater proportion of the landscape is covered by vegetation (*i*, *ii*, *iii*), creating lower sensible heat (*iv*) and higher latent heat flux (*v*), returning more water vapour to the lower atmosphere through turbulent exchanges with wind (*vi*) and through centres of forced convection (*vii*)

convective rainfall is more likely to form along land-cover discontinuities than elsewhere within the region (Anthes 1984; Mahfouf et al. 1987; Savenije 1995; Osborne et al. 2004). In the African Sahel region, Mohr et al. (2003) found that bands of broad leaved evergreen forest set within a dry savannah landscape, resulted in more numerous convective cells with very high rain rates compared to the open savannah areas.

Strong inland breezes can be generated from bands comprised of different soil moisture contents (Courault et al. 2007), although the formation, strength and orientation of thermals is affected by the spatial heterogeneity and alignment of land surface discontinuities and wind patterns (Prabha et al. 2007). Using a two-dimensional cloud-resolving model to study the generation of deep moist convection, Lynn et al. (1998) found a patch length of 128 km was a similar size to alternating patches of wet and dry soil. Mahfouf et al. (1987), found that bare soil and vegetation caused the development of meso-scale circulations and preferential areas of moist air convection at scales as low as 10–20 km. The potential to initiate areas of preferential convection using banded vegetation, however, is likely to only be applicable where atmospheric instability and potential buoyant energy are nearly at the threshold for free convection (Brown and Arnold 1998).

Biological ice nucleators such as bacteria or pollen are widespread in the atmosphere, and may play a vital role toward initiating cloud development and precipitation (Diehl et al. 2001; Mohler et al. 2007; Christner et al. 2008). The link to vegetation is that several of these biogenic nucleators (e.g. *Pseudomonas spp*.) are known to live on plant leaves (Hazra et al. 2004). Their significance is related to their ability to induce ice formation at higher atmospheric temperatures than abiotic particles (Andreae and Rosenfeld 2008). Christner et al. (2008) suggest a doubling of efficiency at which ice nucleation begins to form in clouds (e.g. −10°C to −5°C), while Vali et al. (1976) state that *Pseudomonas syringae* can initiate ice nucleation at −2°C. Depending upon its particular attributes for capillary action, pollen also affects ice condensation (Diehl et al. 2001). While these biogenic ice nucleators may enhance the generation of precipitation, their role is diminished as vegetation is removed through land use change (Andreae and Rosenfeld 2008). This raises an interesting question: has the introduction of pastures and crops affected precipitation patterns due to the removal of native vegetation which otherwise links these biogenic ice nucleators with the lower atmosphere?

v. Restoring catchment functioning

Changes in the interactions between climate, soil and vegetation will affect catchment runoff response, including water quality and quantity (Bari et al. 2005). Compared to woodland and forest catchments, peak flow is greater in cleared catchments (Fig. 2) and arrives sooner after heavy precipitation (Qin et al. 2005). Under the same rainfall regime, runoff will generally decrease as land cover returns to forested conditions. A summary of 94 catchment studies conducted by Bosch and Hewlett (1982) showed that, on average, for each 10% change in cover in a eucalypt forest a 40 mm change in water yield can be expected. As a forest or woodland matures it will generally reduce peak water yield, with fast growing plantations potentially causing major reductions in catchment flows (Calder 2007). On the other hand, Guo et al. (2000) found the discharge of water under forested ecosystems in the Yangtze River basin of China, was reduced during heavy rainfall of the wet season but enhanced during the dry season due to extra water stored within vegetative matter and soils. This highlights the significance of vegetated bands to generate a deep layer of plant litter that enhances ecohydrological functioning but on a relatively small land area (e.g. 20%). Vegetation bands increase the retention of overland flow and 'leak' this water to hillslopes and adjacent streams slowly over time, therefore, helping to buffer streams from large peak runoff rates (O'Loughlin and Nambiar 2001), improving base flows, and enhancing the recycling of water vapour to the lower atmosphere.

Synthesis and conclusions

As McAlpine et al. (this edition) state, landscape ecology needs a problem-solving focus to improve ecological outcomes in human managed landscapes. We need to move into a realm of design that is based on multifunctionality and sustainability, which includes an adaptive learning approach underpinned by long-term monitoring. Of critical importance to such endeavours, however, is that a functional basis to redesigning agroecosystems is recognised as being mandatory to ensure other ecosystem goods and services are also provided. This functional base is also often structured as a complex adaptive system (Ryan et al. 2007). In this paper we highlighted the significance of moisture retention and recycling in landscapes and how vegetation patches affect these processes. While the emphasis was on water recycling, we also included other functions that could be integrated using vegetation bands. Redesigning agroecosystems using vegetation bands, therefore, can increase their resilience to water scarcity and climatic extremes, while also helping to underpin many other ecological and climatic functions concurrently.

The main message of this paper is that integrated designs based on the utilisation of native vegetation as heterogeneous structures within agroecosystems, are important to ensure the delivery of multiple ecosystem services, to arrest land degradation and to buffer climatic extremes. The type, location, configuration and condition of vegetation bands or patches all affect a landscape's resilience to climate changes through their effects on feedback processes, particularly the retention and recycling of water and water vapour. Specific banded forms of vegetation can integrate micro-scale functions which lead to improved water recycling and precipitation generating processes at meso-scales. These same structures can also improve water retention and water quality by arresting sheet and gully erosion and sedimentation of streams, improve soil moisture and biological health, increase biosequestration and provide links to habitat for biodiversity.

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