Re-coupling the carbon and water cycles by Natural Sequence Farming

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Abstract: The techniques of Natural Sequence Farming (NSF) were developed during hands-on management of degraded farmland in the Upper Hunter Valley region of Australia. Early settlement of the continent by people with European cultural assumptions disrupted established interactions of water, soil, and plants resulting in lost fertility. Moreover, agricultural practices such as clearing, burning, ploughing, draining, and irrigation, have implications for global warming. Soils hold twice as much carbon as the atmosphere, and three times as much as vegetation. But carbon in exposed soil oxidises releasing CO_2 into the atmosphere. NSF is designed to restore ecosystem functions by re-coupling the carbon and water cycles.

Keywords: restoring landscape function; NSF; natural sequence farming; water and carbon cycles; plants as heat valves; climate change.

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Biographical notes: Duane Norris is Co-ordinator of the Natural Sequence Farming movement in Australia. He holds degrees in Agricultural Science and Sustainable Landscape Management from the University of Sydney, has worked on rainforest ecology in Papua New Guinea and North Queensland, and is currently engaged in writing a national syllabus on Natural Sequence Farming for farmers, natural resource managers and landcare practitioners. He co-edited the Conference Proceedings: *Natural Sequence Farming: Defining the Science and the Practice* (2006), and has authored numerous papers and blogs for the Natural Sequence Farming Forum.

Peter Andrews pioneered the conservation technique known as Natural Sequence Farming (NSF). He lives in the Upper Hunter River region of New South Wales, Australia, and developed his systematic analysis of how the Australian landscape functions while working as a farmer and horse breeder. Currently, he applies NSF principles in landscape consulting, and specialises in the restoration of degraded land, vegetation, and water systems. His aim is to bring local ecosystems up to fertility levels existing at the time of European settlement. He has authored two books on the NSF approach: *Back from the Brink* (2006) and *Beyond the Brink* (2008).

1 Farming or mining carbon?

Loss of carbon from the land has been going on since the European settlement of Australia began and today, according to one paper, these landscapes contain only one-tenth of the amount of carbon they had 200 years ago (Wells and Prescott, 1983). Moreover, it has been estimated that soils that once contained carbon matter 4000–10,000 years old, are now holding carbon that is only two years old. For when a farmer takes cattle to market around 6% of land productivity has been removed by animal grazing, and another 4% is lost to the atmosphere by oxidation from de-vegetated land (Andrews, 2006, p.116). This suggests that 90% of regenerative capacity remains. But most likely only 20% of carbon matter is held each year, the rest being eroded and leached into the sea by fast-running water flows (Ripl, 2010).

Whatever is in soil that makes it fertile has been put there by plants (Lal, 2009; Andrews, 2006, p.32). Carbon is critical to soil health and plant fertility, but it is lost through oxidation when a ploughed paddock is left fallow. More carbon is released when grassland and trees are cleared. However, when vegetation is allowed to break down, even if it is weedy cover, the carbon content of the soil is raised and growing conditions improve. Plants make soil. Soil is sand and clay with plant material added. Careful water management, planting, and mulch farming, can control this loss, but to be effective, land management techniques must replicate the unique geographic logic of a continent. The roles of water, plants, and soil in maintaining a landscape are each part of a complex historically evolved system of interlocking cycles; a naturally occurring 'design' that is fundamentally controlled by plants, in ways that is often beyond the capacity of humans to fully comprehend.

The environment runs on energy and plants are the means of generating and accumulating that energy. The primary environmental function of a plant is to extract carbon from carbon dioxide in the air by photosynthesis. The green-surface area of a landscape represents the 'extractive and manufacturing' capacity of that landscape, and plant leaves, using the energy of the sun, mix carbon with water making sugars that the plant needs to grow. Everything in the landscape including human food and energy for human use depend on this process. The more a rainforest accumulates energy, the greater diversity of plant species can live off the energy. Burn a forest and the energy dissipates as carbon gas, so fewer plant and animal species can survive there.

Plants moderate the water cycle as well as the carbon cycle and serve as a bridge between the two aspects of landscape productivity, regulating their interchange. Plants have been termed 'heat valves' because of their evaporative cooling function, a process described by Pokorný et al. (2010). Plants stabilise the distribution of water and carbon on the Earth's surface, and by physically slowing the movement of water, plants prevent landscape entropy through loss of carbon matter in soil and debris to the sea. This is what it means to speak of the coupling of hydrological and carbon cycles. As active managers of natural functions, plants are neither an inconvenience to humans, nor a passive convenience – as implied in the political phrase 'carbon sink'. The coupling of the water and carbon cycle by plant transpiration and atmospheric evaporation is the largest transfer of energy on the planet.

Natural Sequence Farming (NSF) is based on the restorative management of biological functions such as these, and observations in the Australian context indicate that the accelerated fertility decline of agricultural landscapes is brought about by deeply gouged stream beds. Stream incision increases the erosive energy of water, leading to soil and nutrient loss, reducing the capacity of a floodplain to hold water, lowering underground water table reserves, and resulting in loss of wetland habitat within a valley. NSF techniques use ponding and overflows from segmented reed beds to reduce stream incision, so restoring flood plain sedimentation, ecological health, and retaining carbon in the ground (Erskine, 1999).

2 Human impacts in Australia

Australia is a land of extremes. In terms of climate, it ranges from tropical to temperate. Its weather patterns fluctuate from drought to 'big wet'. In terms of landscape, it ranges from rain forests to deserts. It has the oldest landscapes in the world, and it also has the youngest. Indeed, given the highly erosive nature of the continent's landscape, an Australian floodplain may be no older than the last flood. Moreover, Australia's landscape is enormously dependent on biodiversity, one reason being that the land was not occupied by humans until relatively recently. The arrival of Aboriginal peoples was only 60,000 years ago, not long in geological time.

Prior to the arrival of Aboriginals, the Australian landscape supported a very different kind of forest mix. In those areas of the continent that were forested the plant mix was made up of palms and other Gondwana-like rainforest trees, gymnosperms including conifers like Araucaria, and a variety of species including eucalypts. Human impacts, first from Aboriginal communities, and then from European colonisers of the land, would bring an end to this biodiversity. Today, eucalypts make up 90% of Australia's forest, since they have been better able to regenerate after fire and other environmental impacts than almost any other plant (Singh et al., 1981; Andrews, 2006, p.150).

Archaeological evidence suggests that before Aboriginal peoples were living on the Australian continent, the landscape rarely burned. The natural burn cycle may have been as much as 300 years apart. Once human habitation was established, the burn cycle appears to have shifted to every two or three years and this had a profoundly transformative effect. Later, early European explorers would describe how Aborigines burned vast tracts of land at a time while hunting, since animals fleeing from a bushfire were easier to spot and kill. Burning also replaced old, dry vegetation with fresh, green re-growth attracting kangaroos and other edible animal species (Hughes, 1981). Other burns may have been accidental, since people carried fire sticks everywhere (Cary et al., 2003). Forests that once covered much of Australia's inland were almost entirely destroyed. The destruction of vegetation in turn, very likely caused the disappearance of mega-fauna. Finally, burning had another devastating effect. Without vegetation to renew and sustain the topsoil, it was readily blown or washed away exposing the clay layer beneath. The arrival of Europeans introducing inappropriate farm practices and hoofed animal stock further reduced both biodiversity and soil cover.

By the time Europeans arrived in Australia in the late 1700s, the landscape was already in decline. Even so, by today's standards it was still relatively rich in fertility. One indication of this is the speed at which introduced animals like sheep, rabbits, rats, and mice, multiplied. Within a few decades these numbered tens of millions. By 1891, barely a century after farmers settled, Australia's sheep population totalled 106 million (Cathcart, 2009). A decade later there was severe drought across more than half the continent. This was called the Federation Drought after the federation of Australian states in 1901, although it really began in the mid 1890s and was at its worst in 1902. During this drought, sheep numbers halved; but a little over 20 years later, they were 100 million. All this is a measure of the health of the environment. Since then, intensive farming has taken a heavy toll on Australian farmland and its fertility is poor. The continent is now subject to encroaching desertification (Williams and Saunders, 2003). Australian farming practices can be described as 'mining carbon'.

Deserts throughout the world are a result of human intervention. In Europe, however, these effects have been masked by the resilience of landscapes there. In Australia, anthropogenic effects are magnified by extremes of climate as well as by the introduction of cattle, goats, and camels. The eminent limnologist Professor Wilhelm Ripl from the Technical University of Berlin has commented that if land managers in Australia learned the lessons of this landscape, they would become international leaders in understanding how the global environment functions (Ripl-Andrews, Personal Communication, 2005). Australia is a laboratory for the world.

3 Observing the land: Peter Andrews' story

As I explain in *Back from the Brink* (Andrews, 2006), my training is not a scientific one. NSF is a practice that has developed from close observation and respectful interaction with the land. I started out as a sheep farmer and racehorse breeder, and my interest in land was driven by practical considerations. I wanted healthier, faster horses, and came to realise that they had a better chance, if they grazed on paddocks with plenty of biodiversity. This was quite a revelation to me at the time, and so I set out to find out more about the inner workings of the landscape. I soon discovered that biodiversity was only one of the vital keys to animal health and landscape sustainability. I next moved on to investigate the formation of in-ground water reserves. Each of these factors – biodiversity and inground water – is generally ignored by Australian farmers, few of whom bother to maintain biodiversity on their land. To the contrary, many spend a large part of their working lives applying artificial fertilisers, which act like a dose of caffeine to the soil, leaving it exhausted afterwards. Others try to eliminate the weedy growth that could help provide their land with functional stability and fertility. Even fewer farmers make an effort to understand the movement and storage of water below the earth's surface.

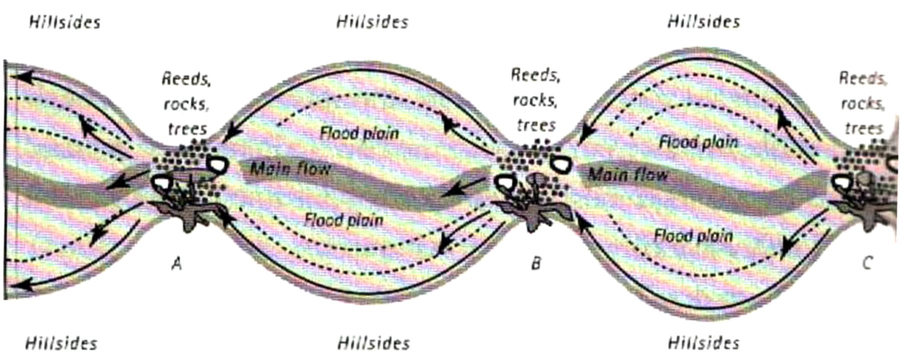
An important scientific question arises from all this: If Australia's landscape is poor today as a result of human intervention, why was it fertile before humans arrived? How did the continental ecosystem run so successfully for millions of years? My initial assumption was that the answer to this should help reinstate the natural processes that once kept the Australian environment and climate functioning. Finding the answer would be a matter of reading clues in the landscape and working out how they related to each other. I also cross checked my immediate observations with the historical record provided by early explorers. What I learned was that the Australian landscape had evolved by sustaining itself with in-ground water. And that this hydrological process, through the mediation of plants, balances the carbon cycle (Field, 2004).

This is how the system worked – and in some respects it is quite counter intuitive to people educated to scientific premises imported from Europe and America. The explorer Mitchell (1831), said that in Australia under natural conditions, water entered higher-ground through a system of cracks, and sandy, gravelly, 'recharge areas'. This water was stored in the layer of clay that underlies much of the Australian continent. On the plains, water travelled in creeks and rivers, but paradoxically these were elevated above the surrounding land and formed more like ponds (Eyles, 1977). A true flood plain was what its name suggests: a plain that was periodically flooded.

The rivers and creeks were not as seen today; they had not gouged out or excised a channel that moved water quickly across the plain. Indeed, explorer Charles Sturt commented that they are not rivers as in England, but more like channels adjoining broad wetlands some 50 miles across (Sturt, 1828–1831). After a rain event, whenever there was enough water in the system, the shallow rivers would spill out of the wetlands and spread water across the plain on either side (Figure 1). It was these floods that slowly soaked the flood plains. Australia has never had enough rainfall to drench the land directly.

Figure 1 Courtesy Peter Andrews, *Back from the Brink* (2006, p.177)

Diagram 8a. *Floodplain steps - How the water moves on elevated ground.*



Australia's flood plain system, as it evolved, was too brilliant a system of water management to have been humanly invented. Each flood plain typically consisted of a chain of separate plains. If you were to have flown over an ancient flood plain system from top to bottom, you would have seen that the valley housing the flood plain alternately opened out to a wide expanse and narrowed to a relatively small channel, thus dividing the flood plain into segments. These segments were arranged in steps, each a little lower than the one before. At the bottom of each step, perched above the step below, was a wetland full of reeds and other vegetation.

How did these wetlands originate? My hunch is that in many cases, the formation of wetlands was triggered by a heavy dump of mulch that trapped other debris and sediment beginning a build-up of carbon matter. Once the wetlands were established, water flowing down the system would be checked by reeds and have the erosive energy taken out as it entered one of these wetlands. The clay was deposited where it was trapped by plants so building new fertility. The ecological functioning of the flood plain stands in marked contrast to the rapid erosive movement of water through an incised stream bed.

4 The natural water cycle

In 1975 I took over a horse stud named Tarwyn Park in the Bylong Valley, a few hours' drive north west of Sydney. The stud was located on an ancient flood plain, although the stream that once supplied the plain with water now ran along the bottom of an eroded channel and hardly ever flooded. I set about reinstating, in miniature, a simulation of the old flood plain system as it once operated in Australia. Using a bulldozer and tractor, I developed a stepped system with a small wetland at the bottom of each step, and I installed pipes and channels to ensure the plain on either side of the stream was periodically flooded.

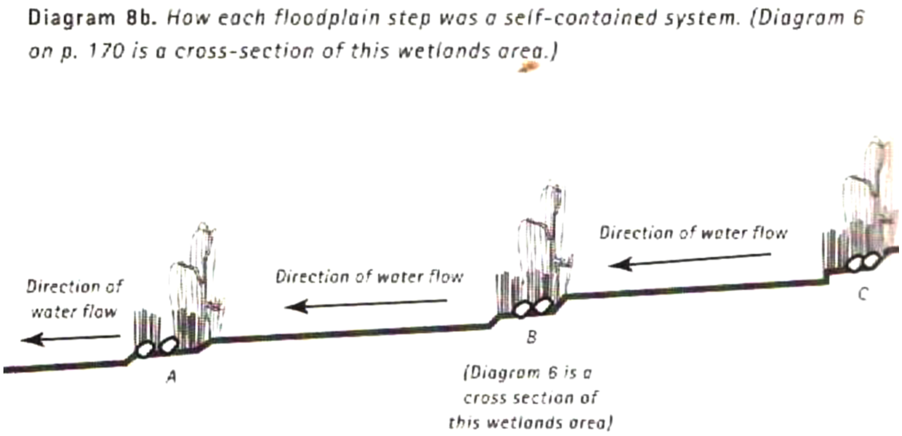
In 1997, local and overseas scientists visited Tarwyn Park to assess the work I had done. Among them was Haikai Tane, chief planner for Australia's biggest river system, the Murray-Darling, and Wilhelm Ripl from Berlin. I shared my conclusions about the role of hydrology in the Australian landscape generally, and at Tarwyn Park, in particular. Tane came up with an excellent description of the system, naming it a broad-acre example of step-diffusion hydroponics (Andrews, 2006). Hydroponics is a method of plant cultivation in which plants grow without soil, either in water with dissolved nutrients, or in an aggregate material like gravel or sand, through which nutrient solution flows. It is the second type of hydroponics that Tane had in mind when he likened Tarwyn Park to a giant hydroponic system.

By my analysis, broad-acre step-diffusion hydroponics is what used to happen in the Australian landscape generally. Water moved down from higher country through a series of flood plain steps, diffusing through each wetland and filling the ground with water laden with nutrients (See Figure 2). The further the water moved down, the richer in nutrients it became. The plants grew and flourished in this slowly moving in-ground water, just as they would in a hydroponic system. Today, human intervention makes the Australian river system into a plumbing and drainage system. Water now runs down gouged creek and riverbeds as if down a pipe, leaving the land on either side dry (Erskine, 1999).

The original flood plain system performed an essential function that was peculiar to Australia: it ensured that sediment and fertility was filtered and thus retained on the land, not washed out to sea. It is reasonable to surmise that, while inland Australia was still forested and inland flood plain systems were still functioning efficiently, Australia's coastal strips were vegetated with sea grasses and mangroves, thanks to carbon leaking from the inland. The coastal strip would have been trapping sand then, rather than losing it, thus providing an evolving landscape rather than a degrading one.

It was streams that formed the flood plains. Most likely reeds growing densely on low ground blocked the flow of the water and forced it onto higher ground. In ancient Australia reeds grew in abundance almost everywhere (White, 2000). One of the most widespread varieties is *Phragmites australis* known as 'common reed'. English colonials referred to it as elephant grass. This plant generally grows to a height of about three metres, although in some locations it can be three times as tall as that. The important thing is that reeds grew in the lower, wetter, fertile areas. Typically, Australia alternates between long, dry periods and short, very wet periods, so water usually comes in a rush. When there was little or no flow, water would trickle through a reed bed. When the water came in a rush, however, it would not be able to get through the reed bed, so it would pond behind it. When the pond grew big enough, the water would escape by flowing around the outside of the reed bed, which meant the water was now on higher ground. This was a self-sustaining process, for once water was redirected to the high ground it leached fertility from the soil there.

Figure 2 Courtesy Peter Andrews, *Back from the Brink* (2006, p.177)



The remains of elevated river and creek beds are an observable feature of the Australian landscape. If you drive from Sydney to Bylong, you get views of the Hunter River winding through the countryside, contained by its banks, but several metres above land on either side. A river or creek flowing in an elevated channel above the surrounding country is a sign of a healthy landscape, not just in Australia but everywhere. In any landscape that is regarded as pristine, the water body is elevated at the level of the trees. Conversely, where a river flows through a deeply incised channel, like the Zambesi River in Africa, or the Colorado River in the USA, it is likely to be running through a desert.

Tane has noted similarities between this perched drainage system and representations of floodplain ecosystems found in traditional Aboriginal artwork (Tane, 1997). The segmented system of flood plains, with each step separated from the next by a narrow channel guarded by a reed bed could work only if all parts did. As soon as one part of the system failed to function, the whole system failed. However, as soon as farmers introduced industrial agriculture and hoofed animals, the system failed – reeds were poisoned or ploughed out, eaten or trampled. Australia's indigenous animals are soft-footed, a fact that was vital to the survival of the ancient flood plain system. Soft-footed animals do not damage vegetation; hard-footed animals introduced for commercial purposes do. Where reed beds had previously controlled the flow of water from one flood plain step to the next, water now roared through and erosion began. Head-wall cuts began running backwards, undermining watercourses. Without reeds to moderate flow, water flowed quickly through the lower land. The old watercourses on higher ground were abandoned, although the ridges they formed still wind across the countryside, relics of a time when plants managed the Australian landscape.

5 Environmental breakdown

The demise of the flood plain system was one of two environmental disasters to have afflicted Australian landscapes. The other was the destruction of trees on high ground. At countless locations around the country, trees on high ground were cut down or otherwise destroyed, with the result that under-storey plants protected by trees disappeared too. It was the fertility generated by trees and under-storey plants on high land that fed the country below, including swamps, with nutrients. On average, trees shed about one seventh of their mass each year, which means that a single tree standing in a field with a mass of, say, 300 tons, can contribute up to 20 tons of mulch to that field each year (Walter Jehne, Personal Communication, 2010).

The contribution of soil nutrients by a forest is considerable, and on high ground these nutrients under force of gravity, work their way to the land below. Swamps then process the sugars and other carbon matter that have seeped down, and when the next flood comes these are spread over the landscape. Without trees and under-storey plants existing above, swamps are starved of nutrients and become exhausted. In the absence of native plants, weeds can be used temporarily to help reinstate this repair. This is not ideal, but at least weeds help restore metabolic functions in the landscape, without which metabolism, no plant will survive long.

In Australia, the destruction of native forests along the continent's East Coast appears to have had another serious consequence: it put an end to the so-called 'biotic pump' effect that previously ensured there was a net daily movement of moist air from the ocean to the land. As a result, eastern Australia is markedly drier than it used to be. The 'biotic pump' theory (Makarieva and Gorshkov, 2010) argues that a heavily forested coastal strip is cooler than the ocean because during the day the forest fills with transpired water vapour. When this vapour condenses, a lowered pressure in the forest attracts moist onshore winds, creating an upward thermal thrust of moist air and inland rainfall. Australian research suggests that desert areas in North Queensland are the effect of rainforest clearing on the coastal strip (McAlpine et al., 2007; Shiel and Murdiyarso, 2009). This scientific observation is consistent with the cultural memory of local Aboriginal people.

Australia is not the only place in the world with environmental problems like these. European scientists are equally concerned about landscape changes. For instance, where spruce trees once grew at 15,000 feet, they are now struggling to grow above 3000 feet, the reason being that it is now too cold above 3000 feet for the young spruces to survive. Since forests in the high country have been thinned out, there are no longer enough trees to moderate the temperature at night, and the young trees cannot cope with the extreme cold (Lovelock, 2005). People cut down trees in high country for timber, not realising its consequences for landscape in the low country where they lived. Trees are huge accumulators of carbon fertility. They attract birds and insects, which leave droppings; they attract sheep and cattle, which leave their dung; and they drop leaves and other debris which produce fertility too. Biochar should never be considered a substitute for natural biomass in the soil. Biochar is a burnt, inert, dead compound; one that may house microbes in a wet climate, but will do nothing for a dry landscape.

6 Hands-on solutions

The term NSF confuses some people, and most of the confusion is over the word 'sequence'. People ask: what sequence do you have in mind? In Europe, the sequence by which the landscape operates is seasonal. In Australia, the sequence is not nearly so regular and it is not determined by seasons. The basic factors that control this landscape are the carbon processing green surface area of plants and the water cycle, operating together in an interrelated sequence of processes. The event that sets the sequence in motion is rain. The key principle is re-coupling of the carbon cycle with the hydrological cycle, which together have the capacity to promote landscape fertility, on the one hand, and to moderate climatic extremes through evaporation, on the other.

Contouring the land, that is, building a bank along the line of a contour and creating a channel behind it, is one restorative NSF technique. It enables a farmer to control the landscape hydrology and use it to advantage. It helps distribute nutrients across the land as far as contour channels extend. Essentially, it is a water management and fertility management system. A farmer who contours is really installing a wetting cycle in the landscape, mirroring the ecological cycle that existed earlier. This achieves mechanically, what plants once achieved naturally. Humans cannot do it as well as plants did, but certainly, contouring solves some of the landscape problems that Australians must deal with, fertility and salinity foremost among them.

The Australian landscape flourished for millions of years operating under a system that, notwithstanding extremes of climate, ensured the continent's sustainability. But currently, it is a landscape in decline. Too many Australian farmers are wedded to the idea that they can clear and then spray a paddock ready for cropping, that is, kill everything growing there, and that nature will stand still until the crop is sewn months later. Fertility is lost as long as that paddock is bare, and the landscape is depleted every day as the sun burns away non-living plant matter; or wind blows it away; or water washes it away. Obviously Australians cannot turn the clock back 100,000 years to recreate the continent existing before humans started disrupting it. This would mean retrieving the millions of tons of material that have been eroded out of the land and carried to the sea. The natural regulating mechanisms that used to exist, most notably wetlands, cannot be replaced. It is possible, however, is to reinstate the functionality of the ancient landscape with processes that simulate the systems which were active long ago.

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References

Andrews, P. (2006) *Back from the Brink: How Australia's Landscape can be Saved*, ABC Books, Sydney.

Andrews, P. (2008) *Beyond the Brink: A Radical Vision for Australia's Landscape*, ABC Books, Sydney.

Cary, G., Lindenmayer, D. and Dovers, S. (2003) *Australia Burning: Fire Ecology Policy and Management Issues*, CSIRO, Canberra, pp.3–14.

Cathcart, M. (2009) *The Water Dreamers: The Remarkable History of Our Dry Continent*, Melbourne University Press, Carlton.

Erskine, W.D. (1999) 'Oscillatory response versus progressive degradation of incised channels in South Eastern Australia', in Darby, S.E. and Simons, A. (Eds.): *Incised River Channels*, Wiley, Chichester, UK, pp.67–95.

Eyles, R.J. (1977) 'Changes in drainage works since 1829, Southern Tablelands, NSW', *Australian Geographer*, Vol. 13, pp.377–386.

Field, C.B. (2004) *The Global Carbon Cycle*, Island Press, Washington DC.

Hughes, P.J. (1981) 'Aboriginal burning and late Holocene geomorphic events in Eastern NSW', *Search*, Vol. 12, pp.277–278.

Lal, R. (2009) 'The potential for soil carbon sequestration', *Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen*, International Food Policy Research Institute, http://carboncoalitionoz.blogspot.com/2009_06_01_archive.html (accessed 11 May 2010).

Lovelock, J. (2005) *Gaia: Medicine for an Ailing Planet*, Gaia Books, London.

Makarieva, A. and Gorshkov, V. (2010) 'The biotic pump: condensation, atmospheric dynamics, and climate', *International Journal of Water*, Vol. 5, No. 4, pp.365–385.

McAlpine, C.A., Syktus, J., Deo, R.C., Lawrence, P.J., McGowan, H.A., Watterson, I.G. and Phinn, S.R. (2007) 'Modelling the impact of historical land cover change on Australia's regional climate', *Geophysical Research Letters*, Vol. 34, http://dx.doi.org/10.1029/2007 GL031524 (accessed 10 May 2010).

Mitchell, T. (1831) *Heading to Northwest New South Wales: Namoi and Gwydir. Extracts from Sir Thomas Mitchell's Travels to the Eastern Interior*, http://freeread.com.au/ebooks/e00035.html (accessed 11 May 2010).

Pokorný, J., Brom, J., Čermák, J., Hesslerová, P., Hurynna, H., Nadyezhdina, N. and Rejšková, A. (2010) 'Solar energy dissipation and temperature control by water and plants', *International Journal of Water*, Vol. 5, No. 4, pp.311–336.

Ripl, W. (2010) 'Losing fertile matter to the sea: How landscape entropy affects climate', *International Journal of Water*, Vol. 5, No. 4, pp.353–364.

Shiel, D. and Murdiyarso, D. (2009) 'How a forest attracts rain: an examination of a new hypothesis', *BioScience*, Vol. 59, No. 4, pp.341–347, www.biosciencemag.org (accessed 10 May 2010).

Singh, G., Kershaw, A.P. and Clarke, R. (1981) 'Quaternary vegetation and fire history in Australia', in Gill, A.M., Groves R.H. and Noble, I.R. (Eds.): *Fire and the Australian Biota*, Australian Academy of Science, Canberra, pp.23–54.

Sturt, C. (1828–1831) Observations on the soil, climate, and general resources of the colony of New South Wales, Vol. I, www.boomerangbooks.com.au/Two-Expeditions-Into-The-Interior-Of-Southern-Australia/Charles-Sturt/book_9781419191473.htm 13/05/10 (accessed 10 May 2010).

Tane, H. (1997) *Bylong Creek Case Study*, www.watershed.net.nz/fpeandwm.htm, Accessed 10 May.

Wells, C.B. and Prescott, J.A. (1983) 'The origins and early development of soil science in Australia', *Soils: An Australian Viewpoint*, Division of Soils, CSIRO, Melbourne, pp.3–12.

White, M.E. (2000) *Running Down: Water in a Changing Land*, Kangaroo Press, Roseville, NSW.

Williams, J. and Saunders, D.A. (2003) *Land Use and Natural Ecosysytems: A Revolution in Land Use is the Key to a Sustainable Landscape*, www.clw.csiro.au/staff/Williams/Landuse_Natural_Ecosysytems.pdf (accessed 10 May 2010).