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Abstract: Stubble farming (conservation farming, minimum tillage, zero tillage) has increased in Australia over several decades with claims of improved productivity, landscape stability and environmental benefit including ecosystem services downstream, yet recent audits show a dramatic and general decline in river health. This review explores explanations for this apparent anomaly. Many confounding factors complicate interactions between land use and river condition and may disguise or over-ride the potential benefits of adoption of stubble systems or other improvements in agricultural land use practice. These factors include climate change and variability; land use changes including an increase in bushfires, growth of farm dams and afforestation; lag times between land use change and expression of benefits in river systems; use of inappropriate scale that disguises local benefit; variations in the extent of ecosystem resilience; impacts of river regulation; and impacts of introduced species. Additionally, the value of river condition and utility is complicated by different local or regional perceptions and by contrasting rural and urban outlooks. The use of indicators, risk frameworks and biophysical modelling may help elucidate the complex relationships between land use and downstream ecosystem impact. The strengthening of local, regional and catchment scale approaches is advocated. This includes the re-integration of land management and governance with water management and planning. It is encouraging that farmers are themselves developing systems to optimise tradeoffs between on-farm activities and ecosystem service benefits. This approach needs to be supported and extended.

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Water resource protection in Australia: Links between land use and river health with a focus on stubble farming systems

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Summary

Stubble farming (conservation farming, minimum tillage, zero tillage) has increased in Australia over several decades with claims of improved productivity, landscape stability and environmental benefit including ecosystem services downstream, yet recent audits show a dramatic and general decline in river health. This review explores explanations for this apparent anomaly. Many confounding factors complicate interactions between land use and river condition and may disguise or over-ride the potential benefits of adoption of stubble systems or other improvements in agricultural land use practice. These factors include climate change and variability; land use changes including an increase in bushfires, growth of farm dams and afforestation; lag times between land use change and expression of benefits in river systems; use of inappropriate scale that disguises local benefit; variations in the extent of ecosystem resilience; impacts of river regulation; and impacts of introduced species. Additionally, the value of river condition and utility is complicated by different local or regional perceptions and by contrasting rural and urban outlooks. The use of indicators, risk frameworks and biophysical modelling may help elucidate the complex relationships between land use and downstream ecosystem impact. The strengthening of local, regional and catchment scale approaches is advocated. This includes the re-integration of land management and governance with water management and planning. It is encouraging that farmers are themselves developing systems to optimise trade-offs between on-farm activities and ecosystem service benefits. This approach needs to be supported and extended.

Keywords: Watershed protection, Aquatic ecology, River health, Water quality, Land use, Ecosystem Services

Introduction

In Australia, agencies have encouraged the adoption of stubble farming systems to achieve both private on-farm and public off-farm benefits. The potential benefits (ecosystem services) and costs measured by effects on individual water quality and quantity characteristics are described elsewhere (Bowmer, n.d.; Table 1).

Stubble farming, sometimes termed conservation farming or minimum, zero or no-tillage, is used on about 70 million ha worldwide (about 46% in Latin America, 37% in the United States and Canada and 13% in Australia) and future demand for cereals from increasing population growth creates challenges to continuously crop the soil while limiting degradation brought about by conventional tillage (West, 2004). In

Europe runoff and soil erosion are major environmental threats and on-farm adoption of soil and water conservation measures is the subject of a special issue of the Land Use Policy journal (Vol. 10 (1), 2010). In Australia stubble farming has increased rapidly in the last ten years (Llewellyn and D' Embden, 2010). In 2007-8 about 40,000 businesses (53%) used zero- till methods over 17 million hectares (Australian Bureau of Statistics, 2010).

In this report the links between adoption of stubble farming systems and trends in water resource condition ('river health') are explored to see whether causative links can be established. This information is required to underpin the appropriate investment in government and regional planning, whether in improved farming systems or other methods. Expert agronomists claim over-riding benefits of stubble farming systems and zero tillage. For example, Pratley (2006) in a recent invited keynote address at the prestigious Fenner conference reports that '*conservation farming has revolutionised soil health, water use efficiency, and landscape stability to give both productivity gains and environmental benefits*'; and (Smith, 2009), a former Director-General of Agriculture for Victoria, in defending agricultural systems against 'green myths', describes zero- till sowing of crops as '*a good example of Australian innovation and sustainability'*. Yet recent audits generally show a dramatic deterioration in river health. This apparent anomaly is explored through: (1) reviews of expectations about the benefits of stubble farming systems; (2) recent audits of river health; and (3) difficulties of linking land use to river health. Finally (4), approaches to integration and optimisation are considered including methods for incorporating ecosystem benefits of land use in planning and practice.

1 Benefits of stubble farming systems

1.1 Comparison with other management methods

Priority water quantity and quality issues are reviewed in Table 1 with management options classified into categories of watershed protection, interception in the riparian zone, and technological treatment.

Table 1 near here

1.2 Erosion and sediment delivery

The many benefits of stubble farming systems include reduction in sediment load and suspended particles (turbidity) through reduction of hillslope erosion and retention of water in the landscape. Benefits at paddock scale have been demonstrated by early experiments and modelling using PERFECT (Freebairn and King, 2003; Freebairn et al. 1993; Freebairn et al., 1986; Littleboy et al., 1992) and APSIM (Connolly et al., 1999; McCown et al., 1996).

However, paddock-scale mitigation processes are confounded by gully and bank erosion in some regions. The National Land and Water Resources Audit (2001) reports that while hillslope erosion is high in north Queensland (0.7-1.3 tonnes/ha/annum), gully erosion is highest in New South Wales and Burdekin regions (0.4-0.5 tonnes/ha/annum), while bank erosion is estimated at 0.2-0.3 tonnes/ha/annum across all regions. Gully erosion is the main source of sediment in south-east Australian rivers (Prosser et al. 2001a; Olley and Scott, 2002) so this process has been the main target for preventative management strategies.

Modelling (SedNet) has been used to identify the sources and flux of sediments at river reach scale (Lu et al., 2004; Wilkinson and Kennedy, 2007) and the use of riparian vegetation for interception has been investigated in an extensive program by Land & Water Australia (Lovett, 2004). Links between sediment dynamics, riparian vegetation and aquatic ecology were explored in the Ovens River by De Rose et al. (2005).

1.3 Water balance

Stubble farming systems provide both public and private benefits. Rainfall capture and retention is recognised as a major on-farm benefit (Scott et al., 2010). There is also increasing evidence that vegetation cover is critical for maintaining the local water cycle through suppression of surfaces temperatures, in turn preventing drying, run-off and ultimately increased erosion (Kravčík et al., 2008).

In spite of the recent floods, water scarcity, growing populations, and increased need for food continue to drive efficiency in water use. '*A national effort is needed to increase the store of water in the landscape*' (Cribb, 2010; Jeffery and Cribb, 2010).

2 Audit of river health

Substantial national and community investments have been made in Australia through public investment in Landcare, the Natural Heritage Trust, the National Action Plan for Salinity and Water Quality and Caring for Our Country, reflecting ideals of catchment care to protect natural assets that include rivers, wetlands, estuaries and associated aquatic ecosystems. Yet, in general, environmental condition appears to be deteriorating. The National Land and Water Resources Audit (2001) found that nutrient concentrations exceeded acceptable standards in 43 of Australia's 246 river basins, turbidity was excessive in parts of 41 basins and salinity exceeded standards in 24 basins. Soil erosion and in-stream turbidity have a particularly strong impact on water quality in much of eastern Australia (National Land and Water

Resources Audit, 2001, p. 44 - 45); and under the heading 'opportunities for improved management' (p.81) a range of deteriorating quality issues are listed. These include: salinity, affecting 1% of the agricultural land; water borne-soil erosion (with hillslope, gully and riverbank erosion varying in proportion according to location); soil and nutrient redistribution and loss; and increasing soil acidity (threatening production on 25% of the land).

The National Water Commission (2007) reported on the condition of river and wetland health in June 2005 to provide a baseline of river condition at the start of the National Water Initiative reform process. The Framework for the Assessment of River and Wetland Health is based on six key indices which are aggregated to produce an index between 0 (severely degraded) and 1 (pristine). Most relevant to this review are the index of catchment disturbance which covers the effects of land use and vegetation cover on run-off of sediments, nutrients and other contaminants to rivers and wetlands, and the index of hydrological disturbance that recognises the importance to aquatic ecosystem function of surface flow and groundwater. In summary: 10% of river length was identified as severely impaired, having lost at least 50% of the types of aquatic invertebrates expected to occur there; more than 95% of the river length assessed in the Murray-Darling Basin had an environmental condition that was degraded; 30% of river length in the Basin was substantially modified from the original condition; and all reaches and catchments in the Basin had disturbed catchments and modified water quality. It was concluded that many parts of the Basin are threatened by multiple stresses, principally land use changes, damaged riparian vegetation, poor water quality and modified hydrology.

More recently the Murray-Darling Basin Sustainable Rivers Audit assessed ecosystem health using fish condition, macroinvertebrate and hydrology condition (Davies et al., 2008; Davies et al., 2010). Thirty out of 45 valleys were rated as in very poor condition and another 12 as poor. Also, Schofield (2010) in a recent collation of river and estuarine condition audits, reports a general widespread decline.

3 River health links to stubble farming systems

3.1 Framework for interactions

As previously noted, the increased adoption of stubble farming systems, together with claims of associated ecosytem benefits, seems at odds with the observed general decline in condition of catchments, rivers and streams, reflecting the effects of other pressures on river health and 'confounding factors' that may over-ride the potential benefits of stubble farming systems in Australian landscapes.

A conceptual framework illustrating the complexity of interactions and separation of cause and effect is given in Fig. 1 where factors that impose stress on rivers and wetlands (stressors or pressures) are linked to symptoms of degradation (or responses) through the buffering capacity (condition-fragility or resilience) of the ecosystem. A similar framework (Pressure State Response and Implications) was used in State of the Environment reports (Hamblin, 1998). This review is focused on the (highlighted) dryland agricultural land use components in the diagram, and specifically on trends in stubble farming systems as a subset of agricultural land use. The diagram also shows the effects of irrigation and urban pressures, illustrating the complexity of attributing water quality characteristics to specific land use changes, as will be discussed later.

Fig. 1 here Caption follows:

Fig. 1. Urban and agricultural STRESSORS impact on ECOSYSTEM HEALTH to give SYMPTOMS of degradation**.** Highlighted boxes are the focus of this review.

Symptoms reflect the combination of stress intensity and the buffering capacity or resilience of ecosystems (modified from Cullen and Bowmer, 1995).

3.2 Confounding factors

Benefits that can be ascribed to stubble farming are difficult to separate from other 'confounding' factors that impact on downstream water quality and quantity.

Detrimental effects include:

- *Reduction in rainfall.* In spite of recent flooding over much of Australia (October 2010 to March 2011) a continuing drought and reduced run-off is predicted in southern Australia (Commonwealth Scientific and Industrial Research Organisation, 2010a).
- *Land use changes.* Water retention by stubble and other farming systems is compounded by other water interception practices, and is additional to interception from forestry plantations (about 2000 GL/yr more in evaporation than would be used in dryland agriculture), farm dams (1600 GL/yr), stock and domestic activities (1100 GL/yr), and overland flows that are harvested from floodplains(900 GL/yr). The volume of water intercepted by these activities totals almost a quarter of all entitlements (Sinclair Knight Merz, CSIRO, and the Bureau of Rural Sciences, 2010). Van Dijk et al. (2006) also describe the risks to shared water resources in the Basin including the effects of bushfires.
- *Diversion of water.* Water extraction from both unregulated and regulated (dammed) streams and rivers has had a major impact on aquatic ecology and river health and this has been exacerbated by a decade of drought. For the Murray-Darling Basin specifically the shortfall of water for environmental

needs is estimated to be 67-81 % of the total available surface water (long term average), equivalent to between 3000-7000 GL per annum (Murray-Darling Basin Authority, 2010).

- *Changes in patterns of flow and connection.* In highly regulated rivers, changes in patterns of flow include reversal of seasonality upstream of irrigation offtakes and reduced occurrence of pulsing flows that are required to maintain ecosystem diversity and function (Watts et al., 2009). Loss of longitudinal connection of rivers caused by weirs and barrages and loss of lateral connection through capture of and storage of water are detrimental to aquatic resilience. Occasional mid-level floods are needed to achieve overbank flow for wetlands, floodplains and forests (Hillman, 2008; Young, 2001). For example, the demise of red gum forests was reviewed recently in New South Wales (NSW Natural Resources Commission, 2009). Extraction from unregulated rivers is also a concern for ecosystem resilience and estuarine condition through effects on flow patterns and volumes. Macro Water Sharing Plans (NSW Department of Environment Climate Change and Water, 2010a) provide some protection for natural features of streams and estuaries in New South Wales.
- *Cold water pollution.* This is another feature of impoundment in some regulated rivers. Extraction of cold water form deep reservoirs affects aquatic ecosystems and can depresses the spawning of native fish far downstream. (NSW Industry and Investment n.d.[a])
- *Acid sulphate soils*. Acid sulphate benthic sediments, an emerging issue in the Murray-Darling Basin, are an indirect result of water scarcity caused by drought, extraction of water upstream , and reduced baseflow in rivers caused

by declining groundwater levels (Akerman, 2008; Hall et al., 2006; Lamontagne et al., 2004; Lamontange et al., 2006; McCarthy et al., 2006).

- *'Blackwater'.* Drainage water returning to rivers after flooding that is rich in organic matter picked up from decaying leaves and organic sediments can deoxygenate the water, disrupting food webs and killing fish. (NSW Industry & Investment, n.d.[b])

Countering these detrimental effects are changes which are likely to improve river health including :

- *Improvements in water quality* through interception of pollutants in the riparian zone. Many pollutants are quickly adsorbed in turbid water (Hart, 1986) so are effectively intercepted by grass buffer strips and riparian vegetation. There is an extensive international literature on the use of natural and constructed wetlands to intercept pollutants (e.g. Hamer, 1990; Kadlec and Knight, 1996). In Australia, major investments have protected river banks against erosion by fencing and providing off- river watering points for stock, and many Catchment Authorities and regional groups have protected and restored riparian revegetation through a range of incentives and on-ground community programs such as Land and Water Management plans, Landcare, the Natural Heritage Trust and Caring for our Country (e.g. NSW Catchment Management Authorities, 2010). A technique named Natural Sequence Farming has been developed recently to create a 'chain of ponds' to avoid incision of the landscape by streams and create a freshwater lens above saline groundwater (Andrews, 2006).

Futher challenges for interpretation include :

- *Other management interventions.* A range of land use and riparian interception options may be used (Table 1) making it difficult to isolate the effects of stubble farming systems.
- *Variation in ecosytem resilience.* Individual ecosystems, streams and rivers or reaches are expected to differ in their vulnerability to stressors (Figure 1) according to their resilience. ‘Regime shifts’ (Folke et al., 2004) and loss of ecological function through irreversible change (‘hysterisis’; Harris, 2006) is a function of diversity as well as effects of pollutants and climate change.
- *Lag time*. The effect of lag time between land use change and impact on river condition has several consequences, both positive and negative. Problems created by earlier land use practices and impacts such as stock trampling, clearing, fire and rabbits will mask the effects of more recent improvements (Scott and Olley 2003; Starr et al., 1999) as sources of fine particulate material in lowland rivers continue to be mobilised for many years, even with a reduction in sediment sources (Norris et al., 2001). In contrast, comparison of erosion over recent decades in a south-eastern Australian catchment by optical dating shows that erosion has been stabilised in recent decades (Rustomji and Pietsch, 2007). This ‘landscape recovery’ is attributed to vegetation growth along gully floors that traps substantial amounts of sediment high in the landscape, reducing sediment catchment yields (Zierholz et al., 2001).
- *Scale.* Obviously, benefits achieved at a local scale or in specific geographic areas might be disguised in national and regional scale assessments. For example, in the Murray-Darling Basin, 80% of the water harvested originates

in 3% if the catchment (Blackmore et al., 1995) and 90% of soil erosion occurs in 20% of the catchment (National Land and Water Resources Audit, 2001, p.82). Also , as noted previously, sediment delivery to rivers and streams is dominated by hillslope erosion in tropical and subtropical cereal growing areas (National Land and Water Resources Audit 2001) while gully erosion dominates in the southern cereal belt (Olley and Scott, 2002; Prosser et al., 2001). In southern systems long term demonstration sites show dramatic amelioration of erosion by stubble farming systems compared with tillage (Harte et al., 1985; NSW Department of Land and Water Conservation, 1979) but the benefits are likely to be overwhelmed by gully sediment sources.

- *Dilution.* The effects of stubble farming on soil water retention as well as water quality need to be considered because, while pollutant loads from stubble farming systems may be reduced in run-off, the concentration of pollutants could increase. Concentration might be further increased during drought by reduction in surface flow, river base flow, and upstream tributary flows leading to less dilution.

Additionally, cost-benefit analysis is complicated by different local perceptions of the value of river and wetland health and by contrasts in rural and urban outlooks. For example, a survey, '*Who Cares about the Environment'* shows much more community interest in river pollution and health in rural than in urban catchments (NSW Department of Environment Climate Change and Water, 2010c). The National River Contaminants Program (NRCP) Strategic Plan (ATECH, 2000) canvasses the views of catchment and river managers about the most important river contaminant issues on a national scale. The objective of the NRCP (Edgar and Davis, 2006) is to understand where contaminants are coming from, how they are transported in river systems, what transformations occur during transport, and the ultimate fate and impacts of river contaminants on water quality, aquatic life and the riverine ecosystem overall, so these are biophysical assessments. However, recent approaches to valuation of river condition and utility provide a broader outlook on ecosystem service benefits that include socioeconomics as well as biophysical approaches. In choice modelling approaches Bennett et al. (2008) have demonstrated that urban communities are prepared to pay for access to rivers and wetlands just to know that they are available; and Morrison and Bennett (2004) showed that people are prepared to pay substantial increases in costs of food and taxes to maintain characteristics of healthy ecosystems.

4 Approaches to integration and optimisation

4.1 Environmental indicators

A key set of 29 indicators for the land was recommended for Australian State of the Environment (SOE) reporting (Hamblin, 1998; Hamblin, 2001). A report card format was developed across six threatening processes: accelerated erosion, changes to natural habitats, hydrological disturbances, the introduction of exotic biota, disturbance of nutrient and salt cycling and anthropogenic pollution. Indicators were selected to reflect pressures, current condition and human response for each process. The central role of vegetation (cover, extent and condition) was identified in many of the proposed indicators because of its critical role in erosion control, nutrient cycling, habitat and maintenance of hydrological balance.

Fewer than ten indicators in the recommended list of 61 were sufficiently developed to be useable without further research effort. Most challenging research, then as now, was listed as '*the nature of the effects of more than one threatening process on* *environmental conditions'* and '*the most sustainable trade-off responses when several pressures affect various environmental domains*.' Similarly we are concerned about isolating the effects of stubble farming from other impacts, and conversely, in assessing the benefits as well as any threats.

In the 2006 SOE Report it is disappointing to note that there was no data to indicate significant changes in the effectiveness of responses to the condition of the land (Gleeson and Dalley, 2006). The 2011 Report is currently being prepared.

4.2 Modelling

Table 2 near here

A main problem in ascribing downstream benefits and costs to stubble farming practices is that the relationship between cause (stubble farming compared with conventional tillage) and effect (environmental benefit or cost downstream) is difficult to quantify. As noted above, a generalised approach is problematical because of time lags and differences at regional and local scale. Various modeling approaches have been used to dissect and integrate the complex relationships. A snapshot of some of the extensive literature on modelling land use and water interactions is given in Table 2. Reviews of these and other models are available in the literature (Arancibia et al., 2007; eWater Ltd Cooperative Research Centre, n.d.[a]; Letcher et al., 2002; Letcher et al., 1999; NSW Department of Environment and Climate Change, 2009; Singh and Frevert, 2002; Williams et al., 1998).

Unfortunately most of the applications listed in Table 2 are focused on salinity, nutrient management, water interception through afforestation, or ecosystem response modeling. Some models separate different land uses but do not differentiate tilled and stubble farming systems. Planning decisions about where investments and incentives may give best return for ecosystem services need models to optimise water quality and quantity that can be expected from different land uses at catchment scale. Rutherford et al. (2005), in developing a catchment scale contaminant model, identify two areas for future research. '*Firstly, current models lump soluble and particulate forms of nutrient together so even though they are transported along different flow pathways they are unable to quantify the effects of different hillslope riparian and in-stream interventions'*. Detailed process-based field scale models (e.g. for hillslope particulate delivery models and riparian filter traps) that can inform catchment scale models are needed. '*Secondly, measurements of ecosystem health that combine macroinvertebrate and fish species composition cannot be predicted by current catchment-scale models.'* Further model development is needed to align measures of ecosystem health with the capability of catchment scale models and to deal with the effects of multiple stressors.

4.3 Risk and sustainability

An Ecological Risk Assessment Framework or Bayesian Network modelling (Hart et al., 2007; Hart and Pollino, 2009) shows promise for application in specific catchments. Bayesian decision networks are graphical models used to establish the causal relationships between key factors (stubble farming versus conventional farming systems in this case) and effects on downstream water quality, aquatic life and ecosystem integrity.

The Sustainability Dashboard is a software application that can be used by farmers to generate a visual report of the key indicators of the condition of their land and associated business and includes a reflection on the ability of farmers to maintain ecosystem services which they define as clean water and sequestration of carbon.

They also include a water budget: '*where you get your water from and how much water coming onto your property actually leaves it.*' As noted by the Sage Farmer Group (2007) '*these measures seek to better understand the ecosystem impact of your water use'*.

The decision about the trade-off between the benefits of a leaky landscape (more water downstream) and a non-leaky one (more on-farm water retention and less downstream pollution) will need analysis at a local or regional level. Case studies are needed to demonstrate the off-farm optimisation of ecosystem services and on-farm profitability through partnerships between farmers, agronomists and catchment /natural resources managers and agencies.

4.4 Regional governance

In Australia, 54 Catchment Management Authorities and Natural Resource Management Regional Groups and Boards have been developed through government investment and allocated responsibility for safeguarding water quality and environmental assets though their degree of autonomy, capacity to raise funds and reporting relationships seems to be highly variable and sometimes uncertain (Campbell, 2005). In New South Wales the framework seems to be better established than in other states with an independent Natural Resources Commission that sets standards and targets at state level and audits Catchment Action Plans (NSW Natural Resources Commission, 2005).

In a recent review of Australia's natural resource management (NRM) governance systems Ryan et al. (2010) list ten principles for managing future challenges that include continuity and stability; subsidiarity (devolving decisions to the lowest level); integrated goal setting; a systems approach to match governance to the nature of the problem; investment in relationships across organisations; managing for resilience of both ecosystems and communities; development of knowledge and innovation; accountability and transparency; and adaptability. Notably 'holism' (planning to address whole systems) is advocated. '*All organisations and activities that impact on natural resources need to be considered. Within government, planning departments and planning decisions should be more included in NRM governance. Water plans and agencies need to be better integrated with land management plans and agencies'*. Similarly , in a recent review of the progress of Catchment Management Authorities in New South Wales, Commissioner John Williams comments that 'w*e now understand that the processes operating in a landscape are essential for providing goods and services - clean air, water, food, fibre and biodiversity - and that our management should be aiming to maintain the integrity of these processes, rather than return the landscape to an impractical pre-development state*' (NSW Natural Resources Commission, 2010a).

5. Conclusions

Links between land use and downstream water quality and ecosystem resilience are difficult to quantify because of the interaction of many confounding factors. Also substantial past investment in water treatment technology has enabled urban Australians to access safe water for drinking and industry, to some extent removing the pressures for greater investment in watershed protection.

However, many rural Australians are still dependent on healthy watersheds and rivers for water quality. There is also the threat of collapse in the state of some aquatic ecosystems that could damage aesthetics, biodiversity and resilience. Choice modelling shows that Australians value these features highly.

We suggest several approaches to optimise land use for water resource protection. These include adoption of appropriate indicators in State of the Environment reporting, development of models that separate the benefit and impact of different land uses, Bayesian risk-based network modelling to untangle complexities, demonstration case studies, and appropriate governance and planning to address land-water systems holistically.

The Sustainability Dashboard is commended as an approach to integration that has the advantage of being developed by farmers themselves. As noted by the Sage Farmer Group (2007) '*the provision of clean water and the maintenance of environmental flows and flooding regimes are important but there are no easily applied measures of water-based ecosystem services. Water balance is proposed as a proxy'*. The framework now needs to be populated with data.

Regional groups, such as Catchment Management Authorities, Regional Natural Resource Management Groups and community organisations such as Landcare are appropriate for integration and optimisation of land use that integrates both on-farm profitability and off-farm ecosystem service benefits and impacts. As noted in recent reviews (Campbell, 2005; Griffiths, 2009; NSW Natural Resources Commission, 2010b; Ryan et al., 2010) the capacity, authority and resourcing of these regional groups needs to be strengthened in Australia. It is encouraging to note that a recent report on the State of the Catchments in New South Wales (NSW Department of Environment Climate Change and Water, 2010[b]) provides condition and trends for land capability, and soil condition at sub-catchment level, including erosion, salinity, acidity, carbon and structure. Riverine ecosystem condition is also described in detail but the links to land management are not explicit.

Stubble farming systems are not generally considered separately from grazing or cropping using tilled systems in audits such as the National Land and Water Resources Audit and State of the Environment reporting. In view of the potential benefits of stubble farming systems this seems to be an obvious information gap. In this context the provision of ecosystem services by stubble farming systems needs to be recognised, quantified and valued.

In general water quality and quantity is expected to reflect land use management but the relationship is confounded by natural variation at larger scale. A catchment-based approach to landscape sustainability and resilience in Australia is advocated.

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