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Antipodean agricultural and resource economics at 60: natural resource management*

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Australian and New Zealand research on the economics of natural resource management (NRM) has a relatively short history. Defining NRM as including water, fisheries, agricultural land, nature conservation and forestry, 65 per cent of all Australasian journal articles in the area have been published since 2005. The most researched NRM issue is water, followed by fisheries and agricultural land. Most of the NRM issues with a high level of economic research are issues that have had major policy initiatives in place at around the time of the studies, highlighting the high policy relevance of most of the research. For each NRM issue, we identify important contributions that have been made by Australian economists. These include the design and implementation of well-functioning water markets, the provision of strong critiques of agricultural NRM programs, advice on the design and implementation of individual transferable quotas for fisheries and many more.

Key words: environmental economics, individual transferable quota, resource economics, soil conservation, water market.

1. Introduction

Commencing in the 1980s, management and conservation of natural resources (including land, fish, water and habitat) attracted growing policy and researcher attention in Australia, leading to an evolving set of national policy programs with investment of billions of dollars (Hajkowicz 2009; Lee and Ancev 2009). The philosophies, strategies, mechanisms and priorities of these programs have varied, and assessments of performance have reached mixed conclusions.

Australian and New Zealand economists working on these issues have made many important contributions. We have often provided cogent critiques of weak current policies and suggested practical solutions. We have worked closely with policy and management agencies, and also with other research disciplines, providing a framework for integration of information to inform decision-making. Management of natural resources has benefited from the implementation of programs based on economic principles.

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In this paper, we have two aims: (i) to summarise the level of research effort by economists in Australia and New Zealand on issues of natural resource management, looking at how that effort has varied over time in quantity and in allocation to different NRM issues; and (ii) to identify key contributions that economists have made in each area of natural resource management.

2. Patterns and emphases of research

Our first aim was to identify trends in Australian published research on the economics of NRM. We used the following procedure:

1. Define the scope of NRM to include management and conservation of land, water, marine resources, biodiversity and forests. Excluded were research on climate change and carbon sequestration, mining and environmental valuation.
2. Identify articles within that scope published in the *Australian Journal of Agricultural Economics*, the *Review of Marketing and Agricultural Economics* and the *Australian Journal of Agricultural and Resource Economics*, from 1952 to 2015.
3. For Australian or New Zealand authors with at least two articles from step 2, use Scopus to identify additional relevant articles that they have co-authored.

This process identified 634 papers, almost all in journals. In later sections of the paper where we identify key contributions, we include all types of publications, including conference papers, government reports and books.

Figure 1 and Tables 1–5 provide an overview of levels and relative emphases of Australian and New Zealand research on the economics of NRM since 1952. In the first three decades of the period, there was an average of less than one paper per year (Figure 1). From 1995, output grew rapidly, averaging 35 papers per year over the past decade. Almost two-thirds of all papers in the study set were published between 2005 and 2015. Most of the growth occurred in journals other than the three associated with the Australian Agricultural and Resource Economics Society.

Table 1 shows a breakdown of this body of research into subfields. The largest subfield by far was water. At the other extreme, forestry and nature conservation had very few publications. (See Supporting Information for a graph of numbers of publications in these subfields over time.)

In agriculture (Table 2), the main issues researched were soil salinity, soil conservation, land use and herbicide resistance. Notably, there was a boom in research into salinity in the 2000s, corresponding with a major national policy and the availability of significant research funding.

In fisheries (Table 3), the main issues researched were the economic performance or efficiency of various fishing strategies, individual transferable quotas (ITQs), marine reserves and governance. ITQs became a prominent

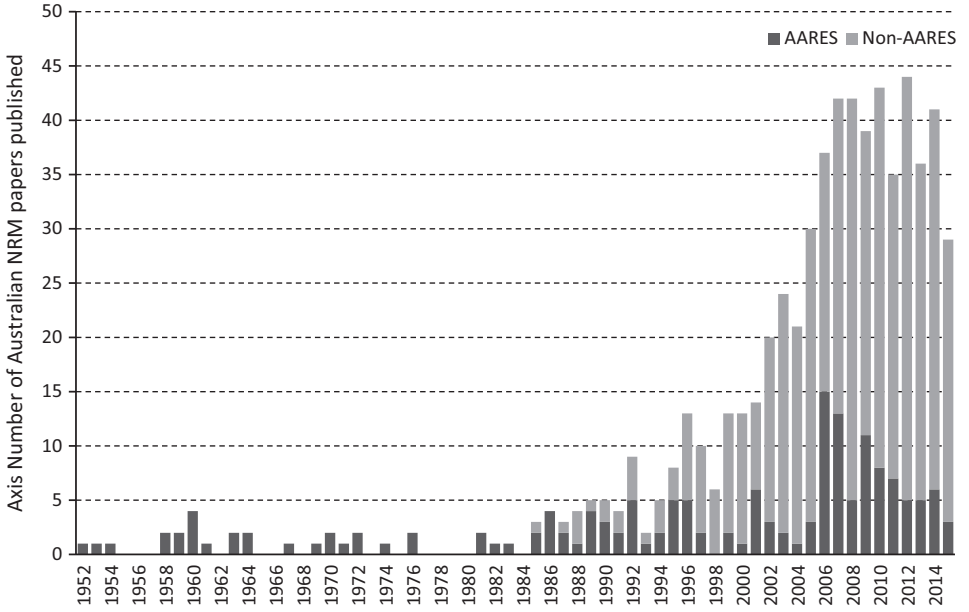

Figure 1 Number of Australian and New Zealand papers on the economics of natural resource management published per year ('AARES' indicates papers published in the *Australian Journal of Agricultural Economics*, the *Review of Marketing and Agricultural Economics* and the *Australian Journal of Agricultural and Resource Economics*.).

Table 1 Total number of Australian and New Zealand papers on the economics of natural resource management, 1952–2015, by subfield

Subfield	Number of papers
Water	347
Fisheries	162
Agriculture	155
Cross-cutting issue*	116
Nature conservation*	16
Forestry	13
Total	809

*Market-based instruments for nature conservation included in cross-cutting issues.

policy issue in the 1990s, whereas the research on marine reserves has been conducted almost entirely over the past decade – a time when it has been a prominent policy and political issue.

The most prominent issues researched in water economics (Table 4) have been water markets, issues related to irrigation, river salinity, water quality more generally, environmental water and issues related to community attitudes and behaviour. The dramatic growth in research on the economics of water after 2005 corresponds with a period of intense politics and policy development, no doubt fed in part by the millennium drought. Water markets and water rights are easily the most researched issue related to the economics

Table 2 Total number of Australian and New Zealand papers on the economics of natural resource management in agriculture, 1952–2015 by issue

Issue	Number of papers
Soil salinity	40
Soil conservation	32
Land use	22
Herbicide resistance	21
Environmental impacts of agriculture	17
Farmer adoption of NRM practices	9
Other	8
Land fragmentation	6
Total	155

Table 3 Total number of Australian and New Zealand papers on the economics of natural resource management in fisheries, 1952–2015 by issue

Issue	Number of papers
Strategy assessment and efficiency	36
Individual transferable quotas and rights	31
Marine reserves	22
Governance	17
Fishing capacity	11
Harvest controls and overharvesting	10
Bycatch and other environmental impacts	7
Community issues and behaviour	6
Other	22
Total	162

of NRM in Australia, reflecting the country's reputation as a world leader in the implementation of water markets.

In subsequent sections, we switch focus to identifying the main contributions of economists working on NRM. These contributions are presented in the context of contemporary developments and policies (See Supporting Information for contributions from cross-cutting papers, which are omitted from the paper for space reasons.).

3. Water

Prior to the 1970s, the dominant focus of water policy in Australia was to develop, expand and support profitable irrigated agriculture. After the 1970s, there was growing awareness of the impacts of water use for irrigation on the aquatic environment, including concerns about toxic blue-green algal blooms and salinity. Over time it came to be accepted that state governments had overallocated water licences to farmers. Musgrave (2008) described how economists (notably Bruce Davidson 1969) initially had great difficulty convincing the public and water agencies that ongoing expansion of irrigation was not in the public interest. Our eventual success in doing so was a major contribution to the Australian community.

Table 4 Total number of Australian and New Zealand papers on the economics of natural resource management in water, 1952–2015 by issue

Issue	Number of papers
Water market and water rights	107
Irrigation	40
River salinity	30
Environmental water	29
Community issues and behaviour	25
Water quality (not exclusively salinity)	22
Governance	17
Policy reform	13
Urban water	12
Politics and policy	11
Strategy evaluation	9
Groundwater	6
Climate change and water resources	5
Water buyback	5
Other	16
Total	347

Central to the reforms that followed was the establishment of a market for water within the Murray-Darling Basin (Crase *et al*. 2004). Relevant research included studies that clarified the definition of property rights for water (Randall 1981; Brennan and Scoccimarro 1999; Heaney and Beare 2001; Freebairn and Quiggin 2006), the unbundling of property rights to land and water (Bjornlund and O'Callaghan 2004), and the interaction between water markets and environmental outcomes (Connor and Perry 1999). The guidance of economists was central to the decision to establish a market, the creation of necessary institutions (Cummins and Watson 2012) and the design and implementation of market-related processes, including metering. Much of the input of economists occurred within the responsible organisations, such as the Murray-Darling Basin Commission, and sometimes in public debates, rather than through the pages of academic journals.

There are a number of overviews of the long process of water market development (e.g. Musgrave 2008; Rolfe 2008; National Water Commission 2011; Cummins and Watson 2012). These make it clear that the process of reform has been challenging intellectually and politically. Rolfe (2008) identifies three challenges for economists: the problem of deciding much water extraction to allow, especially when prices do not reflect the real economic value of water; the problem of initiating and designing the market trading system, especially where private property rights have to coexist with common property rights, or where there are substantial uncertainties; and the problem of imposing constraints on the system to limit potential market failure problems and account for sustainability. Cummins and Watson (2012) highlight a number of costly government failures at various points in the process, including the 4 per cent limit on trade of water out of Victoria, and the excessive reliance on infrastructure investment to generate water savings.

The latter strategy has recently been politically popular as an alternative to purchasing water from farmers, despite criticisms of its costliness and questions about its effectiveness at actually saving water (Gyles 2011). Nevertheless, the benefits flowing from the establishment of water markets have certainly been large – hundreds of millions of dollars per year, according to the National Water Commission (2011).

Beyond issues of markets and irrigation, the other main group of studies on the economics of water have focused on the environment: river salinity, other aspects of water quality and the allocation of water to environmental outcomes. In this area, there has been some strong criticism from economists about the success and cost-effectiveness of government investments (e.g. Lee and Ancev 2009; Pannell and Roberts 2010). Economic research into river salinity peaked in the 2000s, at the same time as research into soil salinity, both being targets for the *National Action Plan for Salinity and Water Quality* (NAP) from 2001. River salinity had previously been targeted by a *Salinity and Drainage Strategy* of the Murray-Darling Basin Commission in 1989, and the *Basin Salinity Management Strategy* in 2001. These strategies were much more successful at reducing river salinity than was the NAP, primarily because they relied on engineering approaches, whereas the latter relied on land-use change. Key economic research on river salinity included studies of the interaction between salinity and water use for irrigation (e.g. Nordblom *et al.* 2006; Adamson *et al.* 2007), and the interaction between river salinity and water markets (e.g. Connor *et al.* 2008a).

There has also been economic research on other aspects of water quality, particularly nutrients and sediment. In Australia, concerns about the Great Barrier Reef have been a prompt for policy initiatives, motivating a range of economics research (e.g. Greiner and Miller 2008). Other Australian work has looked at nutrients and sediment in rivers (Doole *et al.* 2013) or lakes (Roberts *et al.* 2012). In New Zealand, water quality in inland water bodies has become a major concern of policy over the past decade, again supported by a range of economic studies (e.g. Cullen *et al.* 2006; Kerr and Lock 2010). A message from some of this work is that improving water quality through changes in land management within the relevant catchment can be very costly, so that policy targets need to be considered carefully to ensure that they are feasible and worthwhile.

Finally, an element of Australian policy has been the acquisition of water rights for environmental purposes (Lane-Miller *et al.* 2013). The Commonwealth Environmental Water Holder (CEWH) is now the largest holder of water rights in Australia. As at 31 May 2016, the CEWH had holdings totalled 2 400 000 ML of registered entitlements with a long-term average annual yield of 1 700 000 ML (https://www.environment.gov.au/node/18963 accessed 19 July 2016). Economists have researched a number of different aspects of environmental water, including the opportunity costs to irrigators (e.g. Scoccimarro *et al.* 1997; Wheeler *et al.* 2014), and strategies for acquiring water (e.g. Qureshi *et al.* 2007). We observe that, while economists

have assisted governments to acquire environmental water efficiently (by our support for water markets), concerns have been expressed about the capacity of government to allocate this water well. There is scope for economists to make greater contributions to these allocation decisions.

4. Agriculture

Prior to the 1980s, the focus of agricultural policy was to develop the industry. There were few Australian or New Zealand papers on the economics of agricultural NRM. An early landmark was *The Northern Myth* by Bruce Davidson (1965), which highlighted the follies of poorly considered agricultural development in the north of Australia. His insights were sharp and still have relevance as northern agricultural development is again a policy issue.

Interest in the economics of soil degradation and soil conservation in Australia grew in the 1990s, coinciding with the creation of the National Landcare Program. During this period, Jack Sinden at the University of New England publishing work on a range of related issues, including community support for conservation, the influence of conservation on farm land values (King and Sinden 1988) and the damage costs of land degradation (Sinden *et al*. 1990).

A key contribution of papers published in this era was to introduce some economic realism into a debate that was otherwise somewhat idealistic and/or politicised (e.g. Chisholm and Dumsday 1987). Notable in this respect was Tony Chisholm's Presidential Address for AARES in 1991 (Chisholm 1992), the Society's first presidential address to focus primarily on NRM. Chisholm pointed out that, despite widely expressed concerns about soil erosion, Australian agriculture had achieved favourable productivity growth over the previous four decades.

Another important contribution to increasing realism came from studies on adoption of NRM practices by farmers (e.g. Cary and Wilkinson 1997; Pannell *et al*. 2006). These highlighted that adoption of NRM practices is a complex and multifaceted issue but that the economic motivations of farmers are a crucial element.

Pannell identified that Landcare and other related programs had an over-reliance on extension to promote land conservation practices to farmers and developed a widely used framework to assist managers and policymakers identify the most appropriate mechanism (including extension) for encouraging land-use change (Pannell 2008).

Following widespread adoption of zero tillage by crop farmers, concerns about soil conservation diminished somewhat, and its prominence as a topic of research by economists also decreased. However, it was replaced in the 1990s and 2000s by soil salinity and herbicide resistance.

There had been some research on the economics of soil salinity in the 1980s (e.g. Greig and Devonshire 1981), but this effort grew substantially in the

1990s and 2000s, reflecting the high public profile of salinity, the creation of the NAP in 2001 and the availability of dedicated research funding from certain funders.

Various researchers studied the farm-level economics of particular salinity management practices (e.g. Jones and Marshall 1992; Cacho *et al.* 2001; Kingwell *et al.* 2003). A key message from this research was that, in many locations, the available farming practices for mitigating salinity were not sufficiently profitable to attract sufficient adoption by farmers to effectively address the problem.

Romy Greiner's catchment modelling research for the Liverpool Plains in New South Wales (e.g. Greiner 1998) was the largest body of salinity economics research prior to the escalation of salinity as a policy issue. She showed that internalisation of the salinity externality changed farm management significantly. This contrasted with the work of Pannell *et al.* (2001) in Western Australia, who found that internalising salinity externalities would have little impact on farm management, indicating that the extent of market failure was minimal.

Following the perceived success of water markets in Australia, salinity was used as a vehicle for experimenting with market-based policy instruments, in the NAP. However, these experiments were peripheral to the national policy and the various state policies. The core of the approach used in all cases was an evolution from the Landcare Program of the 1990s, with a dominant reliance on extension and volunteerism. Pannell (2001) argued that the existing programs were poorly designed; they needed to adopt a more targeted and evidence-based approach to land-use change and to invest in technology development. This critique influenced the establishment of the Cooperative Research Centre for Plant-Based Management of Dryland Salinity and may have contributed to a subsequent decline in the political priority of salinity.

After salinity, the next most researched NRM issue by Australian economists in the 1990s and 2000s was herbicide resistance. Although this is a national issue (and indeed an important international issue), the economic research was predominantly in Western Australia, with all 21 published journal articles coming from that state, under the leadership of David Pannell. Many of the publications in this body of work evaluated particular systems or strategies for managing or delaying herbicide resistance (e.g. Doole and Pannell 2008). A key finding was that pre-emptive actions to prevent the onset of herbicide resistance are not economically beneficial to farmers in most cases (Pannell and Zilberman 2001), except in the case of glyphosate (Weersink *et al.* 2005). Once resistance has occurred, the economics strongly favour substantial changes in weed management (e.g. Monjardino *et al.* 2004). An important contribution was the development of the Resistance and Integrated Management (RIM) model (Pannell *et al.* 2004), which has been used by thousands of farmers to test resistance management strategies, and remains actively maintained and supported (Lacoste and Powles 2014).

5. Fisheries

Australian fisheries economists have demonstrated positive net benefits from managing fisheries to economic objectives, rather than according to biological thresholds (e.g. Norman-Lopez and Pascoe 2011; Grafton *et al*. 2012). Early policies for fisheries management in Australia tended to rely on input controls, including entry restrictions in the Western rock lobster fishery in 1963 (Meany 2011) and in the northern prawn fishery in 1977 (Kompas *et al*. 2010). However, these programs promote inefficient levels of investment in unregulated inputs (Kompas *et al*. 2004). 'Buyback schemes' have been used try to reduce fishing capacity (Grafton and Nelson 2007), but recent research has shown that in some cases they can increase fishing pressure through removing the least efficient operators first (e.g. Pascoe *et al*. 2012).

From the mid-1980s, rights-based management was adopted more quickly in Australasia than in most countries. An individual transferable quota (ITQ) scheme was established for the southern blue fin tuna fishery in 1984 (Kennedy and Watkins 1985), while New Zealand became the first country to adopt ITQs as national policy in 1986 (Doole 2005). Subsequent studies for ITQs in the region have had a number of key challenges, including incentives to discard bycatch (Pascoe *et al*. 2010), consideration of indigenous take (van Putten *et al*. 2013), potential consolidation of harvesting firms (Abayomi 2012) and potential for stock collapse if population assessments are incorrect (Campbell *et al*. 1993; Doole 2005).

Another mechanism of interest in recent years has been area closures. Sizing and locating these areas is subject to high uncertainty and complexity, but it has been shown that they can improve the stability and level of fishery profit (Grafton *et al*. 2009), particularly when there are substantial spillovers to adjacent fisheries (Yamazaki *et al*. 2010) and when stocks are severely depleted (Buxton *et al*. 2014). However, some research indicates that achieving such benefits is not straightforward (Greenville and MacAulay 2007; Abecasis *et al*. 2015), perhaps explaining ongoing opposition to marine reserves by industry. On the other hand, the ecological and tourism benefits of marine reserves can be large (Kragt *et al*. 2009; Vianna *et al*. 2012).

The need to consider the holistic context of fisheries management is now recognised; delivering benefits from conserved ecosystems and enhanced livelihoods 'requires much more than preventing overfishing' (Grafton *et al*. 2008; p. 630). For example, it needs an understanding of stakeholder goals for management (e.g. Pascoe *et al*. 2009). Taking this need seriously, an attempt was made at self-governance within the New Zealand fishing industry, but this met limited success due to high transaction costs associated with self-organisation (Townsend 2010).

Australian economists have played a pivotal role in the development and application of economic theory in the context of fishery management. Overall, the patterns of research that are observed are driven in response to practical problems, but are influenced by international trends. A key example

is the focus on rights-based management over the last twenty years. There is increasing recognition that single policy mechanisms will seldom be sufficient to meet societal goals in wild fisheries, given the inherent complexity of marine ecosystems (Yamazaki *et al.* 2015).

6. Forestry

The harvest of native and plantation forests has received less attention from economists than other larger primary industries, such as agriculture and mining. Important research includes work on regional and national development (Johnson 1985), conflict between stakeholders (Ananda and Herath 2003), biodiversity (Lindenmayer *et al.* 2015), threats posed by fire (Spring *et al.* 2008) and the social context of forest management (Dare *et al.* 2011).

Australia and New Zealand maintain important agricultural industries that have off-site impacts. The planting of native and exotic forests is a key mitigation strategy for offsetting many of these losses (e.g. salinity, sediment, carbon). Consistent attention has been paid to the external benefits resulting from the establishment of these forests. These include the utilisation of forests to reduce salinisation rates (Nordblom *et al.* 2010), provide habitat for endangered fauna (Spring and Kennedy 2005), reduce nutrient and sediment loss from land (Doole *et al.* 2013), provide for recreational and tourism values (Dhakal *et al.* 2012), and offset greenhouse gas emissions (Polglase *et al.* 2013). Nevertheless, recent work also highlights the need to consider the detrimental off-site impacts of plantation forests, such as declines in water yield (Nordblom *et al.* 2015).

7. Nature conservation

Private landholders manage more than half of the land areas of Australia and New Zealand, with broadscale clearance of land being widely promoted by early government policy focused on economic development in both countries. The clearance of indigenous forest on this land has had profound effects on the environment, but especially on biodiversity (Lindenmayer *et al.* 2012), so conservation of native vegetation has been an ongoing interest of economists (e.g. Tisdell 1985).

Over the past 25 years, a significant proportion of environmental expenditure in Australia has been allocated to farmers for conservation activity, including actions to protect biodiversity (Connor *et al.* 2008b). In many cases, grants to farmers were set at standard rates for particular practices, raising the likelihood that some payments were inefficiently high. Efforts to negotiate efficient payment rates would likely be hampered by asymmetric information between farmers and agencies regarding the true costs of biodiversity conservation (Stoneham *et al.* 2003). This recognition stimulated a major effort to test and establish market-based instruments (particularly conservation tenders) as an efficient approach for achieving biodiversity

conservation (Doole *et al*. 2014). Indeed, Australia has played an important role as a testing ground for the use of market-based instruments for biodiversity conservation. Early groundwork was laid by Mike Young's team at CSIRO (Binning and Young 1999), Bardsley (2003) and Cason and Gangadharan (2004), and subsequent important work included Windle and Rolfe (2008), Whitten *et al*. (2013), and Schilizzi and Latacz-Lohmann (2013).

Research has demonstrated that there are benefits in the targeting of conservation investments (Polyakov *et al*. 2015), reinforcing the benefits of using conservation tenders. Nevertheless, the use of conservation tenders peaked around 2010–2011 and has since fallen, probably due to their need for continued investment, perceived high transactions costs, low participation rates in many cases, dissatisfaction with assessment metrics, the scarcity of people experienced in their design and implementation, and concerns about the potential for crowding out of private investment (Blackmore and Doole 2013).

There remains potential for broader application of economic principles in nature conservation. However, there are inherent difficulties with doing so, particularly with respect to the development of objectives for management, the assessment of benefits and costs, and delineating the impacts of management. This may partly explain the relatively small number of publications by economists in this area. Interestingly, the neglect of this area by economists (other than the work on market-based instruments) appears to have resulted in ecologists stepping in to undertake much research with an economic dimension to it, particularly ecologists associated with Hugh Possingham at the University of Queensland (e.g. Carwardine *et al*. 2010; Wilson *et al*. 2010; Possingham *et al*. 2012).

8. Conclusion

Economists have made major contributions to the management of natural resources in Australia and New Zealand over the past 25 years or so. The establishment of a successful water market in the Murray-Darling Basin (and smaller markets elsewhere) and the introduction of individual tradeable quotas for various fish stocks stand out as clear examples where the application of economic ideas and specific research has generated major benefits. Within agriculture, economic research has positively influenced management and policy in a number of areas, including soil salinity and soil conservation.

Nevertheless, in many aspects of natural resource management, economics has not been as influential as it could have been, partly due to a lack of economics expertise in the sector (Seymour *et al*. 2008). In some cases, conservation-minded stakeholders are actively opposed to the consideration of economics in decision-making (Rogers *et al*. 2015). But it is also beholden on economists to undertake research that is highly relevant to current issues,

to address the specific questions of managers and policymakers, to communicate the results widely and well, and to collaborate well with stakeholders and other disciplines. There are, of course, plenty of examples where these things occur, but also examples where they do not. In all of the areas reviewed here, there are many important research gaps remaining, so we expect to see NRM continue to be the subject of active economic research.

A related study, focussing on American research on natural resource economics, was undertaken by Lichtenberg *et al.* (2010). Although somewhat different in scope and approach, like us they observed a research agenda driven by policy, an interdisciplinary orientation and an emphasis on quantitative analysis. Interestingly, of the three long-standing and pressing challenges they identified, two have been amongst the success stories in Australia and New Zealand: the design of institutions for managing water resources and management of fisheries.

References

Abayomi, K. (2012). Using conditional Lorenz curves to examine consolidation in New Zealand commercial fishing, *Marine Resource Economics* 27, 303–321.

Abecasis, D., Afonso, P. and Erzini, K. (2015). Toward adaptive management of coastal MPAs: the influence of different conservation targets and costs on the design of no-take areas, *Ecological Informatics* 30, 263–270.

Adamson, D., Mallawaarachchi, T. and Quiggin, J. (2007). Water use and salinity in the Murray-Darling Basin: a state-contingent model, *Australian Journal of Agricultural and Resource Economics* 51(3), 263–281.

Ananda, J. and Herath, G. (2003). Incorporating stakeholder values into regional forest planning: a value function approach, *Ecological Economics* 45, 75–90.

Bardsley, P. (2003). Missing environmental markets and the design of "Market Based Instruments". Department of Economics, University of Melbourne, Research Paper number 891.

Binning, C. and Young, M.D. (1999). Talking to the taxman about nature conservation: Proposals for the introduction of incentives for the protection of high conservation value native vegetation. National Research and Development Program for the Rehabilitation, Management and Conservation of Remnant Vegetation, Research Report 4/99, Environment Australia, Canberra.

Bjornlund, H. and O'Callaghan, B. (2004). Property implications of the separation of land and water rights, *Pacific Rim Property Research Journal* 10(1), 54–78.

Blackmore, L. and Doole, G.J. (2013). Drivers of landholder participation in tender programs for Australian biodiversity conservation, *Environmental Science and Policy* 33, 143–153.

Brennan, D. and Scoccimarro, M. (1999). Issues in defining property rights to improve Australian markets, *Australian Journal of Agricultural and Resource Economics* 43(1), 69–89.

Buxton, C.D., Hartmann, K., Kearney, R. and Gardner, C. (2014). When is spillover from marine reserves likely to benefit fisheries?, *PLoS One* 9(9), e107032. doi:10.1371/journal.pone.0107032.

Cacho, O., Greiner, R. and Fulloon, L. (2001). An economic analysis of farm forestry as a means of controlling dryland salinity, *Australian Journal of Agricultural and Resource Economics* 45(2), 233–256.

Campbell, H.F., Hand, A.J. and Smith, A.D.M. (1993). A bioeconomic model for management of orange roughy stocks, *Marine Resource Economics* 8, 155–172.

Carwardine, J., Wilson, K.A., Hajkowicz, S.A., Smith, R.J., Klein, C.J., Watts, M. and Possingham, H.P. (2010). Conservation planning when costs are uncertain, *Conservation Biology* 24, 1529–1537.

Cary, J.W. and Wilkinson, R.L. (1997). Perceived profitability and farmers' conservation behaviour, *Journal of Agricultural Economics* 48, 13–21.

Cason, T.N. and Gangadharan, L. (2004). Auction design for voluntary conservation programs, *American Journal of Agricultural Economics* 86(5), 1211–1217.

Chisholm, A.H. (1992). Australian agriculture: a sustainability story, *Australian Journal of Agricultural Economics* 36(1), 1–29.

Chisholm, A.H. and Dumsday, R. (1987). *Land Degradation: Problems and Policies*. Cambridge University Press, Cambridge.

Connor, J.D. and Perry, G.M. (1999). Analyzing the potential for water quality externalities as the result of market water transfers, *Water Resources Research* 35(9), 2833–2839.

Connor, J., Schwabe, K. and King, D. (2008a). Irrigation to meet growing food demand with climate change, salinity and water trade, *WIT Transactions on Ecology and the Environment* 112, 43–52.

Connor, J.D., Ward, J.R. and Bryan, B. (2008b). Exploring the cost effectiveness of land conservation auctions and payment policies, *Australian Journal of Agricultural and Resource Economics* 52, 303–319.

Crase, L., Pagan, P. and Dollery, B. (2004). Markets as a vehicle for reforming water resource allocation in the Murray-Darling Basin of Australia. *Water Resources Research* 40(8), W08S051–W08S510.

Cullen, R., Hughey, K. and Kerr, G. (2006). New Zealand freshwater management and agricultural impacts, *Australian Journal of Agricultural and Resource Economics* 50(3), 327–346.

Cummins, T. and Watson, A. (2012). A hundred-year policy experiment: the Murray-Darling Basin in Australia, in Quiggin, J., Mallawaarachchi, T. and Chambers, S. (eds), *Water Policy Reform: Lessons in Sustainability From the Murray-Darling Basin*. Edward Elgar, Cheltenham, UK and Northampton, MA, pp. 9–36.

Dare, M., Schirmer, J. and Vanclay, F. (2011). Does forest certification enhance community engagement in Australian plantation management?, *Forestry Policy and Economics* 13, 328–337.

Davidson, B.R. (1965). *The Northern Myth: Limits to Agricultural and Pastoral Development in Tropical Australia*. Melbourne University Press, Melbourne.

Davidson, B.R. (1969). *Australia, Wet or Dry?: The Physical and Economic Limits to the Expansion of Irrigation*. Melbourne University Press, Melbourne.

Dhakal, B., Yao, R.T., Turner, J.A. and Barnard, T.D. (2012). Recreational users' willingness to pay and preferences for changes in planted forest features, *Forest Policy and Economics* 17, 34–44.

Doole, G.J. (2005). Optimal management of the New Zealand longfin eel (*Anguilla dieffenbachii*), *Australian Journal of Agricultural and Resource Economics* 49, 395–411.

Doole, G.J. and Pannell, D.J. (2008). Role and value of including lucerne (*Medicago sativa* L.) phases in crop rotations for the management of herbicide-resistant *Lolium rigidum* in Western Australia, *Crop Protection* 27, 497–504.

Doole, G., Vigiak, O., Roberts, A.M. and Pannell, D.J. (2013). Cost-effective strategies to mitigate multiple pollutants in an agricultural catchment in North-Central Victoria, Australia, *Australian Journal of Agricultural and Resource Economics* 57(3), 441–460.

Doole, G.J., Blackmore, L. and Schilizzi, S. (2014). Determinants of cost-effectiveness in tender and offset programs for Australian biodiversity conservation, *Land Use Policy* 36, 23–32.

Freebairn, J. and Quiggin, J. (2006). Water rights for variable supplies, *Australian Journal of Agricultural and Resource Economics* 50(3), 295–312.

Grafton, R.Q. and Nelson, H.W. (2007). The effects of buybacks in the British Columbia salmon fishery, in Curtis, R. and Squires, D. (eds), *Fisheries Buybacks*. Blackwell, Malden, pp. 191–202.

Grafton, R.Q., Hilborn, R., Ridgeway, L., Squires, D., Williams, M., Garcia, S., Groves, T., Joseph, J., Kelleher, K., Kompas, T., Libecap, G., Lundin, C.G., Makino, M., Matthiasson, T., McLoughlin, R., Parma, A., San Martin, G., Satia, B., Schmidt, C., Tait, M. and Zhang, L. (2008). Positioning fisheries in a changing world, *Marine Policy* 42, 630–634.

Grafton, R.Q., Kompas, T. and Ha, P.V. (2009). Cod today and none tomorrow: the economic value of a marine reserve, *Land Economics* 85, 454–469.

Grafton, R.Q., Kompas, T., Che, T.N., Chu, L. and Hillborn, R. (2012). BMEY as a fisheries management target, *Fish and Fisheries* 13, 303–312.

Greenville, J. and MacAulay, G. (2007). Bioeconomic analysis of protected area use in fisheries management, *Australian Journal of Agricultural and Resource Economics* 51, 403–424.

Greig, P.J. and Devonshire, P.G. (1981). Tree removals and saline seepage in Victorian catchments: some hydrologic and economic results, *Australian Journal of Agricultural Economics* 25(2), 134–148.

Greiner, R. (1998). Catchment management for dryland salinity control: model analysis for the liverpool plains in New South Wales, *Agricultural Systems* 56(2), 225–251.

Greiner, R. and Miller, O. (2008). Reducing diffuse water pollution by tailoring incentives to region specific requirements: empirical study for the Burdekin River basin (Australia), *WIT Transactions on Ecology and the Environment* 108, 31–42.

Gyles, O. (2011). More water for everything? The problem of bogus water savings in northern Victoria, Australia, Paper presented at the 55th Annual Conference of the Australian Agricultural and Resource Economics Society, February 8–11, 2011, Melbourne, Australia.

Hajkowicz, S. (2009). The evolution of Australia's natural resource management programs: towards improved targeting and evaluation of investments, *Land Use Policy* 26, 471–478.

Heaney, A. and Beare, S. (2001). Water trade and irrigation: defining property rights to return flows, *Australian Commodities* 8(2), 339–348.

Johnson, D.T. (1985). The short-term economic effects of environmental constraints on forest industries, *Review of Marketing and Agricultural Economics* 53, 103–124.

Jones, R. and Marshall, G. (1992). Land salinisation, waterlogging and the agricultural benefits of a surface drainage scheme in benerembah irrigation district, *Review of Marketing and Agricultural Economics* 60(2), 173–189.

Kennedy, J.O.S. and Watkins, J.W. (1985). The impact of quotas on the southern bluefin tuna fishery, *Australian Journal of Agricultural Economics* 29, 63–83.

Kerr, S. and Lock, K. (2010). Improving lake water quality through a nutrient trading system: the case of New Zealand's Lake Rotorua, in Claus, I., Gemmell, N., Harding, M. and White, D. (eds), *Tax Reform in Open Economies: International and Country Perspectives*. Edward Elgar, Cheltenham UK and Northampton MA, pp. 241–262.

King, D.A. and Sinden, J.A. (1988). Influence of conservation on farm land values, *Land Economics* 64(3), 242–255.

Kingwell, R., Hajkowicz, S., Young, J., Patton, D., Trapnell, L., Edward, A., Krause, M. and Bathgate, A. (2003). *Economic Evaluation of Salinity Management Options in Cropping Regions of Australia*. Grains Research and Development Corporation, Canberra.

Kompas, T., Che, T.N. and Grafton, R.Q. (2004). Technical efficiency effects of input controls: evidence from Australia's banana prawn fishery, *Applied Economics* 36, 1631–1641.

Kompas, T., Dichmont, C.M., Punt, A.E., Deng, A., Che, T.N., Bishop, J., Gooday, P., Ye, Y. and Zhou, S. (2010). Maximizing profits and conserving stocks in the Australian Northern Prawn fishery, *Australian Journal of Agricultural and Resource Economics* 54, 281–299.

Kragt, M.E., Roebeling, P.C. and Ruijs, A. (2009). Effects of Great Barrier Reef degradation on recreational reef-trip demand: a contingent behaviour approach, *Australian Journal of Agricultural and Resource Economics* 53, 213–229.

Lacoste, M. and Powles, S. (2014). Upgrading the RIM model for improved support of integrated weed management extension efforts in cropping systems, *Weed Technology* 28(4), 703–720.

Lane-Miller, C.C., Wheeler, S., Bjornlund, H. and Connor, J. (2013). Acquiring water for the environment: lessons from natural resources management, *Journal of Environmental Policy and Planning* 15(4), 513–532.

Lee, L. and Ancev, T. (2009). Two decades of Murray-Darling water management: a river of funding, a trickle of achievement, *Agenda* 16(1), 5–23.

Lichtenberg, E., Shortle, J., Wilen, J. and Zilberman, D. (2010). Natural resource economics and conservation: contributions of agricultural economics and agricultural economists, *American Journal of Agricultural Economics* 92(2), 469–486.

Lindenmayer, D., Cunningham, S. and Young, A. (eds) (2012). *Land Use Intensification: Effects On Agriculture, Biodiversity And Ecological Processes*. CRC Press, Boca Raton.

Lindenmayer, D., Messier, C., Paquette, A. and Hobbs, R.J. (2015). Managing tree plantations as novel socioecological systems: Australian and North American perspectives, *Canadian Journal of Forest Research* 45, 1426–1432.

Meany, T.F. (2011). Limited entry in the Western Australian rock lobster and prawn fisheries: an economic evaluation, *Journal of the Fisheries Research Board of Canada* 36, 789–798.

Monjardino, M., Pannell, D.J. and Powles, S. (2004). Economic value of pasture phases in the integrated management of annual ryegrass and wild radish in a Western Australian farming system, *Australian Journal of Experimental Agriculture* 44(3), 265–271.

Musgrave, W.F. (2008). Historical development of water resources in Australia: irrigation policy in the Murray-Darling Basin, in Crase, L. (ed.), *Water Policy in Australia: The Impact of Change and Uncertainty*. Resources for the Future, Washington DC, pp. 28–43.

National Water Commission (2011). *Water Markets in Australia: A Short History*. National Water Commission, Canberra.

Nordblom, T., Hume, I., Bathgate, A. and Reynolds, M. (2006). Mathematical optimisation of drainage and economic use for target water and salt yields, *Australian Journal of Agricultural and Resource Economics* 50(3), 381–402.

Nordblom, T., Christy, B., Finlayson, J., Roberts, A. and Kelly, J. (2010). Least cost land-use changes for targeted catchment salt load and water yield impacts in south eastern Australia, *Agricultural Water Management* 97, 811–823.

Nordblom, T.L., Hume, I.H., Finlayson, J.D., Pannell, D.J., Holland, J.E. and McClintock, A.J. (2015). Distributional consequences of upstream tree plantations on downstream water users in a public-private benefit framework, *Agricultural Systems* 139, 271–281.

Norman-Lopez, A. and Pascoe, S. (2011). Net economic effects of achieving maximum economic yield in fisheries, *Marine Policy* 35, 489–495.

Pannell, D.J. (2001). Dryland salinity: economic, scientific, social and policy dimensions, *Australian Journal of Agricultural and Resource Economics* 45, 517–546.

Pannell, D.J. (2008). Public benefits, private benefits, and policy intervention for land-use change for environmental benefits, *Land Economics* 84(2), 225–240.

Pannell, D.J. and Roberts, A.M. (2010). The National Action Plan for Salinity and Water Quality: a retrospective assessment, *Australian Journal of Agricultural and Resource Economics* 54(4), 437–456.

Pannell, D.J. and Zilberman, D. (2001). Economic and sociological factors affecting growers' decision making on herbicide resistance, in Shaner, D.L. and Powles, S.B. (eds), *Herbicide Resistance and World Grains*. CRC Press, Boca Raton, pp. 251–277.

Pannell, D.J., McFarlane, D.J. and Ferdowsian, R. (2001). Rethinking the externality issue for dryland salinity in Western Australia, *Australian Journal of Agricultural and Resource Economics* 45(3), 459–475.

Pannell, D.J., Stewart, V., Bennett, A., Monjardino, M., Schmidt, C. and Powles, S.B. (2004). RIM: a Bioeconomic model for integrated weed management of *Lolium rigidum* in Western Australia, *Agricultural Systems* 79(3), 305–325.

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F. and Wilkinson, R. (2006). Understanding and promoting adoption of conservation practices by rural landholders, *Australian Journal of Experimental Agriculture* 46(11), 1407–1424.

Pascoe, S., Proctor, W., Wilcox, C., Innes, J., Rochester, W. and Dowling, N. (2009). Stakeholder objective preferences in Australian Commonwealth managed fisheries, *Marine Policy* 33, 750–758.

Pascoe, S., Innes, J., Holland, D., Fina, M., Thebaud, O., Townsend, R., Sanchirico, J., Arnason, R., Wilcox, C. and Hutton, T. (2010). Use of incentive-based management systems to limit bycatch and discarding, *International Review of Environmental and Resource Economics* 4, 123–161.

Pascoe, S., Coglan, L., Punt, A.E. and Dichmont, C.M. (2012). Impacts of vessel capacity reduction programmes on efficiency in fisheries: the case of Australia's multispecies northern prawn fishery, *Journal of Agricultural Economics* 63, 425–443.

Polglase, P.J., Reeson, A., Hawkins, C.S., Paul, K.I., Siggins, A.W., Turner, J., Crawford, D.F., Jovanovic, T., Hobbs, T.J., Opie, K., Carwardine, J. and Almeida, A. (2013). Potential for forest carbon plantings to offset greenhouse emissions in Australia: economics and constraints to implementation, *Climatic Change* 121, 161–175.

Polyakov, M., Pannell, D.J., Chalak, M., Park, G., Roberts, A. and Rowles, A.D. (2015). Restoring native vegetation in an agricultural landscape: spatial optimization for woodland birds, *Land Economics* 91(2), 252–271.

Possingham, H.P., Wintle, B.A., Fuller, R.A. and Joseph, L.N. (2012). The conservation return on investment from ecological monitoring, in Lindenmayer, D. and Gibbons, P. (Ed.), *Biodiversity Monitoring in Australia*, CSIRO, Melbourne, Australia, pp. 49–61.

van Putten, I., Lalancette, A., Bayliss, P., Dennis, D., Hutton, T., Norman-Lopez, A., Pascoe, S., Plaganyi, E. and Skewes, T. (2013). A Bayesian model of factors influencing participation in the Torres Strait tropical rock lobster fishery, *Marine Policy* 37, 96–105.

Qureshi, M.E., Connor, J., Kirby, M. and Mainuddin, M. (2007). Economic assessment of acquiring water for environmental flows in the Murray basin, *Australian Journal of Agricultural and Resource Economics* 51(3), 283–303.

Randall, A. (1981). Property entitlements and pricing policies for a maturing water economy, *Australian Journal of Agricultural Economics* 25(3), 195–220.

Roberts, A.M., Pannell, D.J., Doole, G. and Vigiak, O. (2012). Agricultural land management strategies to reduce phosphorus loads in the Gippsland Lakes, *Australia, Agricultural Systems* 106(1), 11–22.

Rogers, A.A., Kragt, M.E., Gibson, F.L., Burton, M.P., Petersen, E.H. and Pannell, D.J. (2015). Non-market valuation: usage and impacts in environmental policy and management in Australia, *Australian Journal of Agricultural and Resource Economics* 59(1), 1–15.

Rolfe, J. (2008). Water trading and market design, in Crase, L. (ed), *Water Policy in Australia: The Impact of Change and Uncertainty*. Resources for the Future, Washington, DC, pp. 202–215.

Schilizzi, S. and Latacz-Lohmann, U. (2013). Conservation tenders: linking theory and experiments for policy assessment, *Australian Journal of Agricultural and Resource Economics* 57(1), 15–37.

Scoccimarro, M., Beare, S. and Brennan, D. (1997). The Snowy River: opportunity costs of introduction environmental flows, *Australian Commodities* 4(1), 67–78.

Seymour, E., Pannell, D., Roberts, A., Marsh, S. and Wilkinson, R. (2008). Decision-making by regional bodies for natural resource management in Australia: current processes and capacity gaps, *Australasian Journal of Environmental Management* 15(4), 211–221.

Sinden, J.A., Sutas, A.R. and Yapp, T.P. (1990). Damage costs of land degradation: an Australian perspective, in Dixon, J.A., James, D.E. and Sherman, P.B. (eds), *Dryland Management: Economic Case Studies*. Earthscan, London, pp. 265–281.

Spring, D.A. and Kennedy, J.O.S. (2005). Existence value and optimal timber-wildlife management in a flammable multi-stand forest, *Ecological Economics* 55, 365–379.

Spring, D.A., Kennedy, J.O.S., Lindenmayer, D.B., McCarthy, M.A. and Nally, R.M. (2008). Optimal management of a flammable multi-stand forest for timber production and maintenance of nesting sites for wildlife, *Forest Ecology and Management* 255, 3857–3865.

Stoneham, G., Chaudhri, V., Ha, A. and Strappazzon, L. (2003). Auctions for conservation contracts: an empirical examination of Victoria's BushTender trial, *Australian Journal of Agricultural and Resource Economics* 47, 477–500.

Tisdell, C.A. (1985). Conserving and planting trees on farms: lessons from Australian cases, *Review of Marketing and Agricultural Economics* 53(3), 185–194.

Townsend, R.E. (2010). Transactions costs as an obstacle to fisheries self-governance in New Zealand, *Australian Journal of Agricultural and Resource Economics* 54, 301–320.

Vianna, G.M.S., Meekan, M.G., Pannell, D.J., Marsh, S.P. and Meeuwig, J.J. (2012). Socio-economic and community benefits from shark diving by tourists in Palau: a sustainable use of reef shark populations, *Biological Conservation* 145(1), 267–277.

Weersink, A., Llewellyn, R.S. and Pannell, D.J. (2005). Economics of pre-emptive management to avoid weed resistance to glyphosate in Australia, *Crop Protection* 24, 659–664.

Wheeler, S.A., Zuo, A. and Bjornlund, H. (2014). Investigating the delayed on-farm consequences of selling water entitlements in the Murray-Darling Basin, *Agricultural Water Management* 145, 72–82.

Whitten, S.M., Reeson, A., Windle, J. and Rolfe, J. (2013). Designing conservation tenders to support landholder participation: a framework and case study assessment, *Ecosystem Services* 6, 82–92.

Wilson, K.A., Bode, M., Grantham, H. and Possingham, H.P. (2010). Prioritizing trade-offs in conservation, in Leader-Williams, N., Adams, W.M. and Smith, R.J. (eds), *Trade-Offs in Conservation: Deciding What to Save*. Wiley Blackwell, Oxford, pp. 17–34.

Windle, J. and Rolfe, J. (2008). Exploring the efficiencies of using competitive tenders over fixed price grants to protect biodiversity in Australian rangelands, *Land Use Policy* 25, 388–398.

Yamazaki, S., Grafton, R.Q. and Kompas, T. (2010). Non-consumptive values and optimal marine reserve switching, *Ecological Economics* 69, 2427–2434.

Yamazaki, S., Jennings, S., Grafton, R.Q. and Kompas, T. (2015). Are marine reserves and harvest control rules substitutes or complements for rebuilding fisheries?, *Resource and Energy Economics* 40, 1–18.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Number of Australian NRM papers published per year by sub-field.

Figure S1. Number of Australian NRM papers published per year by sub-field.

Appendix S2. Cross-cutting issues.

Table S1. Total number of Australian papers on the economics of natural resource management in cross-cutting issues category, 1952–2015 by issue.