Integrated valuation of ecosystem service benefits from restoring water to the environment in the Murray-Darling Basin, Australia

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Abstract

Evaluating different environmental policy options requires extensive modelling of biophysical outcomes linked with metrics to measure the magnitude and distribution of societal impacts. An integrated ecosystem services (ES) assessment has potential to provide salient, credible and legitimate information for environmental policy- and decision-makers. Here we present an ecosystem services assessment of the Murray-Darling Basin Plan, an Australian Government initiative to restore aspects of river flow regimes to improve the ecological condition of floodplains, rivers and wetlands in south-eastern Australia. We link the effect of policy intervention – reduced limits on water diversions for irrigation – to modeled changes in river flow and flood regimes, then to changes in ecological responses of flow-dependent ecosystems, assessed against a Baseline scenario. The final steps link changes in ecosystem condition and responses to marginal changes in the supply of ES and the monetary valuation of those services at the whole-of-basin scale. We show that the supply of most ES improves as a consequence of increases in water availability for the environment. For each ES assessed we assign a confidence category for both the ecological response modelling and the economic valuation steps and discuss other tools (review and outreach) to enhance legitimacy and credibility.

Key words: water reform; economic valuation; basin-scale restoration; policy assessment; ecosystem services; ecological response

Highlights:

- Basin Plan 2012 is modelled to improve many flow-dependent ES.
- Integrated ES assessment provides information on ecological state & human wellbeing.
- The provision of salient, credible and legitimate information may require new tools.

Introduction

Ecosystem service (ES) assessments have emerged as an integrated approach that links the condition of ecosystems with the provision of benefits from those ecosystems and the value of those benefits to human wellbeing. Practical lessons from the application of these approaches are now emerging. ES assessments can identify the many values nature provides to society (MEA, 2005; Tallis et al., 2013) and these values can be incorporated into decision-making (Fisher et al., 2008), for example, in the context of land-use planning (Bateman et al., 2013; Goldstein et al., 2013), biodiversity conservation (Tallis et al., 2008; Nelson et al., 2009) and water management (Keeler et al., 2009). Ideally an ES assessment will provide salient, credible and legitimate information (Cash et al., 2003) on the benefits associated with natural resources management over and above standard policy assessment tools such as benefit cost analysis (BCA).

Operationalizing the ES framework involves the provision of evidence on the benefits that people receive from ecosystems in a manner that decision-makers can use (Fisher et al., 2008; Daily et al., 2009). ES assessments typically consist of global or national assessments of the stock of natural capital and the flow of ES (Costanza et al., 1997; MEA, 2005; TEEB, 2010; UK NEA, 2011), or analyses of how ES flows are likely to change under the implementation of different policy options: so-called "programme evaluation" (Goldstein et al., 2013; Nelson et al., 2009; Bateman et al., 2011). Both types of assessment require interdisciplinary, integrated research that links ecosystem processes and functions to the supply of ES and then to human wellbeing (de Groot et al., 2010). Integration is complex because ecological and social systems each have their own spatio-temporal and self-organizing dynamics (Levin, 1998; Liu et al., 2007) that generate a multitude of values.

An ES assessment of an environmental policy or program may assist in decision-making, context setting and accountability in contested settings (Trabucchi et al., 2012). It can provide information on whether the benefits to society from preventing and reversing decline of natural ecosystems and ecosystem functions exceed the costs of program implementation (Balmford et al., 2011). In its simplest form, an ES assessment compares intervention against a "business-as-usual" scenario, or comparisons of different policy options. On the face of it these two criteria; worthwhile investment and comparison of alternatives, matches a BCA. However, ES assessments also require an understanding of the type, magnitude, supply, timing and distribution of ES and the consequences of changes in ecosystem condition, functions and resilience (Folke et al., 2004; Mäler et al., 2008).

In this paper we report on an ES assessment of the Murray-Darling Basin Plan (Commonwealth, 2012), a multi-jurisdictional water sharing initiative intended to address over-allocation of water resources for irrigation and other consumptive uses in a major drainage basin in south-eastern Australia. The enabling legislation, *The Water Act 2007* (Cwlth.) sets out the responsibility for preparing a Basin Plan to a federal agency, the Murray-Darling Basin Authority (MDBA). However, implementation remains a State responsibility with Commonwealth oversight (Garrick et al., 2013). The objectives of the Act are to uphold international agreements, to return to environmentally sustainable levels of extraction, to protect and restore the basin's flow-dependent ecosystems (i.e. floodplains, wetlands, rivers, and estuaries), their functions, and to shore up their resilience to climate change and other risks, and subject to the above, to optimise the net economic returns to the Australian community.

To put this task in context, the Murray-Darling Basin occupies one seventh of the Australian continent at a total 1.06 million km^2 (Figure 1). Uses of its water resources are highly contested, reflecting how much people care about the values of stake. Policy makers face problems typical of many large river basins globally: over-extraction of water for irrigation (which accounted for 36% of 2012 AU$18.6 billion gross agricultural product, ABS, 2013), declining health of flow-dependent ecosystems (Davies et al., 2010) and climate change impacts that are expected to reduce inflows (Vörösmarty et al., 2010; Grafton et al., 2013). Balancing the interests of multiple uses of limited water resources – conservation significance, recreational, cultural including Aboriginal, irrigated agriculture, urban and regional water consumers and commercial fisheries – represents a major challenge for National and State governments. The Water Act 2007 is the most recent policy response in what has been a national program of water reform undertaken since the 1980s to address over-allocation and long-term environmental decline through efforts to restore water to the environment (Garrick et al., 2012; Marshall et al., 2013).

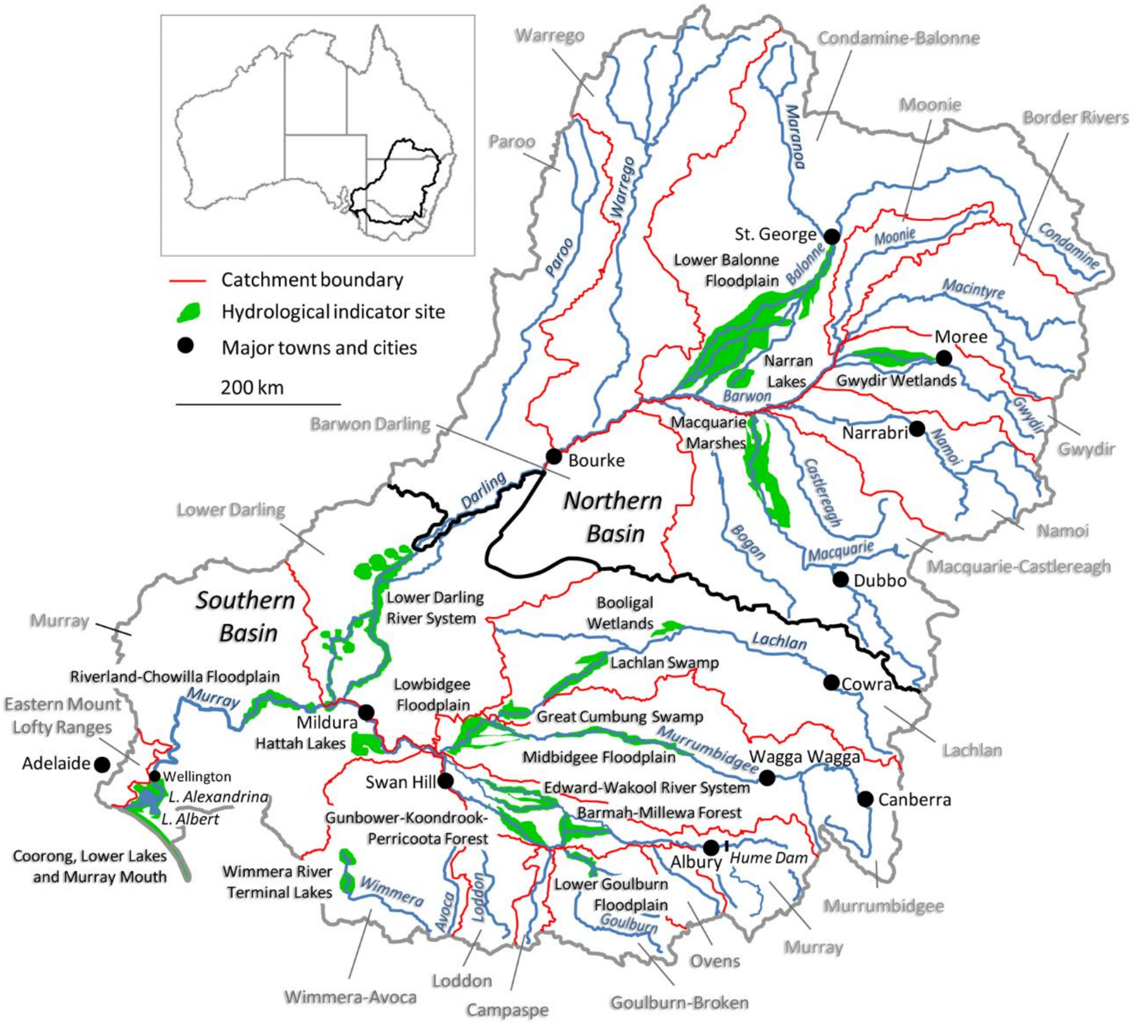

Figure 1. Murray-Darling Basin. The major catchments, rivers and key hydrological indicator sites, subject to ecological targets under the Basin Plan (MDBA, 2012a). Inset: location map within Australia.

Basin Plan 2012 is a policy instrument to achieve water re-allocation, not a prescriptive blueprint for ecological restoration. An annual average of 2,750 GL of water, or 20% of baseline average water diversions, is to be returned to the environment by 2019, with an additional 450 GL by 2024 (Commonwealth, 2012). Recovering water from multiple catchments and re-allocating water to some catchments as environmental flows (Arthington, 2012) is the means by which ecological improvement will be achieved under this Plan. River flows are essential for maintaining ecological condition of rivers and floodplains, driving ecological processes and the stocks and flows of energy, nutrients and biota (Naiman et al., 2005). River regulation and irrigation water diversion have resulted in changed flow regimes, including shifts in frequency, duration, extent and seasonal occurrence of high and low flows and flood events, leading to poor condition of flow-dependent ecosystems, fragmentation of vegetation communities and changes in biodiversity and ecosystem function (Vörösmarty et al., 2010; Ward et al., 1999). To achieve this re-allocation the Australian Government is purchasing irrigation water entitlements from willing sellers, as well as investing in infrastructure to improve irrigation efficiency and the effective delivery of environmental water. The means and efficiency of implementing this reallocation has been extensively researched (e.g. Crase et al., 2012; Wittwer 2011; Bark et al., 2014).

Our objective in this paper is to reflect on the elements of an integrated ES assessment and valuation using a case study from Australia. The study, CSIRO (2012), was undertaken by Australia's federal science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The client was the MDBA which required an integrated, basin-scale, biophysical-economic approach to fulfill the terms of the Water Act which seeks to optimize outcomes once the environments' needs are met. We demonstrate key aspects of integrated biophysical-economic valuation, reveal the methodological challenges when integrating different types of evidence, and discuss the tools we developed to better support operational decision making. The paper proceeds with a description of the scenarios, data, models and methods used followed by a discussion of the benefits and challenges of integrated valuation for achieving credibility, legitimacy and saliency. We end with reflections on our research experience that can inform other integrated ES assessments.

Materials and Methods

The interdisciplinary research team comprised hydrologists, including inundation modellers, ecologists, a biophysicist (water quality), economists and spatial and cultural geographers. The project approach was conceived and designed with the client, the MDBA. An independent scientific review panel (ISRP) oversaw the research from conception to completion. There were elements of transdisciplinary science (Tress et al., 2007) with the client and stakeholders (invited by the MDBA to workshops held throughout the project) contributing to research methods. ES were characterised in a manner intended to explicitly assist decision-making, i.e. to provide evidence as per the Water Act, this required disciplinary expertise and biophysical and economics researchers to work closely together to ensure that the metrics used for assessing ecological responses could be used in the valuation stage. However, in those instances were ES outcomes were not valued, e.g. Aboriginal cultural ES, we nevertheless, report on the approach taken to reveal benefits attributable to the Basin Plan.

The integrated valuation undertaken in CSIRO (2012) used the following biophysical data/modelling: three MDBA basin-scale hydrological scenarios, multiple ecosystem response models at basin and sub-basin scales that linked changes in hydrology to changes in the condition of flow-dependent ecosystems and the ecological outcomes for vegetation, birds and fish, and water quality modelling at sub-basin scale. Monetary estimates of the *marginal* changes in modelled outcomes (ES flows) between two of the scenarios (with and without policy intervention) were valued using multiple monetary valuation studies from the basin both completed for CSIRO (2012) and previously. Figure 2, based on the generalized framework of Keeler *et al*. (2012), illustrates the steps in our integrated valuation, from policy intervention through to monetary estimation of ES non-market benefits. More detail is provided below.

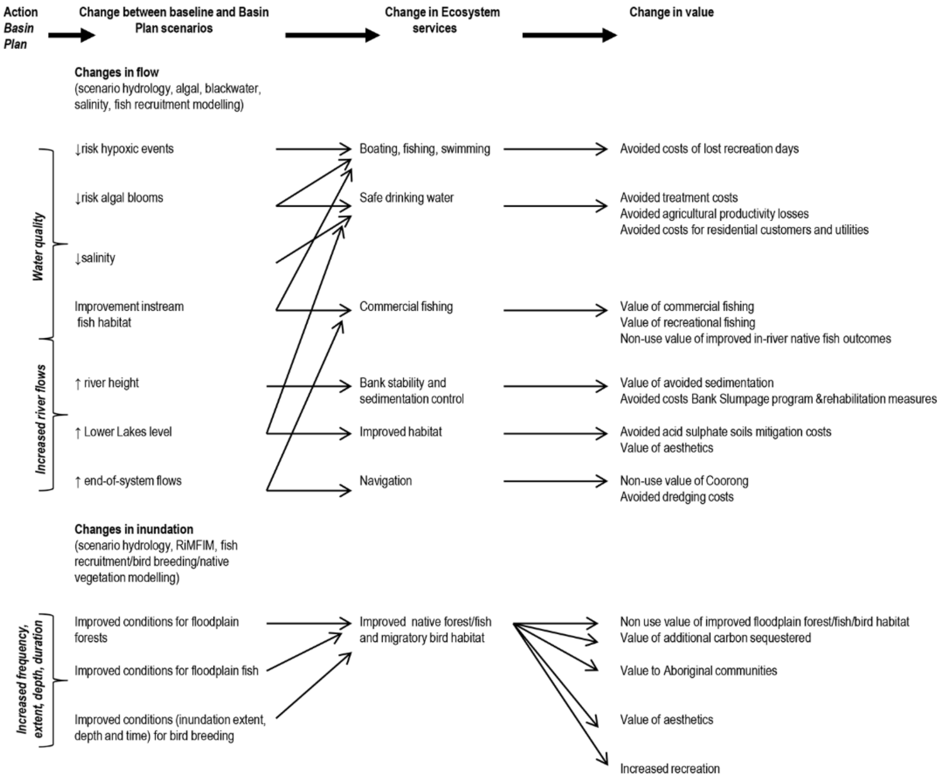

Figure 2. Ecosystem services assessment: conceptual linkages. Connections between policy intervention, changed river flows and inundations patterns, modelled ecological responses and incremental change in ES flows and the monetary valuation of incremental changes.

1. Hydrological scenarios. The MDBA supplied CSIRO with three hydrological modelling runs, or scenarios: a "Without development" scenario corresponding to flow conditions prior to water resources development, a "Baseline" scenario corresponding to flow conditions without the proposed Murray-Darling Basin Plan, and a "2,800" scenario, representing flow conditions following reduction in the Sustainable Diversion Limit for irrigation water by 2,800 GL/yr with the implementation of the Murray-Darling Basin Plan.[1] A consequence of the MDBA scenarios, which it uses in all its planning, is that the integrated assessment and valuation is retrospective. Each scenario is based on a 114-year record of simulated flows (1 June 1895 to 30 June 2009). That is, CSIRO (2012) modelled the marginal benefits that would have occurred if the water resources of the basin had been managed differently whilst preserving the same underlying climatic variability. The benefits of this approach is that variability in flow regimes recorded in the gauged record (frequency, duration and seasonal occurrence) are embedded in the scenarios. *Output*: Each scenario characterizes different flow (including end-of-system flows for the estuary), flood and inundation regimes which determine the extent and condition of flow-dependent ecosystems and the ES that flow from them.

[1] The discrepancy between the 2,800 GL scenario and the proposed 2,750 GL to be restored to the environment under the Basin Plan is because revisions to the final volume were made after we completed our assessment.

2a. Ecosystem response modelling. Modelled flows for all three scenarios were used as an input into ecosystem response models.

Vegetation: Vegetation models focused on the distribution of the four major floodplain tree species (river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens*, coolibah *E. coolabah*, river coobah *Acacia stenophylla*) and one shrub (lignum *Muehlenbeckia florulenta*) that form the most extensive floodplain vegetation communities in the Murray-Darling Basin (CSIRO, 2012). These species are widespread and ecologically important under the Murray-Darling Basin Plan and their environmental water requirements, including requirements for regular inundation, are relatively well known (MDBA, 2010; MDBA, 2011). Data on the location and extent of vegetation communities provided by State agencies (South Australian Department for Water; New South Wales Office of Environment and Heritage; and Victorian Department of Sustainability and Environment) was overlain with flood inundation modelling output from the River Murray Floodplain Inundation Model (RiM-FIM) (Overton et al., 2006). *Output*: At eight sites, number of events and duration of flood inundation, the area (ha) of floodplain vegetation (river red gum and black box) for different average recurrence intervals (1 in 1/2/5/10 years) for each scenario, as well as, % change in area by average recurrence intervals: between 2,800 scenario and Baseline, and % of gain in area relative to lose between Without development scenario and Baseline scenario.

Fishes: Habitat suitability for native fishes, representative of the different hydro-ecological regions of the River Murray, was modelled at the nine sites included in the Murray Flow Assessment Tool (MFAT). Four functional groups of fishes were evaluated based on their flow requirements as follows. 'Main channel generalists' spawn and recruit in the main channel regardless of flow conditions, 'main channel specialists' spawn and recruit during either high or low flows in the main channel, 'flood spawners' spawn and recruit during periods of floodplain inundation and 'rising-flow spawners' do not require floodplain inundation, but spawning and recruitment are enhanced by rising flows. Depending on the group of fishes of interest, preference curves were available for spawning habitat (flood magnitude, spawning timing, rate and duration of flow rise and fall, substrate condition as a function of flushing flows and percentiles of flow); and larval habitat (inundation area and duration, dry period, rate of flow fall and percentiles of flow) (Young et al., 2003). *Output*: Habitat suitability scores for nine sites and four fish groups for each scenario.

Waterbirds: Colonially nesting waterbirds require flood events lasting ca. 4-7 months or more in order to breed successfully, from initiation of breeding to fledging of young. If thresholds of flood depth and duration are not exceeded, successful breeding does not occur (Arthur et al., 2012). Most adult female egrets need to breed in most years for populations to be maintained (Arthur, 2011). Outcomes for colonially nesting waterbirds were assessed at nine major wetlands, using the IBIS decision support system, (Merritt et al., 2010), MFAT (Young et al., 2003) or estimates of environmental flows to meet waterbird breeding targets (Edward-Wakool River System, Lower Goulburn River Floodplain, Lachlan Swamp, Macquarie Marshes) (MDBA, 2012a). These floodplains and wetlands are amongst the most important waterbird breeding sites in the Murray-Darling Basin (CSIRO, 2012).

Output: percentage of years with possible breeding at different sites across the basin for each scenario by model or environmental water requirements.

Estuary: The condition of the Murray estuary, the Coorong (see Figure 1), is dependent on freshwater flows down the river system. An ecosystem response model based on 'ecosystem states' was used to assess ecological condition in the Coorong. (Lester and Fairweather, 2011). The ecosystem states model is a statistical model where existing relationships between the biota that occur within the system are correlated with the environmental conditions at any one point in time. The environmental parameters used to differentiate various states include water quality, volume and flow variables. *Output*: The proportion of time in a given ecosystem state for each scenario.

2b. Other modelling. The basin's water resources are important to the many Aboriginal communities with social, economic and cultural interests in the basin (Weir, 2009). For CSIRO (2012) a methodology was pioneered that focused on cultural ES, specifically spiritual or religious enrichment and cultural heritage including bush tucker, using a case study of the Wamba Wamba community in the Edward River catchment and the Werai State Forest. Flow regimes and modelled ecological outcomes were overlain with maps of land use and Aboriginal cultural practices for the Wamba Wamba community. The Baseline scenario and 2,800 scenario were used to evaluate the outcomes to cultural values (through restoring flows to cultural sites and preferred environmental assets) and to assess cultural water requirements, as distinct from environmental water requirements.

Water quality modelling using each scenario was also completed (CSIRO, 2012), specifically, for salinity concentration, risk of cyanobacterial ('algal') blooms (where water bodies are rendered unsuitable for recreation) and risk of blackwater events (excess dissolved organic carbon leading to low dissolved oxygen of the water and hypoxia in freshwater organisms). The scenarios were also used to assess the risk of acidification of the Lower Lakes (Lakes Alexandrina and Albert, located near the Coorong estuary) using modelled lake levels and the number and duration of events below a threshold.

3. Monetary valuation. In the final step of the integrated valuation our task was to estimate the monetary value of incremental changes in selected variables attributable to changed flows between the 2,800 scenario and the Baseline scenario. A consequence of the retrospective nature of the assessment is incremental benefits are not discounted. This is because there is no information on when during the simulation period the benefits occurred. By adopting this approach we emphasize the importance of long-term water resources management and its effect on ecosystem condition in contrast to outcomes based on shorter-term forecasts that would be strongly influenced by the frequency and sequence of wet and dry years.

To estimate the monetary benefits of improved ecological conditions and water quality – the outputs in Sections 1-2b – we used valuation estimates from a new hedonic valuation study completed as part of CSIRO (2012) and benefit transfer (Johnston and Rosenberger, 2010) of valuation estimates from prior research in Australia (details provided below).

Cultural ES, Aesthetic experience: We undertook a hedonic analysis of house prices in the Murray-Darling Basin for the period 2000 to 2011. During this period river flows and lake levels were highly variable. House prices (in the three months prior to the sale) were modelled as a function of typical structural and neighborhood variables as well as environmental variables, specifically there were two models with stream flows in nearby rivers and lake levels (CSIRO, 2012). Lake levels were found to be positive and significant determinants of house prices in the Coorong and Lower Lakes region of South Australia. Nearby house price premiums were also associated with higher river flows near the Barmah-Millewa Forest and the Lower Darling and mid-Murrumbidgee wetlands in New South Wales. A negative and significant correlation was found between nearby house prices and river flow near the Barmah-Millewa Forest in Victoria. Marginal implicit prices from the lake level and flow models were used in combination with modelled changes in river flow and lake levels between the two scenarios and extrapolated over the respective nearby properties in each model. Tapsuwan et al., (2015), using a sub-set of this data and further modeling, found evidence of a non-linear relationship between flow and property premiums at very high and very low river flows: this preference for more average river flows will be met more frequently under the Basin Plan.

Cultural ES, Cultural heritage of the Basin's ecosystems: A stated preference study (Hatton MacDonald et al., 2011) with a MDBA commissioned benefit transfer study (Morrison and Hatton MacDonald, 2010) was combined with incremental changes in modelled outcomes for floodplain vegetation inundation (as a proxy for condition), changes in native fish spawning habitat availability (as a proxy for population growth) and colonially nesting waterbird breeding between the Baseline scenario and 2,800 scenario in each sub-catchment within the Murray-Darling Basin. In this paper we updated native vegetation outcomes from those in CSIRO (2012) to reflect new ecological modelling and also a revised valuation approach that adheres to the original stated preference study assumptions where survey respondents were asked to value a percent change in native vegetation extent from pre-(water) development extent where recovery was capped to 80% of this level. In some catchments recovery is expected to exceed this cap; we therefore provide capped and uncapped results with the proviso that the uncapped values assume that marginal values do not diminish beyond the 80% threshold.

Cultural ES, Cultural heritage of the Basin's estuary, the Coorong: Responding to a perceived stakeholder need for a range of estimates (Hatton MacDonald et al., 2014) we provide three estimates of the monetary benefits from a healthier Coorong estuary which correspond to: (i) transferring the proportional change in the modelled probability of being in a healthy state (Lester and Fairweather, 2011) to the estimated total value of saving the Coorong from collapse (i.e. a non-marginal value) from (Hatton MacDonald et al., 2011); (ii) the incremental time spent in a healthy ecosystem state in the 2,800 scenario which is used to calibrate the healthy condition values; and (iii) the total uncalibrated value (Hatton MacDonald et al., 2011).

Regulating ES, Climate regulation: Additional areas of river red gum, black box and coolibah inundated under the 2,800 scenario at hydrological indicator sites were calculated from the percent difference in flow parameters required to meet ecological targets for floodplain trees between the Baseline scenario and 2,800 scenarios (MDBA, 2012a). Annual carbon sequestration at each site was estimated by overlaying a map of hydrological indicator sites with zones of increment in carbon dioxide equivalents (median CO_2e; tonnes per hectare per year) predicted for hardwood carbon plantings across the Murray-Darling Basin (Polglase et al., 2008; Fig. 17 therein) and multiplying the value by the additional area of woodland and forest inundated under the 2,800 scenario. The CO_2e estimates for black box and coolibah were adjusted by a third because these trees are slower growing than river red gum. Estimates of CO_2e increments (t ha^{-1} yr^{-1}) were multiplied by three different carbon prices: AU$23 per tonne, the initial price placed on CO_2e under the Australian Government carbon tax legislation (Commonwealth, 2011); the European Union Emissions Trading Scheme price at the end of 2011 (AU$10.50 per tonne; Talberg and Swoboda, 2013, Fig. 2 therein) and an estimate of the benefits of reducing greenhouse gas emissions based on revised 2011 social cost of carbon/marginal damage estimates used by the US government (IWGSCC, 2013; 3% discount rate therein and an annual average exchange rate) at AU$42 per tonne. The estimate of AU$ 15.6 m per year in Table 1 and Figure 3c is based on the AU$23 per tonne price.

Cultural ES, Recreation in the Southern Murray-Darling Basin: The reduced risk of cyanobacterial blooms and blackwater events under the 2,800 scenario (12 fewer days annually and 6 fewer years, respectively) were converted to river days open to recreation (CSIRO, 2012). Estimates of the benefits of improved water quality used these incremental recreation days, estimates of future recreationalist numbers by affected catchment based on actual recreation numbers in the period 2003-2010 (CSIRO, 2012), an estimate of those recreationists involved in water recreation based on survey information (DERT, 2010), and benefit transfer of a general recreational value (Morrison and Hatton MacDonald, 2010). Recreational fishing benefits are transferred from (Deloitte Access Economics, 2012).

Provisioning and regulating ES in the Southern Murray-Darling Basin: ES improvements linked to water quality improvements were estimated using avoided cost methods. Higher flows improve regulation of water quality with fewer cyanobacterial blooms: these benefits were estimated using avoided water treatment and monitoring costs (CSIRO, 2012). This is not double counting of cultural ES because the benefits of water quality are additive: both recreationists and water utilities benefit. Lower salt concentrations result in multiple benefits, with higher crop yields for irrigators (GHD, 1999) and reduced damage to utilities and domestic water supply pipes (Allen Consulting Group, 2004). We provide a new estimate not in CSIRO (2012) of provisioning ES benefits linked to reduced salinity. The commercial catch in the Coorong and Lower Lakes fishery responds positively to increases in freshwater inflows that trigger breeding and recruitment of several commercial species whereas decreased inflows result in high salinity and low fish abundance (Ferguson et al., 2013). The relationship between catch and inflows is complex and non-linear (Gilson et al., 2012), but mean annual catch (excluding European carp and Goolwa cockles) during low inflow years (1999/00-2010/11) was 40% less than in high-to-medium inflow years

(1992/93-1998/99). We therefore estimated a conservative 20% increase in catch associated with achieving the Murray-Darling Basin Plan target of average freshwater inflows of >2,000 GL/y in >95% of years and maintenance of average salinity of <60 g/L in the Coorong Southern Lagoon and <20 g/L in the Northern Lagoon (MDBA, 2012b two of these). Mean annual gross value of fishery production (2006/07-2009/10) was AU$7.04 m (EconSearch, 2012; Table 3.2 therein). We estimate an increase in gross value of fishery production of A$175.56 m (based on an annual gross value of AU$1.54 m). Deloitte Access Economics (2012) provided results based on producer surplus using different modelling (Table 1).

A set of water and soil quality regulating ES benefits were estimated using avoided cost estimates for ES losses catalogued during the 1997-2009 drought (Banerjee et al., 2013and biophysical thresholds. Examples of biophysical thresholds linked to ecological damage and associated costs incurred during the drought are minimum lake height for modelled avoided costs associated with acid sulfate soil formation in the Lower Lakes region (-0.75 m Australian Height Datum [AHD] for Lake Alexandrina and -1.75 m AHD for Lake Albert), and a minimum Mouth Opening Index (Close, 2002) to estimate avoided dredging costs from sedimentation. In the case of erosion prevention, the threshold used was minimum river height as widespread bank instability and bank collapse (damage was incurred during the drought) has been linked to low river height which desiccated the banks leaving them unstable (Liang et al., 2012). Without readily available data on the extent and duration of exposed banks we used a 4-year consecutive low-flow proxy based on average flows during the millennium drought (<2,696 GL at Lock 1; CSIRO, 2012).

Confidence levels: Integrated valuation involves multiple data sources, models, and assumptions. To provide the user of the data with information on our confidence in the results the research team assigned levels of confidence in the modelling and valuation post-hoc using the following criteria: (i) consistency between different models and prior research; (ii) robustness of methods used to derive the data (e.g. a maximum confidence level of 'medium' was assigned to those monetary estimates based on avoided costs methodology); and (iii) degree of congruence between the spatial scale of data and models and the ES. Confidence levels were assigned according to a five-point scale (Mastrandrea et al., 2012). Assignment of 'low' confidence indicated greater reliance on expert opinion and limited evidence to support the assumptions in a model. A 'medium' value indicated supporting evidence for several aspects of the model, whereas a 'high' confidence indicated minimal or no assumptions. No assignment of 'very high' confidence was made because of time constraints on the validation of primary source data.

Results

Table 1 provides a summary of ES evaluated with metrics, models, sources of uncertainty and monetary valuation estimates. The supply of habitat for cultural heritage ('wild species diversity' in UK NEA, 2011) was the largest of the values we estimated. This result provides some evidence that a key objective of the Murray-Darling Basin Plan is highly valued: this value also likely captures the socio-cultural significance of the Murray-Darling

Basin (Connell and Grafton, 2011) and the importance of indicator sites for ecosystem health across the Murray-Darling Basin (Johnston et al., 2012). The assessment also demonstrated that some benefits from water reform remain difficult to capture, for example species of high cultural importance to Aboriginal communities in the Murray-Darling Basin may be different than those species included in existing models and furthermore benefits to these communities may require active co-management of water resources and establishment of alternative flow regimes (Tan and Jackson, 2013; Finn and Jackson, 2011).

Table 1: Data, models, valuation methodology and monetary values of and confidence levels in incremental ecosystem service benefits within the Murray-Darling Basin following implementation of the proposed Murray-Darling Basin Plan

Ecosystem service	Data and metrics	Biophysical Modelling	Economic Modelling	A$ million	Confidence	
Regulating Services					**Biophysical modelling**	**Economic valuation**
Carbon sequestration	Ha native vegetation in good condition + woody carbon potential	RiM-FIM (Overton et al., 2006); modelling to support Basin Plan ecological targets (MDBA, 2012a); growth modelling of carbon plantings (Hatton MacDonald et al., 2011)	Based on carbon price (Deloitte Access Economics, 2012)	50	Low to Medium – RiM-FIM used for Murray, Basin Plan hydrological models used for other sites	Medium - values same in S and N Basin, no risk discount
Moderation of acid sulfate soils	Lower Lakes height threshold	MDBA hydrology (MDBA, 2012)	Avoided costs (Banerjee et al., 2013, CSIRO, 2012)	9.2	High - lake level height data	Medium - avoided cost methodology, S Basin
Moderation of sedimentation	End-of-system flows and Mouth Opening Index	MDBA hydrology (MDBA, 2012) Threshold MO Index (Close, 2002)	Avoided costs (Banerjee et al., 2013, CSIRO, 2012)	17.8	High – developed model	Medium - avoided cost methodology, S Basin
Maintenance of bank stability	River in-channel height and threshold	MDBA hydrology (MDBA, 2012) Threshold river height (CSIRO, 2012, Liang et al., 2012)	Avoided costs (Banerjee et al., 2013, CSIRO, 2012)	23.7	Low – no river height data	Medium – suggests new methodology but no data to use thresholds, S Basin issue
Provisioning Services						
Floodplain grazing	Ha floodplain grazing	Estimates from (GHD, 2012) based on MDBA flow duration curves and overbank flows	Benefit transfer (GHD, 2012)	32.2	Medium – different methodology	Medium - different methodology

Fresh water quality	Salinity concentrations	MDBA hydrology (MDBA, 2012) and BigMOD salinity model	Avoided salinity productivity losses and costs to utilities and users (GHD, 1999, Allen Consulting Group, 2004) and probabilistic calculation (CSIRO, 2012)	1.1	Low - salinity modelling (but unsure of impact of environmental watering on salt loads)	Medium – uses dose response but low congruence with (CIE, 2011)
	Cyanobacterial bloom risk	Cyanobacterial bloom risk model (CSIRO, 2012)	Estimated avoided treatment costs (CSIRO, 2012)	0.9	High – model for outbreak risk	Low - develops a methodology but low congruence with (CIE, 2011)
Fishes	Commercial catch	Difference in mean annual catch under years of medium-high and years of low barrage flow	Estimated increase in catch per unit effort + proportion gross production value (EconSearch, 2012)	175.6	Low - not based on ecological response model	Low - comparable study estimates increase in producer surplus of AU$2.6 (EconSearch, 2012)
Cultural Services						
Aesthetic appreciation	House prices in basin 2003-2010, historic and modeled river flows and lake level height	MDBA hydrology (MDBA, 2012)	Hedonic models (CSIRO, 2012)	337.0	High - Modeled lake levels as highly visible link between lake height, banks exposed and nearby homes Medium- Modeled river flows as river flows proxy for river health, regional economy, recreation, 4 regions in Basin only	High - Project-funded study, visible link lake height, banks exposed and nearby homes Medium - Project-funded study, river flows proxy for river health, regional economy, recreation, 4 regions only

Indigenous values	Geocoded cultural and bush tucker sites for Wamba Wamba of the Werai Forest	Response models: native fish, water fowl, vegetation linked to land use, occupancy and bush tucker maps (CSIRO, 2012)	Qualitative only	+	Low - No explicit modelling of beneficial flows but a methodology developed	Low - Qualitative assessment, expert judgment (Arthur, 2011)
Recreation and tourism	Increased flows, additional days with water quality adequate for recreation Increased flows	Changes in good flow days Changes in cyanobacterial bloom and blackwater risk - days with adequate water quality for recreation (CSIRO, 2012) Improved conditions for recreational fishing (Deloitte Access Economics, 2012)	Recreation and tourism numbers (CSIRO, 2012) benefit transfer values (Morrison and Hatton MacDonald, 2010) Benefit transfer of consumer surplus values (Deloitte Access Economics, 2012)	161.4 10.3-20.6 107.0	Low - Correlation only as no model that links visitation rates with changes in flow High - Modelling of water quality risk combined with health alerts Medium – different assumptions	Low - multiple assumptions, benefit transfer value unrelated to flow characteristics Low - multiple assumptions, benefit transfer unrelated water quality Medium – consumer surplus
Habitat Services						
Native vegetation	Floodplain vegetation mapping (various sources)	Modeled area of inundation for dominant floodplain vegetation communities (Overton et al., 2006)	Choice modelling study from S Basin (Hatton MacDonald et al., 2011) Transfer approach (Morrison and Hatton MacDonald, 2010)	1,902.37 capped/ 2,109.98 uncapped	Medium - S Basin vegetation response model extended to N Basin using ESLT data	High - MDBA-funded study, S Basin extended to N Basin using reproducible method

Native fishes	Habitat suitability of native fish guilds	Response relationships derived (Overton et al., 2006), predictions focusing on hydrologic habitat for recruitment (Young et al., 2003)	Choice modelling study from S Basin (Hatton MacDonald et al., 2011) Transfer approach (Morrison and Hatton MacDonald, 2010)	339.9	Low - Habitat suitability model has limited validation	Medium - MDBA-funded study, based on targets from Native Fish Strategy, S Basin
Colonially nesting waterbird breeding	Frequency and extent of habitat suitability for nesting and fledging of colonially nesting waterbirds	Environmental Water Requirements; Ecological Response Models (Merritt et al., 2010); bird breeding & inundation modelling (Arthur et al., 2012)	Choice modelling study from S Basin (Hatton MacDonald et al., 2011) Transfer approach (Morrison and Hatton MacDonald, 2010)	693.1	Medium - Only threshold responses were available for some sites, whereas other sites were based on habitat-based ecological response models	Medium - MDBA-funded study, S Basin transferrable to N Basin: breeding event is equally ecologically valuable but may be tempered by scope effects
Coorong, Lower Lakes and Murray Mouth	Duration in healthy state	Ecological response model of ecosystem states (Lester and Fairweather, 2011)	Choice modelling (Hatton MacDonald et al., 2011) with new method (CSIRO, 2012)	480.0 4,000.0 4,300.0	High – based on statistical modelling	Medium - MDBA-funded study, new ecology

This integrated valuation provides evidence that returning river flows and restoring flood regimes to a major drainage basin. Maps have been shown to be a powerful tool for communicating the array of ES benefits (Hauck et al., 2013) and to visualize benefits and losses across space in addition to informing regional economic development policy (Bateman et al., 2013). Figure 3a displays the relative proportions of additional water available by catchment to the environment due to reductions in sustainable diversion limit (SDL) within each catchment (MDBA 2012a; MDBA 2011). Figure 3b shows a key policy trade-off from the re-allocation: the distribution of estimated costs to irrigated agriculture with reduction in gross value of production (ABARES, 2011) are strongly negatively correlated (R^2 = 0.87) with reductions in SDLs, but in four catchments (Warrego, Gwydir, Lachlan and Loddon-Avoca) there are modest estimated increases in the value of irrigated production. Figures 3c-f illustrate both the spatial nature of benefits and the relative importance of flow. River flow is a critical driver for many ES benefits, for example, increases in mean annual carbon sequestration tend to be relatively large throughout the Murray-Darling Basin (Figure 3c) and are strongly positively correlated with increases in river flows, as are habitat ES for native species (Figures 3e, 3f), and provisioning and cultural services.

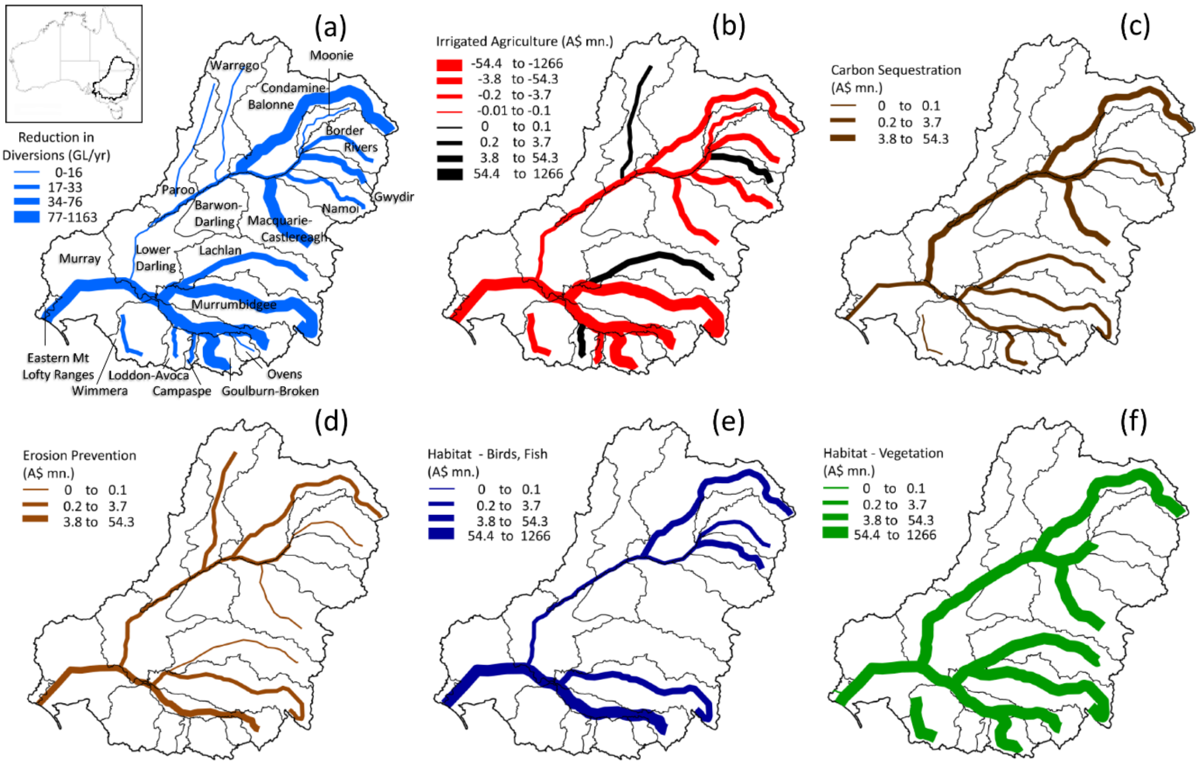

Figure 3. Spatial distribution of the costs and ecosystem service benefits under the Murray-Darling Basin Plan (MDBA, 2012a). (a) Increases in environmental flows, assumed as equivalent to reductions in diversions under the 2,800 scenario (MDBA, 2012b, Table 1, column 3). (b-f) the relative values (in $AU million per year) of marginal changes in the supply of ES within catchments of the Murray-Darling Basin under 2,800 scenario: based on $AU values for each river catchment (CSIRO, 2012; Table 6.3). Assessments are for (b) provisioning services (irrigated agriculture; red = reduction in annual gross value of production; black = increase in value); (c) annual incremental carbon sequestration; (d) prevention of erosion; and (e, f) habitat services. Absence of a line corresponding with a catchment and ES, indicates there was no estimation of value undertaken, not that the value was zero. Scales are based on minimum, maximum, interquartile and median pooled values.

Discussion

The Murray-Darling Basin Plan is a water sharing plan, not a restoration plan. However, a pre-requisite of any restoration plan for flow-dependent ecosystems is to restore aspects of flow and flood regimes. Under the Murray-Darling Basin Plan, one-fifth of water allocated to irrigators will be re-allocated to the environment. This is a far greater proportion than for initiatives elsewhere such as in the Colorado River (Glenn et al., 2013). Water re-allocation at this scale has the scope to improve the current condition of ecosystems in the Murray-Darling Basin and to supply a suite of enhanced ES that benefit human wellbeing. The integrated assessment presented here traced a policy intervention through changes to underlying hydrology, ecosystem responses and water quality improvements attributable to this changed hydrology, to implications for human wellbeing through valuation of marginal changes in ecosystem services.

The methodology and results sections show that interdisciplinary ES research can produce policy relevant information not only on the condition of, in this case, flow-dependent ecosystems, the modelled incremental changes in ES flows from them following water reallocation under Basin Plan 2012, and the valuation of incremental ES, but also provides a case study for ES researchers on the data, metrics and range of biophysical models used and the types of monetary valuation undertaken. Additionally, for this study, to assist the research user, we also record our assessment of our confidence in the data, models and methods utilised. The complexity of Table 1 demonstrates the prerequisite ecological disciplinary expertise and modelling capability as well as the interdisciplinary integration necessary to undertake the ES assessment.

In Crossman et al.'s, (2014) review of CSIRO (2012) the authors discuss four advances of using the ES approach to support decision making. A central aim of this paper has been to learn from the doing of an integrated assessment and valuation. In the introduction we posed three criteria for an integrated valuation; that it provide salient, credible and legitimate information to policy- and decision-makers (Cash et al., 2003). Where, salience is defined as the relevance of the ES assessment to the needs of decision-makers, credibility as the scientific adequacy of the research, and legitimacy encompasses that the research was carried out in a way that was respectful of stakeholders' divergent values and beliefs, was unbiased, and fair it its treatment of opposing views and interests. Table 2 brings together the different types of integration that we achieved – of values, variables, and scales – and the Cash et al., (2003) criteria. We fill the table in part using evidence from Hatton MacDonald et al., (2014), in which research users of CSIRO (2012) were surveyed and use a square bullet to indicate the tools developed to better support operational decision-making, specifically review, confidence metrics, outreach in the form of project workshops, and maps.

Table 2: Integration for policy- and decision-making

Integrating over	Salience	Credibility	Legitimacy
Values	Water Act, 2007 requires the Plan to improve ecosystem condition and ES as well as maximise value to Australian community. Monetary values used in MDBA's Regulation Impact Statement on the Basin Plan in Parliament (MDBA, 2012a)	Ecological modelling was viewed as credible (Hatton MacDonald et al., 2014). The retrospective approach, different from a BCA, may raise issues with the monetary values. The benefit transfer approach was value transfer not functional or meta. Use of avoided costs. ▪ ISRP review. ▪ The confidence heuristics developed	Inclusion of different values and knowledge types, i.e. Aboriginal knowledge, endorses multiple values, not only monetary values. The use of stated preference values includes values from outside of basin, i.e. the Australian community. ▪ Project workshops seen to provide legitimacy (Hatton MacDonald et al., 2014).

		incorporate a method criterion.	
Scales	Whole-of-basin required by MDBA.	▪ ISRP review. ▪ The confidence heuristics incorporate a scale criterion.	Greater spatial specificity of ES benefits and disbenefits was desired by States and regional players (Hatton MacDonald et al., 2014). ▪ Maps, e.g. Figure 3.
Variables	Information is provided on the condition of flow dependent ecosystems and on incremental ES benefits sometimes using proxies, e.g. fish habitat suitability not fish populations.	CSIRO (2012) incorporated the best available biophysical science and biophysical thresholds for valuation. In the economic valuation there is possibility of: Correlated variables, i.e. the stated preference, hedonic, and avoided cost values. ▪ ISRP review. ▪ The confidence heuristics incorporate a consistency with other studies criterion.	In the economic valuation there were omitted variables (the biophysical variables were also omitted), i.e. CSIRO (2012) did not report floodplain benefits (included here) or pollination benefits. ▪ Project workshops.

In Table 2 we can see for example, for the criterion of salience – the relevance of the information to the needs of decision-makers – that for integration over scale we report dichotomous results. The integrated valuation was seen as fit for purpose at the federal level: it was used in the MDBA's Regulation Impact Statement (MDBA, 2012a) submitted to the Australian Parliament, however, at sub-basin scales it was not. In the Murray-Darling Basin Plan's implementation phase water managers discussed a need for research targeted at finer-scale impacts to guide State water allocation planning, inform potential trade-off decisions and to achieve multiple benefits. This tension between broad-scale assessment that is relevant and applicable to policy scenarios and the need for greater fine-scale functional analysis of a single ES that can ultimately be scaled up (Nelson, et al., 2009), will play out in the forthcoming revision of water sharing plans by State water planners. States may wish to incorporate site-specific targets or flow-specific rules that explicitly aim to increase the supply of high value ES in their state.

There are tensions between the three criteria, for example, the MDBA saw as salient all benefits to the Australian community including out-of-basin non-use values, whereas their inclusion undermines, to some, the credibility of the monetary estimates because of the stated preference method used. Furthermore, this requirement combined with the absence of funding for new valuation studies, except for the hedonic study, meant benefit transfer was used. A consideration in using benefit transfer is to fulfil all three NOAA (1996) criteria for good benefit transfer, specifically, (i) close correspondence of sites; (ii) comparability of change in quality or quantity of ES; and (iii) correspondence of quality of studies. In CSIRO (2012), for most ES valued, we satisfied criteria (i) and (iii) by using peer reviewed Australian valuation studies for closely matched type of benefits most of which were undertaken within the Murray-Darling Basin. Integrated valuation simplifies the task of meeting criterion (ii) because valuation studies measure benefits in different ways, e.g. hectares of river red gum, percentage change in populations of fishes, numbers of bird breeding events per decade, value of a recreation day per person, and there is no guarantee that without an integrated study that these metrics coincide with the standard output of ecosystem response and water quality models. However, we also opted for comprehensiveness and therefore did in some cases make a number of assumptions (all openly reported) and use value estimates from reports rather than peer-reviewed literature. In all cases we used the value transfer approach, assumed the relationship between flow, ecology and benefits accrued was linear, and that diminishing marginal returns were not a factor. There remains a need for coupled ecological and valuation research to better understand nonlinear and interdependent ecological responses. Furthermore, as provisioning and regulating ES are particularly amenable to avoided cost methods (Faber et al., 2006) we also used avoided costs. To overcome some of the issues with avoided cost (Bockstael et al., 2000; UNSRC, 2005) we tightly coupled their use with biophysical thresholds and a probabilistic approach.

Another tension between salience and legitimacy is the elicitation of the non-material benefits obtained by a single Aboriginal community, the Wamba Wamba, from flow restoration. Aboriginal cultural benefits are very important to traditional owner groups who have historically been excluded from Basin water governance (Bark et al., 2011) and are now to be given consideration according to the Basin Plan. Chan et al., (2012) pointed out that many cultural ES are overlooked in much ES research and thus in decision-making. Their inclusion poses a challenge to a notion of integration that requires a common numeraire, while it is possible to monetary value Aboriginal cultural benefits (Rolfe and Windle 2006; Zander et al. 2010), we did not in CSIRO (2012). Thus our inclusion of these values while legitimising other types of values and knowledges, without a monetary valuation, will for some, reduce the salience.

To address concerns of credibility and legitimacy the research project incorporated review, outreach and maps. CSIRO (2012) was subject to peer review from an Independent Science Review Panel (ISRP).[2] The research was conducted in a transdisciplinary manner with six workshops in which methodology, preliminary and final results were discussed (for more detail see, Hatton MacDonald et al., 2014). This process enabled knowledge exchange and communication of the data, methodology and results (Villa et al., 2014). In addition, our *post hoc* assignment of confidence levels for the biophysical and monetary results is an effort to provide context for stakeholders and decision-makers in the Basin based on simple heuristics. The criteria underpinning the confidence levels means that over time, confidence is likely to increase, in line with the accumulation of data, modelling and replication of results as reflected in the ongoing process of scientific knowledge generation. Finally

[2] The five-person Independent Science Review Panel comprised an economist, two ecologists, a hydrologist, and a social psychologist.

producing maps show that for some ES, the restoration of flow regimes is insufficient alone to realize benefits. For example, improvement in native fish habitat also requires control of exotic invasive fishes, provision of fish ladders to aid spawning migrations and the active restoration of physical habitat, none of which were included in our assessment. A future assessment could investigate how access to infrastructure affects potential trade-offs and synergies in achieving ES outcomes. Of interest to this study is that it is only when Figures 3a-f are integrated and viewed together that it becomes clear that there are simultaneously beneficiaries and losers in each catchment, which might help shift the policy debate from one of contested values towards policies aimed at reducing losses and maximizing benefits as well as direct attention to the need for inclusive processes that enable stakeholders to deliberate over policy options and their impacts to engender community confidence in water planning (Tan et al., 2012).

The MDBA used the monetary benefit values in CSIRO (2012) in Parliament (MDBA, 2012a) which indicates that a BCA was salient for their needs. However, the integrated valuation provided credibility and legitimacy that the BCA alone would not provide. Credibility was partially achieved through rigorous ecological modelling and the identification of biophysical thresholds for the monetary valuation. The scope of the research derived from the objectives of the Water Act was a facilitator of legitimacy, i.e. by being broad and seeking comprehensibility, the ES assessment focused research on what people and decision-makers care about (Chan et al., 2012), included a diversity of perspectives both in what it assessed and valued and in the research project approach. Finally, the explicit mention of ES in the Water Act not only marks a shift in water management in Australia but meant that for the MDBA to gain evidence on the state of the supply of ES, it commissioned an integrated ES assessment not a BCA. The study undertaken was innovative in this context: Martín-López et al., (2013) call it the first integrated biophysical, socio-cultural and monetary assessment.

Conclusions

To recap, in this integrated assessment, we linked a legislated reduction in Sustainable Diversion Limits to modelled changes in ecosystem functions and responses to higher flows, to shifts in supply of ES and, finally, to the monetary valuation of those marginal changes in ES. The supply of ES for human wellbeing is dependent on the connectivity between abiotic drivers of ecosystem function, ecological responses to those drivers resulting in changes in rates of ecosystem functions and, hence, the supply of ES. In practice an integrated assessment relies on prior investments in data collection, model development, valuation studies and also in building systems to facilitate researchers capable of working in interdisciplinary research teams. The Murray-Darling Basin, Australia is a well-studied basin that has received considerable investment and biophysical and social sciences research interest, yet, in practice it was still necessary to make numerous assumptions and to use unpublished monetary values. In a first-best world integrated models would be developed that are capable of providing the type of biophysical-economics integrated information needed to best assess large-scale restoration.

To assess Basin Plan 2012 we have argued that an integrated ES assessment was necessary as the stated goal of the Water Act 2007 is to increase river flows to maintain and restore ecological condition of rivers, floodplains and wetlands that are considered to be in poor and declining condition due to a history of water resource development and over-allocation for irrigation, rather than specifically to increase supply of ES for human wellbeing. The intent of the Basin Plan 2012 highlights an implicit conceptual disjunction in public discourse, whereby water for the environment is considered an unproductive use. Regardless of the policy intent, increases in supply of ES are likely to eventuate. Rather than regarding water reform solely as a means of achieving large-scale ecosystem restoration, an ES assessment can provide evidence of potential benefit to a broad range of stakeholders and beneficiaries. If valued within the emergent ES framework, water for the environment instead represents a resource that provides multiple benefits for human wellbeing. As an emergent science we anticipate a lag in legislation and policy development of how to reflect ES concepts in environmental management decisions and practices.

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