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1 **Integrated valuation of ecosystem services obtained from restoring water to the environment in a major**
2 **regulated river basin**

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17

18 **Abstract**

19 Evaluating different environmental policy options requires extensive modelling of biophysical processes and
20 attributes linked with metrics to measure the magnitude and distribution of societal impacts. An integrated
21 ecosystem services assessment (IESA) has potential to provide salient, credible and legitimate information for
22 environmental policy- and decision-makers. Here we present results of an IESA of the Murray-Darling Basin
23 Plan, an Australian Government initiative to restore aspects of river flow regimes to improve the ecological
24 condition of floodplains, rivers and wetlands in south-eastern Australia. The main outcome from the IESA is that
25 the supply of most ecosystem services (ES) improves under Basin Plan policy and that these improvements
26 have considerable monetary value. An IESA can provide actionable ecological, economic and social information
27 for policy- and decision-makers. In the Basin Plan case the IESA was underpinned by hydrological scenarios that
28 were input into ecological models and interdisciplinary integration across scales, values and variables.

29 **Key words:** economic valuation; ecosystems restoration; policy assessment; ecological response models;
30 environmental water, cultural values

31 **Highlights:**

- 32 • The Murray-Darling Basin Plan was modelled to assess changes in flow-dependent ES
- 33 • Ecological modelling is required to underpin an integrated ES assessment (IESA)
- 34 • Post-project review of ecological and economic modelling allows for confidence levels to be assessed
- 35 • The use of monetary estimates of ES by government signals a coming of age for IESA

36 **Introduction**

37 Ecosystem service (ES) assessments are an integrated approach that links the condition of ecosystems with the
38 provision of benefits from those ecosystems and the contribution of those benefits to human wellbeing. There are
39 practical lessons from the application of these approaches: ES assessments can identify the many values nature
40 provides to society (MEA, 2005) and these values can be incorporated into decision-making (Fisher et al., 2008),
41 for example, in the context of land-use planning (Bateman et al., 2013), biodiversity conservation (Nelson et al.,
42 2009), water management (Keeler et al., 2009) and infrastructure investments (Crossman et al., 2010). Ideally an
43 ES assessment provides salient, credible and legitimate information (Cash et al., 2003) on the benefits
44 associated with natural resources, and their management, over and above standard policy assessment tools
45 such as benefit cost analysis (BCA).

46 Operationalising the ES framework involves the provision of useful evidence on the benefits received from
47 ecosystems (Fisher et al., 2008; Daily et al., 2009). ES assessments typically consist of global or national
48 assessments of the stock of natural capital and the flow of ES (Costanza et al., 1997; MEA, 2005; TEEB, 2010;
49 UK NEA, 2011), or analyses of how ES flows are likely to change under different policy options: so-called

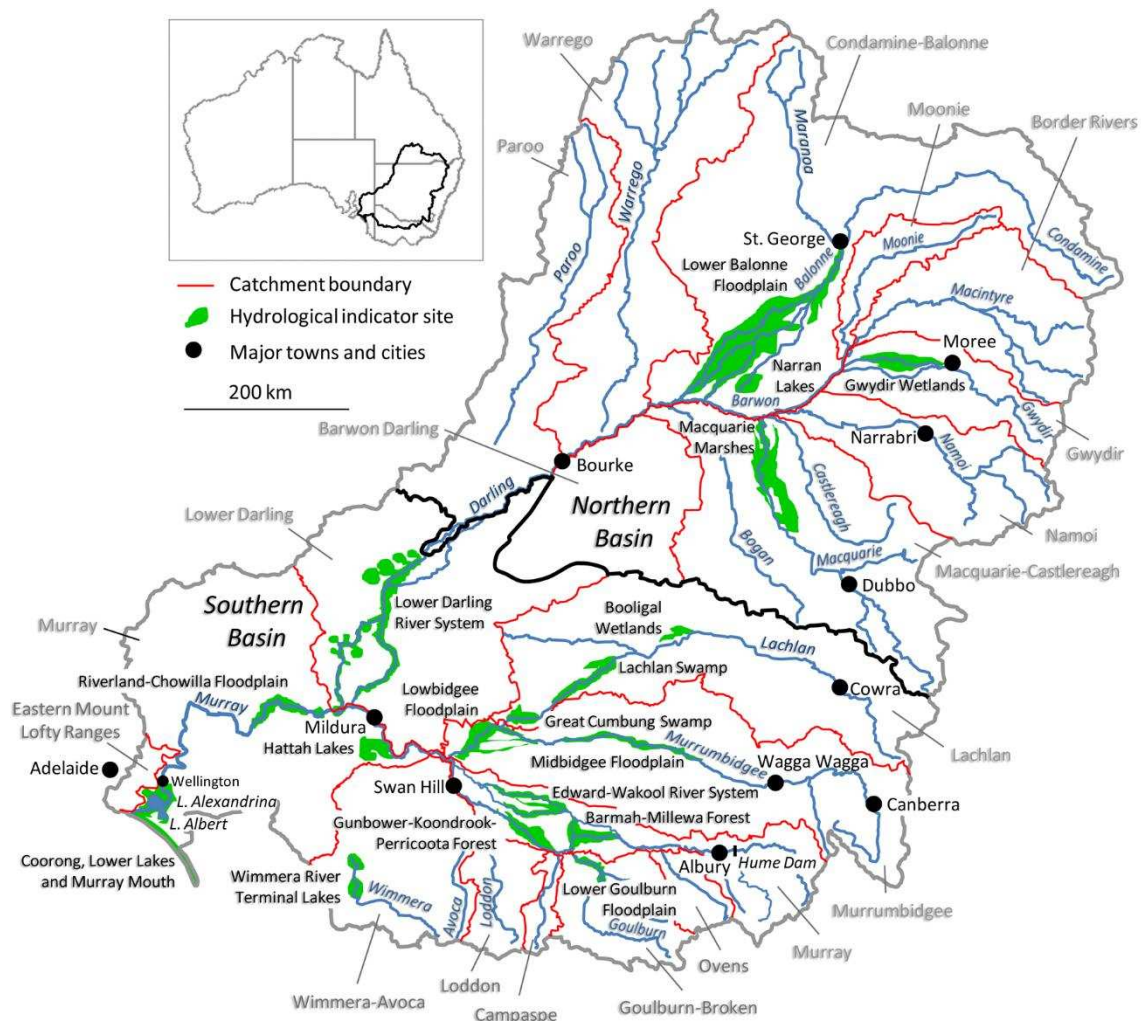
50 “programme evaluation” (Nelson et al., 2009; Bateman et al., 2011). Both types of ES assessment require
51 interdisciplinary, integrated research that links ecosystem processes and functions to the supply of ES and then
52 to human wellbeing (de Groot et al., 2010). Integration is complex because ecological and social systems each
53 have their own spatio-temporal and self-organizing dynamics (Levin, 1998; Liu et al., 2007) and embody a
54 plurality of values, some of which can conflict.

55 An ES assessment may assist in decision-making, context setting and accountability in contested settings
56 (Trabucchi et al., 2012). In its simplest form, an ES assessment compares intervention against a “business-as-
57 usual” scenario, or comparisons of policy options. Superficially the worthwhile investment and comparison of
58 alternatives criteria matches a BCA. However, ES assessments also require an understanding of the type,
59 magnitude, supply, timing and distribution of ES and the consequences of changes in ecosystem condition,
60 functions and resilience (Folke et al., 2004; Mäler et al., 2008). In this way, it provides more comprehensive
61 information, for example, on whether the benefits to society from preventing and reversing decline of natural
62 ecosystems and ecosystem functions, exceed the societal costs (Balmford et al., 2011).

63 In this paper we reflect on an integrated ES assessment (IESA) completed by the Commonwealth Scientific and
64 Industrial Research Organisation (CSIRO, 2012) of the Murray-Darling Basin Plan (Commonwealth, 2012;
65 hereafter, ‘the Basin Plan’), a multi-jurisdictional water sharing initiative intended to address over-allocation of
66 water resources for irrigation and other consumptive uses in a major drainage basin in south-eastern Australia.
67 The paper proceeds with a description of the case study, the methods used and results including updates of the
68 integrated biophysical-economic valuation and tools we developed to better support decision making. We end
69 with a discussion on how an IESA can provide additional credibility, legitimacy and saliency for decision support
70 and on the operational challenges of integrating different values in actual programme assessments.

71 **Case study**

72 The Murray-Darling Basin occupies one seventh of the Australian continent (1.06 million km²; Figure 1). Policy
73 makers face problems typical of many large river basins globally: over-extraction of water for irrigation, declining
74 health of flow-dependent ecosystems (Davies et al., 2010) and climate change impacts that are expected to
75 reduce inflows (Vörösmarty et al., 2010). Additionally, balancing the interests of multiple uses of limited water
76 resources – conservation significance, recreational, cultural, including Aboriginal culture, irrigated agriculture,
77 urban and regional water consumers and commercial fisheries – represents a major challenge for national and
78 State governments. The *Water Act 2007* (Cwth.) is the most recent policy response in a national program of
79 water reform undertaken since the 1980s to address over-allocation and long-term environmental decline.



80
 81 Figure 1. The Murray-Darling Basin showing the major catchments, rivers and key hydrological indicator sites,
 82 subject to ecological targets under the Basin Plan (MDBA, 2012a). Inset: location map within Australia.

83 The Act sets out the responsibility for preparing a Basin Plan to an independent statutory federal agency, the
 84 Murray-Darling Basin Authority (MDBA). The objectives of the Act are to uphold international agreements, to
 85 return to environmentally sustainable levels of extraction, to protect and restore and provide for the ecological
 86 values and ecosystem services of the Murray-Darling Basin (floodplains, wetlands, rivers, and the estuary) and
 87 their functions, and to optimise the economic, social and environmental outcomes to the Australian community.
 88 Recovering water from irrigation diversions and re-allocating water as environmental flows (Arthington, 2012) is
 89 the means by which ecological improvement will be achieved. The Basin Plan is a statutory instrument that sets
 90 a legally-binding extraction limit (the environmentally sustainable level of take), it is not a prescriptive blueprint for
 91 ecological restoration.

92 The rationale is that river flows are essential for maintaining ecological condition of rivers and floodplains, driving
 93 ecological processes and the stocks and flows of energy, nutrients and biota (Naiman et al., 2005). In the basin,
 94 river regulation and irrigation water diversion have resulted in changed flow regimes, including shifts in
 95 frequency, duration, extent and seasonal occurrence of high and low flows and flood events, leading to poor

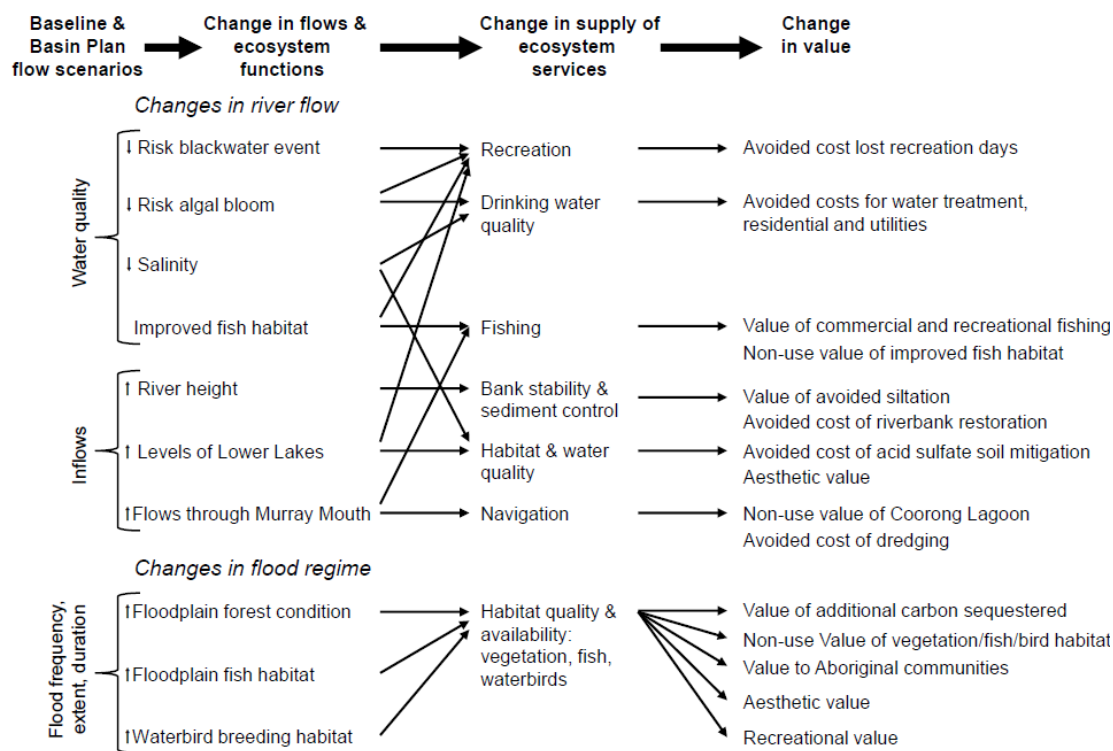
96 condition of flow-dependent ecosystems, fragmentation of vegetation communities and changes in biodiversity
97 and ecosystem function (Vörösmarty et al., 2010). The Basin Plan will re-allocate an annual average of 2,750
98 GL of water, or 20% of baseline average water diversions, to the environment by 2019, with an additional 450 GL
99 by 2024 (Commonwealth of Australia, 2012). To achieve this re-allocation, the Australian Government is
100 purchasing irrigation water entitlements from willing sellers, as well as investing in infrastructure to improve
101 efficiency of irrigation and delivery of environmental water.

102 **Methods**

103 The IESA (CSIRO, 2012) was a “programme evaluation” of the Basin Plan. Our aim in this paper is to reflect on
104 lessons learned in the application of an IESA to inform water reallocation decisions overseen by the
105 Commonwealth government. Here we systematically consider the biophysical, economic and social research
106 reported by CSIRO (2012), as well as the IESA research process. The IESA was subject to peer review by an
107 Independent Science Review Panel (ISRP)¹ and was conducted in a transdisciplinary manner with six workshops
108 in which methodology and results were discussed with stakeholders (cf. Hatton MacDonald et al., 2014 for more
109 detail). A post-IESA review provided the opportunity to fully articulate the development of a conceptual model
110 that underpinned the research project, re-evaluate multiple datasets, models and assumptions and develop
111 confidence scales.

112 An initial step in an IESA is to understand the processes by which ecological and wellbeing outcomes are
113 expected to be achieved. To this end, we adapted a conceptual model based on the generalized framework of
114 Keeler *et al.* (2012). Figure 2 records the flow of logic and outputs used here; it illustrates the steps taken in our
115 integrated valuation, whereby we linked policy intervention through to monetary estimation of incremental ES
116 benefits. We provide detail on each stage below.

¹ The five-person ISRP comprised an economist, two ecologists, a hydrologist and a social psychologist.



117

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

121 **Flow Scenarios**

122 Underpinning the IESA were three river flow scenarios supplied by the MDBA to CSIRO: “Without development”,
 123 corresponding to modelled flows prior to irrigation diversions and water resources development; “Baseline”,
 124 corresponding to modelled contemporary flows without the proposed Basin Plan; and “2,800”, representing
 125 modelled flows following the implementation of the Sustainable Diversion Limit (SDL) where irrigation water is
 126 reduced by an average of 2,800 GL/yr.² Each scenario is based on a 114-year record of simulated flows (1 June
 127 1895 to 30 June 2009) and each preserves the same underlying climatic variability. The marginal benefits were
 128 modelled as if the water resources of the Basin had been managed as per the three scenarios, where each flow
 129 scenario is characterised by different flow and flood regimes that determine the extent and condition of flow-
 130 dependent ecosystems and the ES derived from them.

131 **Ecological modelling**

132 *Vegetation:* Changes in area (ha) of five major floodplain vegetation communities were modelled (river red gum
 133 *Eucalyptus camaldulensis*, black box *E. largiflorens*, coolibah *E. coolabah*, river coobah *Acacia stenophylla*, and

² 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 of water were made after we completed our assessment.

134 lignum *Muehlenbeckia florulenta*) under different flood recurrence intervals (1 in 1, 2, 5 and 10 years) along the
135 River Murray between the 2,800 scenario and Baseline. These communities are widespread, ecologically
136 important and their environmental water requirements are well known (MDBA, 2010; MDBA, 2011). Data on the
137 location and extent of vegetation communities provided by State agencies was overlain with flood inundation
138 modelling outputs from the River Murray Floodplain Inundation Model (RiM-FIM) (Overton et al., 2006).

139 *Fishes*: Habitat suitability scores for native fishes (Young et al., 2003) were modelled for each scenario, for nine
140 different hydro-ecological regions of the River Murray, using the Murray Flow Assessment Tool (MFAT). Four
141 functional groups of fishes were evaluated based on their flow requirements: 'Main channel generalists' spawn
142 and recruit in the main channel regardless of flow conditions, 'main channel specialists' spawn and recruit during
143 high or low flows in the main channel, 'flood spawners' spawn and recruit during periods of floodplain inundation
144 and 'rising-flow spawners' do not require floodplain inundation, but spawning and larval recruitment are
145 enhanced by rising flows. Habitat suitability scores were derived from preference curves for spawning habitat
146 (flood magnitude, spawning timing, rate and duration of flow rise and fall, substrate condition and percentiles of
147 flow) and larval habitat (inundation area and duration, dry period, rate of flow fall and percentiles of flow).

148 *Waterbirds*: The percentage of years in which breeding was likely was calculated at nine important breeding sites
149 for colonially nesting waterbirds for each scenario. Colonially nesting waterbirds require flood events lasting ca.
150 4-7 months. Breeding is successful if thresholds of flood depth and duration are exceeded (Arthur et al., 2012).
151 Most adult female egrets need to breed in most years for populations to be maintained (Arthur, 2011). Outcomes
152 for colonially nesting waterbirds were assessed, using the IBIS decision support system (Merritt et al., 2010),
153 MFAT (Young et al., 2003) or estimates of environmental flows required to meet breeding targets (MDBA,
154 2012a).

155 *Estuary*: The Coorong estuary (Figure 1) is dependent on freshwater inflows. The proportion of time in each of
156 eight ecosystem states (estuarine/marine; marine; unhealthy marine; degraded marine; healthy hypersaline;
157 average hypersaline; unhealthy hypersaline and degraded hypersaline) was modelled for each scenario using
158 the model of Lester and Fairweather (2011). The differentiation of various states was based on water quality and
159 flow variables.

160 *Aboriginal cultural values*: Maps of Aboriginal land use and cultural practices for the Wamba Wamba community
161 of the Edward River and the Werai State Forest were overlain with flow regimes to meet these culturally-
162 important subsistence and spiritual values and modelled ecological outcomes (Jackson et al. 2015).

163 *Water quality*: Salinity concentration, risk of cyanobacterial (blue-green algae) blooms (which render water
164 bodies toxic and unsuitable for recreation), risk of blackwater events (excess dissolved organic carbon leading to
165 low dissolved oxygen and risk of hypoxia to freshwater biota), and risk of acidification of the Lower Lakes from
166 acid sulfate sediments were modelled for each scenario.

167 **Monetary valuation**

168 The monetary values were estimated for incremental changes in cultural and habitat ES and provisioning and
169 regulating ES attributable to differences in flows between the 2,800 scenario and Baseline scenario. While the
170 scenarios have the advantage that they embed the variability in flow regimes recorded in the gauged record
171 (frequency, duration and seasonal occurrence) a consequence of their use is in the valuation stage we do not
172 discount incremental benefits. This is because the scenario approach taken, and required by the MDBA for its
173 purposes, did not require information on the time at which the benefits occurred. Rather it emphasises the
174 importance of long-term water resources management and its effect on ecosystem condition in contrast to
175 outcomes based on shorter-term forecasts that would be strongly influenced by inter-annual variability.

176

177 ***Cultural and Habitat ES***

178 *Aesthetic experience:* An initial hedonic analysis of house prices (2000-2011) were modelled as a function of
179 typical structural, neighbourhood and environmental variables. The modelled values for lake level and flow were
180 used in combination with modelled changes in lake levels and river flow between the two scenarios and
181 extrapolated over nearby properties.

182 *Basin ecosystems:* Incremental changes in modelled outcomes between the Baseline scenario and 2,800
183 scenario in each sub-catchment for floodplain vegetation inundation (as a proxy for condition), availability of
184 spawning habitat for native fish (as a proxy for population growth) and thresholds for colonially nesting waterbird
185 breeding were combined with values from a stated preference study (Hatton MacDonald et al., 2011) and benefit
186 transfer study (Morrison and Hatton MacDonald, 2010). In this paper we update native vegetation outcomes from
187 those in CSIRO (2012) to reflect new ecological modelling. We also revised the valuation approach to adhere to
188 the original stated preference study assumptions in which survey respondents were asked to value a percent
189 change in native vegetation extent from pre-(water) development extent where recovery was capped to 80% of
190 this level. As recovery is expected to exceed this cap in some catchments, we provide capped and uncapped
191 results.

192 *Coorong estuary:* Three estimates of the monetary benefits from a healthier Coorong estuary were calculated
193 based on data from Hatton MacDonald et al. (2011) by: i) transferring the proportional change in the modelled
194 probability of being in a healthy state (Lester and Fairweather, 2011) to the estimated total value of saving the
195 Coorong from ecological collapse (i.e. a non-marginal value); ii) the incremental time spent in a healthy
196 ecosystem state in the 2,800 scenario which is used to calibrate the healthy condition values, and; iii) the total
197 uncalibrated value.

198 *Recreation in the Southern Murray-Darling Basin:* To estimate benefits to general recreational users and to
199 recreational fishers, the reduced risk of cyanobacterial blooms and blackwater events under the 2,800 scenario
200 (12 fewer days annually and 6 fewer years, respectively) were converted to river days open to recreation. These
201 river day estimates were then combined with estimates of future recreationalist numbers by affected catchment
202 based on: i) actual recreation numbers in the period 2003-2010; ii) an estimate of water recreationists based on
203 survey information (DRET, 2010), and; iii) benefit transfer of a general recreational value (Morrison and Hatton
204 MacDonald, 2010).

205 ***Provisioning and Regulating ES***

206 *Climate regulation:* Additional areas of river red gum, black box and coolibah inundated under the 2,800 scenario
207 at hydrological indicator sites were calculated from the percent difference in flow parameters required to meet
208 ecological targets for floodplain trees between the Baseline scenario and 2,800 scenarios (MDBA, 2012a).
209 Annual carbon sequestration at each site was estimated by overlaying a map of hydrological indicator sites with
210 zones of increment in carbon dioxide equivalents (median CO₂e; tonnes per hectare per year) predicted for
211 hardwood carbon plantings across the Murray-Darling Basin (Polglase et al., 2008; Fig. 17 therein) and
212 multiplying the value by the additional area of woodland and forest inundated under the 2,800 scenario. The
213 CO₂e estimates for black box and coolibah were adjusted by a third because these tree species are slower
214 growing than is river red gum. Estimates of CO₂e increments (t ha⁻¹ yr⁻¹) were multiplied by three different carbon
215 prices: AU\$23 per tonne, the initial price placed on CO₂e under the Australian Government carbon tax legislation
216 (Commonwealth of Australia, 2011); the European Union Emissions Trading Scheme price at the end of 2011
217 (AU\$10.50 per tonne; Talberg and Swoboda, 2013, Fig. 2 therein) and an estimate of the benefits of reducing
218 greenhouse gas emissions based on revised 2011 social cost of carbon/marginal damage estimates used by the
219 US government (IWGSCC, 2013; 3% discount rate therein and an annual average exchange rate) at AU\$42 per
220 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.

221 *In the Southern Murray-Darling Basin:* The value of ES improvements linked to water quality improvements were
222 estimated using avoided cost methods. This estimate is entirely separate to recreation values (derived through
223 water quality improvements) because the benefits of water quality are additive: both recreationists and water
224 utilities benefit. A new estimate not found in CSIRO (2012) is of the benefits to the commercial catch in the
225 Coorong and Lower Lakes. This fishery responds to changes in freshwater inflows that affect breeding and
226 recruitment of several commercial species (Ferguson et al., 2013). The relationship between catch and inflows is
227 complex and non-linear (Gilson et al., 2012), but mean annual catch per fisher day during 1984-2008 was 246 kg
228 (derived from total catch divided by fisher days). We estimated a conservative 20% increase in catch per unit
229 effort over the long-term average associated with achieving the Murray-Darling Basin Plan target of average
230 freshwater inflows of >2,000 GL/y in >95% of years and maintenance of average salinity of <60 g/L in the
231 Coorong Southern Lagoon and <20 g/L in the Northern Lagoon (MDBA, 2012b two of these). An increase in

232 annual gross value of AU\$1.54 m based on mean annual gross value of fishery production (2006/07-2009/10) of
233 AU\$7.04 m (EconSearch, 2012; Table 3.2 therein).

234 *Water and Soil Quality ES*: A suite of water and soil quality regulating ES benefits were estimated using avoided
235 cost estimates for ES losses and hazard damage catalogued during the 1997-2009 drought (Banerjee et al.,
236 2013) and biophysical thresholds, e.g. minimum lake height linked to acid sulfate soil formation in the Lower
237 Lakes region, and a minimum Mouth Opening Index (Close, 2002) linked to Murray mouth sedimentation. For
238 erosion prevention the threshold was minimum river height based on a 4-year consecutive low-flow proxy:
239 widespread bank instability and bank collapse has been linked to low river height which desiccated the banks
240 leaving them unstable (Liang et al., 2012).

241 **Valuation of benefits to the Aboriginal community**

242 To estimate the benefits accruing to the Wamba Wamba we used two sets of modelled results: the frequency
243 that environmental flows (the 2,800 scenario) met Aboriginal cultural values based on land use, occupancy and
244 'bush tucker' maps; and an estimate of supplementary flow requirements to meet unmet values.

245

246 **Results**

247 There is evidence that returning river flows and restoring flood regimes to a major drainage basin results in large
248 ES improvements. The largest monetary values estimated were for the supply of habitat: this value likely also
249 captures the socio-cultural significance of the basin and the importance of indicator sites for ecosystem health
250 across the basin (Johnston et al., 2012). Other examples, were higher lake levels (Australian Height Datum)
251 were found to be positive and significant determinants of house prices in the Coorong and Lower Lakes region of
252 South Australia, as were higher river flows near the Barmah-Millewa Forest and the Lower Darling and mid-
253 Murrumbidgee wetlands in New South Wales. Table 1 summarises the metrics, models used, levels of
254 uncertainty and monetary valuation estimates.

255

256 To better support decision making, we also provide confidence levels for the IESA. We assigned confidence to
257 the modelling and valuation using the following criteria: i) consistency between different models and other
258 research; ii) robustness of methods used to derive the data (e.g. a maximum confidence level of 'medium' was
259 assigned to those monetary estimates based on avoided costs methodology), and; iii) degree of congruence
260 between the spatial scale of data, models and the ES. Confidence levels were assigned to a recognized five-
261 point scale (Mastrandrea et al., 2012). Assignment of 'low' confidence indicated greater reliance on expert
262 opinion and limited evidence to support the assumptions in a model. A 'medium' value indicated supporting
263 evidence for several aspects of the model, whereas a 'high' confidence indicated minimal or no assumptions. No

264 assignment of 'very high' confidence was made because of time constraints on the validation of primary source
265 data.

266 Table 1: Data, models, valuation methodology and monetary values of, and confidence levels in, incremental
267 ecosystem service benefits. Abbreviations: AC = avoided costs; BT = benefit transfer, CM = choice modelling;
268 MO = mouth opening; ESLT = environmentally sustainable level of take.

Ecosystem service	Data / metrics	Biophysical / ecological Modelling	Economic Valuation	A\$ million	Confidence	
					Biophysical	Economic
Regulating Services						
Carbon sequestration	Area of woody perennial vegetation in good condition & annual rates of growth and carbon sequestration	RiM-FIM (Overton et al., 2006); modelling to support ecological targets (MDBA, 2012b); growth modelling of carbon plantings	Carbon price (Commonwealth, 2011)	50.0	Low to medium - RiM-FIM used for Murray; Basin Plan hydrological models used for other sites	Medium - values same in southern and northern Basin, no risk discount
Moderation of acid sulfate soil formation	Lower Lakes height threshold	MDBA hydrology (MDBA, 2012b)	AC (Banerjee et al., 2013; CSIRO, 2012)	9.2	High - lake level height data	Medium - AC methodology southern Basin issue
Moderation of sedimentation	End-of-system flows & MO Index	MDBA hydrology (MDBA, 2012b) Threshold MO Index (Close, 2002)	AC (Banerjee et al., 2013; CSIRO, 2012)	17.8	High - established model	Medium - AC, southern Basin issue
Maintenance of bank stability	River in-channel height & threshold	MDBA hydrology (MDBA, 2012b) Threshold river height (CSIRO, 2012; Liang et al., 2012)	AC (Banerjee et al., 2013; CSIRO, 2012)	23.7	Low - no river height data	Medium - new methodology, southern Basin issue
Provisioning Services						
Floodplain grazing	Ha floodplain grazing	Estimates (GHD, 2012) based on MDBA flow duration curves & overbank flows	BT (GHD, 2012)	32.2	Medium - different methodology	Medium - different methodology

Fresh water quality	Salinity concentration	MDBA hydrology (MDBA, 2012b) & BigMOD salinity model	Productivity losses and AC utilities & users (GHD, 1999; Allen Consulting Group, 2004), probabilistic calculation (Banerjee et al., 2013; 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	Hydrological risk model (CSIRO, 2012)	AC (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 & years of low barrage flow	Estimated increase in catch per unit effort & proportion gross production value (EconSearch, 2012)	1.5	Low - not based on ecological response model.	Low – different methodology, comparable study estimates increase in producer surplus of AU\$2.6 (EconSearch, 2012)
Cultural Services						

Aesthetic appreciation	House prices in basin 2003-2010, historic & modelled river flows & lake level height	MDBA hydrology (MDBA, 2012b)	Hedonic models (CSIRO, 2012)	337.0	High - Modelled lake levels Medium - Modelled river flows. Four regions only	High - Project-funded study, visible link lake height, exposed banks for nearby homes Medium - Project-funded study, river flows proxy for river health, regional economy, recreation.
Indigenous values	Geocoded cultural & 'bush tucker' (food) sites for Wamba Wamba People	Response models: native fish, vegetation water fowl, linked to land use, occupancy & 'bush tucker' maps (CSIRO, 2012)	Qualitative only	No dollar value ascertained	Medium - no explicit modelling of beneficial flows, but expert judgment of ecological responses (MDBA 2011) and a methodology developed (Jackson et al. 2015)	Medium - Qualitative assessment, but one that relied upon local sites of interest and opinions of affected community

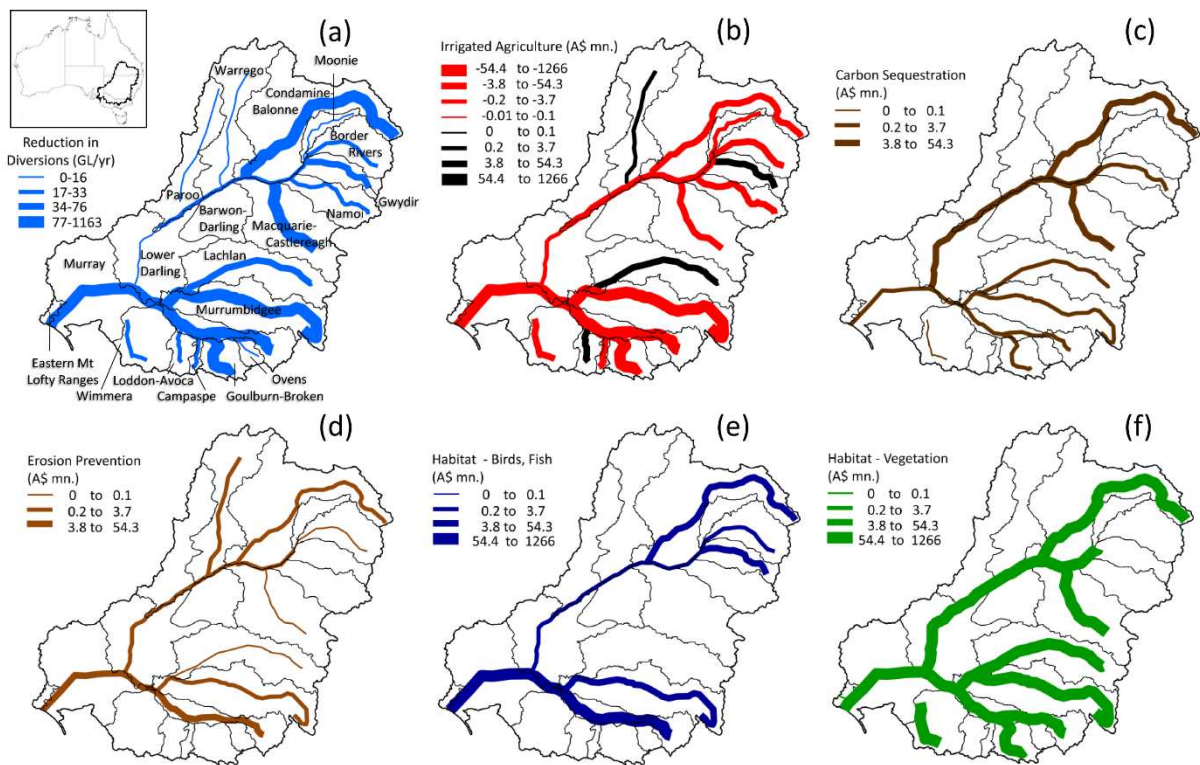
Recreation & tourism	Increased flows, additional days with water quality adequate for recreation	Changes in good flow days	Recreation & tourism numbers (CSIRO, 2012) BT values (Morrison & Hatton MacDonald, 2010)	161.4	Low - correlation only as no model that links visitation rates with changes in flow	Low - multiple assumptions, BT value unrelated to flow
		Changes in cyanobacterial bloom & blackwater risk - days with adequate water quality for recreation (CSIRO, 2012)	BT (Deloitte Access Economics 2012)	10.3-20.6	High - modelling of water quality risk combined with health alerts	Low - multiple assumptions, BT unrelated water quality
		Improved conditions for recreational fishing (Deloitte Access Economics 2012)		107.0	Medium - different assumptions	Medium - consumer surplus
Habitat Services						
Native vegetation	Floodplain vegetation mapping (various sources)	Modelled area of inundation for dominant floodplain vegetation communities (Overton et al., 2006)	southern Basin CM (Hatton MacDonald et al., 2011) & BT (Morrison & Hatton MacDonald, 2010)	1,902.4 (capped) 2,110.0 (uncapped)	Medium - southern Basin vegetation response model extended to northern Basin using ESLT data	High - MDBA-funded study, southern Basin extended to northern Basin using reproducible method
Native fishes	Habitat suitability of native fish guilds	Response relationships derived, predictions based on habitat suitability for recruitment (Young et al., 2003)	southern Basin CM (Hatton MacDonald et al., 2011) & BT (Morrison & Hatton MacDonald, 2010)	339.9	Low - habitat suitability model has limited validation	Medium - MDBA-funded study, based on targets from Native Fish Strategy, southern Basin

Colonially nesting waterbird breeding	Frequency & extent of habitat suitability for nesting & fledging of colonially nesting waterbirds	Environmental water requirements; ecological response models (Merritt et al., 2010); bird breeding & inundation modelling (Arthur et al., 2012)	southern Basin CM (Hatton MacDonald et al., 2011) & BT (Morrison & 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, southern Basin transferable to northern Basin: breeding event is equally ecologically valuable but may be tempered by scope effects
Coorong, Lower Lakes & Murray Mouth	Duration in healthy state	Ecological response model of ecosystem states (Lester et al., 2011)	southern Basin CM (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

269

270 Table 1 provides no information on the spatial distribution of benefits therefore we produced a series of maps
271 that can be useful to communicate the array of ES benefits (Hauck et al., 2013), to visualize benefits and losses
272 across space, and to inform regional economic development policy (Bateman et al., 2013). Figure 3a displays
273 the relative proportions of additional water available to the environment by catchment (MDBA 2012a; MDBA
274 2011). Figure 3b shows a key policy trade-off from the re-allocation: the distribution of estimated costs to
275 irrigated agriculture with reduction in gross value of production (ABARES, 2011) are strongly negatively
276 correlated ($R^2 = 0.87$) with reductions in sustainable diversion limits, but in four catchments there are modest
277 estimated increases in the value of irrigated production. Figures 3c-f illustrate the spatial nature of benefits. River
278 flow is a critical driver for many ES benefits, for example, increases in mean annual carbon sequestration tend to
279 be relatively large throughout the basin (Figure 3c) and are strongly positively correlated with increases in river
280 flows, as are habitat ES for native species (Figures 3e, 3f), and provisioning and cultural services.

281



282
283

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

293 **Discussion**

294 The Basin Plan is a water sharing plan that seeks to restore water-dependent ecosystems and optimise social,
 295 economic and environmental outcomes within a multi-jurisdictional basin. Restoration requires changes to flow
 296 and flood regimes. Under the Basin Plan 2012, an average 2,800 GL/yr of water once allocated to irrigators will
 297 be re-allocated to the environment. Water re-allocation at this scale has the scope to improve the current
 298 condition of ecosystems in the Basin and to supply a suite of enhanced ES that benefit human wellbeing. Our
 299 case study demonstrates that an IESA can produce policy relevant information, not only on the condition of, in
 300 this case, flow-dependent ecosystems, but also provide monetary and non-monetary valuation of incremental
 301 changes.

302

303 In Crossman et al.'s, (2015) review of CSIRO (2012), the authors discuss four advances of using the ES
 304 approach to support decision making. The central aim of this paper is to advance discussions of mainstreaming
 305 IESA and to report on the post-project learnings. The Methods section makes evident the prerequisite ecological
 306 modelling and interdisciplinary integration to undertake an IESA. In the introduction we identified three criteria for
 307 an integrated ecosystem services assessment: that it provides salient, credible and legitimate information to
 308 policy makers (Cash et al., 2003), where salience is defined as the relevance of the ES assessment to the needs
 309 of decision-makers; credibility as the scientific adequacy of the research and legitimacy as an expression that the
 310 researchers acknowledged diverse stakeholder values and beliefs and were unbiased in their treatment of
 311 opposing views and interests. Table 2 summarises the different types of integration we achieved – of values,
 312 variables, and scales – in relation to the criteria. It also extends the findings of Hatton MacDonald et al. (2014),
 313 where users of the CSIRO (2012) report were surveyed and provides examples of tools to better support
 314 decision-making, such as confidence heuristics (CH), maps, comprehensive summary material (Table 1), a
 315 conceptual model (CM) and elements in the research process, specifically, ISRP review and participatory
 316 approaches (PA) including stakeholder engagement to determine comprehensive coverage of all values (e.g.
 317 Jackson et al, 2012).

318
 319 Table 2: Integration for policy-making. Square bullets indicate tools to better support decision-making.
 320

Integrating factor	Salience	Credibility	Legitimacy
Values	Biophysical modelling demonstrated ecological benefits and large monetary values of ES that were used in the MDBA Regulation Impact Statement of the Basin Plan to Federal Parliament (MDBA, 2012a). <ul style="list-style-type: none"> ▪ CM ▪ Table 1 ▪ Maps 	Biophysical modelling was viewed as credible (Hatton MacDonald et al., 2014) but there were issues with monetary values, e.g. the retrospective analysis, BT and AC. <ul style="list-style-type: none"> ▪ ISRP ▪ CH incorporate a consistency with other studies criterion 	Inclusion of different values and knowledge types, i.e. Aboriginal knowledge, widens scope of inquiry and coverage of interests. Some questioned the use of CM values from outside of basin. <ul style="list-style-type: none"> ▪ PA
Scale	Whole-of-basin required by MDBA. <ul style="list-style-type: none"> ▪ Table 1 lists scale of assessment. 	Few of the models and valuations are at basin scale, however, not all of the ES are at this scale. <ul style="list-style-type: none"> ▪ CH incorporate a scale criterion 	Greater spatial specificity of ES benefits and disbenefits was required by States and regional stakeholders (Hatton McDonald et al., 2014). Enables targeted policy responses <ul style="list-style-type: none"> ▪ Maps
Variables	Information is provided on the condition of flow dependent ecosystems and incremental ES benefits. However, sometimes	Based on the best available biophysical science and biophysical thresholds for valuation. Nevertheless, there is possibility of	Omitted variables, e.g. pollination benefits, social measures. <ul style="list-style-type: none"> ▪ PA

	proxies are used, e.g. fish habitat suitability not fish populations. <ul style="list-style-type: none"> ▪ CM 	correlated variables, i.e. the CM, hedonic, and AC values. <ul style="list-style-type: none"> ▪ ISRP ▪ CH incorporate a method criterion 	
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321

322 There are operational challenges to integrating different value systems in IESA. This includes a tension between
 323 Table 1 and 2. While post-project we assigned a low confidence level to some ecological modelling, the same
 324 results were viewed as credible by the research users (Hatton MacDonald et al., 2014). There are also tensions
 325 among the three criteria in Table 2. For example, integration of values in a settler colonial state such as Australia
 326 requires the inclusion of Aboriginal cultural benefits. Traditional owner interests have historically been excluded
 327 from Basin water governance (Bark et al., 2011) but are now given modest consideration under the Water Act
 328 and the Basin Plan. However, while a traditional cost-benefit rests on aggregating individual welfare measured in
 329 dollar values using quite specific economic methodologies, an IESA does not necessarily require a common
 330 numéraire.

331 A key operational challenge is the timeframes required for careful consultation with rural communities³ and
 332 marginalised Aboriginal groups more specifically (Jackson et al. 2012). Developing up-to-date, fit-for-purpose
 333 metrics that are deemed valid and appropriate across cultures may not be possible in the tight timeframes
 334 required by central agencies requesting economic analyses of a programme or of regulatory impacts (Jackson et
 335 al. 2014). The values expressed by the Wamba Wamba in their land uses and cultural practices maps could be
 336 seen as deliberative responses by individuals with complex social relationships. While relevant for decision-
 337 making generally, such deliberative values would be treated as indicative at best in a traditional cost-benefit
 338 analysis. Yet, a deliberative, participatory approach that brings historically disenfranchised groups together with
 339 scientists and water managers can help build trust and relationships that could prove beneficial for future water
 340 management (Ascher and Steelman, 2006).

341 Further, the inclusion of out-of-basin (e.g. of Sydney residents) non-use values fits with the objective of the Water
 342 Act 2007 to maximise benefits to the Australian community, yet to some the inclusion of these values
 343 undermined the legitimacy of the monetary valuations (Hatton MacDonald et al., 2014). The avoided cost
 344 approach although common when valuing provisioning and regulating ES (Faber et al., 2006) also has problems
 345 (Bockstael et al., 2000; UNSRC, 2005). To address these, we utilised biophysical and political thresholds (see
 346 Banerjee et al., 2013). Finally, many of monetary estimates were based on benefit transfer. A consideration in
 347 using benefit transfer is the fulfilment of all three NOAA (1996) criteria for good benefit transfer: i) close
 348 correspondence of sites; ii) comparability of change in quality or quantity of ES, and; iii) correspondence of

³ Since our IESA a large study on the well-being of rural communities, including those in the Murray-Darling Basin, was commissioned which provides self-reported assessments of well-being and resilience at points in time (Schirmer et al., 2016).

349 quality of studies. The IESA, for most ES valued, satisfied criteria (i) and (iii) by using recent peer-reviewed
350 Australian valuation studies for closely matched types of benefits, most of which were undertaken within the
351 basin but not at the whole-of-basin scale. Integrated valuation simplifies the task of meeting criterion (ii) because
352 valuation studies measure benefits in different ways (e.g. areas of river red gum, change in habitat suitability of
353 fishes, numbers of waterbird breeding events per decade, value of a recreation day per person), and there is no
354 guarantee that without an integrated study that these metrics coincide with outputs of ecosystem response and
355 water quality models. Overall the comprehensiveness of the IESA meant that some estimates of monetary value
356 were from reports, not peer-reviewed literature, or required numerous assumptions (e.g. for recreation), and
357 often assumed the relationship between flow, ecological responses and benefits was linear, and that diminishing
358 marginal returns were not a factor, e.g. the uncapped basin ecosystems monetary value estimate assumes
359 marginal values do not diminish beyond the 80% threshold. In summary there remains a need for coupled
360 ecological and monetary valuation research to better understand nonlinear and interdependent ecological
361 responses.

362 For integration over scale, we note a tension between scaling up and scaling down. Ecological models were
363 sometimes extended to another part of the basin to underpin the integrated valuation and while this was seen as
364 fit for purpose at the federal level; it was used in the Regulation Impact Statement (MDBA, 2012a) submitted to
365 the Australian Parliament (salience), it was not deemed as useful for policy purposes at the State level
366 (legitimacy). This tension between broad-scale assessment that is relevant and applicable to policy scenarios
367 and the need for finer-scale, scalable, functional analysis of a single ES (Nelson, et al., 2009), to inform trade-off
368 decisions and achieve multiple benefits, is likely to emerge in iterations of water sharing plans by State water
369 planners. This is because the conventional approach to modelling in the basin is based on icon (sites of
370 inter/national ecological significance) site analyses which may not reveal the benefits that are realised at smaller
371 scales as flows move through the basin. The IESA can reveal local values and on a practical level state water
372 planners may wish to incorporate locally-important site-specific targets or flow-specific rules aimed at enhancing
373 local and Aboriginal valued ES (Robinson et al., 2014).

374 Operationally to address concerns of credibility and legitimacy, we incorporated review, participatory approaches
375 and maps. Review and participatory approaches enabled knowledge exchange and communication of the data,
376 methodology and results (Villa et al., 2014). In addition, our post-project assignment of confidence levels for the
377 biophysical and valuation results provides context for stakeholders and decision-makers in the basin. Over time
378 as new data accumulates confidence levels can be re-evaluated. Maps showed that for some ES, the restoration
379 of flow regimes is insufficient to realise benefits, for example, improvement in habitat for native fishes. A future
380 assessment might include consideration of how installation of pipelines, regulators, weirs, pumps, as well as, for
381 instance the provision of fish ladders to aid spawning migrations, the restoration of physical habitat and control of
382 exotic invasive fishes could affect potential trade-offs and synergies in achieving ES outcomes. Further, when
383 Figures 3a-f are viewed together, it is clear that there are winners and losers in each catchment. Such a

384 realisation might help shift the policy debate from one of contested values towards policies aimed at reducing
385 losses and maximising benefits, as well as directing attention to the need for inclusive processes that enable
386 stakeholders to deliberate over policy options and their impacts to engender improved community confidence in
387 water planning (Tan et al., 2012).

388 The monetary benefit values in CSIRO (2012) were used in federal parliamentary submissions (MDBA, 2012a),
389 indicating that a BCA was salient for their needs. However, the integrated valuation provided credibility and
390 legitimacy that was not provided by the BCA alone. Credibility was partially achieved through rigorous ecological
391 modelling, and the identification of biophysical thresholds for the monetary valuation. The broad scope of the
392 IESA, derived from the objectives of the Water Act, helped provide legitimacy. The comprehensive, whole-of-
393 basin ES assessment embodied a wide range of issues that people care about, including biodiversity values and
394 cultural values of flow-dependent ecosystems. The explicit consideration of ES in the Water Act not only marks a
395 shift in water management in Australia but meant that for the MDBA to gain evidence on the state of the supply
396 of ES, it commissioned an IESA not a BCA. The process represents a step in the evolution of a policy-science
397 action arena. The IESA complements recent initiatives, such as those in the UK, to develop natural capital
398 accounts with a focus on types of ecosystems and their extent and dynamic condition (e.g. Khan and Din, 2015).

399 **Conclusions**

400 The supply of ES for human wellbeing is dependent on the linkages between abiotic drivers of ecosystem
401 function, ecological responses resulting in changes in rates of ecosystem functions and, hence, the supply of ES.
402 In practice, an IESA relies on prior investments in data collection, model development, valuation studies and on
403 researchers working in interdisciplinary teams. The Murray-Darling Basin has been the focus of considerable
404 investment in biophysical and social sciences research. Despite such efforts, confidence in some aspects of the
405 IESA was low. Ideally, integrated models would be developed that are capable of providing integrated
406 biophysical, economic and social information required to assess large-scale environmental policy options.

407 The existence of the water crises that necessitated a Basin Plan, and the multiple objectives the Plan seeks to
408 simultaneously attain, highlight an implicit schism in public values relating to water. Water for the environment is
409 considered by some segments of society as an unproductive use in comparison to consumptive uses. Whilst this
410 IESA provides evidence that water for the environment represents a resource that provides and sustains multiple
411 benefits to a broad range of stakeholders and for human wellbeing, it in turn contains a cautionary insight. If we
412 are to better appreciate the full range of benefits from human use and management of ES, we will need to
413 ensure that monetary outcomes do not exclude all other forms of value in the approaches we take and in public
414 discourse and decision-making.

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421

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