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Ecosystem services from the Coorong, Lakes Alexandrina and Albert Ramsar site

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Executive summary

Critical components, processes and services (CPS) have been identified as part of an update of the Ecological Character Description of the Coorong and Lakes Ramsar site. We present the evidence base for the supply of 26 ecosystem services from the Coorong and Lakes Ramsar site. Of these, the most important for human well-being based on income generation are commercial and recreational fisheries, irrigation and domestic water supply, flow connectivity and water quality, habitat and resource provision for biodiversity, tourism and recreation. All are dependent, directly or indirectly, upon the flow regime as the over-arching driver of the ecological character of the site. Reductions in freshwater inflows and consequent increases in salinity and low lake levels during the Millennium Drought (1999-2009) led to reductions in supply of some major ecosystem services, though there is some evidence of recovery after the drought broke in 2010. Historical water resource development has led to deterioration in ecosystem condition. Under climate change, unless water allocation arrangements are altered, flows to the site are likely to decrease. Salinity in the Lakes increases as barrage outflows to the Coorong decline. Supply of some ecosystem services is likely to decline where altered flows and salinity are linked directly or indirectly to ecological components, habitat availability and ecosystem processes. Continued decline in flow, and increase in salinity, as primary determinants of the ecological character of the site due to climate change is likely to lead to major shifts in the nature and extent of supply of ecosystem services in the future. The determination of those ecosystem services that can continue to be supplied under climate change is an urgent priority and should include an assessment of those ecosystem services that will need to be managed for in the future in order to ensure supply and the successful adaptation to climate change for those communities that depend upon those services for their livelihoods.

1 Introduction

The basis of the Ramsar Convention is the conservation and wise use of wetlands. Implicit to this is the sustainable management of the benefits, or ecosystem services, that contribute to human well-being. Accordingly, the wise use of wetlands is defined as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development" (Ramsar Convention Secretariat, 2013).

The recognition that wetlands provide a wide range of ecosystem services means that those benefits should be considered in decision-making that influences the conservation and sustainable management of wetlands. There is a strong, direct, sequential set of linkages between water quantity and quality, ecosystem functions, processes, structure and character, the provision of ecosystem services and human well-being (Millennium Ecosystem Assessment, 2005a; UK National Ecosystem Assessment, 2011; Russi *et al*., 2013; Vidal-Abarca *et al*., 2014). Several regulating and supporting services are either synonymous with, or closely linked to, ecosystem functions. These include hydrological regulation, habitat provision for biodiversity, nutrient cycling and regulation, primary and secondary productivity and water purification. Thus managing for process, functions and character means that ecosystem services and human well-being are central to the conservation and management of wetlands.

In the process of listing a wetland for Ramsar status, a description of ecological character is prepared and limits of acceptable change in ecological character (or limits for defining change in ecological character) are set. These underpins the site management plan. For the Coorong, Lakes Alexandrina and Albert Ramsar site (hereafter, the Coorong and Lakes Ramsar Site), the original listing was in 1985. An update of the ecological character description prepared by Phillips & Muller (2006) is presently being undertaken due to the availability of further substantial data, knowledge and resources so as to provide a more comprehensive baseline description, meet the Commonwealth's updated guidelines (DEWHA, 2008) and in response to the notification to the Ramsar Secretariat in 2006 of potential changes in the ecological character of the site (Butcher, in preparation). Prolonged low inflows to the Coorong and Lakes Ramsar Site during the Millennium Drought (1997-2010) has resulted in deterioration of habitat quality and major population declines in components of the biota that are important in ecosystem function, including *Ruppia* spp., macroinvertebrates and certain fishes. There are some signs of recovery in some components of the biota since the return of wet conditions in 2010

Identification of the many values and benefits that wetlands provide to humans is the first step in achieving a broader understanding and appreciation of the ecosystem services that provide those benefits, and the ecological functions and processes that underpin those services. From this basis, management actions and policies can be designed, implemented and adjusted in order to support services and functions that are considered critical to the maintenance of the site's ecological character. Trade-offs between co-occurring groups or 'bundles' of services can be made according to shifts in their supply or demand over time. For services from aquatic ecosystems, shifts in supply are likely to be underpinned by changes in water quality and quantity as they affect ecosystem functions. Shifts in demand relate to changing use priorities driven by social and economic considerations, such as between water for irrigation and the environment.

Our objectives in this report are to: 1) assemble the evidence base for the ecosystem services provided by the Coorong and Lakes Ramsar site; 2) determine the ecosystem services that are linked to ecological components and processes that have been identified as being critical to the ecological character of the site; 3) provide information that can aid the setting of limits of acceptable change in components, processes and services (CPS).

1.1 Biophysical setting and ecological drivers

The Coorong, Lakes Alexandrina and Albert Ramsar Site covers 142,530 hectares. Details can be found in the Ramsar Information Sheet (DEWNR, 2013a). The Coorong is a long, shallow brackish to hypersaline lagoon 140 km in length that is separated from the Southern Ocean by a narrow sand dune peninsula (Fig. 1). The Lakes Alexandrina and Albert form the mouth of the River Murray and are predominantly fresh water. Lakes Alexandrina and Albert is separated from the Coorong by a series of barrages (Goolwa, Mundoo, Boundary Creek, Ewe Island, Tauwitchere) completed in 1940 to maintain lake levels for water supply and protect water quality in the Lakes and Murray channel from sea water incursions(Linn, 1988; p. 180). Wetlands included are:

- Lake Alexandrina including Tolderol, Mud Islands and Currency Creek Game Reserves, otherwise mainly Crown Lands;
- Lake Albert - mainly Crown Lands;
- Tributaries including the Finniss River and Currency Creek;
- Coorong – mainly covering Coorong National Park and Game Reserve, otherwise mainly Crown Lands.

The site supports critically endangered, endangered, threatened and vulnerable species and ecological communities. outline that it supports Extensive and diverse waterbird, fish and plant assemblages are dependent upon on its complex mosaic of wetland types (Phillips and Muller, 2006). The area is a popular recreational site, while also supporting a range of commercial activities related to tourism, irrigated agriculture, and commercial fishing most notably. The Ngarrindjeri people have a long association with the Coorong and Lower Lakes and the site has great cultural significance for them.

Historically, the Coorong received inflows via groundwater and surface water from the high rainfall region of south-east South Australia. Drainage channels built in the 1930s have altered inflows, diverting a substantial portion of the surface water to the sea (Williams, 1974; Fig. 63, pp. 178ff therein). The Upper South East Drainage Scheme has involved restoration of inflows, with proposals to further enhance inputs into the Coorong in the future (DfEF, 2009). The excess of evaporation over inflows in the Coorong makes its water hypersaline, drawing in more dilute seawater (Lester *et al*., 2013). Salinity is buffered by flow over the barrages, with flows of 3,000-10,000 GL (rolling two year average) equating with salinities in the North Lagoon of 15-25 g/L and flows of 300-2,000 GL with salinities of 30-45 g/L (MDBA, 2010; Lester *et al*., 2011). Barrage flow also determines water height and exposure of mudflats for foraging habitat for waterbirds.

1.2 Spatial and temporal partitioning of ecosystem services

Supply of particular ecosystem services is dependent upon salinity and water height which, in turn, are dependent upon barrage flows and their interaction with local rainfall and temperature (Webster, 2012; BMT WBM, 2014). Spatial partitioning between the freshwater and estuarine ecosystems within the site is apparent for most sets of services: for example, aquatic food as an ecosystem service is supplied from either side of the barrage, but the relevant species differ. Changes over time in the nature and extent of the provision of particular services can be linked to those parts of the site that have been most affected by changes in salinity and water levels, particularly the South Lagoon and Lake Albert, and the extent, duration and persistence of different ecosystem states (Lester & Fairweather, 2009). Some examples follow. For provisioning services there are differences between estuarine and freshwater ecosystems in target species and the sustainability of stocks for commercial and recreational fisheries. Access to irrigation water from the Lake Alexandrina declined during the Millennium Drought due to falling lake levels, necessitating pipeline construction to ensure supply from upstream in the River Murray. For regulating services, buffering against the detrimental environmental effects from oxidation of pyrite in acid sulfate sediments is an issue for the Lower Lakes, but not for the Coorong. For cultural services, tourism and certain recreational activities are partitioned according to access, water levels, water quality, and the nature of the activity. For supporting services, primary productivity from *Ruppia tuberosa* in the Southern Lagoon has declined dramatically due to increased salinity and lower summer water levels (Rogers & Paton, 2009; Paton and Bailey, 2012). Limited recolonisation has occurred the resumption of barrage flows in 2010/2011 (Frahn *et al*., 2012).

Pollino *et al*. (2011) assessed the environmental water requirements for the Coorong, Lower Lakes and Murray Mouth, as well as modelled outputs of whether the requirements are likely to be met under the Murray-Darling Basin Plan. “Supporting in-stream functions: Coorong, Lower Lakes and Murray Mouth” was listed as one of ten environmental watering priorities for MDBA for 2013/14 (MDBA, 2013).

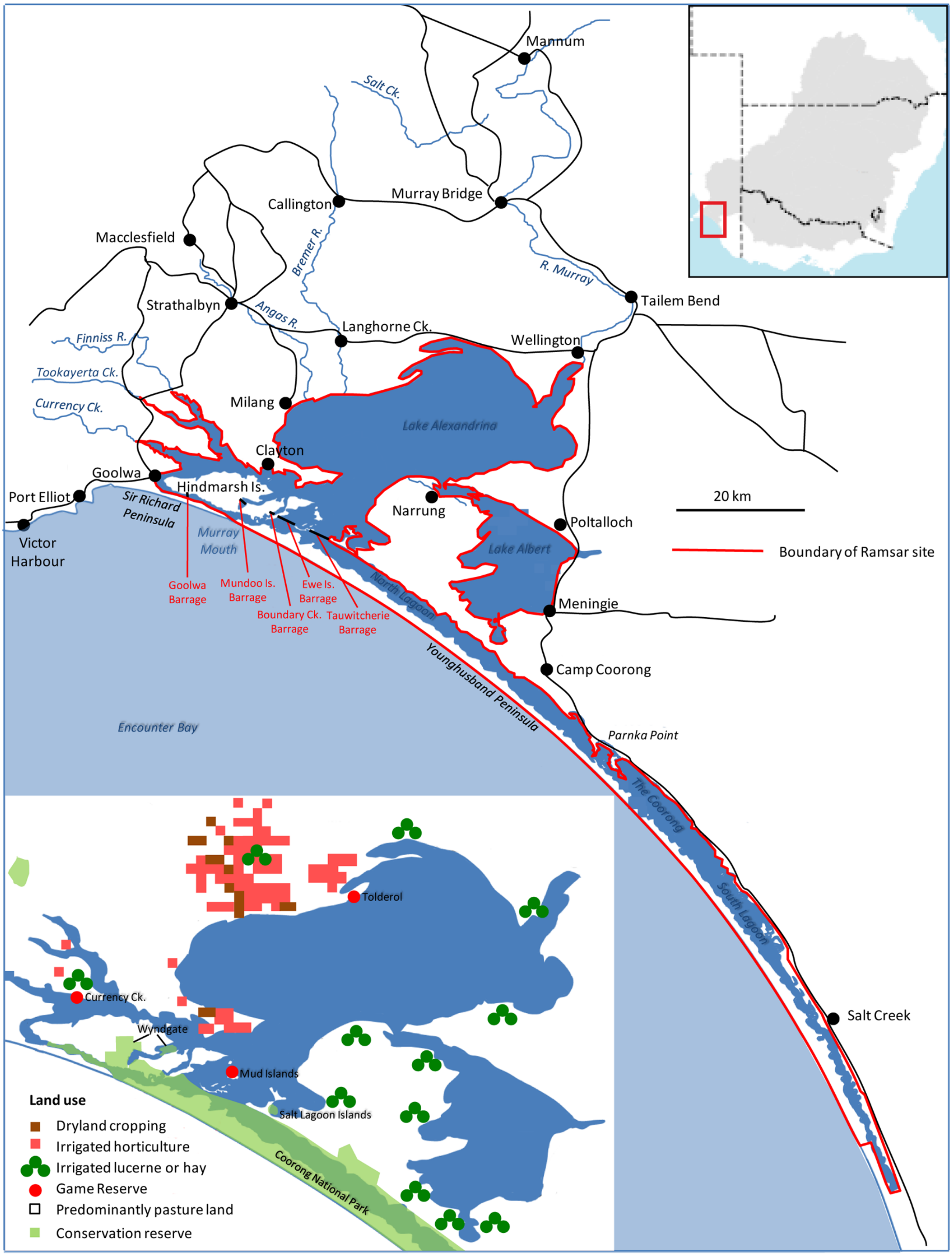

Figure 1. The Coorong and Lower Lakes Ramsar Site and surrounding region showing land uses. Area of irrigated horticulture is based on CSIRO (2007).

2 Ecosystem services of the Coorong and Lakes Ramsar site – the evidence base

2.1 Introduction and scope

Ecosystem services – some underpinning concepts

The ecosystem services concept was intended as a means to help people recognise the benefits they derive from nature and 'natural capital' (Dailey, 1997), and to encourage the conservation of ecosystems. It has become central to sustainable development, combining environmental and economic management and decision-making (UNEP, 2011; Bateman *et al*., 2013). In the following section we outline three features of the ecosystem services concept– typologies, supply and demand and trade-offs – and their entailments for policy, management and decision-making regarding the Coorong and Lakes Ramsar site.

Typologies

Typologies, or classifications, of ecosystems services vary according to their use and the operational setting in which they are applied (Haines-Young and Potschin, 2010). The typologies used in environmental accounting are designed to avoid 'double counting' and are quite different from the Millennium Ecosystem Assessment (2005b) framework that was developed primarily to raise awareness of how ecosystems are being degraded worldwide. The latter classification is based on the four broad categories of *provisioning*, *regulating*, *cultural* and *supporting* services, with the first three linked directly to aspects of human wellbeing (Figure 2a). Supporting services represent those services, or ecosystem processes and functions, that result in the production and availability of services in the other three categories.

In some classifications services are regarded as synonymous with benefits to people (Millennium Ecosystem Assessment, 2005b; Wallace, 2007). In others, they are classed as distinct, with benefits being derived from services (Boyd & Banzhaf, 2007; Fisher & Turner, 2008). Recreation – often regarded as an ecosystem service – is thereby considered the product of ecosystem services as well as conventional goods and services required for people to experience benefits from recreation. The example used by Boyd & Banzhaf (2007) of recreational angling requires the ecosystem services of surface water and fish populations but also conventional goods and services of tackle, boat, time allocation and access. Angling itself, or fish caught, is not a measure of an ecosystem service because catch also depends on tackle (and angling skills), not just that fish are supplied as an ecosystem service. The ecosystem service 'final products' are therefore the fish population, the surroundings and the water body. Boyd & Banzhaf (2007) define *final* ecosystem services as 'components of nature, directly enjoyed, consumed or used to yield human well-being.'

The UK National Ecosystem Assessment (20011) distinguishes between 'intermediate ecosystem services', 'final ecosystem services' and 'goods'. Fisher & Turner (2008) and Costanza (2008) considered that as long as human welfare is affected by an ecological function, then that function should be regarded as an ecosystem service. Some ecosystem processes may also be services, either intermediate or final ones or both. By this definition, pollination by insects is a biodiversity-dependent ecosystem service and ecosystem process that people use indirectly in order to enjoy the benefits of those foods from flowers, fruits and seeds that are dependent upon insect pollination for their production. According to Boyd and Bazhaf (2007) and Wallace (2007), the food is the ecosystem service. According to the UK National Ecosystem Assessment (20011), pollination is an ecological process or an intermediate ecosystem service, the production of crops is a final ecosystem service and the supply of food (which requires other capital inputs) is deemed a good.

The importance of multiple typologies of ecosystem services is that they highlight that relationships between ecosystem functions, services and human well-being are conceptualised differently according to varying perceptions of the benefits that people derive from nature. How ecosystem services are perceived shapes conceptual models and narratives of the value of nature to human well-being and how ecosystems should be used and managed; and for whom by whom. This in turn feeds into debates about priorities for conservation, natural resource policy and management and trade-offs associated with decision-making.

Supply and demand

The ecosystem services concept started as a simple market-based metaphor of nature as a stock that provides a flow of services. This metaphor was intended as a means of engaging with a public perceived as integral to the global economy but that had become detached from the environment. Ecosystem services is essentially an economic concept, with all of the limitations that economic constructs entail for the assessment of global environmental change and for solutions to complex challenges to social-ecological systems (Norgaard, 2010). In short, such systems lack clear boundaries, have complex and non-linear dynamics and feedback mechanisms and there is a high degree of contestability regarding how they are perceived and managed. These are not characteristics that have proved tractable to economic approaches.

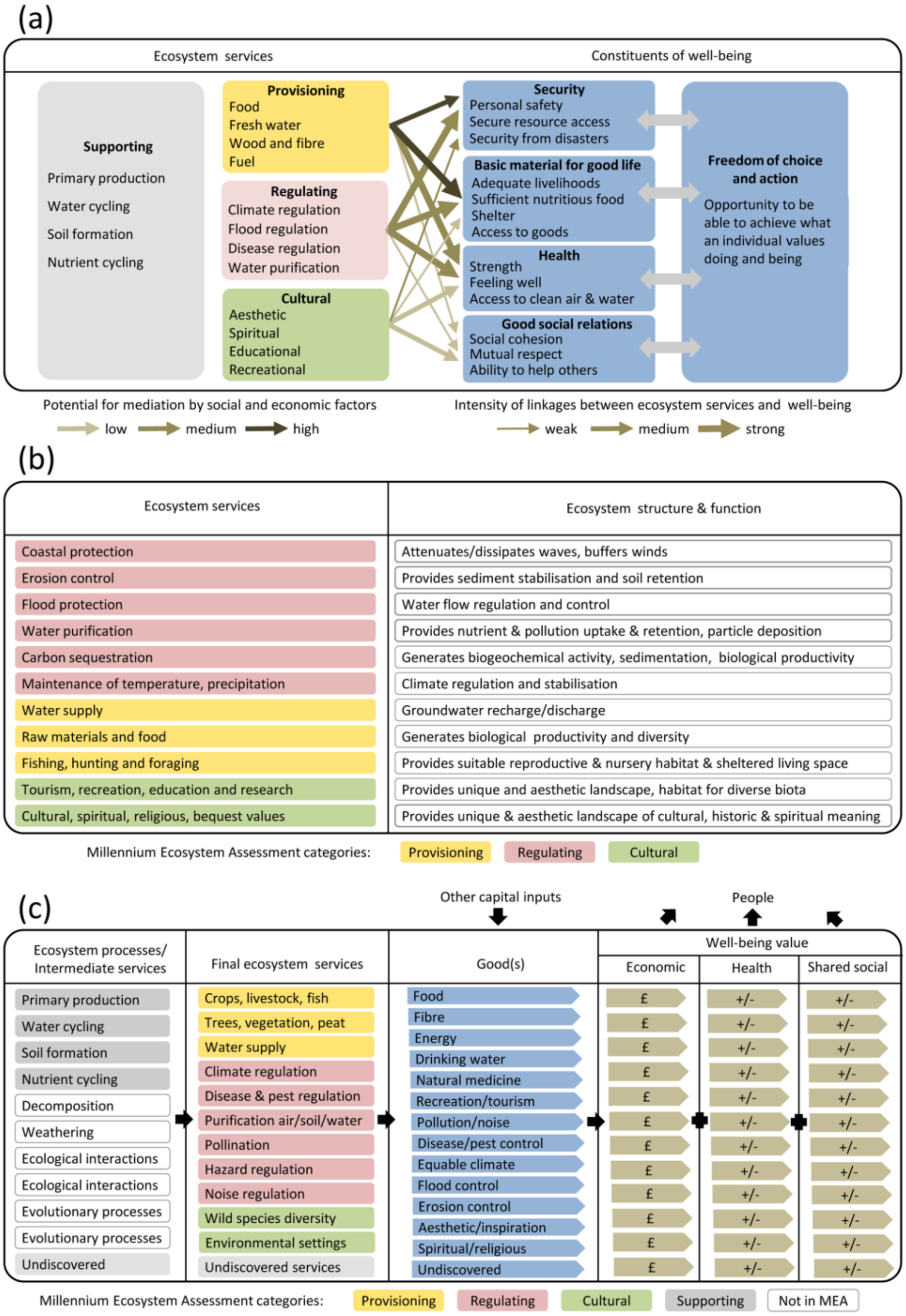

Figure 2. Examples of typologies of ecosystem services. (a) Millennium Ecosystem Assessment (2005), where provisioning, regulating and cultural services are supplied via supporting services; (b) The Economics of Ecosystems and Biodiversity (TEEB; Russi *et al.*, 2013), where supporting services are not identified but are incorporated into ecosystem structure and function; (c) The UK National Ecosystem Assessment (2011) where intermediate ecosystem services or ecosystem processes underpin the supply of final ecosystem services, which are transformed into goods for consumption by the addition of other forms of capital that then confer benefits for human well-being.

The application of a simple stocks-and-flows partial equilibrium economic model to the complex adaptive system of a biome, a landscape or an ecosystem entails certain framings of thinking and decision-making that tend to exclude the many alternative ways of understanding the complexity of the environment. One of these modes of thought relates to how the concept of supply and demand of ecosystem services differs amongst proponents of the ecosystem services concept.

For an ecosystem service to be considered as such it should fulfil some basic criteria relating to how services are characterised by interactions between their supply and demand (Mouchet *et al*., 2014); how their value is perceived, recognised and assessed (Chee, 2004) and how ecosystem services relate, or translate, into benefits to people (Boyd & Banzhaf, 2007). Supply means the ready availability to an identifiable set of beneficiaries of a service provided by the ecosystem. Supply may fluctuate, or change permanently over time according to the extent, condition or functioning of the stocks of ecosystem components or processes that underpin the service. Demand means the desire of would-be beneficiaries for a particular service. Value means the identifiable worth of a particular service to a set of beneficiaries, whether assessed by market or non-market methods.

Two approaches to supply and demand have emerged. In the first, ecosystem services defined by the Millennium Ecosystem Assessment (2005) as the benefits people obtain from ecosystems, includes all benefits or services whether people perceive them or not (Costanza, 2008). The benefits of supporting ecosystem services such as the cycling and regulation of nutrients and water are conferred upon everyone as an overarching 'public good', but of which people may be barely aware, far less express demand or value for them, even though these services may be of vital importance to human wellbeing. In the second, as in the UK National Ecosystem Assessment (2011), benefits accrue only when final ecosystem services are added to by other forms of capital to become goods that are consumed, which implies both perception of benefits and willingness to pay for them. As such, there has been a tendency to regard supporting services such as climate regulation as ecosystem processes or 'intermediate services'.

Trade-offs

The trend towards commodification and monetary valuation of ecosystem services is a consequence of the shift from the original concept of the benefits from nature towards a neoclassical economic framing of prioritisation of provisioning services that have exchangeable, market value, while externalising supporting services that are perceived as non-market (Gómez-Baggethun *et al*., 2010). The emphasis on exchange, or monetary value, entails the idea of trade-offs, whereby the supply of some ecosystem services may be reduced as a result of increased demand for others (Rodriguez *et al*., 2006). It also assumes that ecosystem services are substitutable through technological innovation and manufactured capital, thus eliminating deficits of supply over demand. There is a perception that environmental decision-making risks being driven by cost-benefit analyses. However, ecosystems, natural capital, supporting services and many cultural services are not substitutable. Some provisioning and cultural services are only partly substitutable. Supporting and regulating ecosystem services are likely to be ignored or overlooked in environmental assessments based on cost-benefit analyses in favour of provisioning services (Villamagna *et al*., 2013), even though without the continued supply of supporting and regulating services, provisioning services would decline.

Monetisation of ecosystem services entails cost-benefit decision making and has resulted in the prioritisation of supply of services of quantifiable market value from national parks and protected areas (e.g. tourism that is focussed on recreational experience, including boating, fishing and four-wheel driving) over those without market value but with strong socio-cultural identity with place (e.g. sense of place and spiritual values; Martín-López *et al*., 2014). The latter values are closely related to ecosystem condition integrity and character, whereas the former are far less dependent; indeed may require elements of built infrastructure. For example, Parks Victoria have built mountain bike trails in at least one national park in order to attract younger visitors (Parks Victoria, 2014).

Assessments of the supply of ecosystem services from current stocks of natural capital tend not to identify whether supply is sustainable or is threatened by change in ecological character, either due to threatening processes that result in ecosystem degradation or by changes in environmental drivers that result in the transition of an ecosystem to an alternate state (Norgaard, 2008; 2010). Declines in supply due to changes in ecosystem processes require trade-off decisions around management and use (Geijzendorffer *et al*., 2015). For example, recreation is an important ecosystem service supplied by the Coorong and Lakes Ramsar site, but some recreational activities (such as four-wheel driving) may represent threats to critical processes and services (Butcher, in preparation). Restrictions placed on recreational activities deemed to be damaging will reduce damage at the site, but activities, and damage, may then shift elsewhere.

Ecosystem services of the Coorong and Lakes Ramsar site – background

The complexity of differing concepts of ecosystem services highlighted above presents some challenges of consistency and definition. In relation to the ecosystem services of the Coorong and Lakes Ramsar site, we recognise there are clear differences in approach between the framework proposed by Phillips & Muller (2006), by Butcher (in preparation) and by ourselves herein.

The identification of 30 ecosystem services for the Coorong and Lakes Ramsar site (Table 1) by Phillips & Muller (2006) was based on an assessment of those services implicit in the Ramsar Information Sheet and *The Living Murray* Icon Site Asset Plan (MDBA, 2006), or derived from expert opinion; recognising that the service occurs at the site but may not have been documented. Two regulating services (local climate stabilisation and carbon sequestration) and one supporting service (nutrient cycling) were highlighted as knowledge gaps.

In the updated Ecological Character Description (Butcher, in preparation), 14 ecosystem services and benefits supplied by the site were identified using the following criteria specified in the National Framework and Guidance for Describing the Ecological Character of Ramsar Wetlands (DEWHA, 2008):

1. Are important determinants of the site's unique character;
2. Are important for supporting the Ramsar or Directory of Important Wetlands in Australia (DIWA) criteria under which the site was listed;
3. For which change is reasonably likely to occur over short or medium time scales (less than 100 years); and/or
4. That will cause significant negative consequences if change occurs.

In the present report we have attempted to reconcile the 14 services listed in the updated Ecological Character Description, together with their critical and supporting processes, with those of Phillips and Muller (2006), Butcher (in preparation) and our list (Table 1).

In the following sections we present a review of the available evidence for the categories of provisioning, regulating, cultural and supporting services, including published and unpublished data. Where there is some ambiguity about which category a service should be classified as (for example, whether recreational fishing for fin fish represents a provisioning or a cultural service), priority is given to the primary purpose, or value, that the service represents to the most beneficiaries.

A point of contention concerns whether humans are regarded as part of the ecosystem and therefore contribute to the provision of ecosystem services. This rationale is based on the inclusion of humans in aquatic food webs as consumers, and the recognition that food web structure and population dynamics would be different without the effects of human consumption. An example is the harvesting of an average of 600 tonnes per year of European carp from the Lakes and Coorong fishery (EconSearch, 2012). Removal of this biomass, of an exotic invasive species, could be considered as pest control as an ecosystem service. Herein we do not include such examples as ecosystem services because natural ecosystem functions do not rely upon human activities for their effective operation.

The following set of ecosystem services is based on that of Phillips & Muller (2006) and from Butcher (in preparation). In some cases services have been combined, in others they have been separated.

Table 1. Ecosystem services from the Ecological Character Descriptions (Phillips & Muller, 2006 and Butcher, in preparation) and those identified in the present report. Some services are listed more than once (e.g. hydrological connectivity) where they contribute to more than one service or category of services.

Phillips & Muller (2006)	Current report	Butcher (in prep.)
Provisioning services		
Water source for irrigators	Irrigation, stock & domestic water supply	Irrigation
Drinking water supply		Stock watering
Commercial and recreational fisheries	Commercial fisheries	Provision of aquatic foods for human consumption
Commercial cockle industry		
Grazing	Grazing	
	Genetic and biodiversity resources	
Regulating services		
Maintenance of hydrological stability	Hydrological connectivity	Hydrological processes
Flood mitigation	Flood mitigation	
Groundwater interactions	Groundwater recharge & discharge	
Removal & dilution of wastewaters	Water quality	Pollution control & detoxification via storage & treatment of contaminants
	Dilution flows & regulation of habitat conditions	
Prevention of erosion	Erosion prevention	
Sediment & nutrient deposition		
Local climate stabilisation	Local climate regulation	
Sequestering of carbon	Carbon sequestration	
Support of predators of agricultural pests	Pest control	
Cultural services		
Boating & water-skiing	Boating, camping, four-wheel driving	
Fishing	Recreational fishing	Provision of aquatic foods for human consumption
Bird watching and sightseeing	Birdwatching & wildlife enjoyment	
Swimming, picnicking & camping	Tourism and recreation	
	Duck hunting	
Aesthetics, amenity	Sense of place values	
	Existence & bequest values	
Cultural & spiritual significance for the Ngarrindjeri People	Spiritual, heritage and cultural values	Cultural heritage and identity
		Spiritual and inspirational values
Educational & research site	Education, research & knowledge	
Supporting services		
Nutrient cycling	Nutrient cycling	Food webs
Primary ecosystem production	Natural primary productivity	
	Biotic persistence and regeneration	
	Hydrological connectivity	Ecological connectivity
Representative of an unique ecosystem	Habitat and resource provision for biodiversity	Special ecological, physical or geomorphic features
Supports a large variety of ecological communities		
Supports animal taxa at critical stages of their lifecycle and during drought		
Supports globally & nationally threatened species and communities		Threatened wetland species, habitat & ecosystems
Supports high diversity of species important for conserving biodiversity at bioregional scale		Priority wetland species & ecosystems
Supports significant numbers & diversity of wetland-dependent birds, incl. migratory spp.		Provides physical habitat (for breeding waterbirds)
Supports significant numbers and diversity of native fish, including migratory species		Special ecological, physical or geomorphic features

2.2 Provisioning services

Irrigation, stock and domestic water supply

Irrigated crops include viticulture (Langhorne & Currency Creeks; 20 branded vineyards, ten wineries), orchard crops and cereals, as well as lucerne and hay production using centre pivot irrigation (Figure 1). Some 133 GL of irrigation water entitlements are held in the region and allocations between 2005-2010 totalled 65 GL (CSIRO, 2007; MDBA, 2010). The importance of the Coorong and Lakes Ramsar Site in relation to demand for water as an ecosystem service has declined since listing in 1985, primarily because of the development of alternative water supplies. It is important to make the distinction between supply and demand here. Water resources have continued to be provided until water levels got too low and salinity exceeded use requirements. Demand for stock water declined with the departure of the dairy industry from the Narrung Peninsula. Greater uncertainty over supply occurred during the Millennium Drought, which led to the development of alternative water sources to meet the increasing demand for high reliability supply, as outlined in more detail below. However, we have not found empirical data to support a view that that there is a permanent change in the capacity of the site to supply water to support grazing enterprises or irrigated agriculture.

Before the Millennium Drought, the majority of water used for irrigation on the Angas-Bremer floodplain was sourced from Lake Alexandrina and that for pasture production around Meningie from Lake Albert. Domestic supplies were also taken directly from the Lower Lakes (Phillips & Muller, 2006). For graziers with lake frontage, their stock drank direct from the lakes (Earth Tech, 2002). Stock water access required no licence or fee, so there has been little incentive for graziers to establish alternative watering points or supplies. Groundwater in low-lying areas around the Lower Lakes tends to be to be highly saline (>100,000 mg per L; DEWNR, 2013a), thus stock and domestic bores are not an option for water supply for stock in these regions. However, groundwater is less saline around Currency Creek and in the Angas-Bremer Catchment and is used for irrigation of grapevines.

Falling lake levels and high salinity during the Millennium Drought rendered extraction of water for irrigation and stock extremely difficult and threatened security of supply (Muller, 2012). For graziers who rely on lakeside stock watering, alternative supplies are expensive (Muller, 2012). These include water from some 170 km of pipelines that were constructed during 2008-2009 as part of the Murray Futures Lower Lakes Pipelines project to provide stock and domestic water from the Murray near Tailem Bend to Langhorne Creek, Raukkan and the Narrung and Poltalloch peninsulas. Also for domestic water supply, an extension of the Milang-Clayton pipeline was built to supply Point Sturt and a mains extension now supplies parts of Hindmarsh Island. A separate pipeline was built to supply irrigation water to Langhorne Creek and Currency Creek. Mains water for the Meningie region is piped from the River Murray via an extension of the Tailem Bend–Keith pipeline. When lake levels are high and water quality is adequate, irrigators and graziers prefer to extract water from the lakes because it is cheaper than the pipeline supply (Australian Water Environments *et al.*, 2011).

Phillips & Muller (2006) included augmentation of the water supply to Adelaide as an ecosystem service provided by the site. This was based on a statement in the Ramsar site management plan (DfEH, 2000) that the barrages maintain lake levels upstream as far as Lock 1, enabling water to be piped to Adelaide from the River Murray (via the Mannum pipeline). No water for the domestic water supply to Adelaide comes direct from Lakes Alexandrina and Albert.

Grazing

Much of the land surrounding Lakes Alexandrina and Albert consists of grazing properties (Figure 1). Beef cattle predominate, with some dairy (around Narrung) and sheep (Earth Tech, 2002). Grazing within the boundary of the Ramsar site is centred on the lake margins where stock have access to fresh water and to fringing vegetation, particularly in areas with emergent tall reeds and rushes and on samphire flats. The majority of grazing in the region occurs outside the Ramsar site boundary. While emergent aquatic vegetation provides the ecosystem service of provisioning for stock, landholders generally acknowledge that the impacts of grazing on the lake shore include pugging, erosion and loss of biodiversity (Earth Tech, 2002). Watering points away from emergent vegetation tend to show greatest severity localised erosion. Loss of emergent aquatic vegetation due to grazing makes lake shores more susceptible to wave erosion. Fencing of the lake shores has been undertaken in some areas to keep livestock off the lake bed during the drawdown of the lake during the Millennium Drought and to protect existing emergent aquatic vegetation and areas of restoration and replanting (Muller, 2012). Exclusion of stock from the lake shore requires establishment of alternative watering points, with associated costs to graziers.

Commercial fisheries

The seven commercial species, prescribed in the Management Plan for the Lakes and Coorong Fishery (Sloan, 2005), are black bream (*Acanthopagurus butcheri*), golden perch (callop; *Macquaria ambigua*), greenback flounder (*Rhombosolea tapirina*), mulloway (*Argyrosomus japonicus*), pipi (Goolwa cockle; *Donax deltoides*), yellow-eye mullet (*Aldrichetta forsteri*) and bony bream (*Nematalosa erebi*). The commercial catch is partly dependent upon freshwater inflows. Increases are considered to trigger breeding and recruitment in some species as well as increased supply of food resources (Jones *et al*., 2005), whereas reduced inflows and, consequentially, increased salinity are associated with decreased abundance (Zampatti *et al*., 2010; Ferguson *et al*., 2013).

Catch per unit effort (kg per fisher per day) data for each species was presented by Ferguson (2012), based on 5,800 days fished by 36 licence holders. Gross value of production of the Lakes and Coorong Fishery (1992/3 to 2010/11) averaged $ 4.3 mn per year (in 1992/2 dollars). Value of the catch has grown by 13% over this period (EconSearch, 2012). The commercial cockle industry is focussed on the Coorong beach, with the catch used for human food and for bait for recreational fishing(Sloan, 2005). The average annual harvest (1992/93 to 2010/11) was 680 tonnes and the average gross value of production was $1.8 mn (EconSearch, 2012).

The economic impact of the Lakes and Coorong Fishery, representing the sum of direct values (fishing, processing, transport, retail services and capital expenditure) and flow-on values (trade, manufacturing, business services, transport and other sectors) was worth $31.5 mn in 2009/10, involving 189 full-time equivalent jobs (EconSearch, 2012).

Genetic and biodiversity resources

This service was not listed by Phillips & Muller (2006) and there is an interaction between cultural values and provisioning, particularly for Ngarrindjeri cultural identity (Ngarrindjeri, 2006). Genetic material includes the availability of genetically variable populations of finfish, crustaceans and molluscs for the development of current and future aquaculture industries (cf. EconSearch, 2013;), the supply of native plant source material used in the native bush foods industry and in native plant propagation for gardens and for ecological restoration activities such as those being undertaken in the region presently as part of the CLLMM Recovery project (DfEH 2010).

In relation to native plant material, Bonney (2004) lists 69 common native plants for the Coorong region, of which a remarkably high proportion (65%) have had historical uses, mostly for food, fibre, medicine, fuel and tool making. Several of the food and fibre plants are gathered and used by contemporary Aboriginal people (Ngarrindjeri (2006) . Several plants have current uses in the native foods industry (Table 3). Others have potential. Most can be propagated and used in native plant gardens. Collection of seed and native plant propagation is an important element of current revegetation activities under the CLLMM Recovery Project (DEWNR 2013b). Since 2009 over 3.7 million native seedlings have been planted (DEWNR, 2013c).

2.3 Regulating services

Flood mitigation

The ecosystem service of flood mitigation is represented by the capacity for the Lower Lakes to function as reservoirs for flooding flows during periods of high rainfall, thus protecting adjacent private land and property from flood damage. Flood mitigation is thus a function of wetland storage capacity (Ogawa &

Male, 1986; Acreman & Holden, 2013). Lake Alexandrina and Lake Albert hold 2098 GL at a water depth of 0.85 mAHD and 2015 GL at 0.75 mAHD (DWLBC, 2005). Under current flow regimes, water levels are 0.75-0.8 mAHD ca. 70% of the time (Phillips & Muller, 2006). The flood mitigation capacity is represented by the difference between maximum storage capacity and the depth of the lakes at the time of commencement of high inflows.

Water quality

Water quality as an ecosystem service relates to the regulation of its physicochemical characteristics that render it suitable for consumptive use by humans, their crops and livestock, but also for the maintenance of habitat quality for aquatic organisms. Water quality of Lakes Alexandrina and Albert is determined by flushing: inflows from the River Murray, outflows over the Barrages, evaporation rates, suspended sediments and nutrients and phytoplankton population dynamics (Heneker, 2010, Mosley *et al*., 2013). The ecosystem services provided by flow that relate to water quality include regulation of salinity (Webster, 2010; Mosley *et al*., 2013), prevention of acidification of water caused by oxidation of acid sulfate soils (Fitzpatrick *et al*., 2008; Mosley *et al*., 2013). Surface water connectivity provides dilution flows for the regulation of salinity that determines availability of habitat for many organisms (Webster, 2011).

Hydrological connectivity

This includes surface water and groundwater interactions as well as surface water flows within and between channels that connect different wetlands. Groundwater inflows to the lakes are considered negligible compared with surface water inflows (Heneker, 2010). Water levels in the Lakes below 0.65 m ADH are associated with saline seepage (MDBC, 2006). Rapid Increases in the salinity of surface water were observed during the Millennium Drought when lake levels were low. Graziers around Lakes Alexandrina and Albert reported overnight increases to 8,000–29,000 EC (ca. 5-19 G/L; Muller, 2012). Freshwater flows play an important role in regulating salinity by dilution of surface waters (cf. below) and moderating the effect of saline groundwater discharge.

Dilution flows and regulation of habitat conditions

Freshwater flows into the Lakes help dilute nutrient inputs form surrounding agricultural land. Nutrient inputs are particularly high in reclaimed irrigation areas used for dairy cattle (MDBA, 2006; Mosley *et al*., 2009). Freshwater and saltwater mixing contributes to creation of habitat diversity and complexity of critical habitat for spawning and recruitment of estuarine fish species, whereas high salinity is associated with low species diversity and abundance (Geddes & Butler, 1987). Freshwater flows into the Coorong during spring and summer 'are believed to stimulate estuarine species to spawn' (MDBC, 2006) and Ferguson *et al*. (2008) found that recruitment of mulloway *Argyrosomus japonicus*, a commercially important marine species, was correlated with freshwater inflows to the Coorong. Mixing zones of fresh and salt water that influence nutrient transport and availability are likely to be associated with increased primary and secondary productivity in estuaries (Ferguson *et al*., 2013).

Groundwater recharge and discharge

Rainwater and flooding flows percolate into groundwater storages and this recharge supplies freshwater soaks that discharge along the Coorong (Paton, 2010). These springs support aquatic plants and waterfowl and provide the only source of drinking water for fauna on Younghusband Peninsula (Paton, 2010). The number of running soaks has declined in recent times and those that remain have reduced water quality and pressure (MDBC, 2006).

Erosion prevention

Retention of sediments by roots of aquatic plants prevents erosion. This is particularly important for the Lower Lakes because water levels are held at high, stable levels: between 0.6 and 0.85 m Australian Height Datum (AHD), with an operating rule to maintain average water level at 0.75 m ADH. When inflows are low, evaporation exceeds inflows, so the barrages are closed and the lakes surcharged to 0.85 m at the beginning of summer (MDBC, 2006). Fringing aquatic vegetation that forms a corridor around the lower lakes, particularly reed beds, rushes and sedges, play an important role in preventing the erosion of the lake shore by wave action when lake levels are high. Shoreline erosion has been considered as the single biggest threat to protecting Ramsar habitat on grazing properties (Earth Tech, 2002). Lake shores without extensive beds of reeds, rushes and sedges tended to show signs of active wave erosion in some locations but not in others, whereas there was no erosion in areas with such vegetation (Earth Tech, 2002). Evaporation of seawater from the surface of dunes along the Coorong forms a salt crust that stabilises the shoreline by preventing the movement of sand and reducing erosion (Paton, 2010).

Local climate regulation

The primary effect is generated by diurnal cycles of evaporation and condensation. Shade and shelter may be provided for biota amongst emergent aquatic vegetation at the micro-habitat scale. Extensive areas of shrubland and emergent aquatic and fringing vegetation reduce evaporation from soil surfaces. Following drawdown of the Lower Lakes during the Millennium Drought, graziers remarked on the lack of cooling breezes, generated by evaporation when the lakes held water (Muller, 2012). Shade and shelter are important for live weight gain of stock and for reducing mortality during calving and lambing (Gregory, 1995; Young *et al*., 2010), though the paucity of woody vegetation cover means this service is provided primarily by shade and shelter belts planted outside the boundaries of the Ramsar site.

Carbon sequestration

Carbon sequestration represents the carbon storage capacity of aquatic and terrestrial plants as well as soil and sediments. Due to the lack of extensive tree cover in the region, and the relatively rapid turnover of carbon in aquatic plants, the bulk of carbon stocks are likely to be held in soil and sediment. We found no estimates of sequestration rates for the Coorong and Lakes. For the Hunter Estuary (NSW), Howe *et al*. (2008) estimated total soil carbon content of 1.5-5.8%, lowest in tidal pools and highest in salt marshes, and an annual sequestration rate of 1.2-2 tonnes per hectare.

Pest control

Phillips & Muller (2006) listed control of agricultural pests as an ecosystem service, 'for example ibis feeding on grasshoppers', based on expert opinion ('the recognition that the service occurs at the site'). Straw-necked ibis and Australian white ibis breed around the Lower Lakes and forage for invertebrates in pastures, including insect pests of grasslands. It is not known whether feeding translates to tangible benefits to graziers. Another example of natural pest control is the consumption of European carp and redfin by fish-eating colonial-nesting waterbirds (Australian pelican, herons, egrets, darters and cormorants).

2.4 Supporting services

Nutrient cycling

Phillips & Muller (2006) stated that ' very little is known about the specifics of carbon and nutrient cycling in the Coorong and Lakes but these cycles are likely to contain key ecological components and processes. A decline in submerged and emergent plant cover may lead to a decrease in detritus and nutrients being transformed within the system.' The marked reduction in extent and biomass of the estuarine submergent grasses *Ruppia tuberosa* and *R. megacarpa* in the Coorong, due to exposure and desiccation from low water levels during the Millennium Drought, was associated with contractions in the distribution and abundance of invertebrates, fishes and birds that were part of the food web of primary consumers supported by the plant and detritivores supported by the decomposition and cycling of nutrients from its tissues (Paton, 2010). This is an example of how changes in primary productivity of a keystone species that underpins the nutrient supply to a food web can result in major shifts in the composition of a biotic community.

Skinner *et al*. (2014) found an increase in the proportion of organic particles in sediments in Lake Alexandrina when water levels were low during the Millennium Drought, as well as a shift in primary production from macrophytes to phytoplankton.

Natural primary productivity

Lower Lakes: Primary productivity from phytoplankton is limited in part by turbidity, which affects euphotic depth (Geddes, 1984a; 1988). Turbidity in Lake Alexandrina is typically high, but with seasonal variation determined by inflows that in turn drive phytoplankton biomass and nutrient uptake Biomass of zooplankton, particularly of calanoid copepods, remains high throughout the year indicating a dependency primarily on particulate organic food material rather than phytoplankton (Geddes, 1984b).

Coorong: Geddes (1987) observed profuse flowering of *Ruppia* spp. following freshening flows in October 1983. The primary productivity of a typical bed on *Ruppia megacarpa* in the North Lagoon around 1980 was estimated at 0.24 kg dry weight per m^2, or tonnes per hectare (Snoejis & van der Ster, 1981). On the assumption that this estimate is approximate for *R. megacarpa* also, and based on a typical vegetation carbon content of 40% dry weight, the loss of *Ruppia* spp. constitutes a reduction in total carbon inputs to the food web of the Coorong in the order of 100 kg per hectare of *Ruppia* spp. habitat.

Habitat and resource provision for biodiversity

There are 25 different wetland types in Coorong and Lakes Ramsar Site and over 30 different landforms (beach, channel, mud flat, salt lake and so on; Seaman, 2003). Phillips & Muller (2006; their Table 8) list 23 wetland types according to the Ramsar classification. Wetland diversity of the Coorong and Lakes is extremely high, due to the proximity of coastal, estuarine, riverine and lacustrine habitats and the interaction of environmental drivers (salinity, turbidity and water regime) of the region as a whole. Permanent freshwater lakes, coastal brackish/saline lagoons, permanent freshwater marshes/pools, shrub-dominated wetlands and intertidal mud, sand or salt flats are the most extensive wetland types. About 74% of habitats surveyed in 2003 by Seaman (2003) were classified as in good condition or better, with the remainder degraded. A re-survey in 2010 of a subset of wetland sites surveyed by Seaman (2003) found 54% had declined in condition during the Millennium Drought due to low water levels and disconnection of ringing wetland habitats (Thiessen, 2010). A third set of wetland assessments in 2014 found the water regime had returned to pre-drought conditions for the majority of 191 wetlands (75% were dry in 2010; 10% in 2014) and that 60% showed an improvement in condition above that recorded in 2010. Some 76% of sites maintained or improved their condition ranking above 203 rankings (Billows *et al*., 2014).

Phillips and Muller (2006) provide extensive details of the Ramsar 'biodiversity criteria' for the Coorong and Lakes, i.e. the particular habitats, communities and species that constitute the ecological character of the site. These include significant natural ecological communities, vulnerable or endangered species, keystone species, waterbird populations, fish diversity and habitat provision. The significant ecological communities include *Gahnia filum* tussock sedgeland and the critically-endangered Fleurieu Peninsula swamps are listed as a, located along the lower reaches of Currency Creek, Tookayerta Creek and the Finniss River. Seven plant species, one frog species, 49 fishes and 77 bird species form the basis of the biodiversity criteria for the Ramsar listing.

The lists of species contain a high proportion in the following categories: 1) species that show tolerance to fluctuations in salinity, turbidity and water regime; 2) species that depend upon the interaction of saline and freshwater flows for the completion of their life cycle; 3) species that for their existence on species in one of the previous categories.

Biotic persistence and regeneration

The capacity for recovery and persistence of an ecosystem following extreme events relate to the concept of ecosystem resilience, typically defined as the capacity to absorb disturbance while maintaining function (Walker & Salt, 2006). If an ecosystem does not recover its original functions and processes it tends to shift to a so-called 'alternate stable state'. For example, 'Loss of *Ruppia* spp. from most of the Coorong and the appearance of brine shrimp and algae in Spring and Summer of 2005/06 suggest that an ecological shift is underway in which aquatic plants are being replaced by algae as the primary producers of the system.' (MDBC, 2006). Transition to alternate stable states is very hard to predict at the time because of high uncertainty regarding the reversibility of change.

Resilience is a collective, dynamic, emergent property of the complex, adaptive nature of ecosystems (Walker & Salt, 2006). It is difficult therefore to define, quantify and manage for resilience, although 'management of, or for, resilience' is a goal commonly cited in natural resource management plans and policy documents. Regardless, the ecosystem properties of persistence, recovery and regeneration are highly desirable and attempts to manage for them are important because they relate directly to the continued supply of ecosystem services.

Colloff & Baldwin (2010) detailed important elements for the persistence and recovery of semi-arid wetlands following disturbance events characterised by cycles of flood and drought. These include (1) a supply of reproductive elements, or propagules. This may in the form of a *propagule bank* of seeds, spores, eggs, cysts or other resting and survival stages that can remain dormant until conditions are right for regeneration. Or it may be as *propagule transport* to a site from elsewhere, for which flow connectivity and upstream sources or within-site *refugia* are important; (2) biota that can withstand disturbance in the adult stage. There are two main strategies: *high mobility*, allowing relocation to somewhere more favourable, as for waterbirds and some fishes and *environmental tolerance*, allowing survival and recovery from a broad range of environmental conditions, as for many plant species. Collectively, these properties allow the biota to withstand extended dry periods yet maintain function following the return of the wet phase.

Geddes and Butler (1984) and Geddes (1987) documented decline and recovery in the Coorong during and after a period of low inflows and extreme hypersalinity when the Murray Mouth closed in 1981/82. In relation to the recovery of *Ruppia* spp. in the Coorong following the return of high inflows during 2010 and 2011, Frahn *et al*. (2012) noted limited colonisation of *R. tuberosa* in the South Lagoon and the southern end of the North Lagoon and an extremely depauperate propagule bank. The findings in this report indicate that recovery is slight, precarious and likely to be slow, requiring maintenance of suitable conditions over several generations of seed set and turion development.

2.5 Cultural services

Wetlands have a special and universal place in the human psyche. As an assured source of plentiful water and food, they have come to symbolise security, abundance and life. This is especially so in arid and semi-arid landscapes where wetlands provide a buffer against the variability and uncertainty of resources over time and space. The link between provisioning services and cultural services is strong and abiding, developed over millennia of human cultural evolution. For example, important contemporary recreational services such as fishing, wildfowling, cockling, the gathering of wild foods, birdwatching and nature photography have socio-cultural links to ancient, primal hunting and provisioning behaviours. Spiritual and sense of place values are linked to the development of a cultural awareness and respect for environment through its conservation and wise use.

Tourism and recreation

Recreational value of the Coorong was estimated as $111 per adult visitor per day, or $242 per trip, based on 120,000 visitors; a consumer surplus of $30.5 mn per year (Rolfe & Dyack, 2011). Cultural importance is reflected in a survey of visitors to the Coorong (Dyack *et al*., 2007), particularly in relation to relaxation and mental health. People were asked to nominate particular areas that were important to them, but most considered the whole place was 'special'. Place attachment was extraordinarily high, with almost 40% of respondents having visited 18 times or more. Relaxation and sightseeing were ranked the most important reasons for visiting. Visitation rates for the Lakes site declined during the Millennium Drought in because of public perception of poor ecosystem health (Muller, 2012; CSIRO, 2012).

Recreational fishing

Ferguson (2012) provided estimates for the recreational catch for fin-fish for 2007/08, including 6 tonnes of black bream, 45 tonnes of golden perch, 60 tonnes of mulloway and 35 tonnes of yellow-eye mullet. For black bream and mulloway, the tonnage of the recreational catch is more than half that of the commercial catch. For golden perch and yellow-eye mullet, it is less than 30%. The dollar value (2007/08) of the recreational catch, estimated from commercial gross value of production per species (EconSearch, 2012;

Tables 3.1, 3.2), is $1.4 mn. There is a large recreational fishery for Goolwa cockles, used primarily for fishing bait.

Boating, Camping, Four-wheel Driving

Availability of water for boating is a very important ecosystem service, with an estimated 6,800 watercraft in regular use on the lakes and Coorong in 2001 (120,000 user days per year; MDBC, 2006). Recreational boating was estimated to have a gross economic value of about $14 mn per year and employ approximately 140 people (Helicon, 2004). Hindmarsh Marina is one of the largest in the Southern Hemisphere. Four-wheel driving is popular on the ocean beach along Younghusband Peninsula, but with trade-offs in sand compaction, erosion due to destruction of surface salt crusts as well as mortality of hooded plovers that nest in the dunes (Paton, 2010).

Duck hunting

The Coorong and Coorong and Lakes Ramsar Site contains three game reserves (Currency Creek, Mud Islands and Tolderol, covering an area of 680 ha. (Fig. 1). Hunting within reserves is regulated by bag limit and open season according to wildfowl populations. Species hunted include grey teal *Anas gracilis*, chestnut teal *Anas castanea*, Australian wood duck *Chenonetta jubata* and Pacific black duck *Anas superciliosa*. Duck hunting in wetlands in the South Coorong Region, Fairview Conservation Park and Messent Conservation Park, was worth $42-$62 per hunter per shoot, based on a travel cost survey, worth just over $1 mn per year in net present value (2000) for wetlands in the upper south-east of South Australia, for ca 500-1500 hunters, depending on season (Whitten & Bennett, 2002). However, the conservation costs to society of allowing duck hunting were considered to be over three times greater than the benefits to hunters ($5.8 mn v. $2.2 mn), estimated using choice modelling (Bennett & Whitten, 2003; Whitten & Bennett, 2005).

Spiritual, heritage and cultural values

The Coorong and Lakes has cultural and spiritual significance for the Ngarrindjeri people. Part of their cultural values include the fundamental interactions between landscape, traditional law, seasonal use and provisioning of staple foods, including cockles, waterfowl, fish, tubers and fruit (Ngarrindjeri, 2006). Shell middens along the Coorong along the Younghusband Peninsula hundreds of metres across and 1-2 metres deep, some dated to 5,000 years old (Paton, 2010). Weaving is a particularly important part of Ngarrindjeri cultural identity (Ngarrindjeri, 2006). Wetland plants provided fibre used in net making, basketwork and mats. Particular locations have special significance as burial sites (Lucas, 1990).

Cultural and heritage values for non-aboriginal people including art and photography, including works by colonial illustrators such as George French Angas and well-known contemporary artists including David Dridan, Rosa Merlino and Gary Trevorrow; film and literature such as the popular *Storm* Boy (1977), based on the best-selling book of the same name by Colin Thiele (1963). Historical heritage value, e.g. pastoral homesteads, lighthouses, historical routes along the Coorong to the south-east and Victoria, Historic and heritage towns: Goolwa, Victor Harbour.

Sense of place values

This set of values partly differentiates local residents from visitors, based on the identification with a particular set of lifestyles characteristic of the region, combined with a strong sense of belonging and being part of the landscape. Inherent to sense of place values are an understanding of history and environment and changes over time, recorded in memoir and oral history accounts, such as those in *SA Memory* (State Library of South Australia; www.samemory.sa.gov.au) and the ABC Radio National program "The Cry of the Coorong." (2008); http://www.abc.net.au/radionational/programs/radioeye/the-cry-of-the-coorong/3179722 (cf. also England, 1993).

Education, research and knowledge

Education, research and knowledge feed back into a broader understanding of the ecology, ecosystem function and provision of ecosystems services of the Coorong and Lower Lakes. That knowledge informs the values of society that relate to the environment, which in turn empowers communities to engage in discussion and influence the rules, governance and management arrangements.

The Coorong and Lower Lakes Ramsar site has been the subject of considerable scientific research, biodiversity survey and monitoring. The site is has been intensively monitored, with more long-term data sets (greater than five years) than any other wetland in the Murray-Darling Basin (Colloff *et al*., in press). Monitoring of waterbird populations commenced in 1982, and extensive data exist for freshwater and marine fishes and vegetation communities. These include data for the Coorong on all waterbird species (Paton *et al*., 2009; Leitch, 2009a; 2009b; Paton & Bailey, 2012) and for waders and shorebirds (Wainwright & Christie, 2008; Nebel *et al*., 2008); aquatic invertebrates and fish in the Coorong (Geddes *et al*., 2009; Paton, 2010; Paton & Bailey, 2011; 2012; Ferguson *et al*., 2013) and Lower Lakes (Wedderburn *et al*., 2012) and *Ruppia* spp. in the Coorong (Rogers & Paton, 2009; Frahn *et al*., 2012; Paton & Bailey, 2012).

Detailed and comprehensive surveys of the biota and of habitats have been undertaken for particular areas, such as the Murray Mouth Reserves (Brandle, 2002; Seaman, 2003; Thiessen, 2010). Various natural history books and field guides to the region have been published (Strathalbyn Naturalist Club, 2000; Bonney, 2004; Paton, 2010).

Birdwatching and wildlife enjoyment

Included in this category is membership of natural history groups, conservation organisations and LandCare volunteers. Membership of these strongly reflects sense of place values. There is active engagement in restoration programs such as the Coorong and Lower Lakes Eco-Action project and the CLLMM Recovery Project (Anon., 2013; DEWNR, 2013b). Eco-tourism activities including bushwalking and visits to national parks were reasons for visiting given by about 10% of visitors to the region in surveys by the South Australian Tourism Commission (www.tourism.sa.com.au). A more recent survey of indicated that visitors placed high importance on their experiences of the Coorong and Lakes that focussed on passive activities, particularly enjoyment of the scenery, nature-based recreation and relaxation and learning (Crossman *et al*., 2014).

Existence and bequest values

Existence and bequest values were not listed by Phillips & Muller (2006) but are detailed in the Ramsar Management Plan: 'there is bequest value associated with the region, in which individuals derive utility and satisfaction from endowing future generations with the natural resources of the area; and, most importantly in the case of a Ramsar site, there is existence value where individuals derive utility and satisfaction purely from the continued existence of the resource, even though they may never visit the site. Although many of these economic values are difficult to quantify, they are nevertheless real and should not be overlooked.' (DfEH, 2000). Crossman *et al*. (2014) found all questionnaire respondents considered that we have a moral obligation to maintain the Coorong and Lakes Ramsar site for future generations and almost 90% considered the site should be protected at all costs.

3 Changes in the supply of ecosystem services

Introduction

In the introduction to this report we highlighted that the supply of different types of ecosystem services is broadly spatially partitioned between the estuarine and freshwater ecosystems at the site, i.e. between the Coorong and the lakes. Temporal changes in the supply of particular services can be linked to those parts of the site that have been most affected by changes in water levels and salinity, which are dependent upon barrage flows.

Phillips and Muller (2006) listed climate, geomorphology and hydrology as the natural, abiotic 'system drivers', referred to as critical components and processes by Butcher (in preparation). It is important to note that critical *processes* such as surface flows and salinity are equivalent to 'system drivers', but critical *components* such as vegetation, waterbirds and fishes represent ecological entities that respond to critical processes. The distribution, occurrence, population density and diversity of the biotic components therefore represent ecological response variables to system drivers.

System drivers set boundary limits for the biological, physical and chemical characteristics of the Coorong and Lakes Ramsar site and form a basis for setting the limits of acceptable change in critical components and processes. Limits of acceptable change for each Primary Determinant of Ecological Character for which data was available were defined by Phillips & Muller (2006; their Table 25). Limits of acceptable change in critical components and processes have been revised for the updated ecological character description (Butcher, in preparation).

System drivers operate in concert with anthropogenic drivers of change to determine the nature and interaction of ecosystem processes, particularly the water regime and physicochemical environment that determines the availability of habitat and food resources, biotic communities, primary productivity, nutrient and carbon cycling. Anthropogenic drivers are generally amenable to management intervention at the site scale, and those listed by Phillips and Muller (2006) all relate to flow and include river regulation and inflows, water diversions, barrage operation, dredging and discharge. Bice (2010) identified flow regime, physico-chemical drivers and connectivity as the three abiotic drivers most important for fish assemblages of the Coorong and Lower Lakes and that 'flow regime could be viewed as the over-arching driver as it directly influences both physicochemical parameters and connectivity.'

Assessments of change

Changes in components and processes, 1985-2006

The status of the ecosystem components and processes influences the supply of ecosystem services. Phillips & Muller (2006) undertook condition assessments for the Primary Determinants of Ecological Character (effectively the equivalent of critical components and processes: salinity, turbidity and sedimentation, keystone species, water levels, habitat connectivity and water regime, wetland types and Ramsar Significant Biological Components). They used a 'traffic lights' reporting system based on an assessment of condition in the Coorong and Lakes for the period 1985-2006. Threats, risks and vulnerabilities were identified for each element. Some 42/54 elements were classed as having been subject to 'significant detrimental impact warranting urgent management intervention' (red) or there were 'strong indications that threatening processes are operating' (amber). Only 12 elements were categorised as 'some concerns [were] evident that warrant investigation and perhaps management intervention' (yellow) or 'all known risks were being adequately addressed though management actions' (green). These changes in ecological character triggered the notification process to the Ramsar Secretariat (the so-called 'Article 3.2 Notification'), as occurred for the site on 13 December 2006 (DoEH, 2006; updated 17 October 2008 and 27 October, 2009).

Assessment of condition of critical components and processes assessed by Phillips & Muller (2006) were matched with the list of major ecosystem services in Table 2 in order to provide a basic assessment of possible changes in supply of ecosystem services since Ramsar listing in 1985 and during the Millennium Drought (1997-2009). Some caveats are warranted here.

Table 2. Selected major ecosystem services of the Coorong and Lakes Ramsar site identified in the present report and their underpinning critical components and processes identified in Butcher (in preparation), with trajectories of change in the capacity of the site to supply the services during the Millennium Drought (1997-2009) and since Ramsar listing in 1985 (based on Phillips & Muller, 2006; their Table 26). Habitat template includes the critical process of hydrology and the supporting processes of geomorphic setting and water quality (cf. Butcher, in preparation, Fig. 1 therein). Monetary values of services are provided where cited by authors (valid at the time of estimation), or where value could be estimated.

Ecosystem service	Critical components and processes	Value $AU (mn)	Trajectory of change in supply during Millennium Drought	Trajectory of change in supply since Ramsar listing, 1985
Provisioning services				
Irrigation & domestic water supply	Hydrology	6.5[1]	↘	→
Commercial fisheries	Fish, hydrology	4.3[2]	→	→
Regulating services				
Flow connectivity & water quality	Hydrology	3.6[3]	↘	↘
Erosion prevention	Hydrology	31.8[4]	→	→
Carbon sequestration	Hydrology; lake bed & Coorong vegetation	2.1[5]	↘	↘
Supporting services				
Nutrient cycling	Hydrology; lake bed & Coorong vegetation; salinity		↘	→
Natural primary productivity	Hydrology; lake bed & Coorong vegetation; salinity		↘	→
Habitat & resources for biota	Hydrology; lake bed & Coorong vegetation; salinity		↘	↘
Biotic persistence & regeneration	Hydrology; salinity, biotic components		→	→
Cultural services				
Tourism and recreation	Habitat template, geomorphic setting; biota	30.5	↘	→
Recreational fishing	Fish, hydrology	2.9[6]	↘	→
Boating, camping, 4-wheel driving	Habitat template, geomorphic setting	14[7]	↘	→
Spiritual, heritage, cultural values	Habitat template, biotic components		→	→
Education, research & knowledge	Habitat template, biotic components		→	→

Trends: ↗ = increase; → = stable; ↘ = decline (decline is equivalent to the 'red' and 'amber' classes of Phillips & Muller, 2006). *Values*: [1]replacement cost of 65 GL pipeline water at $100/ML; [2]gross value of production; [3]avoided cost of dredging Murray Mouth (from CSIRO, 2012, p. 161); [4]avoided cost of erosion prevention for SA Murray during Millennium Drought (from CSIRO, 2012, Table 6.9), scaled to Coorong and Lakes by bank perimeter; [5]annual sequestration of 1.5 tonnes of carbon per hectare, at carbon market value of $10 per tonne, over 140,500 ha; [6]average expenditure of $114 per SA fisher per trip (Ernst & Young, 2011) based on 255,000 visits to Limestone Coast region per year (2010-2012), of which 10% were for fishing (South Australian Tourism Commission www.tourism.sa.com.au); [7]boating component only.

The condition assessments of the primary determinants of ecological character by Phillips & Muller (2006) provided quantitative time series for salinity, water levels and inflows only. The assessment of the remaining determinants (turbidity, keystone species, habitat connectivity, wetland types and Ramsar significant biological components) are based on either semi-quantitative estimates of status or expert opinion of the likelihood or magnitude of change. Because the majority of information used for determining condition and change in ecological character was not in the form of time series it does not constitute a basis for determining trends, particularly in relation to whether any perceived changes were likely to be relatively short term and reversible or long-term and potentially irreversible.

Long-term trends: analysis of time series

Fundamental to the assessment of ecosystem character, condition and function is the evaluation of data on status and trends. Data on status tend to represent a 'snapshot' in time, so cannot be used to assess the trajectory of change unless surveys are repeated using the same methods, or unless assessed rigorously against reference conditions at representative sites. Data on ecological trend are based on long-term monitoring and can be used to determine whether the variable of interest is declining, increasing or remaining the same. Long-term monitoring is the best available source of data against which to evaluate ecosystem changes (Lindenmayer and Likens, 2010).

We recently assessed trends of 301 ecological time series (of greater than five years duration, covering the period 1905 to 2013) for floodplains, wetlands and rivers in the Murray-Darling Basin (Colloff *et al*., in press), of which almost a third were from the Coorong and Lakes. Time series were divided into two categories, based on the type of response variable estimated: (1) 'population' (based on direct, quantitative estimates of abundance, biomass or plant cover or extent, and (2) 'non-population'-based estimates, based on condition indices, occurrence of species or relative proportions of the magnitude of breeding events.

For 'population' series we compared trends of native, non-invasive species using: (1) a log.-linear regression model (Eberhardt & Simmons, 1992), which accounts for observation error only and (2) a state-space model that accounts for observation error and environmental, or stochastic 'noise' (Humbert *et al*., 2009). State-space models are particularly suited to the analysis of time series because they account for temporal autocorrelation which may confound inferences drawn from simple linear regression models. For occurrence and proportion data, we modelled the temporal trend of the odds of a recorded presence during the year of survey. 'Non-population' trends were analysed using logit linear regression. We compared the frequency distribution of the annual exponential rate of increase (*r*) of the time series, estimated from each model, as a simple meta-analytical method to determine whether mean population growth differed significantly from zero (with negative values indicating an overall pattern of decline, positive values indicating an overall increase), using bootstrapped confidence intervals.

Here we report on trends for ecological time series (62 'population' and 17 'non-population' series) from the Coorong and Lakes (Tables A1-A3). The longest are records of the relative magnitude of breeding events for Australian pelican (1910-2013) and black swan (1910-2011; O'Connor *et al*., 2013). The majority of series are for waterbirds and fishes, with two for invertebrates and one for plants (Figure 3). The mean duration of time series is 23 years, with 82% of them having commenced in 1983 or thereafter.

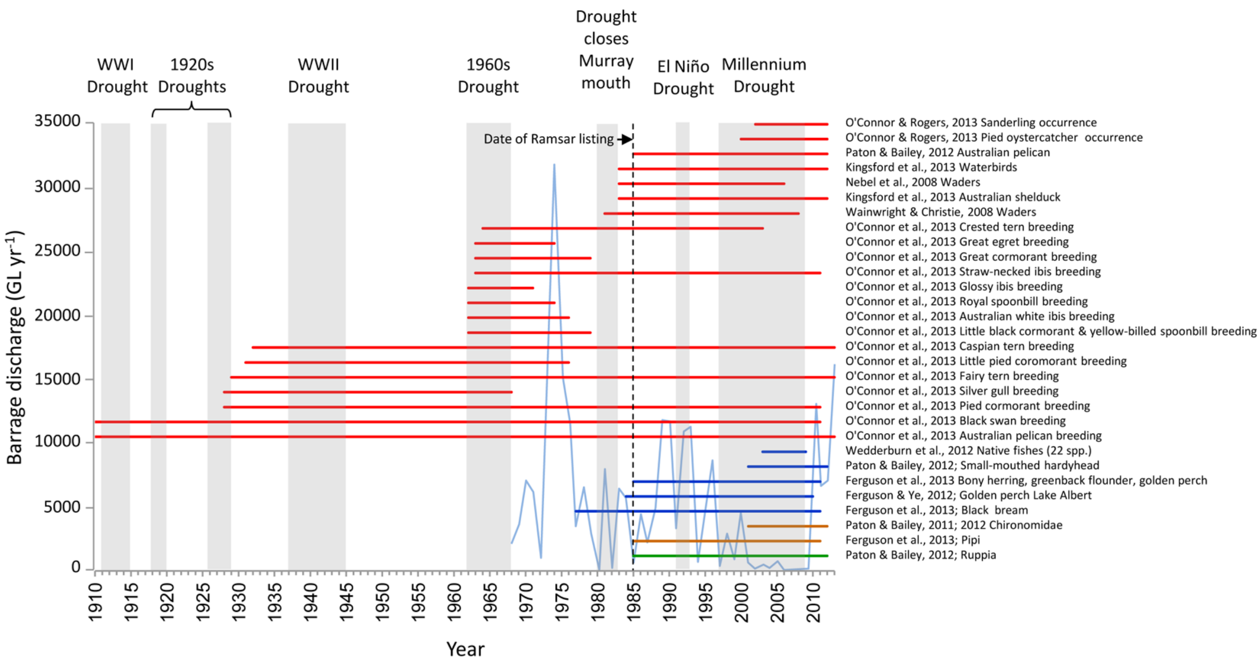

Figure 3. Diagram showing the duration of long-term ecological data sets (containing one or more time series) from the Coorong and Lakes, 1910-2013 in relation to total annual barrage flows (light blue line) and periods of drought (grey shading). Green = vegetation, brown = aquatic invertebrates, blue = fishes, red = birds. Barrage flows based on MSM Bigmod modelled outputs by Murray-Darling basin Authority (cf. Brooks *et al*., 2009; Ye *et al*., 2012).

Of the population series of non-invasive taxa analysed with log.-linear regression (*n* = 62), 5 (10%) showed a statistically significant declining trend, but 57 (90%) were stable and fluctuating with no significant trend (*n* = 50) or showed a statistically significant increase (*n* = 7; Table A2). Statistically significant decreases were found for Yarra pygmy perch in the Lower Lakes (2003-2009; Wedderburn *et al*., 2012), curlew sandpiper and red-necked stint in the Coorong (1985-22012; Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012), *Ruppia tuberosa* in the Coorong (1985-2012; Rogers & Paton, 2009; Paton & Bailey, 2012) and total abundance of wading birds in the Coorong (1981-2008; Wainwright & Christie, 2008). Statistically significant increases were found for estuarine and marine mulloway, golden perch, bony herring, black bream and yellow-eye mullet in the Coorong and Lakes fishery (1985-2010; Ferguson *et al*., 2013) and golden perch in Lake Albert (1985-2011; Ferguson & Ye, 2012) and breeding events of pied cormorant in the Coorong (1928-2011; O'Connor *et al*., 2012).

Of the population series analysed with the state space model (*n* = 61), all of them were stationary, i.e. they showed fluctuations but no statistically significant increase or decrease (Table A2). The time series for 22 species of native fishes from the Lower Lakes (2003-2009; Wedderburn *et al*., 2012) were not included in the state space analysis because they each contained only three data points and the minimum requirement for the state space model is four data points (Humbert *et al*., 2009). Of the 18 non-population time series of waterbird occurrence or proportional magnitude of breeding events analysed by logit-linear regression, none showed a statistically significant decline or increase (Table A3).

The median of the estimated exponential rate of increase (*r*) was 0.003 year^{-1} for population series analysed using the state-space model; -0.005 year^{-1} for population series analysed by log.-linear regression (Fig. 4b) and 0.013 for non-population series analysed using logit-regression. Most estimates were clustered near zero regardless of the statistical method used, with 48.9% greater than zero and 51.1% below zero for population series analysed using the state-space model (Fig. 4a), 45.9% above and 54.1% below zero for population series analysed using the log.-linear regression model (Figure 4b) and 58.8% above and 41.2% below zero for the logit-linear regression model (Figure 4c). The median rates for all three sets of series were not significantly different from zero.

Our analyses indicate there is no overall pattern of long-term declining trends in time series of biotic components from the Coorong and Lakes. The low median values of the exponential rates of increase and their frequency distribution around zero indicates a pattern of stability with fluctuation.

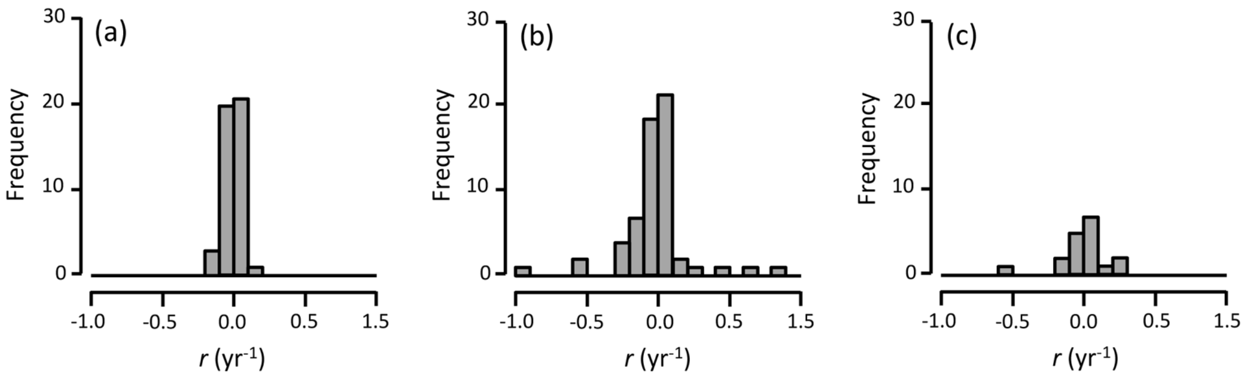

Figure 4. Frequency distribution of estimated exponential rate of increase (*r*), estimated for (a) the population series using the state space model (*n* = 45); (b) the population series using the log.-linear regression model (*n* = 62); (c) the non-population series using the logit-linear regression model (*n* = 18).

Table 3. Responses of time series of native, non-invasive taxa from the Coorong and Lakes that commenced prior to, and post-dated the Millennium Drought (1997-2010). Increases after drought: 1 = yes, 0 = no; >1 SD = increase in mean post-drought value of greater than one standard deviation of mean during Millennium Drought; >2 SD = increase of more than two standard deviations. The 28 waterbird species from Paton *et al*. (2009) Paton & Rogers, (2009) and Paton & Bailey (2012) in Table A1 have been combined.

		Years sampled			**Increase?**		
Species or group	**Location**	2010	2011	2012	>1 SD	>2 SD	**References**
Vegetation							
Ruppia tuberosa	Coorong	×	×	×	0	0	Rogers & Paton, 2009; Paton & Bailey, 2012
Macroinvertebrates							
Chironomid larvae	Coorong	×	×	×	1	0	Paton, 2011; Paton & Bailey, 2010)
Fishes							
Black bream	Coorong & Lakes	×	×		0	0	Ferguson, 2012; Ye *et al*., 2012; Ferguson *et al*., 2013
Bony herring	Coorong & Lakes	×	×		0	0	Ferguson, 2012; Ferguson *et al*., 2013
Golden perch	Coorong & Lakes	×	×		0	0	Ferguson, 2012; Ferguson *et al*., 2013
Small-mouthed hardyhead	Coorong	×	×	×	1	1	Paton, 2011; Paton & Bailey, 2012
Waterbirds							
All spp.	Coorong	×	×	×	1	1	Kingsford *et al*., 2013
All spp.	Coorong	×	×	×	1	1	Paton & Rogers, 2009; Paton & Bailey, 2012
Increase (1)					4	3	
No increase (0)					4	5	

Stochasticity, including demographic and environmental noise or 'process error', is intrinsic to population variation and ecological change. It is independent of 'observation error' from sampling and estimation (Dennis *et al*., 2006). State-space models partition both process and observation error, giving a more accurate inference of population trend, whereas log.-linear regression accounts for observation error only and can result in misleading inferences of trend by ignoring process noise (Clark and Bjørnstadt, 2004; Humbert *et al*., 2009).

Ecological responses after the Millennium Drought

Of eight population time series that contain annual counts and that commenced prior to, and post-dated the Millennium Drought (1997-2009), four showed increases in 2010, 2011 and/or 2012 of more than one standard deviation greater than the mean during the drought (Table 3). For four of them, the maximum post-drought value was >2 SD, indicating a statistically significant probability ($P<0.05$) of the response being due to the onset of wetter conditions, including waterbirds (all spp., data pooled) and small-mouthed hardyhead. For the rest there was little or no sign of post-drought response (<1 SD increase), including black bream, bony herring and golden perch and *Ruppia tuberosa*. None of the fish species underwent significant population decline during the Millennium Drought, as indicated by catch per unit effort (Ferguson, 2012). More than one cycle of flooding may be required for *R. tuberosa* to recover (Frahn *et al*., 2012). With the onset of more frequent and prolonged droughts under climate change, local extinction is more likely for those species that take longer to recover than for those that respond rapidly to the onset of improved conditions.

Impacts of climate change on the supply of ecosystem services

An increase by 2030 in mean surface temperature of +1.6°C relative to 1990 (the 'dry' scenario of Chiew *et al*., 2008), was one of the scenarios used to model water availability in the Murray-Darling Basin (CSIRO, 2008a). Under this scenario it is probable there will be major changes in the flow regime of the Coorong and Lakes. These changes include an increase of 51% in the average period between flood events, a 1.85-fold increase in the maximum period between floods and an 89% decrease in the average volume of floods per event compared with the 'current development, 1895-2006 climate' scenario of CSIRO (2008a). Data on changes in flood return period and volume is taken from Table 7.2 in CSIRO (2008b). Under +1.6°C by 2030 the Coorong Lagoon (Fig. 2) is predicted to receive only 2% of without-development flows (CSIRO, 2008) and become near-permanently hypersaline without management intervention. Mudflats that provide foraging habitat for migratory shorebirds will be permanently exposed, supporting a fraction of the current biomass of marine invertebrates on which shorebirds feed.

Modelling of scenarios using hydrological, hydrodynamic and ecosystem response models indicated that climate change and current water diversions 'has the capacity to devastate the ecology of the Coorong, but much of the degradation could be averted by reducing upstream extractions of water' (Lester *et al*. (2013). However, rises in sea-level are likely to increase hydrodynamic connectivity in the Coorong between the North Lagoon and South Lagoon, limiting the occurrence of low water levels and extreme salinities caused by evapoconcentration. Lester *et al*. (2013) concluded that ecological degradation is not a foregone conclusion and decisions about upstream water allocations will determine the ecological future of the Coorong.

The contraction in wetland extent and connectivity under climate change is likely to cause large scale declines in the distribution, diversity and abundance of flow-dependent biota and major changes in critical components, processes and services. Some wetlands of the Coorong and Lakes are likely to persist, others to transform permanently to alternate ecosystem states, including terrestrial ones.

Supply of some ecosystems services will continue, though with changes in extent and magnitude (Figure 5). These may include certain provisioning services (e.g. commercial fisheries and irrigation water), supporting services (e.g. nutrient cycling and primary productivity), and cultural services (e.g. tourism and recreation). Supply of others is likely to reduce and eventually cease over time, for example some cultural/provisioning services such as duck hunting and certain forms of recreational fishing, and supporting services such as habitat and resource provision for particular components of the biota. New ecosystems services will be supplied by transformed ecosystems. Others which were supplied but have low current demand are likely to increase in importance, for example protection of habitat or infrastructure provided by dunes and vegetation through buffering of extreme events and storm surges.

The nature and extent of changes in supply and demand of ecosystem services under climate change forms the basis for the assessment of *adaptation services*, that supply options and benefits to people from the capacity of ecosystems to moderate and adapt to climate variability and change (Lavorel *et al*., 2015).

Prediction of the likely changes in supply and demand for ecosystem services under climate change and variation, and the identification of adaptation services, could form part of a program of assessment of options for adaptation the Coorong and Lakes under climate change, complementing those already proposed and implemented (DfEH, 2009; DEWNR, 2014).

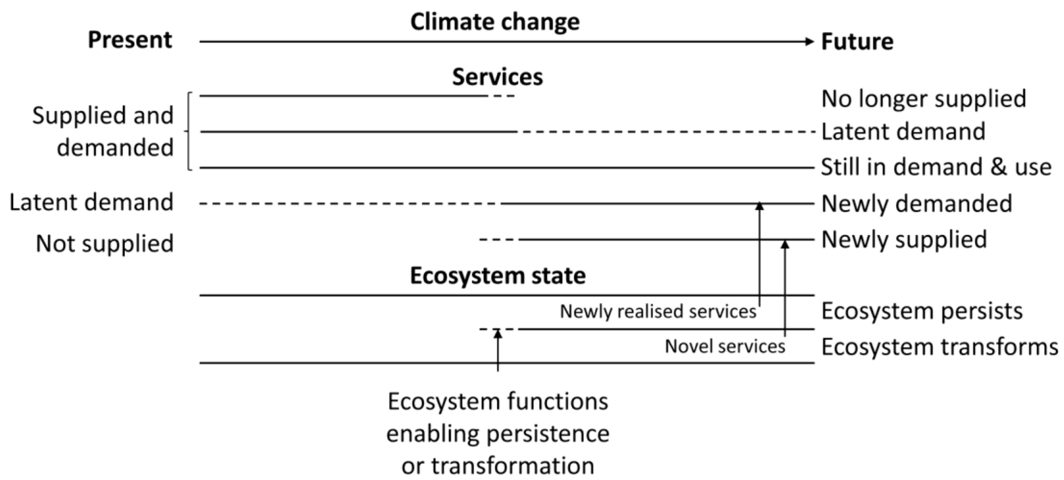

Figure 5. A basic typology of changes in supply and demand of ecosystem services under climate change, based on ecosystem persistence or transformation. Where ecosystems persist, some services will continue to be supplied and used. Demand for some services will reduce and others will no longer be supplied. Under ecosystem transformation, new services will be supplied and others, which were not previously used, will increase in demand.

4 Concluding remarks

The most important ecosystem services for human well-being based on income generation from the Coorong and Lakes are commercial and recreational fisheries, irrigation and domestic water supply, tourism and recreation, flow connectivity and water quality, and habitat and resource provision for biodiversity. All of these are dependent upon the flow regime which determines salinity, lake and estuary water levels and habitat availability.

For some ten ecosystem services for which monetary value could be assessed, the total value was $132 mn per year. This is likely to be an underestimation of the worth of these services because several estimates were undertaken some years ago. The total value of all services would to be considerably higher if habitat and biodiversity benefits were included. These constituted between a quarter and two-thirds (dependent upon the method of calculation) of the total value of ecosystem services from the Murray-Darling Basin (CSIRO, 2012).

Determination of limits of acceptable change in the supply of ecosystem services will allow for characterisation of the relationship between ecological components, process and services, particularly in relation to defining whether relationships are linear, non-linear and whether non-linear relationships are characterised by critical thresholds.

Because flow is critical to so many critical and supporting components, processes and services relating to ecological character, changes in flow regime have a major impact upon the stocks and flows of ecosystem services. This was the case during the Millennium Drought when declines in water availability for irrigation, stock and domestic use required the construction of pipelines from the Murray to ensure security of supply, or when downturns in tourism and visitation led to reduced income to the region.

The high dependency on flow regime of ecosystem services from the Coorong and Lower Lakes makes the region particularly vulnerable to climate variation and climate change because services are likely to reduce in both magnitude of supply and in diversity.

The use of the ecosystem services approach to justify continued management for direct-use provisioning services disregards the prospect that supply will become more uncertain under climate change. Costs of maintaining current services from changing ecosystems are likely to be high and ultimately unsustainable.

Determining the nature and extent of those ecosystem services that are likely to be maintained under climate change should be a matter of urgent priority. Such an exercise would include an assessment of the climate adaptation options for regional communities and economies as well as new or currently under-utilised ecosystem services that may emerge from modified and novel ecosystems in the future.

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Appendices

Table A1. Long-term data sets and series on ecological condition of the Coorong and Lakes. S = time series; DP = number of data points in time series; IF = initial-final studies. Shaded rows = data sets based only on measures of occurrence, condition or diversity: all others contain direct or indirect measures of abundance. References are listed below. Of the 75 waterbird species listed by Paton *et al*. (2009); Paton & Rogers, (2009) and Paton & Bailey (2012), we included only those 28 species that had mean population counts of ≥200 individuals and occurred in all years of record between 2000-2012.

Location	Species or group	Response variable(s)	Predictor variable(s)	Frequency of data collection	Start	End	Yrs	DP	TS IF	Notes	Reference
Vegetation											
Coorong	Ruppia *Ruppia tuberosa*	Extent, abundance of propagules & shoots	Salinity, water level	1985, 1991, 1992 then annually	1985	2012	23	8	TS	Decline linked to high salinity and low water levels	Rogers & Paton, 2009; Paton & Bailey, 2012
Aquatic macroinvertebrates											
Coorong South	Chironomid larvae *Tanytarsus barbitarsis*	Abundance	Salinity	Annual sampling	2001	2012	11	12	TS	2007 decline linked to high	Paton, 2010; Paton & Bailey, 2011; 2012
Coorong & Lakes	Goolwa cockle *Donax deltoides*	Catch per unit effort	Discharge	Annual catch returns	1985	2010	26	27	TS	Stable; decline since 2005	Ferguson *et al*., 2013
Fishes											
Lower Lakes	Australian smelt *Retropinna semoni*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Bony herring *Nematalosa erebi*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Bridled goby *Arenigobius bifrenatus*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Carp gudgeon *Hypseleotris* spp	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Common galaxias *Galaxias maculatus*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Stable to 2008; then steep decline	Wedderburn *et al*., 2012
Lower Lakes	Congolli *Pseudaphritis urvilli*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Stable to 2008; decline in 2009	Wedderburn *et al*., 2012
Lower Lakes	Dwarf flathead gudgeon *Phylipnodon macrostomus*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Pop. max. 2003, decline 2008-09	Wedderburn *et al*., 2012
Lower Lakes	European carp *Cyprinus carpio*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Stable to 2008; decline in 2009	Wedderburn *et al*., 2012
Lower Lakes	Flathead gudgeon *Phylipnodon grandiceps*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2009	Wedderburn *et al*., 2012
Lower Lakes	Gambusia *Gambusia holbrooki*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2009	Wedderburn *et al*., 2012
Lower Lakes	Golden perch *Macquaria ambigua*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Low popn. density throughout	Wedderburn *et al*., 2012
Lower Lakes	Goldfish *Carassius auratus*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Popn. max. 03, then decline	Wedderburn *et al*., 2012
Lower Lakes	Lagoon goby *Tasmanogobius lasti*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Murray hardyhead *Craterocephalus fluviatilis*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Redfin perch *Perca fluviatilis*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Steep increase 2008-09	Wedderburn *et al*., 2012
Lower Lakes	Sandy sprat *Hyperlophus vittatus*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Low popn. density throughout	Wedderburn *et al*., 2012
Lower Lakes	Small-mouthed hardyhead *Atherinosoma microstoma*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2008	Wedderburn *et al*., 2012
Lower Lakes	Southern pygmy perch *Nannoperca australis*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2003, then decline by 2008	Wedderburn *et al*., 2012
Lower Lakes	Tamar River goby *Afurcagobius tamarensis*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Major increase by 2008-09	Wedderburn *et al*., 2012

Location	Species or group	Response variable(s)	Predictor variable(s)	Frequency of data collection	Start	End	Yrs	DP	TS IF	Notes	Reference
Lower Lakes	Unspecked hardyhead *Craterocephalus stercusmuscarum fulvus*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Population maximum in 2003, then decline by 2008-09	Wedderburn *et al*., 2012
Lower Lakes	Western blue spot goby *Pseudogobius olorum*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Stable to 2008, decline in 2009	Wedderburn *et al*., 2012
Lower Lakes	Yarra pygmy perch *Nannoperca obscura*	Abundance	Depth, EC, cover	2003, 2008, 2009	2003	2009	6	3	TS	Popn. max. 03, then major decline	Wedderburn *et al*., 2012
Lake Albert	Golden perch *Macquaria ambigua*	Catch per unit effort	N/A/	Catch returns	1984	2010	26	27	TS	Population max. 1994, 03, 06-08	Ferguson & Ye, 2012
Coorong & Lakes	Black bream *Acanthopagrus butcheri*	Catch per unit effort	Discharge	Annual catch returns	1977	2011	34	35	TS	Decline 1980s; recovery 2003	Hall, 1984; Geddes *et al*., 2009; Ferguson, 2012; Ye *et al*., 2012; Ferguson *et al*., 2013
Coorong & Lakes	Bony herring *Nematalosa erebi*	Catch per unit effort	Discharge	Annual catch returns	1985	2011	21	22	TS	Abund. not linked to inflows	Ferguson *et al*., 2013
Coorong & Lakes	European Carp *Cyprinus carpio*	Catch per unit effort	Discharge	Annual catch returns	1985	2011	24	25	TS	Increase after high inflows 1980s	Ferguson *et al*., 2013
Coorong & Lakes	Golden perch *Macquaria ambigua*	Catch per unit effort	Discharge	Annual catch returns	1985	2011	26	27	TS	Increase in 1993 after flooding	Ferguson & Ye, 2012; Ferguson *et al*., 2013
Coorong & Lakes	Greenback flounder *Rhombosolea tapirina*	Catch per unit effort	Discharge	Annual catch returns	1985	2010	26	27	TS	Population peak 1984-2004	Ye *et al*., 2012; Ferguson *et al*., 2013
Coorong & Lakes	Mulloway *Argyrosomus japonicus* (estuarine)	Catch per unit effort	Discharge	Annual catch returns	1985	2010	26	27	TS	Increase from 1984 to 2010	Ferguson *et al*., 2008; 2013
Coorong & Lakes	Mulloway *Argyrosomus japonicus* (marine)	Catch per unit effort	Discharge	Annual catch returns	1985	2010	26	27	TS	Increase to 05, then decline	Ferguson *et al*., 2008; 2013
Coorong & Lakes	Yellow-eye mullet *Aldrichetta forsteri*	Catch per unit effort	Discharge	Annual catch returns	1985	2010	26	27	TS	Increase from 1984 to 2010	Ferguson *et al*., 2013
Coorong S Lagoon	Small-mouthed hardyhead *Atherinosoma microstoma*	Abundance	Salinity	Annual sampling at 8 sites	2001	2012	11	12	TS	Decline from 2007 linked to salinity; recovery in 2012	Paton, 2010; Paton & Bailey, 2012
Waterbirds											
Coorong & Lakes	Australian pelican *Pelecanus conspicillatus*	Breeding magnitude	N/A	Collated reports & annual monitoring	1910	2013	103	21	TS	Mean no. nests, nesting pairs & chicks reduced 2.4-fold by 2013	O'Connor et al., 2013
Coorong & Lakes	Australian white ibis *Threskicornis molucca*	Breeding magnitude	N/A	Collated reports & annual monitoring	1962	1976	14	12	TS	Magnitude of breeding events highly variable	O'Connor et al., 2013
Coorong & Lakes	Black swan *Cygnus atratus*	Breeding magnitude	N/A	Collated reports & annual monitoring	1910	2011	101	8	TS	Magnitude of breeding events highly variable	O'Connor et al., 2013
Coorong & Lakes	Caspian tern *Sterna caspia*	Breeding magnitude	N/A	Collated reports & annual monitoring	1932	2013	80	12	TS	Magnitude of breeding events declined over five-fold	O'Connor et al., 2013
Coorong & Lakes	Crested tern *Sterna bergii*	Breeding magnitude	N/A	Collated reports & annual monitoring	1964	2013	48	23	TS	Max. 3,300 breeding pairs in 2012;	O'Connor et al., 2013
Coorong & Lakes	Fairy tern *Sterna nereis*	Breeding magnitude	N/A	Collated reports & annual monitoring	1929	2013	84	21	TS	Mean no. nests, nesting pairs & chicks reduced 4.4-fold by 2013	O'Connor et al., 2013
Coorong & Lakes	Glossy ibis *Plegadis falcinellus*	Breeding magnitude	N/A	Collated reports & annual monitoring	1962	1971	9	8	TS	Seven-fold reduction in mean breeding magnitude	O'Connor et al., 2013
Coorong & Lakes	Great cormorant *Phalacrocorax carbo*	Breeding magnitude	N/A	Collated reports & annual monitoring	1963	1979	16	13	TS	Max. breeding event 1320 nest in 1971	O'Connor et al., 2013
Coorong & Lakes	Great egret *Ardea alba*	Breeding magnitude	N/A	Collated reports & annual monitoring	1963	1974	11	8	TS	Breeding very stable -50-100 nests and breeding pairs	O'Connor et al., 2013
Coorong & Lakes	Little black cormorant *Phalacrocorax sulcirostris*	Breeding magnitude	N/A	Collated reports & annual monitoring	1962	1979	16	15	TS	Mean two-fold increase, but not statistically significant	O'Connor et al., 2013
Coorong & Lakes	Little pied cormorant *Phalacrocorax melanoleucos*	Breeding magnitude	N/A	Collated reports & annual monitoring	1931	1976	45	14	TS	Max. breeding event 1000 nest in 1966	O'Connor et al., 2013
Coorong & Lakes	Pied cormorant *Phalacrocorax varius*	Breeding magnitude	N/A	Collated reports & annual monitoring	1928	2011	82	16	TS	Largest breeding events 1966-1972	O'Connor et al., 2013

Location	Species or group	Response variable(s)	Predictor variable(s)	Frequency of data collection	Start	End	Yrs	DP	TS IF	Notes	Reference
Coorong & Lakes	Royal spoonbill *Platalea regia*	Breeding magnitude	N/A	Collated reports & annual monitoring	1962	1974	11	10	TS	Ca. 50 prs. nested on Salt Lagoon Islands each year 1962-1974	O'Connor et al., 2013
Coorong & Lakes	Silver gull *Larus novaehollandiae*	Breeding magnitude	N/A	Collated reports & annual monitoring	1928	1968	40	7	TS	Largest number of breeding pairs 1967-8	O'Connor et al., 2013
Coorong & Lakes	Straw-necked ibis *Threskiornis spinicollis*	Breeding magnitude	N/A	Collated reports & annual monitoring	1963	2011	48	10	TS	Largest number of nests 1965-71	O'Connor et al., 2013
Coorong & Lakes	Yellow-billed spoonbill *Platalea flavipes*	Breeding magnitude	N/A	Collated reports & annual monitoring	1962	1979	17	11	TS	Breeding stable -50-100 nest sand breeding pairs	O'Connor et al., 2013
Coorong & Lakes	Sanderling *Calidris alba*	Occurrence	Water level, EC	20 site visits per year	2002	2012	8	9	TS	Low occurrence, peaking 2004-09	O'Connor & Rogers, 2013
Coorong & Lakes	Pied oystercatcher *Haematopus ostralegus*	Occurrence	Water level, EC	20 site visits per year	2000	2012	12	13	TS	Moderate occurrence, increasing sporadically 2003-10	O'Connor & Rogers, 2013
Coorong S Lagoon	Australian pelican *Pelecanus conspicillatus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Mean annual count 3,500; range 1170-6200	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Australian shelduck *Tadorna tadornoides*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima (>16,000) in 2006, 2009 and 2011	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S	Australian white ibis *Threskicornis molucca*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Popn. max. 2001 and 2007	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Banded stilt *Cladorynchus leucocephalus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	<20,000 between 2000-04; >210,000 in 2009	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Black-faced cormorant *Phalacrocorax fuscescens*	Abundance	N/A	Annual counts	1985	2012	27	13	TS	Population maxima in 2005, 2009 and 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Black swan *Cygnus atratus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Sporadic decline: 2,600 in 2000 to 200 in 2011; recovery in 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Black-winged stilt *Himantopus himantopus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Sporadic increase to 2008; decline 2009-12	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Caspian tern *Sterna caspia*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima (>800) in 2001, 2006, 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Chestnut teal *Anas castanea*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Sporadic decline from 21,000 in 2002 to 5,000 in 2011	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Common greenshank *Tringa nebularia*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Stable 2000-06 then decline	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Crested tern *Sterna bergii*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Strongly fluctuating, 1300 in 2003 to 8600 in 2007	Paton *et al*., 2009; Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Curlew sandpiper *Calidris ferruginea*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Sporadic decline from 8,100 in 2000 to 50 in 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Fairy tern *Calidris ferruginea*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Sporadic decline to 2011, recovery 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S	Great cormorant *Phalacrocorax carbo*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Popn. max. 2002, 2007 and 2012	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Great crested grebe *Podiceps cristatus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Strongly fluctuating, 600 in 2007, 2 in 2011	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Grey teal *Anas gracilis*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population max. in 2002, decline to 2011, recovery in 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012

Location	Species or group	Response variable(s)	Predictor variable(s)	Frequency of data collection	Start	End	Yrs	DP	TS IF	Notes	Reference
Coorong S Lagoon	Hoary-headed grebe *Poliocephalus poliocephalus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Stable to 2008, population max. 2009, 0 in 2011, recovery 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Little black cormorant *Phalacrocorax sulcirostris*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Stable to 2009; population max in 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Little pied cormorant *Phalacrocorax melanoleucos*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Decline to 2011, recovery 2012	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Masked lapwing *Vanellus miles*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Steady sporadic decline to 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S	Musk duck *Bizuria lobata*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Popn. max. 2000, 04, 07 and 2012	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S	Pacific black duck *Anas superciliosa*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Popn. max. 2000, 2007 and 2012	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S	Pied cormorant *Phalacrocorax varius*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Stable to 2009; max in 2012	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Pied oystercatcher *Haematopus ostralegus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima in 2003, 2006 and 2009	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Pink-eared duck *Malacorhynchus membranaceus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maximum in 2006	Paton *et al*., 2009; Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Red-capped plover *Charadrius ruficapillus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Strongly fluctuating, 1640 in 2001, 71 in 2011, recovery in 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Red-necked avocet *Recurvirostra novaehollandae*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima in 2003, 2005, decline to 2011, recovery in 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S	Red-necked stint *Calidris ruficollis*	Abundance	N/A	Annual counts	2000	2012	11	12	TS	Decline to 2011, recovery 2012	Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Sharp-tailed sandpiper *Calidris acuminata*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima in 2003, 2006, decline to 2011, then recovery	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Silver gull *Larus novaehollandiae*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima in 2001, 2006, and 2011	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	Straw-necked ibis *Threskiornis spinicollis*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima in 2001, 2006, and 2011	Paton *et al*., 2009; Paton & Rogers, 2009; Paton & Bailey, 2012
Coorong S Lagoon	Whiskered tern *Childonius hybridus*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	12	13	TS	Population maxima in 2006, 2009 and 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong S Lagoon	White-faced heron *Egretta novaehollandiae*	Abundance	N/A	1985, then annual counts from 2000	1985	2012	27	13	TS	Population maxima in 2001, 2003, 2008 and 2012	Paton *et al*., 2009; Paton & Rogers, 2009; Paton, 2010; Paton & Bailey, 2012
Coorong	Wader spp.	Abundance	N/A	Annual counts, 81, 82, 87, 00-08	1981	2008	27	13	TS	Abundance in 2008 reduced by 85% compared with early 1980s	Wainwright & Christie, 2008
Coorong S	Banded lapwing *Vanellus tricolor*	Abundance	Rainfall, floods	Annual aerial survey	1983	2006	23	24	TS	Popn. max. 84, then decline	Nebel *et al*., 2008
Coorong S	Banded stilt *Cladorynchus leucocephalus*	Abundance	Rainfall, floods	Annual aerial survey	1983	2006	23	24	TS	Max. 1984, then sporadic decline	Nebel *et al*., 2008
Coorong S	Black-winged stilt *Himantopus himantopus*	Abundance	Rainfall, floods	Annual aerial survey	1983	2006	23	24	TS	Max 1984, then sporadic decline	Nebel *et al*., 2008
Coorong S	Masked lapwing *Vanellus miles*	Abundance	Rainfall, floods	Annual aerial survey	1983	2006	23	24	TS	Popn. max. 90, then decline	Nebel *et al*., 2008
Coorong S Lagoon	Pied oystercatcher *Haematopus ostralegus*	Abundance	Rainfall, floods	Annual aerial survey	1983	2006	23	24	TS	Low counts throughout period of record; many zeros	Nebel *et al*., 2008
Coorong S Lagoon	Red-necked avocet *Recurvirostrata novaehollandiae*	Abundance	Rainfall, floods	Annual aerial survey	1983	2006	23	24	TS	Population maximum 1984, then sporadic decline	Nebel *et al*., 2008
Coorong S	All waterbird spp.	Abundance	Rainfall, flood area		1983	2012	29	30	TS	Popn. max. 1985, 1987, 2012	Kingsford *et al*., 2013

Table A2. Long-term trends of population time series of native, non-invasive taxa (European carp, redfin perch, goldfish and Gambusia excluded) based on the state-space model (SS; n = 45) and log.-linear regression of abundance (log.; n = 62). I = invasive species. r = value of exponential rate of increase; CI = credibility interval; Sig = significance level: * = P<0.05; ** = P<0.01; *** = P<0.001.

Species or group	Location	Reference	*r* SS	CI low	CI high	Sig. SS	*r* log.	*P* null log.	Sig. log.
Vegetation									
Ruppia	Coorong	Rogers & Paton 2009	-0.066	-0.212	0.065	n.s.	-0.0581	0.0048	**
Aquatic macroinvertebrates									
Pipi	Coorong & Lakes	Ferguson et al 2013	-0.020	-0.124	0.085	n.s.	-0.0096	0.3575	n.s.
Chironomids	Coorong	Paton & Bailey (2011)	-0.011	-1.772	1.744	n.s.	-0.1257	0.5654	n.s.
Fishes									
Black bream	Coorong & Lakes	Ferguson et al 2013	0.028	-0.083	0.141	n.s.	0.0170	0.0251	*
Bony herring	Coorong & Lakes	Ferguson et al 2013	0.017	-0.007	0.043	n.s.	0.0168	0.0006	***
Golden perch	Coorong & Lakes	Ferguson et al 2013	0.020	-0.116	0.149	n.s.	0.0307	0.0053	**
Greenback flounder	Coorong & Lakes	Ferguson et al 2013	0.001	-0.145	0.148	n.s.	0.0067	0.5974	n.s.
Mulloway (estuarine)	Coorong & Lakes	Ferguson et al 2013	0.047	-0.083	0.165	n.s.	0.0506	0.0001	***
Mulloway (marine)	Coorong & Lakes	Ferguson et al 2013	0.046	-0.134	0.22	n.s.	0.0420	0.0189	*
Yellow-eye mullet	Coorong & Lakes	Ferguson et al 2013	0.029	-0.016	0.083	n.s.	0.0286	0.0000	***
Golden perch	Lake Albert	Ferguson &Ye 2012	0.021	-0.067	0.089	n.s.	0.0193	0.0216	*
Australian smelt	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.2228	0.5507	n.s.
Bony herring	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.0984	0.4851	n.s.
Bridled goby	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.6124	0.1763	n.s.
European carp	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.2311	0.5974	n.s.
Carp gudgeon	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.4021	0.2967	n.s.
Common galaxias	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.2415	0.4817	n.s.
Congolli	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.2839	0.4458	n.s.
Dwarf flathead gudgeon	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.5161	0.2592	n.s.
Flathead gudgeon	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.0684	0.2143	n.s.
Golden perch	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.1668	0.3792	n.s.
Lagoon goby	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.0280	0.9068	n.s.
Murray hardyhead	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.1575	0.4316	n.s.
Small-mouthed hardyhead	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.2228	0.5507	n.s.
Southern pygmy perch	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.3368	0.1261	n.s.
Tamar river goby	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	0.8104	0.0684	n.s.
Unspecked hardyhead	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.6062	0.3946	n.s.
Western blue spot goby	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.0394	0.7202	n.s.
Yarra pygmy perch	Lower Lakes	Wedderburn et al 2012	NA	NA	NA	NA	-0.9782	0.0459	*
Small-mouthed hardyhead	Coorong	Paton & Bailey 2012	0.060	-1.238	1.477	n.s.	-0.1892	0.3049	n.s.
Waterbirds									
Waterbirds	Coorong	Kingsford et al 2013	0.043	-0.307	0.592	n.s.	-0.0281	0.4624	n.s.
Australian pelican	Coorong	Paton & Rogers 2009	-0.006	-0.179	0.171	n.s.	-0.0284	0.1530	n.s.
Australian shelduck	Coorong	Paton & Rogers 2009	0.026	-0.165	0.204	n.s.	0.0275	0.3236	n.s.
Australian white ibis	Coorong	Paton & Rogers 2009	-0.039	-0.317	0.293	n.s.	-0.0480	0.2052	n.s.
Banded stilt	Coorong	Paton & Rogers 2009	0.058	-0.380	0.447	n.s.	0.0871	0.0906	n.s.
Black faced cormorant	Coorong	Paton & Rogers 2009	0.031	-0.147	0.227	n.s.	0.0205	0.4710	n.s.
Black swan	Coorong	Paton & Rogers 2009	0.007	-0.256	0.293	n.s.	-0.0078	0.8131	n.s.
Black winged stilt	Coorong	Paton & Rogers 2009	0.042	-0.286	0.365	n.s.	0.0497	0.273	n.s.
Chestnut teal	Coorong	Paton & Rogers 2009	0.087	-0.155	0.337	n.s.	0.0641	0.0968	n.s.
Common greenshank	Coorong	Paton & Rogers 2009	-0.021	-0.150	0.107	n.s.	-0.0087	0.6538	n.s.
Crested tern	Coorong	Paton & Rogers 2009	-0.001	-0.187	0.182	n.s.	-0.0026	0.9186	n.s.
Curlew sandpiper	Coorong	Paton & Rogers 2009	-0.188	-0.530	0.139	n.s.	-0.1491	0.0081	**
Great cormorant	Coorong	Paton & Rogers 2009	0.159	-0.553	0.983	n.s.	0.1229	0.2057	n.s.
Great crested grebe	Coorong	Paton & Rogers 2009	-0.019	-0.469	0.469	n.s.	-0.0277	0.6703	n.s.
Grey teal	Coorong	Paton & Rogers 2009	-0.102	-0.475	0.360	n.s.	-0.1081	0.0668	n.s.
Hoary headed grebe	Coorong	Paton & Rogers 2009	-0.095	-0.879	0.733	n.s.	-0.1307	0.2199	n.s.
Little black cormorant	Coorong	Paton & Rogers 2009	0.049	-0.414	0.586	n.s.	0.0184	0.7639	n.s.
Little pied cormorant	Coorong	Paton & Rogers 2009	-0.195	-1.233	0.993	n.s.	-0.2202	0.1138	n.s.
Masked lapwing	Coorong	Paton & Rogers 2009	0.004	-0.085	0.095	n.s.	0.0012	0.9176	n.s.
Musk duck	Coorong	Paton & Rogers 2009	-0.088	-0.703	0.525	n.s.	-0.1061	0.1666	n.s.
Pacific black duck	Coorong	Paton & Rogers 2009	-0.053	-0.517	0.394	n.s.	-0.0417	0.4551	n.s.
Pied cormorant	Coorong	Paton & Rogers 2009	0.076	-0.232	0.488	n.s.	0.0435	0.3125	n.s.
Pied oystercatcher	Coorong	Paton & Rogers 2009	-0.001	-0.084	0.080	n.s.	-0.0003	0.9762	n.s.
Pink eared duck	Coorong	Paton & Rogers 2009	0.028	-0.617	0.752	n.s.	0.0727	0.4291	n.s.
Red capped plover	Coorong	Paton & Rogers 2009	-0.053	-0.300	0.213	n.s.	-0.0553	0.1345	n.s.
Red necked avocet	Coorong	Paton & Rogers 2009	-0.054	-0.604	0.554	n.s.	-0.0796	0.2203	n.s.
Red necked stint	Coorong	Paton & Rogers 2009	-0.055	-0.305	0.259	n.s.	-0.0802	0.0327	*
Sharp tailed sandpiper	Coorong	Paton & Rogers 2009	-0.028	-0.506	0.467	n.s.	-0.0333	0.5715	n.s.
Silver gull	Coorong	Paton & Rogers 2009	0.029	-0.083	0.145	n.s.	0.0300	0.0653	n.s.
Straw necked ibis	Coorong	Paton & Rogers 2009	-0.084	-0.809	0.618	n.s.	-0.0963	0.2093	n.s.
Whiskered tern	Coorong	Paton & Rogers 2009	0.008	-0.403	0.445	n.s.	0.0017	0.9729	n.s.
White faced heron	Coorong	Paton & Rogers 2009	0.003	-0.088	0.104	n.s.	-0.0010	0.9392	n.s.
Waders	Coorong	Wainwright & Christie 2008	-0.056	-0.203	0.096	n.s.	-0.0531	0.0026	**

Table A3. Long-term trends of non-population time series: occurrence or proportional data analysed by logit-linear regression (LR; *n* = 18). *r* = value of exponential rate of increase; CI = credibility interval; Sig = significance level: * = *P*<0.05; ** = *P*<0.01; *** = *P*<0.001.

Species or group	Location	Reference	*r* LR	CI low	CI high	Sig. LR
Waterbirds						
Pied sandpiper reporting rate	Coorong & Lakes	O'Connor & Rogers 2013	0.013	-0.323	0.327	n.s.
Sanderling reporting rate	Coorong & Lakes	O'Connor & Rogers 2013	-0.017	-0.44	0.412	n.s.
Australian pelican magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.087	-0.334	0.145	n.s.
Australian white Ibis magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.036	-2.073	2.157	n.s.
Black swan magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.026	-0.687	0.705	n.s.
Caspian tern magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.115	-0.459	0.208	n.s.
Crested tern magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.037	-0.411	0.397	n.s.
Fairy tern magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.077	-0.439	0.36	n.s.
Glossy ibis magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.639	-4.013	2.947	n.s.
Great cormorant magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.017	-1.633	1.71	n.s.
Great egret magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.125	-3.016	3.092	n.s.
Little black cormorant magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.249	-1.260	1.544	n.s.
Little pied cormorant magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.002	-0.949	0.946	n.s.
Pied cormorant magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.038	-0.222	0.304	n.s.
Royal spoonbill magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.234	-2.206	2.461	n.s.
Straw necked ibis magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.046	-0.853	0.841	n.s.
Silver gull magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	0.088	-1.942	2.145	n.s.
Yellow-billed spoonbill magnitude of breeding events	Coorong & Lakes	O'Connor et al 2013	-0.129	-1.626	1.303	n.s.

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