Ecosystem services and associated critical processes and functions: A review relevant to the Coorong and Lakes Alexandrina and Albert Ramsar site.

Final report

Submitted to: Rebecca Quin
Coordinator, Environmental Integration

Strategy & Governance | Major Projects Branch
Department of Environment, Water and Natural Resources
P (08) 8204 1130 | F (08) 8204 1133 | E rebecca.quin@sa.gov.au

29th October 2014

Submitted by: Dr Rhonda Butcher
Principal Consultant
Water's Edge Consulting
Dr Rhonda Butcher
9 McDermott Ave
Mooroolbark VIC 3138

03 9727 5649
0427848108
www.waters-edge.com.au

Contents

1 Introduction

As part of the update of the Coorong, and Lakes Alexandrina and Albert Ecological Character Description (ECD), critical components, processes and ecosystem services have been identified. The links between critical ecological processes, functions and ecosystem services within the site has not yet been documented. The field of ecosystem service (ES) classification, assessment and mapping is rapidly evolving and has seen an increase in the number of publications dealing with this concept since its introduction in 2005. Whilst the concept has much appeal in terms of potentially being able to contribute to policy and management of natural resources and human wellbeing, there remain aspects which still require further research and general acceptance. One key area in which there remain significant challenges are in the adoption of standard techniques for assessment, identifying causal relationships that support the production/supply of ES, and the adoption on standard classifications (Cork et al. 2012; Barnaud and Antona 2014). A major issue for site management at the Coorong and Lakes Alexandrina and Albert Ramsar site is the assessment of the effects of management interventions on the capacity of the site to provide ecosystem services, as opposed to the utilisation of ecosystem services. This is an area that has not been adequately assessed and is necessary to be able to state the ecological character of the site is being maintained.

DEWNR, Water's Edge Consulting and Deakin University held a workshop to discuss issues around ES within the Coorong, and Lakes Alexandrina and Albert Ramsar site. The identification of critical ecosystem services is a key element in the management of Ecological Character at Ramsar sites. To date relatively little attention has been paid to actually assessing ES at Australian Ramsar sites other than to list the fact that most sites support a number of critical ES. DEWNR has recognised in order to *maintain ecological character* of the Coorong and Lakes Alexandrina and Albert Ramsar site they need to be able to map and measure the provision and use of ES to and within the site.

The objectives of the workshop were to establish the scope of the ecological processes and functions as they relate to intermediate and final ecosystem services within the Ramsar site. The classification/ terminology used by Fisher et al. (2009) was to be adopted so as to avoid problems of double counting in environmental-economic accounting should this be undertaken in the future. Specifically the purpose of the workshop was to:

- Clarify terminology.
- Determine what work undertaken in the CLLMM supports the development of the Ecosystem Response Forecasting Tool (ERFT). The ERFT will include hydrodynamic, water quality, ecological response and function, and ecosystem service models. These models will improve the ability of managers to identify and quantify potential impacts of management and the benefits of maintaining intact and functioning wetland ecosystems for the Coorong, and Lakes Alexandrina and Albert Ramsar site (e.g. including environmental watering decisions).
- Identify processes and functions are critical to provision of service and the health of the site.
- Identify how the site provides critical services, including identifying how processes interact with controlling variables/ drivers and therefore management intervention.

This report presents the outcomes of the workshop as well as a series of conceptual models, in both table and diagram form, which summarise hypothesised relationships of processes, functions and critical ES within the site. The approach of expert elicitation is adopted for this report with explicit visualisation of the mental model to a conceptual model being undertaken to promote debate around the concepts being presented. The conceptual models will need to be reviewed by a technical panel or within DEWNR, and will most likely require modification. In addition approaches to assessing ES and general concepts from the literature are very briefly reviewed where relevant, and where they informed the development of the conceptual models. The conceptual models developed will, where possible, highlight the strength of importance of each process and function to the services within the different site management units, potential controlling variables and knowledge gaps. Areas in which future research attention should be directed are also identified.

1.1 Terminology and recent concepts

1.1.1 Ecosystem services terminology

Ecosystem services have been classified in a number of ways since being first introduced by Daily (1997), and then more widely accepted with the advent of the Millennium Ecosystem Assessment in 2005 (Millennium Ecosystem Assessment 2005; Costanza 2008; TEEB 2010). In addition there are differing opinions as to the supply benefit chains (e.g. see Fisher et al. 2009 versus Boyd and Banzhaf 2007 cited in Burkhard et al. 2014; Reid-Piko et al. 2010; Cork et al. 2012; Haines-Young and Potschin 2013). Villamagna et al. (2013) recently identified a series of questions which need to be addressed when considering ES, including how ecosystems produce services, how to consistently quantify ecosystem service flows, how services relate to each other and how landscape changes affect future service delivery (Burkhard et al. 2014).

There is considerable debate over the definitions of ecosystem ‘‘functions’’, ‘‘goods’’, ‘‘benefits’’, and ‘‘services’’ (Barnaud and Antona 2014). Some authors argue for making a distinction between the final ecosystem services that contribute to the well-being of a specific human beneficiary, and the intermediate ecosystem functions that represent the capacity of an ecosystem to give rise to ecosystem services (see Fisher et al. 2009, Lamarque et al. 2011, (Potschin and Haines-Young 2011). Many view ecosystem services as a cascade, with one such cascade illustrated in Figure 1 which forms the basis of the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin 2013).

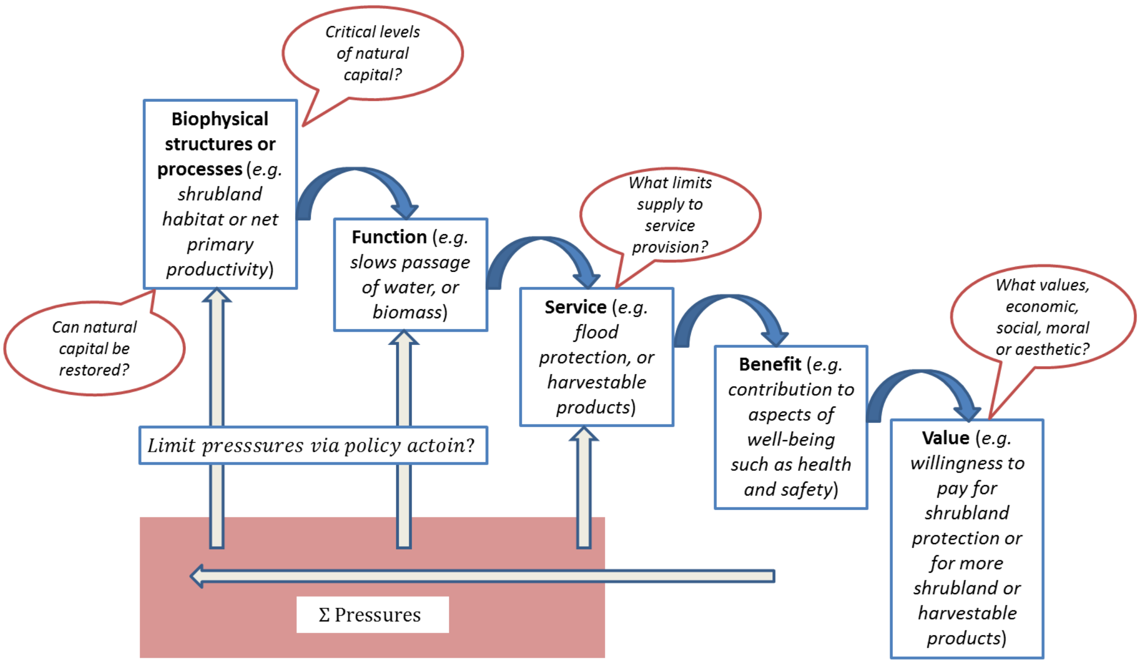

Figure 1: The ecosystem service cascade model. Modified from Potschin and Haines-Young 2011).

Fisher et al. (2009) redefined the MEA "ecosystem services" as including: benefits, intermediate and final ecosystem services. They also redefine the MEA "benefits people obtain from ecosystems" as the aspects of ecosystems utilised (passively or actively) to produce human wellbeing. This redefinition is illustrated in Figure 2. This definition was derived to avoid problems of double counting in environmental-economic accounts of ecosystem services.

Fisher et al. (2009) define intermediate and final ecosystem services as follows:

- **Intermediate ES** — those that form part of a 'cascade of services' that support one another and underpin final services; and
- **Final ES** — those that are directly used by people to provide benefits.

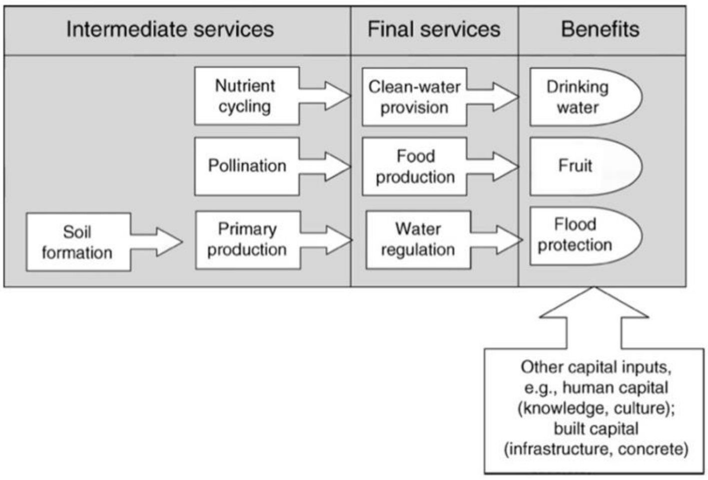

Figure 2: Model of relationship between intermediate and final services and benefits (from (Fisher et al. 2009).

Regulating ecosystem services by nature have a degree of overlap with ecosystem structures, processes and functions. For example nutrient flow, water flow and/or waste regulation have a clear overlap with functions such as water and nutrient cycling. Regulating services can be challenging to separate and may not be perceived to be a service as they can lack a clearly identified benefit (Burkhard et al. 2014).

The focus of the ECD, and this report, is predominantly on the natural ecosystem services that are supplied by the Ramsar site, and do not, except for provision of food and water, relate to agro(eco)services such as grazing, timber production etc. These types of service can have additional inputs to alter the capacity and flow of a service – for example water for irrigation is able to be manipulated to increase volumes and delivery and is a standard characteristic of the service. Most 'natural' ecosystem services do not have these additional inputs (Burkhard et al. 2014) which are defined as:

> non-ecosystem-based anthropogenic contributions to ecosystem services, referring for example to fertiliser, energy, pesticide, technique, labour or knowledge use in human influenced land use systems. These additional inputs (e.g. agro-, forestry or urban system services) converge with (natural) ecosystem service potentials into e.g. agro-, forestry or urban ecosystem services (Burkhard et al. 2014).

1.1.2 Ramsar terminology – ecological processes and functions

The Ramsar Convention provides the following definitions (from Ramsar Resolution V1.1):

- **Ecological processes** are *changes or reactions which occur naturally within wetland ecosystems. They may be physical, chemical or biological*. In laymen's terms, this equates to process such as carbon cycling, denitrification, acidification, sedimentation, migration, breeding, reproduction, etc.

- **Functions** are *activities or actions which occur naturally in wetlands as a product of the interactions between the ecosystem structure and processes*. Functions as defined by Ramsar include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilization and erosion controls; storm protection; and stabilization of local climatic conditions, particularly rainfall and temperature.

Using the Fisher et al. (2009) model and the Ramsar definitions the relationship between processes, functions, intermediate services, final services and benefits are shown in Figure 3.

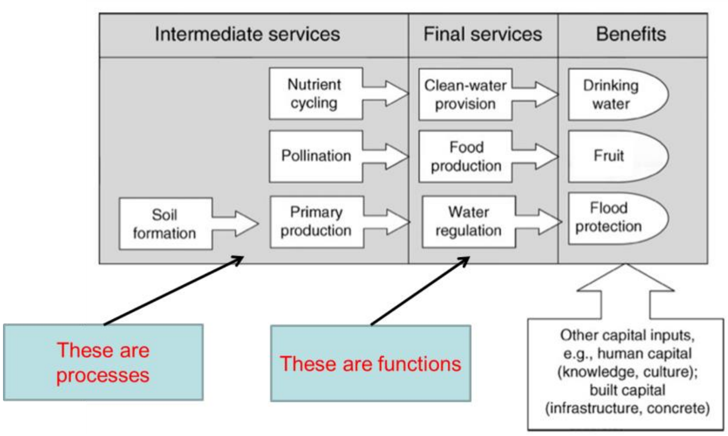

Figure 3: Modified Fisher et al. (2009) mode of ecosystem service with the Ramsar definition of processes and functions added.

For the purposes of this report the CICES division structure (see Appendix B) was used to check the functions relating to each critical ecosystem service, noting that in this report functions are taken to largely equate with final services as defined by Fisher et al. (2009). There is inadequate scope in the current project to finesse the typology for processes, functions and services beyond that presented in Appendix B. Further work may be required to align the typology used here to that used in the ECD for the Coorong and Lakes Alexandrina and Albert Ramsar site.

Recommend DEWNR adopt a consistent terminology for use in the draft ECD and in the Site Operations Manual for the Ramsar site.

1.1.3 Ecosystem service concepts

1.1.3.1 ES supply and delivery

Recent concepts regarding ecosystem services have been presented in the literature including (from Mouchet et al. 2014 and Burkhard et al. 2014):

- **ES capacity** is ''the long-term potential of ecosystems to provide services appreciated by humans in a sustainable way, under the current management of the ecosystem. Capacity may be increased or decreased over time through ecosystem management and land use conversion.'' (Schröter et al. 2014 and references cited). ES capacity also refers as the potential of an ecosystem ''to deliver services based on biophysical properties, social conditions, and ecological functions'' (Villamagna et al. 2013 and references therein).

- **ES potential:** the hypothetical maximum yield of selected ecosystem services (Burkhard et al. 2012 cited in Burkhard et a. 2014).

- **Demand for ES:** ecosystem goods and services currently consumed or used in a particular area over a given time period, not considering where ecosystem services actually are provided (Burkhard et al. 2012 cited in Burkhard et a. 2014).

- **ES flow** is ''the actual use of ecosystem services and occurs at the location where an ecosystem service enters either a utility function [. . .] or a production function [. . .]'' (Schröter et al. 2014) and is also ''the service actually received by people, which can be measured directly as the amount of a service delivered, or indirectly as the number of beneficiaries served'' (Villamagna et al. 2013). However, ES flow is not ES demand.

Ecosystem service delivery includes capacity, flow and demand; all of which need to be considered if ES are to be measured within the Ramsar site. Villamagna et al. (2013) provide a conceptual model of how these elements of ES deliver relate to each other and alternative definitions found in the literature (Figure 4).

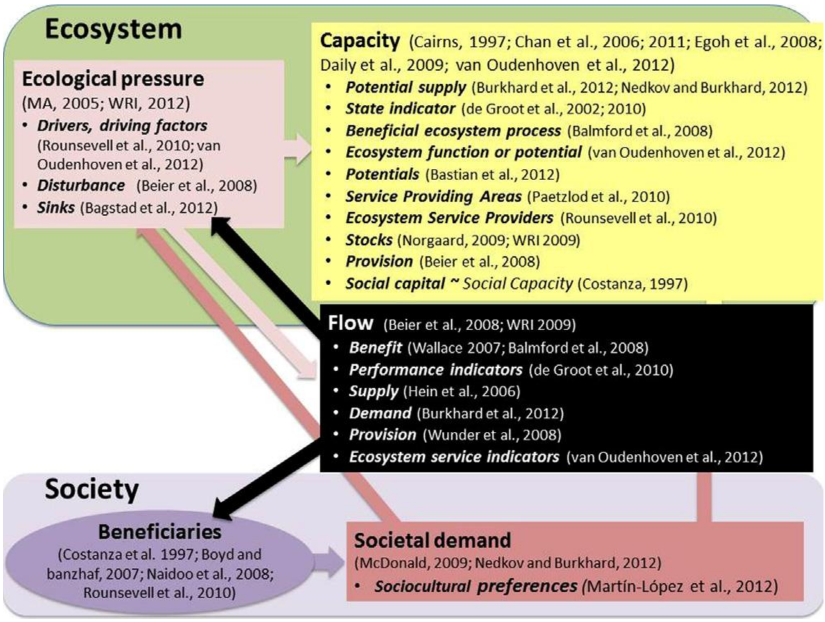

Figure 4: The main components of the ecosystem service delivery process (boxes) are interconnected such that a change in one affects the others (arrows). A wide array of terms has been used interchangeably throughout the literature. For each main component, we cite literature in which that term is used and provide alternative terminology cited in the literature. Ecological pressures (pink box in upper left) have a direct effect on the capacity of an ecosystem to provide a service and can affect the flow of the services (black box). Likewise, societal demand (red box in lower right) can influence ecological pressures and the flow of services from ecosystems to beneficiaries (purple box) and the needs and preferences of beneficiaries influence societal demand (from Villamagna et al. 2013).

1.1.3.2 Spatial relationships supply and benefiting areas

One of the workshop objectives was to identify how the site provides critical services, including identifying how processes interact with controlling variables/drivers and where the important source areas are spatially within the site. Both the spatial and temporal scales at which the ES are provided need to be considered. For example specific times, or 'hot moments' of ecosystem service supply and demand can be as important to identify as spatially relevant hotspots (Burkhard et al. 2013 cited in Burkhard et al. 2014). Burkhard et al (2014) provides a number of definitions in relation to spatial provision of ES, and Syrbe and Walz (2012) provide a conceptual model detailing some of the possible spatial relationships between supply and benefiting areas (Figure 5).

- **Ecosystem service providing units (SPU):** spatial units that are the source of an ecosystem service (Syrbe and Walz 2012). SPU includes all organisms and their traits required to deliver a given ecosystem service as well as abiotic ecosystem components. Hotspot SPU are as the name suggests areas that provide large components of ES in a comparably small area/spot (from Burkhard et al. 2014).

- **Ecosystem service benefiting areas (SBA)**: the complement to SPUs. SBAs may be adjacent to SPU or distant. The structural characteristics of a benefiting area must be such that the area can take advantage of an ecosystem service (Syrbe and Walz 2012) (from Burkhard et al. 2014)..

- **SPU - SBA spatial relations:** spatial characteristics describing the relationships between the place of service production and where the benefits are realized (Fisher et al. 2009; Syrbe and Walz 2012) (from Burkhard et al. 2014).

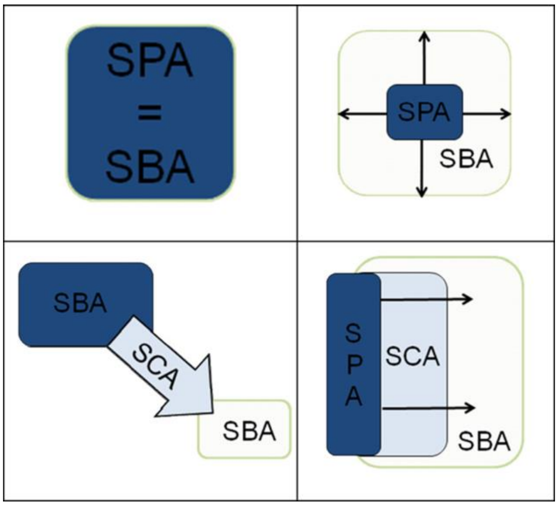

Figure 5: Conceptual model of possible spatial relationships between service providing area (SPA) and service benefiting area (SBA) (according to Fisher et al., 2009): upper left: 'in situ': SPA and SBA are identical, i.e. the service is provided and benefits realized in the same area. Upper right: 'omni directional': SBA extends SPA without any directional bias. Lower left: 'directional' – slope dependent: SBA lies downslope (downstream) from SPA, i.e. the service is realized by gravitational processes (cold air, water, avalanche, landslide). Lower right: 'directional' – without strong slope dependence: SBA lies 'behind' the SPA relating to higher-ranking directional effects (from (Syrbe and Walz 2012).

Regulating services typically show *in situ*, omnidirectional or directional spatial relation between the SPA and SBA. Cultural and provisioning services can also exhibit decoupled SPU-SPA spatial relations, where the ES is traded over long distances (Syrbe and Walz 2012; Burkhard et al. 2014). Spiritual and heritage cultural ES have large intangible elements and as such flows of ES are harder to define/identify (Burkhard et al. 2014). This is likely to be an issue at the Coorong and Lakes Alexandrina and Albert Ramsar site as well as many other Australian Ramsar sites.

Spatial and temporal scales, both key map attributes, and their appropriate selection is a recurring challenge of ecosystem service science and practical application. Ecosystem service assessment units (SPUs and SBAs) and related indicators, models and maps should match scales of their geobiophysical supply origin, flow and demand units on the one hand. On the other hand, they should match scales of administrative units for better application in decision making (Burkhard et al. 2013). Spatial mismatches can result in misinterpretations or inapplicability of assessment results (Kandziora et al. 2013).

1.1.3.3 Biodiversity and ecological integrity and ES

Much of the recent literature reviewed for this report identifies biodiversity as distinct from a final ecosystem service (e.g. de Groot et al. 2010; Müller et al. 2011; Kandziora et al. 2013). In the ES cascade (see Figure 7 below) biodiversity is positioned as a key component which contributes to ecosystem services, but is not considered a service by itself. This contradicts how biodiversity is currently treated within the draft ECD, where it is listed as a critical ecosystem service. Kandziora et al. (2013) make the following points regarding biodiversity and how it relates to ES:

- Biodiversity plays, at least hypothetically, an important role for the creation of all ecosystem services. It provides hierarchical constraints and strongly influences the patterns of processors which in the end are responsible for service provision. In general, biodiversity is strongly correlated with cultural services, it is directly related to the support of some provisioning services (e.g. wild foods), it steadily decreases as provisioning services grow, and it takes influence on several regulating services, some of them being dominated by community effects (e.g. pollination).
- For most services the number of species is less important than the concrete species composition. There are key species which play most important roles for several services, and approaches like functional groups or traits seem to be promising concepts to solve the prevailing questions about the interactions between biodiversity and ecosystem services in detail.

Recommend DEWNR consider if biodiversity is to be retained as a critical service or not. If biodiversity is not to be considered as a critical ES then this has implications for LAC and potentially for the justification for meeting criterion 3.

2 Critical ecosystem services at the Ramsar site

2.1 Workshop outcomes regarding content of draft ECD

A number of decisions regarding changes to the content of the draft ECD were discussed as a result of adopting the Fisher et al. (2009) terminology for ES. These are summarised by critical service in Table 1.

A series of tables listing the ecological processes and functions relating to each of the critical ES were produced in the workshop and subsequently reviewed and rationalised to align with the CICES framework (see Appendix A and B). Consideration of other typologies was also undertaken including those presented by Burkhard et al. (2014) and the Queensland framework (Maynard et al. 2010). Most recent ES classifications do not include the supporting services of the MEA framework as the central tenant of the ES concept is that the services and benefits are delivered for humans, not in support of the environment. This highlights an issue with the manner in which ES are identified in the National guidelines for producing ECD.

Recommend DEWNR discuss the need for the list of ES in the National Framework for preparing ECD (DEWHA 2008) to be updated.

DEWNR could provide DoE with an updated list of ES for inclusion in the National Framework as an addendum, based on the work undertaken at the Coorong and Lakes Alexandrina and Albert Ramsar site. The update should include the following:

- Breakdown the ES into Fisher et al. (2009) categories of intermediate and final ES
- Redefinition/clarification of where supporting services fit into a classification of ES

- How to deal with Biodiversity. In many recent classifications biodiversity is considered a precursor of all ES
- Identify processes and functions for each of the ES describing key features possibly using the CICES framework as a starting point.

Whilst adopting this newer terminology will require some reworking of the draft ECD, it will ultimately provide greater clarity in terms of understanding and managing the Ramsar site to maintain its ecological character. It is important that DoE is made aware of these changes and approves them.

Table 1: Summary of critical ES from draft ECD, Fisher et al. (2009) ES type and updates required in the draft ECD.

Category/service	Original Description from Table 15 of the ECD	Fisher et al. (2009) type	Updates required to ECD
Provisioning			
Stock watering	Barrage installation was undertaken to maintain water quality, lake levels and regular supply for domestic stock watering and irrigation. Considered a critical service.	Benefit	None
Irrigation	Barrage installation was undertaken to maintain water quality, lake levels and regular supply for domestic stock watering and irrigation. Considered a critical service.	Benefit	None
Provision of aquatic foods for human consumption	The site supports a number of commercial fisheries with the main species including greenback flounder mulloway, black bream, pipi, and yellow-eye mullet. Yellow-eye mullet, mulloway and pipi are the most important species targeted by recreational fishers in the Ramsar site. These fisheries are considered critical to the character of the site and incorporate aspects of cultural services (i.e. recreation) as well. Redfin, carp and golden perch are also fisheries which occur in the freshwater components of the site. Aboriginal communities have a long established history of fishing in what are now called South Australian waters. Each community has its own distinct fishing activities and cultural practices.	Benefit	None
Genetic resources	This service is about the role the site potentially plays in preserving a natural reservoir for biological diversity and providing genetic resources that can support colonisation, contribute to maintaining intra-species diversity, and allow for research and development such as selective breeding. Includes the provision of genetic resources for resistance to pathogens, or tolerance to environmental conditions, and the development of new medicines (DEWHA (Department of the Environment, Water, Heritage and the Arts) 2008). This service does not relate to maintaining populations of threatened species *per se*, which are covered under supporting services.	Final service	None
Regulating			
Maintenance and regulation of hydrological cycles and regimes	The Coorong, and Lakes Alexandrina and Albert are the terminal wetland complex on the River Murray and play an important role in retaining and retarding flows, potentially maintaining groundwater–surface water balances through local recharge and discharge processes although this is poorly understood at the site. This service has been compromised prior to listing through the installation of the barrages in the 1940s. Not	Final service	None

Category/service	Original Description from Table 15 of the ECD	Fisher et al. (2009) type	Updates required to ECD
	considered a critical service.		
Coastal shoreline stabilisation and storm protection	Occurs at the site but not critical to character of the site.	Final service	None
Natural hazard reduction	Operation of the barrages allows management of floods to some extent and whilst this service is supplied by the site it is not considered critical to the character of the site.	Benefit	None
Pollution control and detoxification	This service relates to the role a wetland plays in slowing flow, trapping and assimilating sediments, nutrients and other contaminants, and 'buffering' the amount of contaminant transfer that may occur during flow events. Contaminants may arise from natural or anthropogenic sources. Diffuse sources of pollution include stormwater runoff from urban or agricultural land, irrigation areas, degraded landscapes or urban stormwater management systems (DEWHA 2008). At present this service is considered critical.	Benefit	None
Cultural			
Cultural heritage and identity	Information is pending. From a Ngarrindjeri perspective the lands and waters are a living body – the Coorong, and Lakes Alexandrina and Albert Wetland are part of the Ngarrindjeri living body. At the centre of Ngarrindjeri knowledge and identity is an understanding of the interconnectedness of all things – this is termed Ngarrindjeri Ruwe/Ruwar (from DEWNR 2013). The Ramsar site is an internationally significant Sacred Site – The Meeting of the Waters (registered Aboriginal heritage site). This includes the waters and the bed of the lakes, river and estuary. Its spiritual and cultural significance is essential to the wellbeing and productivity of the Ngarrindjeri nation, Ngarrindjeri lands and waters and all living things (Ngarrindjeri Nation 2007).	Benefit	Not sure if this is a benefit, may be considered a final service?
Spiritual and inspirational	Information is pending. The site holds significant spiritual value to indigenous people, with many of the biota characteristic of the site representing important totem species.	Benefit	As above – not sure if a benefit.
Science and education	The site is well studied and important in understanding large terminal lacustrine and estuarine systems, however this service is not considered critical to the character of the site.	Benefit	None
Aesthetic amenity	Not critical, but occurs at the site. Includes unique waterscapes such as Murray Mouth.	Benefit	None
Recreation	Occurs at the site but is not considered a critical services relating to the character of the site.	Benefit	None

Category/service	Original Description from Table 15 of the ECD	Fisher et al. (2009) type	Updates required to ECD
Tourism	Occurs at the site but is not considered a critical services relating to the character of the site.	Benefit	None
Supporting			
Hydrological processes	The site supports the cyclic movement of water through the surface, subsurface, and atmospheric compartments associated with a wetland, and the resultant variation of the spatial and temporal distribution supports a diverse array of wetland types considered critical to the character of the site.	Intermediate service	The definition of hydrological processes should be changed to just include the processes directly related to water movement (and not include the diversity of wetland types).
Special ecological, physical or geomorphic features	Provides drought refuge, supports critical life stages, most notably as spawning and nursery grounds for fish and as a significant migratory stop-over for many waterbirds. Also the presence of the Murray Mouth and the physical nature (shape, water quality and movement) of the Coorong and estuary make this a special feature in the Murray Darling Basin and in South Australia.	Final service	These need to be separated: • Special ecological services: provides drought refuge and supports critical life stages. • Migratory species should be covered under priority species • Special geomorphic features service should be limited to the Murray Mouth with the ecological elements of this description taken out and captured as part of critical process (e.g. provision of physical habitat and ecological connectivity)
Provides physical habitat (for breeding waterbirds)	Thirty eight species of wetland bird have been recorded breeding within the Coorong, and Lakes Alexandrina and Albert Ramsar site, 15 of which breed either regularly or annually within the site. Breeding occurs across a range of guilds and also utilises a number of different habitats, ranging from isolated beach nest sites, to large colonies of colonial nesting species on islands.	Final service	Provides physical habitat should include the description of the diversity of wetland types. This has implications to large portion of draft content being relocated within the current version of the ECD. Discussion of waterbird breeding should be moved to the critical processes. The service is the habitat, not the breeding.
Threatened wetland species,	Two nationally listed ecological community and 19 nationally or internationally listed species of conservation significance, eight of which are considered to be regularly	Final service	None, communities and species are already included in this service in the draft ECD.

Category/service	Original Description from Table 15 of the ECD	Fisher et al. (2009) type	Updates required to ECD
habitats and ecosystems	supported at the site, or for which the wetlands of the site represent core habitat. This is one of the largest number of threatened species supported at a Ramsar site within the Murray Darling Basin, further evidence of the biodiversity value of the site.		
Priority wetland species and ecosystems	The site is highly significant for the number of migratory waterbirds listed under international treaties: Other priority wetland species includes those listed species for which management plans exist such as the Southern emu wren.	Final service	Capture material that was previously under special ecological features, in this service – i.e. that the site is a significant location for migratory species.
Biodiversity	The site supports regionally significant range and number of species comparable to other sites within the Murray Darling Basin. This includes supporting a large number and variety of waterbirds, including breeding habitat for over 30 species, a rich and diverse flora and the most diverse fish assemblage found in a wetland complex within the bioregion. Diversity at the ecosystem level is also high compared to other Ramsar sites within the Murray Darling Basin.	Final service	None
Nutrient cycling	Not critical; to the character of the site, but is believed to play an important role in biogeochemical process, although this remains a knowledge gap for parts of the site.	Intermediate service	None
Primary production	Not critical to the character of the site, but plays an important role as a supporting service, underpinning food webs within the system.	Intermediate service	None
Ecological connectivity	The Ramsar site has a range of distinct wetland types which are both hydrologically and ecologically connected. Connectivity is critical for the maintenance of biodiversity values (i.e. supports high biodisparity in fish species). The connection between the marine, estuarine and freshwater components is significant for fish migration and reproduction. Barrage operation has a significant influence on the degree of connectivity. The site is also one of the most important in terms of supporting migratory waterbirds.	Intermediate service	None
Food webs	The Coorong food web is relatively short but critical to sustaining the character of the site. Keystone species include invertebrate taxa, small-mouth hardyhead and *Ruppia tuberosa*.	Final service	None

3 Conceptual model approaches

3.1 ES capacity, pressure, demand and flow models – Villamagna et al. (2013)

Recent papers have presented a number of different models which could be developed within the Coorong and Lakes Alexandrina and Albert Ramsar site. Villamagna et al. (2013) present a conceptual model approach in which ES delivery is broken down into four components: capacity, pressure, demand and flow of ES (Figure 6). Similar models could be developed for the Coorong and Lakes Alexandrina and Albert Ramsar site for the critical ES of pollution control and detoxification. Measuring regulating service capacity, such as pollution control, requires extensive knowledge of ecological processes, understanding of ecological and hydrologic processes, process based models and their limitations; all of which has been developed through the recent work on ASS during the drought.

Developing capacity, pressure, demand and flow models for the provisioning and cultural services will require some addition work by DEWNR and is beyond the scope of this report.

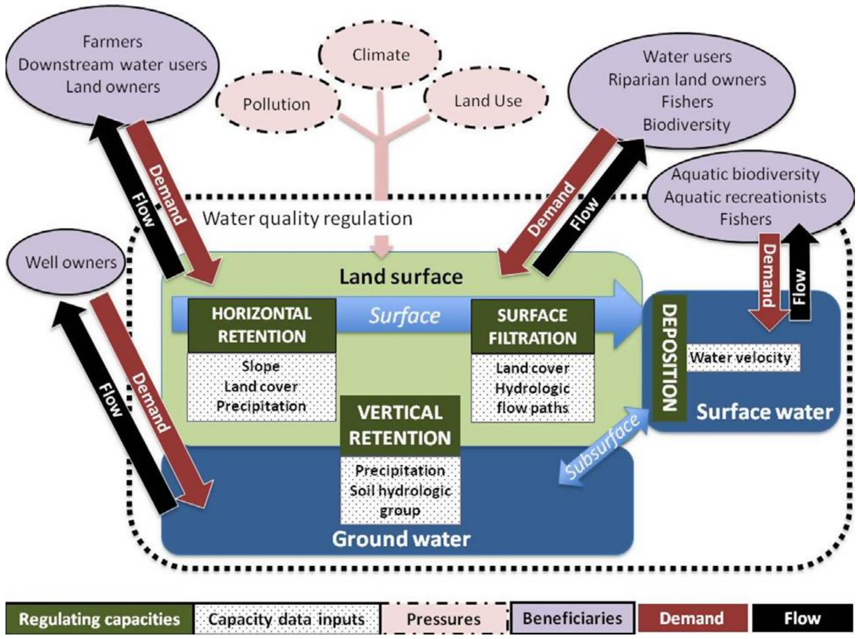

Figure 6: Conceptual model illustrating water quality regulation. The movement of water across the landscape (surface and subsurface), and the major components of the ecosystem service delivery process, including capacity (green boxes), ecological pressures (pink ovals), demand (red arrows), and service flow (black arrows). Beneficiaries (purple ovals) are shown as the source of demand and the recipients of regulating service flow. As water is introduced to the ecosystem, by means of precipitation or upland flow, a series of processes can act to regulate water quality. High capacity of horizontal and vertical retention reduces the ecological pressures on surface filtration and deposition (from Villamagna et al. 2013).

3.2 EBM-DPSIR conceptual approaches – Kandziora et al. (2013)

A conceptual modelling approach which includes consideration of pressures and stressors has been used to add ES to the DPSIR indicator and management cycle (Kandziora et al. 2013) as shown in Figure 7. It should be noted that the stressor models and critical path models for management levers for the Coorong and Lakes Alexandrina and Albert Ramsar site are probably adequate for capturing pressures on ES, but DEWNR may wish to develop these further to align with work being undertaken by CSIRO.

Also the current set of models are focused on the negative impacts associated, predominantly with anthropogenic impacts on the ecosystem. Adopting the approach stipulated in Kandziora et al. (2013) both negative and positive changes, such as those achieved through management intervention can be tracked.

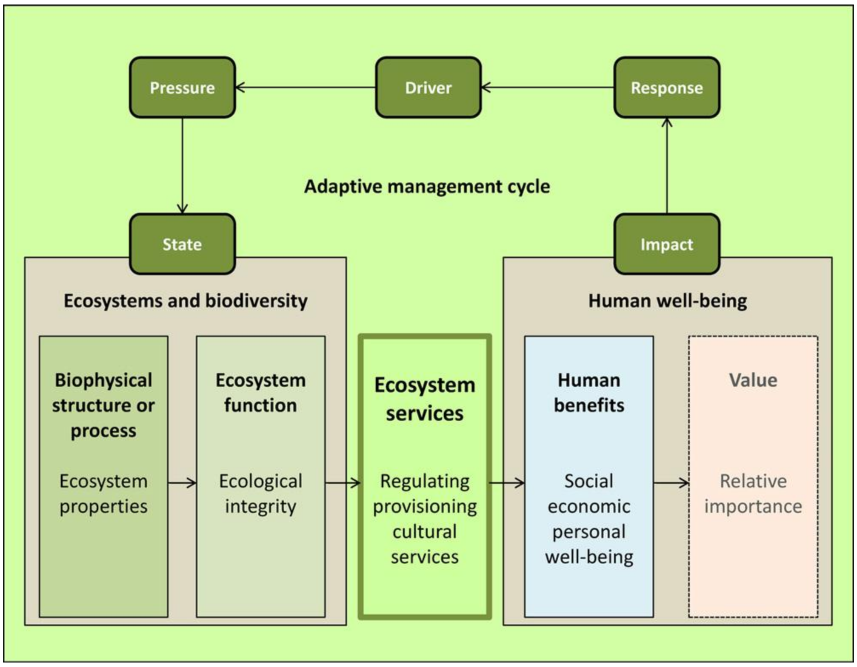

Figure 7: The 'ecosystem service cascade' embedded in the adaptive DPSIR indicator and management cycle. From Kandziora et al. (2013).

Recommend DEWNR review the conceptual models produced under Ramsar Rolling Review and also for the ECD to assess if the stressor models adequately capture ES in terms of being able to identify indicators that can be used to track responses to management interventions.

3.3 Capacity and flow with causal relationships - Schröter et al. (2014)

In a recent review (Martínez-Harms and Balvanera 2012) causal relationships were identified as the most frequently used method to map ES, based on the understanding of ES and readily available information. The use of causal relationship models can help improve the fit of ES to mapping units when primary data are absent, allowing for weighting of land-cover variables by key biophysical variables related to ES supply (Chan et al. 2006 cited in Martínez-Harms and Balvanera 2012). It should be noted that in most cases the use of readily available data such as land-cover has often been used to map ES supply, but the actual relationship between the ES ad land-cover has not been tested (Martínez-Harms and Balvanera 2012) (i.e. use with caution).

Schröter et al. (2014) developed a range of spatial models, including (multiple layer) look-up tables, causal relations between datasets (including satellite images), environmental regression and indicators derived from direct measurements, to spatially map capacity and flow of nine ES. Capacity and flow differ both in spatial extent and quantity, the mapping of which provides an estimation of over- or underuse of the respective service. Spatially explicitly assessment of capacity and flow can support monitoring sustainability of ecosystem use (Schröter et al. 2014) (Figure 8). This broad approach would appear to be suitable for adoption at the Ramsar site.

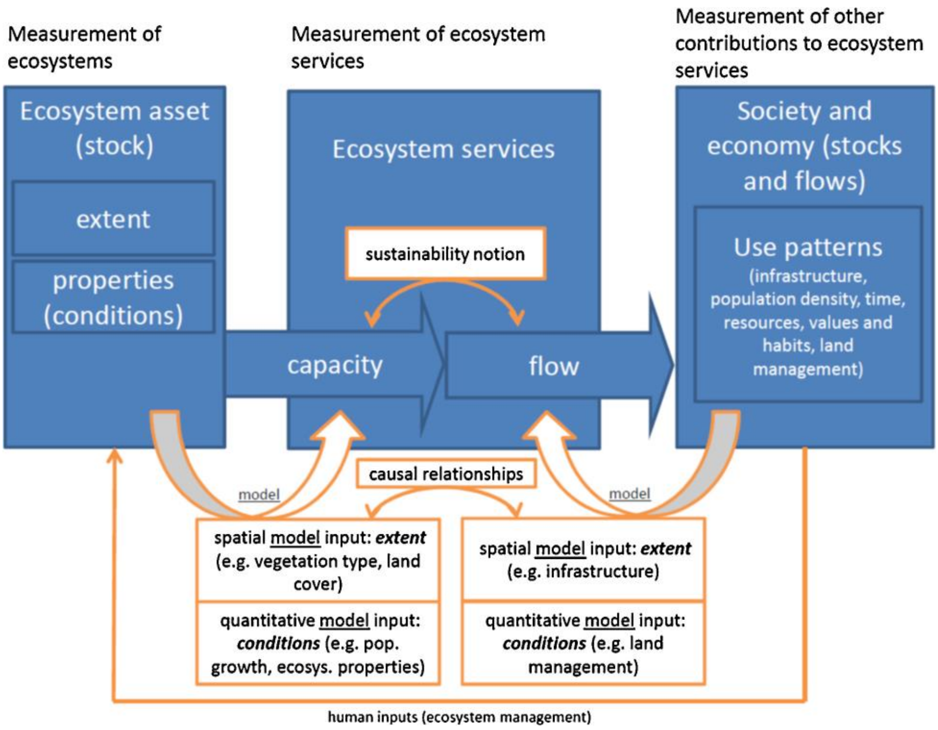

Figure 8: Integration of ES capacity and flow models in ecosystem accounting (from Schröter et al. 2014).

3.4 Landscape matrix models, capacity, flow and demand – Burkhard et al. (2009)

Burkhard et al. (2009) introduced the ES matrix models which identify capacity to supply ES at the landscape scale and is related to landuse and or land cover data. Using quantitative and qualitative assessment data in combination with land cover and land use information anthropogenic impacts on ES can be evaluated (Burkhard et al. 2009). The results achieved by this approach illustrate typical patterns of different ecosystems capacity to provide ES.

The models are a simple matrix with the ES as columns and the geospatial unit as the rows. At each intersection an estimation of the capacity to provide an ES is made, and is initially based on expert opinion. A temporal aspect to supply and demand of ES is also relevant, with services having seasonal aspects, medium to long-term dynamics or 'hot moments', which affect the potential, flow and demands for each service (Figure 9) (Burkhard et al. 2014). Temporal assessment scales could include (from Burkhard et al. 2014):

- short-term (e.g. events, peak flows),
- seasonal (e.g. harvest rhythms, tourist seasons, growing seasons),
- annual (e.g. sums, yearly average values),
- medium-term (e.g. decades) and
- long-term (e.g. generations, centuries, millennia) periods.

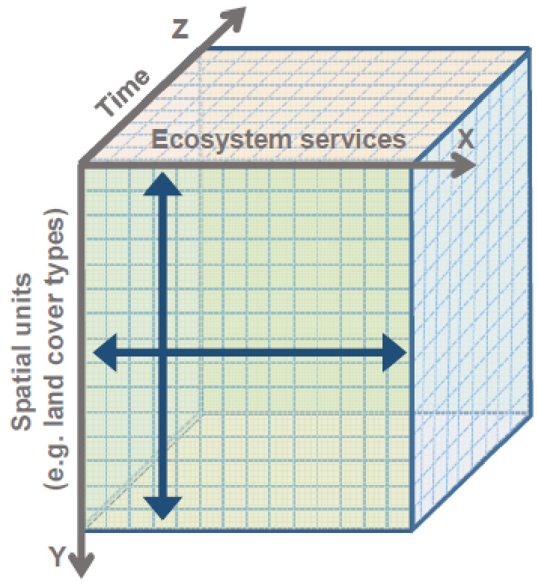

Figure 9: Integration of temporal aspects into the matrix by including a third dimension (3D-Matrix) and horizontal (within spatial units) as well as vertical (within ecosystem service types) cross-comparisons of assessment values (from Burkhard et al. 2014).

Once expert judgement has been used to establish a base case, or set of hypothesis, for the matrix (see example tables in section 3.2.1) the next step in the process is to run computer based model results using statistical data, in depth interview or in situ measurement (Jacobs et al. 2014). This approach is relatively popular and reflects the fact that it is efficient, fast, accessible and adaptable (Jacobs et al. 2014). Jacobs et al. (2014) recommend that measures of confidence, traceability, reliability, consistency and validity be included when using this approach to improve its robustness.

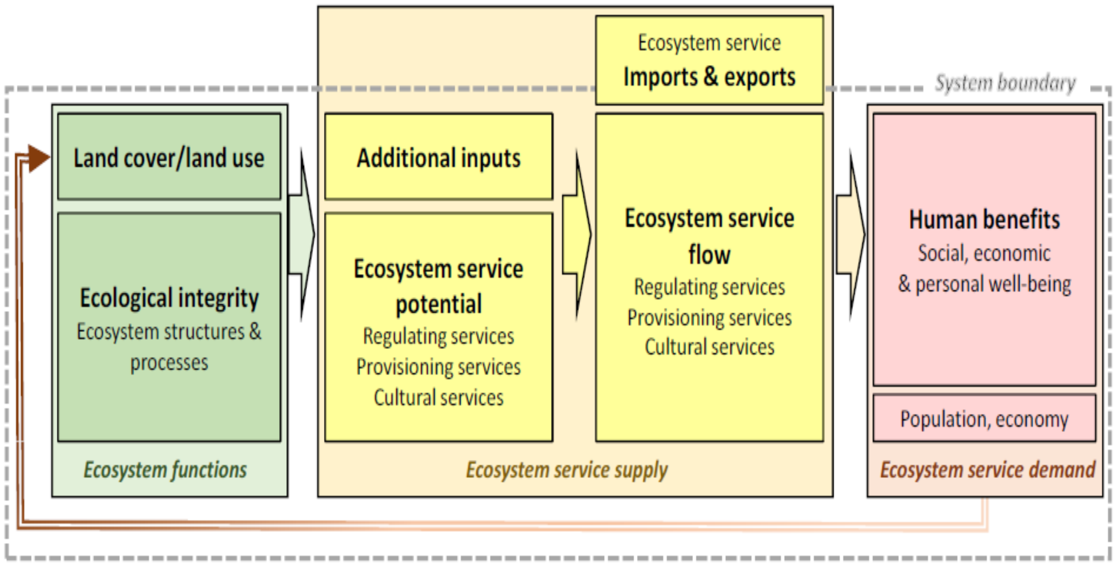

Figure 10: Conceptual model showing relations of ecosystem functions, services and benefits (from Burkhard et al. 2014).

3.4.1 Example ES flow matrix model for freshwater, estuarine, marine and hyper marine units within the CLLMM

The ES matrix concept (as per Burkhard et al. 2009, 2014) would appear to lend itself for use in the Coorong and Lakes Alexandrina and Albert Ramsar site. ES potential, as defined above, is the maximum potential yield for an ES. Flow relates to the period which the service is utilised or occurs at a location. In Figure 11 a hypothetical potential and flow of the ES for priority species (i.e. migratory shorebirds) in the South Coorong is illustrated. In this example the migratory shorebirds have the potential to be present at the South Coorong from late spring, peaking in potential in summer and then potential declining into autumn at which time the birds leave the site. The flow represented in Figure 11 suggests a delayed arrival of the migratory species, with flow being significantly less than potential. If assessed in late summer the potential would be score a five but the flow only 0 to 1.

Table 2 is a first attempt of applying the ES matrix approach for identifying the spatial units (identified in the workshop: freshwater lakes and rivers, estuarine, marine and hyper marine units) which have ES potential relating to the critical ES identified in the ECD. In addition the same scale has been applied to the potential for the ES to be delivered at a specific time. For example in the hyper marine unit (South Coorong) the potential for the unit to supply the critical service of 'Priority wetland species' is very high as the South Coorong supports large numbers of migratory species listed under JAMBA/CAMBA/ROKAMBA/EPBC. The South Coorong also has a strong temporal aspect to this service, in that the migratory species are predominantly only present in summer.

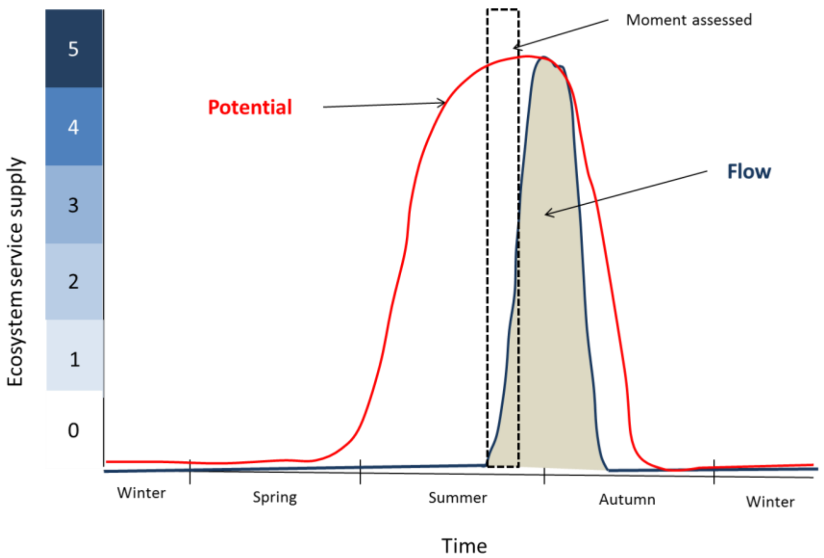

Figure 11: Hypothetical ecosystem potential and flow for priority wetland species (i.e. migratory waterbirds) in the hypersaline section of the Coorong which have peak potential in summer and then leave the Ramsar site by mid to late autumn. In this hypothetical a later than typical arrival of migratory species is suggested and if flow of the service was assessed in later summer (dashed box) then it would score a 0 to 1. Modified from Burkhard et al. (2014).

Table 2: Draft spatial and temporal ES potential matrix for critical ES in summer at time of listing across freshwater, estuarine, marine and hyper marine units of the Coorong and Lakes Alexandrina and Albert Ramsar site. ES type as defined by Fisher et al. (2009): B = Benefit, FES = Final ecosystem service, IES = Intermediate ecosystem service. Scale modified from Burkhard et al. (2014): 0 = no relevant potential; 1 = low relevant potential; 2 = relevant potential; 3 = medium relevant potential; 4 = high relevant potential; and 5 very high (maximum) relevant potential. Temporal scale, 0 = not time dependent, 5 = extremely time dependent/ hot moment.

Category/ service in ECD	ES type	Freshwater		Estuarine		Marine		Hyper marine	
		Spatial	Temp	Spatial	Temp	Spatial	Temp	Spatial	Temp
Water supply	B	5	3	0	0	0	0	0	0
Irrigation	B	5	3	0	0	0	0	0	0
Provision of aquatic foods	B	4	4	5	4	3	4	1	1
Pollution control	B	5	4	0	0	0	0	0	0
Hydrological processes	FES	5	3	3	3	1	1	2	1
Drought refuge	FES	5	5	3	4	0	0	0	0
Nursery, spawning ground	FES	4	4	5	4	3	1	0	0
Murray Mouth	FES	0	0	4	5	5	5	0	0
Provides physical habitat	FES	5	5	5	2	2	0	3	3
Threatened species & communities	FES	5	2	0	0	0	0	0	0
Priority wetland species and ecosystems	FES	3	4	4	4	3	5	5	5
Biodiversity	FES	5	2	5	0	2	0	4	4
Nutrient cycling	IES	5	0	4	0	1	0	3	0
Ecological connectivity	IES	5	5	5	5	3	1	1	3
Food webs - Coorong	IES	0	0	3	3	2	0	5	4

Table 3: Draft spatial and temporal ES flow matrix for critical ES in summer at time of listing across freshwater, estuarine, marine and hyper marine units of the Coorong and Lakes Alexandrina and Albert Ramsar site. ES type as defined by Fisher et al. (2009): B = Benefit, FES = Final ecosystem service, IES = Intermediate ecosystem service. Scale modified from Burkhard et al. (2014): 0 = no relevant flow; 1 = low relevant flow; 2 = relevant flow; 3 = medium relevant flow; 4 = high relevant flow; and 5 very high (maximum) relevant flow. Temporal scale, 0 = not time dependent, 5 = extremely time dependent (in this hypothetical 5 = flow only occurs in summer months, 3 = flow occurs all year round).

Category/ service in ECD	ES type	Freshwater		Estuarine		Marine		Hyper marine	
		Spatial	Temp	Spatial	Temp	Spatial	Temp	Spatial	Temp
Water supply	B	5	5	0	0	0	0	0	0
Irrigation	B	5	5	0	0	0	0	0	0
Provision of aquatic foods	B	3	3	3	3	0	0	0	0
Pollution control	B	5	3	0	0	0	0	0	0
Hydrological processes	FES	5	3	4	3	0	0	0	0
Drought refuge	FES	5	5	0	0	0	0	0	0
Nursery, spawning ground	FES	2	4	5	4	0	0	0	0
Murray Mouth	FES	0	0	4	3	0	0	0	0
Provides physical habitat	FES	5	3	5	3	3	3	5	3
Threatened species & communities	FES	5	3	0	0	0	0	0	0
Priority wetland species and ecosystems	FES	3	5	4	4	4	4	5	5
Biodiversity	FES	4	3	4	3	3	3	2	2
Nutrient cycling	IES	4	3	4	3	1	2	1	2
Ecological connectivity	IES	5	4	5	3	4	3	1	3
Food webs - Coorong	IES	0	0	3	3	2	3	5	3

4 Moving forward

4.1 Landscape matrix and mapping of ES potential and flow in the Coorong and Lakes Alexandrina and Albert Ramsar site

Understanding where and when critical ecosystem services are supplied as opposed to where and when they are utilised is critical to maintaining the ecological character of the Ramsar site. A relatively simple, fast and efficient means of establishing this is to develop a series of landscape matrix models as detailed in Burkhard et al. (2009); Burkhard et al. (2014) and Jacobs et al. (2014). Figure 12 illustrates part of the landscape matrix approach to mapping ES capacity (potential) and flow in relation to land-use cover. This approach has potential for use within the Coorong and Lakes Alexandrina and Albert Ramsar site and fits well with the concept of intermediate and final services (i.e. processes and functions). Figure 13 illustrates the basic concept of the matrix approach with a suggested course of action for application within the Ramsar site.

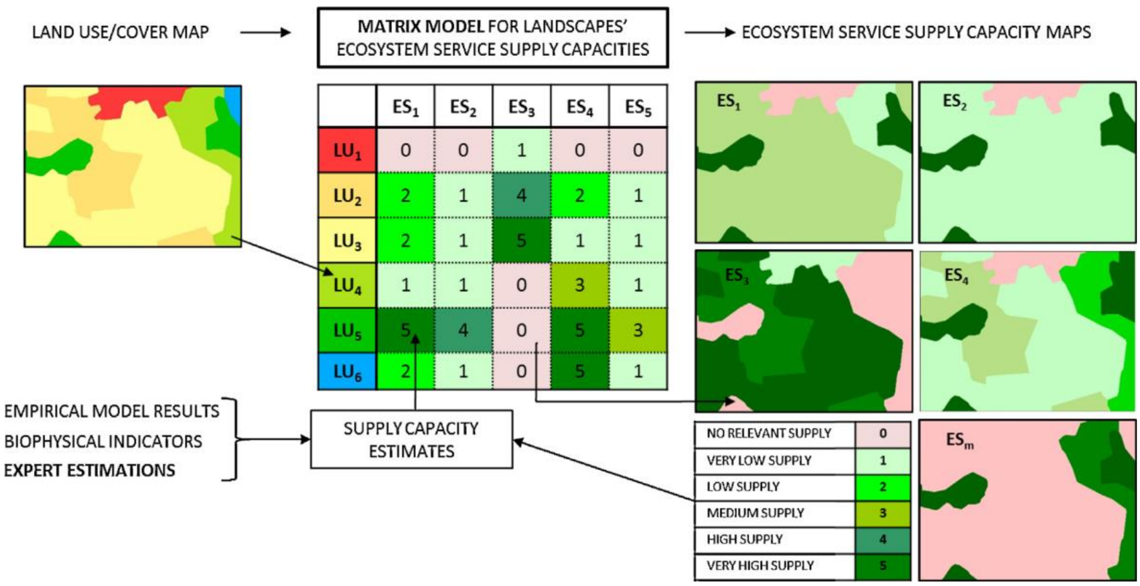

Figure 12: Schematic concept of the ES matrix model (after Burkhard et al. 2009): using expert-based estimations, physical quantifications or empirical model results, ES supply capacities are attributed to land use/land cover LULC classes. The matrix allows comparison of ecosystem services (columns) as well as LULC classes (lines). Map 1: Current application of the matrix model for ecosystem service assessments globally (from Jacobs et al. 2014).

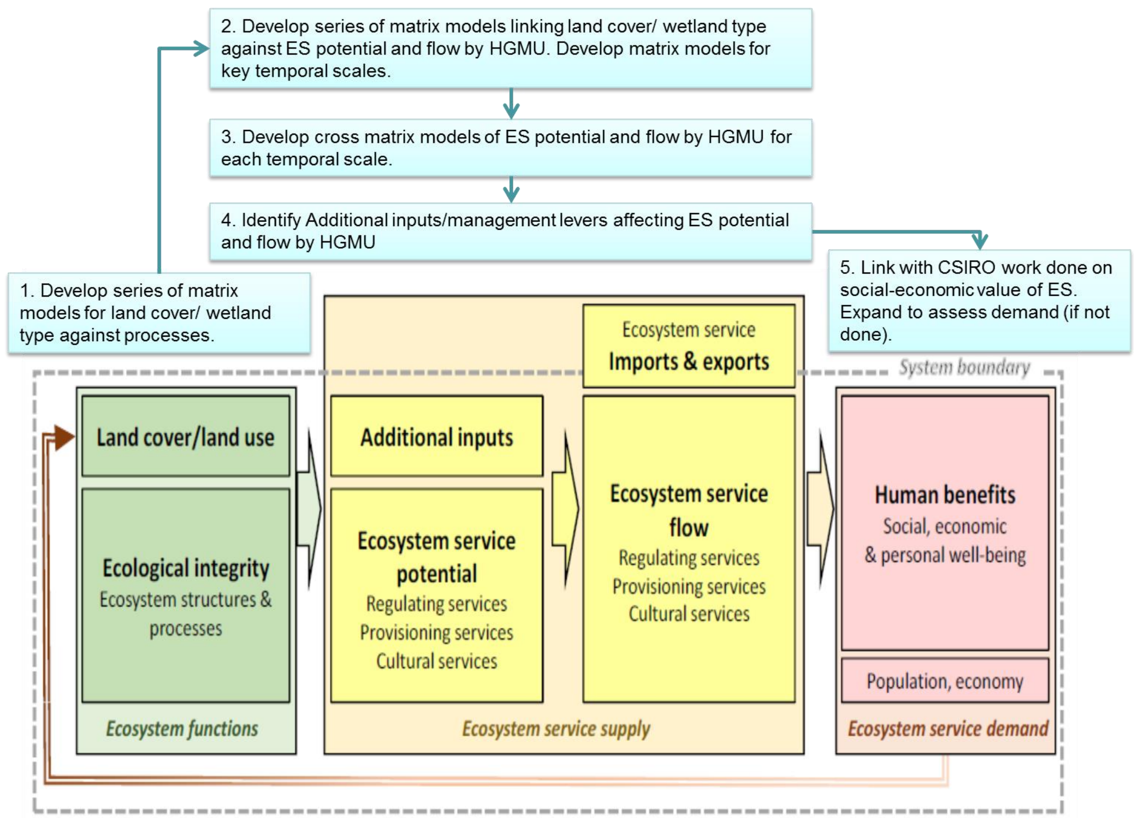

Figure 13: Conceptual model showing relations of ecosystem functions, services and benefits (from Burkhard et al. 2014) (bottom half of image), and steps (1-5) recommended for development of landscape matrix models for the Coorong and Lakes Alexandrina and Albert Ramsar site.

It should be noted however, that whilst this report is mainly concerned with the supply of ecosystem services, to fully appreciate the delivery and sustainable use of ES within the Ramsar site information on supply must be complemented by an assessment of demand. Villamagna et al. (2013) summarised the key aspects of capacity, pressure, demand and flow can differ among provisioning, regulating, and cultural services (see Table 4).

Table 4: Ecosystem service delivery process comprises four distinct components which differ among three ecosystem service categories. A general definition and examples are provided for each category-component combination (from Villamagna et al. 2013)

Components of ES delivery	Provisioning ES	Regulating ES	Cultural ES
Ecosystem service capacity: an ecosystem's potential to deliver services based on biophysical and social properties and functions[a]	Biophysical capacity; feature-based (e.g. modeled water supply)	Biophysical capacity; process-based (e.g. modeled carbon sequestration)	Biophysical and social capacity; feature- and process-based (e.g. potential to provide experience)
Ecological pressures: anthropogenic and natural stressors that affect capacity or flow of benefits; often attributed to overuse or feedback from land management decision to enhance other	Events that reduce stock and/or regenerative capacity (e.g. overharvest; water impoundments)	Environmental disturbances that increase the amount of ecological work required to meet societal demands (e.g. pollution, impervious surfaces)	Events that reduce stock, regenerative, or assimilative capacity of a system; commonly related to overuse (e.g. soil compaction, erosion)

service capacities [b]			
Ecosystem service demand: the amount of a service required or desired by society [c]	Amount of service desired per unit space and time multiplied by the number of potential users (rival service) (e.g. liters of water per person)	Amount of regulation needed to meet pre-determined condition (e.g. % nitrogen reduction; Total Maximum Daily Load [TMDL])	Desired total use (if rival service) or individual use (if non-rival) (e.g. total visitor-days from year prior; individual visitation rates)
Ecosystem service flow: the actual production or use of the service; incorporates biophysical and beneficiary components [d]	Quantity harvested, consumed, or used; number of people served; number of industries served	Ecological work = ecological pressures minus environmental quality (same units) (e.g. nitrogen inputs-minus in-stream load)	Amount of service used measured in units of time and/or space (e.g. total visitor-days from current year; individual visitation rates)

References cited in Villamagna et al. (2013):
a Cairns (1997), Chan et al. (2006, 2011), Egoh et al. (2008), Daily et al. (2009), and van Oudenhoven et al. (2012).
b Beier et al. (2008), Rounsevell et al. (2010), and van Oudenhoven et al. (2012).
c McDonald (2009) and Nedkov and Burkhard (2012).
d Beier et al. (2008), Layke (2009), de Groot et al. (2010), and van Oudenhoven et al. (2012).

Villamagna et al. (2014) use the assessment of a cultural ecosystem services, freshwater recreational fishing, to illustrate how the main elements demand, capacity and flow of ES can affect the sustainable management of cultural ES (Figure 14).

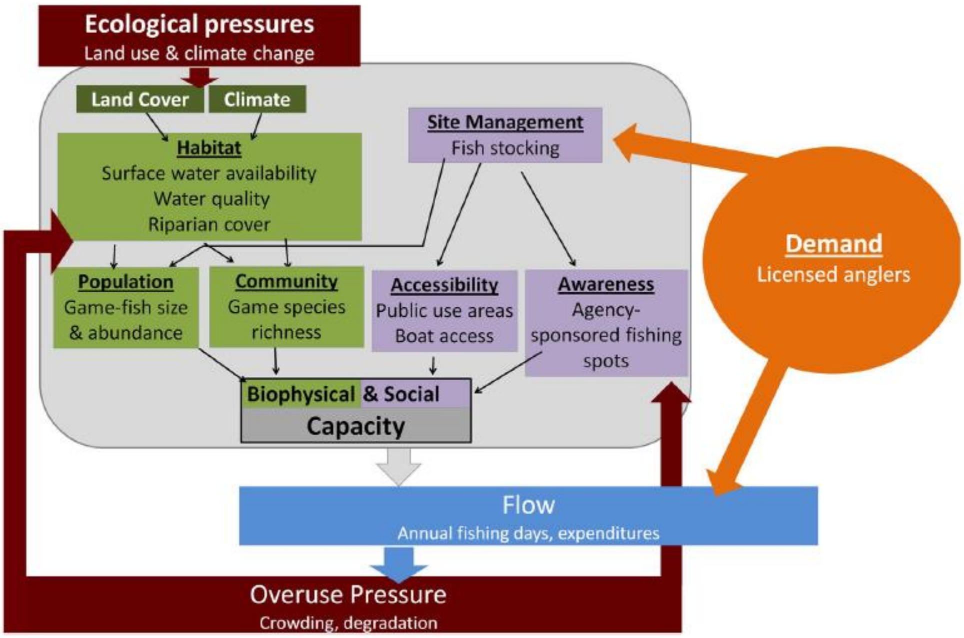

Figure 14: Demand, capacity, and flow are the core components of ecosystem service provision. The demand for a service (orange) is generally independent of the capacity of the ecosystem to provide the service (large gray box), therefore flow (blue) is influenced by the combination of both demand and capacity. Capacity of cultural services comprises biophysical and social elements that influence the overall capacity. Here we describe key biophysical (green) and social (purple) elements that contribute to the capacity to provide freshwater recreational fishing opportunities. If the flow of a service exceeds the long-term capacity, overuse pressures (crimson) may cause biophysical capacity to degrade (from Villamagna et al. 2014).

4.2 Causal relationships models

A series of conceptual models derived from the refined list of process and functions identified in the workshop are presented in Appendix C. Strength of relationships are indicated using different sized arrows (see Figure 15). A limitation of the scope of this report is that the relationships presented in the conceptual models are based on professional opinion and will need to be reviewed to achieve consensus on the relative importance of the relationships. Elicitation of expert opinion to develop and then refine these models is an acceptable approach on which to base further investigation. Quantification of the models for some critical pathways may be possible with data already captured through CLLMM monitoring and research projects.

The causal relationship models serve to provide an indication of the relative importance of processes and functions in relation to supply of ES within the Ramsar site. The critical pathways, once confirmed, can be expanded to illustrate predicted responses to management interventions. The conceptual models illustrated that river inflows, water quality and local climate are all important controlling variables, as is salinity. Soils and geomorphic processes appear to be less important as controlling variables but this may represent a knowledge gap rather than an actuality. The relative importance of groundwater processes is also considered a knowledge gap.

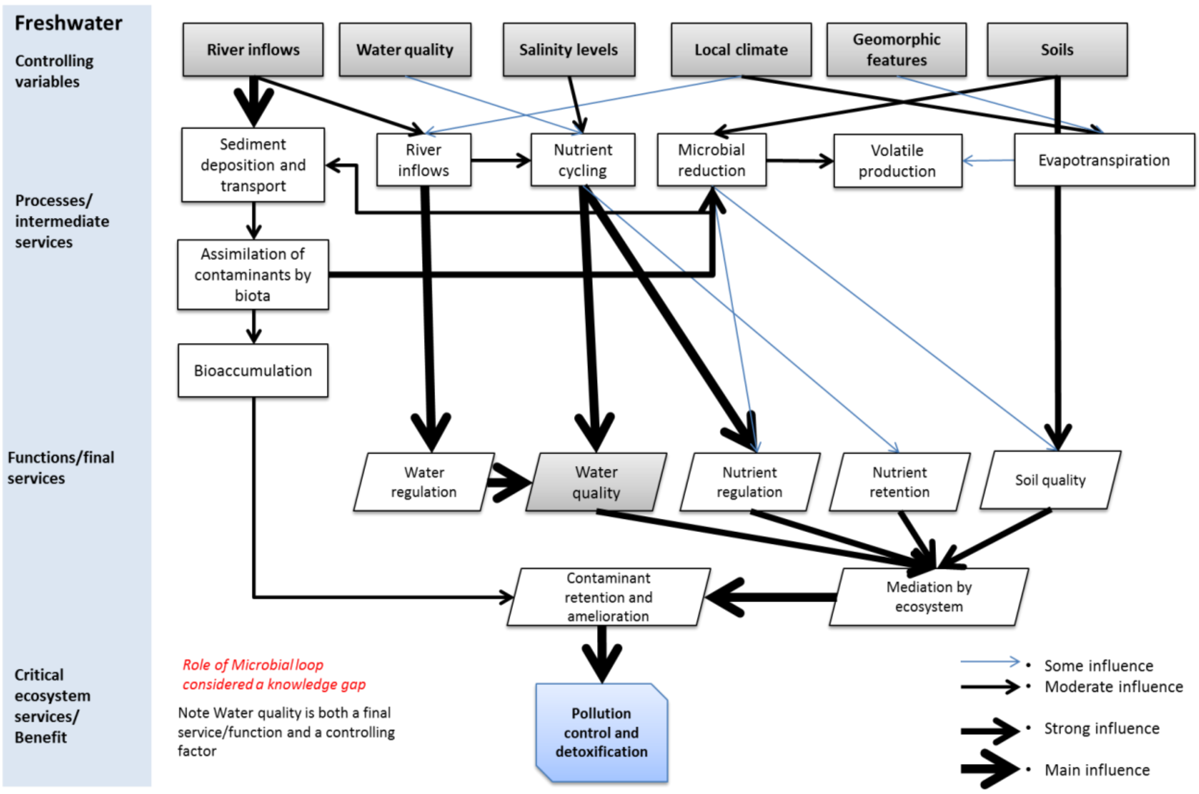

Figure 15: Conceptual model of relationship between processes, functions and the critical ES Pollution control and detoxification.

4.2.1 Building on existing work

For some of the critical ES it may be possible to develop quite detailed, partially quantified, conceptual models, relating processes and functions to a service. The regulating service of 'Pollution control and detoxification' is one such example. Ward et al. (2013) provides a series of detail conceptual models of the processes involved in the production and impacts associated with ASS. The processes identified as relevant include (from Ward et al. 2013):

- sediment and water acidification,
- interactions between surface waters and sediment pore-waters,
- ecotoxicological aspects of metal uptake,
- mineralogical controls of geochemical regime,
- the controlling effects of organic matter inputs by lacustrine vegetation on post re-inundation biogeochemistry,
- sediment erosion as a result of scalding during sediment exposure, and
- post-inundation, and metal mobilisation.

Only some of these processes were identified in the workshop on ecosystem services and it may be possible to develop a more detailed model for this critical service from which thresholds and indicators can be identified. This should be linked to the Limits of Acceptable Change and draft management triggers developed in the update of the ECD.

4.3 An integrated approach to predicting capacity of critical ES

The emphasis of the workshop, and this report, was to identify those processes and functions which affect the capacity for the supply of services within the Ramsar site. However this represents only one side of the sustainable delivery of ES, the ecological aspects of ES, and doesn't address demand and utilisation, or the social-economic aspect of ES. To provide a comprehensive assessment of ES an integrated approach is necessary which addresses both supply and demand aspects (noting that demand can affect flow see Figure 14).

Managing ES individually is problematic as well, as recent work has shown that as with most aspects of ecosystems, the services are often linked and management intervention aimed at one service may impact another (Mouchet et al. 2014).

There are two mechanisms that can lead to associations among ES (Mouchet et al. 2014):

1. When the supply of several ES rely on the same ecosystem process, as in the case of wetlands acting as a buffer against climatic variability, providing flood control and shoreline stability; and,
2. Where a given external factor may affect several ES at the same time as with the use of fertilizers positively influencing crop yield but decreasing water quality.

Quantitative methods are available to assess relationships among ES. Mouchet et al. (2014) undertook a review and of the various approaches discussing the strengths and weaknesses of each approach using the following three steps (see Figure 16):

- detecting ecosystem services associations,
- defining bundles and
- identifying the explanatory variables of ecosystem services associations.

An **ES bundle** refers to a ''sets of ES that appear together repeatedly'' (Raudsepp-Hearne et al. 2010). Within a bundle, ES can be positively (synergy) or negatively (trade-off) associated with associations arising from common driving processes or a response to a common stressor (Mouchet et al. 2014).

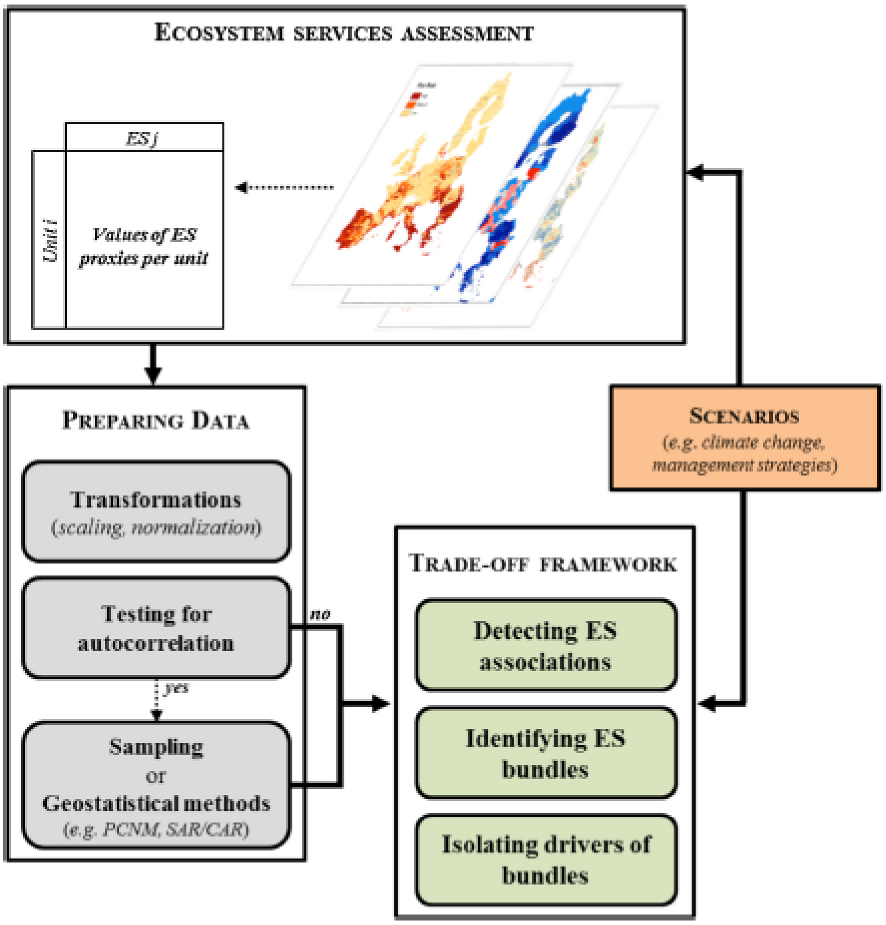

Figure 16: Illustration of the methodological framework for assessing trade-offs. ES indicators may be measured in the field (for either ecological or socio-economic data) or modelled from scenarios and then mapped or directly expressed as ES values per unit (i.e. sites or time steps). ES data may be transformed and normalized to fit validity conditions of statistical methods (from Mouchet et al. 2014).

The identification of ES bundles that operate within the Ramsar site will help inform the management of ES and also provide a more integrated approach to assessment and long term sustainable use. It is considered essential that alongside the assessment of the ecological aspects of the supply of ES that the socio-economic aspects of demand also be investigated.

One of the purposes of the workshop and this report was to begin cataloguing work already undertaken in the CLLMM that would support the development of the Ecosystem Response Forecasting Tool (ERFT). The ERFT is intended to include hydrodynamic, water quality, ecological response, function, and ecosystem service models.

Whilst considerable work has been undertaken on individual components and processes within the Ramsar site, these data have yet to be used to inform the assessment of the spatial and temporal provision of ES. No work has been done as yet on identifying associations between ES (i.e. identifying ES bundles) or common drivers, although the conceptual models provide some insight to this (See Appendix C).

As illustrated in Figure 17 the data collected in assessing ecological character and through CLLMM monitoring and research projects can be used to inform the development of matrix conceptual models. These capture spatial and temporal potential and flow of critical services across the Ramsar site. An example of the landscape matrix approach is provided in section 3.4.1 and 4.2. By comparing the potential and flow matrices information can be gained regarding the sustainable supply of services (Burkhard et al. 2014) at the site.

Recommend DEWNR consider the following options for assessing the supply of ES within the Ramsar site:

1. Develop spatial and temporally maps of ES capacity and flow as per the landscape matrix approach of Burkhard which in turn can inform the refinement of the causal relationships conceptual models (see the Schröter et al. (2014) approach).
2. Run a technical panel/workshop to provide expert opinion/consensus for the matrix models and to also review the causal conceptual models presented in Appendix C.
3. Investigate relationships between ES to identify associations and bundles.
4. Adopt an integrated approach to assessing ES within the Ramsar site which accounts for both supply issues (dealt with in this report) and demand.

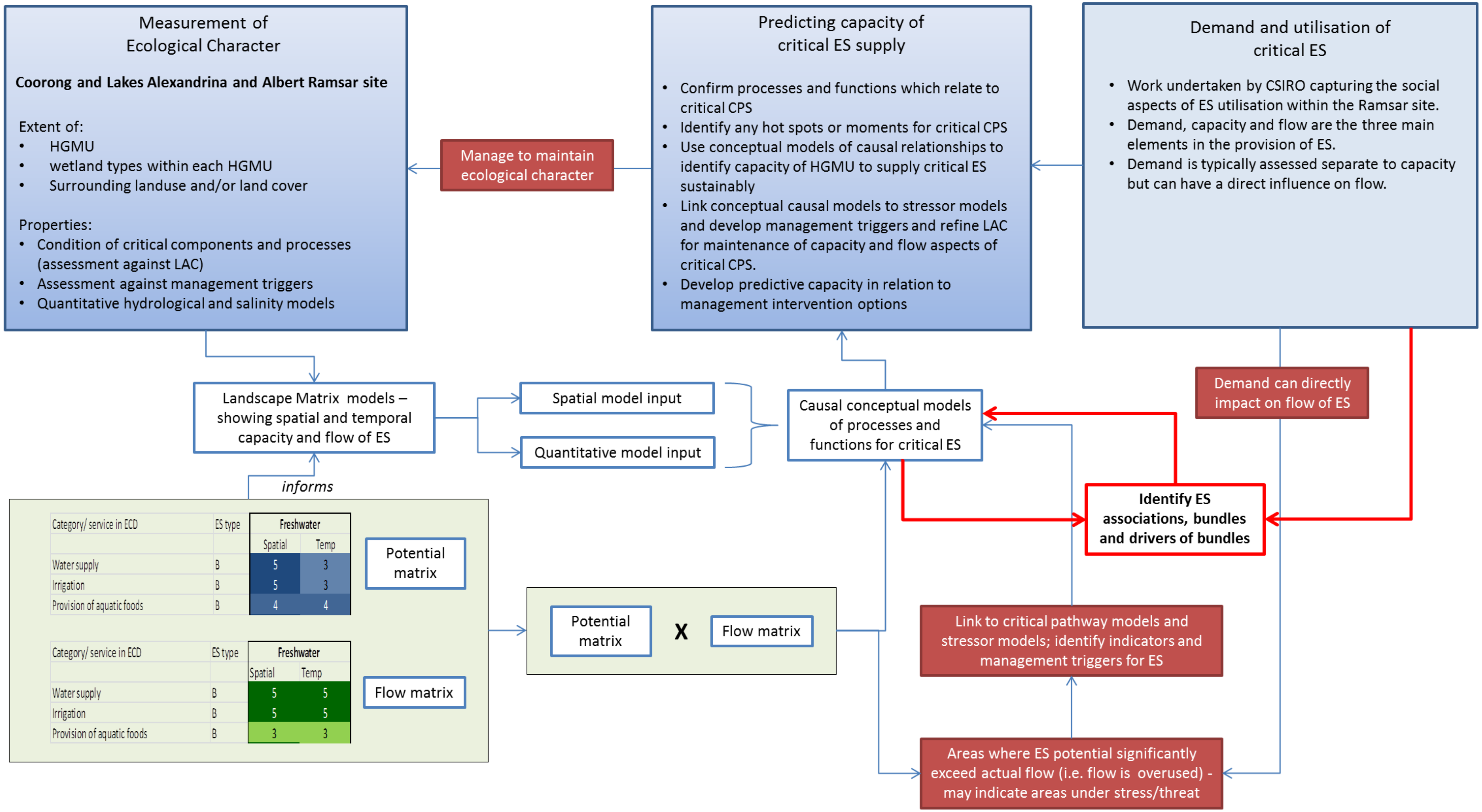

Figure 17: Integrated approach to predicting ES capacity and flow for critical ES for the Coorong and Lakes Alexandrina and Albert Ramsar site. Note that the identification of ES bundles (red box with bold text) has not been undertaken to date.

5 References

Barnaud, C., and Antona, M. 2014. Deconstructing ecosystem services: Uncertainties and controversies around a socially constructed concept. Geoforum **56**: 113–123. doi: 10.1016/j.geoforum.2014.07.003.

Boyd, J., and Banzhaf, S. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics **63**: 616–626.

Burkhard, B., Crossman, N.D., Nedkov, S., Petz, K., and Alkemade, R. 2013. Mapping and Modelling Ecosystem Services for Science, Policy and Practice. Ecosystem Services **4**: 1–3.

Burkhard, B., Kandziora, M., Hou, Y., and Müller, F. 2014. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification. Landscape Online: 1–32. doi: 10.3097/LO.201434.

Burkhard, B., Kroll, F., and Müller, F. 2009. Landscapes‘ Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. Landscape Online: 1–22. doi: 10.3097/LO.200915.

Burkhard, B., Kroll, F., Nedkov, S., and Müller, F. 2012. Mapping supply, demand and budgets of ecosystem services. Ecological Indicators **21**: 17–29.

Cork, S., Gorrie, G., Ampt, P., Maynard, S., Rowland, P., Oliphant, R., Reeder, L., and Stephens, L. 2012. Discussion Paper on Ecosystem Services for the Department of Agriculture, Fisheries and Forestry. Australia 21 Limited.

Costanza, R. 2008. Ecosystem services: Multiple classification systems are needed. Biological Conservation **141**: 350–352. doi: 10.1016/j.biocon.2007.12.020.

Daily, G.C. (*Editor*). 1997. Introduction: what are ecosystem services. *In* Nature's Services. Island Press, Washington, D.C., USA. pp. 1–10.

DEWHA (Department of the Environment, Water, Heritage and the Arts). 2008. National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands. Module 2 of Australian National Guidelines for Ramsar Wetlands – Implementing the Ramsar Convention in Australia.

Fisher, B., Turner, R.K., and Morling, P. 2009. Defining and classifying ecosystem services for decision making. Ecological Economics **68**: 643–653. doi: 10.1016/j.ecolecon.2008.09.014.

De Groot, R.S., Alkemade, R., Braat, L., Hein, L., and Willemen, L. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity **7**: 260–272. doi: 10.1016/j.ecocom.2009.10.006.

Haines-Young, R.H., and Potschin, M.B. 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. EEA Framework Contract No EEA/IEA/09/003.

Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., and Schneiders, A. 2014. "The Matrix Reloaded": A review of expert knowledge use for mapping ecosystem services. Ecological Modelling. doi: 10.1016/j.ecolmodel.2014.08.024.

Kandziora, M., Burkhard, B., and Müller, F. 2013. Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. Ecological Indicators **28**: 54–78. doi: 10.1016/j.ecolind.2012.09.006.

Lamarque, P., Quétier, F., and Lavorel, S. 2011. The diversity of the ecosystem services concept and its implications for their assessment and management. Comptes Rendus Biologies **334**: 441–449. doi: 10.1016/j.crvi.2010.11.007.

Martínez-Harms, M.J., and Balvanera, P. 2012. Methods for mapping ecosystem service supply: a review. International Journal of Biodiversity Science, Ecosystem Services & Management **8**: 17–25. doi: 10.1080/21513732.2012.663792.

Maynard, S., James, D., and Davidson, A. 2010. The Development of an Ecosystem Services Framework for South East Queensland. Environmental Management **45**: 881–895. doi: 10.1007/s00267-010-9428-z.

Millennium Ecosystem Assessment. 2005. Ecosystem Services and Human Well-Being: Wetlands and Water: Synthesis. 2005. Millennium Ecosystem Assessment report to the Ramsar Convention: World Resources Institute, Washington D.C.

Mouchet, M.A., Lamarque, P., Martín-López, B., Crouzat, E., Gos, P., Byczek, C., and Lavorel, S. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. Global Environmental Change **28**: 298–308. doi: 10.1016/j.gloenvcha.2014.07.012.

Müller, F., de Groot, R.S., and Willemen, L. 2011. Ecosystem Services at the Landscape Scale: the Need for Integrative Approaches. Landscape Online. doi: 10.3097/LO.201023.

Ngarrindjeri Nation. 2007. Ngarrindjeri Nation Sea Country Plan, Caring for Ngarrindjeri Country and Culture. Meningie.

Potschin, M.B., and Haines-Young, R.H. 2011. Ecosystem services: Exploring a geographical perspective. Progress in Physical Geography **35**: 575–594. doi: 10.1177/0309133311423172.

Raudsepp-Hearne, C., Peterson, G.D., and Bennett, E.M. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences **107**: 5242–5247. doi: 10.1073/pnas.0907284107.

Reid-Piko, C., Crase, L., Horwitz, P., and Butcher, R. 2010. Ecosystem Services and Productive Base for the Basin Plan. Final Report prepared for the Murray-Darling Basin Authority by The Murray-Darling Freshwater Research Centre. Murray-Darling Basin Authority.

Schröter, M., Barton, D.N., Remme, R.P., and Hein, L. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. Ecological Indicators **36**: 539–551. doi: 10.1016/j.ecolind.2013.09.018.

Syrbe, R.-U., and Walz, U. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. Ecological Indicators **21**: 80–88. doi: 10.1016/j.ecolind.2012.02.013.

TEEB. 2010. The economics of ecosystems and biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB.

Villamagna, A.M., Angermeier, P.L., and Bennett, E.M. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. Ecological Complexity **15**: 114–121. doi: 10.1016/j.ecocom.2013.07.004.

Villamagna, A.M., Mogollón, B., and Angermeier, P.L. 2014. A multi-indicator framework for mapping cultural ecosystem services: The case of freshwater recreational fishing. Ecological Indicators **45**: 255–265. doi: 10.1016/j.ecolind.2014.04.001.

Ward, N.J., Sullivan, L.A., and Bush, R.T. 2013. Lower Lakes acid sulfate soil detailed conceptual models. Southern Cross GeoScience Technical Report No. 113. Prepared for the SA Department of Environment, Water and Natural Resources, Adelaide.

6 Appendix A: Summary of processes and functions for critical ES identified in the workshop

The following series of Tables summarise the processes and functions considered relevant to each of the critical ES identified in the draft ECD.

Table 5: Service: Irrigation and Water Supply (amount and quality of water) (note these are separate service s but the processes and functions are the same.

Processes	Functions
Evapotranspiration	Water regulation (includes lake levels)
River inflows	Water supply (potable water)
Stratification/mixing	
Hydrogeochemical processes (e.g. fluxes of O2, N, carbonate, S and C)	
Wind seiching	

Table 6: Service: Pollution control

Processes	Functions
Evapotranspiration	Water regulation (includes lake levels)
River inflows	Water quality
Sediment deposition and re-suspension	Nutrient retention
Bioaccumulation	Contaminant accumulation and storage by biota
Nutrient cycling	Nutrient regulation (carbon storage)
Assimilation of contaminants by biota	Soil quality
Microbial reduction	Buffering capacity
Sulfidisation - production of sulfidic sediments	Contaminant retention and accumulation by ecosystem
Metal mobilisation/immobilisation	Bio-remediation
Volatile production and uptake	
Groundwater inflows (source of S)	
Carbon accumulation	

Table 7: Service: Provision of aquatic food for human consumption (BENEFIT)

Processes	Functions
Reproduction	Food web support
Migration	Maintenance of freshwater fish stocks
Dispersal	Maintenance of marine and estuarine fish and crustacean stocks
Competition	
Predation	

Table 8: Service: Special geomorphic feature – Murray Mouth

Processes	Functions
Scouring	Storm protection
Sediment transport	Shoreline erosion protection
Sediment re-suspension	Water quality
Tidal movement	Murray Mouth (cultural heritage and identity)
River inflows	

Wind seiching	
Murray Mouth open	

Table 9: Service: Special ecological feature – drought refuge

Processes	Functions
River inflows	Water quality
Dispersal	Water regulation (includes lake levels)
Groundwater-surface water interactions	Hydrological connectivity
Evapotranspiration	

Table 10: Service: Special ecological feature – nursery and spawning grounds

Processes	Functions
River inflows	Water quality
Dispersal	Water regulation (includes lake levels)
Climatic processes - Temperature	Hydrological connectivity
Migration	
Wetland habitat creation (via inflows/inundation)	
Tidal movement	

Table 11: Service: Maintenance and regulation of hydrological processes

Processes	Functions
Wind sieching	Water regulation (includes lake levels)
River inflows	Hydrological connectivity
Evapotranspiration	Water quality
Groundwater-surface water interactions	Natural hazard reduction
Stratification/mixing	
Tidal movement	
Rainfall	

Table 12: Service: Provides physical habitat

Processes	Functions
Geomorphic processes (includes sedimentation)	Provides physical habitat (includes diversity, nursery, refugia, roosting and foraging habitat)
Water quality	Supports critical life stages
Colonisation	
River inflows	
Vegetation community composition and structure (including zonation)	

Table 13: Service: Biodiversity (not genetic)

Processes	Functions
Biotic interactions (e.g. competition, reproduction, predation)	Provides physical habitat (includes diversity, nursery, refugia)
Water quality	Biodiversity (includes biodisparity, α and β diversity, Functional trait diversity)
Geomorphic processes	Resilience (includes consideration of resistance)
Hydrological processes	
Migration	
Dispersal	

Table 14: Service: Ecological connectivity

Processes	Functions
Migration	Biodiversity (including biodisparity)
Dispersal	Supports critical life stages
Hydrological processes	Provides physical habitat (includes diversity, nursery, refugia)
Groundwater and surface water interactions	
Water quality	

Table 15: Service: Supports critical food webs

Processes	Functions
Freshwater inflows	Supports critical life stages
Biotic interactions (e.g. grazing, competition, predation, herbivory)	Provides physical habitat (includes diversity, nursery, refugia)
Water quality	Water quality
Geomorphic processes	Food web support
Wind seiching	
Stratification/mixing	
Nutrient cycling	
Tidal movement	
Light attenuation	

7 Appendix B: Alignment of CLLMM functions relating to critical ecosystem services to CICES classification

Note that ecosystem outputs are regarded as things fundamentally dependent on living processes, and so abiotic outputs from nature are not regarded as an ecosystem service for the purposes of CICES (Haines-Young and Potschin 2013). Whilst not adopting the term final ecosystem services (as per Fisher et al. 2009) the CICES typology nevertheless provides a framework in which information about supporting or intermediate services can be nested and referenced, and this may be particularly useful in a mapping context (Haines-Young and Potschin 2013). Note that not all groups and classes of ES as identified by the CICES classification align with the functions relevant to the critical ES identified for the Ramsar site.

Table 16: Summary of ecological functions (as identified in the workshop) against the CICES classification.

CICES Section	CICES Division	CICES Group	CICES Class	CLLMM Function
Provisioning	Nutrition	Biomass	Wild animals	Aquatic food production
		Water	Surface water for drinking	Water supply (potable water)
	Materials	Water	Surface water non-drinking purposes	Irrigation
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	Bio-remediation
		Mediation by biota	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	Contaminant accumulation and storage by biota
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	Regulation of waste (Contaminant retention and amelioration) - (includes binding of metals)
		Mediation by ecosystems	Dilution by atmosphere, freshwater and marine ecosystems	Buffering capacity
		Mediation by ecosystems	Mediation of smell/noise/visual impacts	n/a
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	Erosion regulation
			Mass stabilisation and control of erosion rates	Coastal shoreline protection and stabilisation

CICES Section	CICES Division	CICES Group	CICES Class	CLLMM Function
			Buffering and attenuation of mass flows	Transport and storage of sediment
		Liquid flows	Hydrological cycle and water flow maintenance	Water regulation (includes lake levels
			Flood protection	Natural hazard reduction (flood control, storm protection)
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	Supports critical life stages - seed dispersal
		Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Provides physical habitat - nursery
		Pest and disease control	Pest control	n/a
			Disease control	n/a
		Soil formation and composition	Weathering processes	Soil formation and condition
			Decomposition and fixing processes	Soil quality
		Water conditions	Chemical condition of freshwaters	Water quality
		Water conditions	Chemical condition of salt waters	Water quality
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	n/a
			Micro and regional climate regulation	n/a
Cultural	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic	TBC

CICES Section	CICES Division	CICES Group	CICES Class	CLLMM Function
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Sacred and/or religious	Murray mouth (cultural heritage and identity)
Supporting*	Intrinsic ecological values	Biodiversity	Genes, species, communities and ecosystem type	Biodiversity (including wetland diversity, community composition and structure, functional trait diversity; biodisparity, α and β diversity)
	Intrinsic ecological values	Biodiversity	Biotic interactions	Food web support
	Intrinsic ecological values	Biodiversity	Resilience	Resilience

*supporting services not part of CICES classification – to be refined by DEWNR.

8 Appendix C: Conceptual models of relationships of process and functions relating to the critical ecosystem services of the Coorong and Lakes Alexandrina and Albert Ramsar site

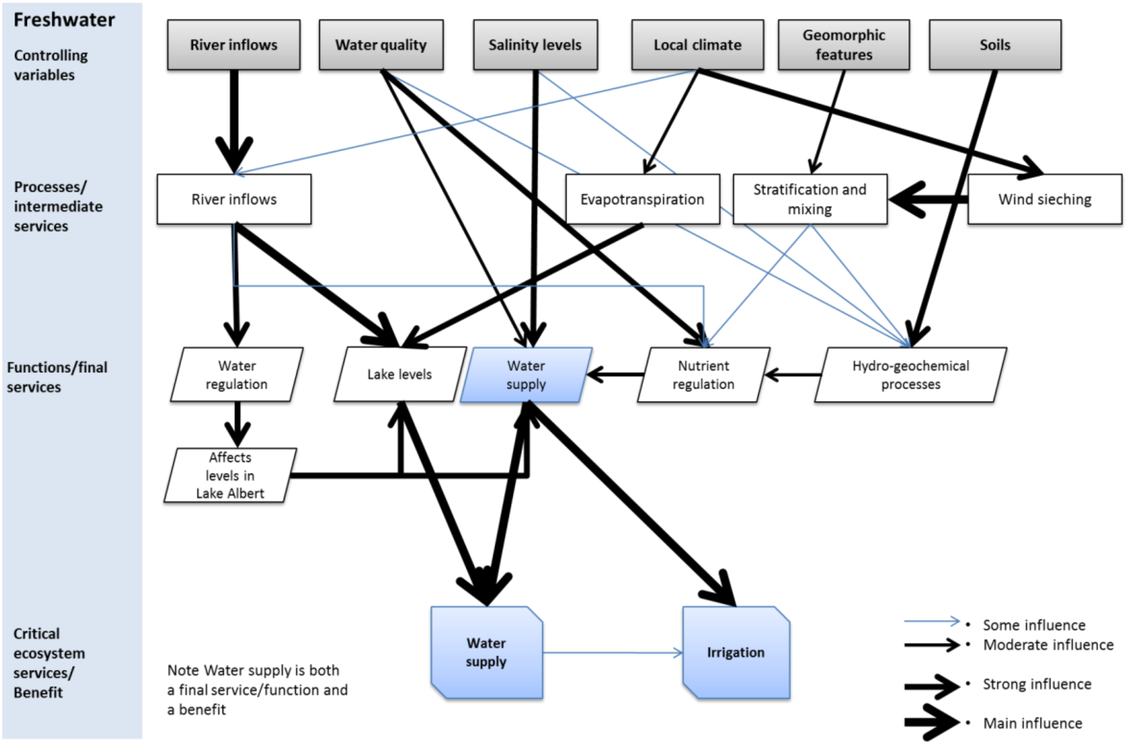

Figure 18: Conceptual model showing strength of relationships between processes, functions and water supply and irrigation services in the freshwater units of the Ramsar site.

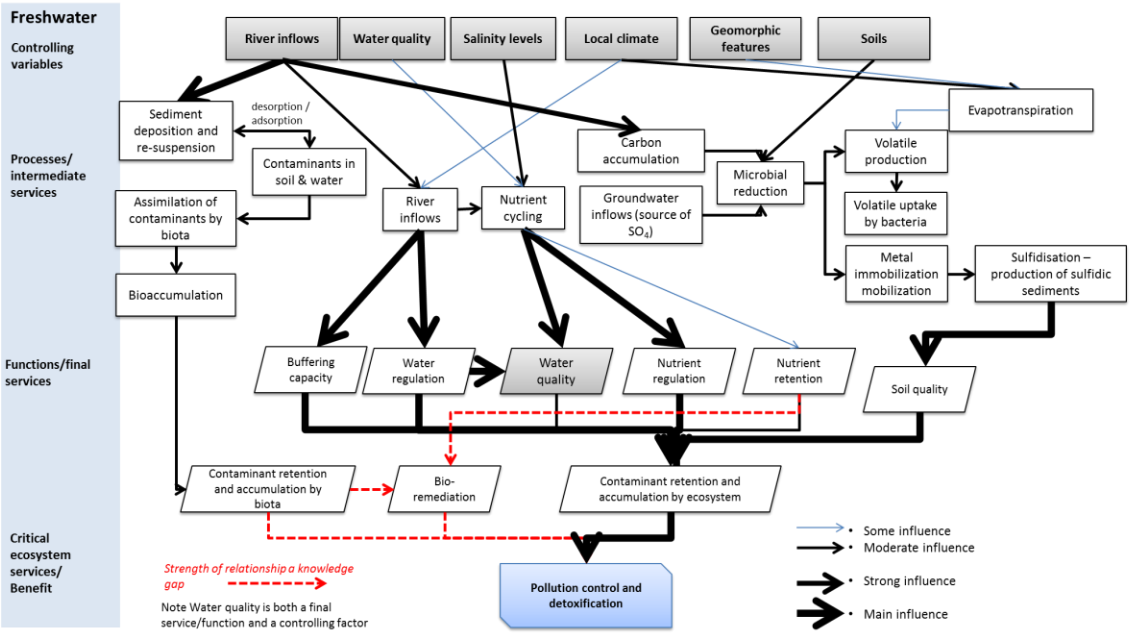

Figure 19: Conceptual model showing strength of relationships between processes, functions and Pollution control and detoxification in the freshwater units of the Ramsar site. Note that the role of the microbial loop in this service and biotic interactions are considered a knowledge gap.

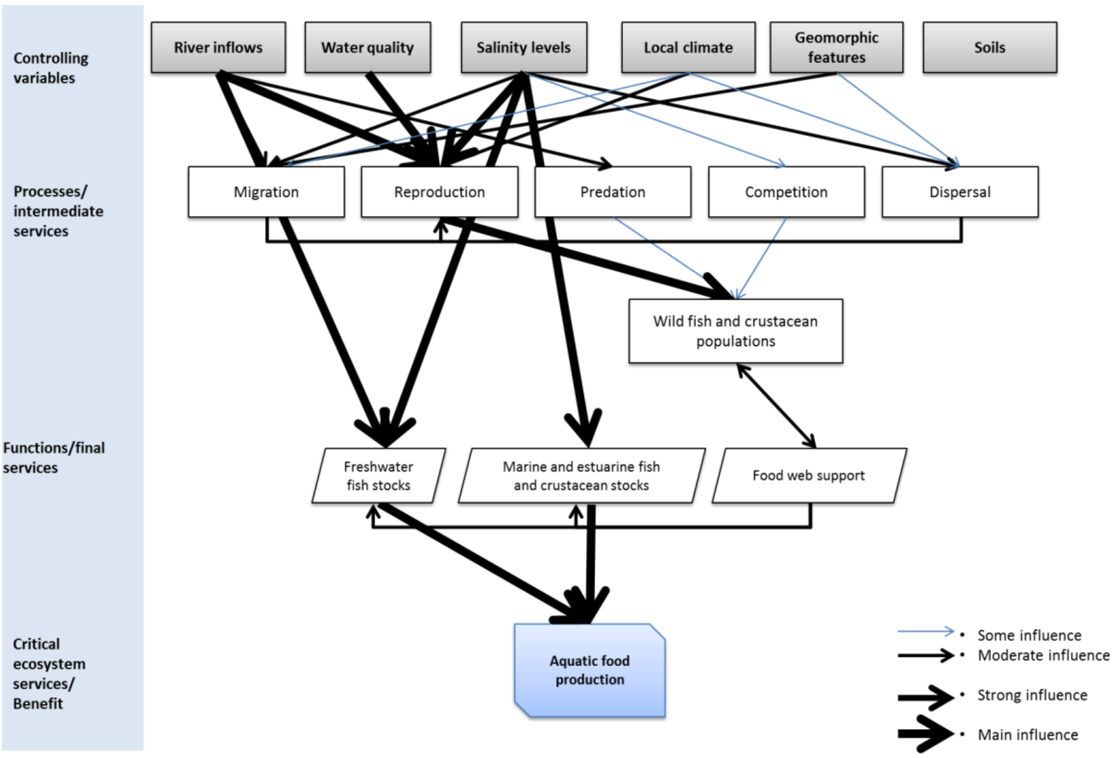

Figure 20: Conceptual model showing strength of relationships between processes, functions and aquatic food production across the Ramsar site.

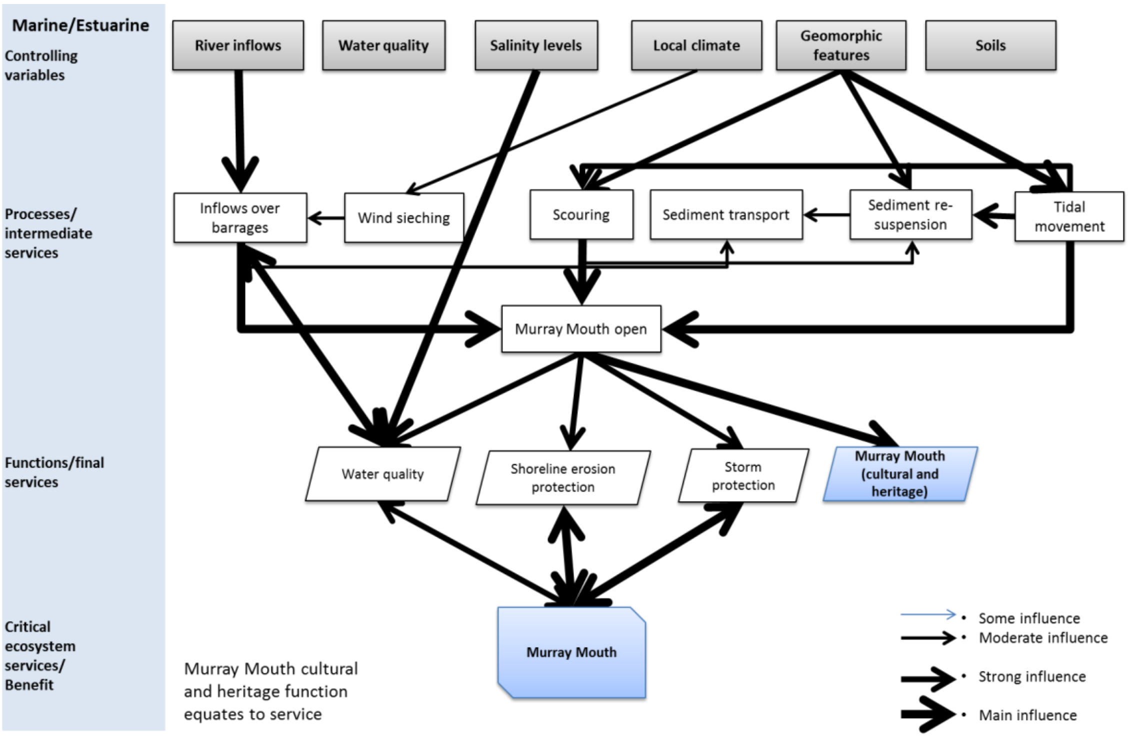

Figure 21: Conceptual model showing strength of relationships between processes, functions and the critical service of Special geomorphic features – Murray mouth.

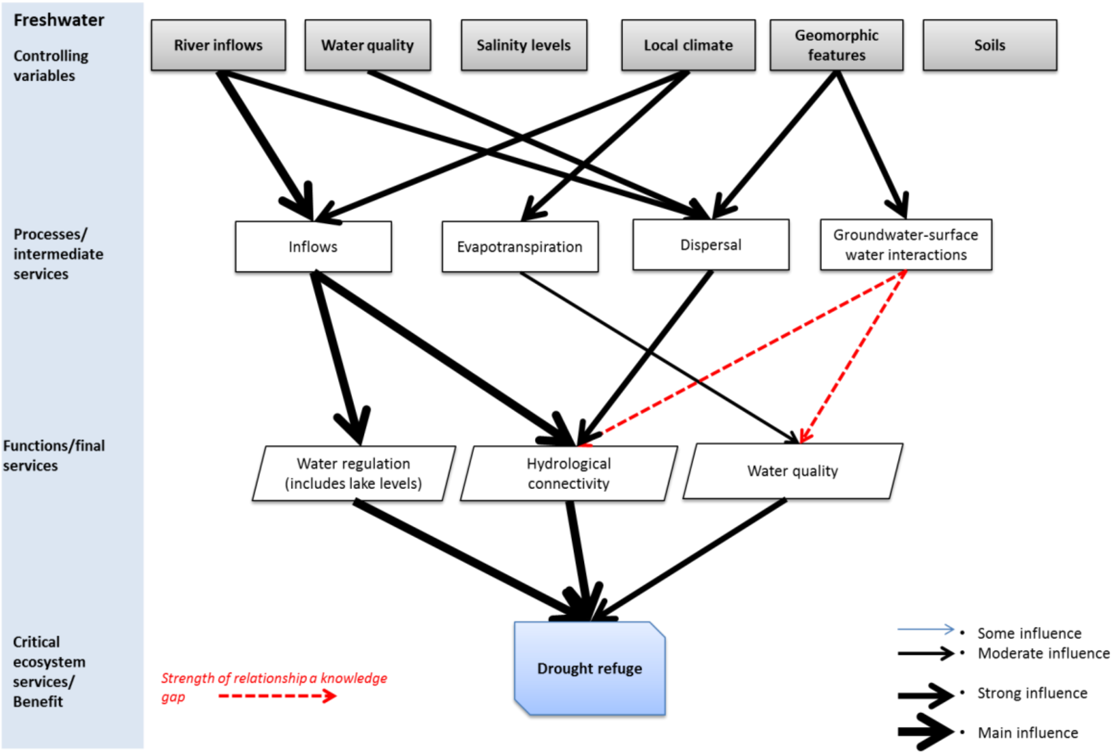

Figure 22: Conceptual model showing strength of relationships between processes, functions and the critical service of drought refuge (freshwater units of Ramsar site).

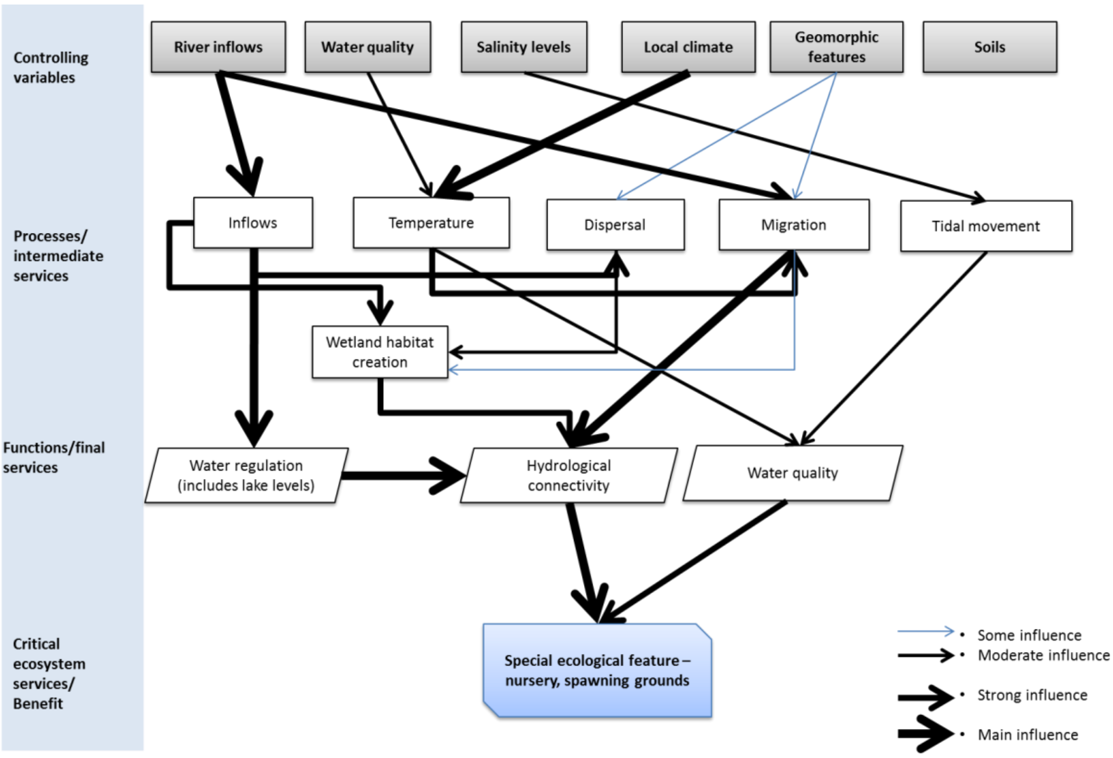

Figure 23: Conceptual model showing strength of relationships between processes, functions and the critical service of Special ecological feature – nursery, spawning grounds.

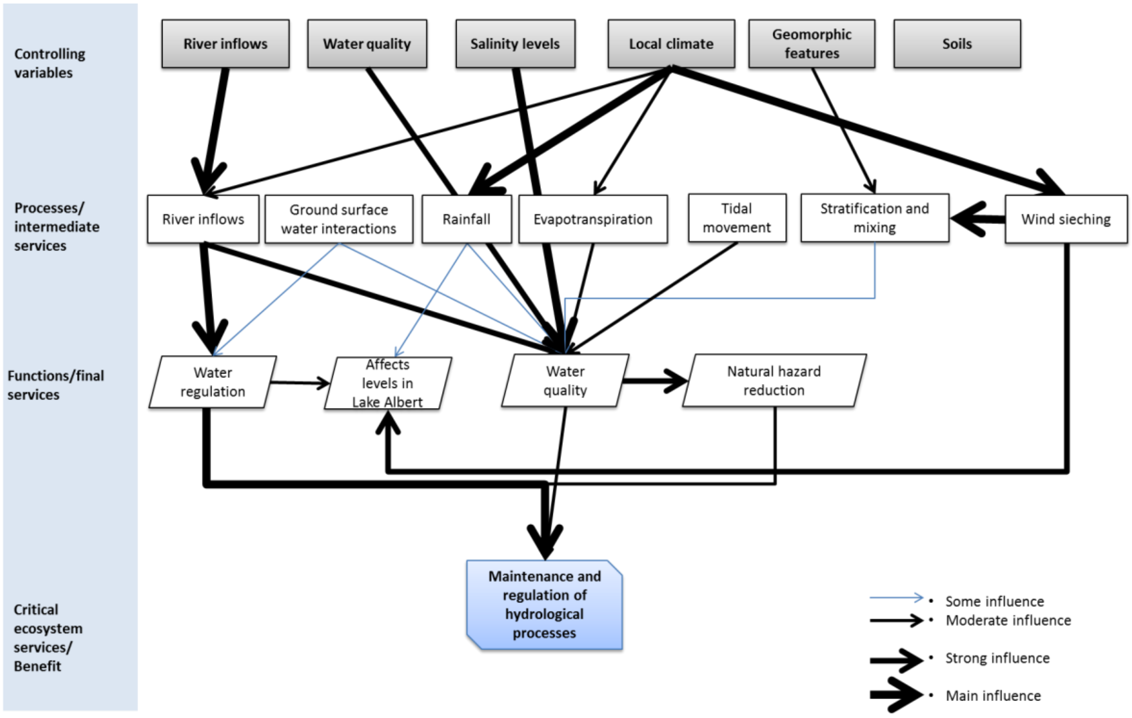

Figure 24: Conceptual model showing strength of relationships between processes, functions and the critical service of maintenance and regulation of hydrological processes.

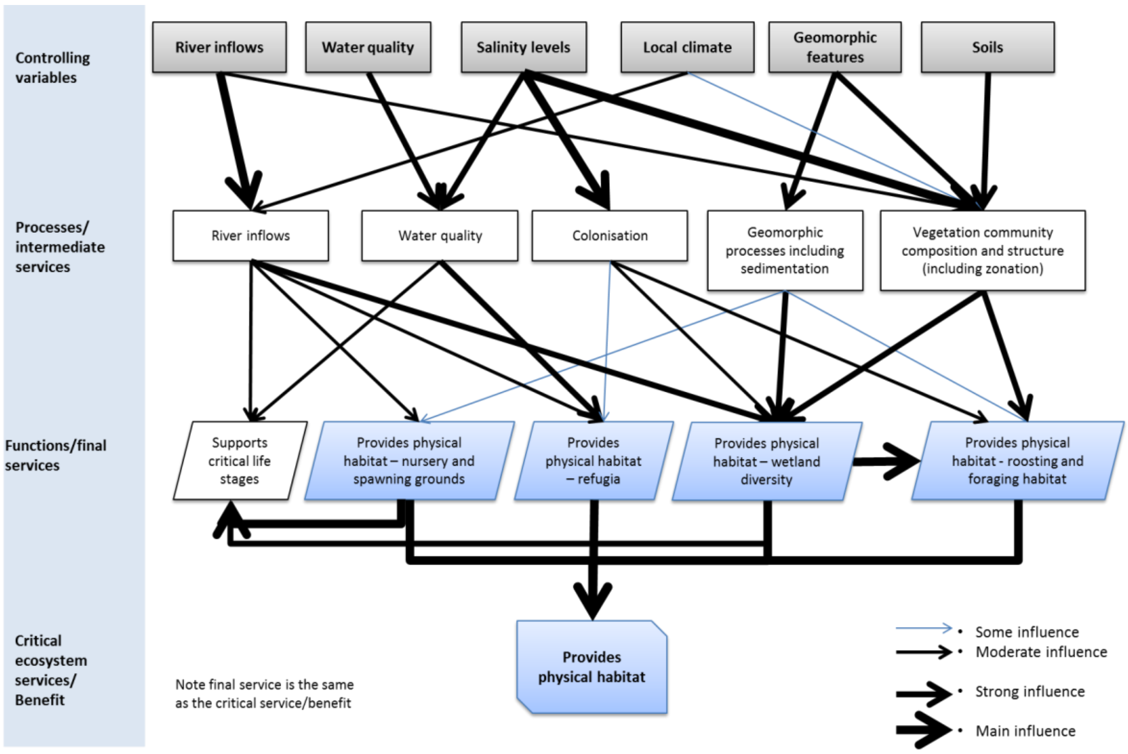

Figure 25: Conceptual model showing strength of relationships between processes, functions and the critical service of Provision of physical habitat.

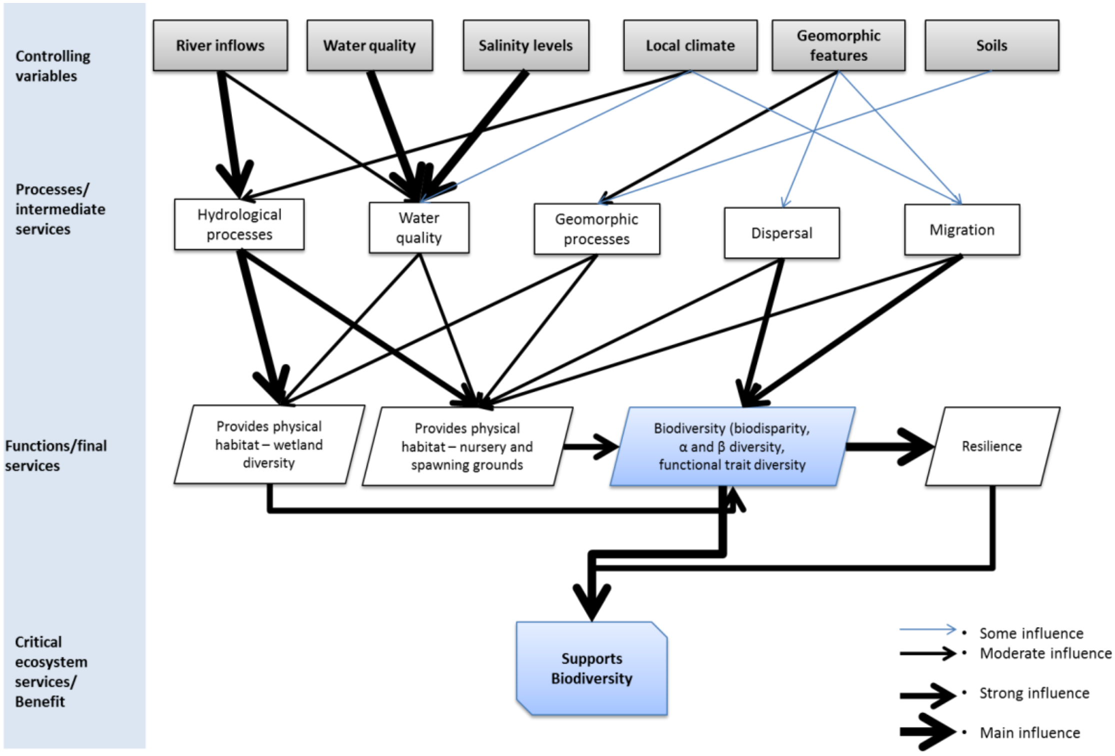

Figure 26: Conceptual model showing strength of relationships between processes, functions and the critical service of Supports biodiversity.

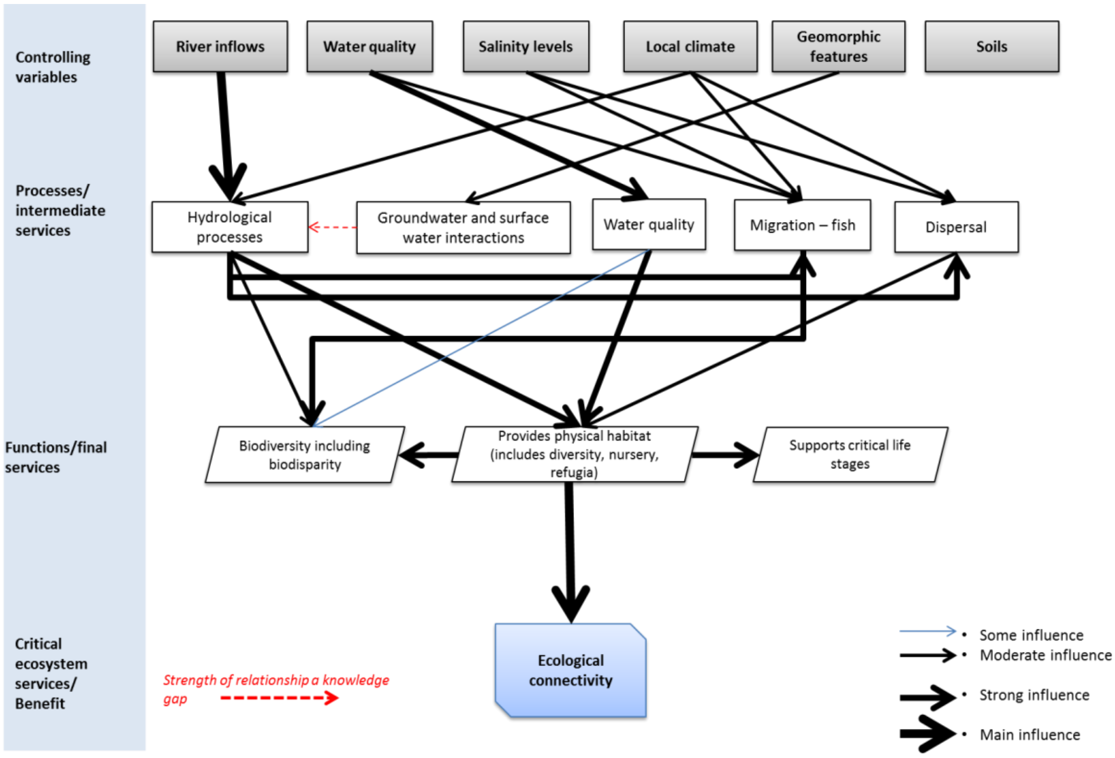

Figure 27: Conceptual model showing strength of relationships between processes, functions and the critical service of Ecological connectivity.

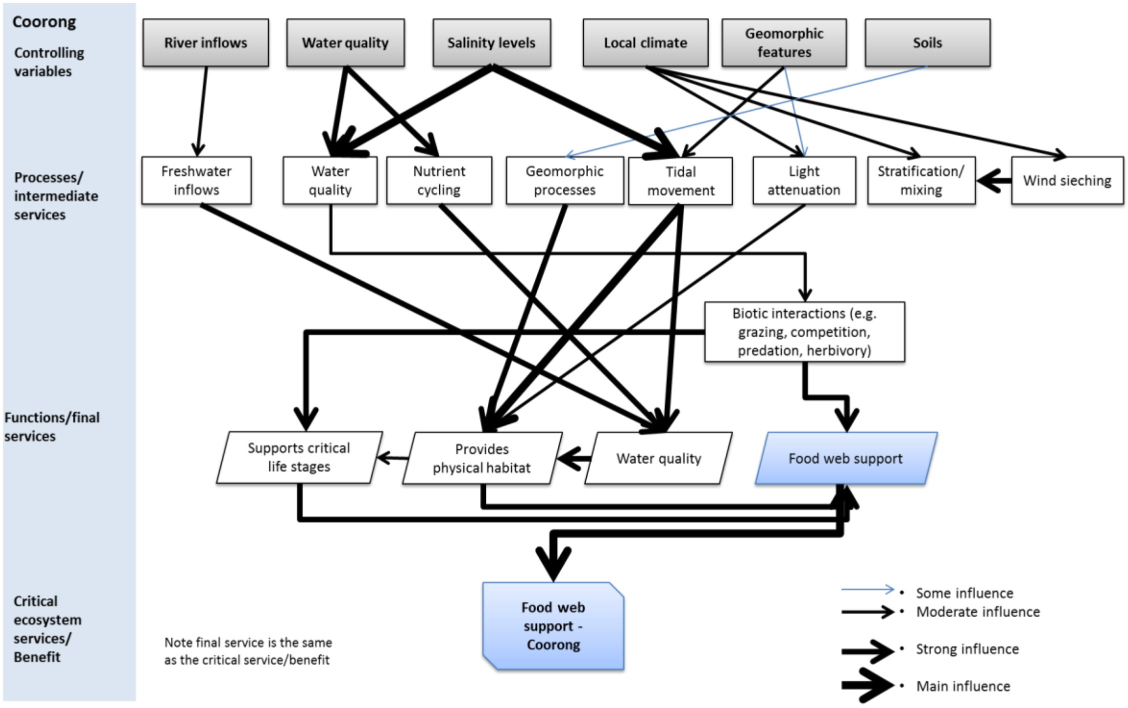

Figure 28: Conceptual model showing strength of relationships between processes, functions and the critical service of Support food web - Coorong.