19 The Coorong lagoons and Murray Mouth inverse estuary, South Australia

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Classification

International and National: The coastal wetland complex represented by the Coorong supports numerous bird species that are listed under the Japan-Australia Migratory Bird Agreement, the China-Australia Migratory Bird Agreement and the Republic of Korea-Australia Migratory Bird Agreement (Phillips and Muller 2006). The Coorong, Lower Lakes and Murray Mouth region itself is a Wetland of International Importance under the Ramsar Convention (Phillips and Muller 2006), one of six identified icon sites under The Living Murray initiative, and a hydraulic indicator site under the draft Murray-Darling Basin Plan (MDBA 2010).

IUCN Habitats Classification Scheme (Version 3.0): 13 Marine Coastal/Supratidal / 13.4 Coastal Brackish/Saline Lagoons/Marine Lakes

Ecosystem description

Coastal wetlands can be relatively simple systems (e.g. riverine estuaries) or can include a complex of estuarine, marine and hypersaline habitats and biota that are often quite dynamic in space and time. This dynamic diversity of habitat types results in a diverse and unique characteristic biota and therefore high ecological values. The Coorong, which is the inverse estuary for the Murray-Darling Basin, Australia's largest river, is the sole example of such a large, diverse and complex ecosystem (Phillips & Muller 2006; Brookes et al. 2009; Kingsford et al. 2011), and so warrants assessment as a potentially-threatened ecosystem. The Coorong is part of a complex of freshwater, estuarine and hypersaline wetlands known as the Coorong, Lower Lakes and Murray Mouth (Figure 1). This case study focuses on the coastal lagoons that comprise the Coorong, and the Murray Mouth estuary, where the River Murray meets the sea. The upstream Lower Lakes are largely freshwater, being separated from the Coorong by a series of artificial barrages that control the flow of water between the two. The Lower Lakes therefore comprise a different characteristic biota to the Coorong and Murray Mouth, so are not included in this assessment, but may warrant separate consideration.

Characteristic native biota

The characteristic biota for such coastal wetland complexes includes a range of typically estuarine, marine and hypersaline taxa, and it is the combination of these that is one of the unique features of this ecosystem.

Characteristic habitat types include submergent macrophytes (Ruppia megacarpa and R. tuberosa, in particular but also including a range of seagrass species; Gehrig and Nicol 2010), littoral samphire shrublands, intertidal marshes, mudflats and emergent freshwater reeds (Typha spp. and Phragmites australis) (Figure 2; Phillips and Muller 2006). Ruppia spp., in particular, provide large areas of physical habitat and are a food source for many of the region's birds, fish and macroinvertebrates (Phillips and Muller 2006).

This ecosystem is particularly noted for the wide range of bird life that it supports (Brookes et al. 2009). Characteristic taxa include piscivores such as Australian pelican (Pelecanus conspicillatus; Figure 2) and cormorants (Phalacrocarax spp.), ducks (Anas spp.), waders (e.g. Calidris ruficollis, Calidris acuminata, Charadrius ruficapillus) and terns (e.g. Sternula nereis) (Phillips and Muller 2006).

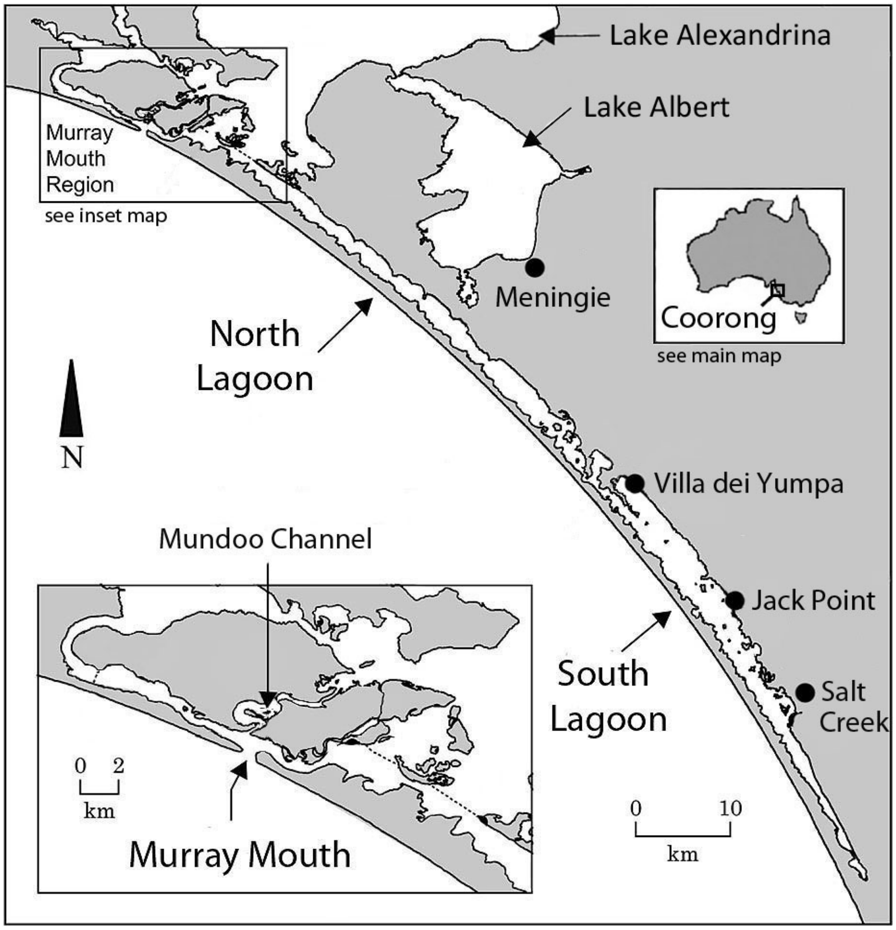

Figure S19. 1. Map of the Coorong and Murray Mouth region, including the North Lagoon, South Lagoon and the Murray Mouth (see inset map). Dotted lines on the inset map show positions of the barrages. Also shown is the location of the study region on a map of Australia. Locations mentioned within the text are shown, except for Victor Harbour, which is 25 km west of the Murray Mouth region shown here. Adapted from a map created by Craig Noell (SARDI Aquatic Sciences, South Australia).

Forty-nine species of fish have been described within this coastal wetland complex ecosystem, including diadromous species such as the culturally-significant congolli (Pseudaphritis urvillii), commercial and recreationally-fished yellow-eyed mullet (Aldrichetta forsteri) and black bream (Acanthopagrus butcheri), and small-mouthed hardyhead (Atherinosoma microstoma), which is an important prey item for many of the birds in the region (Phillips and Muller 2006).

Macroinvertebrate taxa occurring in the intertidal marshes and mudflats include Amphipoda, Oligochaeta, polychaete worms (e.g. Nephtys australiensis, Simplesetia aequisetis, Capitella spp.) and bivalves such as Arthritica helmsi. A calcareous tubeworm (Ficopomatus enigmaticus) and brine shrimp (Paratemia zieziana) are also characteristic.

In order to simplify the definition of characteristic biota for the Coorong, we use the suites of co-occurring biota that are described by the ecosystem state model for the region (Figure 3; Lester and Fairweather 2011). This is a data-derived state-and-transition model that identified eight distinct ecosystem states for the Coorong, including two 'basins of attraction' (i.e. a marine basin and a hypersaline basin) and a trajectory of ecosystem health in each (i.e. ranging from 'healthy' states to 'degraded' states in each basin) (Lester and Fairweather 2011).

The healthy state in the marine basin ('Estuarine/marine') is characterised by a large number of marine and estuarine fish (e.g. yellow-eyed mullet, mulloway (Argyrosomus japonicas), black bream and Australian salmon (Arripis truttacea). Characteristic birds in this state included cormorants, waterfowl, migratory waders and the Australian white ibis (Threskiornis molucca). Amphipoda and polychaete species were characteristic of the infaunal assemblages, while the macrophyte Ruppia tuberosa was present (Lester and Fairweather 2011).

Figure S19. 2. Characteristic biota of the Coorong include samphire shrublands (in the distance) and Australian pelicans (in the foreground)

In the hypersaline basin, two healthy states were identified. The Healthy Hypersaline state is thought to be associated with times of high flow, and is characterised by waders (e.g. red-necked avocet Recurvirostra novaehollandiae), and waterfowl (e.g. teal, black swan Cygnus atratus), but with smaller numbers of waders and piscivores than were found in the marine basin (e.g. red-capped plover, red-necked stint and whiskered tern). This state supported few estuarine and marine fish, but infauna were characterised by polychaete worms and bivalves. The second healthy state in the hypersaline basin ('Average Hypersaline') had few macroinvertebrates other than chironomid (midge) larvae and Amphipoda. Few estuarine fish were again found, and Australian pelican was the only piscivorous species characteristic of this state. Waders and waterfowl again characterised the bird assemblage, with Ruppia tuberosa more common than in other hypersaline basin states.

Abiotic characteristics

A coastal wetland complex of the type described here consists of a long, narrow and shallow series of lagoons. The Coorong is 121 km long, with an average width of 1.9 km. It is divided in to two main lagoons with average depths of 1.2 and 1.4 m for the North and South Lagoons, respectively (Figure 1; S. Benger, Flinders University, pers. comm.; Webster 2010). The Murray Mouth is located at the northern end of the lagoon complex, adjacent to the major source of freshwater flows in the region, the barrages, which allow River Murray water to enter, making it an inverse estuary (sensu Wolanski 1987).

Salinities thus range from estuarine to hypersaline along the length of the system, and this spatial variability is one of the primary abiotic characteristics of the ecosystem (Lester et al. 2011a). Barrage flows (i.e. the flow of freshwater across the barrages), nearby sea levels in Encounter Bay, wind and a seasonal hydrologic disconnection between the North and South Lagoon are the main drivers of complex seasonal and inter-annual patterns in salinity and water level throughout the region (Webster 2010). There is also a smaller input of fresh water in the South Lagoon, via Salt Creek.

The connection to the Southern Ocean, via the Murray Mouth, is highly dynamic, with the effective transmissivity of water (i.e. the amount of water that passes through the mouth as influenced by a combination of depth and width) varying seasonally and inter-annually, largely as a function of barrage flows (Webster 2010).

The ecosystem states model for the Coorong identified the key abiotic characteristics associated with each of the eight ecosystem states. These included the average daily tidal range (i.e. which was responsible for dividing the eight states into two basins), the number of no-flow days over the barrages (i.e. dividing the states into relatively healthy and unhealthy states), the annual average water level, annual average depth from two years previous (i.e. a lag in response time was detected, suggesting this was a leading indicator; Fairweather and Lester 2010) and the annual average salinity. This illustrates the interactions between water levels, flow and salinity that occur within the region thus giving it its unique abiotic characteristics.

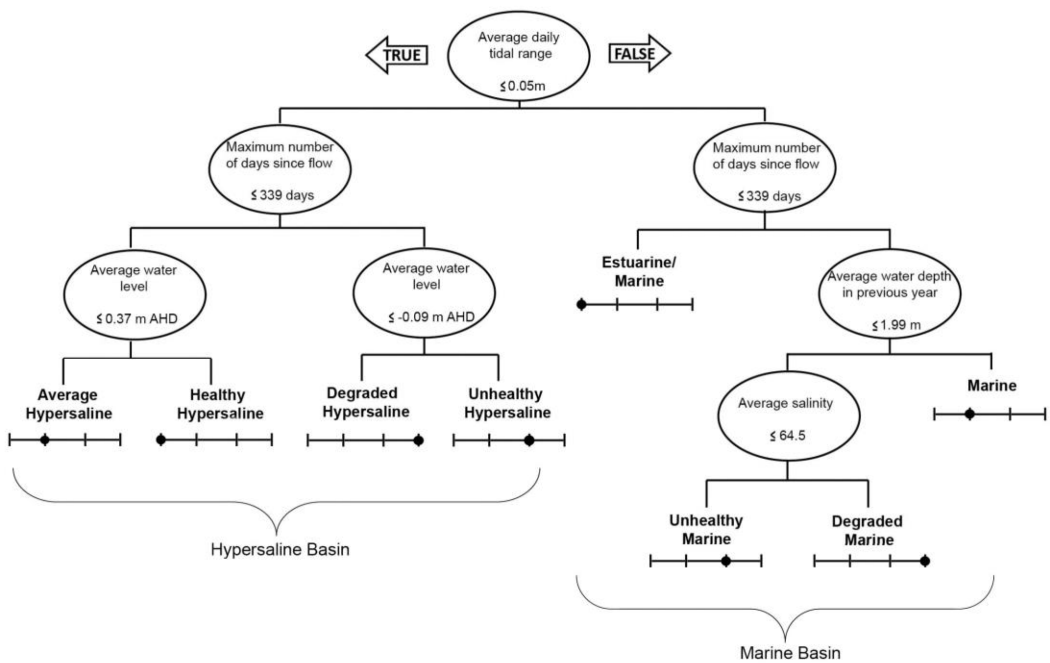

Figure S19. 3. Ecosystem states model for the Coorong (reproduced from Lester and Fairweather 2011) The states are presented here as a logic tree, where each oval should be read as a logic statement. For a given site-year, if the condition in the oval is true, then the tree should be followed to the left-hand side. If the condition is false, then the tree proceeds to the right, until a terminal node is reached. This terminal node determines which state the Coorong is in at any given location and time, based on its environmental characteristics. Under each state is a scale of degradation (from healthiest on the left to most degraded on the right), where a dot represents where each state fell along that trajectory (see Lester & Fairweather 2011).

Key processes and interactions

The key process occurring within this ecosystem is the flow of fresh water entering the system, which in the Coorong occurs from the River Murray over the barrages. This then interacts with mouth openness, water levels, local sea levels, wind, weather systems, flows via Salt Creek and evaporation rates to drive the hydrodynamics of the Coorong lagoons (Webster 2010), which in turn, drive the ecological characteristics of the system (Figure 3; Lester and Fairweather 2011).

An environmental water regime for the region has been identified based on minimum freshwater flow volumes from the River Murray to support salinity targets in the upstream Lake Alexandrina (Heneker 2010). These have also been shown to support characteristic biota and abiotic conditions in the Coorong (Lester et al. 2011b). Heneker (2010) described three regimes of 3-year minimum barrage flow regimes, with different recommendations for the proportion of years where they apply (i.e. a long-term average of 700 µS cm^{-1}, a maximum of 1000 µS cm^{-1} in 95% of years, and an absolute maximum of 1500 µS cm^{-1} in 100% of years). The most relevant to this assessment is the water regime designed to support a salinity of 1000 µS cm^{-1} in Lake Alexandrina in 95% of years. To meet that target, minimum barrage flows in any one year should be the maximum of: i) 650 GL; ii) 4000 GL minus the flow volume of the previous year; and iii) 6000 GL minus the flow volumes of the previous two years (with a cap on the effective volume of the first year in that sequence) (Heneker 2010).

Furthermore, the rate and timing of delivery can have a large influence on the effect of freshwater flows, with prolonged low flows identified as more effective than short, larger flows to avoid high salinities and ecological degradation, for comparable volumes (Lester et al. 2011c).

Threatening processes

The primary threatening process to the Coorong ecosystem is thus a reduction of freshwater inflows from the River Murray. Under unregulated conditions, approximately 52% of flows (or a barrage flow of 10 764 GL $year^{-1}$) in the Murray-Darling Basin reach the sea, and thus pass through the Coorong (Kingsford et al. 2011). Under current water sharing arrangements, the average end-of-system flow is 3075 GL $year^{-1}$, which represents a 71% reduction. This loss of flow is disproportionately high during drought years, so that flows are now zero for 40% of days, compared with <1% under unregulated conditions (Kingsford et al. 2011). Thus, there is an interaction between extractions in the Murray-Darling Basin and drought, and there is likely to be an interaction between extractions and future climate change, as that develops within the region.

The second major threatening process is change to the source and timing of water delivery to the region. That is, while the overall volume may be sufficient, water may not be delivered from a suitable source, or with the timing required by the Coorong ecosystem. As described above, the timing of barrage flows has a large impact on conditions within the Coorong, making suboptimal delivery a potential threat.

Ecosystem collapse

Ecosystem collapse for this ecosystem type is defined conceptually as the loss of the range in estuarine, marine and hypersaline environments that have traditionally coexisted. Thus, it is effectively a loss of diversity of habitat types, rather than a complete loss of species. This is most likely to occur as a result of a loss of freshwater flows to the region that would increase salinity and decrease water levels and marine connectivity.

For the purposes of this case study, we have largely defined thresholds of ecosystem collapse for the Coorong, with respect to the ecosystem states model for the region. We define ecological collapse as occurring when half of the modelled years occur either in degraded ecosystem states or are in a period of recovery following the occurrence of degraded ecosystem states. Periods of recovery are defined as twice the duration of occurrence of degraded ecosystem states, as recovery from drought is likely to take significantly longer than recovery from flooding in freshwater systems (Lake 2000), which is also likely in estuarine systems, and the effect of high flow events is known to last for up to two years after the event (Heneker 2010).

This threshold is intended to capture both periods in which ecological degradation is likely (i.e. due to the occurrence of degraded ecosystem states) and the time required to recover characteristic biota following drought. The rationale for this is that long-term persistence of the characteristic biota for the region is highly unlikely if ecological degradation occurs frequently enough (here, defined at 50% of the time, as a starting point) without sufficient periods of recovery, and then ecological collapse is highly likely.

There are also parts of this assessment where the ecosystem states model is not applied, in an attempt to use multiple lines of evidence in the assessment. Therefore, alternative thresholds of ecological collapse were also required. In Criterion C, we assessed ecological condition relative to two alternative thresholds for salinity (i.e. an annual average of 117 g L^{-1} and an annual maximum of 100 g L^{-1}) in the South Lagoon that have been shown to be correlated with various forms of ecological degradation (Fairweather and Lester 2010; MDBA 2010), and against defined environmental water requirements for the Coorong (Lester et al. 2011e). Therefore, in Criterion C, we defined ecological collapse as occurring when the entire South Lagoon exceeded either threshold in all years within the model simulations used, or when environmental water requirements were not met in all model years.

In Criterion D, we again used an assessment independent of the ecosystem states model. We assessed the decline in the iconic and key macrophytes Ruppia megacarpa and R. tuberosa. There, we assumed that assemblages dependent on Ruppia spp. had collapsed when the percent coverage of Ruppia spp. declined to zero (see Criterion D).

ASSESSMENT

Summary

Criterion	A	B	C	D	E	Overall
Sub-criterion 1	LC	CR	VU	CR	CR(EN-CR)	CR
Sub-criterion 2	LC	EN	CR	DD		
Sub-criterion 3	DD	VU	DD	DD		

Criterion A

The spatial extent of the Coorong is largely geographically defined, and so changes little. Thus, criterion A is unlikely to elucidate changes in the risk of collapse for this case study.

<u>Current decline</u>: There have been no declines in the extent of the Coorong in the past 50 years. Declines in river flow and changes to salinity distributions are assessed further under criterion C. The status of the ecosystem is Least Concern under criterion A1.

<u>Future decline</u>: The extent of the Coorong is very unlikely to decline over the next 50 years or for any period of 50 years including the present to the future. This is because very low barrage flows would be compensated by more seawater flowing in through the Murray Mouth. Thus the status of the ecosystem is Least Concern under criterion A2.

<u>Past decline</u>: No estimate of a long-term reduction in spatial extent exists for the Coorong in the period since 1750. The status of the ecosystem is Data Deficient under criterion A3.

Criterion B

The Coorong is 121 km long, with an average width of 1.9 km, measured from the Goolwa Barrage to the bottom of the South Lagoon (S. Benger, Flinders University, pers. comm.). Areas of the North Lagoon (110.7 km^2) and South Lagoon (94.4 km^2) together are used to approximate the size of the Coorong (Phillips and Muller 2006).

Extent of occurrence: The extent of occurrence is less than 2000 km^2 (i.e. at 205 km^2), and there is evidence of increasing salinity in the Coorong since 1996, with extremely high salinities observed since 2006 (i.e. a decline in environmental quality; see Criterion C1). Further environmental declines (i.e. additional increases in salinity) are also forecast under median and dry future climate projections (see Criterion C2). In addition, barrage flows are predicted to fall under climate change simulations (Lester et al. 2011d), indicating that the processes threatening the Coorong ecosystem are likely to continue to cause declines in environmental condition in the next 20 years. Furthermore, the ecosystem occurs at only one location. Under these circumstances, the status of the ecosystem is Critically Endangered under Criterion B1a,b.

Area of occupancy: The number of 10 x 10 km grid cells occupied by the Coorong ecosystem has been calculated as 17 (S. Benger, Flinders University, pers. comm.). Together with the continuing and future declines in environmental quality described under Extent of occurrence, as well as its restricted occurrence at a single location, this indicates an Endangered status of the ecosystem under Criterion B2a,b.

Number of locations: The Coorong occupies a single location and is prone to the effects of both human activities (i.e. water extraction and changes to flow regimes upstream) and stochastic events (e.g. drought) simultaneously. The recent severe drought between 2006 and 2010 in the region illustrated the impact that the combination of human activity and drought could have on Coorong ecosystems (e.g. Brookes et al. 2009; Kingsford et al. 2011), demonstrating that the ecosystem is capable of becoming critically endangered within a short period of time (here, five years). Therefore, the status of the ecosystem is Vulnerable under criterion B3.

Criterion C

Two main components in the abiotic environment have been identified as reducing habitat quality for characteristic biota of the Coorong ecosystem: small volumes of fresh water delivered to the Coorong via the River Murray, and the extreme salinity of the South Lagoon.

The Environmental Water Requirements for the Coorong specify minimum rolling average volumes of annual barrage flows. Of the three target salinities for Lake Alexandrina, here we assess the likelihood of failing to deliver sufficient water to achieve an average of 1000 $\mu S\ cm^{-1}$, as this is the threshold that should not be exceeded in 95% of years. Failing to meet the rolling average volumes that are sufficient to meet that target would reduce habitat quality for characteristic biota (Lester et al. 2011e). As described above, collapse was defined as failing to meet environmental water requirements in all years included in the model simulation.

We also used two measures of salinity in the South Lagoon to assess the abiotic environment: average annual salinity and maximum annual salinity. Average annual salinity in the South Lagoon has been demonstrated to be a predictor of likely future ecological degradation in the Coorong based on the presence of degraded ecosystem states (Fairweather and Lester 2010). A threshold of 117 $g\ L^{-1}$ has been shown to predate ecological degradation by three years (Fairweather and Lester 2010). A similar threshold (100 $g\ L^{-1}$) has been suggested as the upper limit of suitable habitat for the iconic macrophyte Ruppia tuberosa (MDBA 2010). Thus, crossing either threshold, particularly for any length of time, represents a component of the abiotic environment that is likely to reduce habitat quality for characteristic biota. Here, ecological collapse was considered to occur when each threshold was exceeded for all years simulated.

Current decline: When barrage flows decline, the whole Coorong is affected, so the extent of impact where the thresholds are not met is always 100%. The relative severity was calculated as the proportion of years within the available modelling (see Criterion E for scenario definitions) under Current Conditions for which each site exceeds the threshold.

Under current extraction levels, existing water resources infrastructure and historical climatic conditions, hindcast between 1895 to 2008, minimum rolling-average barrage flow volume targets were not met in 36% of years (Lester et al. 2011e). While this assessment extends for longer than the 50 years specified by Criterion C1, the hindcast cannot be thought of as an accurate simulation of change in the system since 1895, as current extraction levels and current water resources infrastructure are included for the entirety of the model run. Thus, the 114 years of the model run should be thought of as an assessment of possible but realistic variability due to climate, rather than a progression of deterioration (or otherwise) through time. As a result, we have included the whole model sequence in this analysis to indicate the likelihood that environmental water requirements would be met under an historical climate, given current management of the Basin. Thus, as flows were below threshold in 36% of years and this affects 100% of ecosystem extent, the status of the ecosystem Vulnerable under Criterion C1.

Both thresholds (a maximum salinity of 100 g L^{-1} and an annual average of 117 g L^{-1} in the South Lagoon) are calculated based on the whole of the South Lagoon; however, the three sites at which salinity is modelled in the South Lagoon (i.e. Villa dei Yumpa, Jack Point and Salt Creek) were assessed separately to estimate the extent of deterioration. The relative severity was calculated in the same manner as that for annual barrage flow volumes.

Under the same scenario as that used for barrage flow volumes, more than 30% (i.e. 1/3) sites in the South Lagoon exceeded an annual average salinity of 117 g L^{-1} for 18% of years (Table 1). However, all sites (i.e. >80%) exceeded the maximum salinity of 100 g L^{-1} for 41% of years (Table 1). This assessment also finds that the status of the ecosystem is Vulnerable under Criterion C1.

Table S18. 1. Average and maximum annual salinity for the South Lagoon and extent and severity of exceedance of thresholds for each under three alternative climate change projections (refer to Criterion E for additional information).

Scenario	South Lagoon salinity (g L^{-1})	>80% of sites exceed threshold (% model years)	>50% of sites exceed threshold (% model years)	>30% of sites exceed threshold (% model years)
Average annual salinity of 117 g L^{-1}				
Current Conditions	79	3%	17%	18%
Median Future	104	16%	39%	40%
Dry Future	201	81%	94%	94%
Maximum annual salinity of 100 g L^{-1}				
Current Conditions	102	41%	47%	50%
Median Future	140	71%	82%	84%
Dry Future	274	98%	99%	100%

Future decline: Under a median future climate projection for 2030 (Median Future; see Criterion E for a description of the scenarios used), with current extraction levels and existing water resources infrastructure, across 114 years of possible climate variability, minimum rolling-average barrage volume targets were not met in 45% of years (Lester et al. 2011e). Under a dry future climate projection for 2030 (Dry Future), again including current water management conditions and 114 years of possible climate variability resulted in failure to meet those minimum targets for barrage flow volumes in 86% of years. Under a median future climate, the status of the ecosystem would be considered Vulnerable, while under a dry future climate, it would be Critically Endangered.

Using the same median future climate scenario, no combination of extent and severity exceeded the values specified by Criterion C2 for an average annual salinity of more than 117 g L^{-1} (Table 1). However, all sites (i.e. >80%) exceeded the maximum salinity of 100 g L^{-1} for 82% of years (Table 1). This makes the status of the ecosystem Critically Endangered under Criterion C2.

A dry future climate projection, consistent with that used above, resulted in all sites exceeding the annual average salinity threshold of 117 g L^{-1} in 81% of years, and the maximum salinity of 100 g L^{-1} in 98% of years (Table 1), again making the status of the ecosystem Critically Endangered under Criterion C2, regardless of the degree of climate change experienced.

These assessments of the likelihood of future decline show some variability, depending on the future climate scenario used and the environmental variable assessed, but three of the four assessments result in a risk level of Critically Endangered for Criterion C2. Also important to note is that future climatic conditions in these assessments extend only until 2030, not for an additional 30 years, so the likelihood of degradation would probably be higher after the 50 year duration. Therefore the higher estimate of risk is likely to better represent risks over the next 50 years.

Past decline: No estimate of a long-term change in South Lagoon salinities the period since 1750 exists. The status of the ecosystem is Data Deficient under criterion C3.

Criterion D

Ruppia spp. are thought to be a critical component in the structure and functioning of the Coorong and Murray Mouth. Historically, there have been two species present (R. megacarpa and R. tuberosa). Ruppia spp. allow for characteristic biotic interactions through the provision of food and habitat resources for birds (e.g. black swan, Calidris spp.), fish (e.g. small-mouthed hardyhead) and macroinvertebrates (e.g. chironomids) (Rogers and Paton 2009). Ruppia spp. also modify physical and biogeochemical processes in the Coorong (Rogers and Paton 2009). Therefore, the spatial coverage of Ruppia spp. is likely to act as a surrogate measure for changes in some characteristic biotic interactions in the system. As described above, for the purpose of this analysis, it was assumed that the ecosystem reaches a state of collapse when the abundance of Ruppia spp. declines to zero.

Current decline: Ruppia megacarpa once dominated the submerged macrophyte assemblage of the Murray Mouth and North Lagoon (Gehrig and Nicol 2010). However, its range has declined due to the near-closure of the Murray Mouth and ongoing low barrage flows, which have increased salinities, and so the plant has not been observed in the Coorong since the mid-1990s (Gehrig and Nicol 2010). Ruppia tuberosa has traditionally dominated in the South Lagoon. In 1999, 33 to 91% of cores taken from four sites in the South Lagoon contained R. tuberosa shoots. In 2005, R. tuberosa was no longer present at the two southernmost sites, and by 2008, no South Lagoon sites sampled were found to contain R. tuberosa, although it had begun to colonise the North Lagoon by 2005 where it had not previously been recorded (Rogers and Paton 2009). Similar changes were observed for the occurrence of seeds and turions (Rogers and Paton 2009). Despite this colonisation, it is not likely that R. tuberosa was functionally replacing R. megacarpa, as the two species are morphologically different and are thought to support different assemblages. While some colonisation of the North Lagoon was observed for R. tuberosa, the extent and severity of the decline in both species exceeded 80% with R. megacarpa now locally extinct, making the Coorong ecosystem Critically Endangered under Criterion D1.

Future decline: No simulations for future declines in R. tuberosa exist, while R. megacarpa is already extinct from the system, and no evidence of recolonisation has been observed. Thus, the state of the Coorong ecosystem under this assessment would be Data Deficient.

Past decline: No estimate of long-term changes biotic interactions exists. The status of the ecosystem is Data Deficient under Criterion D3.

Criterion E

The ecosystem states model for the Coorong has been used to simulate hundreds of scenarios of possible future climate, water extraction and management options (e.g. Lester et al. 2009, 2011d). Among these scenarios are a number that are directly relevant for the assessment of the likelihood of ecosystem collapse in the next 50 or 100 years.

Scenarios that are likely to be of relevance include those that investigate the likely effect of future climate change (i.e. to 2030) and the effect of water extractions at the current level of take. The potential impact of the current draft Murray-Darling Basin Plan (MDBA 2010) is also relevant, but at this time, the modelled scenarios for water delivery under that Plan are not publically available for analysis.

Hydrologic, hydrodynamic & ecosystem states modelling

The quantitative assessment of the likelihood of ecosystem collapse in the Coorong was undertaken using a chain-of-models approach summarised in Lester et al. (2011d). Here, down-scaled simulations from multiple global climate models were applied to hydrologic models for the Murray-Darling Basin to estimate a time series of flows for each of the scenarios investigated (see below) (CSIRO 2008).

The output from the hydrologic modelling, along with sea levels at Victor Harbour and Meningie, flows via Salt Creek, precipitation and evaporation at Mundoo Channel and wind at Meningie were used as input for a hydrodynamic model of the Coorong (Webster 2010). This model simulated water levels and salinities along the length of the Coorong (Webster 2010). Refer to Webster (2010) for details of the model calibration and validation.

The time series of barrage flows and the outputs from the hydrodynamic model were then used as input to the ecosystem state model (Lester and Fairweather 2011). The average daily tidal range, number of days with no barrage flows, annual average water level, annual average water depth (with a two-year lag) and the annual average salinity were calculated and a series of ecosystem states was simulated for each year at each site for each scenario. This series of ecosystem states was then analysed to identify the likelihood of ecosystem collapse according to the above definition. Refer to Lester and Fairweather (2011) for model development details and relevant caveats.

Scenarios investigated

Six scenarios were investigated to quantify the likelihood of ecological collapse in the Coorong. We used three potential future climate projections for 2030 (i.e. the historical sequence since 1895; the median future climate projection based on three climate change scenarios from 15 global climate models; and a dry future climate projection based on the 10th percentile of the same 45 climate simulations; Chiew et al. 2008). Two extraction levels were used (i.e. with and without current infrastructure and extraction levels, with the latter approximating 'natural' conditions). All scenarios ran for a period of 114-years. The combinations of each are summarised in Table 2. Refer to Lester et al. (2009) for further detail.

Table S18. 2. Definition of the six scenarios investigated

Scenario	Climate	Extraction levels
Current Conditions	historic	+
Without Development	historic	-
Median Future	median	+
Dry Future	dry	+
Median Without Development	median	-
Dry Without Development	dry	-

Note '+' denotes either at current levels and '-' indicates none. Refer to Lester et al. (2009) for additional detail regarding the scenarios modelled.

Likelihood of ecological collapse

In order to calculate the likelihood of collapse for each scenario, the number of years in which degraded ecosystem states were observed for the Coorong under each scenario was counted. Then, the length of each period of degradation and the number of years required to recover from that degradation (i.e. defined as twice the period of degradation, see above) were calculated. These were combined to determine the total proportion of years in which the Coorong was either in a degraded ecological condition, or was recovering from a previous period of degradation. Given that each scenario should be interpreted as 114 years of possible variability due to climatic fluctuations, rather than a realistic progression through time, using the proportion of years occurring in degraded or recovery states effectively provides an assessment of the stochasticity within the system. Where a second period of degradation occurred prior to complete recovery from an initial period of degradation, the remaining period of recovery was added to the period required to recover from the second period of degradation. Scenarios where the definition of collapse was met were identified. Where ecological collapse was not identified, the likelihood of collapse was calculated as the number of years in which the Coorong was in a period of degradation or recovering from such a period divided by half the length of the model run (i.e. the number of years to reach 50% of degraded or recovery years as per the definition above).

Of the six scenarios investigated, ecological collapse was simulated to occur in four (Figure 4). A dry future climate projection with current extraction levels was likely to result always in ecological collapse. Scenarios with water development but using either a median future climate projection or the historical climate did not ever meet the definition for ecological collapse. However, at current extraction levels, the probability of ecosystem collapse under a future climate that resembles the historical climate was 30%, while the probability of ecosystem collapse under a median future climate change projection was 61%. Under quasi-natural conditions (i.e. without extractions or water resources infrastructure), the likelihood of collapse was 0%, except under a dry future climate projection, when it was 4%.

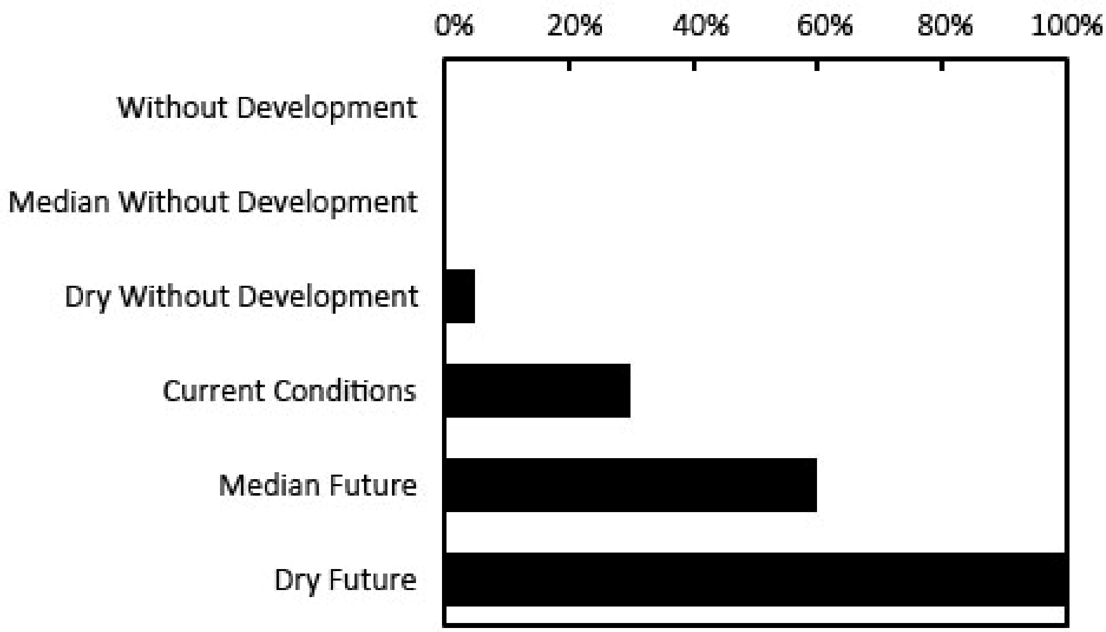

Figure S19. 4. Likelihood of collapse under the six scenarios investigated. Refer to text for definition of each scenario.

While we recognise that completely removing extractions and water-resource infrastructure within the Murray-Darling Basin is impossible, modelling such scenarios provide insight into the amount of degradation that is inherent due to climate change, compared with that caused by extraction levels. Clearly here, extraction levels play the major role in increasing the likelihood of ecological collapse. This means that the upcoming Murray-Darling Basin Plan, and other future changes to water extraction levels and water-resource infrastructure in the Basin, have the potential to dramatically change the likelihood of ecological collapse, so provide a mechanism for addressing threat levels identified here.

One limitation to scenario modelling is that there is rarely an analysis of the likelihood of the different scenarios occurring (Sutherland 2006). This means that it is difficult to identify a single quantitative assessment of the likelihood of ecological collapse, as that assessment depends on which scenario is chosen as the basis of that analysis. However, some estimates of likelihood can be assigned to each of the scenarios. For example, there is no likelihood that water extractions will cease altogether, so the 'without development' scenarios can be discounted from an overall calculation. Thus, three scenarios remain, investigating the likelihood of ecological collapse under current extraction levels under the three climate change projections. Across those three scenarios, the likelihood of ecological collapse ranges from 30% to 60% to 100%. This means that, according to Criterion E, the Coorong is Critically Endangered (plausible range Endangered-Critically Endangered).

Furthermore, the climate simulations included here reflect the median and 10th percentile projections for 2030 climate within the Murray-Darling Basin. Again, for the scenarios using projections for a 2030 climate, the 114 years should be thought of as stochasticity inherent in the Basin-wide climate, rather than a progression from the current climate to a future climate. That is, a possible 2030 climate is simulated for the entire 114 years, with extraction levels and water resources infrastructure held constant throughout. Thus, any assessment of the likelihood of collapse is based on that collapse occurring under conditions likely to occur within the next 18 years, because the climate simulation is for 2030, rather than for a full 50 or 100 year period, as specified by Criterion E. Thus, this assessment is conservative, as the climate in 2062 or 2112 (the required time frames for assessment of criterion E) is highly likely to be more severe than that projected for 2030, and the likelihood of ecological collapse would also be greater than projected for 2030, making it likely that the Coorong is Critically Endangered.

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