A Broad Synthesis of Waterbird Knowledge for the Coorong, Lower Lakes and Murray Mouth region, Including Comment on Future Management and Monitoring Options

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Overview

This report provides broad level synthesis of the current knowledge regarding waterbirds of the Coorong and Lower Lakes to support their management. A series of summary statements are used as subheadings to highlight the key characteristics of the resident waterbirds. These statements are:

1. Recent events inform the description of the ecological character for waterbirds using the Coorong and Lower Lakes
2. Abundances of waterbirds in the Coorong and Lower Lakes vary seasonally
3. Waterbirds use the shallow margins of the Coorong and Lower Lakes
4. The Lower Lakes and Coorong provide complementary habitats for waterbirds
5. Substantial numbers of waterbirds use the Coorong and Lower Lakes over summer
6. The Coorong and Lower Lakes support different waterbird communities
7. High inter-annual variability in waterbird numbers, often caused by external influences, is a key ecological character of the Coorong and Lower Lakes
8. The Coorong and Lower Lakes easily meet the waterbird-related Ramsar criteria
9. Behavioural studies inform waterbird habitat quality in the Coorong and Lower Lakes
10. Limited resilience to disturbance and slow recovery of food chains and waterbird populations is a modern ecological characteristic of the Coorong and Lower Lakes
11. In recent decades, the ecological characteristics of the Coorong and Lower Lakes have changed from a waterbird perspective
12. Future management of the Coorong and Lower Lakes for waterbirds needs to focus on provision of suitable habitat with more emphasis on water levels than salinities
13. Monitoring needs to be broader than simply reporting on numbers of waterbirds by including assessments of habitat availability and quality

1. Recent events inform the description of the waterbird communities of the Coorong and Lower Lakes

The Coorong and Lower Lakes were listed as a Wetland of International Significance in 1985. At that time, there was an appreciation that a large number and high diversity of waterbirds used the region. The waterbirds included migratory and endemic shorebirds (sandpipers, plovers and stilts), waterfowl (ducks, swans and geese) and a range of fish-eating species (pelicans, cormorants, terns and grebes) but the numbers and extent to which each species used the region was poorly documented for most species, particularly in regard to the Lower Lakes. Most of the initial attention in the 1980s was focussed on shorebirds within the Coorong. Re-assessments of the abundances of shorebirds using the Coorong in the 2000s showed declines for most species. There were also substantial changes in the composition, distribution and abundances of waterbirds between the 1980s and 2000s for parts of the

Coorong where there were comparative data for the 1980s (e.g. South Lagoon; Paton *et al.* 2009; Paton 2010).

Important corrollaries for describing the ecological characteristics of the waterbirds using the Coorong and Lower Lakes are the lack of quantitative data for many species in the 1980s and that most of the recent data were collected during a period in which both the Coorong and Lower Lakes have experienced extremes in their physical, hydrological and chemical environments.

The following community descriptions are based largely on surveys of waterbirds for the Coorong and Lower Lakes that have been conducted annually in summer since January 2000 for the Coorong and since January 2009 for the Lower Lakes. These surveys are essentially a complete census of the site's avifauna, with the exceptions that (i) the methods used are unlikely to detect and adequately census cryptic species (rails, crakes, snipe, bittern) that use the fringing vegetation around the freshwater wetlands of the Lower Lakes and (ii) surveys were not designed to census a range of reed-dwelling passerines (warblers, grassbirds, cisticola).

The Coorong and Lower Lakes experienced substantial and unprecedented perturbations during the 2000s. For the Lower Lakes, water levels dropped to well below sea level and all of the fringing wetland vegetation became disconnected from the water. Extensive areas of mudflats were exposed for the first time in recorded history, which changed the waterbird community using the Lower Lakes substantially (e.g. Paton & Bailey 2011, 2012, 2013). When water returned and refilled the Lower Lakes from ca mid-2010 (2009 for the Goolwa Channel), the emergent and submerged aquatic vegetation re-established around the margins of the Lower Lakes. The waterbirds recovered as, over the next two years, the waterbird community that was assumed (expected) to have existed prior to the perturbation was re-assembled. Given that the first four years of waterbird counts for the Lower Lakes were during the period of exceptionally low water levels and subsequent recovery, only the last three years of census data (January 2013-2015) have been used to describe the characteristic waterbird community of the Lower Lakes. This is justified given that the extremely dry conditions should not recur (given the intent of the Murray Darling Basin Plan). Although there have been changes to waterbird use of the Lower Lakes since the time of nomination, those changes are not easily quantifiable, and we can only assume – with limited confidence – that the recent post-drought bird community represents the community at the time of listing. The changes are probably related to managing the water levels of the Lakes a little higher since the 1980s.

In the Coorong, the millennium drought resulted in extremely high salinities in the southern lagoon. There were also more extended periods of low water levels but, because the Coorong is connected to the sea, water levels did not drop below sea level. The high salinities that established in the southern Coorong exceeded the salinity tolerances of the main fish species (smallmouth hardyhead *Atherinosoma microstoma*) and main benthic invertebrate (the chironomid *Tanytarsus barbitarsis*). Both species were excluded from the southern part of the Coorong for several years (e.g., Paton 2010). However, brine shrimps *Parartemia zietziana* established in the southern Coorong in these high salinities and became extremely abundant. Various micro-crustaceans (ostracods) were also abundant in the water column. There were changes in the distribution and abundance of the main aquatic plant - *Ruppia tuberosa* - in the

Coorong, and in the northern Coorong many other benthic invertebrates decreased in abundance and distribution. These extreme ecological changes, like those in the Lower Lakes, also had no precedent. However, for the Coorong, food for different waterbird groups remained throughout the wetland, albeit reduced in extent and/or changes in distribution. When significant flows returned to the Coorong in late spring 2010, the excessive salinities observed during the drought were reduced, and elements of the system recovered to pre-drought condition, although some components like *Ruppia tuberosa* have still not reached their pre-drought abundance. Although various bird species responded to these changes by shifting their distributions, the Coorong was still habitable throughout this period for birds.

A greater perturbation, however, occurred in the Coorong when high flows were experienced in late spring 2010. The Coorong quickly filled such that most of the mudflats were covered by too much water during summer to allow wading birds to access them. Many waterbirds vacated the region during this time. These types of perturbations are likely to recur for the Coorong in the future particularly overfilling of the Coorong during years of high or unregulated flows. In assessing the ecological characteristics of the Coorong waterbird communities, some appreciation of their capacity to respond and recover to these types of changes informs our understanding of their resilience. Thus, for the Coorong, the full set of data collected from January 2000 to 2015 was used as the basis for defining its waterbird community.

2. Abundances of waterbirds in the Coorong and Lower Lakes vary seasonally

The wetlands of the Coorong and Lower Lakes play a significant role in supporting waterbirds within the Murray Darling Basin and, more generally, in south-eastern Australia. As they are permanent wetlands, they support 'resident' populations of waterbirds throughout the year. A significant influx of waterbird populations, including additional species, augments the waterbird communities, particularly from spring until autumn. The additional species include a suite of migratory shorebirds from the Palaearctic. Substantial influxes of Australian endemic waterbirds also occur (Paton 2010), both seasonally, and particularly during periods when the Australian continent is otherwise in a dry phase (e.g. during El Nino phases). Thus, a key characteristic of these wetlands is that the numbers and variety of waterbirds using them fluctuates seasonally and over longer time periods. During the severe millennium drought, these wetlands supported over 400,000 waterbirds at times.

3. Waterbirds use the shallow margins of the Coorong and Lower Lakes

The vast majority of waterbirds using both the Coorong and Lower Lakes use the margins of the lakes and lagoons. The margins are the areas where water depths are typically less than 1m, coinciding with the most productive parts of these wetlands. The high turbidity of the water is assumed to prevent benthic submerged aquatic plants from securing sufficient light to grow in deeper water. For the Lower Lakes, the margins support a mix of open beaches, and reeds and other emergent vegetation that provides resources, as well as cover for waterbirds. These fringing habitats are only available in areas with flat, broad beaches. Shoreline erosion has led to the loss of some flat shoreline areas in the Lower Lakes, creating steep lake margins which are of poor habitat value for waterbirds. This limits the diversity of waterbirds that can use the Lower Lakes (see below). In the Coorong, provided water levels are not too high, there are extensive areas of gently-sloping shoreline suitable for waterbirds that wade in shallow water when foraging. The presence of extensive mudflats covered with shallow water at least during the warmer months of the year makes the Coorong particularly important for shorebirds (migratory and endemic waders).

4. The Lower Lakes and Coorong provide complementary habitats for waterbirds

The Lower Lakes are freshwater systems, where the same habitat features are repeated around the margins of the two lakes. Reeds of various species (*Typha, Phragmites* and *Schoenoplectus*) are prominent around the shorelines but the density, composition and width of these varies. Amongst the reed beds, and between them and the shoreline, are often areas of open shallow water where submerged aquatic plants can be abundant. More generally, areas with reeds are interspersed with areas without reeds, and in these latter areas the margins of the Lower Lakes are usually grassy verges. Such areas tend to be more exposed and have steeper shorelines. Importantly there are very few areas around the Lower Lakes that provide shallow mudflats suitable for wading birds, when lake water levels are in the range of 0.5-0.8 m AHD.

In contrast, the Coorong is an estuarine to hypermarine wetland with extensive areas of shallow, gently sloping shorelines without emergent reeds. The salinity of this system prevents reeds from establishing, except in a few isolated places where freshwater seeps into the Coorong through the dunes of Younghusband Peninsula. In the northern regions of the Coorong, the mudflats become variously exposed during the tidal cycle, while, in the southern Coorong, seasonal shifts in water level of up to 1 m expose the mudflats in summer. Importantly, with a few exceptions (e.g. Red-capped Plover), most shorebirds do not exploit mudflats that are fully exposed, but instead forage over mudflats that are covered with a few centimetres of water.

A key feature of the Coorong for the last 30-40 years (at least) has been the salinity gradient that increases southwards. In a typical year, salinities may range from 10-70 gL^{-1} in winter and spring to 30-110 gL^{-1} in autumn along the length of the Coorong. As a consequence of the salinity gradient, the Coorong supports different ecosystems and food chains along its length and these differ from the food chains of the Lower Lakes, although the food chains of the Lower Lakes are poorly documented. In general, the richness of aquatic invertebrates and fish decreases along the salinity gradient in the Coorong, with fewer species at higher salinities (e.g., Paton 2010). For example, in northern estuarine regions of the Coorong, various species of polychaetes are prominent benthic invertebrates but in the higher salinities of the southern Coorong only the chironomid (*Tanytarsus barbitarsis*) is prominent. Similar patterns exist for fish, with many more species present in the estuarine regions and just one species, the small-mouthed hardyhead (*Atherinosoma microstoma*), prominent in the South Lagoon. This reduction in species richness with salinity, however, is not an indication that the overall production of resources is diminished at the higher salinities.

The other key component of the aquatic ecosystems and food chains of the Coorong are submerged aquatic plants. There have been marked changes in the species composition, distribution and abundance of submerged aquatic plants in the Coorong over recent decades. Several species are now no longer functionally present (e.g. *Ruppia megacarpa*, *Lamprothamnium papulosum*) and others are far less abundant than they have been historically. A key submerged aquatic plant in the southern Coorong is *Ruppia tuberosa,* one of the few plants that can tolerate hypermarine salinities. This species was largely eliminated from the southern Coorong during the millennium drought and is slowly recovering its distribution and abundance. In the North Lagoon, a key species historically, *Ruppia megacarpa*, disappeared prior to the millennium drought. However, a red algae *Gracilaria chilensis* may now provide some substitute ecological functions in the predominantly estuarine areas of the Coorong.

5. Substantial numbers of waterbirds use the Coorong and Lower Lakes over summer

Systematic counts of waterbirds using the Coorong during summer commenced in January 2000 and for the Lower Lakes during January 2009. The counts indicate that the Coorong generally supports twice as many waterbirds as the Lower Lakes in summer. The numbers of waterbirds supported in the Coorong in January has averaged over 167,000 over the last 16 years, while the average numbers for the Lower Lakes has been a little over 79,000 for the last seven years. Although more than 80 species of waterbirds have been detected using the Coorong and over 70 species using the Lower Lakes during these counts, more than half the species are only present in small numbers. Of the 72 species counted in the Lower Lakes since 2009, only 33 were detected in all seven years and only 22 of these had more than 100 individuals present. For the 82 species detected during counts in the Coorong, 35 species were present in all years, with another 5 species present in all but one year. Of these 33 species were in abundances of more than 100 birds.

6. The Coorong and Lower Lakes support different waterbird communities

In line with the complementary habitats provided by the Lower Lakes and Coorong, the waterbird communities that use the Lower Lakes and Coorong are markedly different. The key differences are that the Coorong supports large numbers of waders, particularly Red-necked Stints, Banded Stilts, Sharp-tailed Sandpipers and to a lesser extent Red-necked Avocets, Curlew Sandpipers, and Red-capped Plovers (Table 1). These species are only in very small numbers in the Lower Lakes (typically <1% of the numbers in the Coorong). A range of other waders are also largely, if not entirely, restricted to the Coorong, including Black-winged Stilt, Greenshank, oystercatchers, godwits, Eastern Curlew, Hooded Plover and Sanderling.

However, waterfowl and fishing-eating species are prominent in both wetland systems (Table 1). For the Coorong, Grey Teal, Australian Shelduck, Chestnut Teal and Black Swans are prominent species of waterfowl, while Australian Shelduck, Pacific Black Duck, Grey Teal, Eurasian Coot and Black Swan are the most abundant waterfowl using the Lower Lakes (Table 1). A key compositional difference between the two wetland systems is in the prominence of Chestnut Teal in the Coorong, and Pacific Black Duck in the Lower Lakes. Musk Duck are present in relatively low numbers and are predominantly found in the Coorong. Other waterfowl including Australasian Shoveler, Pink-eared Ducks and Hardheads use both wetland systems when present in the region, while Freckled Ducks mainly use the Lower Lakes.

In the Lower Lakes, Great Cormorants, Pied Cormorants, Australian Pelicans and Whiskered Terns are the most prominent piscivorous species, while Whiskered Terns, Hoary-headed Grebes and Australian Pelicans are the most abundant members of these groups in the Coorong. Crested Terns are also prominent in the Coorong but this species also fishes in the adjacent ocean. Five species of cormorants use the Coorong, and Great Cormorants and Little Black Cormorants are the most abundant of these. Other fish-eating species using these wetlands include Caspian Terns, Great Crested Grebes, Great Egrets and White-faced Herons and these species use both wetlands to comparable extents. One other important fish-eating species is the Fairy Tern, which is restricted to the Coorong region.

The Coorong and Lower Lakes also support significant numbers of Royal Spoonbills, Australian White Ibis, Straw-necked Ibis and Silver Gulls. Silver Gulls are widespread in both the Coorong and Lower Lakes, while the spoonbills and ibis are more abundant around the margins of the Lower Lakes. Although present in small numbers, Yellow-billed Spoonbills are also present and primarily associated with the Lower Lakes.

The freshwater swamps and reeds of the Lower Lakes also support a suite of largely cryptic birds, including Australian Bittern, Latham Snipe, and various rails (crakes) and water hens. The most conspicuous of these is the Purple Swamphen. Little Grassbirds, Clamorous Reed Warblers and Golden-headed Cisticolas are also associated with the emergent and fringing vegetation of these freshwater systems.

7. High inter-annual variability in waterbird numbers, often caused by external influences, is characteristic

The number of waterbirds using the wetlands from one year to the next can vary substantially. An extreme example is the Banded Stilt. In January 2009, in excess of 210,000 Banded Stilts used the Coorong but in the last three years fewer than 2,000 have been present in January in any year. The factors influencing the variations are poorly understood. However, factors outside the Coorong and Lower Lakes, as well as factors within the wetlands themselves, are likely to be influential.

The variability in the abundances of many species of waterbirds using the Coorong and Lower Lakes reflects the nature of the use of these wetlands. Most species of waterfowl (ducks, swans) do not breed to any extent in the Coorong or Lower Lakes and move away from the Coorong, and to a lesser extent the Lower Lakes, during winter and spring to breed. The likely breeding areas are freshwater swamps that were dry over summer, but have filled during winter. Before the barrages were constructed, the margins of the Lower Lakes were likely to have provided breeding opportunities for many waterfowl but the management and maintenance of water levels within a narrow range may no longer provide the stimulus for breeding. The numbers of waterfowl that return to the Coorong and Lower Lakes from breeding areas in the following summer will depend on the extent of successful breeding, and the timing of their arrival will be influenced by the quality and availability of the breeding (and any transitional/staging) wetlands. For these birds, the permanent wetlands of the Coorong and Lower Lakes function as a critical "summer" refuge, and the degree of criticality increases in importance in dry years.

For the migratory shorebirds that use the Coorong over the summer months a similar argument holds. These birds breed in the northern hemisphere and migrate annually between there and wetlands such as the Coorong, in the southern hemisphere. The abundances of migratory species in any one year in the Coorong are likely to be influenced by the extent of breeding, successful migration and whether other potential ephemeral wetlands hold water and are available for them to use on arrival. The endemic Banded Stilt and Red-necked Avocet rarely breed in the Coorong and also move away from the Coorong to exploit inland saline wetlands for breeding when these fill with water. Black-winged Stilts too may shift to nearby freshwater swamps when these hold water to breed. Other species that do not breed in the Coorong and show dramatic reductions in abundances when the availability of inland wetlands increases include Hoary-headed Grebe, Whiskered Tern and Eurasian Coot.

Most of the waterbirds that regularly breed within the Coorong and Lower Lakes are piscivorous species. These include the Australian Pelican, Fairy Tern, Crested Tern and Caspian Tern, which breed on islands in the southern Coorong, and the Pied Cormorant in the Lower Lakes. Although Crested Terns breed in the southern Coorong and forage to an extent in the Coorong and Lower Lakes, they largely forage in the adjacent marine environment when breeding. Caspian Terns and Australian Pelicans also forage substantial distances (probably at least 100 km) from their breeding colonies in the southern Coorong. Breeding for these species in the Coorong still occurred even when the South Lagoon supported no fish. Fairy Terns on the other hand vacated their breeding islands in the South Lagoon when fish were absent in the southern Coorong. Although this species attempted to breed near the Murray Mouth at these times, these breeding events were prone to human disturbance and predation by foxes.

Pied Cormorants build nests and regularly breed in reed-beds and other emergent vegetation particularly on several of the islands within the Lower Lakes. During the late 2000s, Pied Cormorants did not breed when exceptionally low water levels disconnected the reeds from the water line. Although Little Black Cormorants and Little Pied Cormorants have been recorded breeding historically in the Lower Lakes, they have not been detected breeding in the region in recent years, while the Great Cormorant, although abundant, has never been recorded breeding in the Lower Lakes. Thus, many of the cormorants using the Coorong and Lower Lakes must also move away to breed.

Only two other species are recorded as breeding regularly in the Coorong and Lower Lakes: Silver Gulls on islands in the southern Coorong and Straw-necked Ibis in reed-beds around the Lower Lakes. Silver Gulls are adaptable and feed on a variety of foods and their breeding may be linked to the breeding of pelicans and terns, as they can scavenge food at those sites. Straw-necked Ibis largely feed on terrestrial invertebrates away from wetland areas and so their abundances in any one year are likely to be influenced by rainfall and the extent to which nearby areas are irrigated. A range of other species also exploit terrestrial sources of food (pasture, grain and invertebrates) while using the Coorong and Lower Lakes during summer. These include, at least to some extent, Australian Shelduck, Pacific Black Duck, Australian White Ibis, Whiskered Tern and White-faced Heron.

In summary, the key ecological services that the permanent wetlands of the Coorong and Lower Lakes provide are suitable habitats and food resources to support a wide range of waterbirds during the summer months when other areas that they use are not suitable for them.

8. The Coorong and Lower Lakes easily meet the waterbird-related Ramsar criteria

Much of the historical and current assessments of the importance of the Coorong and Lower Lakes for waterbirds are based on the abundances of various species using the wetlands and whether various Ramsar criteria are met. For example, the Coorong and Lower Lakes supports in excess of 1% of the global populations of 27 species or subspecies of waterbirds in most years and so clearly meets this criterion (and all other waterbird related criteria) for listing as a Wetland of International Significance (O'Connor *et al.,* 2012). For some taxa, the percentages of global populations that are supported are much higher than 1%. For example, the Coorong regularly supports more than 10% of the south-eastern Australian population of Fairy Terns and, in January 2009, supported in excess of 213,000 Banded Stilts, greater than the (immediately prior) estimate of global population at the time.

9. Behavioural studies inform waterbird habitat quality in the Coorong and Lower Lakes

Numerical statistics, alone, do not adequately summarise waterbird functioning in these wetlands. Wetland management should address the provision of suitable habitats and resources for the different species of waterbirds. To function as a refuge in most summers, and particularly during droughts, the quantity and quality of the food and habitat resources and access to those resources is critical.

One method of assessing the quality of the habitats in terms of providing food, and hence the capacity of the Coorong and Lower Lakes to service this need of waterbirds, is by assessing the birds' behaviour. Birds are understood to allocate more time to foraging when food resources are thinly spread and difficult to harvest than they would when those resources are more available (Paton *et al.* 2015 in prep.). For the Coorong, where such data exist, a range of piscivorous species spend typically around 20-50% of the day foraging (Table 2). These efforts are considered to indicate that these species had no difficulty securing food. Breeding by a range of fish-eating species in the Coorong and Lower Lakes is also consistent with good availability of food. However, some herbivorous species (e.g. Black Swans) and many of the shorebirds usually allocate over 50% of their day to foraging, and sometimes as much as 80%, or more in some years. This may suggest that their food resources, various aquatic plants and aquatic invertebrates, are not as rich or as easily harvested as fish. For these species, the reductions in the productivity of the mudflats on which they forage beyond what is critical for their survival is an outcome that management should be directed to avoid. Management needs to focus on maintaining, if not improving, the availability of food resources. This is of high priority, since the foraging data collected in January 2015 suggest that migratory shorebirds will have difficulty increasing their food intake as autumn approaches and day lengths decline.

10. Limited resilience to disturbance and slow recovery of food chains and waterbird populations is a modern ecological characteristic of the Coorong and Lower Lakes

The millennium drought challenged the capacity of the Coorong and Lower Lakes to support waterbird populations but at the same time provided insights into the resilience of the wetlands, the food resources that they provide, and insights into the adaptability of the waterbird populations. Those dynamics inform an appreciation of the ecological character of this system.

Associated with the millennium drought, there were negligible if any flows of freshwater over the Barrages for eight consecutive years. This was as much a consequence of over-extraction of water for human use rather than drought *per se* but the drought brought the issue of over-extraction into sharp focus (e.g., Paton 2010). Throughout this period, continuous dredging was needed to keep the Murray Mouth open and maintain a tidal prism in the northern Coorong. The major perturbations affecting the food chains that support waterbirds were: (1) higher salinities that eliminated hardyhead fish and chironomids from the southern Coorong but allowed brine shrimps to establish; and (2) a coupling of high salinities with consistent low water levels during spring, which eliminated *Ruppia tuberosa* from the southern Coorong and prompted the establishment of new populations over several years in the middle sections of the North Lagoon (e.g., Paton 2010). Other aquatic invertebrates and fish species using the northern Coorong also declined during this period.

Waterbird responses to these perturbations were varied, depending on species and location. In the southern Coorong, some species switched to feeding on brine shrimps. These included Banded Stilts, Hoary-headed Grebes, Chestnut Teal, Whiskered Terns and Silver Gulls. Other species, such as Fairy Terns and Black Swans, vacated the southern Coorong but were able to use the northern Coorong.

In the Lower Lakes, the major perturbation was extremely low water levels (-0.5 to -1.0 m AHD) that were unprecedented. This disconnected the fringing aquatic vegetation from water and exposed extensive areas of dry mudflats. Reed-dependent waterbirds were largely absent, and most species of waterbird became less abundant except for a range of shorebirds (sandpipers, plovers, stilts) that used the newly-exposed mudflats, particularly so where they abutted the Coorong.

Ironically, the major changes in abundances of waterbirds across the Lower Lakes and Coorong came not during the drought but when flows first returned to the region. The flows when they returned in spring 2010 were substantial and quickly filled, before subsequently overfilling, the Coorong and Lower Lakes. The overfilling prevented many species of shorebirds and other species that forage at the water margins (e.g., egrets, herons and spoonbills) from accessing their usual food resources owing to increased water levels. Abundances of waterbirds using the Coorong and Lower Lakes during this period of high water levels were the lowest of the last 16 years (e.g. Figure 1). Many other wetlands carried water at this time because of extensive rains, and so the waterbird populations are presumed to would have been able to use these alternative wetlands. However, these alternatives may not always exist in years when unregulated flows restrict access to productive mudflats in the Coorong and Lower Lakes. Managing water levels, both during periods of negligible flows and during periods of extensive flows, will be needed to secure suitable resources and make them accessible to waterbirds in the future.

The recovery of the waterbird communities following these perturbations was not immediate. For example, Purple Swamphens took three years to re-occupy suitable habitat around the Lower Lakes. For the southern Coorong, there was a one-year time lag before hardyhead fish populations had recovered and Fairy Terns had returned to breed in the southern Coorong. The key aquatic plant *Ruppia tuberosa* is yet to fully recover, and intervention efforts to facilitate recovery by translocating seeds from outside sources onto former productive Coorong mudflats have been undertaken. Although chironomids quickly re-colonised the southern Coorong once salinities were suitable, other aquatic invertebrates in the northern Coorong have taken several years to build substantial population densities. From a waterbird perspective, all of the species are still present but abundances for some species, like Common

Greenshank, are still lower than they were in January 2010 at the end of the drought. Abundances of other species, particularly waterfowl, remain low in areas like the southern Coorong that have traditionally been used extensively in the past.

As most of the current components of these wetlands have demonstrated a capacity to recover, albeit with time lags, and so can be considered to have resilience. However, the limited recovery of *Ruppia tuberosa* , and the rate of recovery recorded, are of concern. Recovery has been hampered by water levels falling in spring and exposing plants to desiccation before they have reproduced (ref). Historically, flows to the Murray Mouth were substantial during spring and into summer and this is understood to have kept the extensive *Ruppia tuberosa* beds covered with water for sufficient time for the plants to produce seeds and turions to maintain population densities (e.g., Paton 2010). The current water allocations, even when the Murray Darling Basin Plan is fully implemented, suggest the volumes of water will continue to be inadequate to facilitate much seed bank recovery. Thus, the resilience of *Ruppia tuberosa* in the Coorong is comparatively low and, as a consequence, the capacity of the Coorong to meet the needs of waterbird populations during droughts may be significantly compromised, which may have negative consequences for its ecological character.

11. In recent decades, the ecological characteristics of the Coorong and Lower Lakes have changed from a waterbird perspective

Although much of the focus has been on recent decades, the quality of the Coorong and Lower Lakes as habitat for waterbirds has probably been deteriorating over a longer period of time. This is reflected in the loss of a range of aquatic plants (e.g., *Ruppia megacarpa* in the North Lagoon and *Lamprothamnium papulosum* in the South Lagoon) that were abundant in the Coorong in the 1980s but were totally absent in the 2000s, if not before. Even some of the abundant invertebrates that were present in the mid-1980s and early 1990s (e.g., the gastropod *Coxiella striata*) have been absent from the Coorong for several decades now. There is ample evidence (cite) over that same period to show that a range of waterbirds, including species of shorebird, waterfowl and tern, have also declined. When the Coorong and Lower Lakes were nominated as a Wetland of International Significance in 1985, the wetlands were already likely to be on a trajectory of decline. Since then, the subsequent management and increased use of water within the Murray Darling Basin has likely accelerated the rate of decline.

12. Future management of the Coorong and Lower Lakes for waterbirds needs to focus on provision of suitable habitat with more emphasis on water levels than salinities

The root cause of the perturbation to the Coorong and Lower Lakes of greatest significance to waterbirds is the substantial reduction in the volumes of River Murray water that reach the Murray Mouth. In the absence of upstream extraction and retention of water for human use, the long-term average volume reaching the Murray Mouth would have been around 12,000 GL (e.g. Paton 2010). These natural flows had a strong seasonal pattern with the volumes increasing over spring and peaking in November or December. The flows were at their lowest in autumn.

With extraction of water for human uses, the flows reaching the Murray Mouth have not only been substantially reduced but the seasonal pattern has been truncated to earlier in spring with the length of the period of higher flows also reduced. These reduced flows have three major effects on the Coorong and Murray Mouth region. First, the reduced flows increase the risks of the Murray Mouth region silting because of decreased flushing of the incursions of coarse marine sands back out to sea. This in turn increases the risk of Mouth closure and the loss of the tidal prism. That would have negative consequences for shorebird habitat, as when there is a tidal prism a broader width of mudflat is both accessible and productive for shorebirds. Deposits of coarse marine sands rather than fine river sediments on the mudflats in the estuarine regions of the northern Coorong are also likely to reduce the quality of the sediments for benthic invertebrates (e.g. polychaetes) and in turn, reduce foraging efficiencies for shorebirds. Second, in the absence of freshwater flows into the northern Coorong, significant volumes of marine water are drawn into the Coorong to offset its evaporative water losses during summer months. Although the volumes of marine water may be relatively small (of the order of a few tens of gigalitres), a gigalitre of marine water carries 37,000 tonnes of salt, so salinities in the Coorong start to rise. Changes in salinity will in turn influence the distribution and abundance of aquatic biota that contribute to the food chains of waterbirds. Third, and importantly, large flows of water over the Barrages to the Murray Mouth in spring maintain (if not raise) water levels in the northern Coorong and also prevent water levels in the southern Coorong from falling. This in turn maintains water over the *Ruppia tuberosa* beds and allows them to complete their reproductive cycles. The environmental water requirements of the species are that its beds are covered for most of the year - which allow *Ruppia tuberosa* to reproduce and develop substantial numbers of turions (both type I and type II) during summer. Turions are swellings located either on the stolons (type I) or in leaf axils (type II); they function as short-term nutrient storage organs. The type 1 turions are larger and favoured by waterfowl (e.g. Delroy 1974) but have been all but absent from the Coorong for the last 20 or so years (D. Paton pers. obs.).

Once the Murray Darling Basin Plan is fully implemented the average annual volumes reaching the Murray Mouth are only likely to reach 7,100 GL. This average flow is misleading, since most years will have flows that fall well below the predicted average which are punctuated with occasional years in which the flows are unregulated (floods) and hence substantially above the average. Gone are the intermediate flows that are near the average that provide adequate water to keep the *Ruppia* beds covered with water at least through spring and into summer, and not so great that the productive mudflats are covered with too much water such that shorebirds are denied access to food. Thus the volumes of water reaching the Murray Mouth and Coorong region even with the new Murray Darling Basin Plan fully implemented are unlikely to be ideal in most years. Furthermore, the Plan which may never be fully implemented, fails to take into account the likely reductions in rainfall in the Murray Darling Basin in coming decades due to climate change. Managers need to appreciate that in most years there will be inadequate water delivered to the Murray Mouth to maintain a healthy Coorong. This inadequacy in the flows also needs to be communicated regularly to the community.

There is merit in still adjusting the volumes and releases of water over the Barrages during spring to limit both the incursions of marine water into the Coorong and the rates at which water levels drop in the southern Coorong. However, in isolation, these are considered unlikely to sustain the ecology of the Coorong because the volumes are inadequate. Other management actions will be required. Three are considered here: dredging of the Murray Mouth and associated channels in the northern Coorong; increasing flows of South-East water into the southern Coorong; and, inserting a regulator or similar structure across the middle of the Coorong to prevent water levels falling in spring in the southern Coorong.

Dredging of the Murray Mouth and associated channels between the Mouth and Barrages should be maintained for longer periods (if not a permanent fixture), and not just implemented once the Murray Mouth has started to clog. Importantly dredging should be maintained during those years and times when there are substantial flows to the Mouth. This will help reduce overfilling of the Coorong and loss of feeding habitat for shorebirds and other waders. Simply dislodging compacted sediment and allowing the flows to transport the material out of the Mouth will also reduce any sediment pumping costs.

There are plans to increase flows of freshwater into the southern Coorong by redirecting existing South-East (SE) drainage flows westward to the sea northwards into the southern Coorong. This is known as the SE Flows Restoration Project (SEFRP). The project is promoted as benefiting the southern Coorong by reducing the risk that excessively high salinities re-establish. However these flows, like the existing flows from the Upper South-East drainage scheme, have the potential to impact the southern Coorong under typical salinity conditions, through lowering salinities below the target management range (60-100 gL^{-1}) and increasing net nutrient loads. Those water quality changes are considered likely to favour filamentous green algae over *Ruppia tuberosa*. This was recorded recently, following discharge of water from the Upper South-East into the southern Coorong. Filamentous green algae were widespread in the southern Coorong after this event and most populations of *Ruppia tuberosa* were affected by it. Ironically the one population of *Ruppia tuberosa* that survived the millennium drought in the southern Coorong was eliminated when filamentous green algae (*Enteromorpha* sp.) swamped and smothered this population. This population had survived the high salinities of the millennium drought because a sandbar caused a natural sill that mitigated against water level declines under the circumstances. A pre-occupation with management of salinity could overlook nutrient risks for *Ruppia tuberosa*. The SERFP, however, has merit in facilitating the recovery of freshwater wetlands en route to the Coorong, and if managed well, significant improvement in the overall availability of waterbird habitats are likely to be achieved in these wetlands (e.g. Paton *et al*. 2015 in prep) without necessarily having to release water into the Coorong. Importantly, as the SEFRP does not address falling water levels in spring, it is not anticipated to improve the ecological performances of *Ruppia tuberosa*.

Consideration should be given to addressing the inadequacy of water levels in the southern Coorong during spring by using an engineering solution. One option of doing this is a regulator or similar structure across the middle of the Coorong (this could be inserted near The Needles, to capture the core *Ruppia tuberosa* mudflat habitat). The regulator level should be lower than the typical winter-spring period heights, allowing water to flow over it between the lagoons, and only function as a barrier for water movement once water levels had dropped to a critical level with regards depths over mudflats. . Without this type of intervention, the likelihood of maintaining a healthy and resilient Coorong that includes *Ruppia tuberosa* as a key and characteristic element is considered to be minimal.

Another possibility for improving waterbird habitat is management of water levels in the Lower Lakes. Historically these were likely to have fluctuated more and were likely to have been more frequently maintained at lower levels than they are under current management. Certainly in the early 1970s water levels were lower and there were large numbers of sandpipers using mudflats covered with a few centimetres of water (D. Paton pers. obs.) which are now covered consistently by as much as 30 cm of water, effectively excluding these birds (Paton & Bailey 2011, 2012). If habitat creation within lake margins is not practicable, a program of establishing fringing wetland systems that can re-establish these 'lost' habitat features should be pursued. This is likely to require some on ground works to increase the areas and locations of wetlands, as well as provision of water (from the Lower Lakes). The value of these wetlands for some of the shorebirds and other waterfowl were well illustrated when water was returned to Tolderol in late 2014. For the constructed wetlands and the natural ephemeral wetlands most should receive water each year rather than the wetlands having to bid for water and taking turns. These sorts of actions will be increasingly important should conditions in the Coorong deteriorate.

13. Monitoring needs to be broader than simply reporting on numbers of waterbirds by including assessments of habitat availability and quality

Many factors both within a wetland system and beyond that system are likely to influence the numbers of waterbirds present at any one time and this is certainly the case for the Coorong and Lower Lakes. Thus the numbers of birds present is not necessarily a good measure of the quality of the wetland. However numbers and diversity of waterbirds using a wetland are key criteria for recognising wetlands of international importance, so the numbers present will still need to be reported. The key is to provide suitable context for the numbers that are counted, and at present this is impossible to do with confidence because the alternative wetlands that might be used by the birds are not known. There is an urgent need to determine movement patterns for waterbirds that use the Coorong and Lower Lakes to allow better management. Such knowledge is needed to shift management away from a single wetland focus to managing multiple wetland assets across greater regional scales.

One of the primary attributes of the Coorong and Lower Lakes wetland is their role as a drought and summer refuge for typically 250,000 or more waterbirds. If suitable productive habitats are not provided, then many of these waterbirds will not survive, particularly in severe droughts. Thus the goal of management should be to provide suitable, productive and resilient habitats that are capable of supporting large numbers of birds each year, even if the birds do not come. In addition to the numbers of birds, other information like the Area of Occupation (AOO) and Extent of Occurrence (EOO) of different species informs on the distribution of useable habitat, while the amount of time spent foraging informs on the quality of the habitats that they are using. Detailed information on how these features can be used to improve monitoring outputs have been provided elsewhere (Paton et al. 2015 MS).

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Table 1: Median abundances of major groups of waterbirds and selected individual species using the Coorong and Lower Lakes in January. Data for the Coorong are based on 16 annual counts from 2000 to 2015, while those for the Lower Lakes are based on three counts from 2013 to 2015. Species are arranged in order of median abundances within major groups.

	COORONG	LOWER LAKES
Shorebirds	***62,720***	***989***
	Red-necked Stint (26,286)	Masked Lapwing (565)
	Banded Stilt (15,125)	Sharp-tailed Sandpiper (214)
	Sharp-tailed Sandpiper (13,179)	Black-winged Stilt (85)
	Red-necked Avocet (3,007)	Red-kneed Dotterel (56)
	Curlew Sandpiper (2,256)	Red-necked Stint (30)
	Red-capped Plover (1,234)	+ 13 other species (39)
	Masked Lapwing (468)	
	Greenshank (434)	
	Black-winged Stilt (417)	
	Pied Oystercatcher (158)	
	+ 21 other species (156)	
Waterfowl	***29,731***	***28,715***
	Grey Teal (11,848)	Australian Shelduck (13,249)
	Australian Shelduck (8,426)	Pacific Black Duck (4,981)
	Chestnut Teal (7,231)	Grey Teal (3,912)
	Black Swan (1,647)	Eurasian Coot (3,339)
	Pacific Black Duck (228)	Black Swan (1,799)
	Musk Duck (172)	Cape Barren Goose (1,010)
	Cape Barren Goose (97)	Hardhead (874)
	Eurasian Coot (75)	Australasian Shoveler (143)
	+ 7 other species (7)	Pink-eared Duck (84)
		Australian Wood Duck (70)
		Chestnut Teal (56)
		Freckled Duck (56)
		Musk Duck (9)
		+ 2 other species (7)
Fish-eaters	***17,586***	***37,613***
	Great Cormorant (1,287)	Great Cormorant (14,963)
	Little Black Cormorant (1,253)	Pied Cormorant (8,759)
	Pied Cormorant (271)	Little Black Cormorant (907)
	Little Pied Cormorant (258)	Little Pied Cormorant (84)
	Black-faced Cormorant (130)	Darter (73)
	Darter (1)	
	Australian Pelican (3410)	Australian Pelican (6239)
	Hoary-headed Grebe (4222)	Great Crested Grebe (128)
	Great Crested Grebe (201)	Hoary-headed Grebe (103)

	COORONG	LOWER LAKES
Fish-eaters Continued		
	Whiskered Tern (5,371)	Whiskered Tern (4,497)
	Crested Tern (3,897)	Caspian Tern (609)
	Caspian Tern (598)	Crested Tern (490)
	Fairy Tern (337)	+ 2 other terns (2)
	+ 3 other terns (8)	
	White-faced Heron (157)	Great Egret (133)
	Great Egret (73)	White-faced Heron (119)
	Little Egret (7)	Little Egret (2)
	Nankeen Night Heron (1)	Nankeen Night Heron (12)
		+ 1 other species (1)
Other species	***8,645***	***4,274***
	Silver Gull (8,296)	Silver Gull (1,823)
	Australian White Ibis (300)	Straw-necked Ibis (1,620)
	Straw-necked Ibis (25)	Australian White Ibis (611)
	Royal Spoonbill (22)	Royal Spoonbill (209)
	Yellow-billed Spoonbill (1)	Yellow-billed Spoonbill (12)
	+ other species (1)	+ other species (1)

Table 2: The percentage of time selected species of waterbird allocated to foraging over the course of a day. Data were collected from up to 10 sites spread along the length of the Coorong from the Northern section of the Murray Estuary to Salt Creek in the South Lagoon, with at least seven of these sites sampled in any one year. Not all species were present at the sites sampled in each year and those that only occurred in low numbers were excluded to avoid having samples that were not representative.

	2007	2008	2011	2012	2013	2014	2015	***Mean***
Shorebirds								
Banded Stilt	89	89	70	76	76	77	82	***80***
Common Greenshank	49	74	52	77	73	68	68	***66***
Red-capped Plover	59	62		82	84	64	58	***68***
Red-necked Avocet	51		35	52	57	48	51	***49***
Red-necked Stint	72	70	43	88	89	83	70	***74***
Sharp-tailed Sandpiper	66	73		88	92	81	66	***78***
Waterfowl								
Australasian Shelduck	23	15	10	18	21	16	7	***16***
Black Swan	58	61	22	28	74	49	77	***53***
Chestnut Teal	43	33	16	40	35	61	35	***38***
Grey Teal	44	3	10	43	51	37	48	***34***
Fish-eaters								
Australian Pelican	9	18	11	18	12	24	27	***17***
Caspian Tern	2	5	56	30	18	17	36	***23***
Hoary-headed Grebe	42	32		51	58	71	58	***52***
Whiskered Tern	22	22		54	45	40	46	***38***

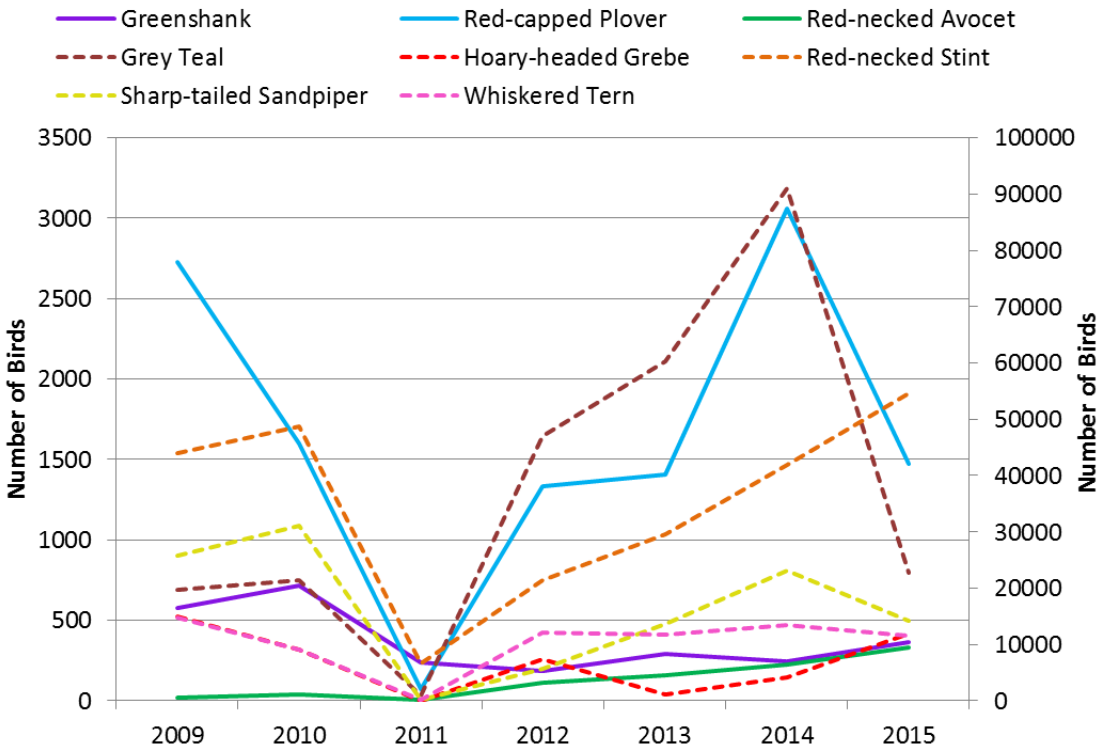

Figure 1: The total number of birds using the Coorong and Lower Lakes for a selection of species from 2009 to 2015. Numbers of birds for Greenshank, Red-capped Plover and Red-necked Avocet are plotted on the primary (left) axis and delineated using solid lines, while numbers of birds for all other species are plotted on the secondary (right) axis and are delineated using dashed lines.