Annual monitoring of *Ruppia tuberosa* in the Coorong region of South Australia, July 2013

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Summary

In the 1990s *Ruppia tuberosa* was widespread and abundant within the southern Coorong, with populations present thoughout the South Lagoon and into the southernmost sections of the North Lagoon. From around 2002, *Ruppia tuberosa* progressively declined from the southern end of the South Lagoon northwards. By July 2008 no plants were detected growing in the South Lagoon and the remaining propagule banks were low compared to historical levels. This coincided with a period of increasing salinities and low water levels in spring. During the same period of time, *Ruppia tuberosa* established in the middle of the North Lagoon and by July 2010 there were extensive beds *of Ruppia tuberosa* in the North Lagoon. With the return of substantial flows of freshwater over the barrages from spring 2010, the extremely high salinities along the Coorong declined. In the North Lagoon the reduction in salinity resulted in significant reductions in *Ruppia tuberosa*, with the plant all but disappearing from the middle sections of that lagoon by July 2011. However, with the return of more typical salinities to the South Lagoon, some *Ruppia tuberosa* re-established at Villa dei Yumpa, the northernmost sampling site in the South Lagoon. Despite similar salinities at other sites further south in the South Lagoon, no *Ruppia* plants were detected at more southerly sites in July 2011 and July 2012.

The distribution and abundance of *Ruppia tuberosa* in July 2013 was similar to the distribution and abundance recorded in the previous two years, but the populations had increased at the two northernmost sites of the South Lagoon, and to a lesser extent the southernmost site of the North Lagoon. Little recovery of *Ruppia tuberosa* had taken place across the rest of the southern Coorong, despite the establishment and maintenance of salinities ideal for the establishment, growth and expansion of *Ruppia tuberosa*. Salinities in the southern Coorong in July 2012 were in the range of 60-70 gL^{-1} and although higher in July 2013 (80-95 gL^{-1}) were still within an appropriate target salinity range. The salinity at Villa dei Yumpa where *Ruppia tuberosa* was abundant was 86 gL^{-1} in July 2013, supporting the notion that salinities were not limiting plant performance. The lack of recovery across the southern Coorong, however, was consistent with very low propagule banks (seeds and turions) and on-going limited seed production at all sites in recent years due to low water levels in spring.

As a consequence of the extensive loss of *Ruppia tuberosa* from the North Lagoon and only modest re-establishment in the northern parts of the South Lagoon, the overall abundance of *Ruppia tuberosa* has continued to remain substantially lower compared to its distribution and abundance prior to the commencement of the drought in 2002.

Two factors continue to limit the recovery of *Ruppia tuberosa* in the southern Coorong: inappropriate water levels in spring that prevent remaining plants within the Coorong from completing their reproductive cycle; and a severely depauperate seed bank throughout much of the South Lagoon.

Ruppia tuberosa remains vulnerable to further losses within the Coorong as it lacks resilience (an adequate propagule bank) even in the few places where it has re-established in the Coorong. Given this, the plant's capacity to survive further perturbations (such as additional years with inadequate water levels in spring) remains limited. There is an urgent need to restore this resilience and this will require not just ongoing translocation of *Ruppia tuberosa* into the South Lagoon to facilitate recovery but also the provision of suitable flows over the barrages to maintain water levels in the southern Coorong through spring. If adequate flows cannot be provided or other interventions cannot be implemented then *Ruppia tuberosa* may not re-establish on a large-scale.

Introduction

This report summarises the results of monitoring of *Ruppia tuberosa* undertaken in the Coorong region in July 2013 and compares the performances of *Ruppia tuberosa* with similar data collected during the previous fourteen years (e.g. Paton 1999; Paton & Bolton 2001; Paton 2003; Paton 2005, Paton 2006, Paton & Rogers 2007, Paton & Rogers 2008, Paton 2009; Paton & Bailey 2010, 2011, 2012a, 2013a). The monitoring program was established in 1998 and the four monitoring sites in the South Lagoon were within the distribution of *Ruppia tuberosa* in the Coorong at that time. A fifth site at Noonameena in the North Lagoon was outside the distribution of *Ruppia tuberosa* in the Coorong when the monitoring began but in response to the species extending its distribution northwards three additional sites in the North Lagoon were added to the monitoring program from July 2009, to better capture changes in distribution and abundance. A further monitoring site outside the Coorong (Lake Cantara) was also established in July 2009. This site had been identified as a potential source population for use in translocations of *Ruppia tuberosa* back into the South Lagoon. In 2012 a further four monitoring sites were added to the monitoring program to further enhance the documentation of any recovery.

Ruppia tuberosa is essentially an annual plant that exploits the ephemeral mudflats around the shores of the southern Coorong and ephemeral saline lakes such as Lake Cantara. These ephemeral areas are covered with water from late autumn through spring and into summer but are often dry from late summer through autumn. During this dry period the plant remains on the mud surface as seeds and turions. Most, if not all, of the turions that survive this period of desiccation sprout and some of the seeds germinate, when water levels rise again in late autumn and winter. The plants then grow over winter and, provided water levels remain adequate, reproduce sexually (producing seeds) and asexually (producing turions) during spring and early summer. The extent to which water remains over the ephemeral mudflats during spring and summer, however, is related to releases of water over the barrages. If the barrages are closed during spring, water levels in the southern Coorong drop, leaving *Ruppia tuberosa* plants exposed before they have the opportunity to reproduce. However, water levels in the southern Coorong can remain higher even into February, if the barrage gates remain open until this time (Paton 2010, & unpubl.). Given this, a sequence of years with little or no spring releases of water over the barrages is likely to restrict the ability of this annual plant to reproduce and hence maintain its presence in the southern Coorong. Because of its importance in the South Lagoon, the decline of *Ruppia tuberosa* has critical flow-on effects for other species, and the ecological character of the Coorong as a whole (Paton 2010).

The best time to monitor the performance of *Ruppia tuberosa* is during winter after the seeds and turions have germinated. At this time the shoots are relatively short, 1-4 cm in length, and are more easily counted. Later in the season individual plants are larger, and can form dense mats that are difficult to quantify.

This report builds on previous reports by adding the monitoring results for July 2013 to those of previous years. This is required to understand how the distribution and abundance of *Ruppia tuberosa* has changed over time and provides the basis for assessing the extent of any recovery. There is a need to set some qualitative and quantitative criteria to define when *Ruppia tuberosa* has recovered within the southern Coorong as whole, and also for individual sites. In this report some initial criteria are defined and used to assess the extent of any recovery.

Methods

Study sites

Four sites in the South Lagoon where *Ruppia tuberosa* was known to exist in previous years were selected for annual monitoring in 1998 (Table 1). These four sites were spread along the length of the South Lagoon (Tea Tree Crossing (TTX), Salt Creek (SC), Policemans Point (PP), and Villa dei Yumpa (VDY)) and were sites that were also monitored in 1984-85. Three of the four sites (all but SC) were also monitored intensively from July 1990 to June 1993. One site in the North Lagoon (Noonameena (NM)) was monitored in July from 1998 onwards, where *Ruppia tuberosa* had not been formerly detected. In July 2009 a further four sites were added to the annual winter monitoring program. These were Lake Cantara (LC), an ephemeral lake south of the Coorong that supported a population of *Ruppia tuberosa*, and three additional sites in the North Lagoon, Magrath Flat (MF), Robs Point (RP) and Long Point (LP). These sites were added to the annual monitoring program because *Ruppia tuberosa* had gradually shifted its distribution into the North Lagoon. Based on other monitoring conducted during January from 2001 onwards (e.g. Paton 2003; Paton & Rogers 2008; Paton 2010), *Ruppia tuberosa* was known to be present and abundant in 2000-2001 at Magrath Flat but then gradually declined but was still present in 2007-08. For the sites at Robs Point and Long Point, *Ruppia tuberosa* was detected at increasing frequency from 2005 onwards for Robs Point and 2008 onwards for Long Point.

In July 2012 a further four sites were added to the winter sampling program. Three of the sites were on the western side of the South Lagoon and the fourth site was on the eastern shore between Policeman Point and Villa dei Yumpa. These additional sites were intended to confirm the patterns found on the eastern shore and to provide a little more precision along the South Lagoon respectively.

Table 1. Location of monitoring sites for *Ruppia tuberosa* in the Coorong with Eastings and Northings (Datum WGS84, Map 54H) for the start of the third transect (see methods) at each site.

Site	Site details	Easting	Northing
TTX	5 km south of Salt Creek outlet	378832	5996641
SC	Bay north of Salt Creek entrance	377782	6000984
PP	Bay just north of Policeman's Point	372607	6009074
VDY	Bay just north of shack at Villa dei Yumpa	360339	6025095
NM	Opposite NPWS store shed at Noonameena	342635	6042214
Additional sites added in July 2009			
LC	Lake Cantara (western side)	387124	5978174
MF	Magrath Flat (middle of bay)	354909	6029549
RP	Rob's Point (north of the middle of bay)	345015	6039121
LP	Long Point (2nd bay north of Long Point)	334165	6048619
Additional sites added in July 2012			
S39W	western side of Coorong 3km S of SC	376658	5997276
PS	Princes Soak (western side of Coorong opp PP)	369797	6008099
S21E	Near Woods Well	370410	6013413
S06W	western side of Coorong opposite VDY	357927	6024000

Sampling procedure for *Ruppia tuberosa* and benthic invertebrates

At each sampling site a series of five parallel transects were established. The five transects were 25 m apart and ran perpendicular to the 100 m baseline that ran along the shore. The starting points for each transect were marked along this baseline at 25 m intervals and recorded with a GPS. Along each transect the water depth was measured at 50 m intervals to the nearest centimetre, until the water level was 0.9 m deep or deeper. Midway along each of the five transects, a litre water sample was collected and a Secchi disc lowered into the water to estimate turbidity. The salinities of the water samples were subsequently measured in the laboratory with a Hanna conductivity metre or a TPS meter, with samples being diluted when conductivities were above the optimum measuring range of the meters. Conductivities were converted to salinities using the conversion equation developed by Ian Webster (unpubl.). This equation provides a better measure of the actual salinities, particularly when salinities are high compared to the equation developed by Williams (1986). Along each transect ten 7.5 cm diameter x 4 cm deep mud samples were collected, with two samples coming from each of the following water depths: 0.2 m, 0.4 m, 0.6 m, 0.8 m and 0.9 m. Each sample was subsequently sieved through a 500 µm endecott sieve and all of the seeds, turions, and shoots of *Ruppia tuberosa* were counted, along with the numbers of chironomid larvae and/or polychaete worms. In 1998 and 1999 transect lines and distances along them were determined using tape measures, but from 2000 a Garmin 12 XL GPS was used to follow a transect line and estimate the distances along the line. Since the water levels in Lake Cantara did not exceed 25 cm, core samples were taken every 50 m along the 5 transects and water depths noted at each sampling location.

In 1999 an additional monitoring program was established to better capture changes in the local distribution and performance of *Ruppia tuberosa*. This involved collecting 50 core samples (7.5 cm diameter x 4 cm deep) in water depths ranging from 0.4 to 0.7 m between the first and second transects, second and third transects, third and fourth transects, and fourth and fifth transects (e.g. Fig. 1). This range of water depths covered the major *Ruppia tuberosa* beds at each site in the Coorong. This sampling gave four sets of 50 core samples and a total of 200 core samples for a site. These samples were not sieved, but the number of shoots present in each sample was counted *in situ* and recorded.

Figure 1 Colin Bailey sampling *Ruppia tuberosa* in the Coorong region using a corer (left) to collect a 7.5 cm diameter x 4 cm deep core to check for presence of *Ruppia tuberosa* (right). Note the turbidity of the water. (Photo courtesy Coby Mathews)

Results

<u>Historical salinities and water depths in July</u>

The salinities in July 2013 across the sampling sites in the South Lagoon of the Coorong were typically around 60-95 gL^{-1} (Fig. 2), and at least 20gL^{-1} higher than the previous year, except for Salt Creek (SC). The salinities in the South Lagoon, nevertheless, were typical of the winter salinities recorded during 1998-2002 prior to the extended drought (2002-2010).

The salinities at or near Salt Creek were about 10 gL^{-1} lower than the previous year, consistent with local freshening of the South Lagoon following the commencement of releases of 200-300 ML of fresh water per day out of Salt Creek in late June. This localised freshening had not yet affected the salinities at monitoring sites that were 5-10 km away (i.e. TTX; PP; Fig. 2).

The salinities at the sampling sites in the North Lagoon contrasted with those of the South Lagoon and were typically around 30-40 gL^{-1}. The salinities in July 2013 were similar to those recorded in July 2012 and typical of the winter salinities experienced in the 1998-2002 period prior to an extended drought (2002-2010).

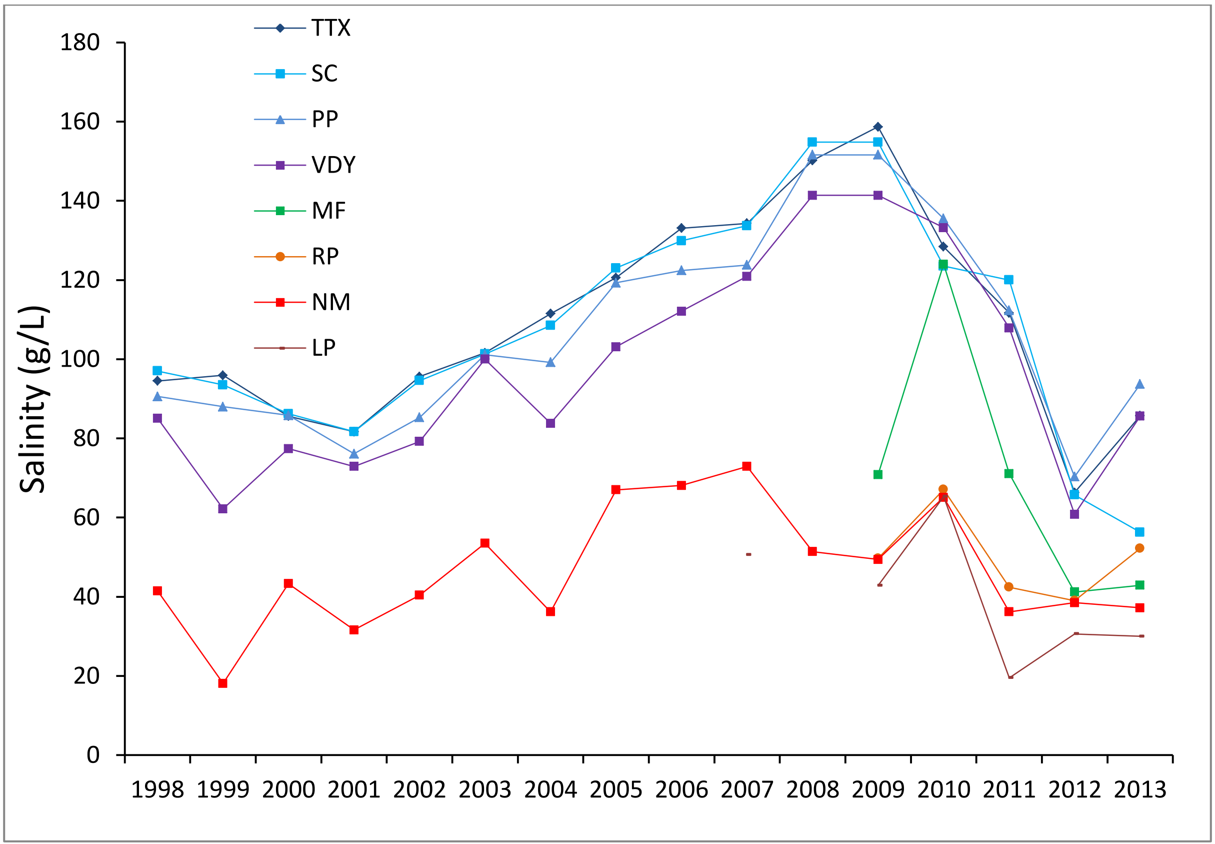

Figure 2. Winter salinities at monitoring sites for *Ruppia tuberosa* in the Coorong in July from 1998 to 2013. Sites TTX (Tea Tree Crossing), SC (Salt Creek), PP (Policermans Point) and VDY (Villa dei Yumpa) were spread along the South Lagoon, while MF = Magrath Flat, RP = (Robs Point), NM = Noonameena, and LP (Long Point) were spread along the North Lagoon. South Lagoon sites are shown in blue to black colours and those in the North Lagoon in green to red colours. TTX is the southernmost site and LP the northernmost site amongst the eight sites. MF, RP and LP were only sampled annually in July from 2009 onwards.

Salinities were also collected at the three sampling sites on the western side of the Coorong (Table 2). These generally were consistent with the salinities measured on the adjacent eastern shore, except for S06W where the salinity was much lower than for Villa dei Yumpa (VDY). Two factors are likely to account for that difference. First strong north-westerly winds were pushing water from the north lagoon into the South Lagoon when S06W was sampled (4 July) three days after VDY (1 July). S06W also sits within the channel connecting the two lagoons and this site will experience lower salinities before VDY in these conditions, as VDY sits on the other side of Hacks Peninsula. Water from the north lagoon needs to pass this peninsula before mixing with or displacing water at VDY.

In most years a systematic gradient in salinity establishes along the Coorong with the salinities gradually increasing from north to south. In July 2013 this gradient had been disrupted around the junction of the two lagoons with slightly fresher water present at Magrath Flat (North Lagoon) than either to the north or south of this site, and at Salt Creek because of recent releases of freshwater at this site.

Despite these disruptions, the salinities in the Coorong were typical of the winter salinities that existed prior to 2002 when recent extended drought commenced and fell within the target ranges of salinities for the north and south lagoons.

Table 2. Salinities (gL^{-1}) along the Coorong in July 2013.

Site Code	Site Name(s)	Distance from Murray Mouth	Salinity (gL^{-1})	
		km	East side	West side
N29	Long Point	27	30.0	
N19	Noonameena	37	37.2	
N15	Rob Point	41	52.2	
N02	Magrath Flat	54	42.9	
S06	Villa dei Yumpa / S06W	62	85.6	62.2
S21	S21E	77	89.3	
S26	Policeman Pt/ Princes Sk	82	93.7	95.3
S36	Salt Creek	92	56.3	
S39	S39W	95		91.1
S41	Tea Tree Crossing	97	85.7	

Water levels in July have ranged by over 50 cm over the last 16 years. They were highest in July 2002 and lowest in July 2006 (Table 3). In July 2013 water levels in the Coorong were in the middle of this historical range (Table 3), about 20 cm higher than the lowest levels and 30 cm below the highest levels. They were 5 cm lower than in July 2012.

Ruppia tuberosa (200 core samples) abundance at monitoring sites

Figure 3 shows the percentage of 200 core samples that contained *Ruppia tuberosa* shoots in July of each year from 1999 to 2013 for five sites in the Coorong and for three additional sites (MF, RP and LP) from 2009 to 2013.

There are four striking patterns to the changes in the distribution and abundance of *Ruppia tuberosa* that have taken place in the Coorong since 1999 (Fig. 3). First, there was a significant decline ($p<0.01$) and then loss of *Ruppia tuberosa* from the four long-term monitoring sites spread along the South Lagoon, such that there was no *Ruppia* detected growing in July at any of these sites from 2008-2010 (Fig. 3). Second, from July 2005 onwards there was a gradual colonisation of sites in the middle of the North Lagoon such that in July 2009 and July 2010 extensive *Ruppia tuberosa* beds (>90% of cores with plants) had established midway along the North Lagoon (e.g. Robs Point & Noonameena; Fig.3). These populations were outside the historic distribution of *Ruppia tuberosa* within the Coorong. Third, by July 2011, following the return of flows to the Murray Mouth in spring 2010, there had been a rapid reduction in the cover of *Ruppia tuberosa* in the North Lagoon, with *Ruppia tuberosa* all but eliminated (Fig.3) except for a few plants at Magrath Flat and Noonameena (<5% of cores with plants). While *Ruppia tuberosa* was lost from the North Lagoon, some *Ruppia tuberosa* (present in 32% of cores) re-appeared at Villa dei Yumpa, the northernmost monitoring site in the South Lagoon in July 2011. Fourth, despite suitable salinities throughout the South Lagoon the only sites where *Ruppia tuberosa* has re-established to some extent by July 2013 has been at the northernmost sites of the South Lagoon (S06W, Villa dei Yumpa) and to a lesser extent at the southernmost site in the North Lagoon (Magrath Flat). The species is yet to re-establish to any significant extent at the monitoring sites further south in the South Lagoon, where the species was once present and abundant prior to 2005 (Figs 3, 4).

Table 3. Changes in water levels between years during the July sampling period. The table shows the average water level difference relative to the water levels measured in July 1998. Average water level difference is calculated from the difference in water levels recorded at five sites, 100m out from the shoreline and averaged across the five sites (Tea Tree Crossing, Salt Creek, Policeman Point, Villa dei Yumpa, and Noonameena).

Year	Water level (cm)
1998	0
1999	34
2000	18
2001	3
2002	40
2003	13
2004	37
2005	2
2006	-10
2007	2
2008	25
2009	28
2010	-1
2011	24
2012	10
2013	5

The mean numbers of shoots per core for the 200 core samples taken over the beds of *Ruppia tuberosa* show a similar pattern to cover (Fig. 4). In July 2011 the average number of shoots per core was highest at Villa dei Yumpa (7 shoots/core) with 0.28 and 0.06

shoots/core for Magrath Flat and Noonameena respectively. In July 2012 the densities of shoots were similar to those detected in July 2011 with 5 shoots/core at Villa dei Yumpa and 0.1 shoots/core at Magrath Flat. There were no *Ruppia* plants detected at Noonameena in July 2012. The numbers of shoots detected in cores In July 2013 were also low and similar to the numbers in previous years. The abundances of shoots detected at these sites were low compared to historical abundances and low compared to the abundances of shoots at Lake Cantara (81.7 ± 2.5 (s.e) shoots/core in July 2011; 46.3 ± 1.7 shoots/core in July 2012; 15.4 ± 0.7 shoots/core in July 2013). Heavy grazing pressure was likely to account for the much lower abundances of shoots at Lake Cantara in July 2013 as over 95% of the shoots that remained had been grazed (also see Paton & Bailey 2010).

In 2012 three additional sites were sampled on the western side of the Coorong. The distributions and abundances of *Ruppia tuberosa* at these sites were consistent with the sites sampled along the eastern shore of the Coorong. The site (S06W) in the northern reaches of the South Lagoon and approximately opposite Villa dei Yumpa had a reasonable density of *Ruppia tuberosa* (e.g. Fig. 5) in July 2012, while the two sites further south had no *Ruppia tuberosa* plants. In July 2013, a small amount of *Ruppia tuberosa* was detected at Policeman Point (PP), 82 km from the Murray Mouth, and at Princes Soak (PS) immediately opposite Policeman Point on the western shore of the South Lagoon (Fig. 5).

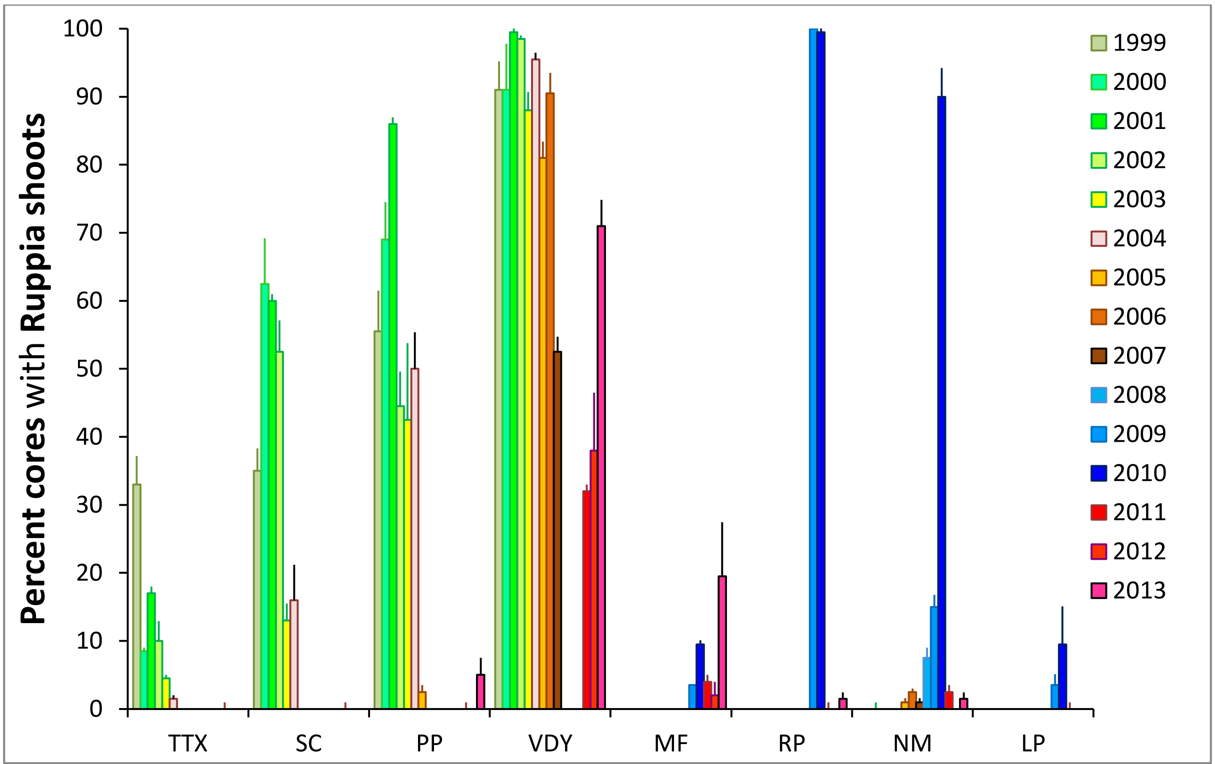

Figure 3. The percentage of 200 cores (75mm diam x 40mm deep) that contained *Ruppia tuberosa* shoots at each of 8 sites spread along the North and South Lagoons during July from 1999 to 2012. See Table 1 for the locations, but sites are arranged from the southernmost site (TTX) in the South Lagoon to the northernmost site (LP) in the North Lagoon, with the four sites on the left in the South Lagoon and the four on the right the North Lagoon. Data are shown as the mean (+s.e.) percent of cores with *Ruppia* for four sets of 50 cores at each site. Blue and red colours are used to highlight more recent years.

Changes in the availability of *Ruppia tuberosa* seeds and turions in July.

The data collected along the five transects at each site provide a comparable but less robust data set for shoots of *Ruppia tuberosa* relative to the 200 core samples and are not presented in this report. The samples collected along the transects, however, provide a basis for assessing changes in the prominence of seeds and turions in the sediments in July over time. The abundances of seeds and turions at each site are provided in Table 3 for 1998-2000, 2010-2012 and 2013. In the last four years (2010 - 2013) only small numbers of seeds have been detected at sites in the Coorong with abundances generally highest at Villa dei Yumpa. However, the numbers of seeds in samples was highly variable and patchy (as indicated by the standard errors in Table 3).

In previous years (2010-2012) over 600 seeds from the South Lagoon were examined and none contained internal contents (see Paton & Bailey 2013a). Thus the reported abundances of seeds in Table 3 in recent years will over-estimate the functional seed abundance. The low viability of seeds in the South Lagoon reflects the absence of any recent seed production in the South Lagoon.

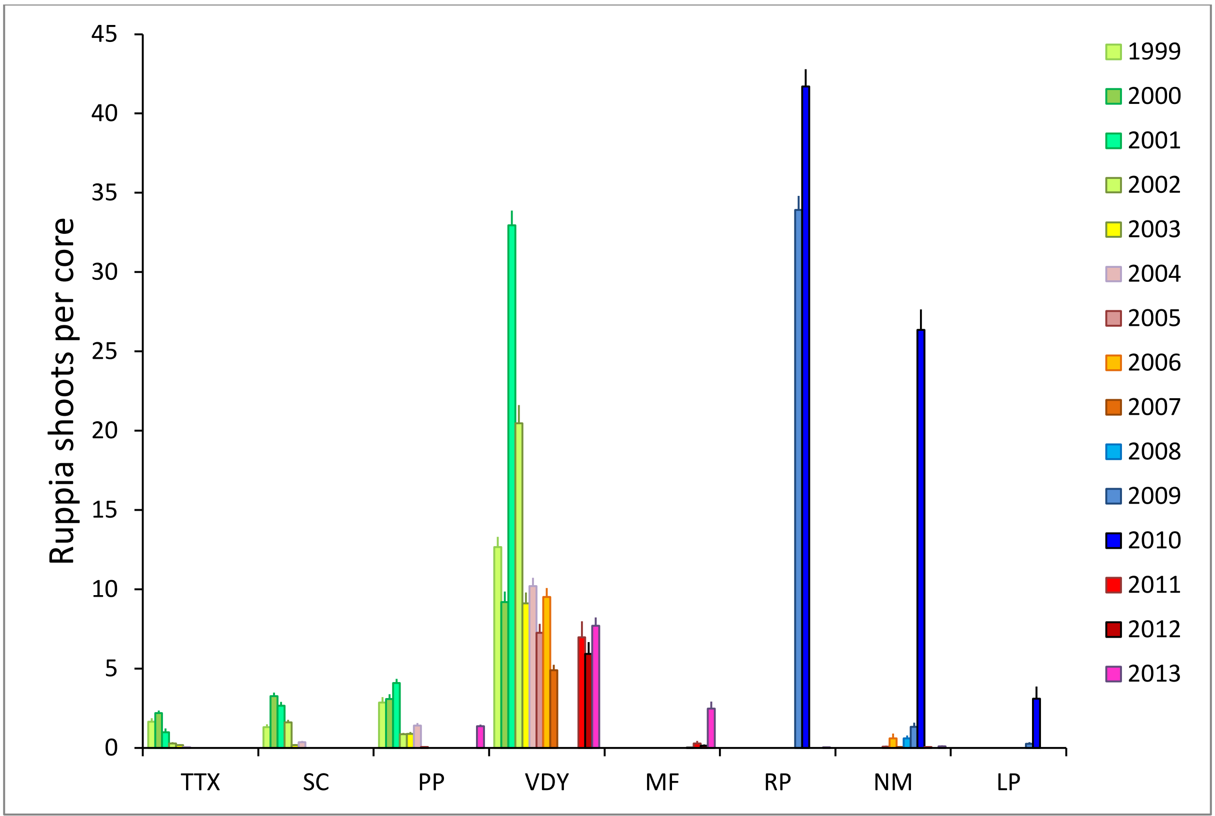

Figure 4. Mean number of *Ruppia tuberosa* shoots counted in 200 cores taken in July from eight sites spread along the Coorong from 1999 to 2013. Data show mean number of shoots per core + s.e. Shoots per core can be converted to shoots per m^2 by multiplying by 226. Blue and red colours are used to highlight data collected in recent years.

Seed abundances for *Ruppia tuberosa* during the initial three years of monitoring (1998-2000) in the Coorong were about 10-fold higher compared to current abundances (Table 3), but seed abundances in the Coorong were 10-100 fold lower compared to Lake Cantara where there have been 51.9, 53.3, 30.6 and 20.7 seeds per core in July for 2010 to 2014 respectively. Few turions have been detected in recent years (Table 3) but turions have never been prominent in samples taken in July.

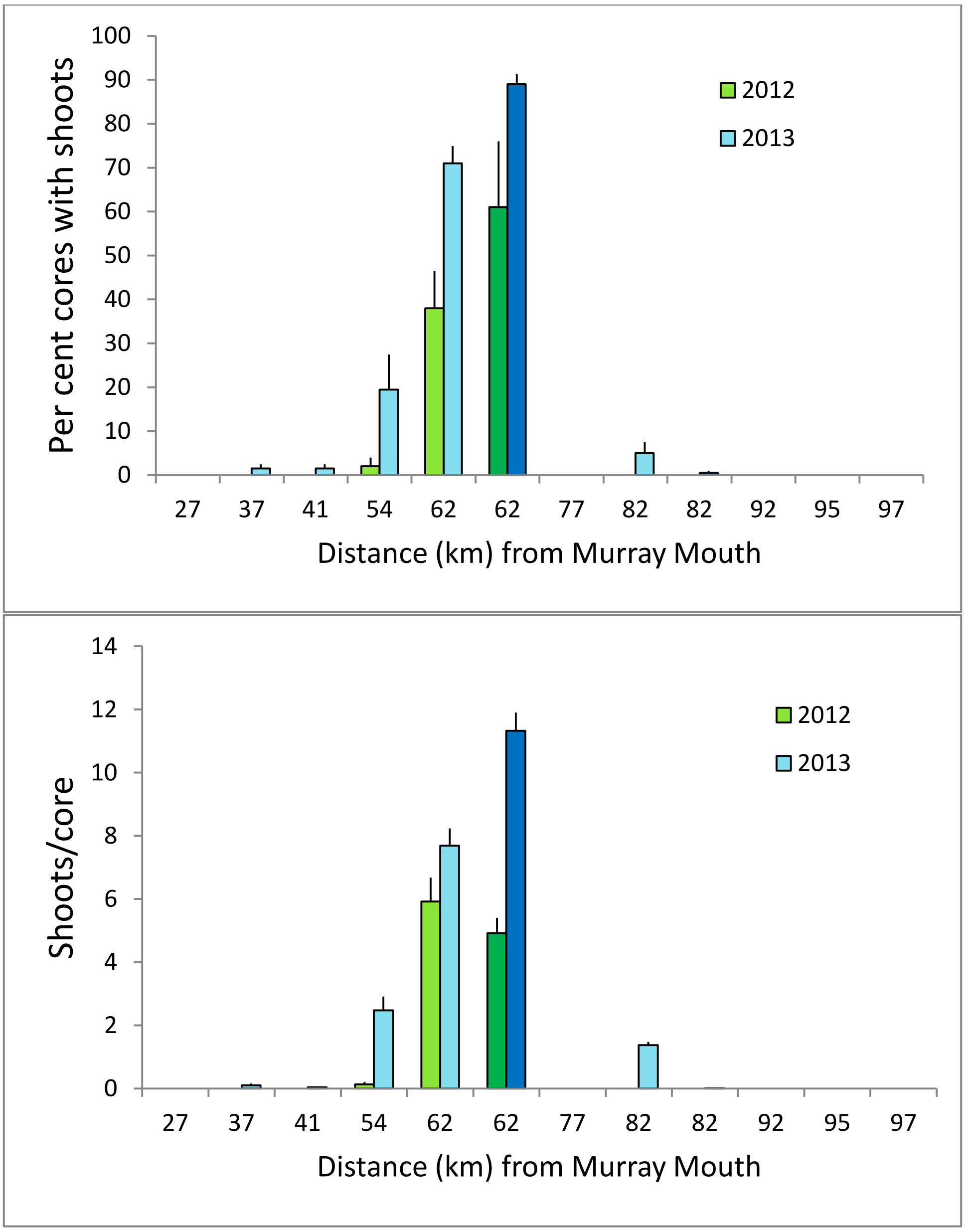

Figure 5. Percent of cores with *Ruppia tuberosa* shoots and mean number of shoots per core counted in 200 cores taken in July 2012 (green) and July 2013 (blue) from 12 sites spread along the Coorong. Data show means + s.e. Shoots per core can be converted to shoots per m^2 by multiplying by 226. The junction of the two lagoons is 56 km from the Murray Mouth. Darker columns represent sites on the western side of the Coorong, paler columns are on the eastern side of the Coorong.

Table 3. Abundances of seeds and turions detected in core samples along transects at each of thirteen monitoring sites in July 2012 and for five of these sites for the three years (combined) from July 1998-00. The data for July 2010, July 2011 and July 2012 are means ± s.e. for 50 core samples except for Lake Cantara which are based on 10 samples. The 1998-2000 data are based on 150 cores, 50 in each of the three years.

	July 1998-2000		July 2010-2012		July 2013	
Site	seeds per core	turions per core	seeds per core	turions per core	seeds per core	turions per core
South Lagoon						
TTX	1.57	0.23	0.23	0.0	0.52 ± 0.21	0
SC	2.34	0.12	0.15	0.0	0.04 ± 0.03	0
PP	3.88	0.48	0.47	0.0	1.28 ± 0.60	0
VDY	14.06	0.12	2.38	0.41	1.04 ± 0.78	0.08 ± 0.08
S06W			1.26	0.0	2.56 ± 0.82	0
S21E			0.40	0.0	0.02 ± 0.02	0
PS			0.70	0.0	0.02 ± 0.02	0
S39W			0.02	0.0	0.00 ± 0.00	0
North Lagoon						
MF			0.57	0.0	0.40 ± 0.18	0
RP			0.78	0.0	0.32 ± 0.21	0
NM	0.0	0.0	0.05	0.01	0.04 ± 0.04	0
LP			0.10	0.0	0.00 ± 0.00	0
Outside						
LC			48.6	0.0	20.7 ± 2.74	0

<u>Changes in the distribution and abundances of benthic invertebrates in July</u>

Changes in the distributions and abundances of chironomids (*Tanytarsus barbitarsis*) and polychaetes (*Capitella* spp) during winter along the Coorong are shown in Tables 4 and 5, and are based on the 50 cores taken along the five replicate transects at each site. These reflect similar patterns to those of *Ruppia tuberosa*.

Chironomid larvae were prominent in the South Lagoon in July from 1998 to 2006 but for the next four years (2007-2010) none were detected in winter at the four long-term monitoring sites in the southern Coorong (Table 4). Salinities in the South Lagoon in winter typically ranged from 80-120 gL^{-1} during 1998 to 2005 but slightly exceeded 120 gL^{-1} in July 2006 (Fig. 1). During the winters of 2007-2010 salinities in the South Lagoon were consistently above 120 gL^{-1} and exceeded 140 gL^{-1} in the winters of 2008 and 2009. In July 2011, however, the salinities were around 113 gL^{-1} and chironomid larvae were once again widespread across the South Lagoon. This suggests that the upper salinity tolerance for *Tanytarsus barbitarsis* in the Coorong is around 120 gL^{-1}. The distribution of *Tanytarsus barbitarsis* in the Coorong in July 2013 was similar to the distribution in the previous two years but the abundances were generally higher at all sites (Table 4). Salinities were lower in July 2012 (60-70 gL^{-1}) compared to July 2013 (80-95 gL^{-1}). This suggests that slightly higher salinities in July 2013 may have favoured this species. However the lower abundances in July 2012 may have been in response to lower salinities and or to higher numbers of predatory fish in the southern Coorong in July 2012 (Paton and Bailey 2012b).

Chironomid larvae were not detected at Noonameena in the North Lagoon of the Coorong in July 1998 and July 1999. However, from 2002-2010 they were generally prominent at Noonameena or at nearby sites in the North Lagoon (e.g. Robs Point; Table 4). In July 2010 chironomid larvae were present at all four monitoring sites in the North Lagoon, but were particularly abundant at Robs Point and Noonameena where *Ruppia tuberosa* was also most abundant. This distribution, however, changed dramatically in July 2011 with no chironomids detected at the three northernmost sites (RP, NM and LP) in the North Lagoon. *Tanytarsus barbitarsis* was also absent from these sites in July 2012 and July 2013. Generally the presence of chironomid larvae in surface sediments in the North Lagoon in July coincided with salinities that were on or above 40gL^{-1}. These data suggest that *Tanytarsus barbitarsis* may be limited to conditions where the salinity is above 40 gL^{-1} within the Coorong.

Polychaetes (*Capitella* sp.) were only detected in the North Lagoon (Table 5). They were generally prominent at Noonameena in July from 1998 to 2002 when salinities at this site were typically on or below 45 gL^{-1} (Fig. 2). From 2003 to 2006 polychaetes were still present in July at Noonameena but their abundances were lower. Winter salinities during this period typically ranged from 40-70 gL^{-1}. From 2007-2010 they were absent from Noonameena but present at Long Point. Salinities at Noonameena and nearby Robs Point (4km S) were typically in the range of 50-70 gL^{-1} during this period, while salinities at Long Point were 42 gL^{-1} in July 2009 (when polychaetes were abundant) and 65 gL^{-1} in July 2010 (when abundances were low). In July 2011 the salinities from Robs Point to Long Point were in the range of 20-42 gL^{-1} and polychaetes were abundant across all three sampling sites (Table 5). They were even more abundant at these sites in July 2012 and still prominent at these sites in July 2013. However there was a major expansion southwards in the distribution of polychaetes in July 2013, with large numbers detected at Magrath Flat for the first time (Table 5). The salinity at Magrath Flat in July 2013 was 42.9 gL^{-1} and similar to the salinity in July 2012. These field data suggest that *Capitella* sp. performs best when winter salinities are below 45 gL^{-1}. Unlike *Ruppia tuberosa*, these polychaetes and the chironomid *Tanytarsus barbitarsis* both responded quickly to the re-instatement of appropriate salinities in the Coorong.

Table 4. Changes in the distribution and abundance of chironomid (*Tanytarsus barbitarsis*) larvae along the Coorong in July from 1998 to 2011. Data are means for 50 core samples taken from each site in each year of sampling (1998-2011) except for Magrath Flat (MF), Robs Point (RP) and Long Point (LP) which were sampled only from July 2009 onwards and S06W, S21E, Princes Soak (PS) and S39W which were sampled only from July 2012. To convert these mean values to chironomid larvae/m^2 multiply by 226. Standard errors were typically around 15% of the means and have been provided in other reports for all years bar 2011 (e.g. Paton & Bailey 2011). TTX (Tea Tree Crossing, SC (Salt Creek), PP (Policemans Point) and VDY (Villa dei Yumpa), S06W, S21E, PS (Princes Soak) and S39W are spread along the South Lagoon, while the other sites including NM (Noonameena) are spread along the North Lagoon.

	Mean number of chironomid larvae per core											
	TTX	SC	PP	VDY	MF	RP	NM	LP	S06W	S21E	PS	S39W
1998	2.1	1.6	10.4	1.9			0					
1999	0.1	0.5	1.4	6.5			0					
2000	0.1	1.9	3.2	2.4			0.1					
2001	3.8	7.8	9.8	14.6			0					
2002	0.1	0.4	0.5	2.0			0.5					
2003	0.02	0.02	0.12	5.6			15.2					
2004	0	0	0	1.2			3.2					
2005	0.1	0.5	3.2	0.3			7.5					
2006	0.3	10.1	12.6	10.8			1.9					
2007	0	0	0	0			0.6					
2008	0	0	0	0			3.3					
2009	0	0	0	0	0	7.4	0	0.5				
2010	0	0	0	0	4.7	21.5	15.3	3.8				
2011	3.2	10.5	14.3	4.1	2.2	0	0	0				
2012	1.5	2.7	5.6	1.8	1.3	0	0	0.04*	6.5	5.3	9.9	6.5
2013	3.4	5.0	9.4	5.2	10.4	1.8	0	0	2.3	7.0	14.1	17.7

*different species of chironomid

Table 5. Changes in the distribution and abundance of polychaetes (*Capitella* sp.) along the Coorong in July from 1998 to 2012. Data are means for 50 core samples from each site in each year of sampling (1998-2012) except for Magrath Flat (MF), Robs Point (RP) and Long Point (LP) which were sampled from July 2009 onwards and S06W, S21E, Princes Soak (PS) and S39W which were sampled only in July 2012. To convert these mean values to polychaetes/m^2 multiply by 226.Standard errors were typically around 15% of the means and have been provided in other reports for all years except 2011 (e.g. Paton & Bailey 2011). TTX (Tea Tree Crossing, SC (Salt Creek), PP (Policemans Point), VDY (Villa dei Yumpa), S06W, S21E, Princes Soak (PS) and S39 W are spread along the South Lagoon, while the other sites including NM (Noonameena) are spread along the North Lagoon.

	Mean number of polychaetes per core											
	TTX	SC	PP	VDY	MF	RP	NM	LP	S06W	S21E	PS	S39W
1998	0	0	0	0			21.9					
1999	0	0	0	0			15.1					
2000	0	0	0	0			6.4					
2001	0	0	0	0			5.5					
2002	0	0	0	0			14.7					
2003	0	0	0	0			0.5					
2004	0	0	0	0			0.04					
2005	0	0	0	0			2.4					
2006	0	0	0	0			1.4					
2007	0	0	0	0			0					
2008	0	0	0	0			0					
2009	0	0	0	0	0	0	0	35.4				
2010	0	0	0	0	0	0	0	1.2				
2011	0	0	0	0	0	4.7	11.7	8.2				
2012	0	0	0	0	0	37.7	37.1	14.3	0	0	0	0
2013	0	0	0	0	9.6	11.9	20.5	54.8	0	0	0	0

Discussion

In general *Ruppia tuberosa* was more abundant in July 2013 than in the previous July, with plants being detected at more sites in 2013. However, *Ruppia tuberosa* was still absent from sites across the southern half of the South Lagoon where *Ruppia tuberosa* was prominent in the late 1990s and early 2000s (Figs 3, 4). So, although there were signs of recovery with respect to the distribution of the plant along the Coorong, the species has yet to recover its former range and abundance. For sites where the plant was detected in July 2012, the abundances (% cores, shoots per core) were higher in July 2013, consistent with slow recovery but they were still lower than the abundances recorded at those sites prior to the extended drought. On these grounds, *Ruppia tuberosa* is yet to fully recover in the Coorong.

<u>Establishing criteria for assessing the recovery and resilience of *Ruppia tuberosa*</u>.

Two components are required to document the recovery of *Ruppia tuberosa* in the Coorong and these operate at different spatial scales. One is required to document the recovery of *Ruppia tuberosa* at individual sites; and a second for measuring the extent of recovery along the Coorong. Recovery infers that the populations of *Ruppia tuberosa* return to a pre-disturbed condition or abundance. In the Coorong, although there are some quantitative data on distribution and abundance dating back to the 1980s (e.g. Paton 2010), *Ruppia tuberosa* was likely to be in decline even then. Using those early data as a basis for assessing recovery, therefore, may be misleading, either underestimating the parameters (% cover, shoots/core) of a healthy population or overestimating what can be recovered now, some 30 years later. An alternative is to use an existing healthy population of *Ruppia tuberosa* (e.g. the population at Lake Cantara*)* as a basis for defining parameters when the population has recovered and built resilience.

(i) Assessing Ruppia tuberosa *at the individual site level*

The current winter monitoring program began in 1998 at five sites (four with *Ruppia tuberosa* populations) with additional sites added in recent years. This monitoring provides two types of data that can be used in assessing recovery: the per cent of cores containing plant material (shoots, turions and seeds) and the abundances of shoots, turions and seeds in the cores. Importantly, this monitoring was established well before the extended drought that ran between 2002 and 2010 and so provides minimum recovery targets that need be achieved. For example, the per cent of cores with *Ruppia tuberosa* shoots in July 1999 was above 30% for all four sites in the South Lagoon of the Coorong, and three had at least 50% (and up to 99%) of cores with shoots in one or more years prior to the drought (Fig. 3). Thus a reasonable expectation of recovery is for *Ruppia tuberosa* to once again be present in 30% of cores taken in winter at all of the sites formerly occupied. An alternative to using pre-drought data from the Coorong is to use data from a self-sustaining population outside the Coorong, such as Lake Cantara. For Lake Cantara more than 95% of all cores contained *Ruppia tuberosa* shoots in each year of sampling. Similar levels of cover were detected in the Coorong at some sites, and ultimately this high level of cover may be required to secure resilience. The Coorong, however, is a more challenging environment for *Ruppia tuberosa* than Lake Cantara primarily because of the extent of day to day fluctuations in water parameters (water level changes, salinities, and wave action). Thus an expectation of securing over 90% of cores with *Ruppia tuberosa* shoots is unrealistic across all sites, but setting a minimum target of 30% of cores with shoots in winter has a historical, pre-drought basis.

The numbers of shoots found in cores can be used as a measure of abundance. Counts of shoots, however, do not measure the number of individual plants *per se* but are a measure of the number of plants and growth. *Ruppia tuberosa* grows by extending lateral stolons along or just below the surface of the sediment. New shoots are produced at regular intervals of about 1 cm along the stolons, particularly when the plant is expanding in distribution. In a healthy and well established population of *Ruppia tuberosa*, like at Lake Cantara, there can be more than 100 shoots in a 7.5 cm diameter core. However the numbers of shoots can vary dramatically at a site from one year to the next. For example, at Lake Cantara the average numbers of shoots present in cores in early July over the last five years has varied from 13 to 86. Low densities of shoots (15.4 shoots per core) at Lake Cantara in July 2013 coincided with heavy grazing pressure from waterfowl. In the Coorong the density of shoots also varies. For example, the density of shoots in early July for the population at Villa dei Yumpa varied from 7 to 33 shoots per core (9 to 33 for cores with *Ruppia* present) between 1999 and 2006 (Fig. 4) prior to this population collapsing. Many factors may influence the number of shoots present in early July, including the numbers of viable propagules present in the sediments prior to winter, the length of time the mudflats have been covered with water prior to sampling in July, and the intensity of any grazing pressure from waterfowl. Based on the performance of *Ruppia tuberosa* at Villa dei Yumpa an initial minimum target of 8 shoots per core (for cores with *Ruppia tuberosa*) could be set to indicate recovery. When there are 8 shoots within a core in early July then this is likely to indicate that either several individual plants have established and or these plants have grown, with potential for further production of shoots.

For individual sites two simple measures of abundance could be used to indicate the extent of any recovery: the percent of cores with *Ruppia tuberosa* shoots, and the number of shoots per core with *Ruppia tuberosa* in the areas in which the main beds of *Ruppia tuberosa* exist (judged from the transect lines). An initial minimum target of 30% of cores and 8 shoots per core in early July could be used as indicating the re-establishment of a population of *Ruppia tuberosa*. Applying these performance indicators to the July 2013 sampling only 2 sites exceed the target of 30% of cores with *Ruppia* and more than 8 shoots per core (VdY and S06W) out of nine potential sites. Both of these sites had also met these targets in July 2012. Two other sites had less than 30% cores with *Ruppia* in July 2013 but had more than 8 shoots per core for cores with *Ruppia* (PP, MF) suggesting that populations of *Ruppia tuberosa* were consolidating their presence at these sites albeit slowly.

(ii) Assessing recovery of Ruppia tuberosa *at the regional level*

In addition to measuring recovery at individual sites there is also a need to assess recovery across the Coorong. Two parameters borrowed from the IUCN for assessing threatened species can be used: Extent of Occurrence (EOO) and Area of Occupation (AOO).

Extent of Occurrence

In the 1980s and 1990s *Ruppia tuberosa* was distributed from the southernmost parts of the South Lagoon (at least 10 km S of Salt Creek) to southern sections of the North Lagoon (at least to Magrath Flat where *Ruppia tuberosa* was still abundant in the late 1990s and early 2000s, Paton pers. obs.). The distance between the southernmost and northernmost locations is in excess of 50 km. Thus one simple measure of recovery could be the extent to which *Ruppia tuberosa* is found growing along the Coorong, with a target of 50 km. In July 2012 the extent of occurrence was around 8 km while in July 2013 the extent of occurrence was 45 km, albeit this included the presence of small amounts of *Ruppia tuberosa* north of the typical distribution for this plant (Figs 3, 4 & 5). Excluding sites with negligible presence (<5% of cores with Ruppia shoots in July) which includes the more northerly sites (i.e. Robs Point and Noonameena) then the extent of occurrence for *Ruppia tuberosa* shoots in July 2013 was 28 km.

As has been the case for most of the last 8 years, there have been virtually no plants detected within the southern half of the plant's former range, except for some plants around

Policeman Point in July 2013 (82 km from the Murray Mouth) where dispersal of seeds from the nearby translocation areas may have facilitated the reappearance of this plant at that site in July 2013. Clearly *Ruppia tuberosa* is still to recover across the southern parts of the Coorong.

Area of Occupation

Extent of occurrence provides a measure of the spread of a species within a region, but does not measure the prominence or frequency with which a species occupies a region. In theory a species could be present at two locations that are widely spaced and record a high extent of occurrence yet be absent from most of the area. A second statistic – area of occupation – provides further resolution. In the 1980s, 1990s and early 2000s *Ruppia tuberosa* was present at most, if not all, of the sites sampled along the southern Coorong. Thus most of the sampling sites within the extent of occurrence should be occupied by *Ruppia tuberosa*. A reasonable expectation might be for *Ruppia tuberosa* to be present and growing (shoots present) at 80% of sampling sites within the extent of occurrence. If this was applied to the current data sets then in July 2012 the species had an extent of occurrence (EOO) of 8 km, with an area of occupation (AOO) of 100% (3 of 3 sites) within that EOO. In July 2012 the EOO was 28 km and the AOO was 83% (i.e. 5 of 6 sites sampled within this EOO had *Ruppia tuberosa* shoots). However three of the six sites sampled within the EOO had less than 10% cover of *Ruppia tuberosa*, and if a minimum level of cover is required before a species can be regarded as having reasonable presence then the functional AOO would be 50%. The AOO would be just 33% if the per cent of cores with *Ruppia* shoots needs to exceed 30% (see above).

Ultimately full recovery of *Ruppia tuberosa* in the southern Coorong should consist of the following. An extent of occurrence that approaches or exceeds 50 km along the Coorong, with 80% of sites within this region supporting *Ruppia tuberosa* with at least 30% of cores (75 mm diameter) containing *Ruppia tuberosa* shoots in early July with an average density of at least 8 shoots per core. Full recovery has therefore not been met.

(iii) *Defining and assessing resilience for* Ruppia tuberosa

For an annual plant, like *Ruppia tuberosa*, which needs to re-establish each year from propagules (seeds. turions, plant fragments), resilience can be assessed from the size of the propagule bank. Turions and plant fragments do not survive periods of desiccation, so seeds are the primary mechanism that allows *Ruppia tuberosa* to survive and re-establish on ephemeral mudflats (mudflats that dry out for part of the year). Not all the seeds germinate each year which means if the seed bank is not replenished in one year then there are still viable seeds present from previous reproductive events to re-establish plants in the next growing season. Ultimately annual plants need to reproduce to replenish the seed bank before there are too few seeds left to re-establish plants. Many factors will influence the size of the seed bank produced in any one year within the Coorong. The key factors are: failure to flower and reproduce in late spring because of falling water levels; heavy grazing pressure from waterfowl which reduces plant biomass and hence capacity to produce flowers as well as removing floral stalks; interference by filamentous green algae that smother plants and also dislodge flowering stalks; wave action that can re-distribute seeds towards the shore and away from the most suitable places for plants to grow; and potentially loss of seeds to foraging shorebirds.

The seed banks at long-term monitoring sites in the Coorong have declined in most cases by about 10 fold since 1998-2000 (e.g. Table 3). The numbers of seeds recorded at the start of this long-term monitoring program (1998-2000) were also lower than the seed abundances recorded in the early 1990s. For example for July 1990-1992, VDY had mean seed densities of 22.3 seeds per core, PP had 10.1 seeds per core and TTX 3.9 seeds per core. The equivalent densities in 1998-2000 were 14.1, 3.9 and 1.6 respectively (Table 3). This suggests that the seed banks may have already declined by 1998-2000. For comparison, seed densities in July for the population of *Ruppia tuberosa* at Lake Cantara averaged 48 seeds per core in July from 2010-2012, but the abundance of seeds was lower in July 2013 (20.7 seeds/core). Although these seed abundances have been taken in July when some seeds will have already germinated they provide an indication of the likely maximum abundances of seeds that will be present in the following year should *Ruppia tuberosa* fail to reproduce in the coming spring. Based on measures of seeds/core in July at Lake Cantara and also at some of the sites in the Coorong in the 1990s an initial minimum target number of seeds per core to ultimately secure some multiple year resilience is probably 20 seeds per core. None of the populations within the Coorong currently meet this target, while the population at Lake Cantara has always met this target.

At all of the monitoring sites within the Coorong the numbers of seeds present in cores in July continues to be very low and this reflects ongoing limited reproductive output for *Ruppia tuberosa* in the Coorong. As has been the case in recent years falling water levels in spring prevented plants from completing their reproductive cycle in spring 2012 (Paton & Bailey 2013b), and the maintenance of low seed abundances since 2010 is consistent with negligible seed production in recent years. Given the on-going low numbers of seeds at sites, *Ruppia tuberosa* has limited capacity to re-establish and maintain a substantive presence at most sites within the Coorong on its own, even for those sites (S06W, VDY) where there were substantial numbers of shoots in July 2013. Ongoing failure to reproduce during spring continues to limit the recovery of this species and ultimately threatens the long-term existence of this species within the Coorong.

In terms of establishing parameters to assess resilience of *Ruppia tuberosa*, then additional assessments in addition to the numbers of seeds in sediments in July are warranted. The two logical ones are: the extent of flowering and numbers of flower-heads produced in spring; and the numbers of seeds present immediately post-flowering (measured in January). For the time being measures of seed abundances in July indicate that there has been negligible increase in seed banks, with most seed banks well below any pre-drought or historical abundance. The first indication of any recovery of resilience should be seen as an increase (of any magnitude) in seed abundances at monitoring sites. To date there has been no evidence of any recovery.

The issue of inadequate water levels, however, will also need to be addressed for *Ruppia tuberosa* to be able to re-establish in the southern Coorong and have any chance of accumulating an adequate seed bank to provide any resilience to future perturbations. The maintenance of adequate water levels will be difficult to deliver because it will require the re-establishment of, and then maintenance of, adequate spring flows over the barrages and unfortunately there are issues at both Commonwealth and State Government level that currently hinder the delivery of this water at the right time. There is also an inadequate volume of water available for maintaining adequate flows over the barrages in most springs to maintain water levels in the southern Coorong. Alternative interventions, such as building structures across the Coorong to hold water levels up during spring are also not favoured.

In comparison to *Ruppia tuberosa,* the prominent aquatic invertebrates, the chironomid *Tanytarsus barbitarsis* and the polychaete *Capitella* sp. have been able to quickly re-colonise and so re-establish their former distributions and abundances.

In summary*, Ruppia tuberosa* is a keystone species in the Coorong, a quintessential element that helps define the ecological character of this Ramsar Wetland of International Importance. Its continued absence from much of the South Lagoon indicates an inability for the ecological character of this system to recover on its own. The re-establishment of the species across its former range in the Coorong is now urgent. This will require *Ruppia* *tuberosa* to be translocated back into much of the South Lagoon. If the Murray Darling Basin Plan can provide water conditions suitable for the plant to maintain itself, the ecological asset in the southern Coorong will be protected and not transition to a different ecological state.

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