Annual winter monitoring of *Ruppia tuberosa* in the Coorong region of South Australia, July 2016

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Executive Summary

In the 1990s, *Ruppia tuberosa* was widespread and abundant within the southern Coorong, with populations present throughout the South Lagoon and into the southernmost sections of the North Lagoon. From around 2002, *R. 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, *R. tuberosa* established in the middle of the North Lagoon and, by July 2010, there were extensive beds *of R. 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 *R. tuberosa*, with the plant all but disappearing from the middle sections of that lagoon by July 2011. However, despite the return of more typical salinities to the South Lagoon, the recovery of *R. tuberosa* in recent years has been steady but slow.

In July 2016, *R. tuberosa* even showed a reversal of the recovery that was observed in preceding winters, meeting only one of three regional criteria that can be assessed in winter. With an extent of occurrence of 41 km, the plant failed to meet its 43 km target, and while plants were detected at all eight monitoring sites within this extent of occurrence, abundances at many sites were low, particularly at the southern end of the range. Three of these sites had at least 30% of cores with *R. tuberosa* shoots but only one of these sites – Villa dei Yumpa, had densities of at least 10 shoots per 75 mm diameter core, indicating a vigorous population of *R. tuberosa.* This falls well short of the requirement that 50% of populations of *R. tuberosa* should be vigorous. All sites continued to lack resilience, with seed banks falling well short of the target (> 2,000 seeds/m^2) required to provide initial resilience. This reflects limited effective reproduction over the previous 12 months, which was not unexpected, given the particularly low water levels during spring and summer 2015-16. Low water levels over spring and summer are now commonplace and the flowering and seed production of *R. tuberosa* continues to be severely disrupted annually. There is an urgent need to address the low water levels that establish in spring and summer in the southern Coorong if *R. tuberosa* is to recover.

Contents

1 Preamble

In preparing annual reports on the monitoring of *Ruppia tuberosa*, substantial parts of previous reports are reiterated so that each annual report contains the relevant background and historical perspective, as well as details of methods and monitoring targets, so that they can be read independently of previous reports.

2 Introduction

This report summarises the results of monitoring of *R. tuberosa* undertaken in the Coorong region in July 2016 and compares the performances of *R. tuberosa* with similar data collected during the previous seventeen 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, 2014a; Paton *et al.* 2015a, 2016a,b,c). The monitoring program was established in 1998 and the initial four monitoring sites in the South Lagoon were within the distribution of *R. tuberosa* in the Coorong at that time. A fifth site at Noonameena in the North Lagoon was outside the distribution of *R. 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, namely Lake Cantara, was also established in July 2009. This site had been identified as a potential source population for use in translocations of *R. 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 as seeds and turions either on or just below the mud surface. 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. However, the extent to which water remains over the ephemeral mudflats during spring and summer is related to releases of water over the barrages. If the barrages are closed during spring, water levels in the southern Coorong drop, leaving *R. 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 (e.g., as a major food source for herbivorous waterfowl), the decline of *R. 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 *R. 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 (although this has not occurred in recent years, e.g., Paton *et al.* 2016a,c).

This report builds on previous reports by adding the monitoring results for July 2016 to those of previous years. This is required to understand how the distribution and abundance of *R. 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 *R. tuberosa* has recovered within the southern Coorong as a whole, and also for individual sites. In recent years, there has been a concerted effort to define a series of measures at both a regional and local (site) scale that can be used to assess the health of *R. tuberosa* in the Coorong (Table 1, Paton & Bailey 2014a; Paton 2014; Paton *et al.* 2015b). The July 2016 monitoring results will be assessed against these targets as well.

Table 1: Criteria used to define the status of R. tuberosa *in the southern Coorong.*

Criterion	Target
REGIONAL SCALE	
R.1 Extent of Occurrence (EOO)	*Ruppia tuberosa* plants distributed along 43 km of the southern Coorong
R.2 Area of Occupation (AOO)	*Ruppia tuberosa* plants present at 80% of sites monitored within the EOO in winter and spring
R.3 Population Vigour (VIG)	Vigorous *Ruppia tuberosa* populations at 50% of sites within the EOO, where a vigorous population has at least 30% cover with at least 10 shoots per core (75mm diam)
R.4 Population Resilience (RES)	At least 2,000 seeds/m^2 at 50% of sites with *Ruppia tuberosa* (target set for 2019)
LOCAL SCALE	
L.1 Population cover	At least 30% cover in winter and in summer
L.2 Population (shoot) density	At least 10 shoots per core (75 mm diam) in winter
L.3 Propagule (seed) density	At least 50% of surface sediment cores (75 mm diam) with seeds
L.4 Reproductive output	At least 50 flower heads/m^2 for 50% of the area sampled (with *Ruppia tuberosa*) at a site during spring flowering
L.5 Asexual reproduction	At least 50% of cores (75 mm diam) taken across the *Ruppia tuberosa* beds in late summer should contain turions
FUTURE RESILIENCE	
RS.1 By 2019	2,000 seeds/m^2 at 50% of sites (> 8 seeds per core (75 mm diam))
RS.2 By 2029	10,000 seeds/m^2 at 50% of sites (> 40 seeds per core (75 mm diam))

3 Methods

3.1 Study sites

Four sites in the South Lagoon, where *R. tuberosa* was known to exist in previous years, were selected for annual monitoring in 1998 (Table 2). These four sites were spread along the length of the South Lagoon (Tea Tree Crossing (TTX), Salt Creek (SC), Policeman's 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 *R. 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 *R. tuberosa*, and three additional sites in the North Lagoon, namely Magrath Flat (MF), Rob's Point (RP) and Long Point (LP) (Table 2). These sites were added to the annual monitoring program because *R. 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), *R. tuberosa* was known to be present and abundant in 2000-2001 at MF, then gradually declined, but was still present in 2007-08. *Ruppia tuberosa* was detected at increasing frequency from 2005 onwards for RP and 2008 onwards for LP until 2011.

In July 2012, a further four sites were added to the winter sampling program (Table 2). Three of the sites were on the western side of the South Lagoon and the fourth site was on the eastern shore between PP and VDY. 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.

3.2 Sampling procedure for R. 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 meter 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 75-mm diameter x 40-mm deep mud

Table 2: 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

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 *R. 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 hand-held Garmin 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 at a depth of 0.2 m, and water depths noted at 50 m intervals, along the five transects.

In 1999, an additional monitoring program was established to better capture changes in the local distribution and performance of *R. tuberosa*. This involved collecting 50 core samples (75-mm diameter x 40-mm 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., Figure 1). This range of water depths covered the major *R. 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.

Field sampling for winter 2016 was conducted between 27 June and 3 July 2016, consistent with all previous years.

Figure 1: Colin Bailey sampling Ruppia tuberosa in the Coorong region using a corer (left) to collect a 75-mm diameter x 40-mm deep core to check for presence of Ruppia tuberosa (right). Note the turbidity of the water. (Photo courtesy Coby Mathews).

4 Results

4.1 Historical salinities and water depths in July

The salinities in July 2016 in the South Lagoon of the Coorong across the sampling sites ranged from 91-113 gL^{-1} (Table 3). These salinities were higher than those in the previous four years and most similar to those at the start of the millennium drought and in 2011 (Figure 2). Of note, most sites in the South Lagoon did not have salinities within the recommended range of salinities (60-100 gL^{-1}) for *R. tuberosa* (Table 3).

The salinities in July 2016 at the sampling sites in the North Lagoon were much lower than in the South Lagoon, ranging from 49-66 gL^{-1}, with a gradual increase in salinities from north (N29) to south (N02) (Table 3). However, like the South Lagoon salinities, the July 2016 salinities of the North Lagoon were, in general, higher than those in the previous four years, being most similar to the salinities recorded at the beginning of the millennium drought (Noonameena), at the end of the millennium drought (Long Point, Noonameena and Rob Point) and in 2009 and 2011 (Magrath Flat) (Figure 2). Only the salinity at Magrath Flat was within the recommended range of salinities (60-100 gL^{-1}) for *R. tuberosa* (Table 3).

Water levels in July 2016 were 36 cm higher than in 2015 (lowest on record) and 30 cm lower than in 2014 (highest on record) (Figure 3), with the marked differences likely related to weather conditions. Strong north-westerly winds coupled with high tides will push water into the southern Coorong and lift water levels, as will significant rainfall but to a lesser extent. The period leading up to early July 2016 included some moderate northerly wind events and slightly above-average rainfall (e.g., June rainfall for Meningie was 71 mm in 2016, compared with an average of 62 mm; Bureau of Meteorology, 2016).

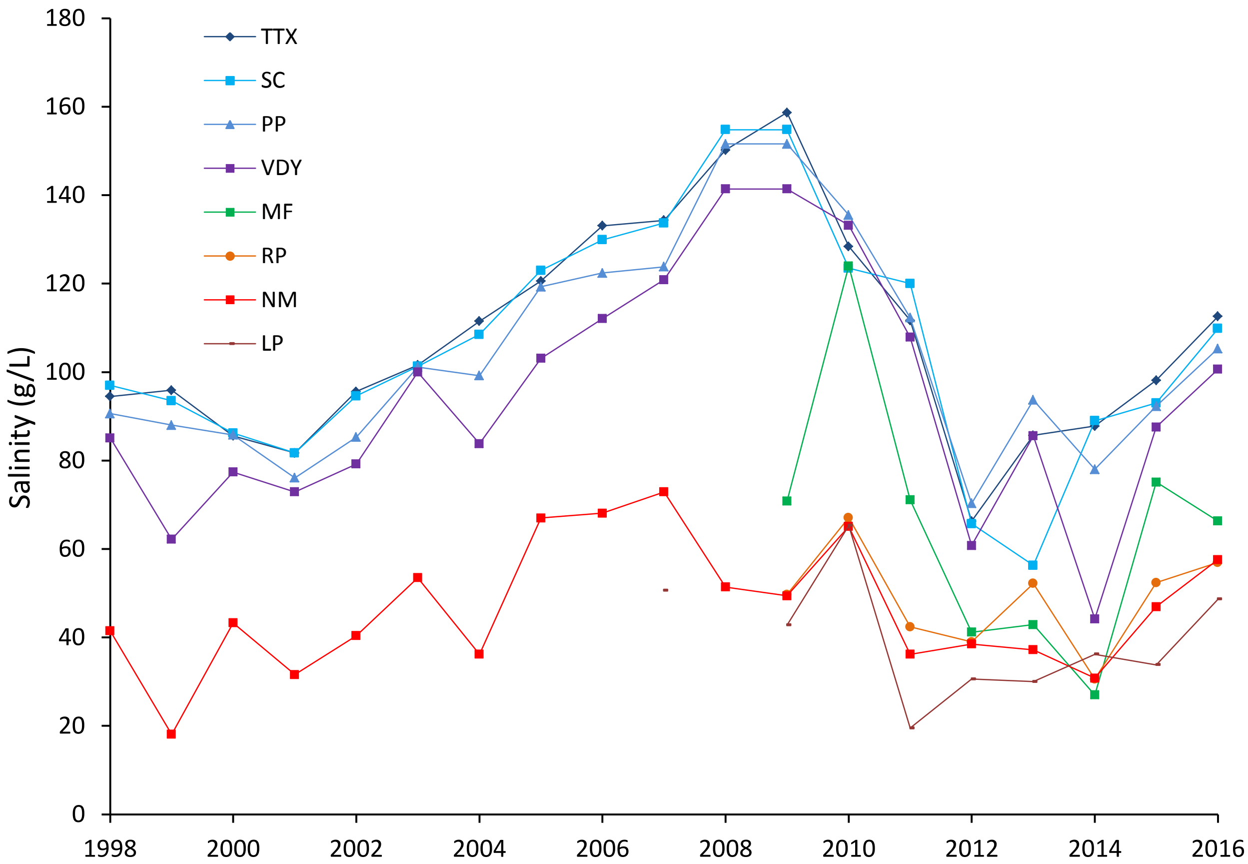


Figure 2: Winter salinities at monitoring sites for R. tuberosa *in the Coorong in July from 1998 to 2016. Sites TTX (Tea Tree Crossing), SC (Salt Creek), PP (Policeman's Point) and VDY (Villa dei Yumpa) were spread along the South Lagoon, while MF (Magrath Flat), RP (Rob's Point), NM (Noonameena), and LP (Long Point) were spread along the North Lagoon. South Lagoon sites are shown in navy through to purple 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.*

Table 3: Salinities (gL^{-1}) along the Coorong in July 2016.

Site Code	Site Name(s)	Distance from Murray Mouth	Salinity (gL^{-1})	
		km	East side	West side
N29	Long Point	27	48.7	
N19	Noonameena	37	57.6	
N15	Rob Point	41	57.0	
N02	Magrath Flat	54	66.3	
S06	Villa dei Yumpa / S06W	62	100.6	91.2
S21	S21E	77	99.9	
S26	Policeman's Pt/ Princes Sk	82	105.3	108.6
S36	Salt Creek	92	109.9	
S39	S39W	95		112.2
S41	Tea Tree Crossing	97	112.6	

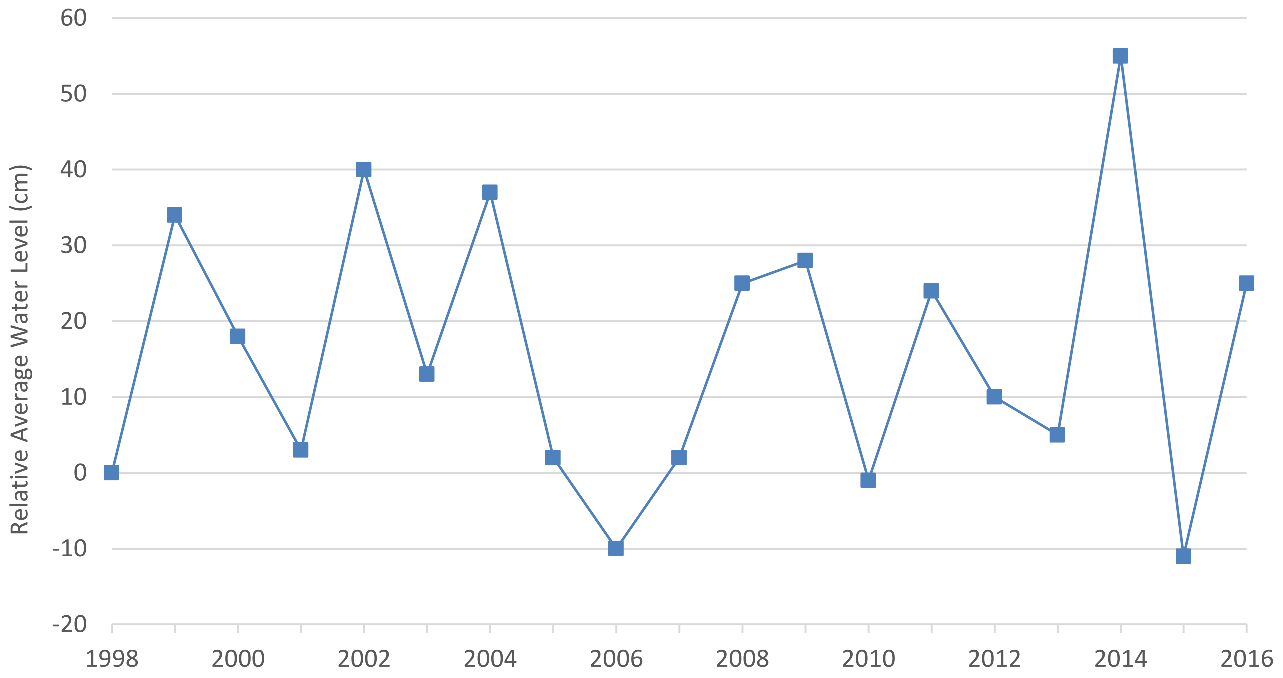


Figure 3: Changes in water levels between years during the July sampling for R. tuberosa*. The figure shows the average water level difference relative to the water levels measured in July 1998. Average water level difference is calculated from the difference in water levels recorded at five sites, 100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

4.2 Ruppia tuberosa *(200 core samples) abundance at monitoring sites*

Figure 4 shows the percentage of 200 core samples that contained *R. tuberosa* shoots in July of each year from 1999 to 2016 for five sites in the Coorong and for three additional sites (MF, RP and LP) from 2009 to 2016, while Figure 5 shows the density of shoots for these sites over the same time periods.

There are five striking patterns to the changes in the distribution and abundance of *R. tuberosa* that have taken place in the Coorong since 1999 (Figure 4 and Figure 5). First, there was a significant decline and then loss of *R. tuberosa* from the four long-term monitoring sites spread along the South Lagoon, such that there was no *R. tuberosa* detected growing in July at any of these sites from 2008-2010 (Figure 4 and Figure 5). 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 *R. tuberosa* beds (>90% of cores with plants and > 10 shoots/core) had established midway along the North Lagoon (e.g., Rob's Point & Noonameena; Figure 4 and Figure 5). These populations were outside the historic distribution of *R. 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 *R. tuberosa* in the North Lagoon, with *R. tuberosa* all but eliminated (Figure 4 and Figure 5) except for a few plants at Magrath Flat and Noonameena (<5% of cores with plants, <0.3 shoots/core). While *R. tuberosa* was lost from the North Lagoon, some *R. tuberosa* (present in 32% of cores),

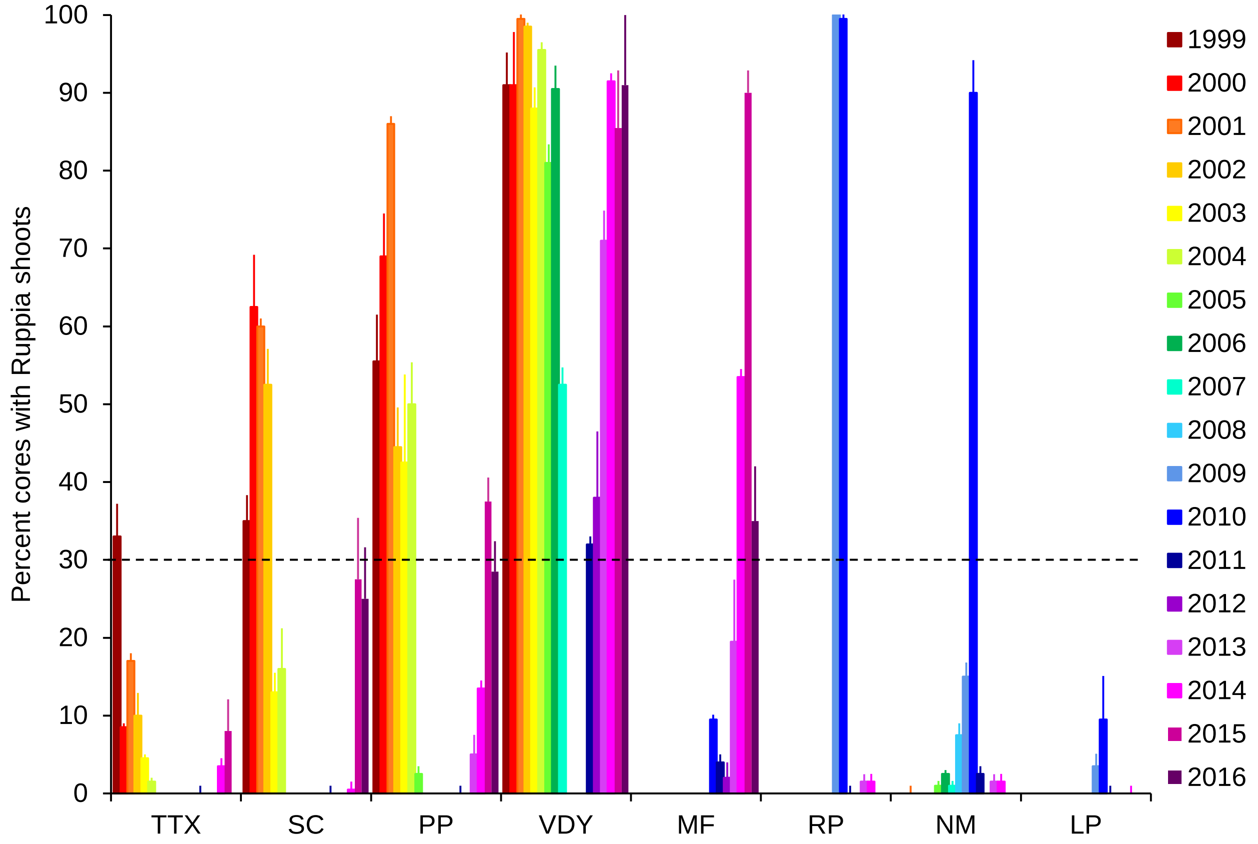


Figure 4: The percentage of 200 cores (75-mm diam x 40-mm deep) that contained R. tuberosa *shoots at each of eight sites spread along the North and South Lagoons during July from 1999 to 2016. See Table 2 for the locations, but sites are arranged from the southernmost site (TTX) in the South Lagoon 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* R. tuberosa *for four sets of 50 cores at each site. Pink colours are used to highlight more recent years. The dashed line represents the 30% target value for percent cores as defined in Table 1.*

re-appeared at Villa dei Yumpa, the northernmost monitoring site in the South Lagoon in July 2011. Fourth, from 2011-2015, there was evidence of recovery of *R. tuberosa;* however, despite suitable salinities throughout the South Lagoon over this period, recovery was slow and steady. For example, by winter 2013, only two sites met the target of at least 30% of cores having shoots, which increased to three sites in winter 2014 and then six sites in winter 2015 (Figure 6). Fifth, in winter 2016, *R. tuberosa* was still absent from the three most northern sites of the North Lagoon, namely Robs Point, Noonameena and Long Point, while there was also a decrease in cover and density at Magrath Flat (Figure 4 and Figure 5). *Ruppia tuberosa* had also disappeared from the southernmost site of the South Lagoon (Tea Tree Crossing) (Figure 4 and Figure 5). There was little difference in cover and density for Salt Creek and Policeman's Point, while Villa dei Yumpa was the only site to exhibit a small increase in cover and a large increase in shoot abundance (Figure 4 and Figure 5). The resulting number of sites that met the ">30% cores with shoots" criterion was halved from six in 2015 to three in 2016, while only one of these sites met the ">10 shoots per core" criterion (Figure 6).

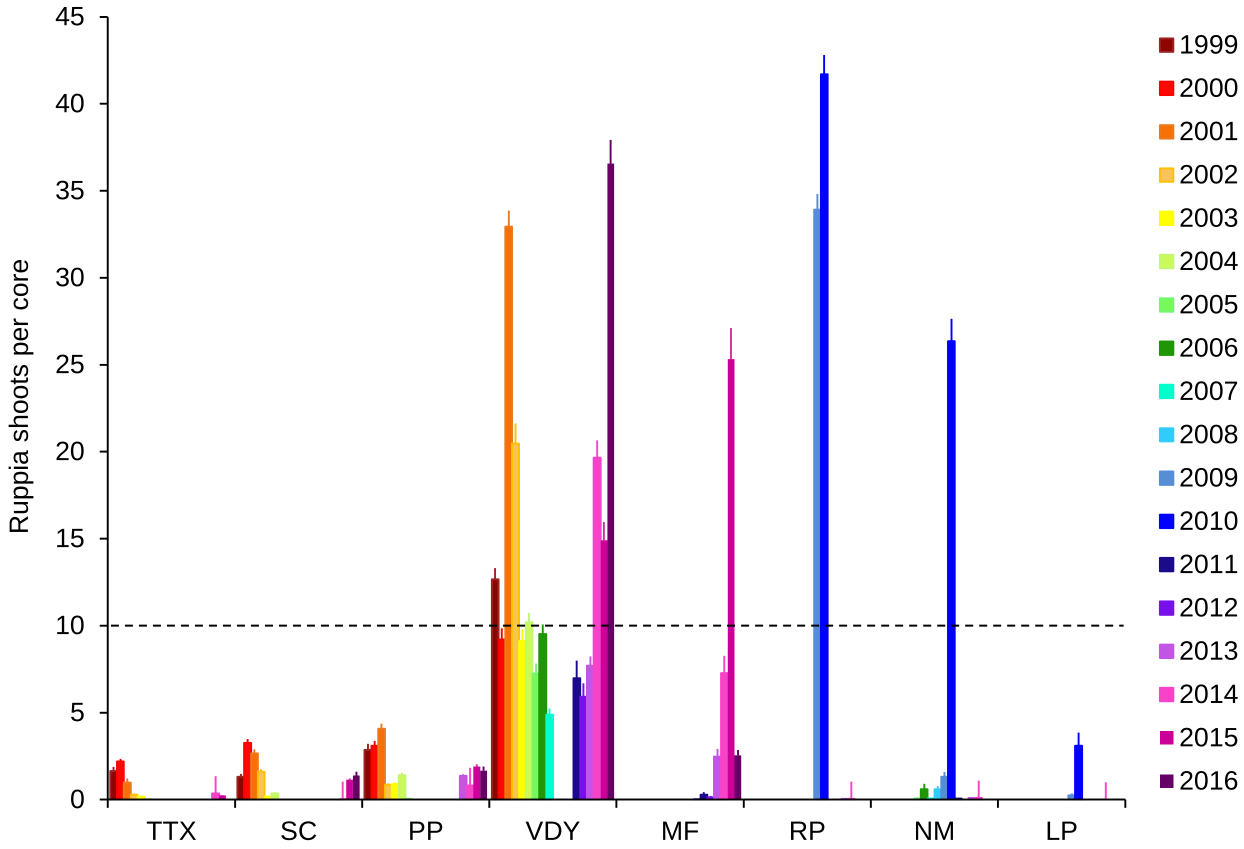
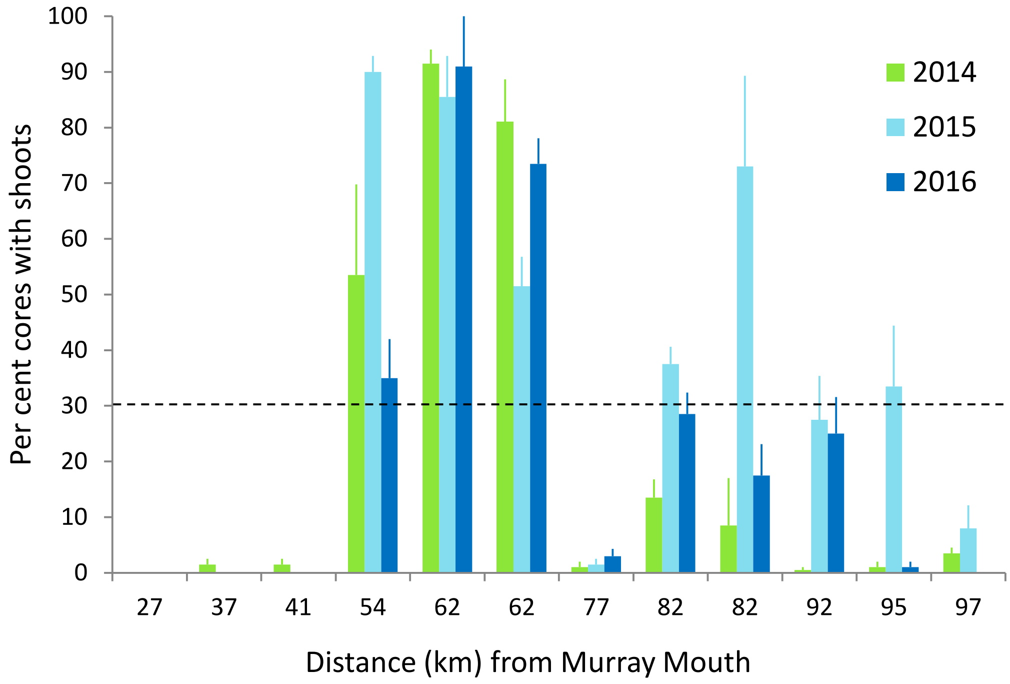


Figure 5: Mean number of R. tuberosa *shoots counted in 200 cores taken in July from eight sites spread along the Coorong from 1999 to 2016. See Table 2 for the locations, but sites are arranged from the southernmost site (TTX) in the South Lagoon to the northernmost site (LP) in the North Lagoon, with the four sites on the left in the South Lagoon and the four on the right the North Lagoon. Data show mean number of shoots per core + s.e. Shoots per core can be converted to shoots per m^2 by multiplying by 226. Pink colours are used to highlight more recent years. The dashed line represents the 10 shoots per core target value as defined in Table 1.*

4.3 Changes in the availability of R. 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 *R. tuberosa* relative to the 200 core samples and are not presented in this report. However, the samples collected along these transects 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 4 for 1998-2000, 2012-2014, 2015 and 2016. In 2016, only small numbers of seeds were detected at sites in the Coorong, with the greatest number of seeds detected at VDY and S06W and, albeit it to a lesser extent, S21E and MF (Table 4). This is similar to the previous four years, whereby the northernmost sites of the South Lagoon and southernmost sites of the North Lagoon have had the greatest abundances of seeds, which are also generally the sites that have had the highest cover in winter in recent years (Table 4).



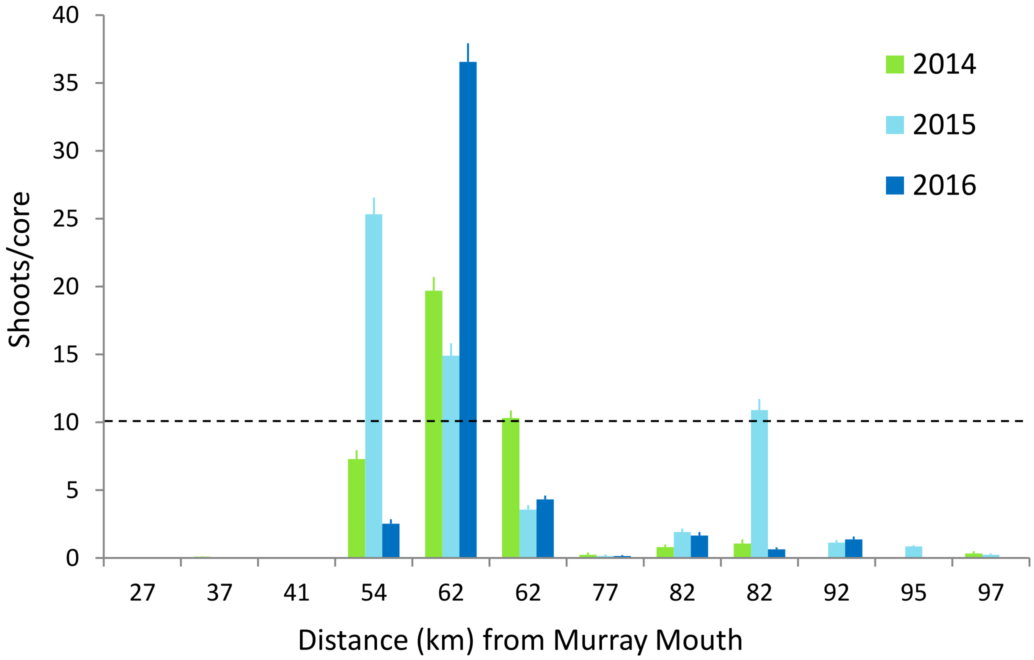


Figure 6: Percent of cores with R. tuberosa shoots and mean number of shoots per core counted in 200 cores taken in July 2014 (green), July 2015 (light blue) and July 2016 (mid blue) from 12 sites spread along the Coorong. Data show mean number of shoots + s.e. Shoots per core can be converted to shoots per m^2 by multiplying by 226. The junction of the two lagoons is 56 km from the Murray Mouth. The right-hand series of data for 62 km and 82km, and the data for 95 km are from sites on the western side of the Coorong, while all other sites are on the eastern side of the Coorong. The dotted lines on each graph represent the local (site) target values for these variables, as detailed in Table 1.

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 4 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 substantial seed production in the South Lagoon.

Seed abundances for *R. tuberosa* during the initial three years of monitoring (1998-2000) in the Coorong were an order of magnitude higher compared to abundances in recent years (Table 4), but seed abundances in the Coorong were 10-100 fold lower compared to Lake Cantara, where there have been 20-50 seeds per core in July in recent years. Very few turions have been detected in recent years (Table 4). Turions, however, are generally not abundant or expected to be abundant in winter.

4.4 *Status of* R. tuberosa *in the southern Coorong in July 2013-2016*

Ruppia tuberosa met only one of the three regional criteria (Area of Occupation (R.2)) that can be assessed in winter (Table 5). There has been a decrease in the R.1 and R.3 criteria over the past year, such that the Extent of Occurrence (R.1), which was met in both July 2014 and July 2015, was not met in July 2016, and only one site within the EOO was considered healthy, meaning target R.3 was also not met (Table 5). Only 11% of sites (or one of nine sites) in the southern Coorong had >30% cover and more than 10 shoots per core in July 2016, while all sites continued to have <2000 seeds/m^2 (Table 5). Consequently, resilience was negligible, with sites still lacking an adequate seed bank. In fact, apart from the northernmost sites of the South Lagoon and Magrath Flat, seed densities at sites were less than 150 seeds/m^2 (Table 4). For comparison, there were approximately 5,500 seeds/m^2 for *R. tuberosa* at Lake Cantara (Table 4). In conclusion, while a slow and steady recovery of *R. tuberosa* in the southern Coorong since the millennium drought was apparent up to July 2015, results from monitoring in July 2016 indicate that, over the past year, the *R. tuberosa* population of the southern Coorong has deteriorated.

4.5 *Changes in the distribution and abundances of benthic invertebrates in July*

Changes in the distributions and abundances of chironomids (*Tanytarsus barbitarsis*) and polychaetes (predominantly *Capitella* sp.) during winter along the Coorong are shown in Table 6 and Table 7, respectively, and are based on the 50 cores taken along the five replicate transects at each site.

Chironomid larvae were considerably less abundant in July 2016 than they were in July 2015 (Table 6). They occupied the same number of sites as in July 2015, but had a shift in distribution northwards. Chironomid larvae were distributed throughout the South Lagoon and at three sites in the North Lagoon (including up to Noonameena, some 20 km from the junction of the two lagoons) (Table 6), and across a salinity range of 57-105 gL^{-1} (Figure 2).

Table 4: Abundances of seeds and turions detected in core samples along transects at each of thirteen monitoring sites for July 1998-2000, July 2012-2014, July 2015 and July 2016. See Table 2 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. Data for July 2016 are means ± s.e. for seeds and turions, while for other years the data simply show the mean number of seeds and turions. Data in 2015 and 2016 are based on 50 core samples at each site, except for data for Lake Cantara, which are based on 10 samples in each year. The 1998-2000 data and the 2011-2013 data are based on 150 cores, 50 in each of the three years (except for Lake Cantara, which are based on 30 cores, with 10 taken in each year).

	July 1998-2000		July 2012-2014		July 2015		July 2016	
Site	seeds per core	turions per core	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	0.36	0	0.60	0.10	0.36 ± 0.10	0.02 ± 0.02
SC	2.34	0.12	0.27	0	0.16	0	0.52 ± 0.11	0
PP	3.88	0.48	1.27	0	0.46	0.64	0.56 ± 0.23	0.10 ± 0.08
VDY	14.06	0.12	1.77	0.17	1.12	0	3.28 ± 1.09	0.02 ± 0.02
S06W			1.52	0.07	1.70	0	3.32 ± 0.49	0.32 ± 0.16
S21E			0.23	0	0.08	0.02	1.12 ± 0.33	0
PS			0.33	0	0.30	1.10	0.12 ± 0.06	0.08 ± 0.06
S39W			0.01	0	0.02	0.74	0.06 ± 0.03	0.04 ± 0.03
North Lagoon								
MF			0.52	0.01	1.20	0.18	1.46 ± 0.38	0.04 ± 0.04
RP			0.16	0	0	0	0.30 ± 0.10	0
NM	0.0	0.0	0.03	0	0.06	0	0.14 ± 0.06	0
LP			0	0	0	0	0	0
Outside								
LC			24.47	0	38.4	0	24.2 ± 3.43	0

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 6). 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 (Figure 2). During the winters of 2007-2010, salinities in the South Lagoon were above 120 gL^{-1} and exceeded 140 gL^{-1} in the winters of 2008 and 2009. In July 2011, however, the salinities were around 110-115 gL^{-1} and chironomid larvae were once again found in the South Lagoon. This suggests that the upper salinity tolerance for *Tanytarsus barbitarsis* in the Coorong is around 120 gL^{-1}. However, in July 2016, and for the first time in six years (i.e., since 2010), chironomid larvae were not detected at either Tea Tree Crossing or Salt Creek, the two southernmost sites on the eastern shore of the South Lagoon. The cause is likely linked to salinity but not necessarily winter salinity, as salinity was about 110 gL^{-1} in July 2016, which was slightly less than July 2011 (Figure 2), when chironomid larvae were found at

Table 5: Status of R. tuberosa *in the Coorong in July 2014-2016, assessed using 12 sites from TTX in the south to Long Point in the north. The shaded section of the Table provides the statistics (number of sites reaching target) on which the regional indices, R.3 (VIG) and R.4 (RES), were based.*

Criterion	Target	July 2014	July 2015	July 2016	Comments for 2016
R.1 distribution along Coorong (km) **EOO**	43	60	43	41	Target not met in 2016; EOO has decreased over past 3 years.
R.2 % sites with plants within EOO **AOO**	80	100	100	100	As in previous years, although target met, abundances at many sites were low, particularly at the southern end of the range (EOO)
R.3 % sites with vigorous populations within EOO **VIG**	50	18	33	13	As in previous years, target not met in 2016; only 1 of the 8 sites within the EOO had good population densities (based on L.1 & L.2); VIG has decreased from 2015.
R.4 % sites with resilience (> 2,000 seeds/m^2) **RES**	50	0	0	0	As in previous years, target not met in 2016; No sites had resilience - all sites still lack an adequate seed bank.
L.1 # sites > 30% cover		3	6	3	
L.2 # sites > 10 sh/core		2	3	1	
Both L.1 & L.2		2	3	1	
RS.1 # sites with > 2,000 seeds/m^2		0	0	0	

these sites, and less than the suggested upper salinity tolerance of 120 gL^{-1}. However, salinities at these sites in January 2016 were similar to those in January 2010 and notably higher than in any of the preceding five years (Paton *et al.* 2016d). This suggests that while there is likely an upper salinity threshold for chironomid larvae, it may be the salinity in summer or even autumn, when salinity peaks, which is the critical salinity for chironomid larvae and, hence, governs their distribution.

*Table 6: Changes in the distribution and abundance of chironomid (*Tanytarsus barbitarsis*) larvae along the Coorong in July from 1998 to 2016. Data are means for 50 core samples taken from each site in each year of sampling (1998-2016) except for Magrath Flat (MF), Rob's Point (RP) and Long Point (LP), which were sampled only from July 2009 onwards and S06W, S21E, Princes Soak (PS) and S39W, which were only sampled from July 2012 onwards. To convert these mean values to chironomid larvae/m^2 multiply by 226. Standard errors were typically around 15-30% of the means and have been provided in other reports for earlier years (e.g. Paton & Bailey 2011; Paton* et al. *2015a). TTX (Tea Tree Crossing, SC (Salt Creek), PP (Policeman's 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.*

Year	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
2014	0.1	0.4	0.6	0.02	0.3	0.3	0.04	0	3.1	0.9	5.0	5.9
2015	0.8	1.6	7.6	5.1	15.8	0	0	0	1.1	2.1	9.0	12.5
2016	0	0	0.1	3.7	1.5	0.5	0.8	0	1.0	0.1	2.8	0.8

*different species of chironomid

Table 7: Changes in the distribution and abundance of polychaetes (predominantly Capitella sp.*) along the Coorong in July from 1998 to 2016. Data are means for 50 core samples from each site in each year of sampling (1998-2016), except for Magrath Flat (MF), Rob's Point (RP) and Long Point (LP), which were sampled from July 2009 onwards and S06W, S21E, Princes Soak (PS) and S39W, which were only sampled from July 2012 onwards. 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 (e.g., Paton & Bailey 2011 and Paton* et al. *2015a). TTX (Tea Tree Crossing), SC (Salt Creek), PP (Policeman's Point), 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 polychaetes per core											
Year	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
2014	0	0	0	0	0	20.0	32.9	48	0	0	0	0
2015	0	0	0	0	0	28.0	40.8	43.9	0	0	0	0
2016	0	0	0	0	0	39.6	39.0	22.3	0	0	0	0

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., RP; Table 6). In July 2010, chironomid larvae were present at all four monitoring sites in the North Lagoon, but were particularly abundant at RP and NM, where *R. 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 the northernmost of these sites in July from 2012 to 2015. Generally, the low numbers and or absence of chironomid larvae in surface sediments in the North Lagoon in July over multiple years coincided with salinities that were below 40-50 gL^{-1}. These data suggest that, within the Coorong, *Tanytarsus barbitarsis* may be limited to conditions where the salinity is above 40-50 gL^{-1}.

Consistent with four of the preceding five years, polychaetes were detected in similar numbers at the three northernmost sites in the North Lagoon in July 2016 (Table 7), where salinities ranged from 49-58 gL^{-1} (Figure 2). Polychaetes (predominantly *Capitella* sp.) have only been detected in the North Lagoon during the nineteen years of sampling (Table 7). Polychaetes were generally prominent at Noonameena in July from 1998 to 2002 when salinities at this site were typically on or below 45 gL^{-1} (Figure 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 Rob's Point (4 km 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 Rob's Point to Long Point were in the range of 20-42 gL^{-1} and polychaetes were abundant across all three sampling sites (Table 7). They were even more abundant at these sites in July 2012 and still prominent at these sites in July from 2013-2015. The expansion in the distribution of polychaetes southwards in July 2013, with large numbers of polychaetes detected at Magrath Flat for the first time in that year, was not maintained and no polychaetes have been detected at this site since (Table 7). Overall, these field data suggest that *Capitella* sp. performs best when winter salinities are below 60 gL^{-1}.

In summary, over the last eighteen years, chironomids have shown shifts in distribution that generally match the changes in distribution for *R. tuberosa*. However, unlike *R. tuberosa*, polychaetes and the chironomid *Tanytarsus barbitarsis* have both responded quickly to the re-instatement of appropriate salinities in the Coorong.

5 Discussion

In general, *Ruppia tuberosa* was less abundant in July 2016 than in July 2015 and July 2014 (e.g., Figure 6), indicating a reversal of the slow and steady recovery of *R. tuberosa* observed over the past few years in the southern Coorong. Similar to last year, the extent of occurrence contracted but, this year, it was to the extent that it did not meet the 43 km target of criterion R.1. There was also a reduction in the number of sites which held a vigorous population of *R. tuberosa*, and like previous years, the R.3 criterion target was not met. The only criterion that was met (of the three that can be assessed in winter) was R.2, or the area of occupation (AOO); however, as in previous years, abundances at many sites were low, particularly at the southern end of the range. That the cover and abundance of *R. tuberosa* improved at some sites and not others was not unexpected as most of the populations of *R. tuberosa* in the Coorong have lacked vigour and all continue to lack resilience. In recent years, water levels in the southern Coorong over spring and early summer have been poor for *R. tuberosa*, such that reproductive outputs have continued to be minimal or non-existent at each site. Consequently, few seeds and turions have been produced, restricting the capacity of populations to re-establish in the following winter. A reduction in abundance of *R. tuberosa* compared with previous years was also not unexpected, as the spring and early summer conditions in 2015-16 were even poorer for *R. tuberosa* than previous years, with water levels steadily declining in spring and being consistently 10-20 cm lower than the previous four years (Paton *et al.* 2016c). Furthermore, *R. tuberosa* populations have, in general, not recovered to levels comparable to those prior to the millennium drought, while all continue to lack resilience.

The apparent anomaly between the sometimes high numbers of shoots detected in cores in winter and the low numbers of seeds and turions produced in the previous year is easily explained. The numbers of shoots counted in cores in July includes not just the small numbers of propagules (seeds, turions) that give rise to plants but also includes the shoots subsequently produced along rhizomes as those plants grow. This vegetative rhizomatous growth continues during winter and spring (provided conditions remain suitable of course), leading to higher cover and density of shoots prior to flowering. Some care is therefore required in interpreting numbers of shoots. For comparison, the population of *R. tuberosa* at Lake Cantara can have 100% cover and over 80 shoots per core in early July in good years, while at least a further 20 seeds/core (and usually more), remain in the sediment.

The basin-wide environmental watering strategy also sets targets for *R. tuberosa* that need to be met by 2019 and 2029 (Murray-Darling Basin Authority 2014). These targets are a sustained and adequate population of *R. tuberosa* in the south lagoon of the Coorong, including:

(i) by 2019, *R. tuberosa* to occur in at least 80% of sites across at least a 50 km extent; and

(ii) by 2029, the seed bank (10,000 seeds/m^2) to be sufficient for the population to be resilient to major disturbances.

These basin-wide targets need refinement in that a 'sustained and adequate population' of *R. tuberosa* is not clearly defined. Simply basing the assessment on the extent of occurrence (EOO target currently 50 km, but should be adjusted to 43 km, Paton *et al.* 2015b) and area of occupation (AOO target 80% of sites) alone does not define conditions where the distribution and abundance of *R. tuberosa* in the southern Coorong is adequate and sustainable. Although the AOO target for *R. tuberosa* was met in July 2016, the EOO target was not met. Ultimately the assessment should include measures of vigour and initial resilience (Table 1 and Table 5) as part of the overall basin-wide targets set for *R. tuberosa* that need to be reached by 2019. This refinement would set additional targets of at least 50% of sites with *R. tuberosa* having vigorous populations (>30% cover in winter) and an initial level of resilience (>2,000 seeds/m^2; e.g., Table 1).

The fact that *R. tuberosa* populations have not yet recovered their vigour and resilience reflects the lack of suitable conditions during spring and early summer over the last five years, as these targets are not overly onerous and would require only one or two good seasons to achieve. Therefore, the ability of *R. tuberosa* to meet the 2019 targets that have been set will depend on whether suitable conditions through spring and early summer are provided in the next three years to allow adequate reproduction to occur. Given the lack of suitable water levels in the southern Coorong during spring and into early summer over the last five years, none of which have been drought years in the Murray-Darling Basin, alternative management strategies are likely to be required to maintain such water levels. One option would be the installation of a barrier across the Coorong, near the Needles, to restrict water flow out of the southern Coorong and maintain water levels during spring and into early summer to enable the completion of the reproductive cycle of *R. tuberosa*. There is incentive to act now, not only while *R. tuberosa* still has the capacity to recover, but also because in its current depleted state, *R. tuberosa* has a diminished ability to support waterbirds (including migratory shorebirds) that use the southern Coorong over summer and depend on *R. tuberosa* for food (either directly or indirectly) (Paton et al., 2015c).

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