Response of *Ruppia tuberosa* in the Coorong South Lagoon to environmental water delivery over summer 2012-13

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Front image: R*uppia tuberosa* growing in shallow water at Lake Cantara illustrating the extent of cover expected from a healthy population.(photo courtesy of D. Paton)

Summary

The distribution, abundance and reproductive performance of *Ruppia tuberosa* was monitored in the southern Coorong to determine whether the addition of environmental water to flows over the barrages benefitted this plant. The critical need for additional environmental water was to maintain water levels over the *Ruppia* beds to allow them to complete their reproductive cycles. This, however, did not eventuate with water levels dropping during November, December and January to levels that prevented *Ruppia tuberosa* from reproducing successfully. Not only did the plants fail to flower, but the production of type II turions was also to no avail for many plants, since the turions produced by these plants in November were also left out of the water when water levels dropped further over summer, exposing the type II turions to desiccation. These findings indicate that *The Living Murray's* monitoring target (V-2) to maintain or improve *Ruppia tuberosa* colonisation and reproduction in the Coorong was not met in 2012-13.

Consistent with poor reproductive performances was the extremely low numbers of seeds and turions present in sediments in January after the spring flowering season. There was no measurable change in the numbers of seeds detected in sediment samples over the last 3 years indicative of an extended period of little or no reproduction. Clearly the seed banks for *Ruppia tuberosa* remain precariously low in the Coorong, doubly so because the vast majority (>99%) of seeds detected and counted were not viable.

The low abundance of *Ruppia tuberosa* throughout most of the Coorong contrasted with the plant's performance at Gemini Downs Bay (S33E) where a sandbar prevented water levels from receding to the same low levels as elsewhere in the Coorong during spring and summer. *Ruppia tuberosa* plants in this small bay were abundant and producing many type II turions in January but these plants had also flowered and produced seeds in spring. This productivity occurred despite heavy grazing by waterfowl and the presence of filamentous green algae and indicates that the maintenance of adequate water levels through spring is the critical issue that needs to be addressed.

Despite the low water levels in summer, small numbers of *Ruppia tuberosa* plants were present at many sites in the southern Coorong in January, indicating that there were at least a few viable seeds present in the sediments. The healthy plants that were present in January 2013 were in water that was 30-60 cm deep. These were generally small plants that were likely to have germinated in late spring when water levels had dropped to an extent that light could penetrate to the Coorong floor at these sites. Most were yet to produce turions. As water levels dropped further during February and into March some of these plants and many of the turions that had been or were to be produced would have been exposed to desiccation. Consistent with the wide distribution of plants were modest numbers of short fragments of *Ruppia tuberosa* being washed ashore along the eastern side of the southern Coorong. Foraging by waterfowl and wave action were likely to be dislodging plants from the sediments. Filamentous green algae were also attached to many of the fragments along the length of the southern Coorong and may interfere with plants in the future.

Until the low water levels during spring are addressed, *Ruppia tuberosa* will struggle to re-establish in the southern Coorong. Even recent translocation programs for *Ruppia tuberosa* may fail because of this. If appropriate water levels cannot be re-instated, then exploring the use of sandbars to prevent low water levels may provide some additional refuge sites for *Ruppia tuberosa* in the Coorong. The small supplementary volumes of environmental water used during 2012-3 allowed

flows of water over the barrages of 4,000-6,000 $ML.day^{-1}$ during November and December. Such flows were inadequate to safe guard against low water levels. Volumes of around 30,000 $ML.day^{-1}$ may be required to protect most of the *Ruppia tuberosa* beds from falling water levels during spring.

Introduction

Ruppia tuberosa was once widespread along the length of the South Lagoon of the Coorong. However during the millennium drought the River Murray did not flow to its mouth for extended periods and *Ruppia tuberosa* disappeared from the South Lagoon and its seed bank was severely eroded (Paton 2010, Paton & Bailey 2012). The key driver for the loss of *Ruppia tuberosa* has been attributed to low water levels during spring. Consistently low water levels in spring, particularly, during the drought left many of the beds of *Ruppia tuberosa* exposed during spring preventing the plants from setting seeds or producing turions before dying. *Ruppia tuberosa* performs poorly when salinities exceed 100 gL^{-1} and as the salinities in the South Lagoon were consistently above 100 gL^{-1} and at times exceeded 150 gL^{-1}, high salinity has been implicated as the driving factor for the loss of *Ruppia tuberosa*. When salinities are high (>100 gL^{-1}) germination of seeds and growth of seedlings are impeded (Paton *et al.* 2011; Paton & Bailey 2010, 2012; Kim *et al.* 2013). However *Ruppia tuberosa* declined and had largely disappeared from much of the South Lagoon by June 2004 before high salinities were reached (Paton 2010). Thus low water levels during spring rather than high salinities eliminated the plant from much of the South Lagoon (Paton 2010). When substantial flows returned to the Murray in the latter half of 2010 an emphasis was placed on restoring salinities to more typical levels with little emphasis placed on water levels. The expectation was that *Ruppia tuberosa* would, like other aquatic biota, quickly recover once the salinities returned to more typical levels. This has not happened.

Since the return of freshwater flows to the region there has been little if any recovery of *Ruppia tuberosa* in the South Lagoon (Paton & Bailey 2012, 2013) and the extensive beds that had gradually established in the North Lagoon between 2006 and 2010 were also quickly lost (e.g. Paton & Bailey 2012; unpubl.). The net result was that *Ruppia tuberosa* became even less abundant following the return of freshwater flows to the Murray Mouth, than immediately prior to the end of the drought and there has been no improvement since (Paton & Bailey 2013). Two factors have contributed to this poor recovery. First, the quantities of propagules (seeds) remaining in the sediments are extremely low and on their own unlikely to facilitate the rapid recovery of *Ruppia tuberosa* throughout most of the South Lagoon (Paton & Bailey 2012, 2013). Second, although flows returned to the region in spring 2010 during each of the next two years (spring 2011 and spring 2012) flows diminished dramatically in spring resulting in water levels once again falling at critical times. This project aimed to monitor the influence of additional releases of water over the barrages on the remnant populations of *Ruppia tuberosa* in the southern Coorong.

Environmental water (e-water) was released over the barrages from 28 October 2012 until the end of June 2013. This allocation of e-water had multiple purposes but the e-water released from December to February was to enhance barrage releases primarily to benefit *Ruppia tuberosa*. The extra volume of water was aimed at sustaining water levels in the Coorong between 0 - 0.2 m AHD over summer. Due to delivery constraints this resulted in 150 GL of e-water being released in December, 100 GL over January and 50 GL over February (A. Frears pers. comm.). This additional water resulted in flows around 4,000 - 6,000 $ML.day^{-1}$ over the barrages during November and December, with flows around 1,000 $ML.day^{-1}$ during January and 400-700 $ML.day^{-1}$ during February (Figure 1). The majority of the water was released over the Tauwitcherie Barrage (A. Frears pers. comm.). Essentially this environmental allocation of water was hoped to extend the period of time that remnant *Ruppia tuberosa* beds were covered with water in the hope that this would allow them to complete their reproductive cycle.

Based on historical and on-going monitoring most of the beds of *Ruppia tuberosa* are found on mudflats at elevations of around -0.2 m AHD to 0.2 m AHD in the southern Coorong, and this can be used to provide an estimate of the water levels needed through spring to allow the plants to reproduce. *Ruppia tuberosa* is sensitive to desiccation and because wind-induced changes in water level in the Coorong are around 0.3 m, water levels over these beds need to be at least 0.3 m. This equates to having a water level of at least 0.5 m AHD if all of the beds are to be adequately covered with water. Water levels over the beds should also not exceed 0.9 m, as *Ruppia tuberosa* generally does not grow in water deeper than about 0.9 m in the Coorong because the high turbidity of the water reduces light penetration to the sediment bed (Paton & Bailey 2010). Thus the maintenance of water levels of around 0.5-0.7 m AHD provides the ideal depths for the existing beds of *Ruppia tuberosa* to flourish. This provides a basis to assess the ability of supplementing flows with environmental water. If water levels drop below 0.5 m AHD, then some of the higher elevation areas of the *Ruppia* beds risk periodic exposure. If the water levels drop below 0.1 m AHD then most of the lower elevation areas of the beds also risk exposure. Given this, the use of e-water to maintain water levels at 0 - 0.2 m AHD in 2012-13 is only likely to protect *Ruppia tuberosa* growing at the lower elevations.

Methods

Field work for this project consisted of:

- conducting reconnaissance surveys to check on the flowering of *Ruppia tuberosa* at key sites in the South Lagoon in November and December and measuring the extent of flowering;
- measuring the abundances of seeds, turions and shoots of *Ruppia tuberosa* in January across the South Lagoon; and
- monitoring the presence of *Ruppia* shoots and filamentous green algae along the eastern shorelines of the South Lagoon in the Coorong during January.

<u>Reconnaissance surveys in November and December 2012</u>

Sampling in July 2012 detected that the only sites where there was reasonable cover (>30%) of *Ruppia tuberosa* was in the northern sections of the South Lagoon (Paton & Bailey 2013). These populations were checked monthly for signs of flowering and in October a few floral stalks were being produced. The reconnaissance surveys in November and December were aimed at following the fate of these plants, and if flower-heads were produced, these would be measured by using a quadrat (1 m^2) and counting the numbers of inflorescences on or near the surface within replicate quadrats. Any entanglement of algae around the flower-heads would also be scored. In November 2012 the water levels had dropped, and flowering had not proceeded and so instead of measuring the numbers of floral heads being produced, we scored the cover of existing plants, their condition (extent of brown shoots) and any production of turions from 100 cores (75 mm diameter x 4 cm deep) at each of four water levels (10 cm, 30 cm, 50 cm and 60 cm).

Distribution and abundance of *Ruppia tuberosa* in the southern Coorong in January 2013

During January 2013 the abundance and reproductive activity of *Ruppia tuberosa* was assessed at eight sites on the eastern side of the South Lagoon in the Coorong, and eight sites on the western side of the South Lagoon. These sites were spread along the shoreline at 5 km intervals. The western sites were approximately opposite the eastern sites. These 16 sites coincided with sites that were originally sampled in 1984-85 as part of an initial monitoring program for the South Lagoon. *Ruppia tuberosa* was detected at all sites in 1984-5. In addition, four sites were sampled along the eastern shoreline of the North Lagoon in January 2013. These were sites where *Ruppia tuberosa* was recorded in recent years (i.e. during the latter parts of the millennium drought). The eight sites in the South Lagoon of the Coorong along the eastern shoreline and the four sites in the North Lagoon form part of an annual monitoring program that has run since 2000. A system for defining sites was adopted that incorporated the lagoon, the distance (km) north or south from the junction of the North and South Lagoons (respectively), and the eastern or western shoreline, unless the site also had a well-defined place name. For example, site S06W was in the South Lagoon, 6 km south of the junction and on the western side of the Coorong.

At each site 25 core samples (75 mm diam, 4 cm deep) were taken at each of four water depths: dry mud surface approximately midway between the current waterline and the high water line (and if known positioned on areas where *Ruppia tuberosa* was growing in July 2012 (e.g. sites Villa dei Yumpa (S06E) and S06W); waterline; 30 cm water depth; and 60 cm water depth. Each core sample was assessed for presence of *Ruppia tuberosa* shoots and then sieved through 500 µm Endecott sieves enabling seeds and turions to be extracted and counted. An additional site, a bay opposite Gemini Downs (now known as Bonshaw) was also sampled for comparison. This bay in the South Lagoon is buffered from falling water levels because a sandbar cuts it off from the rest of the Coorong halting further reductions in water level.

Scoring the numbers of shoots and presence of algae washed onto eastern shorelines.

Within 1 km sections of the South Lagoon, three replicate 50m transects were established running along the shoreline. The numbers of fragments of *Ruppia tuberosa* (stolons with shoots) and the lengths of these (measured as the number of nodes (with shoots) along the fragment) were counted along the tape for a 4m width out into the water. These counts were used to provide a further estimate of *Ruppia* presence and abundance in the vicinity of that site. Although the relationship between the amount of material washed ashore and abundance of *Ruppia* is not known, historically, when *Ruppia* was abundant large quantities of *Ruppia* were regularly dislodged from beds and washed ashore. Due to the water being very turbid and *Ruppia* likely to be thinly and sporadically distributed, sampling by taking sediment cores may miss some patches. This technique provides a further method for assessing such thinly dispersed plants. In addition we also aimed to score the prominence of filamentous green algae along the shore and the extent to which the rhizomatous *Ruppia* fragments had been entangled in algae. Note that we did not count material that had already been deposited and left high and dry above the shore, as we did not know how long these had been stranded and could not be consistent between areas. Our counts provide a more instantaneous measure of the current availability of fragments of *Ruppia tuberosa* plant.

Results

Maintenance of suitable water levels through spring

The flows of water over the barrages were typically in the order of 40 – 60 $GL.day^{-1}$ in August and September 2013 but then steadily declined during October and were around 4-9 $GL.day^{-1}$ in November and December (Fig. 1). Flows over the barrages were lower again in January 2013 (~1GL.day-1) and February 2013 (0.4-0.7 $GL.day^{-1}$; Fig.1). Water levels across the South Lagoon of the Coorong generally tracked these changes in flows and were typically around 0.6 - 0.8 m AHD in August 2012 and remained above 0.5 m AHD until around mid-October. From mid-October onwards water levels fell steadily and by December were around 0 - 0.2 m AHD (Fig. 1). At these water levels, beds of *Ruppia tuberosa* detected in July were all but exposed in December (see below). Water levels continued to drop steadily through January and February and were below 0 m AHD. The lowest water levels of -0.2 m AHD were reached in mid-March. Although the environmental water may have dampened the speed with which water levels dropped, the water levels by early December were nevertheless such that the higher elevation components of the *Ruppia tuberosa* beds were exposed. The salinities during August, September and October were in the range of 50 - 60 gL^{-1} but increased slightly in November and December to 60 – 70 gL^{-1}. These salinities were within the targeted salinities expected to promote the growth of *Ruppia tuberosa* in the Coorong. Salinities continued to increase during January and February and exceeded 80 gL^{-1} by the end of February.

Reconnaissance surveys in November and December

In November water levels were around 0.2 m AHD and the main areas with *Ruppia tuberosa* were now covered by less than 10 cm of water. Substantial areas were also fully exposed and the plants had desiccated. There was no evidence of successful flowering at these sites. There were, however, occasional snapped floral stalks probably caused by interference from filamentous green algae. The exposed *Ruppia* beds, however, had succeeded in producing type II turions prior to being exposed and where those desiccated plants existed, there were mean numbers of type II turions of 24, 27 and 22 per core at Magrath Flat, Parnka Point and Villa dei Yumpa respectively (Table 1). However, these type II turions once exposed have a short life span.

For the mud flats that were still covered with water, there were *Ruppia tuberosa* plants particularly in the shallower depths but many of the shoots covered by less than 30 cm of water were browning indicative of them experiencing some exposure to the air or high temperatures. There were no flower-heads associated with these plants but there were some type II turions being produced (Table 1). The differences between sites in % cores with *Ruppia* were consistent with the Villa dei Yumpa site having higher cover in winter (Paton & Bailey 2013).

Based on this assessment there was some prospect that if water levels could be maintained or even elevated slightly then improved outcomes for *Ruppia tuberosa* might be measured as increased cover, increased abundances of plants and increased numbers of turions (but not seeds as there had been no successful flowering at these sites).

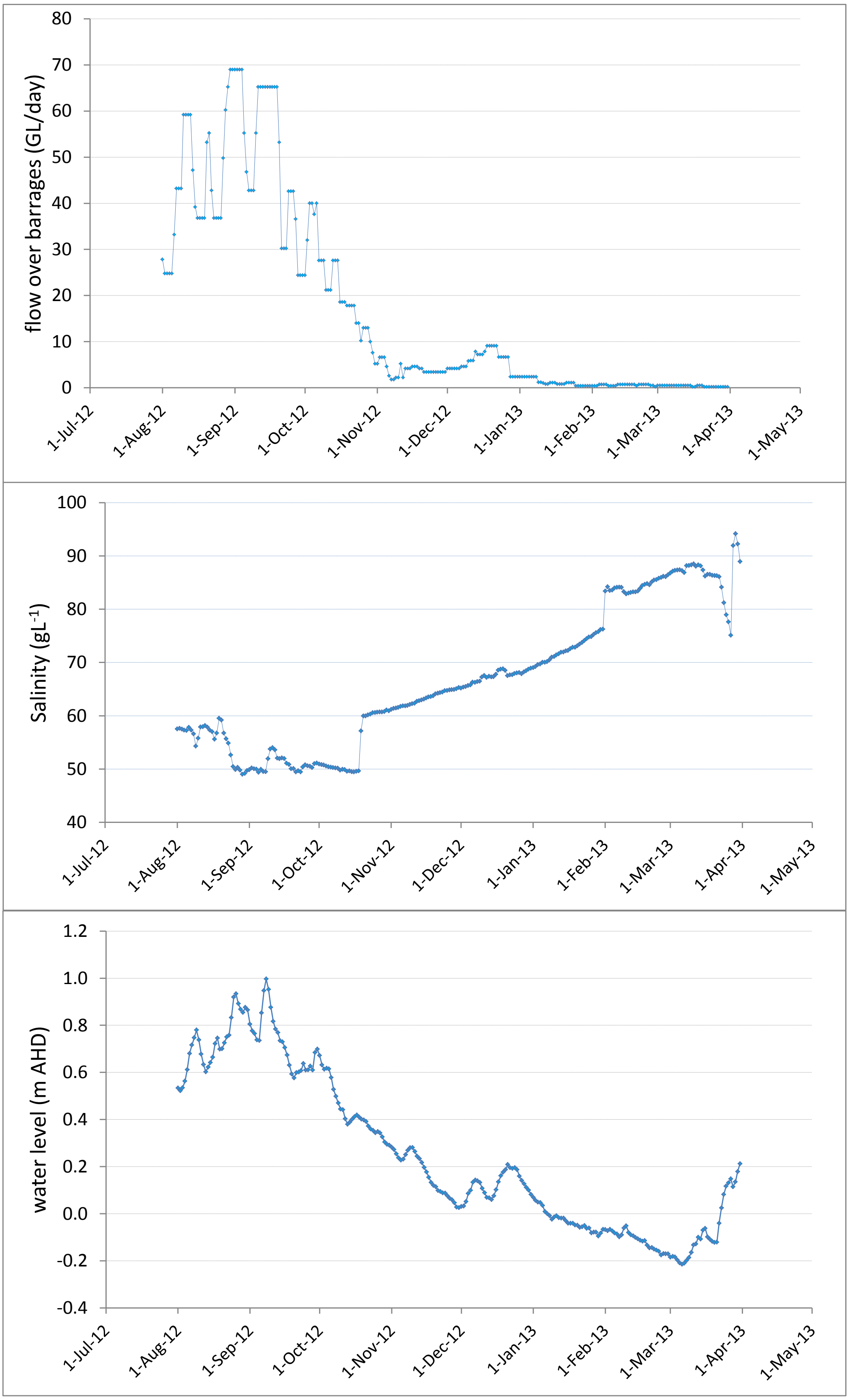

Figure 1. Daily flows of water over the barrages, average salinities and water levels for the South Lagoon from August 2012 to March 2013. Figures based on data held by DEWNR (courtesy A. Frears).

Table 1. Summary statistics for *Ruppia tuberosa* monitoring at selected sites in the southern Coorong in November 2012. Note data are based on measurements taken from 100 core samples (75 mm diam, 4 cm deep) at each water depth at each site.

Location	Water depth (cm)	% cores with *Ruppia* shoots	% shoots browning	shoots per core	Flower heads per core	turions (type II) per core
Magrath Flat (N02E)	10	14	23	4.62	0	1.68
	30	0		0	0	0
	50	1	0	0.01	0	0
	60	5	20	0.25	0	0
Parnka Point (S03E)	10	0		0	0	0
	30	1	0	0.02	0	0
	50	0		0	0	0
	60	0		0	0	0
Villa dei Yumpa (S06E)	10	50	69	17.0	0	5.00
	30	6	33	1.02	0	0.06
	50	3	3	0.06	0	0.15
	60	5	5	1.15	0	0.22

Table 2. Per-cent of cores with *Ruppia tuberosa* plants present at different water depths across 20 sites in the southern Coorong in January 2013. Twenty-five cores were taken at each depth at each site.

Site	km from Mouth	East				West			
		dry	waterline	30cm	60cm	dry	waterline	30cm	60cm
N19	38	0	0	0	0				
N12	45	0	0	36	0				
N07	50	0	0	0	0				
N02	55	0	0	4	0				
S06	62	0	0	28	0	0	0	40	0
S11	67	0	0	12	0	0	8*	0	0
S16	72	0	0	0	0	16*	24*	8	0
S21	77	0	0	0	0	12*	8*	0	0
S26	82	0	32*	16	8	0	24*	0	12
S31	87	0	0	0	0	0	0	0	0
S36	92	0	0	0	0	0	0	0	0
S41	97	0	0	0	0	0	0	24	36

* shoots were brown

In early December when these sites were revisited, the water levels had dropped further to around 0 m AHD and so additional areas of *Ruppia tuberosa* were now fully exposed, including those that were covered by 10-20 cm of water in November 2012.

<u>Distribution and abundance of *Ruppia tuberosa* in the southern Coorong in January 2013</u>

Summary statistics on the presence of live *Ruppia tuberosa* plants across the 20 sampling sites are provided in Tables 2 and 3. *Ruppia tuberosa* continued to maintain a low presence within its historical range within the southern Coorong with plants still present (and not browning) at 8 locations but the numbers of cores and plants per core were generally low (Tables 2 and 3). Additional plants since December had been exposed and these plants were brown in colour and had not survived. Most of the healthy plants that were present in January 2013 were in water that was 30 – 60 cm deep. These were generally small plants that were likely to have germinated when water levels in spring allowing more light to reach the sediments.

Table 3. Mean numbers of *Ruppia tuberosa* shoots present in cores (75 mm diameter x 4 cm deep) taken at four water depths at 20 sites spread across the southern Coorong in January 2013. Data are based on 25 cores taken at each water depth at each site. To express these data as shoots.m^{-2} multiply by 226.

Site	km from Mouth	East				West			
		dry	waterline	30cm	60cm	dry	waterline	30cm	60cm
N19	38	0	0	0	0				
N12	45	0	0	5	0				
N07	50	0	0	0	0				
N02	55	0	0	0	0.16				
S06	62	0	0	4.2	0	0	0	3.6	0
S11	67	0	0	0.52	0	0	0.28*	0	0
S16	72	0	0	0	0	0.26*	1.80*	1.56	0
S21	77	0	0	0	0	1.36*	0.28*	0	0
S26	82	0	1.12*	4.92	1.04	0	0.28*	0	0.52
S31	87	0	0	0	0	0	0	0	0
S36	92	0	0	0	0	0	0	0	0
S41	97	0	0	0	0	0	0	5.44	6.08

* shoots were brown

The abundances of propagules associated with these plants were also extremely low. Tables 4 and 5 show the data for turions. Ony type II turions were present. Type II turions carry much smaller reserves than type I turions and have limited capacity to survive any extended period of desiccation. Consistent with this is the very low percentages of cores now carrying turions in samples taken from dry mud flats and at the waterlines. For some sites such as S06E (Villa dei Yumpa) these areas previously had *Ruppia tuberosa* and turions in November (e.g. see Table 1). Equally though plants that were in water that was 30 cm or 60 cm in depth in January 2013 had also not accumulated large numbers of turions. These plants were small, were being heavily grazed and were likely to have germinated only when water levels had dropped during spring. During winter these plants were likely covered by more than 1 m of water and with high turbidity were unlikely to be able to grow because of a lack of light penetration until the water levels had dropped.

Table 4. Per-cent of cores containing *Ruppia tuberosa* turions (Type II only) across 4 water depths at 20 sites in the southern Coorong in January 2013. Data are based on 25 cores taken at each depth at each site.

Site	km from Mouth	East				West			
		Dry	waterline	30cm	60cm	dry	waterline	30cm	60cm
N19	38	0	0	0	0				
N12	45	4	20	48	0				
N07	50	0	0	0	0				
N02	55	0	0	0	4				
S06	62	0	0	12	0	0	0	0	0
S11	67	0	0	0	0	0	0	0	0
S16	72	0	0	0	0	0	0	0	0
S21	77	0	0	0	0	12	0	0	0
S26	82	0	24	8	0	0	24	0	4
S31	87	0	0	0	0	0	0	0	0
S36	92	0	0	0	0	0	0	0	0
S41	97	0	0	0	0	4	0	4	0

Table 5. Mean number of type II turions per core (75 mm x 4 cm) across 4 water depths and at 20 sites within the southern Coorong in January 2013. Data are based on 25 cores taken at each water depth at each site. To express these data as turions.m^{-2} multiply by 226.

Site	km from Mouth	East				West			
		Dry	waterline	30cm	60cm	dry	waterline	30cm	60cm
N19	38	0	0	0	0				
N12	45	0	0.32	1.32	0				
N07	50	0	0	0	0				
N02	55	0	0	0	0.04				
S06	62	0	0	0.6	0	0	0	0	0
S11	67	0	0	0.08	0	0	0.2	0	0.12
S16	72	0	0	0	0	0.28	0.92	0.4	0.64
S21	77	0	0	0	0	0.56	0.16	0	0
S26	82	0	1	2.36	0	0	0.28	0	0.12
S31	87	0	0	0	0	0	0	0	0
S36	92	0	0	0	0	0	0	0	0
S41	97	0	0	0	0	0	0	0.04	0

Tables 6 and 7 provide summary statistics for the presence and abundances of *Ruppia tuberosa* seeds at the 20 sites. Overall around 25% of all of the cores contained seeds, but the percentages varied from 0 to 60% in individual sets of samples from different water depths across sites (Table 6), in part reflecting the patchy distribution of seeds between sites, water depths and individual cores. The average numbers of seeds in cores were exceptionally low as well (Table 7). Mean numbers of seeds per core ranged from 0 to 1.84 in individual sets of 25 cores from different water depths across sites. Importantly of more than 200 seeds checked for contents only one was intact, the others consisted of testa filled with fine sand.

Table 6. Per-cent of cores containing *Ruppia tuberosa* seeds at 20 locations in the southern Coorong at four different water depths in January 2013. Data are based on 25 cores taken at each depth at each site.

Site	km from Mouth	East				West			
		Dry	waterline	30cm	60cm	dry	waterline	30cm	60cm
N19	38	0	0	4	0				
N12	45	4	0	0	0				
N07	50	8	8	24	4				
N02	55	32	24	4	32				
S06	62	32	28	8	16	20	10	50	0
S11	67	44	0	0	8	8	8	16	8
S16	72	0	0	0	0	8	44	44	0
S21	77	4	0	4	0	40	36	28	24
S26	82	52	48	16	24	0	4	32	36
S31	87	12	8	0	4	24	52	48	32
S36	92	52	32	4	0	0	0	0	0
S41	97	60	20	0	44	4	0	20	0

Table 7. Mean number of *Ruppia tuberosa* seeds per core (75 mm diameter x 4 cm deep) at 20 sites along the southern Coorong across four water depths in January 2013. Data are based on 25 cores taken at each depth at each site. Note that the vast majority of these seeds (>99% when checked) lacked intact contents and so were not viable. To convert these data to seeds.m^{-2} multiply by 226.

Site	km from Mouth	East				West			
		Dry	waterline	30cm	60cm	dry	waterline	30cm	60cm
N19	38	0	0	0.04	0				
N12	45	0.04	0	0	0				
N07	50	0.08	0.12	0.24	0.04				
N02	55	0.80	0.36	0.04	0.52				
S06	62	0.68	1.24	0.08	0.40	0.70	0.10	0.80	0
S11	67	0	0	0.52	0	0.08	0.12	0.44	0.12
S16	72	0	0	0	0	0.12	0.96	0.72	0
S21	77	0.04	0	0.04	0	0.40	0.64	0.6	0.36
S26	82	1.76	0.72	0.32	1.84	0	0.04	0.68	1.56
S31	87	0.24	0.08	0	0.04	0.88	1.28	0.48	0.96
S36	92	1.36	0.44	0.04	0	0.68	0.22	0.02	0
S41	97	1.4	0.28	0	0.56	0.72	0.14	0.16	0.28

Changes in seed abundances along the Coorong 2011-2013.

The abundances of seeds detected in sediment cores in January 2013 were similar to (and not statistically different from) the abundances of seeds detected in January 2011 and January 2012 (Table 8). This confirms that there has been no increase in the abundances of 'seeds' for *Ruppia tuberosa* across the southern Coorong during the last 2-3 years, despite salinities being favourable since early 2011. The actual abundances of potentially viable seeds, however, are much lower than this because the majority of seeds (~99%) consisted of sand-filled seed coats.

Table 8. Abundances of *Ruppia tuberosa* seeds (seeds per core) in sediments at 12 sites along the eastern shore of the southern Coorong in January 2011, 2012 and 2013. Data are based on 75-100 cores (75 mm diameter x 4 cm deep) taken at a range of water depths at each site in each year and are means ± s.e.. In each year over 200 of the seeds were checked for contents, and all but one of these (in 2013) was sand-filled and so not viable. To convert these data to seeds.m^{-2} multiply by 226.

Site	km from Mouth	January 2011	January 2012	January 2013
N19	38	0.00 ± 0.00	0.19 ± 0.07	0.01 ± 0.01
N12	45	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01
N07	50	0.17 ± 0.05	0.29 ± 0.20	0.12 ± 0.04
N02	55	1.39 ± 0.22	0.27 ± 0.08	0.43 ± 0.10
S06	62	3.48 ± 0.68	1.13 ± 0.33	0.60 ± 0.19
S11	67	1.09 ± 0.38	0.10 ± 0.04	0.23 ± 0.07
S16	72	0.01 ± 0.01	0.03 ± 0.02	0.00 ± 0.00
S21	77	0.05 ± 0.04	0.07 ± 0.05	0.02 ± 0.01
S26	82	0.12 ± 0.05	1.35 ± 0.47	1.16 ± 0.35
S31	87	0.00 ± 0.00	0.00 ± 0.00	0.09 ± 0.04
S36	92	008 ± 0.04	0.18 ± 0.07	0.46 ± 0.29
S41	97	0.19 ± 0.07	0.57 ± 0.14	0.56 ± 0.11

Gemini Downs Bay (S33E)

Ruppia tuberosa performed well in Gemini Downs Bay (S33E). Water levels at this site did not drop to the same extent, relative to the other monitoring sites along the Coorong, due to a sand bar disconnecting the bay from the rest of the Coorong, preventing further rapid declines of water levels in spring. In this bay most of the *Ruppia tuberosa* was still covered with 20-30 cm of water. Water level fluctuations in this bay were also negligible because the bay was no longer connected to the rest of the Coorong and so not influenced by wind-induced water level changes that were as much as 30 cm from day to day within the Coorong. Sampling of this small population of *Ruppia tuberosa* in January 2013 indicated that it had flowered in spring. In January 2013 there were at least 3 seeds per core found in sediments in areas still covered with water (Table 9). Furthermore 100% of core samples taken at this site in water depths of 30 cm or more in January 2013 contained shoots, seeds and or turions (Table 9). Again only type II turions were present but the numbers present were above 8 per core in water that was at least 30 cm deep. There were several hundred waterfowl foraging over these beds, the highest concentration detected in the southern Coorong in January 2013 and the majority of the shoots had been grazed.

Table 9. Per-cent cover and abundances of *Ruppia tuberosa* shoots, seeds and turions (type II) at Gemini Downs Bay in the southern Coorong in January 2013. Data are based on 25 cores taken at each water depth. Note that the maximum depth within this bay was 35 cm in January 2013. Samples collected at this water depth are shown in red so that they are not mistakenly compared to the 60 cm water depths sampled elsewhere in the Coorong.

Site	km from Mouth	*Ruppia* units	dry	waterline	30 cm	35 cm
S33	89	% shoots	0	20*	60	92
S33	89	% seeds	28	84	100	96
S33	89	% turions (type II)	0	12	100	100
S33	89	mean # shoots	0	0.52*	4.48	15.08
S33	89	mean # seeds	0.88	3.36	3.28	3.48
S33	89	mean # turions (type II)	0	0.16	8.08	20.84

* shoots were brown

<u>Shoreline surveys for *Ruppia tuberosa* and algae</u>

Small fragments of *Ruppia tuberosa* were being washed ashore along the length of the South Lagoon. The fragment lengths were typically around 3-4 nodes in length (measured as the number of leaf shoots (nodes) along a section of stolon (stem giving rise to roots and shoots; Fig. 2). The numbers of fragments washed ashore varied within and between sites in part reflecting changes in local topography and the direction of wave movement relative to the section of shoreline being measured (Fig. 3). The variation between transects at a site is shown by the large standard errors at many locations shown in Figure 3. However, there was a tendency for the amount of material to be higher near areas with higher abundances of *Ruppia* (e.g. S33, S34; Fig. 3). All sections of shoreline that were surveyed had filamentous green algae being washed ashore as well, and many of the *Ruppia tuberosa* fragments had filamentous algae attached to them if not entangling them.

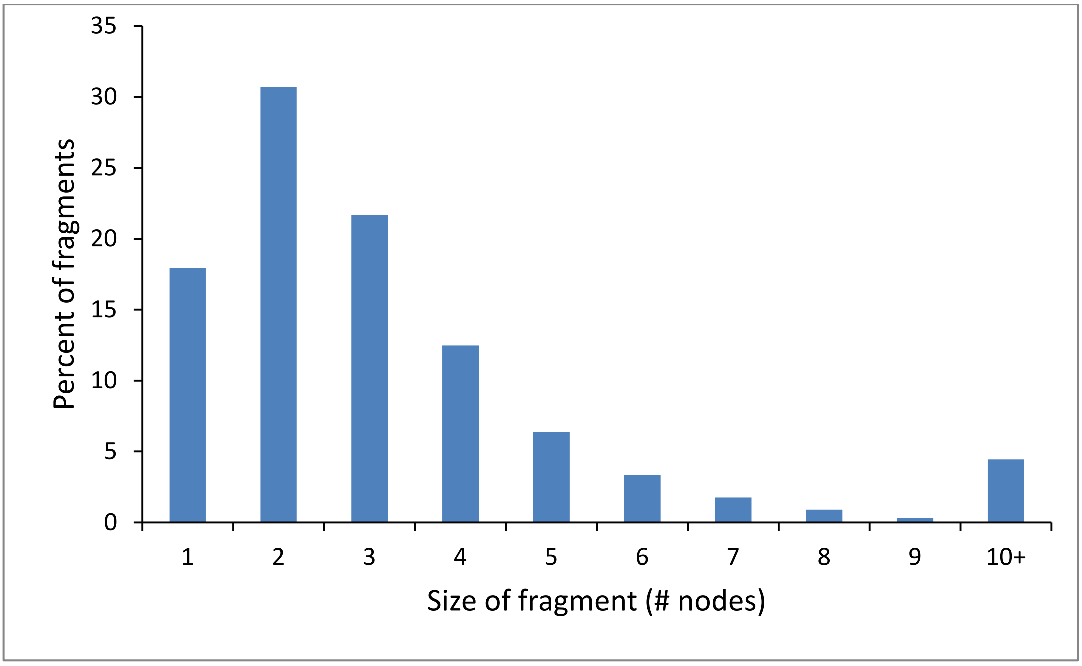

Figure 2. Frequency of different sized fragments of *Ruppia tuberosa* plants washed to shore along the eastern side of the southern Coorong. Size of fragments was determined by the number of nodes producing leaf shoots along a segment of stolon. Data based on scoring 5,789 fragments.

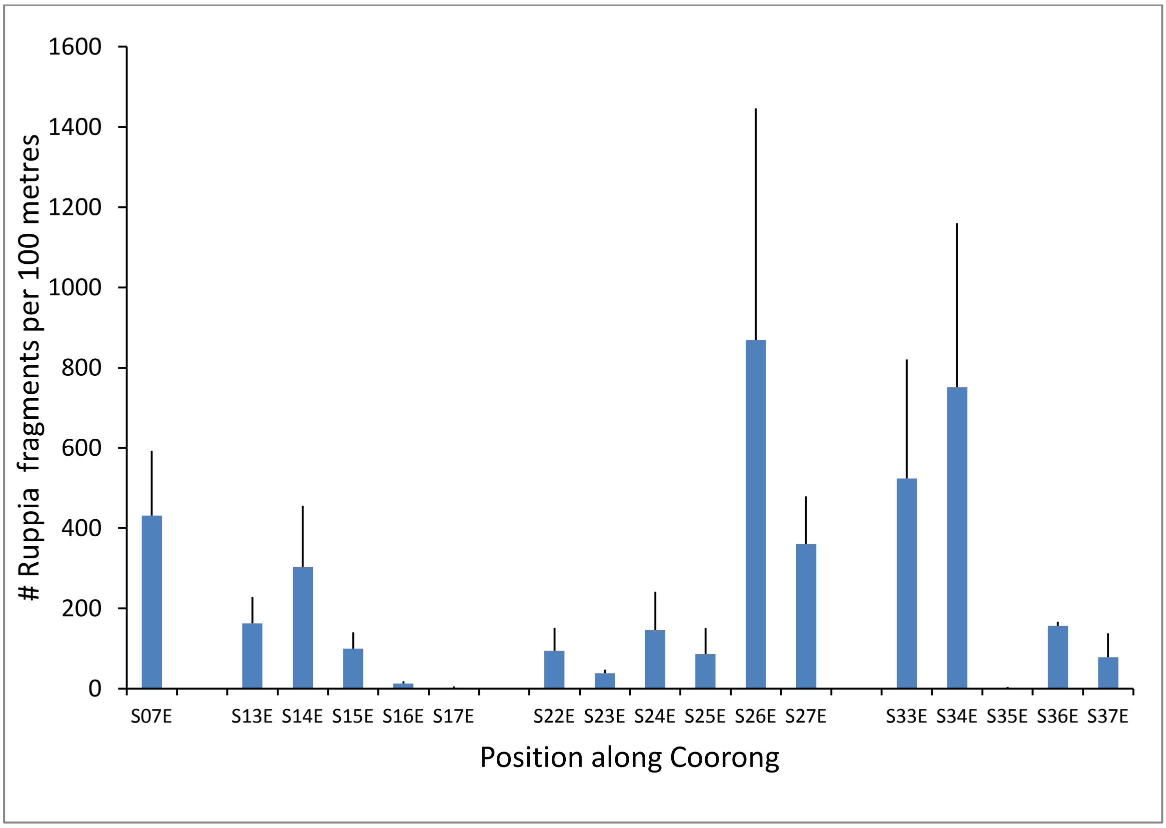

Figure 3. Abundances of small fragments of *Ruppia tuberosa* (# fragments/100 m) washed ashore along the eastern side of the Coorong. Locations are defined by the lagoon (S = South Lagoon), distance (km) S from the junction of the two lagoons, and E for the eastern shore. Date are means + s.e. for three replicate 50m transects at each site. Note for S07E the transect length was 20m.

General Discussion and Conclusions

A primary objective sought from the allocation of environmental water to the Coorong in 2012-2013 was to maintain water levels in the South Lagoon of the Coorong between 0.0 – 0.2 m AHD over summer (Dec-Feb). This objective was only met during December when the overall volume of water flowing to South Australia was between 15,000 and 20,000 $ML.day^{-1}$ (Appendix 1) and flows over the barrages varied from 4,000 to 6,000 $ML.day^{-1}$. The flows into South Australia dropped below 10,000 $ML.day^{-1}$ in January, with the subsequent flow over the barrages dropping to around 1,000 $ML.day^{-1}$ when the additional dilution flow to South Australia ceased and the volume of environmental water released also declined. Water levels in the southern Coorong at these times were below 0.0 m AHD and reached -0.2 m AHD in March 2013. In November and December 2012 when water levels were in the range of 0.0 – 0.2 m AHD, the high elevation components of the *Ruppia tuberosa* beds were exposed to desiccation, and only plants growing at lower elevations were covered with adequate water. These observations indicate that to protect the full extent of the *Ruppia tuberosa* beds water levels in the South Lagoon need to be maintained during late spring and early summer at a higher level, and ideally around 0.5 m AHD. There is a need to calibrate the likely flow of water into South Australia, and the subsequent flow over the barrages needed to meet this target. Based on flows over the barrages in 2012-3 (Figure 1), the volume required is probably around 30,000 $ML.day^{-1}$. This is equivalent to about a 1,000 GL of water being released over the barrages per month. This compares with around 300 GL of environmental water being allocated over three months in 2012-3. Some work modelling flows to South Australia, flows over the barrages and water levels in the southern Coorong is required to improve the ability to predict the water needs for the Coorong, and so manage Coorong water levels more effectively.

Prior to high levels of extraction of water upstream, flows to the Murray Mouth typically increased across spring, peaking in November or December and these flows would have maintained water levels at much higher levels throughout spring and early summer in the southern Coorong than occurs now (Paton 2010). This would have allowed *Ruppia tuberosa* to have completed its reproductive cycle in most years and so allow the species to maintain an adequate seed bank and prominence in the Coorong. In the last two years when there have been flows over the barrages, there has been a substantial drop in flows in spring resulting in water levels dropping prematurely. Until the natural pattern of flows is re-established and the flows adequate the prognosis for recovery of *Ruppia tuberosa* will remain poor. Well-intentioned attempts to alleviate falling water levels by releasing additional environmental water over the barrages in 2012-13 failed to prevent water levels dropping to below critical levels for the high-elevation components of the *Ruppia* beds in spring, in part because the volumes were small relative to the actual volumes that would be needed.

The key reason for maintaining water levels in the Coorong between 0.0 – 0.2 m AHD in 2012-13 was to increase the distribution and cover of *Ruppia tuberosa* and increase the density of the seed bank. This is linked to a key objective (V2) under *The Living Murray* condition monitoring plan to maintain or enhance *Ruppia tuberosa* colonisation and reproduction. When water levels were between 0.0 - 0.2 m AHD in November and December, the high elevation components of the *Ruppia tuberosa* beds were exposed to desiccation and did not complete effective reproduction. There were, however, plants present (albeit in low numbers) at lower elevations that were still covered in water, that without the allocation of environmental water would have been exposed to desiccation from November onwards. Thus the allocation of environmental water had some benefit in allowing low elevation *Ruppia tuberosa* to survive, grow and potentially reproduce in late spring and early summer. However, with low cover and subsequent drops in water level in early January, little or no successful reproduction was detected.

Ruppia tuberosa populations continue to perform poorly within the southern Coorong. This is based on the low abundances of plants detected in January 2013 and low abundances of seeds and turions compared to healthy populations of *Ruppia tuberosa.* Healthy *Ruppia tuberosa* populations, like the population at Lake Cantara, would be expected to have plants approaching 100% cover (in spring) and maintain typically around 50 seeds per core at the end of the flowering season, with more than half the seeds intact (Paton & Bailey 2013, unpubl.). The abundances of seeds and plants along the southern Coorong fell well short of this and, furthermore, there was no increase in the numbers of seeds relative to previous years consistent with plants failing to produce seeds in 2012-13. The recovery of *Ruppia tuberosa* in the Coorong therefore remains precarious.

There is a hierarchy of factors that are likely to influence the ability of *Ruppia tuberosa* to establish, grow and successfully reproduce. The ultimate factor within the Coorong is an appropriate cover of water (between 0.3 m and 0.9 m based on field observations over that last 20 years, e.g. Paton & Bailey 2010). Three other factors are likely to influence the ability of plants to grow and reproduce: salinity, grazing by waterfowl, and interference from filamentous green algae. Being covered by adequate water, however, is a prerequisite for survival, growth and reproduction and is critical, the other three factors simply disrupt the plant's performance. There is a fourth factor that will influence the distribution and abundance of plants within a site and also between sites in any one year, and that is the size and distribution of the seed or propagule bank. For *Ruppia tuberosa* to regain a level of resilience, the plants must reproduce and re-build a sizeable seed bank. In 2012-13 *Ruppia tuberosa* largely failed to reproduce in the Coorong as has been the case for the last decade (e.g. Paton 2010, Paton & Bailey 2012).

The failure to produce seeds in 2012-13 is best illustrated by following the fate of plants detected growing in the northern parts of the South Lagoon in July 2012. In July 2012 the cover was reasonable at these sites (>30%; Paton & Bailey 2013) and the plants would have been expected to flower in late October or early November. In October, these beds were initiating small numbers of floral stalks. However, by November with falling water levels these beds were all but exposed and there was no evidence of mature floral stalks (with developing seeds). The remaining plants (most in water 10 cm deep) had produced modest numbers of type II turions by November (Table 1) but, with further drops in water levels during December and January (Fig. 1) these beds became fully exposed and in January no turions remained at these now dry sites.

There can be no doubt that falling water levels in spring 2012 was the key factor that hampered the recovery and performance of *Ruppia tuberosa* across the southern Coorong. Further support for this is provided by the performances of *Ruppia tuberosa* at Gemini Downs Bay (S33E) where a sand bar disconnected this bay from the rest of the Coorong, so dampening the extent to which water levels continued to fall as summer approached. Within this bay, *Ruppia tuberosa* had flowered and was in substantially higher abundance than elsewhere in the southern Coorong in January. Furthermore the seed bank and numbers of turions were also substantially higher than elsewhere and this was despite heavy grazing by waterfowl and the presence of filamentous algae. Other bays like this may also exist in parts of the Coorong but were not detected during the 2012-13 sampling.

Small amounts of *Ruppia tuberosa* were, nevertheless, growing along much of the South Lagoon of the Coorong in January 2013 at lower elevations that were still covered with water, indicating some benefit from the allocation of environmental flows. Healthy plants were generally growing in water 30-60 cm deep. However, these plants were generally small and many were yet to produce turions suggesting that they were young plants that had only germinated recently (i.e. in late spring). In winter and early spring these areas were covered by more than a metre of turbid water. Falling water levels during spring would have increased the amount of light reaching the sediment floor and improved light conditions may have allowed some plants to establish. The presence of these plants is encouraging and suggests there was still some low level capacity or resilience for *Ruppia tuberosa* to re-establish naturally. Despite low seed abundances there must have been a few viable seeds remaining. The prognosis that these populations will continue to recover on their own, however, remains poor while there is a depauperate and potentially diminishing seed bank. Each year in which seeds are stimulated to germinate, but the plants fail to reproduce (as has been the case in recent years), the chances of recovery diminish further because the depauperate seed bank is further depleted without replenishment.

Asexual reproduction, in the form of turion production was also limited in 2012-13. Some plants had produced short-lived type II turions in November and December. However these were exposed by January when water levels dropped further. No turions were subsequently found in the sediments where these plants were growing, when sampled in January. Similarly some of the plants found in January had also produced type II turions, but further reductions in water levels through February (Fig. 1) would have exposed many of these plants, so few of these turions would have survived to re-establish plants in the next winter. Thus asexual reproduction was not compensating for a lack of sexual reproduction. The only exception was for plants at Gemini Downs Bay where water levels over the plants were maintained at around 0.3 m through summer, and here the plants had produced between 1,600 – 4,500 type II turions per square metre. These plants had also reproduced sexually.

The three other factors that are likely to influence the performance of *Ruppia tuberosa* at any one location are salinity, grazing by waterfowl and interference from filamentous green algae. Studies on the influence of salinity have largely focussed on measuring germination responses (e.g. Lim *et al.* 2013). These studies have found that germination is delayed and germination rates are lower as salinities approach 90 gL^{-1} compared to lower salinities (30-40 $g.L^{-1}$). Mesocosm experiments also found that at high salinities of 90 gL^{-1} *Ruppia tuberosa* did not grow as well as plants exposed to 30 and 60 gL^{-1} (Paton *et al.* 2011). Furthermore, in these experiments, only plants growing in low salinities (30 gL^{-1}) produced floral stalks, suggesting reproductive activity might be curtailed at the higher salinities. However, these experiments differed from observations of plants *in situ* in the Coorong and at Lake Cantara over the last five years where plants were flowering extensively in salinities that were above 60 gL^{-1} and up to 86 gL^{-1} (Paton *et al.* 2011). Thus mesocosm experiments failed to mimic the responses of plants in the field and results from them should be treated cautiously. For 2012-13, salinities in the South Lagoon of the Coorong during winter and spring (July – October) were typically around 50-60 gL^{-1} and from November to December in the range of 60-70 gL^{-1} (Paton & Bailey 2013, Figure 1). These salinities are within the range of salinities considered ideal for *Ruppia tuberosa* in the Coorong (e.g. Paton & Bailey 2010; Kim *et al.* 2013). Thus salinity is not preventing recovery of these populations. Ironically lower salinities may exacerbate recovery as low salinities may stimulate more seeds to germinate in winter and if coupled with inadequate water levels in spring, this might lead to drawing down the remaining seed bank at a faster rate, and so exhausting the seed bank more quickly, reducing resilience faster.

Grazing by waterfowl and entanglement and smothering of plants by filamentous green algae may also dampen the reproductive outputs of *Ruppia tuberosa* once plants have established. Previous exclusion trials showed that grazing pressure can reduce the amount of plant biomass that accumulates and also reduces turion production (Paton & Bailey 2010). However, turions were still produced in the presence of heavy grazing (~80% of shoots grazed) and were at densities of around 10 turions per core or 2,200 turions per square metre (Paton & Bailey 2010). The influence of heavy grazing on flower production has not been measured but the population of *Ruppia tuberosa* at Lake Cantara still produces significant quantities of seed each year despite heavy grazing by waterfowl. Similarly, the population of *Ruppia tuberosa* at Gemini Downs Bay flowered and produced seeds and turions in 2012-3, despite being grazed heavily. Thus, grazing does not eliminate reproduction entirely but reduces the numbers of propagules produced.

Filamentous green algae can also interfere with populations of *Ruppia tuberosa* through entanglement and smothering. In 2012-13 filamentous green algae were present throughout the South Lagoon but the extent to which algae interfered with populations of *Ruppia tuberosa* was not measured. Filamentous green algae can interfere with established plants through entanglement that smothers plants, blocking light. Filamentous green algae can also interfere by attaching itself to flowering stalks creating extra drag, increasing the chances that floral stalks will snap (Paton & Bailey 2012). Further work is required to document patterns relating to the seasonal distribution and abundance of filamentous green algae in the Coorong, and on the extent to which algae disrupt growth and reproduction of *Ruppia tuberosa*. Paton & Bailey (2012) implied that filamentous green algae caused the collapse of populations of *Ruppia tuberosa* in the middle sections of the North Lagoon over 2010-11 when salinities dropped from around 100 gL^{-1} to 40 gL^{-1} and filamentous green algae became prominent. Lower salinities in the southern Coorong coupled with an increase in available nutrients may favour the establishment and growth of filamentous green algae and further work on interactions between filamentous algae, *Ruppia tuberosa*, salinities and nutrient loads is warranted.

The dispersal of small fragments of *Ruppia tuberosa* along shorelines may facilitate re-colonisation of areas. However, only those fragments dispersed late in the season are likely to have a chance of establishing. Fragments of stolon do not survive when left out of water, so those that settle at the waterline in December, January and February (when water levels were still falling) would be exposed to desiccation and consequently die. However a few fragments might settle in shallow water in autumn just prior to water levels rising and these might survive and grow and contribute to re-establishment. To some extent the presence of filamentous green algae attached to fragments will add drag and so may facilitate settlement of fragments.

Monitoring the extent of any recovery of *Ruppia tuberosa* in the southern Coorong is time-consuming because the turbidity of the water prevents visual assessment of large areas and so demands a sampling program. The presence of small fragments of *Ruppia tuberosa* washed ashore, however, may provide a simple semi-quantitative method of determining areas of the Coorong where *Ruppia tuberosa* is present. Monitoring of fragments along shorelines to gauge where *Ruppia* is present will work best along the eastern shoreline where the prevailing winds in summer are on-shore. The initial intention of this shoreline sampling was not for this purpose, and further work would be required to determine the factors that result in small fragments being dislodged from the sediments. Two factors would seem to be involved: wave action and waterfowl grazing. These are likely to vary spatially and temporally and so the amounts washed ashore on any one day may not be a good guide to abundance of *Ruppia* in adjacent waters. Most of the fragments that had been washed ashore in January 2013 were small fragments that lacked type II turions and had been grazed. Many also had filamentous green algae attached to them and the algae may have increased the chances of wave action dislodging fragments of plants.

Based on the field observations during 2012-13 there has been limited flowering and seed production by *Ruppia tuberosa* in the southern Coorong, despite the return of suitable salinities. Low and falling water levels during spring and early summer continue to challenge the ability of this species to reproduce and re-build a propagule bank. As a consequence the propagule bank remains extremely low and whilst this is the case, the recovery of *Ruppia tuberosa* along the southern Coorong will be compromised. One option for improving the rate of re-establishment of *Ruppia tuberosa* is translocation, and a translocation program using abundant seed from Lake Cantara is now underway. But this translocation remains vulnerable if rapidly falling water levels in spring recur. At present this seems likely. If water levels cannot be addressed through improvements in the volumes and timing of releases of water over the barrages, then buffering some sites with the use of strategically-placed sandbars like those at Gemini Downs Bay might allow some additional small populations to be established to act as refugia for *Ruppia tuberosa* in the southern Coorong.

In summary, the provision of environmental water to supplement flows over the barrages during spring and early summer was not sufficient to arrest falling water levels, and certainly not sufficient to allow *Ruppia tuberosa* to successfully produce seeds during 2012-13. Until water levels are managed effectively in the southern Coorong during spring, *Ruppia tuberosa* will continue to struggle to re-establish.

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Appendix 1. Daily flows of water to South Australia along the Murray River during 2012-13, indicating the sources of water and seasonal patterns of flow. Figure provided by Adrienne Frears (DEWNR)