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EFFECTS OF AN ENHANCED FLOOD ON RIPARIAN PLANTS OF THE RIVER MURRAY, SOUTH AUSTRALIA

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ABSTRACT

In October 2000, the flow of the River Murray entering South Australia was increased from 32 000 to 42 050 ML day^{-1} by release of water from an offstream reservoir, and a downstream weir was raised by 500 mm to impound the flood and enhance local floodplain inundation. The flood was maintained for about two weeks, although the duration of inundation was longer at low elevations on the floodplain. Vegetation at three sites was surveyed before and after the flood to examine the impact of inundation on the growth and germination of flood-tolerant, flood-dependent and flood-intolerant species. Among 32 recorded species, *Atriplex vesicaria* (bladder saltbush, Chenopodiaceae), *Sporobolus mitchellii* (rats tail couch, Graminae) and *Sarcocornia quinqueflora* (samphire, Chenopodiaceae) accounted for nearly 82% of the total cover/abundance. Flood-tolerant and flood-dependent species (e.g. *S. mitchellii*) grew and germinated and flood-intolerant species (e.g. *A. vesicaria*) senesced. No aquatic plants germinated or established, despite favourable conditions, suggesting an impoverished seed bank or grazing. Based on the growth but lack of germination of flood-tolerant and flood-dependent species, the value of small, occasional interventions in environmental flow management may be to maintain existing communities rather than restore degraded ones.

KEY WORDS: Murray-Darling Basin; floodplain; riparian vegetation; weir; flood; restoration; seedbank

INTRODUCTION

Flooding promotes the growth and reproduction of some riparian plants (e.g. Lenssen *et al.*, 2000; Robertson *et al.*, 2001) and activates the sexual and asexual propagules of aquatic and semi-aquatic species (Brock and Rogers, 1998; Casanova and Brock, 2000). It may also eliminate flood-intolerant species that have colonized the floodplain during dry periods (e.g. van der Valk and Davis, 1976). The balance between these responses is influenced by the depth, duration, frequency and timing of wetting and drying (e.g. Rea and Ganf, 1994; Blanch *et al.*, 1999; Nicol and Ganf, 2000).

The floodplain of the River Murray once experienced periods of wetting and drying associated with a naturally variable flow regime (e.g. Maheshwari *et al.*, 1995), but over the last 100 years regulation and diversions have markedly changed the frequency, duration, magnitude and timing of river flows (e.g. Walker, 1992; Walker and Thoms, 1993). These changes have adversely affected the flora and fauna (e.g. Blanch *et al.*, 1999, 2000; Walker, 2001), and state and federal governments are actively promoting environmental flow management as a strategy to maintain and restore habitats. One such initiative occurred in October 2000, when the South Australian Department for Water, Land and Biodiversity Conservation (DWLBC) negotiated a flow release from Lake Victoria, an offstream water storage in New South Wales, to augment a natural high flow in the Murray entering South Australia. To prolong the flood and increase the area and depth of floodplain inundation, albeit in a restricted area, a 3 m weir on the Murray at Lock 5 (near Renmark, South Australia) was raised by 500 mm for about two weeks. The area had not been flooded for four years.

We anticipated that the enhanced flood would promote the growth and germination or sprouting of propagules of a variety of flood-tolerant and flood-dependent species, and that the responses would be greatest at those elevations

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flooded deepest and for longest. In contrast, flood-intolerant species were expected to senesce or die. Here, we describe the status of three dominant species during and after the recession of the flood, and consider the moderating effects of the depth and duration of flooding and other abiotic and biotic factors. In addition, we consider the value of the enhanced flood as a model for future trials.

METHODS

Sites and sampling

The study region has a semi-arid climate with an annual average rainfall 250 mm y^{-1} and an average annual potential evaporation 2000 mm y^{-1} (Jolly *et al.*, 1993). The floodplain soil is alluvial grey cracking clay up to 5 m deep (Hollingsworth *et al.*, 1990).

Three sites were selected to represent the flooded area (Figure 1): two at Bulyong Island (Ninkle Nook (NN): 480 000 E 6 225 000 N; Jane Eliza (JE): 478 500 E 6 220 500 N) and one at Reny Island (Wide Waters (WW): 475 000 E 6 230 500 N). Wide Waters is adjacent to Ral Ral Creek, an anabranch of the Murray, and is influenced by weir manipulations at Lock 5. The likely extent of the flood at each site was predicted by a local environmental manager (M. Harper, Australian Landscape Trust, Renmark, pers. comm.).

At each site, three transects were established perpendicular to the river and 100 m apart (transects T1–T3 at NN, T4–T6 at JE, T7–T9 at WW). On each transect, 5×1 m quadrats (five contiguous 1×1 m 'cells') were placed at five elevations (see 'Water regime'): E1 was located just above the predicted maximum flood height, E5 at the lowest elevation that would be submerged, and E2–E4 at 25, 50 and 75%, respectively, of the difference between E1 and E5. Intermediate elevations were determined using a theodolite. Each site therefore was represented by single quadrats at five elevations on three transects.

Surveys were conducted prior to the flood (8–10 October 2000) and after recession (8–10 November 2000, 3–5 December 2000, 5–7 February 2001). The sites were visited also on 24 October 2000, seven days after the flood peak, but no plant responses were evident.

Plant cover in each quadrat was visually assessed and scored from 0 to 6, where 0 = absent, 1 = rare and 6 = continuous cover (Blanch *et al.*, 1999). Species were identified following Jessop and Toelken (1986) and classified as 'flood-tolerant', 'flood-dependent' or 'flood-intolerant' (cf. Sainty and Jacobs, 1994; Brock and Casanova, 1997).

Incidental measurements of soil conductivity and pH were made in 1:5 suspensions of air-dried soil samples (surface 15 cm) in deionized water (Rayment and Higginson, 1992). Measurements were made for all elevations at WW in the pre-flood, November and December surveys.

Water regime

River height (metres above the Australian Height Datum: m AHD) was monitored using Dataflow 392 loggers attached to 0–5 m differential pressure sensors and 3 m capacitance probes located in the river near each site. Water levels at each site were measured by sensors from 5 October to 7 November 2000 (JE) or 1 December (NN, WW), and otherwise estimated from backwater curves (longitudinal profiles of water surface elevation in relation to discharge) and daily river heights recorded at Lock 5 (B. Porter, SA Water, pers. comm.). At the flood peak, depths across the floodplain were recorded and combined with the known river height to determine the actual heights of the sampling elevations. These data were combined with site hydrographs to indicate water level fluctuations and 10 water regime classes (above: 0, 5, 10, 20 and 40 cm; below: 0, −5, −10, −20 and −40 cm). At JE, floodplain topography prevented surface outflow from E2–E5, so that water there must have receded due to evaporation and seepage. Net evaporation was recorded at Lock 5 (B. Porter, SA Water, pers. comm.), but no data were available to indicate seepage.

Analysis

As three of 32 recorded plant species accounted for 78% of total cover, and all but one of the remainder had scores <2%, ordination analysis was precluded. Rather, scores for the dominant species at each site were

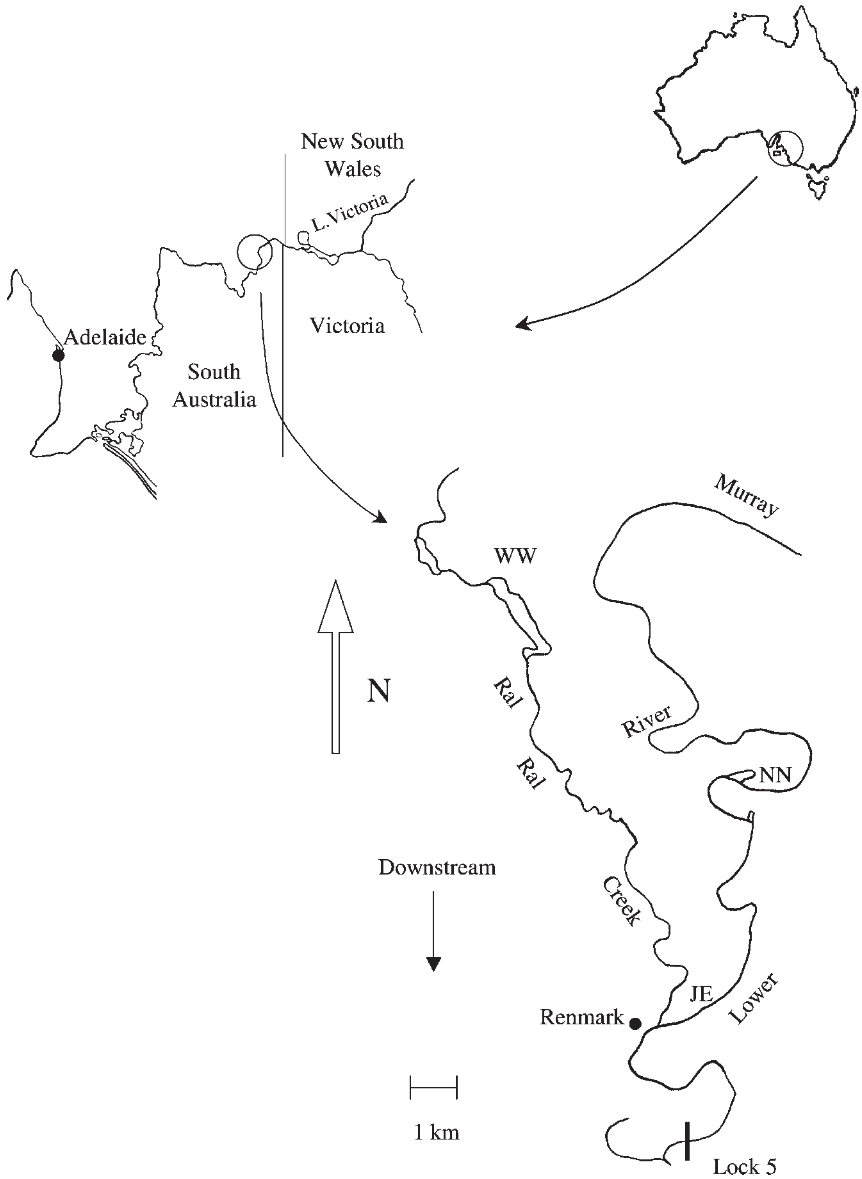

Figure 1. The Lower River Murray showing the three floodplain areas: NN (Ninkle Nook), JE (Jane Eliza) and WW (Wide Waters). Ral Ral Creek is an anabranch of the Murray. Renmark is 568 km from the mouth of the river. Lock 5 is shown as a bar across the river; Locks 4 and 6 are located south (47 river km) and north (58 river km) of Lock 5, respectively

compared by ANOVA (factors elevation and time, transects as randomized blocks; no replication). One of the three transects at JE proved to have a different flooding regime from its two neighbours and was excluded from analysis. Missing data (T2 in the first survey, E3 at T3 and E5 at T8 in the second survey) caused the analytical program (SPSS for Windows 11.0.1: SPSS Inc., Illinois) to substitute approximate values (fractional degrees of freedom, see Table II).

RESULTS

Flood hydrograph

The diversion from Lake Victoria increased flow in the Murray from 32 000 to 42 050 ML day^{-1} (DWLBC, 2002), and the raised weir at Lock 5 ensured that the flood peak covered about 11% of the floodplain

Table I. Numbers of days when water was above or below the sediment surface at five elevations (E1–E5) at three floodplain sites (Ninkle Nook, NN; Jane Eliza, JE; Wide Waters, WW), from 1 October 2000 to 12 February 2001 (135 days). Topography at JE precluded some estimates

Site: Elevation	Days above					Days below				
	0 cm	5 cm	10 cm	20 cm	40 cm	0 cm	5 cm	10 cm	20 cm	40 cm
NN:E1	0	0	0	0	0	135	135	135	135	135
NN:E2	0	0	0	0	0	135	135	135	135	122
NN:E3	0	0	0	0	0	135	133	126	121	99
NN:E4	14	13	10	0	0	121	115	110	94	53
NN:E5	44	36	29	18	3	91	83	75	53	27
JE:E1	14	11	7	0	0	121	120	117	109	70
JE:E2	48	46	39	10	0	87	—	—	—	—
JE:E3	61	59	52	40	0	74	—	—	—	—
JE:E4	75	71	66	53	14	60	—	—	—	—
JE:E5	90	89	81	66	41	45	—	—	—	—
WW:E1	0	0	0	0	0	135	135	135	128	115
WW:E2	0	0	0	0	0	135	128	125	120	92
WW:E3	13	10	7	0	0	122	121	115	104	67
WW:E4	25	20	14	10	0	110	104	94	79	50
WW:E5	49	40	30	19	5	86	80	68	53	11

Table II. Analyses of variance in cover of the three plant species at each site (Ninkle Nook, NN; Jane Eliza, JE; Wide Waters, WW)

Site	Source	*A. vesicaria*		*S. quinqueflora*		*S. mitchellii*	
		F (df)	*P*	*F* (df)	*P*	*F* (df)	*P*
NN	Elevation	9.27 (4,7.9)	0.002	—	—	12.10 (4,7.9)	0.002
	Time	33.95 (3,4.8)	0.001	—	—	4.50 (3,4.9)	0.071
	Elevation × time	2.35 (12,19)	0.047	—	—	2.44 (12,19)	0.040
JE	Elevation	0.19 (4,4)	0.933	0.38 (4,4)	0.815	0.656 (4,4)	0.653
	Time	52.43 (3,3)	0.004	9.48 (3,3)	0.049	16.83 (3,3)	0.022
	Elevation × time	0.14 (12,12)	0.999	0.43 (12,12)	0.921	0.68 (12,12)	0.746
WW	Elevation	3.56 (4,8)	0.060	0.46 (4,8)	0.764	4.25 (4,8)	0.039
	Time	4.31 (3,6)	0.061	2.79 (3,6)	0.127	6.51 (3,6)	0.026
	Elevation × time	2.31 (12,24)	0.039	1.72 (12,23)	0.127	3.03 (12,24)	0.010

The decimal degrees of freedom (df) for site NN are approximations produced by SPSS for Windows to overcome missing data (T2 in the first survey, E3 at T3 and E5 at T8 in the second survey). The analysis for *S. quinqueflora* at site WW also was affected by missing data, but the values for df remain as integers.

(924 ha) between Locks 5 and 6 (I. Overton, CSIRO Land and Water, pers. comm.). Under normal operating conditions, this requires a flow of 70 000 ML day^{-1}. The flooded reach is little affected by levees or flood runners, so that rates of rise and fall were governed mainly by the slope of the floodplain. From 6 October, the weir pool rose at 3 cm day^{-1} above its normal level of 16.3 m AHD, and was maintained above 16.7 m AHD for 11 days (Figure 2). The river level peaked at 16.8 m AHD on 17 October, and flow peaked at 42 300 ML day^{-1} on 18 October. The river thereafter receded at 3 cm day^{-1} and returned to pool level on 5 November. To ease pressure on the weir at Lock 5, the weir at Lock 4, 47 km downstream, was raised by 400 mm for the duration.

The lowest elevations at Ninkle Nook (NN) and Wide Waters (WW) were flooded for 31 days. At Jane Eliza (JE) there was surface water at all elevations, but receding water in some areas was trapped in depressions and flooding there persisted for up to 90 days. Table I shows the periods when the water level was within fixed intervals above and below the sediment surface.

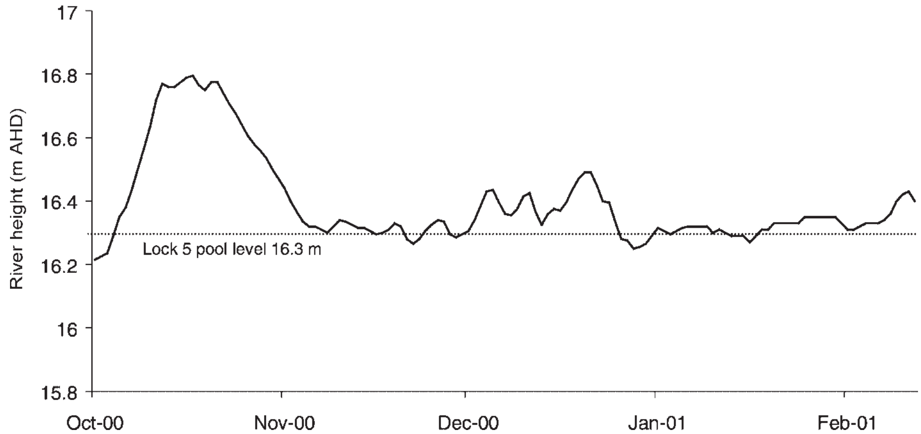

Figure 2. The hydrograph of the River Murray upstream of Lock 5 from 1 October 2000 to 12 February 2001. Water levels peaked on 17 October 2000 and returned to weir pool level on 8 November

The Murray rose again in December 2000 (Figure 2). This second flood (peak 45 914 ML day^{-1}) was larger than the enhanced flood, but flooding was limited to the lower elevations at NN and WW because the weir at Lock 5 was not raised.

Plant responses

Prior to the flood, *Atriplex vesicaria* (bladder saltbush, Chenopodiaceae), *Sporobolus mitchellii* (rats tail couch, Gramineae) and *Sarcocornia quinqueflora* (samphire, Chenopodiaceae) accounted for 81.5% of total cover among 32 recorded species. Seven days after the flood peak (17 October 2000) there were no seedlings or other apparent positive responses within quadrats, although flooded *A. vesicaria* lost some leaves, and shoots from rhizomes of *Eleocharis acuta* (common spike rush, Cyperaceae) occurred between elevations E4 and E5 at NN. In post-flood surveys, the same three species were predominant and *Wilsonia rotundifolia* (round-leaved wilsonia, Convolvulaceae) also occurred sporadically (5.9% of total cover).

Ninkle Nook

At its peak, the flood at NN inundated the lowest quadrats (E4 0.19 m, E5 0.42 m) and approached the sediment surface at E3 (−0.04 m). Water levels remained below the sediment surface at E1 (−0.50 m) and E2 (−0.27 m) (Table I). Only E5 was re-wetted in December. *S. quinqueflora* was absent at this site.

Table II indicates a significant interaction between elevation and time for the response of *S. mitchellii* at NN. This arose because plants lower on the elevation gradient (E3–E5) increased their median score by 1 when there was no change at E2 and a reduction in cover at E1 (Table III). The effect at E1 was due to grazing by grey kangaroos (*Macropus giganteus*).

The response of *A. vesicaria* also was influenced by the interaction between time and elevation (Table II). This was reflected in October and February by losses of cover at E4–E5, but a stable score at E3 (Table III). At E5, the median score of 3 before inundation fell to 0 in February, although scores were not zero in all quadrats because some seeds germinated after the flood's recession. At E1–E2, kangaroos again caused an apparent decline.

Jane Eliza, JE

At JE, all elevations were flooded (Table I). E1 was flooded to >10 cm for 7 days and E5 was flooded to >20 cm for 66 days. At this site, time had a significant effect on the responses of the three species (Table II), and depth and duration did not. *S. mitchellii* responded positively, especially at E3, where the median score rose from 1 to 3, and at E5. The status of plants at E2 in February was less variable than prior to the flood, suggesting that some grew

Table III. Median cover (range 0–6; 25–75 percentiles in parentheses) of *S. mitchellii* and *A. vesicaria* at five elevations (E1–E5) at Ninkle Nook

		E1	E2	E3	E4	E5
S. mitchellii	Oct.	1 (0–2)	2 (2–2)	3 (2–3)	3 (3–3)	2 (2–2)
	Nov.	1 (0–2)	2 (2–3)	3 (2–3)	3 (2–4)	2 (2–3)
	Dec.	0 (0–1)	2 (1–2)	4 (3–4)	3 (2–4)	3 (2–3)
	Feb.	0 (0–1)	2 (1–3)	4 (3–4)	4 (3–5)	3 (2–4)
A. vesicaria	Oct.	3 (3–4)	3 (3–3)	0 (0–1)	1 (1–1)	3 (3–3)
	Nov	3 (2–3)	2 (2–2)	0 (0–1)	1 (0–1)	0 (0–1)
	Dec.	2 (2–3)	2 (1–2)	0 (0–0)	1 (0–2)	0 (0–1)
	Feb.	2 (2–2)	2 (1–2)	0 (0–0)	0 (0–1)	0 (0–1)

Table IV. Median cover (range 0–6; 25–75 percentiles in parentheses) of *S. mitchellii*, *A. vesicaria* and *S. quinqueflora* at five elevations (E1–E5) at Jane Eliza

		E1	E2	E3	E4	E5
S. mitchellii	Oct.	3 (1–3)	1 (0–3)	1 (0–3)	2 (1–5)	0 (0–0)
	Nov.	3.5 (2–4)	1.5 (0–3)	1.5 (0–3)	1 (0–2)	0 (0–0)
	Dec.	3 (2–4)	1.5 (1–3)	2 (1–3)	3 (3–3)	0 (0–1)
	Feb.	3 (2–4)	3 (2–3)	3 (2–4)	3.5 (3–4)	1 (0–2)
A. vesicaria	Oct.	0.5 (0–1)	1 (1–1)	0.5 (0–1)	0 (0–2)	1 (0–1)
	Nov.	0 (0–0)	0.5 (0–1)	0 (0–0)	0 (0–0)	0 (0–0)
	Dec.	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
	Feb.	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
S. quinqueflora	Oct.	0.5 (0–1)	0 (0–2)	1.5 (0–5)	0.5 (0–1)	2 (0–2)
	Nov.	0 (0–1)	0 (0–2)	1.5 (0–4)	0 (0–0)	0 (0–2)
	Dec.	0 (0–0)	0 (0–1)	1.5 (0–3)	0 (0–1)	0 (0–1)
	Feb.	0 (0–1)	0 (0–2)	1 (0–3)	0 (0–0)	0 (0–0)

after the recession (Table IV). Plants at E4–E5 did not respond until December. *A. vesicaria* declined at all elevations (Table IV). Reductions in cover of *S. quinqueflora* were greatest at E5, followed by E3 and E4.

Wide Waters, WW

The flood hydrograph at WW was more like that at NN than at JE, as not all elevations were inundated (Table I). Elevation E1 was the only elevation to remain dry; water rose to the sediment surface at E2 and E3–E5 were all submerged. E4–E5 were flooded again in December. *S. mitchellii* was sparse at this site. There was a significant interaction between time and elevation (Table II), produced by a rise in median cover scores at E3 but no response at E4 (Table V). Plants at E1 declined, due probably to grazing kangaroos. No plants occurred at E5.

A. vesicaria, like *S. mitchellii*, occurred sparsely at WW. Changes in cover between October and February were moderated by an interaction between elevation and time (Table II), reflected in minor losses at E3 and no changes at E1 and E4 (Table V). *S. quinqueflora* was widespread at WW (Table V) and apparently was unaffected by changes in elevation and/or time (Table II). Minor reductions were apparent, however, for deep-flooded plants (Table V).

Soil conductivity and pH at Wide Waters

At WW, no changes in conductivity or pH were detected at E1–E2, suggesting that the rising floodwater did not affect the topmost 15 cm of soil. At the shallow-flooded E3, conductivity declined from the pre-flood survey (4.2 dS m^{-1}) to the post-flood surveys (November: 1 dS m^{-1}; December: 0.6 dS m^{-1}; $F_{2,24} = 23.13$, $P < 0.0001$).

Table V. Median cover (range 0–6; 25–75 percentiles in parentheses) of *S. mitchellii*, *A. vesicaria* and *S. quinqueflora* at five elevations (E1–E5) at Wide Waters

		E1	E2	E3	E4	E5
S. mitchellii	Oct.	2 (0–2)	3 (1–3)	2 (1–2)	0 (0–0)	—
	Nov.	2 (0–2)	2 (1–3)	2 (2–3)	0 (0–0)	—
	Dec.	2 (0–3)	2 (0–3)	2 (2–2)	0 (0–0)	—
	Feb.	1 (0–2)	2 (0–2)	2 (2–3)	0 (0–0)	—
A. vesicaria	Oct.	0 (0–1)	1 (0–1)	1 (0–1)	0 (0–0)	—
	Nov.	0 (0–1)	0 (0–1)	0 (0–0)	0 (0–0)	—
	Dec.	0 (0–1)	0 (0–1)	0 (0–0)	0 (0–0)	—
	Feb.	0 (0–1)	0 (0–1)	0 (0–0)	0 (0–0)	—
S. quinqueflora	Oct.	1 (0–2)	1 (0–2)	1 (1–2)	3 (2–3)	2 (2–3)
	Nov.	0 (0–1)	2 (0–2)	1 (0–2)	1 (0–2)	0 (0–2)
	Dec.	1 (0–1)	1 (0–2)	1 (0–2)	1 (0–2)	0 (0–2)
	Feb.	1 (0–2)	1 (0–2)	1 (0–1)	1 (0–2)	0 (0–1)

At E4, conductivity decreased from 2.3 dS m^{-1} prior to the flood to 1.2 dS m^{-1} in November, then increased to 2.6 dS m^{-1} (December). At E5, conductivity did not change.

At E3–E5 there were no changes in soil pH (E3: pre-flood 6.0, November 6.5, December 6.4; $F_{2,24} = 3.33$, $P = 0.06$; E4: 6.0, 6.3, 6.0; $F_{2,21} = 1.41$, $P = 0.27$; E5: 6.1, 6.0, 6.3; $F_{2,17} = 2.14$, $P = 0.15$).

Uncommon species

Less common plants included *Alternanthera denticulata*, *Centipeda cunninghamii*, *Cotula coronopifolia*, *Eleocharis acuta*, *Marsilea drummondii*, *Mimulus repens* and *Myriophyllum verrucosum* (Table VI). *C. coronopifolia* (JE), *E. acuta* (NN) and *M. drummondii* (JE) appeared at flooded elevations after the recession in November. *C. cunninghamii* appeared at JE and WW in December, and *M. verrucosum* and *A. denticulata* appeared in February. The combined total cover for these apparently flood-dependent species was 1.4%. None occurred in samples prior to the flood.

Five exotic species had an aggregate 3.2% of total cover: *Aster subulatus*, *Heliotropium curassavicum*, *Lepidium campestre*, *Mesembryanthemum crystallinum*, *Spergularia diandra* and *Xanthium occidentale* (Table VII). Only

Table VI. Pooled cover scores for seven uncommon, flood-dependent plants at sites denoted by combinations of transect (T: Ninkle Nook T1–T3, Jane Eliza T5–T6, Wide Waters T7–T9) and elevation (E). None occurred during the pre-flood survey, but all appeared after the flood

	Pre-flood	November	December	February
A. denticulata	0	0	0	T3E5 2
C. cunninghamii	0	0	T5E2 2 T7E3 1 T8E3 3 T9E3 1	T5E2 2 T7E3 1
C. coronopifolia	0	T5E1 2 T6E1 1	0	0
E. acuta	0	T1E3 4 T1E4 3 T1E5 3	0	0
M. drummondii	0	T5E3 2	0	0
M. repens	0		T5E5 2 T6E5 1	T5E5 5 T6E5 2
M. verrucosum	0		0	T5E5 1

Table VII. Sum cover scores of three exotic species at sites denoted by combinations of transect (T: Ninkle Nook T1–T3, Jane Eliza T5–T6, Wide Waters T7–T9) and elevation (E). Scores refer to juvenile plants, none of them present until after the flood recession

	Pre-flood	November	December	February
A. subulatus	0	T5E1 1	T5E1 1	0
H. curassavicum	0	T7E2 1 T8E3 3	T7E2 1 T7E3 1 T8E3 3 T8E4 4	T7E5 3 T8E4 1
X. occidentale	0	T5E1 3	T5E1 1 T8E4 1	0

three species (*A. subulatus*, *H. curassavicum*, *X. occidentale*) occurred at flooded elevations, and all germinated following recession in November. Only *H. curassavicum* survived beyond February.

DISCUSSION

Plant responses

Sporobolus mitchellii (rats tail couch) was the only one of the three dominant species to respond positively to flooding. It is a spreading perennial grass, 20–45 cm high, with wiry stems running for 1–3 m, and is common in occasionally inundated areas of the Murray–Darling Basin. Many plants were <15 cm high (cf. Cunningham *et al.*, 1999), and so were completely submerged at low elevations. At NN, *S. mitchellii* responded to 44 days' flooding in October and December. At JE, however, prolonged flooding at elevation E4 delayed the response relative to E3. The critical duration for top-flooding appears to be 50–60 days (cf. JE:E3), as plants declined after 70–75 days (cf. JE:E4). Nevertheless, sufficient individuals survived to enable the population to recover and expand by February. In areas along the Murray channel, *S. mitchellii* endures 20–60 cm flooding for up to 73 days (Blanch *et al.*, 1999).

Sarcocornia quinqueflora (samphire) is a leafless, low-growing (20–100 cm), perennial chenopod shrub typical of saline areas (Cunningham *et al.*, 1999). It declined at deep-flooded sites (e.g. JE:E5, WW:E4, WW:E5), but did not respond at sites that were shallow-flooded. The local distribution of *S. quinqueflora* was consistent with its tolerance of water-logged saline soils (Jessop and Toelken, 1986). It may be unable to photosynthesize when top-flooded.

Atriplex vesicaria (bladder saltbush) is a perennial shrub that attains 70 cm height and diameter, and is distributed widely in semi-arid areas of southeastern Australia, including alluvial plains (Jessop and Toelken, 1986; Cunningham *et al.*, 1999). Its cover was reduced at all inundated sites, suggesting intolerance of flooding. The four years without inundation prior to October 2000 probably had encouraged the local population to extend its range.

Among less common species, flooding promoted *A. denticulata*, *M. verrucosum* and *M. repens* at the lowest elevations, *E. acuta* at intermediate to low elevations and *C. cunninghamii* and *C. coronopifolia* at higher to intermediate elevations. The emergence of *A. denticulata* and *C. cunninghamii* in December suggests delayed germination and a preference for moist rather than water-logged soils. The variable responses of these and other species suggest patchy germination, or a lack of seed and other propagules, including rhizomes. Adult *E. acuta* initially were absent (perhaps due to dry conditions, grazing by kangaroos, or both), but re-sprouted from buried rhizomes. The record of *M. verrucosum* (JE) also arose from a vegetative propagule.

Germination was rarely observed, despite flooding and favourable air temperatures of 21–24°C (Commonwealth Bureau of Meteorology data, Renmark; Britton and Brock, 1994). This suggests an impoverished seed bank or, less likely, the effects of grazing. Wetland seed densities may be as low as 1300 m^{-2} (Brock and Rogers, 1998) but typically are >10 000 m^{-2} (McIntyre, 1985; Nicol and Ganf, 2000). Various studies (Chong 2002; Frears 2001; Stone 2001) suggest that the soil seed bank in some areas of the Murray floodplain is indeed sparse. The changed flooding regime associated with river regulation may have limited the opportunities for flood-tolerant and responsive species to replenish the seed bank so that, when floods do occur, there is little capacity to respond. Comparable changes are described by Poiani and Johnson (1989) and Brock and Rogers (1998).

Grazing also may have limited plant responses. Flooding produced attractive new growth for kangaroos, and limited their access to some areas; they ate *S. mitchellii* and *A. vesicaria* and the shoots of less common species like *E. acuta*. Where grazing animals like these are abundant, they may counter the benefits of environmental flows for riparian vegetation (cf. Robertson and Rowling, 2000).

Terrestrial weeds may compete with re-establishing wetland vegetation (e.g. Baird, 1989). In this case, however, only five of 32 recorded plant species were weed species, and only three were recorded at flooded elevations. While exotic species may benefit from flooding (e.g. *Panicum repens*, torpedo grass: David, 1999), the low incidence of germination, and the death of most germinants, suggest that in this case the flood did not promote exotics.

As parts of the Murray floodplain are saline, flooding might be expected to increase near-surface soil salinity (e.g. Jolly, 2001). In this study, however, no increases were detected in conductivity or pH in the topmost 15 cm of soil at WW (the primary root zone for most plants recorded here); indeed, conductivity declined at WW:E3. The hydrostatic pressure from rising floodwaters may have been insufficient to draw saline water nearer the surface.

Future trials

In this study the quadrats at each elevation were not replicated, and a revised sampling design is a priority for future trials. We also recommend that the depth and duration of inundation be increased to promote aquatic and semi-aquatic species. Increased depth would promote flood-tolerant species higher on the elevation gradient, and increased duration would promote clonal growth and the production and dispersal of propagules by flood-tolerant and aquatic plants (cf. Cellot *et al.*, 1998). This will increase the time available for plants like *E. acuta* to spread via clonal growth. Species like *E. acuta, C. coronopifolia* and *M. drummondii* responded to the enhanced flood, and the succeeding flood in December, but died back by February. On the other hand, *S. mitchellii* apparently is able to endure at least 4 years without flooding. If it is desirable to avoid adverse effects on this species, flooding to 20–60 cm should not exceed 2 months (Blanch *et al.*, 1999).

The long-term value of an enhanced, artificial flood rests upon recruitment of new individuals, and not merely the survival, growth and reproduction of established plants. In this study, although some new vegetative ramets developed, recruitment from new seed was not observed. Seeds produced during one flood might not germinate until later flooding, however, and recruitment properly should be monitored over a longer period. A single flood event in isolation may have very limited effects, and repeat flooding may be necessary to sustain the response. It is possible that plant responses to trial floods will be muted until serial floods are restored, effectively to enrich and maintain the seed bank and thereby ensure greater capacity to respond to flooding. The role of small, isolated events such as the enhanced flood described here may be more in maintenance of existing communities rather than restoration of degraded ones.

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