Responses of riverbank and aquatic vegetation to an instream environmental flow

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Key Points

- Comparison of riverbank and aquatic vegetation among hydrological zones that receive different flows can facilitate the evaluation of responses to environmental flows.
- This study showed that riverbank and aquatic vegetation can respond positively to in-stream environmental flows. The duration and rate of recession of the environmental flow in Yallakool Creek, in southern New South Wales, were important for facilitating the response.
- There were more riverbank and aquatic taxa recorded in the hydrological zones that received an environmental flow than in a nearby zone that did not receive the environmental flow.
- The vegetation assemblage was significantly different among zones, with some taxa occurring only in zones receiving the environmental flow and other taxa having low abundance in the hydrological zone that did not receive an environmental flow.

Abstract

Environmental flows can help restore rivers by creating conditions that improve recruitment, growth and survival of riverbank and aquatic vegetation. The study aim was to compare responses of riverbank and aquatic vegetation among hydrological zones with different flow regimes. The species richness and cover of riverbank and aquatic vegetation at sixteen sites across four hydrological zones in the Edward-Wakool system in south-eastern Australia were monitored monthly from October 2014 to June 2015. Three zones received an instream environmental flow and one zone did not. The cover of vegetation was significantly different among zones ($F=21.548$, $p<0.000$), with higher cover of vegetation in two of the zones that received the environmental flow. There were more taxa in all zones that received the environmental flow than in the zone that did not. The vegetation assemblage was significantly different among zones (ANOSIM $R = 0.402$, $p = 0.001$). *Potamogeton tricarinatus*, *Myriophyllum* spp. and *Azolla* spp. occurred only in zones receiving the environmental flow, and *Chara* spp., *Eleocharis acuta* and *Limosella* spp. were in low abundance in the zone with no environmental flow. There has been a gradual improvement in riverbank and aquatic vegetation in this system over the four years since environmental flows commenced.

Keywords

Instream environmental flow, aquatic plants, Edward-Wakool system, monitoring, flow management, regulated rivers, vegetation cover, vegetation assemblage

Introduction

Water management and the flow regime of a river system can affect the growth and maintenance of adult plants and strongly influence aspects of the reproductive cycle, including flowering, dispersal, germination and recruitment. Riverbank plant survival and growth is affected by the frequency and duration of inundation (Toner and Keddy 1997; Johansson and Nilsson 2002; Lowe et al. 2010) along with other factors, such as light availability and disturbance by grazing. For riverbank plants, frequent inundation can delay reproduction (Blom and Voesenek 1996), whilst an extended duration of inundation can reduce growth or survival (Blom et al. 1994; Johansson and Nilsson 2002; Lowe et al. 2010). Favourable soil moisture and nutrient conditions created by a receding flood can encourage rapid recovery and root and shoot development and many plants, including emergent macrophytes and riparian understorey herbs, often germinate on flood recession (Nicol 2004; Roberts and Marston 2011). Under some circumstances a high level of sediment deposition during periods of inundation can reduce the survival of some herbaceous riverbank species (Lowe et al. 2010).

The distribution and abundance of submerged and emergent aquatic macrophytes is also strongly affected by flow. In general, mosses tend to dominate areas with high water velocities (>0.6 ms^{-1}) and rocky substrates such as those found in headwater streams, whereas vascular macrophytes generally dominate habitats with lower water velocities (<0.6 ms^{-1}) and finer substrates (French and Chambers 1996). Species with floating leaves are usually limited to areas with lower water velocities due to the higher drag of floating leaves, and emergent species tend to be restricted to edge habitats in flowing water, as flow can damage stems. Flows that increase the area and duration of shallow, slow flowing hydraulic patches enable aquatic plants with rhizomatous roots to extend their roots and shoots from nodes, facilitating increase in cover of these species.

The Edward-Wakool system is a large anabranch system of the Murray River main channel in the southern Murray-Darling Basin, Australia. It is a complex network of interconnected streams, ephemeral creeks and flood-runners. Like many rivers of the Murray-Darling Basin, the flow regime of the Edward-Wakool system has been significantly altered by river regulation (Green 2001; Hale and SKM 2011). The natural flow regime of this system was historically strongly seasonal, with high flows occurring typically from July to November. Flow regulation has resulted in a marked reduction in winter high flows and an increase in daily flows during February and March (Watts et al. 2016).

Environmental flows can help restore rivers by creating conditions that improve the recruitment, growth and survival of riverbank and aquatic vegetation. The Australian federal government has been delivering in-stream environmental flows to rivers in the Edward-Wakool system since 2010 to improve the diversity and condition of native fish and other biota, increase longitudinal and lateral hydrological connectivity and inundation of low-lying habitats, maintain or improve water quality, and improve ecosystem and population resilience through supporting ecological recovery and maintain aquatic habitat. Monitoring of ecosystem responses to environmental flows in this system (Watts et al. 2013a, 2013b, 2014, 2015) has had a strong focus on water quality and fish responses. One of the objectives in 2014-15 was to maintain or improve vegetation condition, including fringing vegetation and emergent and submerged aquatic plants (Water Use minute 10008).

The aim of this study was to evaluate the effects of small (below half bankful) instream environmental flows on the percent cover, abundance and taxonomic richness of riverbank and aquatic vegetation at a number of reaches in the Edward-Wakool system. We hypothesised that the total percent cover and cover of abundant taxa across the 2014-15 monitoring period would be higher in the zones that received the environmental flow compared to the upper Wakool River that did not receive the environmental flow, due to the increased area of inundation and extended duration which should facilitate plant germination, recruitment and growth.

Methods

Study area

The study was undertaken in Yallakool Creek and the Wakool River, which are part of the Edward-Wakool system in New South Wales (Figure 1). Commonwealth environmental water was delivered through a regulator at the upstream end of Yallakool Creek (zone 1), and flowed downstream into the Wakool River (zones 3 and 4). The upper Wakool River (zone 2) between the Edward River and the confluence with Yallakool Creek did not receive environmental water. There is an escape regulator from the Mulwala irrigation canal into Wakool River zone 2, which was used in 2014-15 to deliver operational flows.

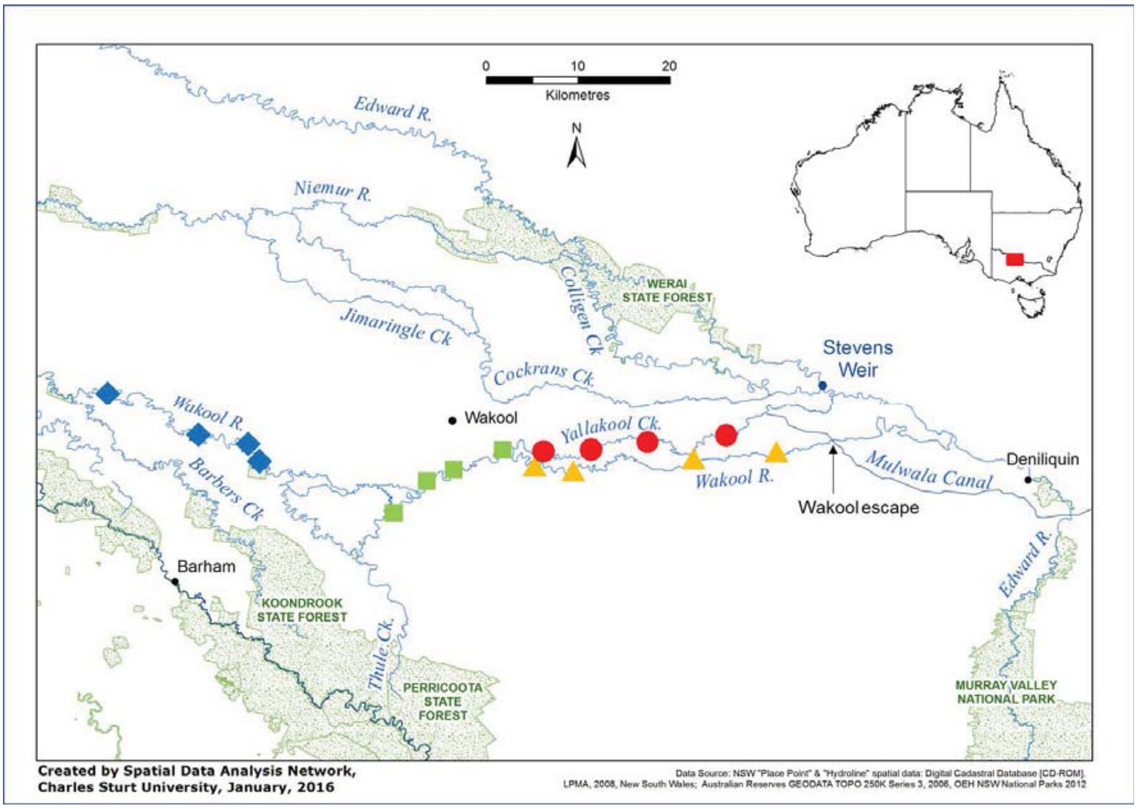

Figure 1. Map of the Edward-Wakool system showing location of sampling sites for monitoring of riverbank and aquatic vegetation. Red circles indicate Yallakool Creek zone 1, orange triangles indicate Wakool River zone 2, green squares indicate Wakool River zone 3 and blue diamonds indicate Wakool river zone 4.

The environmental flow remained in-stream and was below half-bankful. The relevant discharge data for automated gauges was downloaded from NSW Waterinfo website and daily discharge data from the Wakool escape was provided by WaterNSW. The daily volume of water (ML/day) accounted for as Commonwealth environmental water was provided by WaterNSW and the Commonwealth Environmental Water Office. The hydrographs of Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2014 to 30 June 2015 grouped into three different hydrological regimes in 2014-15:

a) In Yallakool Creek (zone 1) there was a spring fresh followed by an in-stream environmental flow of approximately 500 ML/day from August until 16 December 2014, followed by a recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day. (Figure 2).

b) The Wakool River zone 2 received no environmental flow in 2014-15. There was an extended period of base operational flows in the range of 50 to 100 ML/day between August and March. In order to meet downstream demands in the lower Murray River the Murray-Darling Basin Authority delivered an operational flow into the Wakool system via the irrigation channel network (Wakool escape) in March and April 2015. This resulted in a fresh in zone 2 in March and April 2014 of approximately 300 to 330 ML/day that had both a steep rise and recession (Figure 2).

c) The Wakool River zones 3 and 4 had similar hydrological regimes in 2014-15. The environmental flow in Yallakool Creek resulted in an environmental flow of approximately 450 ML/day in Wakool River zones 3 and 4 from August until December 2014, followed by a recession to operational flows in the range of 200 to 240 ML/day. The environmental flow significantly increased the area of slack and slackwater (<0.3ms^{-1}) in these zones (Watts et al. 2016). These two zones also received the MDBA operational flow from the Wakool Escape as described above.

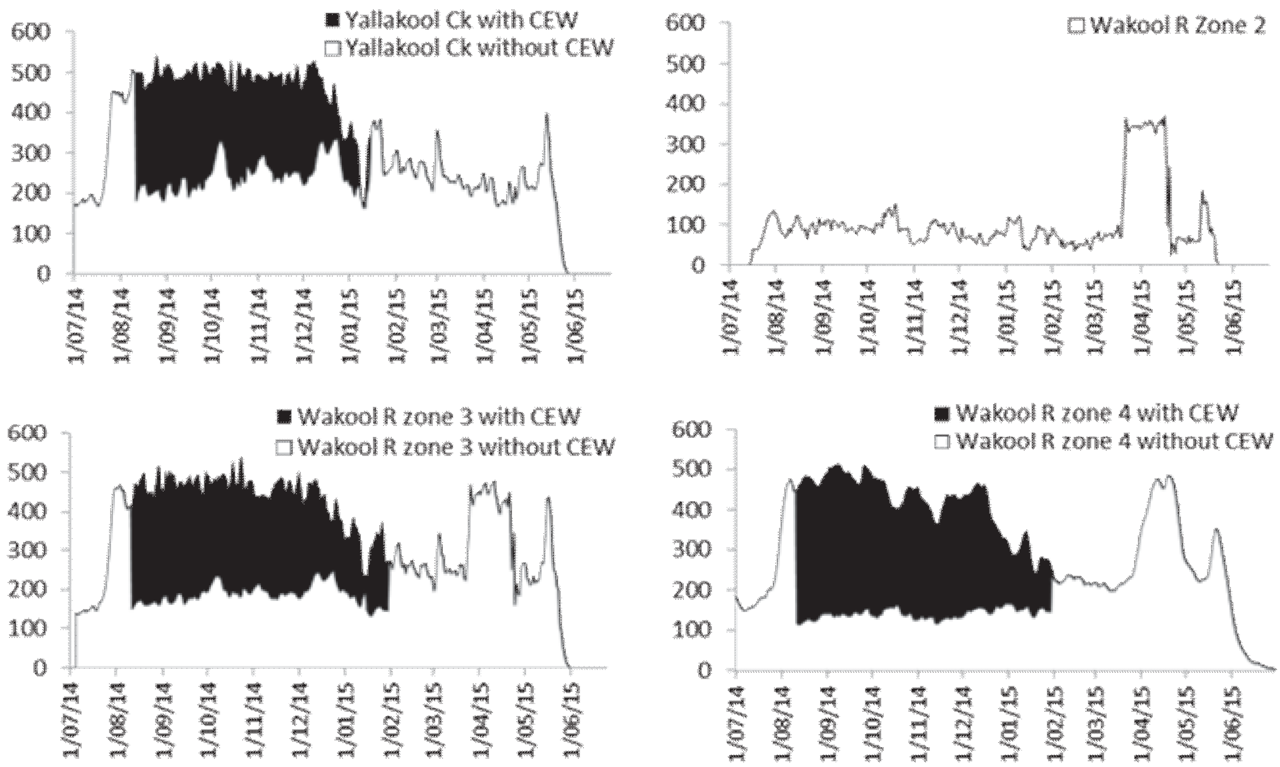

Figure 2. Hydrographs of zone 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2014 to 30 June 2015. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. There was an unregulated flow in zones 1, 3 and 4 in August 2014. The MDBA operational flow from the Wakool Escape is evident in the hydrograph of zones 2, 3 and 4 in March 2015.

Vegetation surveys

Four sites in each of four hydrological zones were surveyed monthly between October 2014 and June 2015. At each site five permanent 20 m long transects were established parallel with the river channel. Star pickets were installed at each end of the permanent transect. The transects were surveyed so they were 25 cm apart in vertical height, with the five transects thus covering 1 m of vertical height of the river bank. Transect one was in the water at base operational flows, and the other four transects further up the riverbank had the potential to be inundated during the environmental flow, unregulated flows or during periods of higher operational flows.

At each of the transects on each sampling date a 20 m tape measure was laid out running horizontally along the riverbank between the star pickets that were at the same height of riverbank. The taxa at each 50 cm point quadrat along the 20 m transect (40 points on each transect) was recorded. Plants were identified to genus, with the exception of a few common taxa that could be consistently identified to species level. Terrestrial grasses were not identified taxonomically and were recorded collectively as grass. If no vegetation was present at a point, then that point was recorded as bare ground, leaf litter or log/tree trunk. When the transects were in the water the tape measure was laid at the edge of the water and a flexible fibreglass pole held from the tape out to the water surface to locate the point on the transect for recording data.

Data analysis

Each plant was classified into one of three categories (submerged, amphibious and terrestrial) using a range of sources including Brock and Casanova (1997), Casanova (2011) and Roberts and Marston (2011). Although there are some limitations of using water plant functional groups to classify taxa, the approach of classifying into these three general groups is sound for common taxa that can be reliably distinguished. The point quadrat data were used to estimate the percent cover of riverbank and aquatic vegetation for each transect at each sample date. If there were any logs or tree trunks recorded in a given transect, the percent cover for that transect was calculated from a reduced number of points, being 40 minus the number of points recorded as log/tree trunk. This is because no vegetation would have been able to grow at that point if a log or tree trunk was present.

A one way ANOVA with zone as the treatment factor was undertaken to test if the percent cover of vegetation was significantly different among the four zones. Analyses were undertaken incorporating the data across the entire monitoring period (October 2014 to June 2015). This enabled a comparison of zones that received the environmental flow to the zone with no environmental flow. Analysis of the percent cover for the eight most common taxa were undertaken individually using Kruskal-Wallis nonparametric test because the data were not normally distributed. Statistical analyses were carried out using the freeware R and the R package MASS (R Development Core Team 2013) and IBM SPSS Statistics v20. P-values of <0.05 were used to determine the significance of each ANOVA test. When significant differences were indicated, post hoc pairwise comparisons were undertaken to determine differences between hydrological zones.

The species richness observed in transects that received the environmental flow was compared to transects that did not receive the environmental flow. The vegetation assemblage was compared among zones using one-factor analysis of similarities (ANOSIM) (PRIMER v6). Similarity percentages (SIMPER) was used to identify the taxa contributing most to the dissimilarities across zones. The ANOSIM and SIMPER analyses were undertaken using PRIMER V6 software. The data were plotted using non-metric multidimensional scaling ordination.

Results

Vegetation

Thirty four riverbank and aquatic vegetation taxa were recorded across the sixteen sites between October 2014 and June 2015. Three taxa were classified as submerged, 14 were amphibious and 17 were terrestrial. The eight taxa having the highest percent cover were the rush *Juncus* spp., floating pondweed (*Potamogeton tricarinatus*), old man sneeze weed (*Centipeda cunninghamii*), a charophyte (*Chara* spp.), mudgrass (*Pseudoraphis spinescens*), common spikerush (*Eleocharis acuta*), milfoil (*Myriophyllum* spp.) and grasses. Seven of the eight most abundant taxa were classified as submerged or amphibious taxa, which is expected as the surveys were undertaken in the littoral zone of the riverbank.

The cover of riverbank and aquatic vegetation differed significantly among the four zones ($F=21.548$, $p<0.000$, Table 1). The cover of vegetation was higher in the Wakool River zones 3 and 4 that received the environmental flow compared to the Wakool River (zone 2) with no environmental flow (Figure 3, 4). The percent cover of vegetation in Yallakool Creek zone 1 that received the environmental flow was not significantly higher than that in the Wakool River zone 2 with no environmental flow (Figure 3).

There were three types of responses of individual taxa to environmental flows. *P. tricarinatus* and *Myriophyllum* spp. had significantly higher cover in Wakool River zone 3 compared to all other zones, and were absent from zone 2. *Chara* spp., *E. acuta, C. cunninghamii, P. spinescens* and grass had increased cover in one or more of the zones that received environmental flows, compared to zone 2 which received no environmental flow. For *Juncus* spp there was no difference in mean percent cover among zones (Table 1).

Table 1. Results of one-way ANOVAs comparing mean percent cover of aquatic and riverbank vegetation cover of all taxa and individually for the eight most common taxa across river zones for the period October 2014 to June 2015. P values <0.05 indicates a significant difference in cover of vegetation among zones.

Analysis	df	F-value	p	significance
All taxa	3	21.548	0.000	***
Juncus spp.	3	1.788	0.158	n.s.
Potamogeton tricarinatus	3	23.368	0.000	***
Centipeda cunninghamii	3	16.563	0.000	***
Chara spp.	3	3.540	0.028	*
Psuedoraphis spinescens	3	5.441	0.050	**
Eleocharis acuta	3	7.621	0.000	**
Myriophyllum spp.	3	15.456	0.000	***
Grass	3	3.914	0.016	*

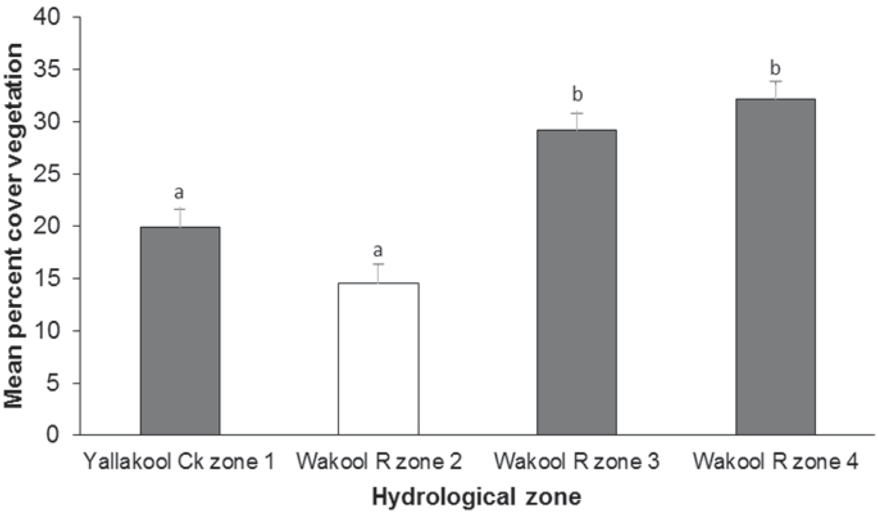

Figure 3. Mean percent cover (±SE) of riverbank and aquatic vegetation sampled in 2014-15 in Yallakool Creek and the Wakool River. Yallakool Creek zone 1 and the Wakool River zones 3 and 4 received the environmental flow in 2014-15 (black bars), whereas the Wakool River zone 2 did not receive the environmental flow (white bar). a and b denotes unique subsets based on posthoc tests.

Figure 4. Photos of aquatic vegetation in the Edward-Wakool system, showing higher cover in the Wakool River zone 3 (left) and zone 4 (middle) that received the environmental flow, compared to the upper Wakool River zone 2 (right) that did not receive the environmental flow.

More taxa were recorded in zones 1 (n=22), zone 3 (n=21) and zone 4 (n=24) that received the environmental flow than in zone 2 (n=18) that did not receive the environmental flow. The four hydrological zones had significantly different assemblage of vegetation (Global R = 0.402, p = 0.001). The vegetation assemblage in zone 3 (environmental flow) was different to zone 2 (no environmental flow)(Figure 5). However, there was overlap of the vegetation assemblages between zone 1 and 4 (environmental flow) and the Wakool River zone 2 (no environmental flow)(Figure 5).

The taxa contributing most to the dissimilarity between zone 2 (no environmental flow) and zones 1, 3 and 4 (environmental flow) include *Centipeda cunninghamii* that responds to wetting of the riverbank (Table 2). Several aquatic taxa such as *P. tricarinatus*, *Myriophyllum* spp. and *Azolla* spp. were absent from zone 2 (no environmental flow (Table 2). The zones that received the environmental flow had higher abundances of aquatic taxa such as *Chara* spp., *P. tricarinatus*, *Myriophyllum* spp., and taxa that respond after inundation of riverbank, such as *Limosella* spp. There were more eucalypt seedlings in the zone without the environmental flow (zone 2) than in all three zones that received the environmental flow (Table 2).

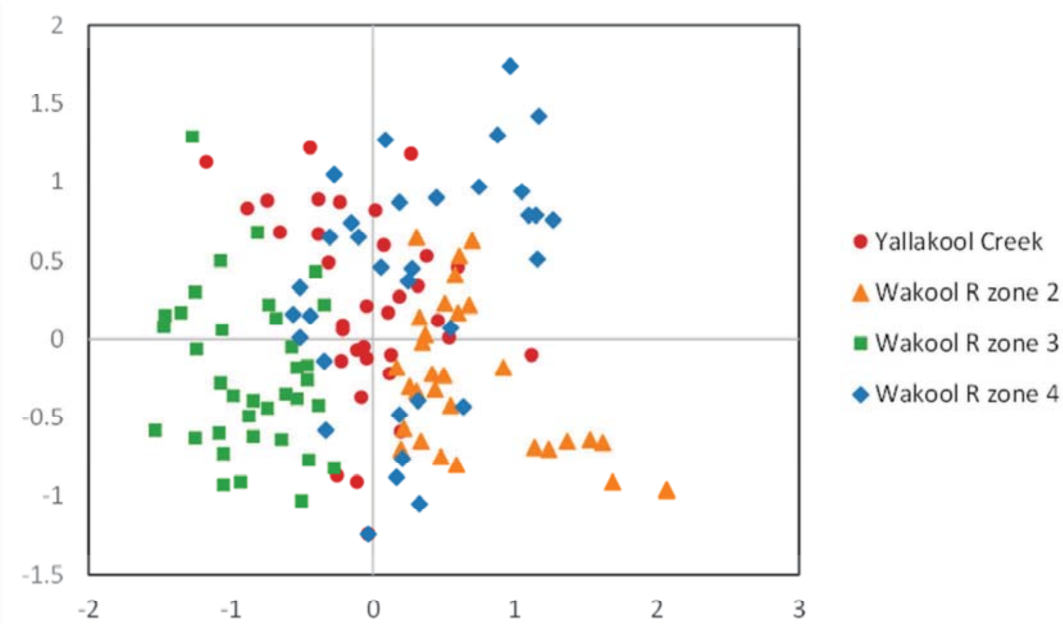

Figure 5. Multi-dimensional scaling ordination plot based on riverbank and aquatic vegetation assemblages from four hydrological zones in the Edward-Wakool system. Symbols represent sites within each hydrological zone. Stress = 0.24. Points that are closer together in the ordination have the most similar vegetation assemblage. Yallakool Creek and the Wakool River zones 3 and 4 received the environmental flow and Wakool River zone 2 did not receive the environmental flow.

Discussion

There was a significant response of riverbank and aquatic vegetation to an in stream (less than half bankful) environmental flow with higher percent cover observed in two of the three zones that received the environmental flow. Several aquatic taxa such as *Potamogeton tricarinatus*, *Myriophyllum* spp. and *Azolla* spp. occurred only in zones that received the environmental flow, and other taxa such as *Chara* spp., *Eleocharis acuta* and *Limosella* spp. were in low abundance in zone 2 that did not receive the environmental flow.

Table 2. Results of SIMPER analysis showing the abundance of taxa that contributed most to the difference between zone 2 (no environmental flow) and zones 1, 3 and 4 (received environmental flow)

Comparison	species	% contribution to difference between zones	Average abundance Zone 2 (no e-flows)	Average abundance (zones with e-flows)
Wakool R zone 2 and Yallakool Creek zone 1			**Zone 2**	**Zone 1**
	Centipeda cunninghamii	11.91	0.94	1.39
	Juncus spp.	10.83	2.16	2.06
	grass	10.24	0.67	1.08
	Chara spp.	9.53	0.02	1.01
	Eucalypt seedling	9.10	0.87	0.06
	Pseudoraphis spinescens	8.18	0.17	0.87
	Myriophyllum spp.	6.00	0.00	0.62
Wakool R zone 2 and Wakool R zone 3			**Zone 2**	**Zone 3**
	Potamogeton spp.	18.22	0	2.54
	Myriophyllum spp.	9.77	0	1.44
	Chara spp.	9.64	0.02	1.15
	Juncus spp.	8.51	2.16	2.25
	Centipeda cunninghamii	6.68	0.94	0.58
	Azolla spp.	6.60	0	1.02
	Eucalypt seedling	6.05	0.87	0.35
Wakool R zone 2 and Wakool R zone 4			**Zone 2**	**Zone 4**
	Juncus spp.	10.51	2.16	2.34
	Centipeda cunninghamii	10.23	0.94	1.71
	Pseudoraphis spinescens	8.42	0.17	0.97
	Eleocharis acuta	8.05	0.05	1.11
	Polygonum spp.	7.94	0.37	0.96
	Mudwort	7.64	0.04	1.02
	grass	7.27	0.67	0.82
	Eucalypt seedling	6.22	0.87	0.31

Some of the taxa that responded positively to the environmental flow were those that germinated and grew in the shallow water during the period of inundation during the environmental flow. For example, *Chara* spp, a green algae in the family Characeae that grow submerged attached to the muddy bottom of the river, increased in cover during the environmental flow. Other taxa such as *E. acuta* and *Cyperus* spp. increased in cover following the recession of the environmental flow, with observations of plants sprouting on the edge of the riverbank following the recession. *E. acuta* are able to grow more vigorously in damp or saturated soils than in shallow water (Blanch and Brock 1994) and *Cyperus* spp. does not germinate under water but regeneration occurs following water level recession (Roberts and Marston 2011). Some taxa, such as *P. tricarinatus*, *Myriophyllum* spp and *Ludwigia* spp that have rhizomatous roots occurred only in zones 1, 3 and 4 that received the environmental flow. The duration of the environmental flow would have enabled these plants to extend roots and shoots from nodes, and store starches, proteins, and other nutrients when the plants died back during winter. One of the longer lived taxa, *Juncus* spp*.* did not significantly increase in cover in response to the environmental flow, however there appeared to be a recruitment response of this species to the environmental flow as *Juncus* sp. seedlings were observed in zones 1, 3 and 4. Thus the inundation of the riverbank during the environmental flow, though achieving less than half bankful levels, increased the opportunity for different types of riverbank and aquatic plants to germinate and grow in the zones receiving the environmental flow than in the Wakool River zone 2 that did not receive the environmental flow but instead had a constant operational base flow over an extended period of time.

The response of aquatic and riverbank vegetation to the environmental flow was not consistent among the three hydrological zones that received environmental water. Riverbank and aquatic vegetation responded significantly to the environmental flow in zones 3 and 4, but the response in Yallakool Creek zone 1 was not significantly different to zone 2 (no environmental flow). The lack of the predicted response in Yallakool Creek may be due to a number of factors such as river channel geomorphology, which would influence both the area of riverbank inundated during environmental flows and the velocity of flows. These factors were examined by Watts et al. (2016) in a study where hydraulic modelling was used to compare the distribution of hydraulic patches and the depth profiles of the hydrological zones under different discharges. Watts et al. (2016) showed that there was a loss in the area of slow water at two of the four sites in Yallakool Creek (zone 1), whereas, at seven of the eight sites in the Wakool River zone 3 and 4 there were substantial increases in the area of slow water under the environmental watering scenario.

The 2014-15 environmental flow was managed with a slower rate of recession than in previous years' events (Watts et al. 2014; Watts et al 2015). This was done to avoid stranding of biota and enable aquatic vegetation to persist over an extended period of time. In 2012-13 the recession at the end of an environmental watering action in Yallakool Creek was too rapid and aquatic vegetation was exposed and desiccated immediately after recession of e-watering (Watts et al. 2014). The longer recession in 2014-15 resulted in longer duration of persistence of some taxa, such as *Chara* spp and *Limosella* spp. The dried algae and aquatic plants that persisted on the riverbank sediment after desiccation may have provided nutrients to help 'kick-start' a river productivity response during subsequent inundation events.

The species richness and cover of riverbank and aquatic vegetation in zone 2 that received no environmental water was lower than in the other zones. Some of the responses of individual taxa reflect the absence of environmental watering. For example, there were no *Juncus spp*. seedlings in zone 2 and all *Juncus* plants were of similar height, occurring in one or two narrow bands at a height on the riverbank that possibly corresponds with the height of a previous unregulated flow event. In contrast, there were more eucalypt seedlings in zone 2 than in all three zones that received the environmental flow. Eucalypt incursion into the stream bed has occurred in other systems (e.g. lower Goulburn River in Victoria) during the Millenium Drought, and is still occurring in some wetland systems in the absence of regular inundation (e.g. mid-Murrumbidgee wetlands). The lower abundance of eucalypt seedlings in the zones receiving environmental flows is a reverse trend to the amphibious and submerged vegetation groups, but is a desirable outcome.

The response of aquatic and riverbank vegetation to environmental flows has been ongoing and the observations in 2014-15 are part of a gradual improvement in vegetation that has been observed in this system over the past few years. In addition to the environmental flows in 2014-15, Commonwealth environmental water was delivered to Yallakool Creek in 2011-12, 2012-13 and 2013-14, thus zones 1, 3 and 4 have been influenced by environmental flows over the past 4 years. While vegetation was not formally monitored in all of the hydrological zones during that period, both scientists, landholders and other community members have observed the change in riverbank and aquatic vegetation over this period. It is likely that the environmental watering in previous years would have enabled rhizomes of plants, such as *E. acuta,* to spread or plants to set seed. This would contribute to the continuous improvement in response of riverbank and aquatic vegetation to environmental watering that has been observed in this system over time.

Conclusions

This study has shown that riverbank and aquatic vegetation can respond positively to relatively small (below half bankful) in-stream environmental flows. There were more riverbank and aquatic taxa recorded in all three hydrological zones that received the environmental flow than in a nearby river zone that did not receive the environmental flow. The vegetation assemblage was significantly different among zones, with some taxa occurring only in the zones receiving the environmental flow and other taxa being in very low abundance in the hydrological zone that did not receive the environmental flow. The duration and rate of recession of the environmental flow contributed to the positive response of the riverbank and aquatic vegetation. The duration of the environmental flow would have enabled aquatic plants with rhizomatous roots to extend roots and shoots from nodes. The longer rate of recession would have extended the period where there is damp soil on the riverbank, enabling amphibious plants to sprout and grow in the damp riverbank sediment. This study contributes to the knowledge on ecosystem responses to instream environmental flows that has tended to focus on fish and water quality responses to flow.

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