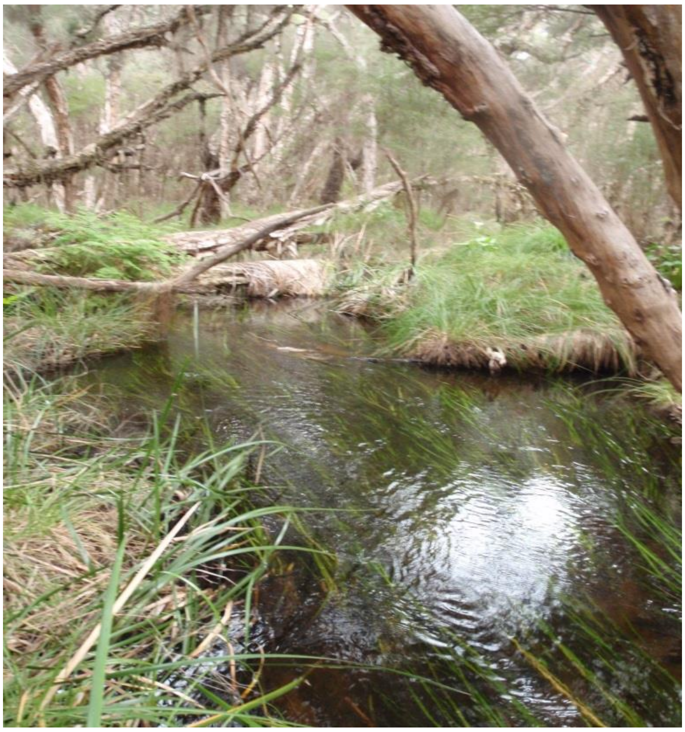
An assessment of the associated environmental benefits of riparian vegetation in the Ellen Brook Catchment



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Introduction

One of the key services provided by riparian vegetation is its capacity to intercept nutrients and improve in-stream water quality (Narumalani *et al.* 1997; Lyons *et al.* 2000; Brian *et al.* 2004). However, previous research has identified that riparian vegetation benefits the environment in several ways (Naiman and Decamps 1997). Riparian vegetation provides habitat, food, water and shelter for terrestrial animals, together with passage along linear habitat corridors (Naiman *et al.* 1993; Naiman and Decamps 1997). Riparian vegetation creates physical barriers (roots and log jams) in streams, increasing structural complexity and providing new habitats (Gregory *et al.* 1991; Dobkin *et al.* 1998; Opperman and Merelender 2004; Naiman *et al.* 2008; Pettit *et al.* 2013), for a greater diversity of animals, improving ecological condition (Tabacchi *et al.* 2000). The contribution of large woody debris provides habitat for fish populations (Opperman and Merelender 2004; Howson *et al.* 2012; Pettit *et al.* 2013) while providing surfaces for algae, fungi, bacterial communities, plants and macroinvertebrates to colonise (Gregory *et al.* 1991; Lemly and Hilderbrand 2000). Riparian vegetation can block up to 95% of solar radiation to narrow streams (Hill 1996; Mosisch *et al.* 2001), affecting the density of aquatic plants (Bunn *et al.* 1998; Mosisch *et al.* 2001), and limiting algal growth (e.g. phytoplankton and benthic algae), reducing primary productivity (Hill 1996; Mosisch *et al.* 2001). Shading can moderate and lower stream water temperatures (Rutherford *et al.* 2004; Bowler *et al.* 2012), affecting metabolic rates of in-stream organisms and influencing the diversity of macroinvertebrate communities (Rutherford *et al.* 2004; Naiman *et al.* 2008; Stewart *et al.* 2013). Finally, riparian vegetation contributes labile organic matter to streams (Graca *et al.* 2002), which is utilised by different invertebrates and can dictate stream food webs (Hladyz *et al.* 2011b).

Leaching and biological breakdown of this organic matter releases nutrients and carbon into the water (Meyer 1990; Graca *et al.* 2002; Hladyz et al 2011b). Refractory carbon remaining after leaching and decomposition colours the water with tannins and humic acids increasing gilvin concentrations (Graca *et al.* 2002). Highly coloured streams can limit light penetration, reducing the growth of algae and macrophytes in streams (Smock and Gilinsky 1992), which can have a similar effect to shading (Meyer 1990; Bunn *et al.* 1998; Mosisch *et al.* 2001). Therefore, it is essential to distinguish between the effect of shading and reduced light penetration of coloured streams on in-stream processes and biological communities.

Current and historical land use practices such as clearing and agriculture can have long lasting impacts on riparian and stream condition (Burcher *et al.* 2007; Maloney *et al.* 2008;

Hladys *et al.* 2011b). Clearing can increase nutrient inputs by removing its buffering capacity and increases the available light in streams. This results in greater in-stream primary productivity and communities becoming more reliant on autotrophic food sources (Reid *et al.* 2008b; Hladys *et al.* 2011a). Furthermore, invertebrate composition differs significantly between cleared (pasture) and forested reaches because the reduction of riparian vegetation density and condition leads to a reduction in the quality and quantity of organic matter entering streams (Danger and Robson 2004; Reid *et al.* 2008a, 2008b; Arnaiz *et al.* 2011; Hladyz et al 2011b). At larger spatial scales, Sponseller *et al.* (2001) identified that macroinvertebrate diversity decreases among catchments with the increasing percentage of non-forested land.

Revegetating riparian zones is a common best-management practice used to intercept incoming nutrients (Narumalani *et al.* 1997; Lyons *et al.* 2000; Brian *et al.* 2004), however, it is also used to improve stream condition (Parkyn *et al.* 2003; Webb and Erksine 2003; Hughes *et al.* 2005). Vondracek *et al.* (2005) identified that water quality, channel characteristics, available habitats, fish and macroinvertebrate communities all improve by increasing the amount of permanent riparian vegetation. Furthermore, replanting and rehabilitating riparian vegetation increases habitat complexity (Robertson and Rowling 2000) and provides a higher proportion of palatable food (Bunn *et al.* 1999). The benefits of replanting riparian vegetation can extend downstream, by improving water quality (Harding *et al.* 2006), helping moderate temperatures (Davies 2010), adding detrital matter (Reid *et al.* 2008b) and improving macroinvertebrate communities in cleared reaches (Sponseller *et al.* 2001; Burcher *et al.* 2007). However, Becker and Robson (2009) showed that in-stream biological communities can take in excess of eight years following restoration to return to conditions exhibited in remnant forests. Indeed, invertebrate assemblages at restored sites continued to resemble those in unrestored willow-infested sites following revegetation with native species. Thus, when designing revegetation projects it is imperative to consider current and historical land use practices as they continue to affect in-stream biological communities (Maloney *et al.* 2008; Becker and Robson 2009).

The makeup of aquatic macroinvertebrate assemblages can vary widely between intermittent and perennial streams (Bunn *et al.* 1986). By definition, intermittent streams refer to those that only flow for part of the year, while perennial streams flow all year round. Many Australian streams are intermittent due to climate. For example in Western Australia they flow only over winter as a result of hot, dry summers and mild, wet winters of the

Mediterranean climate (Bunn *et al.* 1986). Intermittent streams often have a lower diversity and abundance of macroinvertebrates due to stressors such as limited water availability, temperature fluctuations and poor water quality (Williams and Hynes 1976, 1977; Boulton and Lake 1992; Gasith and Resh 1999; Garcıa-Roger *et al.* 2011). However, there are species that show physiological adaptations (aerial adults, burrowing and desiccation resistant eggs) to survive in intermittent streams (Stanley *et al.* 1994; Chester and Robson 2011; Wickson *et al.* 2012). In Mediterranean-climate regions, perennial streams provide sources of colonists for intermittent streams and thus help conserve regional biodiversity (Chester and Robson 2011). Furthermore, riparian vegetation can act as a refuge for invertebrates during drought by keeping sediment temperatures lower, retaining moisture and providing large woody debris for refuges (Storey and Quinn 2013). Riparian vegetation is often planted along intermittent streams, with the assumption that it will provide the same services as vegetation on perennial streams, however there are few published studies to support this assumption.

In the Ellen Brook Catchment, much of the riparian vegetation has been removed, potentially affecting in-stream condition and macroinvertebrate communities. As a result, revegetation has been carried out in some stream reaches, mainly along intermittent streams. This report investigates the environmental benefits associated with riparian vegetation, both remnant and revegetated, within the riparian zone itself and in perennial and intermittent streams. Both clear and coloured (tannin-stained) intermittent streams occur in the Ellen Brook Catchment, so the effects of vegetation in clear and coloured reaches were also assessed. There were no coloured perennial streams. Macroinvertebrate assemblages were sampled to assess composition and indicate ecosystem health. The key questions addressed in this study are:

- How does riparian vegetation structure and condition affect in-stream physico-chemical conditions?
- What is the effect of riparian vegetation, flow regime and colour on the ecological health of streams?

Methods

Study sites

Ellen Brook is a relatively large catchment (715 km^2), mainly underlain by sandy soils. Extensive land clearing has left little riparian vegetation along both perennial and intermittent streams flowing into Ellen Brook. Intermittent streams occur primarily in the southern half of the catchment and the few perennial streams are in the north. Intermittent streams ceased to flow and were visibly dry over summer (observed in 2012). Perennial streams flowed all year round and never dried out (determined from local knowledge and observations in 2012). Both coloured (stained brown with tannins) and non-coloured (clear) streams occur within the catchment, but none of the perennial streams were coloured. Clear streams predominantly flowed from the east (east to west) and coloured streams from the west (west to east).

Sampling design

Coloured water duplicates two effects of riparian vegetation: it may limit both light and temperature, potentially limiting in-stream primary production, as well as having direct effects on the biota. The effects of water colour therefore needed to be separated from those of riparian vegetation, in order to determine whether riparian vegetation was affecting invertebrate assemblages in streams in the Ellen Brook Catchment. This distinction could only be tested in intermittent streams due to the absence of coloured perennial streams in this catchment. Also, intermittent and perennial streams in the same catchment often contain different invertebrate assemblages, so the effect of vegetation could be difficult to disentangle from the effect of flow regime. Furthermore, there is a limitation in the sampling design as perennial streams have more continuous vegetation than intermittent streams, which may influence the results. Thus, three hypotheses were tested to separate the effects of vegetation, water colour and flow regime: (1) that invertebrate assemblage composition differed between vegetated and unvegetated sites; (2) that composition differed between coloured intermittent streams and non-coloured intermittent streams; (3) that composition differed between non-coloured perennial streams and non-coloured intermittent streams.

To test these hypotheses, twelve stream segments were selected across the catchment (Figure 1): two vegetated and two unvegetated segments each in: non-coloured perennial streams, coloured intermittent streams and in non-coloured intermittent streams. At each site, riparian, water and in-stream habitat quality were assessed and invertebrates sampled once in spring (September 2012).

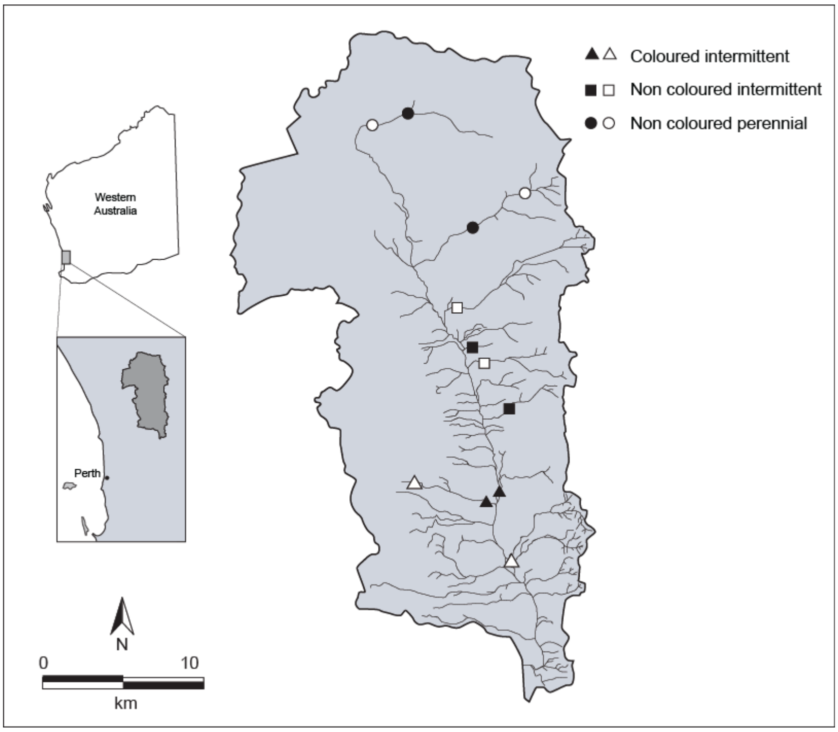

Figure 1- A map of sample sites throughout the catchment for the three stream segment types. The solid black shapes represent vegetated sites and the white unvegetated sites.

Vegetation assessment

Vegetation sampling was undertaken at all vegetated riparian sites in spring (September 2012). Classifying the health of riparian vegetation is essential, as changes in cover, density, structure and composition modify the degree of riparian influence on the physical, chemical and biological characteristics of streams. Riparian condition was determined using the condition scale developed by Keighery (1994), which ranked vegetation condition from pristine to completely degraded. The classification was based on a composite scale (Appendix One), that firstly assessed the structure of riparian vegetation and plant community health (presence of healthy leaves and regeneration) and secondly on the level of disturbance (presence of dieback, grazing, aggressive exotic weeds and the degree of clearing).

Vegetation structure was assessed by the presence or absence of a canopy (> 2 m), understorey (0.2-2 m) and groundcover (< 0.2 m). The composition of these layers was typically defined as canopy (trees), understorey (shrubs) and groundcover (sedges/rushes, grasses and herbs). Total projected foliage cover ("crown cover") was measured in each structural layer.

Cover categories used by Keighery (1994) were adapted for the definition and classification of vegetation assemblages and were defined as follows: <2 % (not considered to constitute a structural layer), 2-10 %, 11-30 %, 31-70 %, 71-100 %. Three replicate samples using standardised quadrat sizes were used for each structural layer, being canopy (10 m^2), understorey (4 m^2) and groundcover (1 m^2).

Stream orientation and shading capacity

The shading capacity of riparian vegetation on stream segments was determined by measuring stream width, distance of riparian vegetation from the stream, height of riparian vegetation, riparian vegetation bank cover and the orientation of the stream. Sites with no riparian vegetation were assessed to have no shading capacity. Shading was calculated for three times (September, November and January) to assess how shading potential changed with more sunlight hours. These months were selected as from September onwards temperature and light periods increase and represent times when shading is likely to have the greatest effect on intermittent streams, particularly before they dry out. The length of shadow created by riparian vegetation was calculated using the equation:

$$length\ of\ shadow = h/\tan(a)$$

Where h = vegetation height and a = sun altitude at a given time (Chang 2006)

The shadow length and direction were compared against stream width, distance of vegetation and the stream orientation to estimate the maximum potential stream shading by riparian vegetation. This was calculated for all daylight hours to assess the total number of hours the stream segments would be shaded. Shading potential represents potential and not actual shading, as it does not incorporate vegetation width and canopy cover. Therefore the values calculated represent the maximum possible shading.

Stream water quality

Physio-chemical readings (pH, dissolved oxygen (DO, mg/L and % saturation), temperature (°C), redox potential, salinity and conductivity) were taken using a YSI multi-parameter probe (YSI 556MPS).

Grab samples were taken from each stream segment using water quality bottles. Samples were processed, bottled, stored on ice and returned to the laboratory on the same day. Samples were then processed for: total phosphorus (TP), filterable reactive phosphorus (FRP), total nitrogen (TN), oxidised-nitrogen (NO_X-N), ammonium-nitrogen (NH_4-N), dissolved organic carbon (DOC), chlorophyll a and gilvin (colour). Methods for water quality analysis are described in O'Toole *et al.* (2013). Furthermore water quality data was compared to ANZECC (2000) guidelines.

In-stream habitat assessment

In-stream assessment identified bed type (sand, gravel, clay, silt and pebble), reach type (run or pool), average stream depth, habitat type (undercut banks, leaf packs, large woody debris) and the presence and type (floating, submergent, emergent or terrestrial) of vegetation within the stream. Where vegetation was present, it was sampled, identified and percent cover and density of vegetation across the stream segment were estimated.

Invertebrate sampling

Six random samples of invertebrates were taken from each stream segment over a two day period. Each sample comprised a 30 second sweep sample along a 5 metre transect with a dip net (250 µm mesh size). Samples were checked for tadpoles and fish, which were noted and then released.

Invertebrates sampled were preserved in 70% ethanol in the field and transported to the laboratory, where invertebrates were counted and identified to family level where possible.

Data analysis

Multivariate analyses used Primer (PRIMER v6; PRIMER-E Ltd, Plymouth, UK). The Bray-Curtis similarity measure was calculated for the invertebrate abundance data, which then formed the basis for the hypothesis tests. To test the hypotheses about invertebrate assemblage composition, a two way crossed ANOSIM was used. The two factors were: vegetation type (2 levels: vegetated or unvegetated; hypothesis 1) and flow regime and colour (3 levels: clear and intermittent, coloured and intermittent, clear and perennial). Three single factor ANOSIM tests on subsets of sites were used to determine the effects of the presence or absence of riparian vegetation within each flow regime and colour-type category. Thus, the effect of colour was tested by comparing coloured and non-coloured intermittent streams, (hypothesis 2 above) and the effect of flow regime was tested by comparing perennial and intermittent non-coloured streams (hypothesis 3 above). To determine the invertebrate families associated with the differences among factors and factor levels, Similarity Percentages (SIMPER) were calculated. Non-metric multidimensional scaling plots were used to visualise the differences among the factor levels; high stress values necessitated the use of three-dimensional plots.

Macroinvertebrates respond to anthropogenic pollutants and indices utilising macroinvertebrate assemblage data can be used to rapidly gauge the ecological condition of freshwater systems. The only indices available for use in Western Australia are the Stream Invertebrate Grade Number – Average Level (SIGNAL and SIGNAL 2) and Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity- Families (SWAMPS-F). Scores for each of these indices were calculated following the methods outlined by Gooderham and Tsyrlin (2002), Chessman (2003) and Chessman *et al.* (2002). Individual families were given a score depending on their resilience to disturbance, which were added up and divided by the numbers of families to provide an overall score. To calculate SIGNAL 2 scores, families were given a score and abundance given a weight factor (Chessman 2003). The family score is multiplied by the weight factor and this was divided by the sum of the weight factor values, which provides the SIGNAL 2 score.

Results

Vegetation assessment

The composition and condition of riparian vegetation can dictate physical, chemical and biological characteristics of streams and, within the Ellen Brook Catchment, it varied markedly. Riparian condition was ranked from degraded to good (Table 1). Two thirds of the sites were fenced, but most had a high level of disturbance (poor plant health, low regeneration of native species, evidence of stock access) and a high exotic species index. Canopy cover varied across sites (highest at perennial sites), although understorey cover was consistently low and groundcover was consistently high (Table 1). The composition of riparian vegetation across the three layers was consistent across most sites, with a native canopy, a mixed native/exotic understorey and groundcover, which was predominantly exotic (Table 1). Two sites had been revegetated (both on intermittent streams) and four had remnant vegetation, however vegetation composition and the level of disturbance were similar. The cover of riparian vegetation along stream reaches was lower adjacent to intermittent streams (coloured and non-coloured) when compared with perennial streams (**Error! Reference source not found.**). The riparian zone in the Lennard Brook Catchment (a perennial stream) is nearly completely forested and has high connectivity, whereas the intermittent streams were highly fragmented and had substantially less cover.

Table 1- Comparison of riparian vegetation condition characteristics at the six vegetated sites which were assessed in Spring 2012. Int= Intermittent Per= Perennial

	Colour Int 1	**Colour Int 2**	**Non colour Int 1**	**Non colour Int 2**	**Non colour Per 1**	**Non colour Per 2**
Remnant or Revegetated	Remnant	Remnant	Reveg	Reveg	Remnant	Remnant
Fenced	Yes	Yes	Yes	No	Yes	No
Riparian condition	Degraded	Good	Degraded	Degraded	Excellent	Good
Level of disturbance	Medium	Medium	High	High	Low	High
Width of riparian zone (m)	30m	30m	20m	25m	30m	10m
Canopy height (m)	5m	15m	10m	8m	15-20m	15m
Canopy cover (%)	11-30%	31-70%	31-70%	>2%	71-100%	71-100%
Understorey cover (%)	11-30%	11-30%	2-10%	31-70%	11-30%	11-30%
Groundcover (%)	100%	71-100%	31-70%	71-100%	71-100%	71-100%
Natural regeneration of native species	Abundant	Occasional	None	Occasional	Common	None
Canopy exotic species index	0%	0%	0%	0%	0%	0%
Understorey exotic species index	33%	50%	0%	0%	33%	50%
Groundcover exotic species index	90%	100%	100%	88%	40%	80%
Overall exotic species index	64%	67%	75%	36%	38%	67%

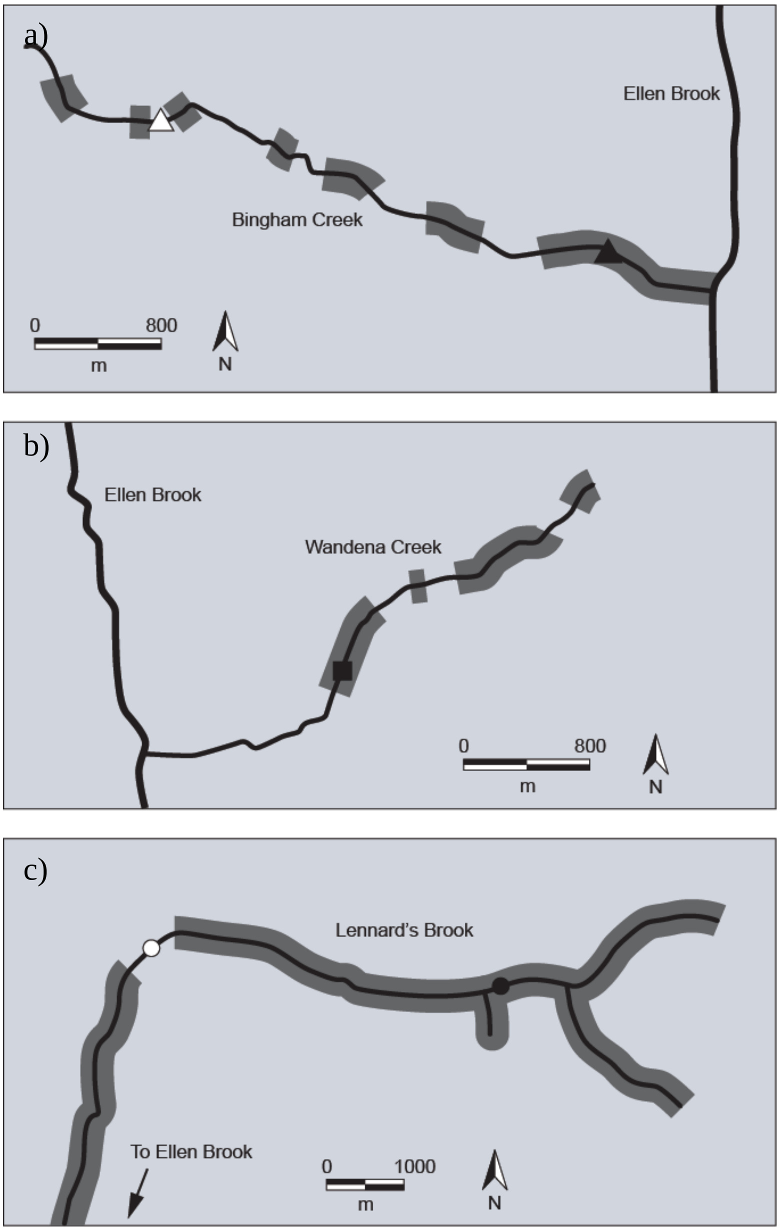

Figure 2- Comparison of riparian vegetation (presence shown by shaded sections) across a) coloured intermittent stream, b) non-coloured intermittent stream and c) non-coloured perennial stream

Shading potential

The riparian vegetation at each site provided differing periods of shading to stream segments (Table 2). The shading potential (percentage of the day shaded) of riparian vegetation at the vegetated stream segments was greatest overall in September and decreased into summer (Table 2). The non-coloured perennial streams and one coloured, intermittent stream had 100% shading potential, which correlated with the presence of tall vegetation close to the stream edge. The remaining sites had a shading potential of less than 60% across all time periods, due to shorter riparian vegetation (Table 2). At the sites with reduced shading, there was no shading during the middle of the day when the sun is at its peak. However, these results only highlight the maximum shading potential, the true shading capacity is likely to be lower due to incomplete canopy cover.

Table 2- An assessment of the maximum shading potential at vegetated stream segments, values in brackets represent percentage of total daylight hours shaded. Int= Intermittent Per= Perennial

Shading potential	**Colour Int 1**	**Colour Int 2**	**Non colour Int 1**	**Non colour Int 2**	**Non colour Per 1**	**Non colour Per 2**
September 1st	7 hours (58%)	12 hours (100%)	7 hours (58%)	7 hours (58%)	12 hours (100%)	12 hours (100%)
November 1st	7 hours (50%)	14 hours (100%)	7 hours (50%)	7 hours (50%)	14 hours (100%)	14 hours (100%)
January 1st	8 hours (57%)	15 hours (100%)	8 hours (57%)	8 hours (57%)	14 hours (93%)	15 hours (100%)

Stream characteristics

The depth of streams varied across the catchment, with the shallowest (0.05-0.15 m) all being non-coloured, intermittent stream segments and the deepest, a coloured intermittent stream (1 m). In-stream vegetation was found in five stream segments. Most common was the emergent macrophyte *Cycnogeton* sp. and submerged grasses, which were both found in three stream segments. However, there was no clear pattern in vegetation presence or absence (Table 3). While in-stream woody debris was encountered in five stream segments, it was only found in streams with riparian vegetation. Fish were observed in eight out of twelve stream segments, both vegetated and unvegetated. Crayfish were found in two vegetated stream segments. The threatened freshwater mussel (*Westralunio carteri*) was only found in the two vegetated perennial streams.

Table 3- Comparison of in-stream characteristics at the twelve sites sampled in the Ellen Brook Catchment in Spring 2012

	Coloured intermittent vegetated		**Coloured intermittent unvegetated**		**Non-coloured intermittent vegetated**		**Non-coloured intermittent unvegetated**		**Non-coloured perennial vegetated**		**Non-coloured perennial unvegetated**	
	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2
Bed type	Clay	Sand	Sand	Silt	Silt	Pebble	Gravel	Pebble	Sand	Sand	Sand	Sand
Stream depth	1 m	30 cm	30 cm	60 cm	10 cm	15 cm	5 cm	10 cm	60 cm	50 cm	30 cm	40 cm
Stream width	2 m	1.5 m	3m	1.2 m	1.2 m	1.1 m	1 m	1.2 m	3.5 m	3 m	2.5 m	10 m
Stream type	Mixed	Mixed	Pool	Run	Mixed	Run	Run	Mixed	Run	Mixed	Mixed	Pool
In-stream vegetation	No	Yes	No	Yes	Yes	No	No	No	Yes	No	Yes	No
In-stream woody debris	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	No	No
Fish present	Yes	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
Crayfish present	No	Yes	No	No	No	No	No	No	Yes	No	No	No
Mussels present	No	No	No	No	No	No	No	No	Yes	Yes	No	No

Dissolved oxygen concentrations were similar between sites, ranging between 6-8 mg/L and the salinity of all stream segments was considered fresh (Bayly and Williams 1973; Figure 3-b). Stream pH was neutral in the coloured intermittent and non-coloured perennial stream segments and slightly acidic (5.45) and outside ANZECC guidelines in the non-coloured intermittent stream segments (Figure 3a). Phosphorus concentrations (FRP and TP) were substantially higher and exceeded ANZECC guidelines in coloured intermittent stream segments while there was no detectable FRP in non-coloured intermittent stream segments (Figure 3-c). TN concentrations were very high (exceeding ANZECC guidelines) in coloured intermittent and non-coloured perennial stream segments, however, non-coloured perennial stream segments had substantially higher NO_x-N concentrations. All stream segment types had low NH_4-N concentrations, well below ANZECC guidelines (Figure 3-d). The coloured intermittent stream segments had substantially higher DOC and gilvin concentrations than non-coloured stream segments (Figure 3e).

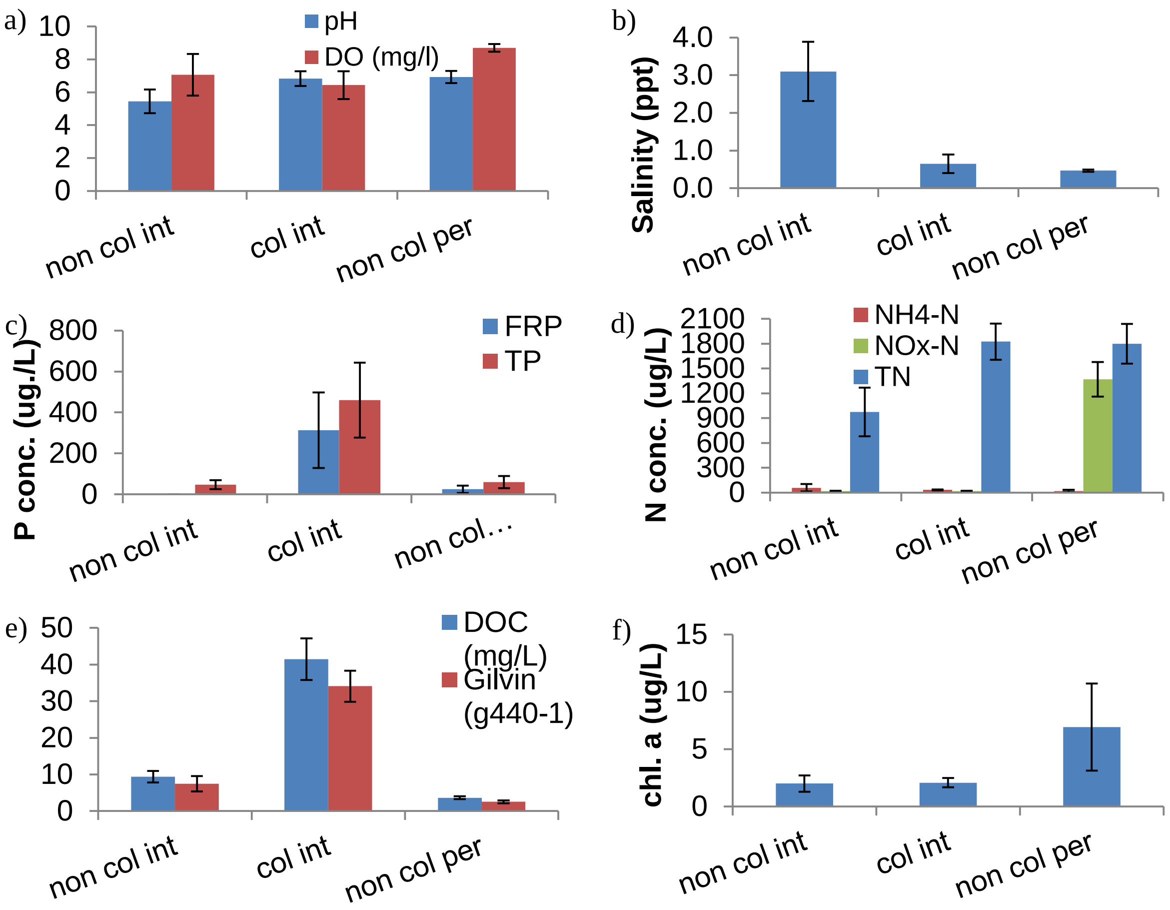

Figure 3- A comparison of a) pH and DO b) salinity c) FRP and TP d) NOx-N, NH_4-N and TN e) DOC and gilvin and f) chlorophyll a concentrations between coloured intermittent and non-coloured intermittent and perennial stream segments. Int= Intermittent Per= Perennial

Macroinvertebrates

A total of 49140 macroinvertebrates from 62 families/orders were collected during the study (Appendix Two). The average number of families collected from a stream segment was 15.88 and the highest number of families in a single sample was 26. The average number of families within stream type was highest in unvegetated perennial stream segments with 34 families (±1), followed by vegetated perennial segments with 32.5 families (±2.5), vegetated intermittent segments with 29.5 families (±1.6) and unvegetated intermittent segments with 23.5 families (±3.7). Ostracods from the family Cyprididae represented 17% of the total number of macroinvertebrates sampled, followed by chironomids from the sub-family Orthocladiinae (12%).

Variability between locations

Invertebrate assemblages differed between vegetated and unvegetated segments (Global $R = 0.407$, $P < 0.001$) and between flow regime and colour categories (Global $R = 0.444$, $P < 0.001$). The similar size of the two global R values suggests that the two factors have a similar size effect on the invertebrate assemblages. Pairwise comparisons showed that invertebrate assemblage composition differed between the two flow regimes (perennial, intermittent) in uncoloured stream segments ($R = 0.513$, $P < 0.001$) and between coloured and non-coloured intermittent stream segments ($R = 0.283$, $P < 0.001$), suggesting that the impact of flow regime on invertebrate assemblages was larger than that of stream colour (at least for intermittent streams).

The single factor hypothesis tests confirmed that the presence or absence of riparian vegetation was associated with differences in invertebrate assemblage composition among all levels of stream colour or flow regime type: when non-coloured intermittent stream segments were compared ($R = 0.368$, $P = 0.002$; Figure 4c), when coloured intermittent stream segments were compared ($R = 0.317$, $P < 0.001$; Figure 4b) and when non-coloured perennial stream segments were compared ($R = 0.537$, $P < 0.001$). The largest effect was observed in perennial stream segments (Figure 4a).

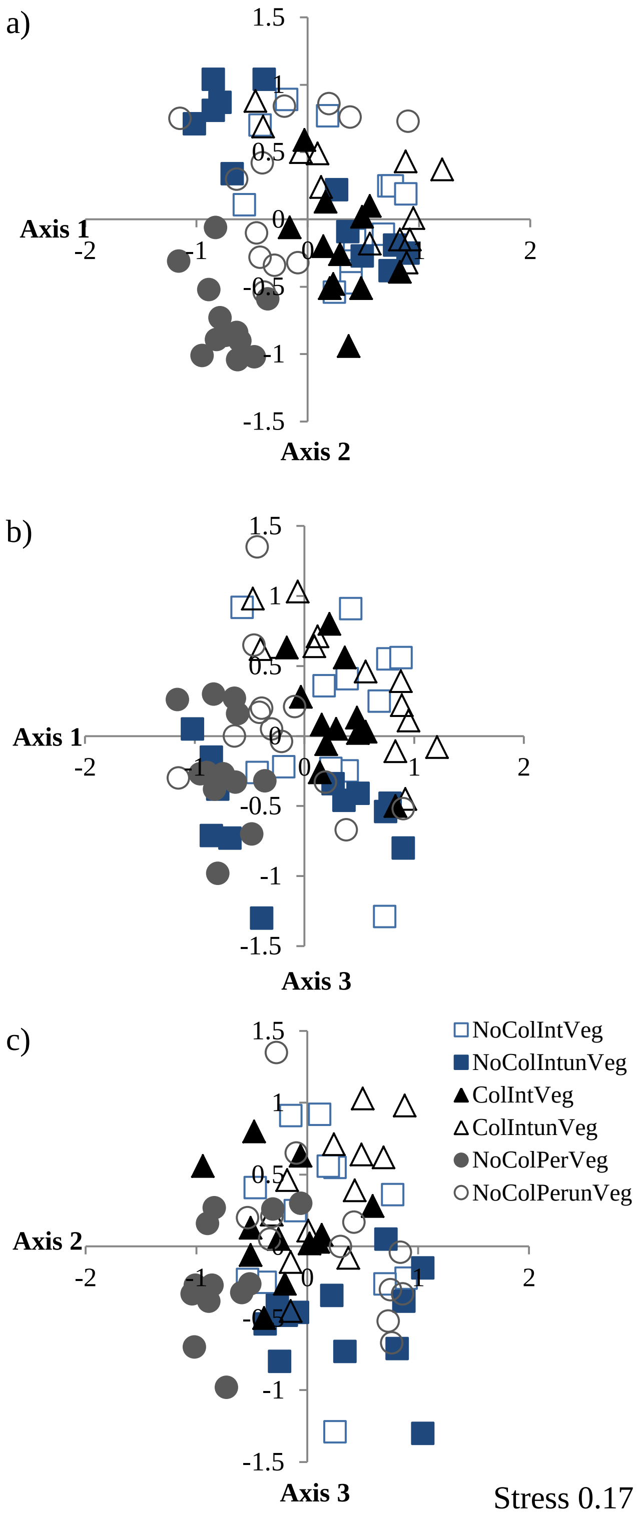

Figure 4- Best configuration of 3D multidimensional scaling plot results comparing stream invertebrate diversity, a) Colour Intermittent Vegetated vs Colour Intermittent Unvegetated b) Non-coloured Perennial Vegetated vs Non-coloured Perennial Unvegetated c) Non-coloured Intermittent Vegetated vs Non-coloured Intermittent Unvegetated

The family with greatest contribution (16.37%) to invertebrate abundance was Cyprididae, but their average abundance was similar in coloured and non-coloured intermittent stream segments. Cladocera from the family Ilyocryptidae were only found in non-coloured intermittent streams. In coloured intermittent streams, two gastropod families that are predominantly grazers (Physidae and Lynceidae) had much greater average abundance. The families Orthocladiinae, Ilyocyprididae and the sub-family Chironominae were all more abundant in the non-coloured streams (Table 4).

Table 4- SIMPER results comparing family composition according to whether streams are clear intermittent or coloured intermittent

		Non coloured Intermittent	**Coloured Intermittent**	**Av Dissimilarity 77.59**
Rank	Family	Av Abundance	Av Abundance	Contribution %
1	Cyprididae	154.04	181.04	16.37
2	Orthocladiinae	121.17	62.71	10.76
3	Ilyocyprididae	146.46	42.04	9.71
4	Chironominae	81.17	4.96	7.72
5	Collembola	79.92	32.79	7.34
8	Physidae	1.50	39.88	4.13
14	Lynceidae	1.83	16.33	2.10
16	Ilyocryptidae	15.29	0.00	1.74

The two highest contributing families in non-coloured intermittent and non-coloured perennial stream segments were Cyprididae (12.56%) and Orthocladiinae (10.35%) and their average abundance was substantially higher in the clear intermittent streams (Table 5). Cyprididae and Ilyocyprididae represented the greatest difference between stream types, with the greater proportion in intermittent stream segments. Within the clear perennial stream segments the leptocerid caddisflies families had higher average abundances and the families Gripopterygidae, Caenidae and Baetidae were only found in the perennial streams all of which is due to these families preference for permanent water.

Table 5- SIMPER results comparing family composition according to whether stream segments are clear intermittent or clear perennial

		Non coloured Intermittent	**Non coloured Perennial**	**Av Dissimilarity 85.23**
Rank	Family	Av Abundance	Av Abundance	Contribution %
1	Cyprididae	154.04	14.63	12.56
2	Orthocladiinae	121.17	57.50	10.35
3	Chironominae	81.17	36.67	8.22
4	Ceinidae	40.38	17.79	7.12
5	Ilyocyprididae	146.4	11.83	6.75
11	Gripopterygidae	0.00	28.33	3.70
12	Caenidae	0.00	28.25	3.67
14	Ilyocryptidae	15.29	0.00	1.95
18	Leptoceridae	0.75	13.42	1.65
20	Baetidae	0.00	23.75	1.46

There was a high rate of dissimilarity (80.80%) between vegetated and unvegetated sites. Once again, the greatest contributor was Cyprididae (12.71%), which in the unvegetated stream segments had an average abundance more than double that of the vegetated sites (Table 6). The sub-families Orthocladiinae and Chironominae and the families Physidae and Ceratopogonidae had average abundances substantially higher in the unvegetated stream segments. Five commonly occurring families (Ilyocyprididae, Simuliidae, Caenidae, Gripopterygidae, Ceinidae) had a higher average abundance in vegetated than in non-vegetated sites. The Simuliidae are suspension feeders that require bare surfaces to attach to and a current to survive. Their prevalence in vegetated sites may arise from there being more hard substrata free of a thick coating of algae than in unvegetated sites. The other four families are mainly collectors or collector/grazers but may prefer fine organic matter arising from leaf litter than from algae.

Table 6- SIMPER results comparing family composition according to whether stream segments had riparian vegetation or not

		Vegetated	**Unvegetated**	**Av Dissimilarity 80.80**
Rank	Family	Av Abundance	Av Abundance	Contribution %
1	Cyprididae	71.11	162.03	12.71
2	Orthocladiinae	54.58	106.33	10.00
3	Chironominae	16.33	65.53	7.32
4	Ilyocyprididae	97.97	35.58	6.48
5	Ceinidae	46.42	19.78	6.00
11	Simuliidae	41.22	7.97	4.13
12	Gripopterygidae	18.92	0.11	2.95
13	Physidae	3.5	24.89	2.81
14	Caenidae	14.92	4.00	2.34
15	Ceratopogonidae	1.44	19.92	2.04

Ecological health indexes

Stream Invertebrate Grade Number – Average Level (SIGNAL and SIGNAL2) and Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity- Families (SWAMPS-F) demonstrated little variability between the perceived health of stream segments (

Table 7). Comparing SIGNAL scores nine stream segments had a score <4, which indicates severe pollution and the remaining three were between 4-5 showing moderate pollution. SIGNAL 2 delivered similar results, however, only two (vegetated perennial stream segments) were scored to have moderate pollution. There was no correlation between scores and the presence of riparian vegetation. There was less variability for SWAMPS-F scores, with eleven stream segments having scores >44 indicating cultural eutrophication is unlikely. The final stream segment scored between 42-44, inferring cultural eutrophication may be present (Table 7). Similar to SIGNAL there were no clear patterns in SWAMP-F scores related to riparian vegetation.

Table 7- A comparison of SIGNAL, SIGNAL 2 and SWAMP scores across all stream segments sampled

		SIGNAL[1]	**SIGNAL2**[1]	**SWAMPS-F**[2]
Coloured intermittent vegetated	Rep 1	3.23	2.99	46.23
	Rep 2	3.32	3.34	46.82
Coloured intermittent unvegetated	Rep 1	3.04	2.84	43.60
	Rep 2	3.24	3.21	49.49
Non-coloured intermittent vegetated	Rep 1	3.3	3.27	49.47
	Rep 2	3.23	3.25	48.43
Non-coloured intermittent unvegetated	Rep 1	2.64	2.55	53.51
	Rep 2	2.85	2.98	48.25
Non-coloured perennial vegetated	Rep 1	4.65	4.94	46.69
	Rep 2	4.01	4.17	48.07
Non-coloured perennial unvegetated	Rep 1	4.04	3.91	46.37
	Rep 2	3.41	3.47	47.47

[1] SIGNAL and SIGNAL 2 score health >6 healthy habitat, 5-6 mild pollution, 4-5 moderate pollution, <4 severe pollution (Gooderham and Tsyrlin 2002).

[2] SWAMPS-F score health <42 cultural eutrophication likely, 42-44 cultural eutrophication may be present, >44 cultural eutrophication is unlikely (Chessmen *et al.* 2002).

Discussion

How does riparian vegetation structure and condition affect in-stream physico-chemical conditions?

Vegetation structure and function

Riparian vegetation within the Ellen Brook Catchment is highly disturbed and poorly structured. Although all sites had a native tree canopy, there was limited understorey and mostly exotic groundcover species. These changes occur due to the cumulative effect of natural and anthropogenic disturbances that are common in agricultural catchments, such as vegetation clearing, stock access, invasion of exotic plant species and other disturbances (Wissmar and Beschta 1998). Compromised riparian vegetation, as a result of disturbance, can lead to poor riparian condition and an increase in exotic species. This in turn may reduce the functionality of riparian zones, affecting in-stream habitat, nutrient dynamics and water quality and can lead to shifts in terrestrial and aquatic food webs (Naiman and Decamps 1997; Richardson *et al.* 2007; Hladyz *et al.*2011b).

Comparisons of sites with remnant and revegetated riparian zones showed that riparian condition and the level of disturbance was similar. Revegetated sites were only located on intermittent stream segments, but had similar characteristics to sites with remnant vegetation, having a native canopy, limited understorey and exotic groundcover. This suggests revegetation is effective in restoring riparian vegetation at least to the capacity of degraded natural vegetation and that the effect of riparian vegetation in stream segments with remnant and revegetated vegetation would be similar. They were therefore considered together as to their effects on macroinvertebrate assemblages.

One of the key terrestrial ecological benefits of riparian vegetation is its ability to provide habitat corridors for wildlife (Naiman and Decamps 1997), however this can be compromised by poor riparian condition and extensive clearing (Naiman *et al.* 1993; Fischer and Lindenmayer 2007). This study has shown the poor state of existing riparian vegetation in the Ellen Brook Catchment and a high degree of fragmentation between patches, particularly along intermittent streams. The fragmentation of native vegetation reduces connectivity within the landscape, compromising both aquatic and terrestrial diversity (Naiman *et al.* 1993; Naiman and Decamps 1997; Fischer and Lindenmayer 2007). Riparian vegetation along perennial streams in the north of the catchment was in better condition and had a higher degree of connectivity, potentially allowing riparian vegetation to act as a habitat corridor for terrestrial species. For riparian vegetation to provide ecological benefits in the future, revegetation (especially along the intermittent streams in the catchment) should occur along extended stream reaches to increase connectivity among patches of native vegetation. Revegetation should include planting native understorey species to replicate natural conditions and to provide greater structure for native animals.

Results from this study indicated that riparian vegetation was contributing large woody debris to streams, as it was only encountered in vegetated stream segments (perennial and intermittent). Coarse woody debris can alter stream flows, increase the structural complexity, create new habitats and improve stream condition (Lemly and Hilderbrand 2000; Naiman *et al.* 2008). The lack of large woody debris in unvegetated stream segments reduces available habitats, which can influence community structure (Lemly and Hilderbrand 2000). The loss of large woody debris from streams can be detrimental to native fish species and result in a loss of abundance and diversity (Howson *et al.* 2012; Pettit *et al.* 2013).

Effects of riparian vegetation on in-stream physico-chemical conditions

As a result of historical land clearing (Swan River Trust 2009), stream shading is limited throughout much of the catchment and the poor condition of existing riparian vegetation could further reduce the degree of shading. The fragmentation of riparian vegetation in the Ellen Brook Catchment is likely to limit the effectiveness of riparian vegetation to regulate stream temperatures, as continuous vegetation is more effective at influencing water temperatures (Rutherford *et al.* 2004; Davies 2010). Rutherford *et al.* (2004) demonstrated that a 600-960 m stream length of dense riparian shade can reduce temperatures by 4°C and cleared stream reaches could heat by a similar degree. Given the patchy nature of riparian vegetation (less than 600 m) and reduced shading potential along the intermittent streams, the effect of shading on temperature is likely to be reduced. In contrast, the perennial streams had extensive riparian vegetation (blocks in excess of 600 m in places) and high shading potentials, providing greater temperature regulation. This is significant because Stewart *et al.* (2013) identified the upper thermal tolerance of sensitive aquatic taxa to be 21°C in south-west Western Australia. When exceeded, it can lead to the loss of sensitive taxa such as Ephemeroptera, Amphipoda and Plecoptera and contribute to a shift in community structure (Stewart *et al.* 2013). Due to diurnal fluctuations, we are unable to compare data collected during this study with this. However, data from previous sampling (O'Toole *et al.* unpublished), indicated that steam temperatures exceeded 21°C in vegetated intermittent stream segments. Thus, an important role of revegetation along streams would be to decrease water temperatures and help maintain functioning stream communities (Davies 2010).

What is the effect of riparian vegetation, flow regime and colour on the ecological health of streams?

Riparian vegetation, stream colour, flow regime and invertebrate assemblages

In the Ellen Brook Catchment, flow regime and the presence/absence of riparian vegetation were the most influential factors associated with invertebrate assemblage composition. Fewer invertebrate families were present in the intermittent streams. Intermittent streams often lack some sensitive species that exist in perennial streams (Chessman *et al.* 2006; Bonada *et al.* 2008; Reid *et al.* 2013). This can be driven by stressors such as reduced water availability, temperature stress and poor water quality, which can strongly affect sensitive species (Chessman *et al.* 2006; Bonada *et al.* 2008). However, water quality was similar between the intermittent and perennial streams, and thus was not responsible for differences in invertebrate assemblages.

Ostracods (represented by Cyprididae and Ilyocyprididae) and Chironomids (represented by Orthocladiinae and Chironominae) were more abundant in intermittent than in perennial streams. Ostracods have been used extensively as indicators of good water quality (Poquet *et al.* 2008) and their response to drying can rely on desiccation resistant eggs or the ability to burrow into the sediment and aestivate (Strachan *et al.* in press). In contrast, perennial streams had a substantially higher abundance of gripopterygid stoneflies than intermittent streams. Many gripopterygids have desiccation resistant eggs (Chester and Robson, 2011), so the species found here may have been more abundant in perennial streams because of their preference for faster flows. Caenidae and Baetidae mayflies and Leptoceridae caddisflies were also more abundant in the perennial streams, possibly owing to their preference for perennial water (Boulton *et al.* 1992; Chester and Robson 2011), although some leptocerids are known to aestivate (Wickson *et al.* 2012). Continuous flows are essential for some species, such as the threatened mussel *Westralunio carteri* (Walker *et al.* 2014), which was only encountered in perennial stream segments. These mussels can survive in intermittent water bodies, but must be shaded and not experience prolonged periods of drying (Walker *et al*. 2014). These results again demonstrate the importance of perennial streams for maintaining populations of freshwater invertebrates (Chester and Robson 2011) as well as being essential for the continued survival of freshwater fish within the catchment.

Despite the poor condition of much of the riparian vegetation in the Ellen Brook Catchment, there were strong differences between invertebrate assemblages in vegetated and unvegetated stream segments, especially in perennial streams. Riparian vegetation was more extensive and in better condition along perennial stream segments, which may explain why riparian vegetation was associated with larger differences in assemblage composition in perennial streams. In unvegetated streams, the high abundance of grazing invertebrates from the gastropod family Physidae and chironomid sub-family Orthocladiinae indicated an algal based food web. The reduced shading in unvegetated streams increases light availability, which promotes algal growth (Bunn *et al.* 1998; Mosisch *et al.* 2001) and supports algal grazers (Hladyz *et al.* 2011a). In contrast, mayfly and stonefly nymphs from the families Ceinidae, Baetidae and Gripopterygidae were more abundant in vegetated stream segments; Danger and Robson (2004) also found baetids to be associated with vegetated reaches. These families may be primarily collecting organic matter in Ellen Brook streams; their greater abundance explained by higher organic matter inputs from riparian vegetation leading to increased amounts of fine detritus (Danger and Robson 2004; Reid *et al.* 2008a).

These results show that even in poor condition, riparian vegetation has the capacity to influence in-stream communities, at least where mature stands of trees exist (Becker and Robson, 2009; Death and Collier 2010). Furthermore, Pusey and Arthington (2003) identified that the integrity of riparian vegetation is linked to healthy fish assemblages. However in this study, fish were observed in vegetated and unvegetated stream segments alike, indicating neither the presence nor condition of riparian vegetation was influencing fish occurrence. However, the Ellen Brook Catchment is relatively small, and fish may have been moving throughout the system, using both vegetated and unvegetated reaches and both perennial and (when inundated) intermittent streams. In contrast, freshwater crayfish were only found in two reaches, both vegetated. Other studies of burrowing crayfish have found them to be more abundant in remnant than revegetated or pasture reaches (e.g. March and Robson 2006). Nevertheless, revegetating streams and improving the condition of existing riparian vegetation could improve conditions (more shelter and food, consistent temperature and oxygen concentrations) for invertebrate, crayfish and fish assemblages in the future.

Colour (elevated gilvin concentrations) in streams has the capacity to limit stream diversity and affect algal productivity by being toxic to some organisms and limiting light penetration (Scalbert 1991). In the coloured streams, gilvin concentrations were relatively high ranging from 27.41-46.52 g_{440} m^{-1}, but somewhat lower than the 52 g_{440} m^{-1} threshold noted by Davis *et al.* (1993) that results in changes in aquatic biota. Within the Ellen Brook Catchment, the presence of stream colour was not correlated with the presence of riparian vegetation. Instead, it was related to soil type, with streams flowing from the west of the catchment, underlain by Bassendean Sands typically being coloured, because carbon leaches readily from these soils (Barron *et al.* 2008). However, extensive clearing throughout the catchment is likely to lower gilvin concentrations due to reductions in organic matter deposition into streams, which reduces the availability of tannins. The results obtained here suggest that decreasing colour has the potential to decrease abundances of grazing gastropods (F. Physidae, Lynceidae) but to favour a range of other invertebrate families that had higher abundances in non-coloured streams. The replanting of riparian vegetation with native species may increase gilvin concentrations and lower benthic algal growth, leading to more natural in-stream biological communities.

Water quality throughout the Ellen Brook Catchment is likely a result of previous land uses coupled with contemporary land use practices. High nutrient concentrations throughout the catchment can primarily to be attributed to agriculture (Swan River Trust 2009a). Although higher phosphorus concentrations in the coloured streams is a factor of agricultural land use and soil association, with Bassendean Sands associated with a poor phosphorus holding capacity (McPharlin *et al.* 1990; Barron *et al.* 2008). Total nitrogen concentrations were high in many stream segments, however, invertebrate assemblages did not respond negatively to phosphorus or nitrogen. This is best highlighted by nutrient sensitive gripopterygid stoneflies (Gooderham and Tsyrlin 2002) existing in stream segments with high nitrogen and phosphorus concentrations. Similar to nutrients, stream physico-chemical conditions (primarily pH) differed between streams types, with non-coloured intermittent streams having low pH (5.45), however, this did not reduce invertebrate composition. Vegetated and unvegetated stream segments had similar water quality, yet they exhibited differences in invertebrate composition, further demonstrating that in-stream water quality had a limited effect on invertebrate composition.

Effectiveness of biological indexes

Biological indices based on macroinvertebrate communities have been used extensively worldwide (Gordon *et al.* 2004; Chang *et al.* 2014), but do not appear to be particularly useful in Ellen Brook Catchment streams. Results indicated that the biological indexes used (SIGNAL, SIGNAL 2 and SWAMPS-F) were not appropriate for the stream fauna. For example, the SIGNAL score of an intermittent stream with a pH of 3.28 and no vegetation was 2.64, severe pollution, but was considered as having a similar condition to eight other stream segments, some of which were home to environmentally sensitive species. Scores from SIGNAL and SIGNAL 2 were consistently low, particularly in streams with intact riparian vegetation, and which harboured environmentally sensitive species. In contrast, SWAMPS-F indicated all stream segments (bar one) were unlikely to be affected by eutrophication and human impacts. This is inaccurate as many of the stream segments sampled were degraded and had nutrient concentrations which exceeded ANZECC guidelines.

The contradictory results from SIGNAL and SWAMP-F cast doubt on the effectiveness of biological indexes used to measure stream health in the Ellen Brook Catchment and in south-western Australia more generally. SIGNAL scores were developed in eastern Australia, and omit families that are common in Western Australia (e.g. Cyprididae), resulting in nine of the families collected not having a signal score and thus being omitted from the index. Also, SIGNAL was developed for perennial streams, limiting its effectiveness anywhere with a high proportion of intermittent streams (Lind 2004), which is also an issue for other international indices (Davis *et al.* 2003). Intermittent streams can be harsh environments, where natural stressors are more influential than anthropogenic stressors, a factor which the SIGNAL score does not take into account. SWAMPS-F was designed for Western Australian fauna, but for wetlands on the Swan Coastal Plain, rather than for streams, and this may limit its application due to differences in invertebrate species in lentic and lotic environments. Consequently, fourteen families were not included in the SWAMPS-F score, probably lowering its accuracy.

A short-coming of biological indices is that they focus on anthropogenic rather than natural stressors (Rose *et al.* 2008). This can create misleading results that indicate streams are suffering severe pollution when in fact they are not. Within the Ellen Brook Catchment there are many flat sandy intermittent streams which are poorly studied and do not fit into existing indicator paradigms. However, because biological indices provide valuable management tools that are used successfully elsewhere (Rose *et al.* 2008; Chang *et al.* 2014), a new index is needed that takes into account these natural stressors and includes families that are better represented (e.g. Ostracoda, Cyprididae) in Western Australian streams. This new index needs to re-rank the families to represent local conditions, from pristine to highly degraded. Biological indices can be important tools for measuring stream health and be utilised by people with a range of skill levels (Chessman *et al.* 2002). The potential misuse of currently available indices warrants future development of indices for Western Australian streams.

One limitation encountered during this study was the lack of water temperature measurements over an extended period. Therefore, it was difficult to determine the effect shading on stream temperatures and how this may affect macroinvertebrate assemblages. Another limitation was the lack of sampling over different time periods, to see how water quality and availability affected in-stream biological communities. To remediate these limitations, future work could include putting temperature loggers in streams to compare temperature variations in perennial, intermittent and vegetated and unvegetated stream segments. Future work could also include sampling macroinvertebrates over different time periods to assess how in-stream assemblages vary according to water quality and quantity.

Conclusion

This study has shown that riparian vegetation throughout the Ellen Brook Catchment has been compromised, potentially affecting connectivity throughout the catchment, reducing stream shading and the degree of influence on in-stream environments. Assessment of in-stream macroinvertebrate assemblages showed that both flow regime and the presence or absence of riparian vegetation were associated with significant effects on assemblage composition. In the Ellen Brook Catchment, riparian vegetation was associated with the largest effect in the perennial streams, and a weaker effect in intermittent streams. However, the weaker effect in intermittent streams is likely because the total extent and quality of riparian vegetation in the Ellen Brook Catchment is greater along perennial than intermittent streams. The apparent influence of riparian tree presence on invertebrate assemblages in intermittent streams suggests that further restoration that links existing patches of riparian vegetation into a continuous corridor would be valuable, as suggested by Arnaiz *et al.* (2011). Furthermore, the two vegetated perennial stream sections supported populations of the threatened mussel *W. carteri* and to ensure their continued survival, protection of vegetated sections should be maintained and revegetation undertaken. Consideration should be given to the habitat and access requirements of the host fish species (*Tandanus bostocki*) that enables *W. carteri* populations to reproduce and disperse (Klunzinger *et al.* 2011).

Future revegetation projects need to be fenced to limit stock access to riparian zones to conserve both riparian vegetation and stream condition (Kauffman and Krueger 1984; Vondracek *et al.* 2005). To optimise effectiveness, revegetation projects should ensure shading potential is maximised by planting vegetation close enough to the stream while taking stream orientation into consideration (Davies *et al.* 2010). Our results show that riparian vegetation is beneficial for perennial and intermittent streams alike and further revegetation should occur to improve connectivity, provide habitat and improve and maintain regional biodiversity.

Management recommendations to protect and improve stream condition through the use of riparian vegetation

Considering the high proportion of intermittent streams within the Ellen Brook Catchment and internationally, what management recommendations can be made based on the findings of this study? The following points summarise the key recommendations to improve in-stream biological communities, which are described in detail below.

- Limit water abstraction (surface and groundwater) from perennial streams to ensure flows remain perennial, to help protect flow sensitive species.
- Replant riparian vegetation along intermittent and perennial streams to provide shade, organic matter and colour; key variables which shape community assemblages.
- Plant riparian vegetation over continuous (600 m) stretches to provide connectivity and help regulate stream temperature (Rutherford *et al.* 2014).
- Develop a new biological index (using macroinvertebrates) which can be used for the rapid appraisal of stream condition.

Water abstraction from groundwater mounds feeding perennial streams and the perennial streams themselves need to be limited and monitored to conserve permanent water bodies. Protection of perennial streams is integral to ensure regional diversity of in-stream organisms (Chester and Robson 2011), with particular reference to the threatened freshwater mussel (*W. carteri*) and fish assemblages (Pusey and Arthington 2003). Furthermore, in south-west Western Australia and other areas where climate change is expected to significantly reduce rainfall in the future (Bates *et al.* 2010) protection of perennial streams through careful water abstraction is a priority. This recommendation is relevant internationally, particularly in regions which are dominated by intermittent streams and few perennial waterbodies.

Riparian vegetation should be planted along intermittent and perennial streams alike, as results from this study indicate that riparian vegetation has a positive effect on both stream types. Replanting and restoring riparian vegetation has shown to improve water quality, regulate temperature, contribute organic matter (both particulate and dissolved (e.g. colour)) and improve stream condition (Webb and Erksine 2003; Hughes *et al.* 2005). Replanting vegetation should occur with the view of long-term benefits, as Becker and Robson (2004) identified that stream condition takes more than eight years to return to historical (or control) condition. All revegetation works should be fenced to limit stock access to riparian zones, to allow for riparian vegetation to become established and to reduce future disturbance (Robertson and Rowling 2000).

Replanting riparian vegetation should extend over a minimum of 600 m stretches (Rutherford *et al.* 2004), as it has been identified that this level of cover is required to moderate stream temperature. Furthermore, when replanting riparian vegetation along streams the type and location must be considered. The vegetation needs to be tall enough to provide shade across the entire stream and it must be orientated so that it delivers maximum shade to the stream as the sun passes across the sky (Rutherford *et al.* 2004). Furthermore, invertebrates respond better to continuous vegetation due to a greater input of organic matter for food and habitat and consistent water quality (Sponseller *et al.* 2001; Davies 2010; Death and Collier 2010).

Biological indices based on macroinvertebrate communities have been used extensively worldwide (Chang *et al.* 2014) and provide an accessible tool for managers to rapidly assess stream condition. This study has identified the shortcomings of using the biological indexes SIGNAL, SIGNAL 2 and SWAMPS-F for streams in the Ellen Brook Catchment. The contradictory results between SIGNAL and SWAMPS-F suggest that they are not representative of streams in south-west Western Australia. SIGNAL in particular was created on the east coast in perennial streams and therefore its effectiveness is limited due to the higher number of intermittent streams and different stressors (such as temperature and salinity) in Western Australian streams. Furthermore, a considerable number of taxa were omitted from the index further highlighting its ineffectiveness. Currently if these indices were used it will result in an inappropriate assessment of these systems and lead to misinformed management strategies. Therefore, a new biological index should be developed, which can be used by managers to rapidly assess stream condition using macroinvertebrates. This index needs to be based on Western Australian streams, which incorporates intermittency, higher temperatures and higher salinity. This will provide a rapid cost effective tool, which can be used by mangers to identify streams under stress and be utilised to identify streams that could benefit from replanting riparian vegetation.

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Appendices

Appendix One- Vegetation Condition Scale and the explanatory factors as defined by Keighery (1994).

Vegetation Condition Scale	Explanatory factors
Pristine	Pristine or nearly so, no obvious sign of disturbance.
Excellent	Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive. For example damage to trees caused by fire, the presence of non-aggressive weeds and occasional vehicle tracks.
Very Good	Vegetation structure altered, obvious signs of disturbance. For example disturbance to vegetation structure caused by repeated fires, the presence of some more aggressive weeds, dieback, logging and grazing.
Good	Vegetation structure significantly altered by very obvious signs of multiple disturbances. Retains basic vegetation structure or ability to regenerate it. For example disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds at high density, partial clearing, dieback and grazing.
Degraded	Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management. For example disturbance to vegetation structure caused by very frequent fires, the presence of very aggressive weeds, partial clearing, dieback and grazing.
Completely Degraded	The structure of the vegetation is no longer intact and the area is completely or almost completely without native species. These areas are often described as ‘parkland cleared’ with the flora composing weed or crop species with isolated native trees or shrubs.

Modified from Trudgen (1991) by Keighery for the Swan Coastal Plain Survey 1993.

Appendix Two- Table comparing invertebrate abundances between stream segments.

	Non-coloured Intermittent vegetated rep 1	Non-coloured Intermittent vegetated rep 2	Non-coloured Intermittent unvegetated rep 1	Non-coloured Intermittent unvegetated rep 2	Coloured Intermittent vegetated rep 1	Coloured Intermittent vegetated rep 2	Coloured Intermittent unvegetated rep 1	Coloured Intermittent unvegetated rep 2	Non-coloured Perennial vegetated rep 1	Non-coloured Perennial vegetated rep 2	Non-coloured Perennial unvegetated rep 1	Non-coloured Perennial unvegetated rep 2
Unknown Acarina	42	220	0	0	126	212	2	12	12	15	13	12
Cyclopoida	42	156	0	364	109	23	159	256	3	30	204	631
Cyprididae	376	457	22	2842	730	964	2044	607	0	33	65	253
Ilyocyprididae	3308	192	0	15	16	3	990	0	0	8	0	276
Daphnidae	281	0	0	6	221	44	582	12	0	60	164	1402
Nymphulinae	6	1	0	0	0	0	0	0	0	0	0	0
Tanypodinae	315	106	355	108	133	35	18	217	73	75	128	360
Orthocladinae	495	116	38	2259	367	533	513	92	251	203	272	654
Chironominae	466	0	1287	195	61	5	9	44	18	38	127	697
Dystiscidae juv	113	25	223	93	47	12	4	9	0	0	0	17
Dysticidae adu	10	4	24	2	2	0	0	3	0	1	1	2
Hydrophilidae juv	44	0	1	7	31	1	0	16	0	1	2	12

Hydrophilidae adu	4	0	37	3	1	0	0	1	0	0	0	0
Collembola	90	44	1137	647	266	365	41	115	47	21	75	18
Simuliidae	622	1	0	264	263	311	13	4	120	167	6	0
Ceinidae	93	875	0	1	653	26	308	0	0	24	0	403
Culcidae	84	31	128	41	19	13	2	4	4	39	2	135
Ilyocryptidae	367	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae	17	0	0	1	9	1	1	68	174	86	25	37
Lestidae	5	0	0	0	0	2	1	0	0	0	0	53
Hermicorduliidae	64	11	0	0	13	5	3	17	0	5	1	8
Hydroptilidae	55	30	0	0	3	1	7	403	1	5	3	223
Dolichopodidae	17	1	1	12	0	0	0	5	0	0	0	0
Orabatidae	35	176	1	14	16	54	0	40	0	21	24	52
Hirunidea	5	0	0	0	0	4	4	0	0	0	0	0
Chydoridae	45	32	0	114	261	174	256	4	3	0	0	2538
Oligochaet	41	98	0	5	8	64	35	16	5	34	59	32
Amphisopidae	4	0	0	0	4	0	0	0	0	0	0	0
Libellulidae	3	5	0	0	0	0	0	0	0	0	0	0
Ceratopogodinae	7	2	139	1	8	1	24	138	16	18	6	409
Lynceidae	12	32	0	0	0	0	0	392	0	0	86	3
Corixidae	2	0	0	1	0	0	0	0	0	0	0	65

Physidae	0	1	0	35	100	13	7	837	0	12	7	10
Tabanidae	0	7	0	0	0	1	4	48	2	2	2	1
Coenagrionidae	0	2	0	0	0	3	0	189	0	0	3	0
Ecnomidae	0	8	0	0	0	0	0	4	24	46	7	17
Limnocharidae	0	0	4	0	0	0	0	0	0	0	0	0
notonectidae	0	0	1	0	0	4	1	1	0	0	0	8
Nematoda	0	0	0	12	0	0	0	0	0	0	4	0
Leptoconopinae	0	0	0	4	0	2	1	0	0	0	0	0
Curculionidae	0	0	0	1	0	0	0	0	0	0	0	0
Psychodidae	0	0	0	0	2	0	0	0	0	0	0	0
Ancylidae	0	0	0	0	4	69	0	0	19	1	2	0
Pionidae	0	0	0	0	4	0	0	0	6	0	0	0
Pyralidae	0	0	0	0	1	0	0	93	2	0	0	1
Gyrinidae juv	0	0	0	0	1	0	0	0	5	10	0	0
Gyrinidae adu	0	0	0	0	0	0	0	0	0	5	0	0
Stratiomyidae	0	0	0	0	3	0	0	0	0	0	0	0
Gripopterygidae	0	0	0	0	0	15	0	0	653	23	4	0
Hydrachnidae	0	0	0	0	0	3	0	0	38	3	0	0
Aeshnidae	0	0	0	0	0	1	0	33	5	0	0	7
Caenidae	0	0	0	0	0	3	0	0	212	322	49	95

Temnocephalans	0	0	0	0	0	0	2	0	0	0	0	0
Ephydridae	0	0	0	0	0	0	0	107	0	0	3	0
Chrysomelidae	0	0	0	0	0	0	0	4	0	0	0	2
Baetidae	0	0	0	0	0	0	0	0	73	38	4	455
Notonemouridae	0	0	0	0	0	0	0	0	9	0	0	0
Leptophlebiidae	0	0	0	0	0	0	0	0	31	7	1	39
Hydropsychidae	0	0	0	0	0	0	0	0	60	86	0	3
Scirtidae	0	0	0	0	0	0	0	0	35	1	10	0
Palaemonidae	0	0	0	0	0	0	0	0	8	0	28	0
Planorbidae	0	0	0	0	0	0	0	0	1	0	0	13
Sphaeriidae	0	0	0	0	0	0	0	0	0	0	48	0
Parastacidae	0	0	0	0	0	0	0	0	0	0	2	0
Oniscidae	0	0	0	0	0	0	0	0	0	0	0	1