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The potential effect of re-snagging on hydraulic habitat

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Abstract Within riverine ecosystems, physical diversity facilitates biodiversity. In particular, large wood within river channels influences the distribution of hydraulic patches and their character, within the river landscape. We surveyed 30 reaches along the Barwon–Darling River in southeastern Australia to describe their hydraulic character, before and after the reintroduction of large wood (re-snagging). We found considerable hydraulic diversity within the reaches, but there was little difference between reach types (control, reference or re-snagged) and survey times. No significant differences were observed between the re-snagged reaches at the two survey times when all reaches were considered together, although differences were identified in some individual hydraulic patch variables. These results may be due to the low-flow conditions during and between survey runs. Successive surveys at a range of flow levels, both before and after the occurrence of larger flow events (which may encourage scour around re-introduced large wood), will be required to clarify this.

Key words large wood; acoustic doppler profiler; Barwon-Darling River; hydraulic diversity

INTRODUCTION

Physical diversity is a key component of the biodiversity of riverine landscapes (Poff *et al.*, 1997; Thorp *et al.*, 2008). At the reach scale, physical diversity can be described as variations in hydraulic characteristics, such as water depth, flow velocity and turbulence, which create distinct hydraulic patches or areas of similar hydraulic character (Thoms *et al.*, 2006). The pattern or configuration of hydraulic patches at the reach scale is influenced by the morphology of the river bed and banks, and obstacles that may be present within the river channel (Dyer & Thoms, 2006). In many inland rivers, large pieces of wood form major in-channel obstacles to flow. The influence of large wood on hydraulic character depends on placement within the channel, and the size and shape of each piece (Gippel *et al.*, 1996). Large wood has been shown to increase hydraulic diversity within river channels (Hughes *et al.*, 2007), and promote bed scour through deepening and pool formation on the downstream sides (Crook & Robertson, 1999).

Large wood is an important type of physical habitat for riverine fishes in many large lowland river systems (Crook & Robertson 1999; Gehrke & Harris 2004; Boys, 2007). For example, the presence and abundance of Murray cod (*Maccullochella peelii peelii)* and golden perch (*Macquaria ambigua*), two iconic native Australian fish, have been found to be strongly associated with the diversity of large wood in the mid reaches of the Barwon–Darling River, New South Wales (Boys, 2007). However, large wood has been removed from many large Australian lowland rivers in the Murray–Darling Basin to improve navigation (Gippel *et al.*, 1996; Crook & Robertson, 1999). This has had a detrimental effect on native fish communities within the basin (Gehrke & Harris, 2004). Currently, native fish numbers are estimated to be 10% of pre-European settlement levels (MDBC, 2003). Iconic species, such as freshwater catfish (*Tandanus tandanus*) and silver perch (*Bidyanus bidyanus*), are also showing evidence of declining abundance and distribution (Schiller *et al.*, 1997; Gehrke & Harris 2004).

The re-introduction of large wood to rivers (re-snagging) is an important restoration strategy in many countries (Crook & Robertson 1999; Piegay *et al.*, 2005; Lester & Wright 2008). In the Murray–Darling Basin, several demonstration reaches have been established to test the effectiveness of the re-introduction of large wood to rivers at the reach scale (Barrett, 2004). One demonstration reach is located between the townships of Bourke and Brewarrina on the Barwon–Darling River, within the upper section of the Murray–Darling Basin in New South Wales. Large wood was re-introduced at selected trial reaches within the larger demonstration reach. The biological response of fish was monitored and the influence of re-snagging on hydraulic diversity was quantified. This quantification allowed us to examine the distribution of patches of distinct hydraulic character in the selected reaches and to assess the influence of re-snagging on the hydraulic diversity.

METHODS

Site details

The Barwon–Darling River drains 650 000 km^2 of the northwest portion of the Murray–Darling Basin in southeast Australia (Fig. 1). The catchment is characterised by extreme climatic

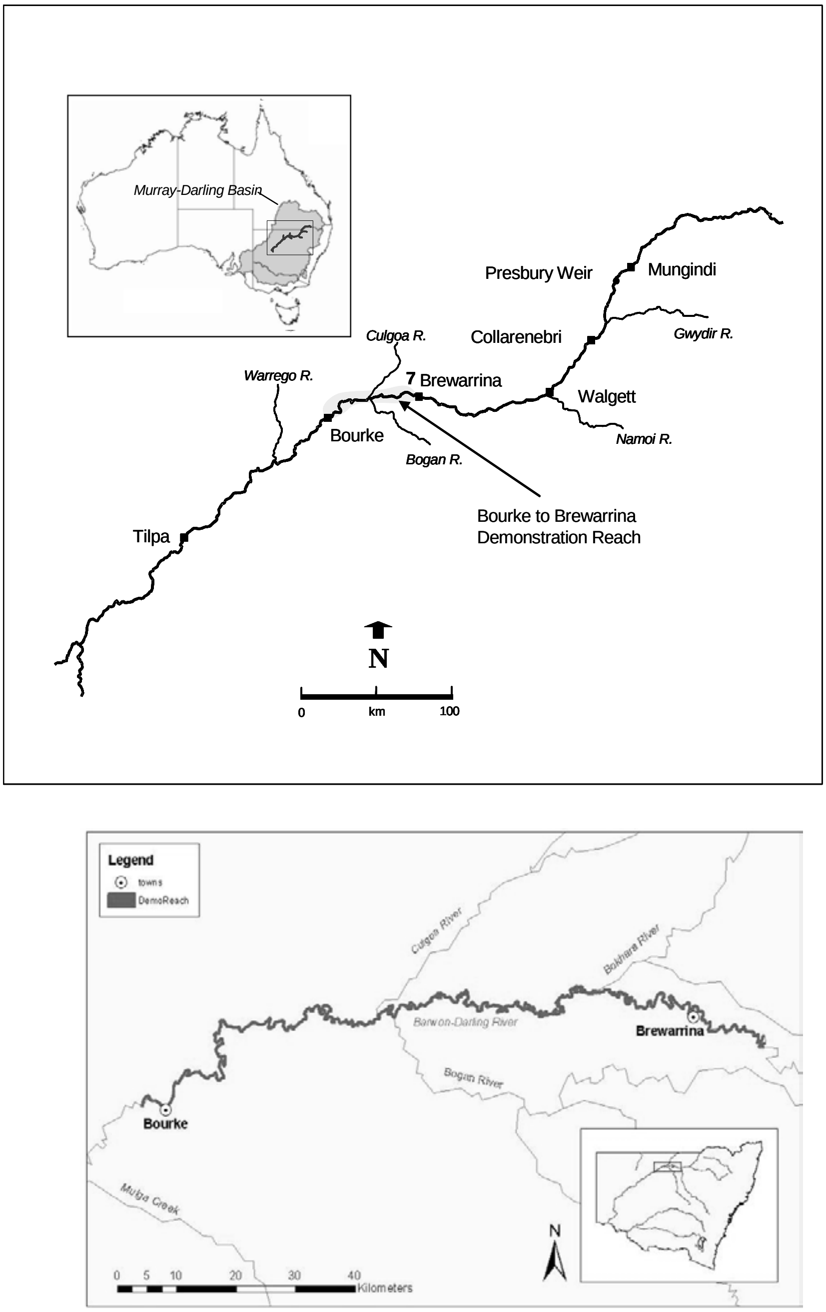

Fig. 1 Barwon–Darling River, Australia, showing major towns, tributaries and the location of the demonstration reach.

variability and runoff, with average annual rainfall in the range 200–1000 mm and evaporation in the range 500–1800 mm (Thoms & Sheldon, 2000). Hydrological variability is also a feature of the Barwon–Darling River. Although low flows predominate, these are punctuated by occasional floods, which inundate anabranch channels, billabongs and extensive areas of semi-arid flood plain. We studied the mid-reaches of the Barwon–Darling River between the towns of Brewarrina and Bourke (Fig. 1). A deeply-incised channel occurs along this section of river, which has a relatively simple low-flow channel structure. Increased structural diversity occurs at higher river flow levels or stages within the channel, due to the presence of in-channel benches, bars, flood runners and anabranches (Woodyer *et al.*, 1979; Thoms *et al.*, 2004, 2005).

Thirty reaches were surveyed, corresponding to the same reaches used in the larger Bourke to Brewarrina Demonstration Reach monitoring and evaluation programme (Boys, 2009). Reaches were between 100 and 400 m in length and were grouped into either control, reference or re-snagged types. Control reaches had low amounts of large wood, reference reaches had near natural amounts and re-snagged reaches had large wood re-introduced. The number of individual pieces of large wood introduced to re-snagging reaches varied from 3 to 30 pieces per reach and all were larger than 60 cm in diameter. The number of snags re-introduced was determined by comparing the number of pieces of large wood at an individual reach with the average number of snags in a similar length of river along a section of the river that had never been subjected to large wood removal (i.e. Brewarrina to Mungindi; Fig. 1) (Boys, 2009). Ten individual reaches formed each reach-type group.

Field methods

Flow surveys were carried out along the 30 study reaches between Bourke and Brewarrina on two occasions; in May 2008 (1 May–8 May), several weeks before re-snagging began, and in November 2008 (10 November–14 November), after re-snagging was completed. Both survey periods had low-flow conditions: 40–63 ML/day in May and 26–46 ML/day in November (measured at the Bourke town gauge station). Flow velocities were recorded along each reach using a boat-mounted acoustic doppler profiler (ADP). Depth–velocity profiles and point-depth measurements were recorded at 5-second intervals as the boat was driven slowly in a zigzag pattern from bank to bank up each reach. This method gave an average of 261 depth–velocity profiles for each reach. Coordinates (x and y) were recorded using the ADP for each profile to derive reach-scale depth-averaged velocity grids.

Data analysis

Individual velocity profiles were summarised as depth-averaged velocities (in cm s^{-1}) using the Sontek River Surveyor software program. For each reach and survey time, the depth-averaged velocities were interpolated to raster grids in ArcGIS 9.1 using an inverse distance weighted transformation. Grids were then re-organised into classes (or hydraulic patches) based on boundaries determined from the break points in the cumulative frequency curve of all depth-average velocity points. These grids, which represent a “landscape” or “reach-scape” of velocity patches, were used to derive a number of metrics using the spatial analysis software package FRAGSTATS Version 3.3 (McGarigal & Marks, 1995). The nine metrics selected describe the abundance, shape, size, spatial arrangement and diversity of hydraulic patches belonging to each of the *a priori*-determined classes for each reach-scape.

The character of each reach-scape was investigated using a range of multivariate statistical analyses. First, association matrices were calculated using the Gower environmental difference measure, as suggested for non-biological data by Belbin (1993). Matrices were calculated for two data sets: a data set containing all patch variables and all reach-scapes (all reach data set), and a data set containing only re-snagged reach-scapes (re-snagged only data set). An analysis of similarity (ANOSIM) was then run on these association matrices to test for differences between times, reach types, times and reach types combined for the all reach data set, and times for the re-snagged only data set.

Semi-strong hybrid multidimensional scaling, MDS (Belbin, 1993) was then used to represent the matrices graphically. Stress levels of less than 0.2 indicated that the ordination solutions were not random. Principle axis correlation, PCC (Belbin, 1993) was then used to identify relationships between the patch variables and the location of each reach-scape in multidimensional space. Only those patch variables with an R^2 of greater than 0.8 were considered. In addition, univariate Student *t*-tests were used to compare individual patch variables between the two survey times, when the data were separated by reach type.

RESULTS

Depth-averaged velocities (DAV) recorded during the two survey times ranged from 0 to 1.81 ms^{-1}. The median DAV was 0.13 ms^{-1} and the 10th and 90th percentiles fell at 0.05 ms^{-1} and 0.3 ms^{-1} during the May and November survey times, respectively. A total of five DAV classes (or hydraulic patches) were determined from the cumulative frequency curve of all DAV points (Fig. 2). Ranges of the DAV classes and the percentage of occurrences in each class are listed in Table 1. An example of two of the resultant reach-scapes are shown for both sampling times (Fig. 3).

The mean number of hydraulic patches in individual reach-scapes was greatest at the November survey (98 patches) and was also greatest in re-snagging reaches (99 patches), whereas mean patch size was similar both between times and reach types (Table 2). Although some variation can be seen in individual patch mean variables in Table 2, ANOSIM results suggest a poor separation of sites in multidimensional space: global $R = 0.041$ ($P < 0.05$), global $R = 0.123$ ($P < 0.001$) and global $R = 0.144$ ($P < 0.001$) for time, reach type, and time and reach type combined, respectively. This poor separation can be seen in the ordination plots displayed in Fig. 4, where the data have been grouped by time, reach type, and time and reach type combined. Global R values >7 suggest that groups are clearly different, global R values = 0.5–0.69 suggest some overlap between groups, and global R values of <0.5 indicate a high degree of overlap (Clarke & Warwick, 1994).

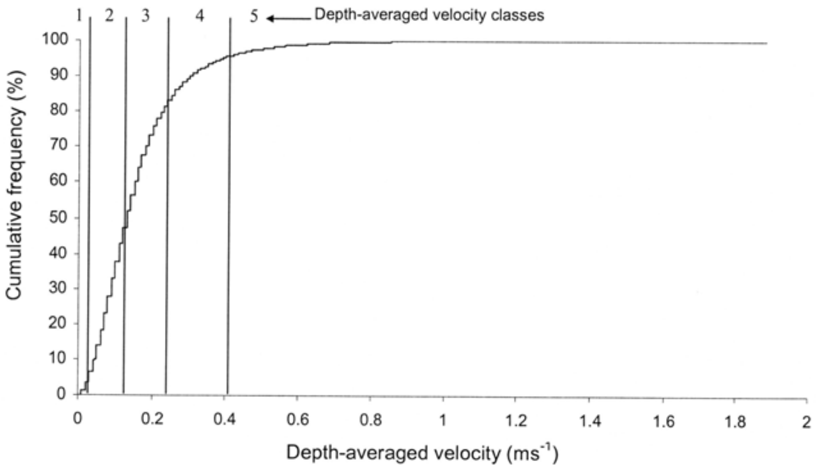

Fig. 2 Cumulative frequency curve of depth-averaged velocities from all reaches and sampling times; vertical lines correspond to breaks in slope which delineate velocity classes.

Table 1 The character of hydraulic patches identified in the study area.

Velocity class	Depth-averaged velocity (m/s^{-1})	Profiles in each class (%)
1	<0.04	6.29
2	0.04–0.13	41.08
3	0.13–0.24	33.93
4	0.24–0.43	14.83
5	>0.43	3.86

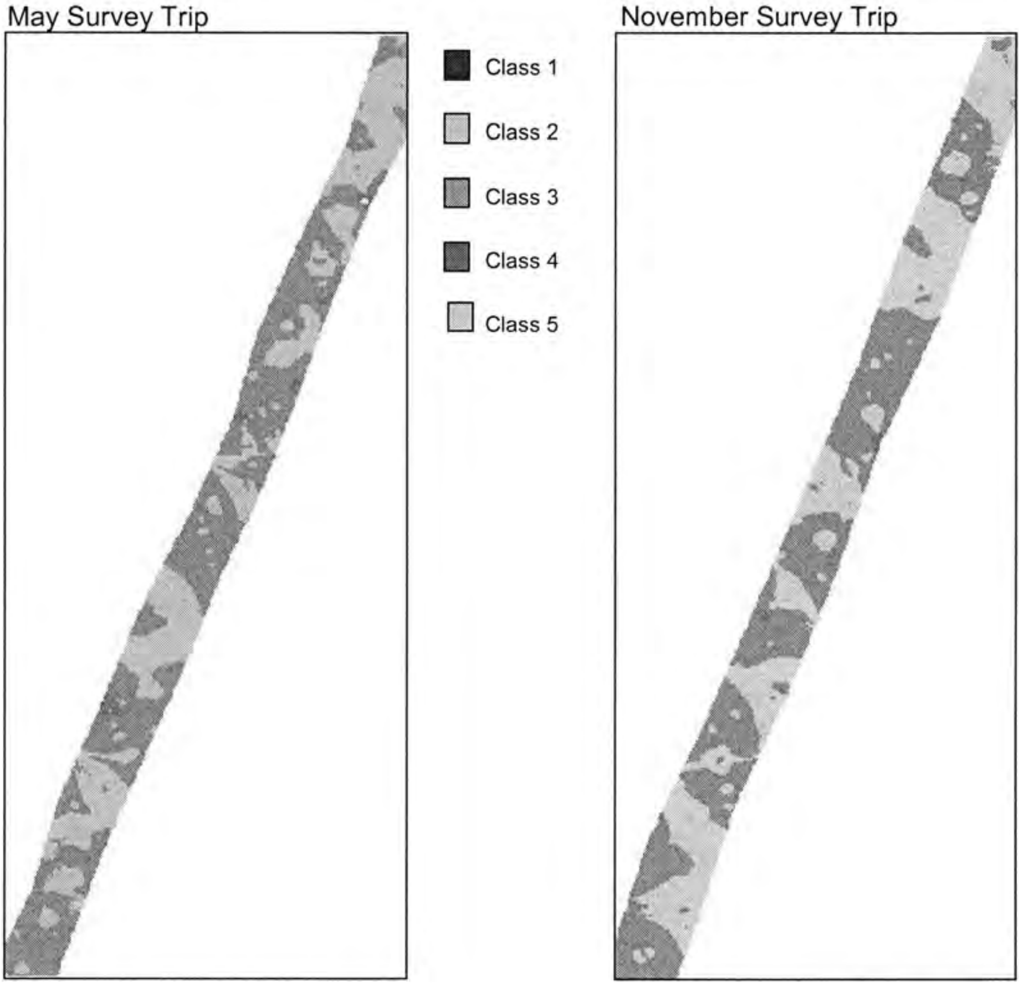

Fig. 3 Raster images of the study reach 12 km upstream from the downstream end of the demonstration reach displaying the velocity classes (images are not to scale).

Table 2 Summary patch metrics for each time and reach type in the study.

	Time		Reach type		
Patch variable	May	November	Reference	Control	Re-snagged
Mean reach area (ha)	2.93	2.77	1.83	3.09	3.63
Mean number of patches	85	98	91	85	99
Mean patch density (N^o/Ha)	4153	4746	6119	4195	3035
Mean landscape shape index	6.93	7.53	7.37	7.25	7.06
Mean Simpsons diversity index	0.52	0.50	0.51	0.52	0.50
Mean Simpsons evenness index	0.66	0.63	0.65	0.65	0.63
Mean patch area (ha)	0.03	0.03	0.02	0.04	0.04
Mean patch shape	1.32	1.29	1.30	1.29	1.31
Mean patch proximity (m)	64.28	36.74	37.88	29.62	84.03

To investigate the specific influence of re-snagging, we analysed the re-snagged reaches only and made comparisons between the May (before re-snagging) and November (after re-snagging) survey times. ANOSIM results suggest a higher degree of separation between May and November for the re-snagged only data set, compared with the degree of separation found in the all reach data set (global $R = 0.216$, $P < 0.005$) however, considerable overlapping of the May and November groupings is evident from the MDS plot (Fig. 5(a)).

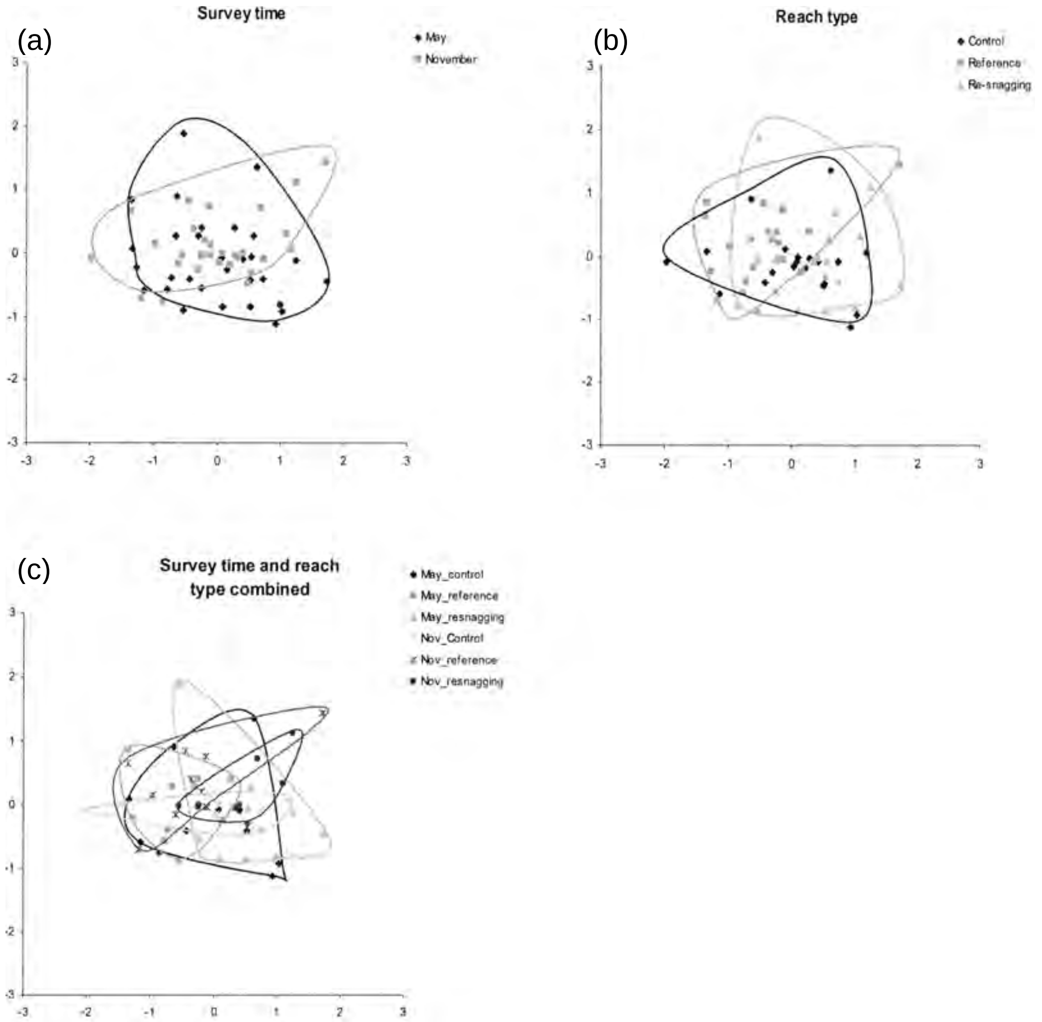

Fig. 4 Graphical summaries of the multivariate analysis of the reach all reach data set; ordinations are presented grouped by: (a) survey time, (b) reach type and (c) survey time and reach type combined. Stress level for the ordination is 0.15.

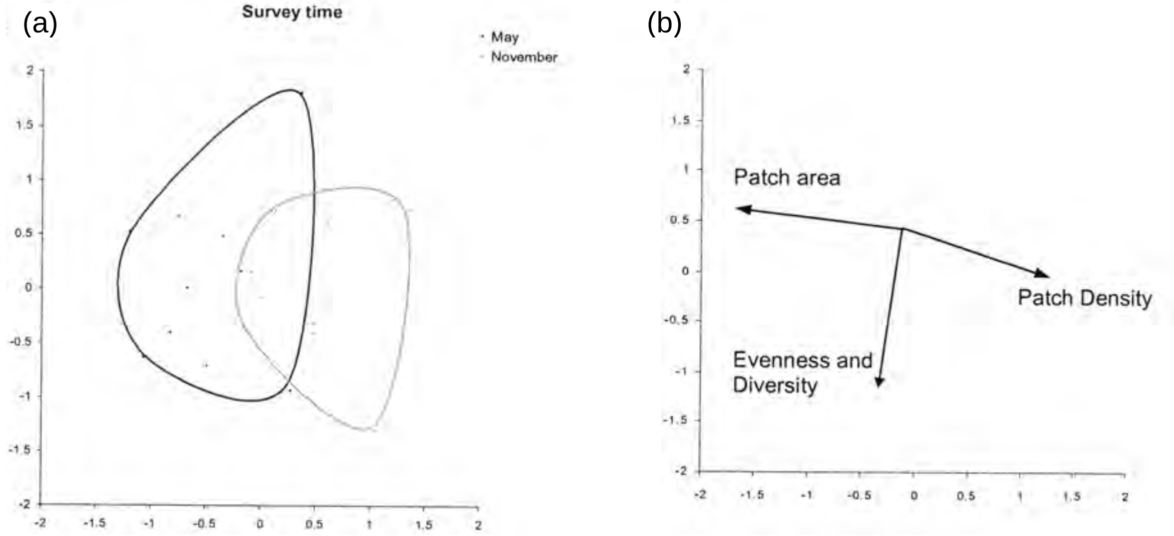

Fig. 5 Graphical summaries of the multivariate analysis of the re-snagging only data set: (a) ordinations grouped by sampling time (b) resultant PCC analysis.

PCC analysis showed that only four of the nine patch variables (Table 2) – patch area, patch diversity, Simpson's diversity index and Simpson's evenness index were responsible for influencing the position of re-snagging sites in ordination space at the 0.8 confidence level (Fig. 5(b)). The before re-snagging reach-scapes tended to plot to the left in the ordination space (Fig. 5(a)), in the direction of the increasing influence of Patch size (Fig. 5(b)), suggesting these before re-snagging reach-scapes may be associated with larger patch areas. Post-re-snagging reach-scapes tended to plot to the right in ordination space, suggesting that they may be associated with higher patch diversity (i.e. number of patches per ha).

Student *t*-tests on individual patch variables for each re-snagged reach type showed that there were significantly ($P < 0.05$) more patches in reach-scapes after re-snagging than before. These patches were also significantly smaller and in higher density post re-snagging. Control reaches showed significantly more patches at the November survey and reference reaches showed lower patch proximity (i.e. they displayed shorter average distances between similar patches) during the November survey.

DISCUSSION

A diverse range of velocity readings were taken within the 30 survey reaches of the Barwon–Darling River. These may be grouped into five distinct hydraulic classes, based on depth-averaged velocity cumulative frequency curve. Velocity readings observed in this study fit within the lower range of flows reported by Thoms *et al.* (2006) on the mid reaches of the River Murray, Australia, where river flows were measured ranging from 2000 ML/day to 9000 ML/day. For example, the most abundant velocity class in the current study was class 2 (0.04–0.13 m s^{-1}) which accounted for 41% of the total depth-averaged velocities recorded, compared to the Thoms *et al.*, (2006) study in which class 3 (0.23–0.35 m s^{-1}) accounted for 48% of all recordings. The comparatively low flow velocities demonstrate the low-flow conditions present during both survey occasions in the present study.

The results of this study suggest that only moderate differences exist between reach-scapes of the three different reach types (reference, control and re-snagged). Even fewer differences were evident when the data were compared according to survey time. This result is not surprising, given that both surveys were done in very low flow conditions of similar magnitude. Greater differences in the diversity of hydraulic patches over time between different magnitude flows were found along various river reaches by Thoms *et al.* (2006) and Dyer & Thoms (2006), and these differences appear to be much greater than those found in the current study. Both previous studies also found that the relative proportions and diversity of hydraulic patches changed with increases in discharge, but not always in a predictable manner. Further, Dyer & Thoms (2006) identified several threshold discharges in the Cotter River, Australia, where distinct changes to the hydraulic character of river reaches were observed when river flows exceeded these threshold discharges. The current data set is not adequate to identify potential changes in the diversity of hydraulic patches along the Barwon–Darling River in response to changes in discharge; however, future surveys at a range of flow levels could provide a more complete picture of hydraulic diversity along this stretch of river.

When we analysed the re-snagged reaches data set only, the results suggested that re-introduced large wood may be influencing the hydraulic diversity of these reaches. However, the low global *R*-value (0.216) indicates that these differences are not significant. After re-snagging, the reaches tended to contain greater numbers of smaller sized patches, and higher patch densities. It may be presumptuous to assume that these changes were a direct result of the re-snagging as both reference and control reaches, when analysed separately, also showed changes in patch proximity and patch number between the two survey times, respectively. Even so, the observed changes in the re-snagging reaches may have been a result of the size of the re-introduced logs. Lester & Wright (2008) found that there was little change to average velocity and stage parameters at the reach scale with the addition of wood into a number of agricultural streams in Victoria, Australia. They did observe some short-term increases in the variability of channel shape; however, this stabilised over the long-term in treatment sites — it may be the case that the small size of the logs (0.05–0.35 m diameter) hampered their effectiveness to influence local velocity profiles and stage in these systems (Lester & Wright 2008), even though channel sizes were smaller than those in the current study. The large wood used in the current study was considerably larger, with trunk thicknesses generally larger than 0.6 m in diameter and up to 8 m in length, which probably increased their potential influence on reach-scale hydraulics. Pieces of large wood are considered to be effective obstacles to river flow (Gippel *et al.*, 1996). Not only do they change flow in the downstream direction, but they also cause upwelling and turbulence that can significantly alter the local hydraulic diversity around them (Hughes *et al.*, 2007).

We suggest that the relatively small impact of large wood on hydraulic diversity observed in the current study may be a reflection of the low-flow conditions under which the river was surveyed. Previous work has suggested that large wood tends to have minimal influence on hydraulic diversity during low-flow conditions and that the relative influence increases as flow levels increase (Thoms, unpublished data). Successive hydraulic surveys are required to collect data for a full appreciation of the influence of introduced large wood on hydraulic diversity along these reaches of the Barwon–Darling River.

Low-flow conditions may have had two different consequences for the measurement of hydraulic diversity in the current study. First, if a flow event of a magnitude sufficient to scour around the pieces of introduced large wood had occurred after their introduction, then we might have expected to find associated changes to the hydraulic character of the reaches during the second survey trip. However, no such flow event occurred between survey trips. Second, most of the large wood introduced in the re-snagged reaches was placed in close proximity to the river banks; therefore, under low-flow conditions, the logs were surrounded by shallow water (<1 m in depth). The ADP used for these surveys has a non-detection distance of less than 0.5 m; therefore, it does not record data for 0.5 m directly below the surface of the water. In the current study, much of the water surrounding the introduced logs would have been outside the recording range of the equipment used (and not included in the analysis). It is probable that the inclusion of these data would have led to a more sophisticated analysis of the influence of the re-introduced logs in the present study.

Results from the present study suggest that, although distinct hydraulic patches are present within the channel of the Barwon–Darling River, slight differences exist between the reach-scapes from the difference reach types measured and between the two surveys. Our analysis of the re-snagged only reach-scapes suggests that the introduction of large wood had only a minimal impact on hydraulic diversity within these reaches. We suggest that the low-flow conditions overall and the lack of flows of sufficient size to promote scour around the large wood between surveys, are likely to have contributed to the similarities in reach scale hydraulic diversity between reach types and survey times, and further surveys under a range of flow conditions are required in the future to assess the full influence of re-snagging on reach scale hydraulic diversity.

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