Associations between channel morphology and large woody debris in a lowland river

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Abstract Associations between channel morphology and the distribution and character of large woody debris (LWD) within a 95-km reach of the River Murray, Australia were examined at different scales. At the reach scale there was a uniform pattern of LWD distribution along the river. Most LWD was associated with eroding sites, close to the bank and aligned at 90° or less to the flow. At the sub-reach scale (0.5–1.5 km) strong associations were found between the curvature of the river channel and LWD distribution. Distribution patterns at this scale suggest that LWD is mainly recruited by bank erosion and falls into the river perpendicular to the flow. It subsequently remains close to where it falls and is realigned rather than actively moved by the river. Within meander bends there was twice as much LWD along the outer bank as there was along the inner bank, and while the amount on the inner bank declined with increasing distance into the bend the reverse was true for the outer bank.

Key words large woody debris (LWD); eco-geomorphology; lowland river; multivariate statistics

INTRODUCTION

The ecological importance of large woody debris (LWD) in rivers has been explored by many authors (e.g. Crook & Robertson 1999). This interest stems in part from an increasing focus on physical–biological associations in freshwater systems over the past 10 years (cf. Townsend & Hildrew, 1994). Relationships between channel morphology and LWD have also been investigated by many (e.g. Gregory & Davis 1992; Brooks, 1999) but this has generally been from the perspective of how LWD influences river channel morphology. Some studies (e.g. Piegay, 1993; Piegay & Gurnell, 1997) have demonstrated associations between river geomorphology and the distribution of LWD but these studies were conducted in high energy river systems where slopes are typically >5 m km^{-1}. Given differences in the structure and function of upland and lowland systems (Thoms & Walker, 1993) it is perceivable that associations between channel morphology and LWD may differ between the two.

Links between river channel morphology and LWD have generally been studied at the local habitat scale of tens of metres (e.g. Marsh *et al.*, 1999). However, Crook *et al.* (2001) have shown that spatial scale influences the use of habitat (LWD) by native fish. Rivers are nested hierarchical systems that operate at many scales (Petts & Amoros, 1996) and therefore any study must identify and analyse data at relevant scales. This paper examines associations between channel morphology and LWD at multiple scales in an Australian lowland river.

STUDY AREA

This paper concerns a 95 km section of the River Murray between the towns of Yarrawonga (538 km from the source) and Tocumwal. In this reach the channel width:depth ratio is approximately 20, cross-sectional area approximately 500 m^2, maximum width 120 m, and maximum depth 8 m (Rutherfurd, 1994). Bed slope averages 0.09 m km^{-1}. The records of the New South Wales Department of Land and Water Conservation indicate that the study reach has not been desnagged (personal communication, Tony Crawford DLWC).

The River Murray drains over 420 000 km^2 of southeastern Australia. It originates from a wet upland region at an elevation of 1430 m above sea level and flows in a northwest direction through a predominantly semiarid region, before turning due south in South Australia to meet the sea. The average annual discharge of the River Murray is 318 $m^3 s^{-1}$ (range 20–1564 $m^3 s^{-1}$; data for Blanchetown, 1950–1980), half of this coming from catchments within 500 km of the Murray's source. The high flow variability, in comparison to world rivers (Finlayson & McMahon, 1988), is a function of low relief and high evaporation potential. A salient feature of the river is its extended long profile (Thoms & Walker, 1993) with 89% of the length of the Murray (2560 km) having a channel gradient of less than 0.17 m km^{-1}.

METHODS

The analysis of channel morphology LWD associations along the study reach was conducted at three scales (Fig. 1): *reach*, *functional set* and *functional unit* scales (Petts & Amoros, 1996). Reaches are deemed to be repeatable lengths of river channel with similar morphology, within a larger functional process zone. Functional sets scale are

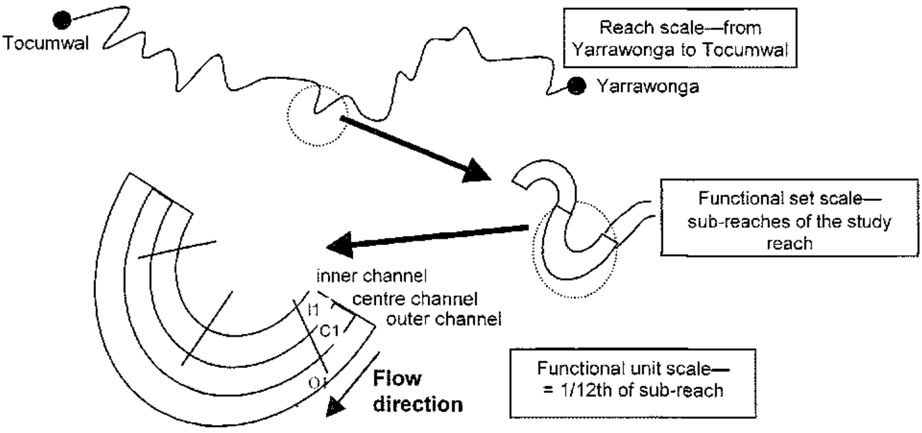

Fig. 1 Investigation scales used in this study of distribution of LWD showing the lateral and longitudinal division of sub-reaches into functional units. In straight sections functional units are referred to as L1 (i.e. left channel first quarter) etc.; C1 (centre first) etc.; and R1 (right first) etc.. In bends they are referred to as I1 (inner first) etc.; C1 etc.; O1 (outer first) etc.

smaller in size, identified as different sections within a reach and are determined by ecological or physical properties. Functional units are subsets of functional sets and can be arranged along a gradient such as water depth.

A series of 90 small-scale (1:5000) aerial photographs, taken of the study reach during a period of extreme low flow (equivalent to the 98 percentile on the annual flow duration curve at Tocumwal), were used to identify and describe LWD. Much of the LWD was visible in the river channel at this flow, although no field verification of LWD was undertaken. However, the high-resolution nature of the photography was deemed adequate for such an exercise (Maling, 1989).

Data were collected for the entire reach, then for sub-reaches (functional set scale), which were delineated on channel curvature (i.e. bends and straight sections). The beginning and end of each sub-reach was determined visually from inflection points in the channel. For each sub-reach the length (at channel centre), bankfull width, radius of curvature, arc angle, amplitude, direction of bend, meander wavelength (MWL) and meander belt width (MBW) were recorded (cf. Rosgen, 1996). Each sub-reach was then divided longitudinally into quarters and then laterally into thirds giving 12 functional units (Fig. 1).

Each piece or unit of LWD identified along the study reach was described by its position in the channel, length, angle to flow, distance from bank, structural complexity and whether its site was erosional, depositional or indeterminate. Linear measurements were made in 1 mm increments (5 m at scale) and angle to flow was recorded as one of six classes representing 30° increments between 0° and 180°. The percentage cover of the vegetation in the riparian zone was estimated at 500 m intervals.

Associations between channel morphology and LWD were examined using a suite of multivariate, univariate and descriptive statistical techniques. Initially, classification and ordination of the data were undertaken to elicit groups of LWD at the different scales (Belbin, 1993). Following this, a series of univariate and descriptive techniques including chi-square analyses, linear regressions and histograms were used to explore how channel morphology attributes of the various woody debris groups differed.

RESULTS

LWD at the reach scale A total of 6322 pieces of LWD were identified along the study reach. Of these, 88% were less than 20 m in length with 57% being structurally simple i.e. having single trunks or branches and 37% having a trunk with one level of branching. The majority of the LWD (90%) was within 25 m of the bank and 87% was orientated at 90° or less to the angle of flow (Fig. 2). While 59% of LWD was found at eroding sites, only 8% was found at sites identified as depositional. Ordination of the LWD characteristics at whole of reach scale revealed no distinct groupings of LWD in multivariate space. Hence, there are no parts of the study reach with a distinctive LWD character.

The mean tree cover (and standard error) of the bank adjacent to the channel, measured at 0.5 km intervals along the reach was 70.7±1.25% (range = 68.3–73.2, n = 370), indicating that the riparian zone is generally well vegetated in the immediate

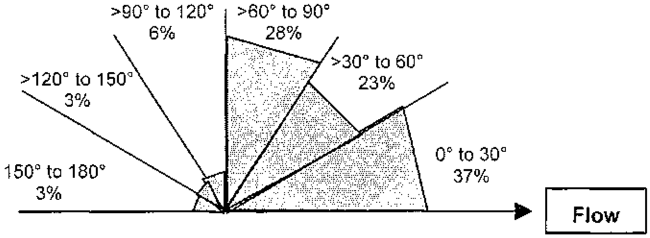

Fig. 2 Distribution of angle to flow classes, showing the percentage of LWD found in each angle class.

vicinity of the channel. A regression of LWD density against tree cover on the adjacent bank showed no significant relationship ($R^2 = 0.01$). Riparian vegetation density did not differ between banks (Student's *t* test, $p = 0.36$). A regression of tree cover against distance downstream showed no trend along the reach ($R^2 = 0.07$).

Functional set scale The classification of channel morphological attributes revealed eight functional sets (of sub-reaches) (Fig. 3), each with a distinct plan form character (Table 1) and these were used for the analysis of LWD attributes. At functional set scale there was an association between the curvature of sub-reaches and the proportional distribution (i.e. number of pieces) of LWD on either side of the channel. In the functional set of straights, LWD was distributed evenly between the left and right sides of the channel (51.6% in the left channel, 48.4% in the right channel). In the functional sets of bends, 33% of LWD was in the inner channel and 67% in the outer channel. The outer channel is larger in area by 21% on average than the inner channel but that is not sufficient to account for the outer channel having 100% more LWD than the inner channel.

Functional unit scale The eight geomorphic functional sets were also used for the analysis of LWD attributes at functional unit scale. There are three pertinent findings at this scale; the first two relate to the proportional distribution of LWD among functional units and the third relates to differences between functional units in the character of LWD.

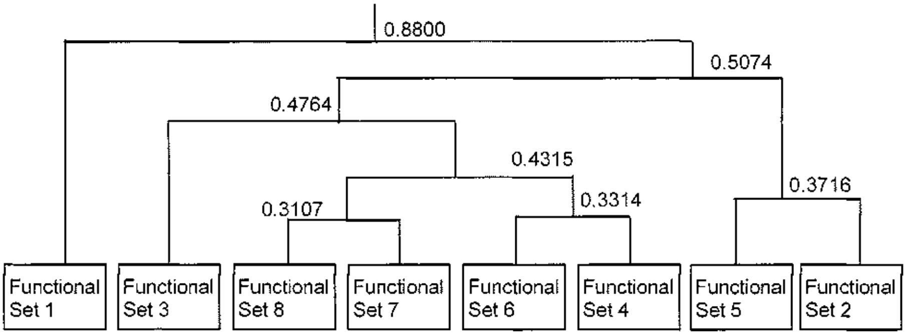

Fig. 3 Simplified dendrogram of the eight functional sets derived using classification of geomorphic variables using the Gower metric recommended for non-biological data, numbers on horizontal line indicate level of dissimilarity.

First, only 4.7% of LWD was located in the channel centre functional units even though these units represent one-third of the channel area. Second, each of the eight functional sets had a unique proportional distribution of LWD among its functional units (Table 2). In the straights LWD is distributed relatively evenly among the different functional units located on the left and right banks. This is in contrast to the bend functional sets. In bends, the number of LWD pieces along the inner bank decreases with distance through the bend i.e. the Inner 1 functional unit always contained the largest number of pieces and then the amount per functional unit declines sharply further into the bend. In the outer channel the number of LWD pieces per functional unit increases with increasing distance into the bend, so that most is found in Outer 4. However, even though all bend functional sets have the same broad pattern of LWD distribution described above, each of the functional sets has its own unique pattern. The third finding at functional unit scale was that the character of LWD (specifically its distance from bank and angle to flow) varies according to its position in the bend. When data for all bends were combined, it was found that mean distance from bank in

Table 1 The geomorphic character of the eight functional sets identified along the study reach. Values are means and (standard errors).

Functional set	Description	Width (m)	Length (m)	Tightness (Rc/w)	Angle (°)	Amplitude (m)	MBW (m)	MWL (m)
1 (*n* = 26)	Straights	103.4 (3.7)	306.5 (40.0)	0	0	0	0	0
2 (*n* = 14)	Very open, short bends	90.1 (1.7)	312.9 (26.6)	5.40 (0.84)	49.9 (8.2)	57.1 (13.4)	186.4 (16.1)	578.6 (47.8)
3 (*n* = 13)	Open, average length bends	117.7 (4.2)	624.6 (66.0)	4.21 (0.70)	94.0 (14.8)	244.6 (41.2)	430.8 (34.2)	996.9 (66.1)
4 (*n* = 15)	Open, long bends	104.7 (2.7)	889.3 (26.7)	4.18 (0.26)	104.6 (7.1)	460.0 (28.2)	583.3 (21.4)	1380.7 (55.8)
5 (*n* = 43)	Open, short bends	108.6 (2.4)	391.3 (16.3)	4.03 (0.29)	58.9 (3.6)	106.7 (9.40)	258.8 (14.9)	738.1 (28.7)
6 (*n* = 8)	Tight, long bends	113.3 (3.9)	946.3 (72.7)	2.72 (0.28)	187.4 (11.8)	735.0 (46.9)	872.5 (41.4)	947.5 (84.0)
7 (*n* = 11)	Tight, average length bends	123.6 (4.3)	560.5 (35.3)	2.25 (0.27)	119.1 (8.8)	260.9 (27.3)	387.3 (30.5)	891.8 (64.4)
8 (*n* = 48)	Very tight, average length bends	107.6 (1.9)	537.8 (22.8)	1.90 (0.09)	140.7 (4.0)	297.3 (13.0)	434.0 (12.2)	737.9 (27.2)
Mean of all 178 sub-reaches		107.6 (1.2)	507.0 (18.1)	2.83 (0.16)	87.6 (4.4)	216.0 (14.6)	338.0 (16.5)	709.0 (29.7)

Table 2 Percentage of LWD pieces in the left and right (straights), inner and outer (bends), functional units for the eight functional sets.

Functional set	Functional unit							
	L1	**L2**	**L3**	**L4**	**R1**	**R2**	**R3**	**R4**
1. Straights	13.1	12.0	14.1	12.1	12.3	12.6	13.1	10.2
	I1	**I2**	**I3**	**I4**	**O1**	**O2**	**O3**	**O4**
2. Very open, short bends	20.3	9.5	6.4	7.0	9.2	12.3	15.0	18.7
3. Open, average length bends	13.9	7.8	5.3	4.5	12.2	9.6	18.6	20.4
4. Open, long bends	14.7	2.2	1.3	2.1	13.3	18.2	21.7	25.7
5. Open, short bends	24.2	12.6	3.2	2.8	6.5	9.1	15.1	20.0
6. Tight, long bends	16.6	1.3	0.7	0.2	16.1	19.7	18.2	20.0
7. Tight, average length bends	18.5	6.7	1.1	0.2	6.2	15.7	19.5	24.5
8. Very tight, average length bends	22.5	8.7	0.2	0.6	7.1	12.8	19.6	23.6

functional unit Inner 1 is greater than mean distance from bank in Inner 2, and mean distance from bank in Inner 2 is greater than in Inner 3 and Inner 4 (I1 > I2 > I3 = I4) (Fig. 4(a)). Thus, in the inner channel LWD is located closer to the bank with increasing distance into the bend. In the outer channel O1 < O2 < O3 <O4 (Fig. 4(a)) and so LWD is located further from the bank with increasing distance into the bend. Angle to flow in the inner channel appears to increase with increasing distance into the bend (I1 < I4) although the error range of I3 and I4 make this difficult to confirm (Fig. 4(b)). In the outer channel, angle to flow declines with increasing distance into the bend; O1 = O2 > O3 = O4 (Fig. 4(b)).

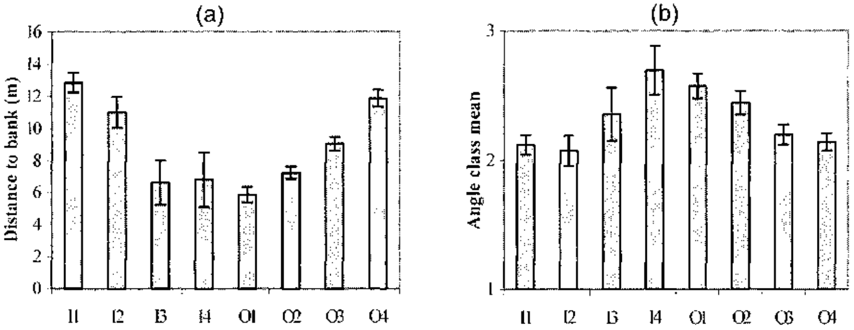

Fig. 4 Large woody debris properties by inner and outer channel functional units for all bend functional sets combined. x axes = functional units. Error bars = 2 standard errors. (a) Mean of distance to bank, y-axis in metres. (b) Mean of angle class; higher value = more perpendicular to flow.

DISCUSSION

Large woody debris in the study reach of the lowland River Murray was mainly associated with eroding sites, suggesting that it is relatively immobile. This contrasts with the associations described by Piegay (1993) and Piegay & Gurnell (1997) for relatively higher-energy European rivers, where LWD was predominantly located in depositional sites and hence thought to be highly mobile. In the lowland River Murray it is suggested that LWD is recruited through bank erosion, perhaps from meander development, and remains substantially where it falls into the main river channel. Once deposited into the river if it moves at all, it is realigned rather than actively transported.

Scale-dependent associations between plan form geomorphology and the distribution of LWD can be related to the dominant processes at those scales. At whole of reach scale LWD was distributed uniformly along the reach to a particular pattern. This pattern can be related to the relatively uniform nature of hydrological processes along the study reach. The flow and sediment regime (Rutherfurd, 1994) and the character of riparian vegetation (Murray Darling Basin Commission, 1990) have all been reported to be similar throughout the study reach. Thus, the processes that affect the recruitment and fate of LWD—essentially the bank erosion rate and stream power—may be expected to be similar for the whole of the reach, resulting in the uniform pattern of LWD distribution.

At the smaller functional set scale, geomorphology/LWD associations appear to be related to local or bend scale patterns of stream energy. The similar proportion of

LWD along both sides of the straight channel is consistent with a relatively even distribution of flow energy along both sides of the channel in a straight river reach (Dietrich, 1987). By contrast, in meander bends the much greater proportion of LWD found in the outer channel is consistent with higher stream velocities and energy in that part of the channel in which channel migration through erosion is expected to be maximized (Dietrich, 1987). Distribution patterns at functional unit scale were consistent with those at functional set scale, but a further level of complexity was added because the character of LWD varies among functional units. The greater distance of LWD from the bank in higher energy parts of the channel is consistent with a greater degree of bank erosion. The increased alignment to flow in higher energy parts of the channel also reflects the stream energy patterns.

The re-introduction of LWD is becoming a popular river management tool especially in large Australian lowland rivers (Koehn & Nicol, 1997). Efforts to date have been relatively unsophisticated and generally place individual LWD pieces to simulate the natural physical character of the river channel, e.g. create riffles and pools (Till, 2000). Thus management is generally undertaken at the habitat scale. Results of this study suggest that in lowland rivers similar to the Murray, LWD reintroduction needs to be managed at the scale of individual meander bends. To best simulate natural LWD distribution it is suggested that large woody debris should be positioned in clusters that are relatively close to riverbanks, in the high-energy eroding parts of bends, and at a variety of angles between 0° and 90° to streamflow. This general pattern may need to be adjusted for bends of different curvature.

The realignment of large woody debris so that angle to flow does not exceed 30° has in the past been advocated as an instream management practice (Gippel *et al.*, 1996). In this study over 50% of large woody debris was at an angle of greater than 30°. If such large amounts of large woody debris were realigned, large-scale sediment mobilization may occur (Brooks, 1999), resulting in loss of fish habitat. Hence, realignment seems to be a management option that should be approached with caution.

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