A gradient or mosaic of patches? The textural character of inset-flood plain surfaces along a dryland river system

MARK SOUTHWELL & MARTIN THOMS

Water Research Lab, Institute of Applied Ecology, University of Canberra, Australia Central Territory 2601, Australia

m.southwell@student.canberra.edu.au

Abstract This paper investigated the textural character of surface sediments across a range of inset-flood plain surfaces on the Barwon Darling River, Australia. Surface sediments ranged in size from clay to coarse sand (–1ϕ – <4.75ϕ) but varied in composition between different inset-flood plain surfaces. Multivariate entropy analysis detected five sediment classes based on the grain size distributions of individual samples. River channel sediments were present in two of the entropy classes, whereas the different inset-flood plain surfaces were present in four or more of the identified entropy classes. A number of factors may be influencing the spatial distribution of sediment texture across the inset-flood plain surfaces including: (1) decreasing energy gradients with increasing elevation from the channel; (2) variable sediment supply conditions during flow events; and (3) local sediment inputs. The resulting patterns found in the study area demonstrate there to be a mosaic of sediment texture patches rather than a simple gradient of changing sediment texture with increasing distance from the channel.

Keywords Barwon-Darling River System; entropy analysis; flood plain sediment patterns; grain-size distribution

INTRODUCTION

Flood plains are aquatic-terrestrial transition zones (ATTZs) (Naiman & Decamps, 1990). Gradients of hydro-geomorphic character and ecological response are a key feature of ATTZs, with transitional changes or gradients in the hydrological, physical, chemical and ecological character of flood plains occurring from areas proximal to the river channel to those in distal flood plain regions. Conceptual flood plain–river models such as the Flood Pulse Concept of Junk *et al.* (1979) and the Riverine Productivity Model of Thorp & Delong (1994) are founded upon structural and functional gradients within flood plain–river ecosystems. However, recent research describes flood plain–river ecosystems as dynamic patch mosaics that are intermittently connected or disconnected as flow levels change (Tockner *et al.*, 2002; Thoms, 2003). A patch is a surface area that differs from its surroundings in nature or appearance and may be represented by its different morphological features. Flood plain river patches may include the main river channel, levees, scroll swales, oxbows and anabranch channels. Patches differ in size and quality; with their size being a product of current and past geomorphic activity and their quality being measured in terms of several factors including sediment texture, associated plant biomass, soil productivity or nutrient status (Thoms, 2003).

Sediment character influences a range of processes in flood plain river ecosystems. Nutrients associated with fine-grained sediments, for example, play a significant role in regulating productivity on flood plain systems (Spink *et al.*, 1998). During inundation, flood plain sediments release dissolved organic carbon and nutrients from flood plain surface sediments, making them potentially available, along with plant matter, to be transported back into the main river channel (Thoms *et al.*, 2005). In addition, the ecological response to inundation is dependant, amongst other things, upon the spatial arrangement of flood plain sediment character (Thoms, 2003). Thus, knowledge of the nature of flood plain sediments and their spatial arrangement is essential for an improved understanding of these dynamic ecosystems (Naiman *et al.*, 2005).

The textural character of flood plain sediment reflects both the supply of sediment from upstream sources (Marriot, 1992; He & Walling, 1998) and the delivery of that sediment to the flood plain during inundation (Walling *et al.*, 1997). Systematic changes in sediment texture occur across flood plain surfaces, grading from relatively coarser material on levees proximal to the river channel to relatively finer particles in distal areas (Asselman & Middelkoop, 1995). Local variations in flood plain topography and hydraulic processes can disrupt this pattern resulting in a “patchy” distribution of sediment texture (Marriot, 1992; He & Walling, 1998). Existing studies of flood plain sediment character have relied on the use of summary statistics such as mean grain size (D_{50}), skewness, kurtosis or individual fractions (e.g. <63 μm, percent sand) to determine their conclusions (He & Walling, 1998; Walling & He 1998). The usefulness of such an approach to describe the nature of the sediment textural environment has been questioned (Forrest & Clark, 1989) because of the reliance on bivariate comparisons of one sediment characteristic against distance from the main channel, or on correlations between two factors that may have a causal relationship (Owens *et al.*, 1999). Multivariate statistical techniques are standard in ecology being useful for identifying patterns in complex data sets (Digby & Kempton, 1987). Although they have received limited use in geomorphology and flood plain sedimentology (see Brown 1985; Walling *et al.*, 1993, for exceptions), multivariate analyses have the potential to identify areas of flood plain sediment with similar textural character. Thus multivariate statistical techniques can accommodate the study of whether sediment gradients exist on flood plain surfaces or whether different patterns of sediment character may emerge.

While inset-flood plains, also termed benches, occur along rivers both in Australia (Woodyer, 1968) and overseas (Changxing, 1999), little information exists on their textural character. This study investigates patterns of inset-flood plain sediment texture along the Barwon-Darling River in southeast Australia. It considers the influence of inset-flood plain elevation, distance from the main channel, and the degree of channel confinement on sediment texture in order to determine whether a gradient or a mosaic of inset-flood plain sediment textural patches exists. Entropy analysis, a non-parametric multivariate analysis, is employed to investigate the spatial arrangement of inset-flood plain sediment texture.

STUDY AREA AND METHODS

Large flood plains are a characteristic feature of Australian lowland rivers (Thoms & Sheldon, 2000). In addition to the extensive flood plains that border the main river

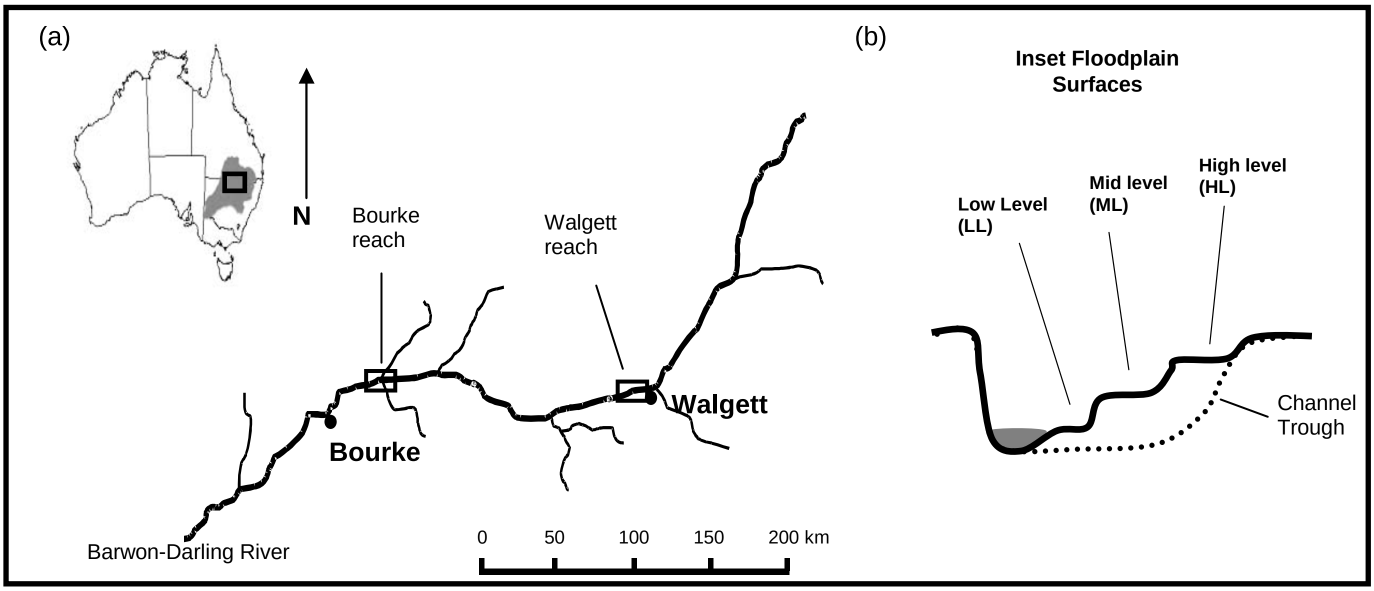

Fig. 1 (a) Study location on the Barwon-Darling River, Australia. (b) Cross-section of the channel trough showing relative elevations of inset-flood plain groups in the study area.

channel, rivers in semiarid regions display numerous smaller flood plain surfaces that are inset within a broader river channel trough (Woodyer, 1968). Inset-flood plain surfaces are a common morphological feature along the Barwon-Darling River (Fig. 1(a)) and are located at a range of elevations in the channel trough. For the purpose of this study, the inset-flood plain surfaces along the Barwon-Darling River were placed into three categories—low level, mid level and high level groups—based on inundation character following Woodyer (1968) (Fig. 1(b)). These surfaces have been formed by the contemporary flow regime of the river (Thoms & Olley, 2004), and store large quantities of nutrients and organic material which become available to the river during inundation (Thoms & Sheldon, 1997).

The study was conducted along two 10-km reaches of the river, one below the township of Walgett and the other above the township of Bourke (Fig 1 (a)). Within each, inset-flood plains were also categorized into unconfined and confined settings (~30% difference in channel trough width). These settings allow for an investigation into the influence of environmental confinement on the character of sediment texture. Forty-seven sediment samples were collected from a number of low, mid and high level inset-flood plain surfaces along both reaches. On each flood plain surface five replicate surface sediment samples were randomly collected and then pooled to produce one representative sample per surface. Samples were also collected from within the main low flow channel at the top, middle and bottom of the Bourke reach by taking three sub samples and pooling these at each location.

Sediments were oven dried at 50°C and then disaggregated before being passed through a series of graded Wentworth sieves, the data from which were used to calculate a series of standard textural statistical measures as per the methods outlined in Pettijohn (1949). These data were then analysed using a multivariate statistical procedure—Entropy—as outlined in Forrest & Clark (1989), to identify groups of samples with similar sediment grain-size distributions.

RESULTS

Surface sediment on the river-bed and different inset-flood plain surfaces were dominated by a range of sand and silt-clay mixtures. Median grain sizes (D_{50}) ranged from 0.100 to 0.293 mm and overall D_{50} decreases slightly from the river channel (0.205 mm) to the uppermost inset-flood plain surface (0.164 mm) (Fig. 2). Differences between the various surfaces were not statistically significant (ANOVA, $F = 1.77$; d.f. = 3, 51; $p > 0.05$). Entropy analysis successfully identified five distinct grain-size distribution groups (Fig. 3) and these accounted for 71.8% of the total variation between individual samples. Class 1 had a relatively fine grain size distribution while Class 5 had the coarsest. The D_{50} for each of the five classes were 0.140 mm, 0.161 mm, 0.203 mm, 0.197 mm, 0.230 mm respectively and differences between the individual entropy classes were significantly different in terms of their median grain size (ANOVA, $F = 19.32$; d.f. = 4, 48; $p < 0.005$).

The five entropy classes were distributed across most of the four inset-flood plain surfaces in the study area (Fig. 4(a)). River channel sediments were found in two of the entropy classes; the lower level inset-flood plain surfaces were found in all five classes; and the mid and upper inset-flood plain surfaces were found in four classes (Fig. 4(a)). There was no association between the sediment entropy class of a morphological unit and its planform position, as has been identified by others, e.g. (Walling *et al.*, 1998). Entropy classes were relatively evenly spread between straight reaches and those located on the inner or outer section of a river bend (Fig. 4(b)).

There was no statistical difference in sediment texture between the confined and unconfined settings of the Barwon Darling River (ANOVA, $F = 0.017$; d.f. = 1,51; $p = 0.895$). Entropy analysis of the different confinement settings revealed six classes of sediment texture for each setting and these accounted for 79.14% and 83.75% of the total variation in the confined and unconfined settings respectively. The entropy

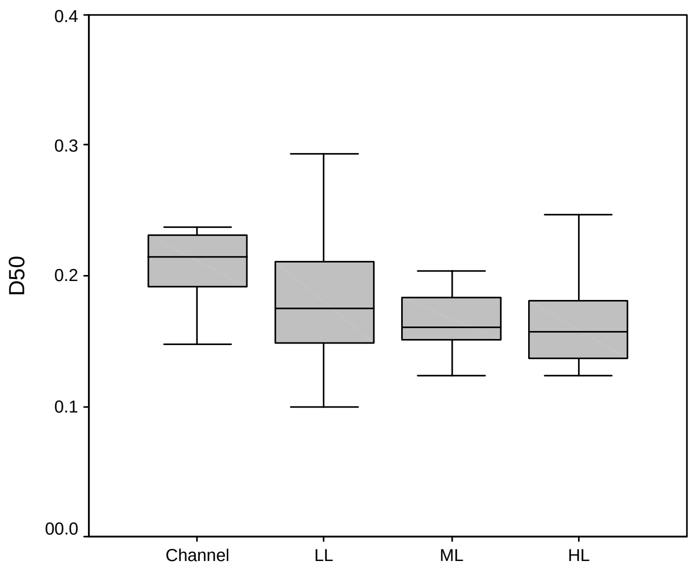

Fig. 2 Box and whisker plot of Median grain size (D_{50}) for the river channel and flood plain levels of the Barwon-Darling River.

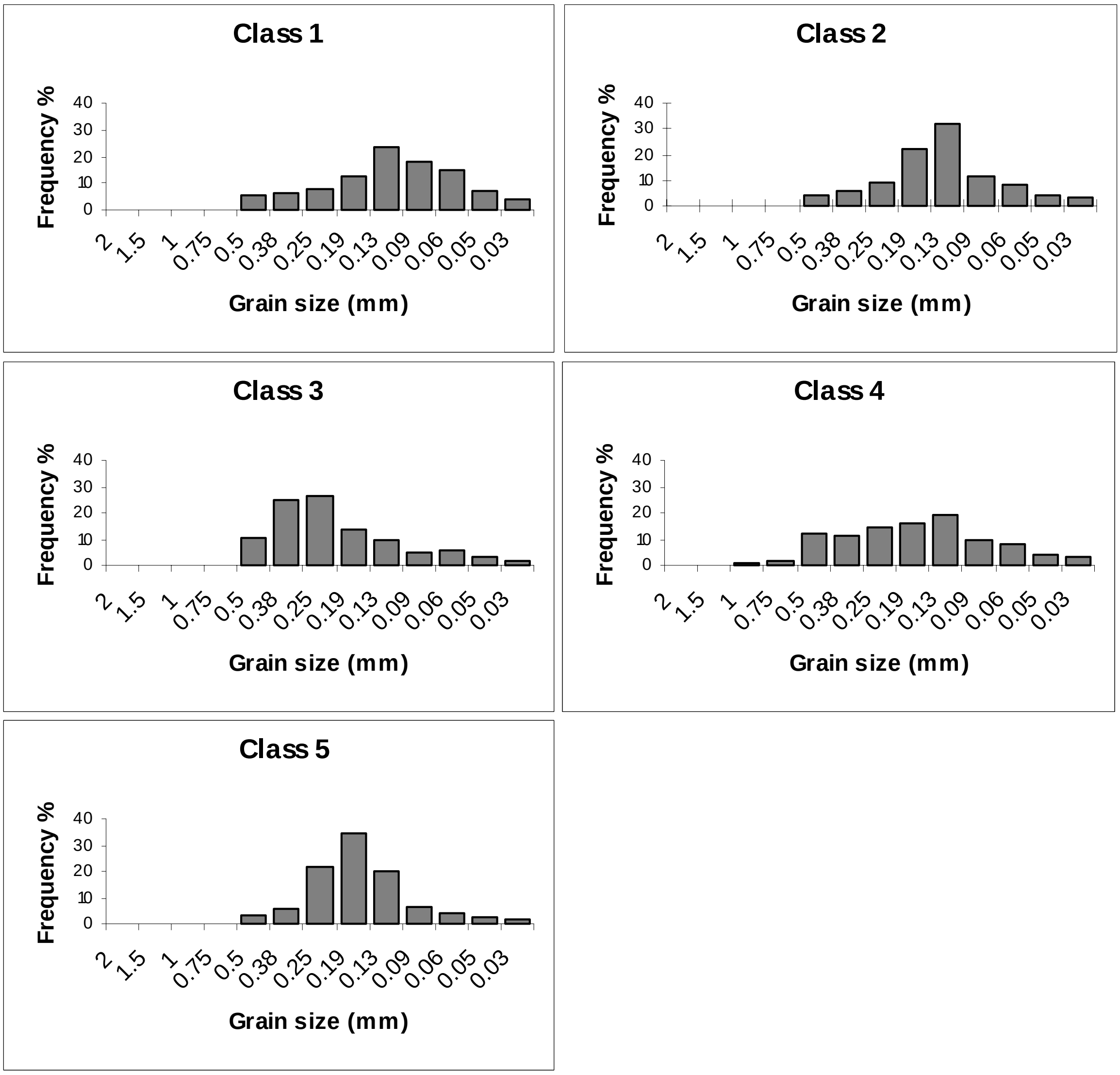

Fig. 3 Average grain size distributions for the five entropy classes found in the study.

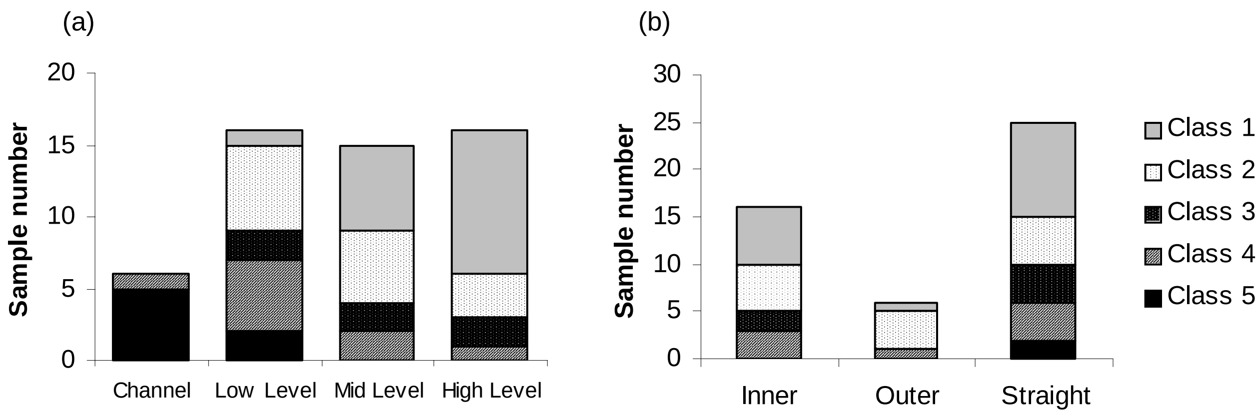

Fig. 4 Distribution of entropy classes relative to: (a) river channel and flood plain level, and (b) channel planform for sediment in the study area.

classes in the confined settings had median grain sizes ranging from 0.101 to 0.219 mm and differences between the mean grain size of classes were statistically significant (ANOVA, $F = 9.240$; d.f. 5,22; $p < 0.005$). River channel sediments were represented by three of the entropy classes whilst the different inset-flood plain surfaces contained four classes (Fig. 5(a)). By comparison the six entropy classes in the unconfined channel settings had average median grain sizes ranging from 0.094 to 0.222 mm and differences in median grain size were also statistically significant (ANOVA, $F = 12.57$; d.f. 5,19; $p < 0.005$). River channel sediments were represented by one entropy class; the low and medium inset-flood plain surfaces were represented by four classes; and the upper inset-flood plain surfaces had three entropy classes (Fig 5(b)). Grain-size distributions of similar entropy classes between the different channel settings were similar in texture, as confirmed by chi-square tests (Class 1 $\chi^2(1) = 2.54$, $p > 0.05$; Class 2 $\chi^2(1) = 3.84$, $p > 0.05$; Class 3 $\chi^2(1) = 7.4$, $p > 0.05$; Class 4 $\chi^2(1) = 1.28$, $p > 0.05$; Class 5 $\chi^2(1) = 9.92$, $p > 0.05$; Class 6 $\chi^2(1) = 10.32$, $p > 0.05$). This suggests there are no significant differences in sediment texture between the unconfined and confined settings for any of the entropy classes observed.

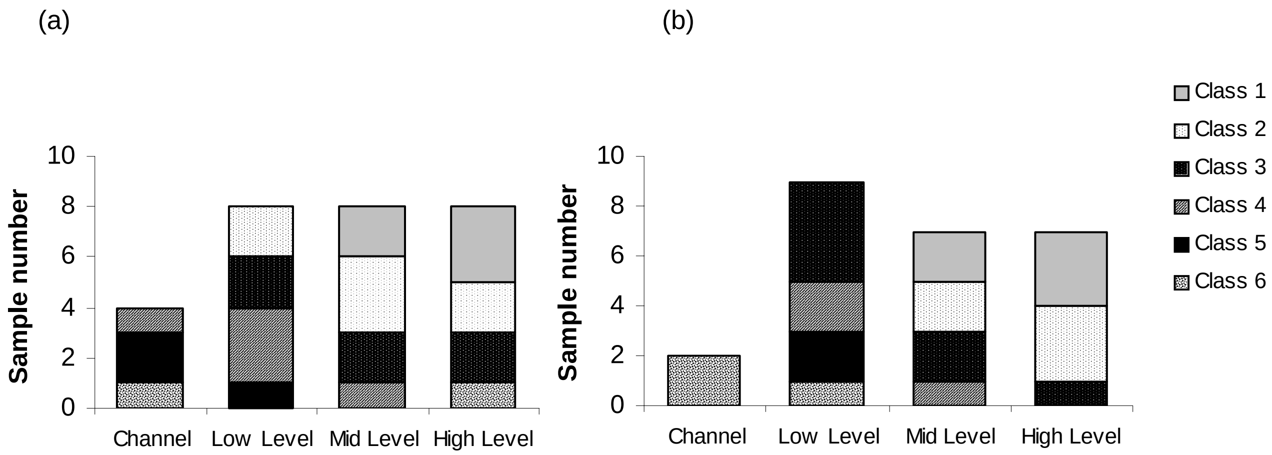

Fig 5. Distribution of entropy classes across geomorphic units in: (a) confined channel settings and (b) unconfined channel settings in the study area.

DISCUSSION

A multivariate approach to investigate patterns in inset-flood plain sediment texture differs somewhat from the traditional approach to flood plain sediment studies, and offers several advantages. First, a range of sediment variables can be analysed simultaneously, which bypasses the necessity for a large number of individual analyses that compare one variable against another. Second, consideration of a range of variables facilitates greater interrogation of data, and provides increased scope to generate hypotheses. Third, multivariate analyses elicit patterns and infer process in a quantitative rather than a qualitative manner. Fourth, multivariate analyses allow investigation of scale-dependant relationships within a large data set, and facilitate a hierarchical analysis sequence in which results from higher scales are incorporated into the interpretation of patterns at smaller scales. For example, whilst a range of sediment classes were identified in the study area and these may represent a textural gradient at the individual inset-flood plain surface scale, at the broader reach scale a mosaic of patches was inferred. We suggest the textural character of individual inset-flood plain surfaces is embedded within the broader scale pattern of the location of the different surfaces. Hence, multivariate statistical techniques are an extremely powerful analysis and interpretation tool that can be used to complement traditional examinations of flood plain sedimentation.

This study has shown there to be significant variations in sediment texture between different inset-flood plain surfaces and between these and the main low flow channel. Variations in sediment texture between different inset-flood plain surfaces along the Barwon-Darling River have also been described by Woodyer *et al.* (1979) and Thoms & Olley (2004). In this study, the five sediment textural classes were identified by entropy and these form a gradient of sediment texture in terms of the median grain size of each class. However, this gradient was not reflected spatially across the landscape. The spatial arrangement of inset-flood plain surfaces results in a patchy distribution of sediment character across the channel and different inset-flood plain surfaces. Thus, inset-flood plain elevation and distance from the main channel appear to have a poor association with sediment texture and flow magnitude may not be a dominant factor determining inset-flood plain sediment composition. This contrasts to the studies of Marriot (1992) and Asselman & Middelkoop (1995), amongst others, who have reported textural gradients, laterally, with distance from the main channel.

A patch mosaic of sediment texture exists across the inset-flood plains of the Barwon-Darling River (Fig. 6) reflecting several factors, including variable sediment

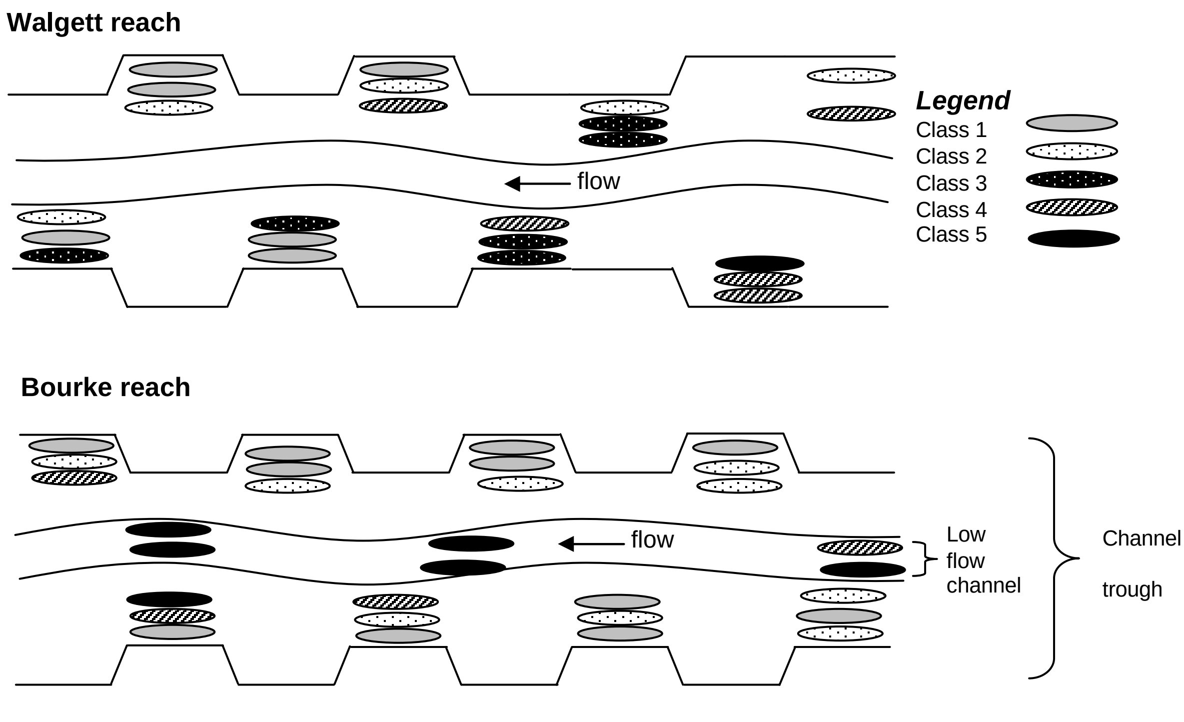

Fig. 6 The mosaic of sediment textural classes along the two reaches in the study area.

supply, and local scale sediment redistribution within the channel trough. The Barwon-Darling River is a suspended load channel (Olley & Caitcheon, 2000) characterized by high variability both between and during individual flow events (Woodyer *et al.*, 1979). This variability in the sediment regime has been confirmed by Thoms & Olley (2005) who studied the stratigraphy of various flood plain surfaces of the Barwon-Darling River. Here the presence of several grading configurations were reported and interpreted to reflect spatial and temporal variations in sediment supply during depositional events. Pulses of sediment with varying textural composition are supplied to different flood plain surfaces thereby contributing to the patchy distribution of sediment character. Patterns of inset-flood plain sediment character may also be influenced by local conditions. Bank erosion is a feature of the Barwon-Darling River that may influence the redistribution of sediments between inset-flood plain surfaces after flooding events. Unconformities in the sediment record of a number of inset-flood plain surfaces along the Barwon-Darling River were reported by Thoms & Olley (2004). These were interpreted as periods of partial stripping, erosion and removal of sediment from these surfaces. Thus, it appears that local erosion may not only provide a source of sediment for deposition on inset-flood plain surfaces, but also cause the removal of material from surfaces, potentially exposing sediment of different textural character.

CONCLUSION

This study revealed distinct sediment textural classes that showed a patchy distribution on inset-flood plain surfaces and within the main channel of the Barwon-Darling River. While these classes, determined by entropy analysis, could be placed on a gradient of fining median grain size, this gradient was not expressed spatially, suggesting that a combination of factors including variable sediment supply and local redistribution of sediment may be influencing sediment character in this system. The occurrence of a sediment textural patch mosaic may well influence the distribution of nutrients and organics on inset-flood plain surfaces within the study area. This may in turn give rise to hotspots of flood plain productivity that could be targeted in the future management of this flood plain river system.

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