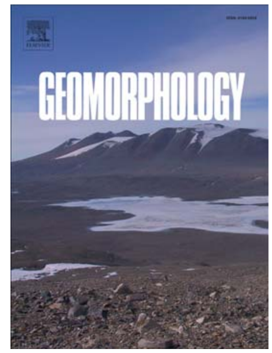


Defining large river channel patterns: Alluvial exchange and plurality

John Lewin, Philip J. Ashworth

PII: S0169-555X(13)00111-6
DOI: doi: 10.1016/j.geomorph.2013.02.024
Reference: GEOMOR 4274

To appear in: *Geomorphology*

Received date: 9 March 2012
Revised date: 5 November 2012
Accepted date: 19 February 2013

Defining large river channel patterns: alluvial exchange and plurality

John Lewin [a*] and Philip J. Ashworth [b]

[a] *Institute of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, SY23 3DB, U.K.*

[b] *Division of Geography and Geology, School of Environment and Technology, University of Brighton, Lewes Road, Brighton, BN2 4GJ, U.K.*

** Corresponding author*

Email addresses: john1lewin@btinternet.com; p.ashworth@brighton.ac.uk

ABSTRACT

Large rivers have anabranching channels with components that may be defined as braided, meandering or straight. This paper shows that application of such holistic terminologies is complicated by recognition of within-type and transitional-type variety, a confusingly varied use of terms, and a coverage of pattern characteristics that for many large rivers is incomplete. In natural states, big rivers can be *plural systems* in which main, accessory, tributary and floodplain channels and lakes differ functionally and vary in terms of morphological dynamics.

A distinction is drawn between the hydrological and geomorphological connectivity of components in big river plural systems. At any one time, even at flood stage, only some channels are geomorphologically active. Six types of geomorphological connectivity are described that range from coupled, through to partially-coupled and decoupled. The interplay between geomorphological and hydrological connectivity in large rivers is shown to determine habitat status and therefore ecological diversity.

For improved understanding of the dynamics as well as the forms of these large composite systems, it is helpful to: (1) adopt element-level specification, not only for sediment bodies, but also for functioning channels; (2) track the sediment transfer processes and exchanges that produce channel forms over the highly varied timescales operating within large rivers; (3) recognise the ways in which partially coupled and connected geomorphological systems produce naturally a composite set of forms at different rates. Such augmenting information will provide an improved platform for both river management and ecological understanding.

Keywords: Fluvial geomorphology; Big rivers, River channel patterns; Classification; Channel-floodplain coupling; River management

1. Introduction

The study of large rivers may be hindered by confusing and under-developed terminologies. Large channels can follow single or multiple courses with diverse styles at both the reach and floodplain scale (Latrubesse, 2008; Assine and Silva, 2009; Ashworth and Lewin, 2012). Included are meandering, braided and straight elements, though each of these patterns may emerge in different ways. Such river systems also naturally include hydrologically and biologically interconnected assemblages of main, accessory or tributary channels, and periodically inundated floodplain and ponded-water environments. The functional variety of these unequal waterbodies is significant for sedimentation and for biota (e.g., Iriondo et al., 2007; Tockner et al., 2010). In this paper we term these *plural systems,* and for practical application we advocate a wider and composite approach to the patterning of big rivers that is geomorphologically grounded and process-based.

A greater emphasis on observed and variable types of sediment transfer is suggested herein because this is how morphological patterns in alluvial rivers are achieved. The scale of big river phenomena can be so large and dynamically variable that it is the tracking of km-scale elements such as individual bars and particular bends, and the local presence of major and minor channels, that come to be of practical management concern (Mosselman, 2006; Best et al., 2007). Local complexities also involve a range of short- and long-term dynamics, from dune migration during single flood events to inherited Quaternary forms that have continuing ecological and water-conveying functions. Further extension of analytical frameworks should benefit the wider earth science and freshwater ecology communities, especially for those dealing with the management of large river morphological assemblages, dynamics and sedimentation.

This paper describes for the world's largest rivers: (i) the main channel patterns and hydraulic systems that characterise big rivers; (ii) the global variety in large river pattern, dynamics and sedimentation; (iii) the river and floodplain depositional elements that are responsible for alluvial storage and exchange; (iv) the coupling and connectivity between geomorphological and hydrological components of big rivers and floodplains; and (v) management challenges within morphologically-diverse and plural systems.

2. The development of traditional pattern terminologies

Apart from a limited number of coding systems (Rosgen, 1994; Brierley and Fryirs, 2005), current geomorphological practice in channel-pattern naming has grown unsystematically. Patterns include meandering, braided and straight, together with a range of multiple channel combinations especially significant on large rivers (Latrubesse, 2008). However, each of these is varied in nature, whilst terminological ambiguity has also become common.

'Meandering' involves sinuous channels with repeated bends. Some researchers restrict the term to ones that have regular and repeated bend geometries, or to channels with a sinuosity of >1.5. On this basis not all sinuous channels are technically meandering. Furthermore, research now shows that 'meandering' does not imply a simple form, a singular pattern of development, a particular location of slack water zones, or an erosion/sedimentation type or frequency at particular locations on river bends (e.g. Hooke, 1995; Luchi et al., 2010; Hooke and Yorke, 2011). Russian distinctions (in translation) are made between limited (i.e., 'confined'; see also Lewin and Brindle, 1977; Brierley and Fryirs, 2005), free, and incomplete meandering (Kulemina, 1973; Alabyan and Chalov, 1998). Where meander bends do get reoriented or are confined, there may also be sedimentation against concave banks, primarily caused by flow-separation and reverse flow. Vietz et al. (2011) observe that the most effective discharges for concave bench formation in the Owens River (a tributary of the Murray River, Australia) are not rare large floods but ones in a range of 40 to 80% of bankfull discharge where predominantly suspended, silt-sized sediment is deposited at the outer bends.

'Braiding' is a pattern usually thought of as dominated by multiple emergent bedforms that form mid-channel bars. Paola (1996) and subsequently Lane (2006) suggested that braided rivers are the default river channel state, and other channel patterns are only created by the introduction of cohesive sediment, vegetation or a geological control. Bars may be relatively simple 'morphed' variants or trimmed parts of linguoid or lozenge shapes, or composites that grow by lateral, upstream or downstream accretion (Bristow, 1987; Ashworth et al., 2000; Rice et al., 2009). Individual increments may form from migrating unit bars or dunes that stall and become attached to or wrapped around existing forms (Best et al., 2003; Sambrook Smith et al., 2009; Horn et al., 2012). Largely following from theoretical studies, it is suggested that channels that are bar generating but wide may have multiple 'row bars' in the cross-stream direction (Yalin, 1971; Parker, 1976; Crosato and Mosselman, 2009). These 'higher mode' bars (lower modes are strings of bank-attached side bars or single mid-channel/side bar combinations) may only be exposed at lower flows, so that the degree of observed braiding is stage-dependent. What appear as multiple 'channels' may thus be lower flow drainage adaptations, more or less passively following topographic lows between major bars/islands developed at high flows. At high flows when bars and dunes are below the water surface, the channel outline may be straight or gently sinuous, whilst at lower flows (particularly in large sand-bed rivers) individual threads or thalwegs may be highly sinuous and competent to trim and adjust the higher-flow forms emergent between them (Nicholas et al., 2012; Sandbach et al., 2012).

A rather different approach models multi-thread systems as networks of active channels (Murray and Paola, 1994) that bifurcate and re-join around bar-islands, and in which avulsion is important in driving the process and extent of channel branching

(Bolla Pittaluga et al., 2003; Jerolmack and Mohrig, 2007). Field studies and physical modelling of braid belts suggest that at any one time the actual number of channels and bars that are actively sedimenting and eroding may be limited (e.g*.,* Ashmore, 1991; Lane, 2006). Other channels may be relicts from earlier phases that remain unfilled by sediment; they may passively transmit water at flood stages without significantly changing their form. Older bar surfaces may become more permanent islands or continuous floodplain with vegetation growth (see, for example, Reinfelds and Nanson, 1993; Nicholas et al., 2006; Gurnell et al., 2009). As with meandering, braiding does not necessarily relate to a single process set or evolutionary model.

Other patterns identified, and ones of particular relevance to big rivers, are focused on divided main channels. Terms used include anabranching, anastomosing and wandering, though usage of these terms differs between authors. This nomenclature is usually applied at the floodplain scale, rather than at the reach or low-flow exposure scale (cf. Alabyan and Chalov, 1996). It has been suggested that, with an accompanying reduction of channel width, divided channels can be more efficient at transporting sediment than single ones (Nanson and Huang, 1999; Huang and Nanson, 2007). Component channels may be actively co-evolutionary, proportionate to their flows (Federici and Paola, 2003; Kleinhans et al., 2011). Leopold and Wolman (1957) regarded 'anastomosing' and 'braiding' as equivalent, although this equivalence is not now commonly accepted (Nanson and Knighton, 1996). 'Anastomosing' can be applied to multichannel system with more permanent vegetated and extensive islands (Thorne, 1997), or, alternatively, ones with negative relief wetland depressions between rapidly aggrading levee-lined channels or channel belts. The terms anastomosing and anabranching are also sometimes taken as interchangeable. Russian usage has equated the two as '*floodplain* multibranching', using '*channel* branching' as the equivalent of braiding (Alabyan and Chalov, 1998). Others restrict the term anastomosing to an anabranching sub-type characterized by low energy, relatively stable multiple courses, fine sediment, bed and bank aggradation, inter-channel depressions, and avulsive relocation into these inter-channel wetlands (Smith and Smith, 1980; Makaske, 2001; Slingerland and Smith, 2004; Makaske et al., 2009). Other branching styles (as yet without a specific name) may involve active meandering and braiding on each of two or more main channel branches divided by emergent islands, in which case the pattern is both anabranching and braided/meandering (see Fig. 8A later). The useful patterning scheme proposed by Nanson and Knighton (1996) recognised straight, braided and meandering (the last subdivided into active and stable) patterns which can be in single or multi-channel forms.

Transitional styles are being increasingly recognised (Church, 2006), as in recent approaches involving meandering and braiding/anabranching by Eaton et al. (2010) and Kleinhans and van den Berg (2011). These authors introduce different terminologies and usages of the term 'stable' (either for pattern consistency or immobility). Although they appear visually similar, patterns intermediate between meandering and braided are defined differently. Earlier on, Church (1983) following Neill (1973), also identified transitioning combinations or downstream successions of meandering and braided reaches as 'wandering', later using the term as a transitional type between braiding and meandering on gravel-bed rivers (Church, 2006; Church and Rice, 2009). Carson (1984) used 'wandering' for two different styles (I and II). Others use the term 'irregular' for sinuous channels without repeated bend geometry (e.g., Kleinhans and van den Berg, 2011).

Straight (or very low sinuosity) alluvial rivers have been rather neglected but can occur in a wide range of domains (Lewin and Brewer, 2001), including reaches on very large rivers like the Amazon (Latrubesse and Franzinelli, 2002). They may be considered a 'non-pattern' in the sense that their outline is mostly unaffected by the major patterning processes of arcuate cut bank erosion, bedform emergence or avulsive breakout. But again broad similarity of form does not imply particular processes and such rivers can be:

(i) *Passively straight* or deranged when below sediment-transport thresholds. Kleinhans and van den Berg (2011) observe that channels in this domain are not necessarily straight and may be highly irregular or sinuous, but they are laterally immobile. Passive straightness or outline immobility may nevertheless not imply a total lack of sediment transport (Parker, 1978). Passive straightness can also be associated with erosional channels that have dissected a valley almost full of sediment forming an impeded drainage system around km-scale islands (Latrubesse and Franzinelli, 2005). Delta channels can also be created straight where jet flows are paralleled by prograding levees as they extend out into waterbodies (Edmonds et al., 2011).

(ii) At intermediate energy levels rivers may be *transitorily straight* following cutoffs or avulsions, but may then go on to develop as meanders or braids. It is in this domain that artificial straightening is most difficult to sustain.

(iii) At higher energies they may be *dynamically straight* where relatively wide braided channels have localised bank trimming and edge-straightening as smaller-scale migrating bars, individual channels, and bank scallops shift in location (Warburton et al., 1993). Most of the straight channels in the original Leopold and Wolman (1957) data set were high energy streams, though some were small and confined. The reverse is true of the Parker (1976) data set. At steeper slopes on alluvial fans, rivers may be straight (e.g. Kosi fan, Bridge and Mackey, 1993) with predominantly plane-beds (Blair and McPherson, 1994), and there is an upper limit to bedform and sinuosity development (Hooke and Rohrer, 1979).

So altogether, there are various circumstances in which large sediment-transporting channels may be straight, temporarily or more permanently, and without strong bank interaction.

From this brief review of patterning classification, it is clear that:

(i) Holistic categories have emerged in a bolt-on fashion as styles have been studied, defined and diversified;

(ii) There is ambiguous use of terms, as when researchers use anastomosing, anabranching or stable with different meaning;

(iii) Within-type process alternatives and styles, and the intermediate categories added to the pioneer tripartite system of Leopold and Wolman (1957), have complicated the picture considerably.

As demonstrated by Latrubesse (2008), many large rivers seem too complex in pattern to be simply categorised other than as ‘anabranching’ in the broadest sense. Following Nanson and Knighton (1996), these may be subdivided into different types with individual components described as meandering, braided or straight passing between more permanent vegetated islands or backswamps. But this has to be with reservations because of the variant and transitional styles now recognised. Figure 1 illustrates three large anabranching rivers that are very different at the floodplain scale, with islands between different numbers of channel branches and different styles of linked waterbodies. Anabranching itself results from different process sets (Ashworth and Lewin, 2012), and the term may incorporate considerable dynamic variety, internal complexity and sediment-processing activities along interconnected river systems with plural channel and waterbody types.

3. Alluvial systematics – ensembles and elements on big rivers

In the geomorphology and sedimentology literature, several alternative names have been given to active alluvial complexes or *ensembles* − as large rivers appear to be. The terms 'alluvial architecture' (Allen, 1965, 1983), 'alluvial style' (Miall, 1996), 'alloformation'(Autin, 1992), 'genetic floodplain' (Nanson and Croke, 1992) or 'river style' (Brierley and Fryirs, 2005) have been used when writing from different perspectives. These are hierarchical entities made up of *elements* viewed as sediment bodies, forms or processes (Happ et al*.,* 1940; Beerbower, 1964; Miall, 1985; Brierley, 1989; 1991; Nanson and Croke, 1992). At lower levels these elements themselves may subdivide into strata sets/sedimentation sheets, and below that to sediment particles. At higher levels, valley-floor alluvial bodies may combine with earlier ensembles from Quaternary palaeoenvironments. How these levels are named and defined varies according to objective and author. At the *element* level (Table 1), Beerbower's (1964) seven elements are morphological. Miall (1985) focuses on strata sets that are especially significant for vertical profile modelling. Brierley (1991) defines elements based on morphostratigraphy – surface morphology and sedimentary characteristics combined. Nanson and Croke (1992) nominate six ‘accretion processes’ producing floodplains.

For large rivers, differentially-functioning channnel elements and ponded waterbodies, as well as more traditionally recognised sediment bodies, have to be added to form assemblages. Figure 2 shows a reach of the Amur valley in Eastern Asia which, unusually for a large river at the present time, has remained relatively unmodified by human activity and currently contains no dams along its 4700 km-long course. A range of components is identifiable (1-8). The main channel is a branching one, some channels at the time of imagery being turbid and sediment-laden with clear-water flow-separation zones in places along the banks (1), but others with intermediate concentrations (2). A few active bars are visible in these channels (3), some detached and others pendant from vegetated shorelines. Associated with the main channels are vegetated bar-islands (4); these show indications of trimming, streamlining and lateral accretion. Individual main-channel branches have low-sinousity and meander-like eroding bank curves. Beyond this ‘braid-plain’ is a wide alluvial zone with much smaller meandering accessory channels (5) and associated sets of evolving scroll bars and swale ponds (6). This extensive ‘meander plain’ also has internal drainages, some following palaeochannel alignments (7), some following tortuous courses, and others with weak dendritic development. Finally, tributary valleys entering from the valley margins have lakes ponded behind the main alluvial valley fill (8).

It appears from this and from other examples that large river waterbodies may consist of divisible types. At any one time only some are geomorphologically active; this varies with flood stage. Some are *partially* decoupled from transiting main channels in their geomorphological development, even though the main river dominates flood flow levels, gradients and sediment supply. The geomorphic components of large rivers subdivide into:

(i) *The main river channel belt(s)* that may be branching (as on the Amur, 48^{o} 47'N, 135^{o} 47'E), but with a range of possible patterns on what are mostly low-gradient sand-bed rivers – braiding (Brahmaputra-Jamuna, 25°50'N 89°39'E), meandering (Mississippi, 33°53'N 91°15'W) or near-straight (Paraná, 31°41'S 60°33'W). These may or may not migrate laterally to dominate alluviation across the whole valley floor. Separate branches of the main channel with islands between can be quasi-independent and not equi-functional at any one time, with some playing a greater sediment-throughput and active-erosion function than others.

(ii) *Accessory channels* (also known as offtakes, or side, secondary and tie channels) that may remove part of the sediment load, possibly reworking this to form the surface morphology of a proportion of the alluvial plain. Whilst the main channel may be relatively straight, conveying most coarser sediment through a reach, it may be the finer materials in accessory meander belts that become worked into the floodplain surface. These channels may both convey floodwater out onto the alluvial surface, and drain water from it.

(iii) *Tributary channels* may be relatively ineffective at sediment delivery and become ponded valleys in their lower reaches (for example, tributary rivers of the lower Amazon, e.g. 2°57'S 55°08'W). The main valley may be aggrading more rapidly than tributary valleys. In other environments, by contrast, such tributaries may be high-rate sediment deliverers, injecting braid-belt material into alluvial surfaces (e.g., along the Ganga in India).

(iv) *Internal drainages* that may passively link and drain depressions in a chaotic pattern, with minimal active erosion (e.g., on the Ob, 57°30'N 85°59'E). Alternatively they may develop dynamically, for example as headward-extending 'trees' fed by floodwater drainage and ground water effluent flow. These deranged or dendritic patterns contrast with those of both main, accessory and tributary through-channels.

(v) *Lacustrine (lentic) environments* and wetlands in negative relief that form an integral part of these alluvial morphologies at a range of scales: 1. swale ponds between accretionary ridges, 2. ponded water in palaeochannels, 3. floodbasins ponded between channel belts and/or valley sides, and 4. dammed tributary valleys. These may be variously connected according to flood stage, both to each other and to the main river. They may dominate whole valley floors characterised by subsidence and relatively low sediment supply and main-channel immobility (e.g., Magdalena, 8°55'N 74°29'W).

Essentially these are all negative relief elements within alluvial environments, created by active erosion and/or demarcated by bounding positive-relief sediment bodies. They are also associated with the dispersion and deposition of sediment. Sediment exchanges involving morphological and sedimentological elements within large river systems are summarised in Figure 3. In process terms, it appears reasonable to concentrate on this element level within the fluvial hierarchy (Richards et al., 2002; Brierley and Fryirs, 2005; Rice et al., 2009). Not all elements are present in a specific hydraulic corridor and their relative degrees of development go to make up large-river variety. This relates to the partitioned water flows and sediment feeds going to each. The eight elements identified (a-h) follow previous researchers like Beerbower (1964; see Table 1) and are much as for any alluvial ensemble, except that accessory and tributary streams are separately listed (d, j). These may have their own internal subsystems and distinctive character. Together with lacustrine elements (e), elements d and j appear to be much more significant than for reported smaller systems (Paira and Drago, 2007). Overall, the floodplain or 'overbank environment' on big rivers can itself incorporate a range of channels and channel belts. It is linearly differentiated with ridges and wetland/water-filled depressions, and less tabular than the word 'floodplain' might suggest. Day et al. (2008) appropriately refer to floodplains on the Fly River (7°05'S 141°08'E) as having a 'depositional web'.

Alluvial sequestration of sediment on large rivers can also be a more complex advective process than in many smaller channel-floodplain systems. A kind of elutriation or decanting process allows for finer sediment export to floodplains via linear systems, but dispersal of the coarsest sediment from the main-channel only where its boundary is laterally or vertically mobile. This degree of mobility varies considerably (cf. Swanson et al., 2008) and may even be negligible despite a throughput of bed sediment in the form of dunes and free bars. The degree of main channel/ floodplain coupling is also very varied in practice. We have suggested elsewhere (Ashworth and Lewin, 2012), and perhaps counter-intuitively, that many large rivers are relatively sediment-poor. Sediment may be in short supply on some rivers having exhausted sources of loose regolith, whilst on some others the sediment may have already been dispersed in the upper reaches leaving a diminishing sediment load further downstream (Meade, 2007; Meade et al., 2000). Holocene big rivers may not have adjusted to fill the structural troughs they occupy, so leaving larger areas as freshwater lacustrine environments (Latrubesse and Franzinelli, 2002; 2005). Geologically, this river style (a limited-width channel belt within a wider tectonic trough) is of high significance in that it provides a preferred locus for organic sedimentation. Ecologically, there is seasonally-varied interplay between lentic and lotic environments. Main channel sediment-laden water does not always spread across the whole floodplain (Mertes, 1997), especially if ponded waters there are equilibrated to an equally high level. But mobile biota may nevertheless pass freely from fast-flowing and sediment-laden streams into stiller waters. Orfeo and Stevaux (2002) report that the right floodplain of the Middle Paraná is divided into two parts of different elevation – the adjacent floodplain is 8 km-wide and floods every year whilst the ‘outer’ floodplain is connected in only extraordinary floods and adds a further 13 km on average to the connected channel-floodplain sedimentary system.

In many populated parts of the world the elements and processes under discussion have been considerably modified: by channelisation of the main river, including restriction to a single deepened and bank-protected course to improve navigation or flood transmission; by flow regulation through impoundment, including for irrigation and power generation; and by wetland and land drainage substituting flood embankments and reticulate systems of ditches and drainage/irrigation canals for former conditions. Both freshwater habitats and alluviation have become very restricted on major European rivers like the Rhine, Rhone and Danube, whilst in other parts of the world large-scale impoundment has modified the water and sediment supply regime (Nilsson et al., 2005), for example on the Paraná, Niger and Indus. On smaller rivers, anthropogenic soil erosion has also blanketed formerly more varied sediment and wetland surfaces to contribute to their planar form. Big river elements take a long time to evolve, but there has also been recent anthropogenic decoupling of rivers from the full range of their former sedimentation and habitat systems.

4. Global variety

Table 2 summarizes reach characteristics selected from twenty large global rivers here ranked by discharge. Discharges derived from the authors indicated have been adjusted in some cases to discount recent flow regulation, and contemporary discharges of water and sediments are also subject to a range of estimates (cf. chapters in Gupta, 2007, and Latrubesse et al., 2005) . All are low gradient and sand-bedded but with a varied relationship between main-channel dimensions and alluvial valley floor width. This ranges from rock confinement to the extreme width of the Indus alluvial surface. The Mekong reach is an example of ‘bedrock anastomosis’ where the river divides up into multiple channels etched into bedrock. Most unconfined main channel patterns are anabranching: some with braided or meandering reaches around islands, and some anastomosing. At the reach scale individual branches may be relatively straight though with intermittent emergent bars.

As well as channel patterns, the sedimentation elements present (Fig. 3) are very varied: the twenty valley floor reaches are all different. This reflects an evolving relationship between accommodation space (largely set tectonically) and sediment feed rates (cf. Church, 2006). These feeds are partitioned and allocated differently amongst sedimentary environments. As discussed above, different ranges of excess stream power or shear stress have been related to particular channel patterns (including transitional styles) although sediment supply rates are also crucial. If these patterns are maintained without marked degradation or aggradation, then the supply of sediment (either from upstream, or from local exchange) must match the transporting ability. A degree of aggradation is evident on some systems, as indicated by tributary-valley ponding, though the timescale and rate of this is uncertain. Others cross subsiding depobasins. But at low gradients and elevations above base levels such vertical adjustment of large-river systems is limited.

'Overbank' sediment dispersion as earlier conceived for smaller rivers (a-c in Fig. 3 and Table 2) is much more complex on many large rivers. This depends on overbank suspension loads available and their outreach at flood-stage. But deposition by accessory streams leading off from main channels is also evident on rivers like the Amur and Paraná. The Ob is unusual amongst large rivers in having multi-channel meandering (Ashworth and Lewin, 2012); also less common are single-channel meandering rivers like the Mississippi and the Danube that meander at the reaches given in Table 2. Elsewhere on the Danube, for example in Upper Austria (48°11'N 14°46'E), historic maps show that the river was anabranching with periodic avulsive relocation being dominant before channelisation in the nineteenth century (Hohensinner et al., 2011). Contemporary mainstream sediment exchanges with floodplains/islands by erosion and accretion (f, g) dominate on some actively meandering and braided rivers like the Amazon (Mertes et al., 1996), Orinoco (Meade, 2007), Fly and Strickland (Swanson et al., 2008) and Brahmaputra-Jamuna (Best et al., 2007), but very little on others like the Congo or Magdalena.

The 'forcing' relationship between bar growth and eroding banks that is seen as significant on small rivers (Neill, 1987), may be far less important on many wide and large rivers, although in-channel deposition may be associated with major thalweg relocation. Figure 4A shows one reach of the Paraná for a period of over a century. Over time, there is channel widening and narrowing, bar/island growth and destruction, and thalweg oscillation – but within a wide channelway that maintains a simple outline, although at times the left bank edge is fixed against 30-m high Pleistocene terraces (Orfeo et al., 2009). Kilometre-scale bars migrate down through the active braidplain of the Paraná but take decades to move distances 3-4 times their lengths (see bar labelled 1 on Fig. 4B). These only locally influence bank erosion rates or the morphology of in-channel vegetated bar-islands.

Flow separation and sediment-load partitioning occurs both within actively sediment-transporting channels (giving slack-water embayments that once were being eroded before thalweg realignment), between active and inactive branches, and between main and accessory systems. These are important characteristics of many large rivers, and under natural conditions this provides a whole range of habitats. Ecozones change both downstream (the 'river continuum' concept); according to flood stage (the 'flood pulse' concept); and also dynamically within reaches over time. Partitioning of flows and sediment conveyance means that alluviation is accomplished at any one time by particular branches and accessory channels rather than across the channel pattern as a whole. This autogenic but partitioned dynamism needs to be appreciated fully, especially in view of anthropogenic floodplain and channel transformations that may remove such natural habitat diversity created cyclically over extended timespans.

5. Discussion

5.1 The role of feed rates

Using conventional terms, reaches on both large river main channels and their sub-branches may be straight, meandering, anastomosing, wandering or braiding. In

Figure 5, the reach patterns identified in Table 2 are shown in approximate order of lateral shift rate, although meandering systems may over time accomplish a wider sweep-zone within a channel belt. Not all branches are equally active at any one time. Avulsion may shift such belts entirely. As has been suggested, patterns reflect bed sediment transport rates (Church, 2006). However, linking this to system-representative shear stress/stream power is more problematic than in the case of small streams. Latrubesse (2008) suggests that low specific stream powers of < 25 W m^{-2} are characterisic of his mega rivers. They are at low gradients (generally < 0.1 m km^{-1}) and sand bedded, though gravel-bedded exceptions do exist (Rice et al*.,* 2009). Considering pattern as a morphological outcome of sediment system operation, rather than as a prelude to analysing particular patterns like meandering or braiding, brings categorisation nearer to the analysis of distributed processes. These figure empirically in digital elevation difference models, and numerically in sediment flux models (Lane, 2006; Nicholas et al., 2006; Van De Wiel et al., 2011). Empirical data covering extended timescales for assessing component developments are required for large rivers (see Fig. 4A).

Main-channel branches that are actively transporting bed-sediment respond to shear stresses differentially. Transport involves migrating sand dunes, coalescing bars and transitory islands. These bars may have a ‘life’ of decades to centuries on both sand (Best et al., 2007, see Figs 4A-B) and large gravel-bed rivers (Church and Rice, 2009), although heavily vegetated islands may have a ‘waiting time’ of *c.* 1000 years between floodplain formation and subsequent re-entrainment of the bank as the channel migrates laterally (Aalto et al., 2008). Lobate unit bars appear far less commonly to dominate forms than on some smaller rivers (Ashworth and Lewin, 2012). On many rivers, bedforms only locally affect outline channel morphology (with temporary channel-outline widening and narrowing as pulsed sediment feeds are processed through) and outlines are effectively straight or gently sinuous. Here channel pattern detail involves only moderate bank exchange. On meandering systems with greater sinuousity (like the Mississippi or the branches of the Ob), there may be a much clearer relationship between development and local cut bank to downstream point bar sediment transfer, and thus of channel/floodplain bed-sediment exchange. Paradoxically, higher down-channel transport rates in straight or braided channels may achieve *narrower* sweep zones than meandering channels involved especially with local floodplain/channel sediment exchanges (e.g., Himalayan tributaries of the Ganga, 26°48'N 91°53'E).

The distinction drawn by Leopold and Wolman (1957) between different mechanisms for branching in braided channels also applies to anabranching ones that develop islands. Mid-channel islands may *either* form in-channel from coalescing dunes and bars (Bridge, 1993; Ashworth et al., 2000), *or* through out-of-channel avulsions where both old and new branches remain open (Ashmore, 1991; Lunt and Bridge, 2004). For example, the latter occur at a range of scales on the Ob where there is slow lateral channel mobility but also floodplain relief not eliminated by overbank sedimentation (e.g., at 58°22'N 82°43'E). This kind of relief exploitation promotes a rather different branching process than perched channel or aggradation-related avulsion (Heller and Paola, 1996; Slingerland and Smith, 2004; Makaske et al., 2009).

5.2 The concepts of plurality, coupling and connectivity

The range of large river-reach patterns (Table 2) is summarized parsimoniously in Table 3 and Fig. 5. Between the extremes of bedrock confinment and floodbasin dominance, some large channel sedimentation systems are single-channel ones, but most are branching *plural systems.* These are ones that consist of sets of contrasted channels and sedimentation elements across hydraulic corridors. Large rivers particularly reflect the ways in which such plurality functions, with branches that are similar (as in braids between islands) or different (as with near-straight main channels and accessory meandering ones). Visually-similar and hydrologically linked main channels may also be functioning quite variably (cf., Makaske et al., 2009). Because at any one time (even at flood stage) only some channels are geomorphologically active, any purely morphological channel-outline classification will incorporate active and relict elements. Their diversity – some channels charged with sediment and actively changing form, but others not – provide valuable habitat diferentiation. In this, large rivers resemble modelled braid systems (Nicholas et al., 2006), although many large rivers are actually quite straight in outline with only sporadic emergent bar formation.

Channels and floodplains may display differences in *hydrological* connectivity varying according to flood stage. Freshwater biologists have given considerable attention to lateral and stage-dependent water connectivity involving flowing water (rheophilic) and stagnant water (limnophilic) communities. Figures 6A-D show the response of reaches on the anabranching Rio Paraná and the dominantly single-channel River Ob to large, overbank floods. In the case of the Middle Paraná near Itati (Figs 6A-B), the floodwater reoocupies a Late Quaternary mega-fan that is adjacent to the right-bank of the main channel (Iriondo and Paira, 2007). Figure 6A shows that despite the strong connectivity of the entire right-bank floodplain with the main channel, the sinuous accessory channel in the floodplain (labelled 1) still routes a substantial proportion of the flow through the floodplain and back into the main channel further downsteam. Because the left bank floodplain is higher with occassional outcropping Pleistocene bedrock, floods rarely inundate the floodplain and therefore there is negligible sediment sequestration. Figures 6C-D show that the Ob main channel occupies a relatively immature floodplain dominated by a series of fully- and partially-connected swales and palaeochannels arising from early-stage channel migration features unmasked by later infill. During overbank floods, the floodplain stores slow-moving or standing water (Fig. 6C) that acts as a sink for fine-grained and organic sedimentation. Suspended sediment concentrations are low, and negative-relief depressions remain largely open.

Hydrological or biological connectivity is not the same as *geomorphological connectivity*. Indeed, it is precisely because they are not equivalent that alluvial corridors are able to provide such a range of flowing-water and stagnant aquatic habitats for migration, feeding, spawning, refuge and plant growth in negative relief zones that are not being eroded or rapidly infilled. Active sediment transfer produces longer-term channel and floodplain dynamics, but persistent negative-relief aquatic habitats are part of this system. For large rivers, the task for geomorphologists is to account for the naturally rich range of meso- and macro-scale topography, and particularly from a freshwater ecology point of view, the varied timescales over which negative relief water habitats are formed, filled or renewed. This includes *fully coupled*, *partially coupled* and *decoupled* geomorphological systems. Six types are recognised here:

(i) Main channels may be laterally or vertically mobile so that a floodplain sediment body reflects mainstream activity, with bed material transport and sequestration of both bedload and suspended load. Depressions may be left in floodplain surfaces in the form of swales and palaeochannels (Figs 7A-B). In the longer term, this represents full channel-floodplain connectivity, characteristic of active braiding or meandering systems that migrate fully across their valley floors.

(ii) In the shorter term, *some* branches, or patches within main channels with flow separation, are morphologically inactive. These are effectively dormant geomorphologically even though they equilibrate with water levels and transmit some water flow. These backwater or channel-side zones may eventually fill with fine sediment. This is a form of partial connectivity generated in association with main channels (see Figs. 2 and 7).

(iii) Accessory or tributary channels can be dynamic and accomplish floodplain sedimentation (Figs. 7B and 7D). There may be a contrast in the sedimentation styles of main channels and the floodplains through which they flow – for example, a braided main channel transmitting coarse sediment, with an accessory meandering system conveying finer sediment with developing meanders and point bars. This form of partial disconnection occurs especially where main channels are of limited lateral mobility, are dominated by tributary inflows, or disperse water and sediment via a secondary ‘sedimentation web’.

(iv) Mainstream suspended sediments may spread across floodplains in a non-channel, size-selective form of partial connectivity. There may be insufficient sediment to fill tectonic troughs and smaller water bodies.

Lacustrine environments may be intermittently connected in terms of floodwaters, but not so in terms of geomorphological activity that might fill them in. This also depends on sediment supply rates, and is affected by the lateral gradient of the floodplain surface and the rate of decrease in sedimentation with distance from the main channel levee (Tornqvist and Bridge, 2002; Day et al. 2008).

(v) Main channel may hardly affect their riparian environment in direct geomorphological terms – they may be rock-confined, entrenched, laterally inactive or buffered by high adjacent lake levels, and simply in transient passage in terms of sediment load. In effect, there is no sediment sequestration or geomorphological connectivity. However, floodwaters may passively invade riparian environments and inherited forms such as palaeochannel systems, some of considerable age.

(vi) Floodplain inheritance complicates the relationship between hydraulic floodplains and alluvial geomorphology. Deep Pleistocene incision and subsequent partial sedimentation has affected many large rivers, whilst Holocene variations in river regimes have given variety to palaeochannel and sedimentation patterns within valley floors but still at floodplain level. Sedimentologically these may be regarded as separate architectures or alloformations. The tectonic stability and erosion resistance of cratonic continental areas (which the lower courses of most large rivers pass across) means that sets of Quaternary incision terraces are less prominent than elsewhere (Bridgland and Westaway, 2008), but there may nevertheless be inherited forms still dominating ongoing hydrological systems (e.g., Sidorchuk et al., 2009; Valente and Latrubesse, 2012).

Figure 8A shows a reach of the Yukon River in Alaska. This has shown little vertical development in the Holocene (Froese et al., 2005) and has a range of active meandering and braided main, tributary and accessory channels. By contrast, the Rio Negro valley floor in Argentina (Fig. 8B) has an inner set of active channels, but also sets of cross-cutting palaeochannels These are of middle and late Holocene age and are partly water-occupied in extreme floods (Luchsinger, 2006). Elsewhere extensive floodplain-level lacustrine environments have persisted throughout the Holocene (Latrubesse and Franzinelli, 2005). The outline of present drainages may also reflect pre-Holocene geomorphological generation as is illustrated by those of the Bananal Basin in central Brazil (Valente and Latrubesse, 2012).

Table 4 summarizes in broad terms the geomorphological and hydrological connectivity that is probable at different river stage, and shows also how this may link to habitat status. Channel patterns of large rivers are complex, and include relatively tranquil channel-margin, back-water and lacustrine elements. These are biologically highly significant but geomorphologically relatively inactive. Hydrological connectivity in large rivers can also involve floodplain inundation through rising groundwater wihout any direct channel contact (Mertes, 1997; Stevaux et al., 2012). The complex mosaic of flows and linked forms in large rivers is increasingly being documented in the field (Iriondo et al., 2007), but numerical modelling is only in its infancy and relies heavily on verification from remote sensing images (Schumann et al., 2007). The dynamic complexes that are being reported are not readily captured by single traditional pattern descriptors.

An emphasis on floodplain geomorphological connectivity, as also reflected in sediment transfer modelling, balances in a reverse sense the coupling concepts that mostly have been applied to headwaters and tributary-trunk stream combinations. Here sediment transfers from hillslopes, fans or tributaries may or may not be fully connected (coupled) to larger channel systems (Harvey, 2002; Hooke, 2003; Fryirs et al., 2007); this may be size-selective, so that colluvial or coarser materials are deposited in footslope or fan environments, and variable according to event magnitude. Down-channel the process is reversed. The sediment loads of large rivers (generally sandy bedload and variable amounts of suspended/wash load) may be plurally dispersed, sequestered, or recycled within floodplain environments, via active pathways that vary between different rivers, with flood stage and over time. Low rates of sediment supply from upstream may be balanced by low rates of dispersal downstream and the inefficient filling of available accommodation space. In alluviating environments, just as in sediment-supply environments, the concepts of coupling and plural environments help to explain the variable morphologies and dynamics encountered.

5.3 Biological relationships

Backwaters in large rivers and the temporary and permanent water bodies in the floodplain offer a range of sheltered ecological niches for riparian vegetation and phytoplankton growth (Iriondo et al., 2007). Hydrological connectivity and its temporal variability, rather than geomorphological connectivity (Table 4), may be seen as controlling the organisation fluvial biota systems (Amoros and Bornette, 2002; Ward et al., 2002; Tochner et al., 2010; Stevaux et al., 2012). Slackwater zones in main channels, backwater arms and lacustrine environments are part of natural large-river channel ecosystems and, as we have suggested, the dynamic nature of their geomorphological development and replacement need to be understood.

Vegetation can also have a strong impact on sediment retention, particularly in tropical large rivers. For example, Poi de Neiff et al. (1994) recorded that the roots of water hyacinth (*Eichhornia crassipes*) vegetation in the floodplain ponds of the Upper Paraná in Brazil can retain an average of 200-300 g m^{-2} of suspended sediment during low water and up to 2000 g m^{-2} during floods. As Orfeo and Stevaux (2002) noted, the mechanisms for the retention and re-transport of this suspended sediment load is not well known at present, but undoubtedly has a great influence on the geomorphology of the floodplain. Gurnell et al. (2009) have equally pointed to the positive role of vegetation in braided river patterning. Thus there is also reverse linkage between hydrological and biological processes and sedimentation.

5.4 Issues for management

The long-term trend towards river regulation and the confinment of rivers into controlled and dyked channels, however beneficial, has implications for the long-term sustainability of natural hydraulic and biological systems. Large alluvial rivers in particular are complex and diverse in their natural state as a result of the sediment transfer processes leading to the morphological variety discussed above. Residual negative relief on floodplains, which is basic to wetland and lacustrine habitats, is formed and recycled over variable but often extended time periods. This cannot easily be recreated in the short term when rivers have become detached from their sediment exchange systems. Channelisation has led to incision and to main-channel isolation, whilst floodplain engineering and construction restrict ongoing alluvial process activities. After incision and channelisation, it may not be possible to sustain former conditions even locally, or to re-instate them, should that appear desirable. This suggests that when needed development does take place, it should be in the context of adequate prior monitoring of active and long-term river dynamics. This includes the plural functioning of broad hydraulic corridors as a whole so that likely impacts are anticipated. The partial rehabilitation of regulated rivers, in order to improve their ecological status, is a major issue for the much-modified rivers in Europe and North America (Buijse et al., 2005). Again, visionary designs need to be formulated in light of sediment dynamics and potential morphological change patterns as well as the biological communities which crucially are based upon them.

6. Conclusions

Many large rivers are anabranching and *plural* systems. Characteristic main-channel anabranching may arise from intra-channel island formation, or from extra-channel avulsion. Geomorphologically, there may also be a *partial* functional-decoupling between branches, and between them and their hydraulic floodplains. Accessory and tributary channels as well as main-river branches may determine patterns of floodplain morphology. Bedform-dominated mainstreams may have accessory ones that actively meander to accomplish near-surface floodplain sedimentation, although this may be to a shallower depth than that of deeper main channels. Alternatively, valley troughs may be partially unfilled with sediment, and at a range of scales (swales, palaeochannels, floodbasins and dammed tributaries) ponded negative relief waterbodies can form a large part of hydraulic corridors. Geomorphologically dormant or low-activity forms give varied habitats of considerable significance, though they have been widely transformed by anthropogenic activities.

Although it is possible to use holistic terms for channel patterns on large rivers, these conventional patterns are themselves varied, and they do often occur in combination and in close proximity. From both a practical and an analytical point of view it is useful to undertake *element level* accounting of these plural environments (Fig. 3), separating out the forms, functions and activity rates of each. This means development-tracking of bedforms, islands, sinuosity generation, geomorphologically active and inactive main channel branches, accessory and tributary channels, and overbank/palaeochannel sedimentation.

Process linkage and *sediment exchange* between main channel elements, and between them and the rest of their hydraulic systems (actively operating to maximum extent during flood pulses) is highly variable. Bed material moves especially in the form of sand sheets and dunes that may coalesce and stabilise as woody-vegetated islands with a ‘life’ of decades to millenia. But some main channels may be effectively straight (a significant natural pattern element along large rivers) with limited bank mobility, lateral bed-material dispersal or outline channel change. Others may have a wide meander sweep zone. Finer ‘overbank’ sediments may not greatly mask relict bedforms and channels, or fill available accommodation space. Despite their size, many large rivers downstream are sediment-poor, both because of restricted upstream sources, and following prior sequestration up-river. With downstream sediment fining and low gradients, it might be expected that fixed channels and overbank sediment-blanketing would be set to dominate, but this is by no means always the case. Sandy bedforms continue to dominate in-channel morphology, whilst the dispersal and sequestration of fines is commonly a web-like outreach process involving accessory systems and other negative relief elements, or is spatially limited because of the buffering ponded-water levels that are present.

Acknowledgements

PJA would like to thank the UK Natural Environment Research Council (NERC) for support under grant NE/E016022/1 that funded fieldwork on the Rio Paraná, Argentina, together with colleagues Mario Amsler, Jim Best, Rich Hardy, Stuart Lane, Andrew Nicholas, Oscar Orfeo, Dan Parsons, Arjan Reesink, Greg Sambrook Smith, Steve Sandbach and Ricardo Szupiany. We are grateful to Chris Simpson of Fulcrum Graphic Communications Inc., Vancouver, B.C., for producing the figures. We thank Edgardo Latrubesse and Gary Brierley for materially improving the text.

References

Aalto, R.E., Lauer, J.W., Dietrich, W.E., 2008. Spatial and temporal dynamics of Strickland River floodplains during the past century. Journal of Geophysical Research - Earth Surface 113(F1), 1-22, 10.1029/2006/JF000627

Alabyan, A., Chalov, R., 1998. Types of river channel patterns and their natural controls. Earth Surface Processes and Landforms 23, 467-474.

Allen, J.R.L., 1965. A review of the origin and character of recent alluvial sediments. Sedimentology 5, 89-191.

Allen, J.R.L., 1983. Studies in fluviatile sedimentation: bars, Bar-complexes and sandstone sheets (low sinuousity braided streams in the Brownstones (L.Devonian) Welsh Borders. Sedimentary Geology 33, 237-293.

Amoros, C., Bornette, G., 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. Freshwater Biology 47, 761–776.

Ashmore, P.E., 1991. How do gravel bed streams braid? Canadian Journal of Earth Sciences 28, 326-341.

Ashworth, P.J., Lewin, J., 2012. How do big rivers come to be different? Earth-Science Reviews 114, 84-107. doi: 10.1016/j.earscirev.2012.05.003.

Ashworth, P.J., Best, J.L., Roden, J.E., Bristow, C.S., Klaassen, G.J., 2000. Morphological evolution and dynamics of a large, sand braid-bar, Jamuna River, Bangladesh. Sedimentology 47, 533-555.

Assine, M.L., Silva, A., 2009. Contrasting fluvial styles of the Paraguay River in the northwestern border of the Pantanal wetland, Brazil. Geomorphology 113, 189-199. doi: 10.1016/j.geomorph.2009.03.012.

Autin, W.J., 1992. Use of alloformations for definition of Holocene meander belts in the middle Amite River, southeastern Louisiana. Geological Society of America Bulletin 104, 233-241.

Beerbower, J.R., 1964. Cyclothems and cyclic depositional mechanisms in alluvial plain sedimentation. Bulletin of the Kansas University Geological Society 169, 31-42.

Best, J.L., Ashworth, P.J., Bristow, C.S., Roden, J.E., 2003. Three-dimensional sedimentary architecture of a large, mid-channel sand braid bar, Jamuna River, Bangladesh. Journal of Sedimentary Research 73, 516-530.

Best, J.L., Ashworth, P.J., Sarker, M.H., Roden, J.E., 2007. The Brahmaputra-Jamuna River, Bangladesh. In: Gupta A. (Ed.), Large Rivers: Geomorphology and Management. Wiley, Chichester, pp. 395-433.

Blair, T.C., McPherson, T.G., 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes and facies assemblages. Journal of Sedimentary Research A64, 450-489.

Bolla Pittaluga, M., Repetto, R., Tubino, M., 2003. Channel bifurcation in braided rivers: equilibrium configurations and stability. Water Resources Research 39, 1046. doi:10.1029/2001WR001112.

Bridge, J.S., 1993. The interaction between channel geometry, water flow, sediment transport and deposition in braided rivers. In: Best, J.L., Bristow, C.S. (Eds.), Braided Rivers. Geological Society of London Special Publication 75, pp.13-71.

Bridge, J.S., Mackey, S.D., 1993. A revised alluvial stratigraphy model. In: Marzo, M., Puigdefabregas, C., (Eds.), Alluvial sedimentation: International Association of Sedimentologists Special Publication 17, 319–336.

Bridgland, D., Westaway, R., 2008. Climatically controlled river terrace staircases: a worldwide Quaternary phenomenon. Geomorphology 98, 285-315.

Brierley, G.J., 1989. River planform facies models: the sedimentology of braided, wandering and meandering reaches of the Squamish River, British Columbia. Sedimentary Geology 61, 17-35.

Brierley, G.J., 1991. Floodplain sedimentology of the Squamish River, British Columbia: relevance of element analysis. Sedimentology 38, 735-750.

Brierley, G.M., Fryirs, K.A., 2005. Geomorphology and River Management: Application of the River Styles Framework. Blackwell, Oxford. 398pp.

Bristow, C.S., 1987. Brahmaputra River: Channel migration and deposition. In: Ethridge, F.G., Flores, R.M., Harvey, M.D. (Eds.), Recent Developments in Fluvial Sedimentology. Special Publication Society of Economic Palaeontology and Mineralogy 39, pp. 63-74.

Buijse, A.D., Klijn, F., Leuven, R.S.E.W., Middelkoop, H., Scheimer, F., Thorp, J.H., Wolfert, H.P., 2005. Rehabilitation of large rivers: references, achievements and integration into river managemenet. Archiv für Hydrobiologie Suppl. 155/1-4, 715-738.

Carson, M.A., 1984. Observations on the meandering-braided river transition, Canterbury Plains, New Zealand. New Zealand Geographer 40, 89-99.

Church, M., 1983. Patterns of instability in a wandering gravel bed river. In: Collinson, J.D., Lewin, J. (Eds.), Modern and Ancient Fluvial Systems, International Association of Sedimentologists Special Publication 6. Blackwell, Oxford, pp.169-181.

Church, M., 2006. Bed material transport and the morphology of alluvial rivers. Annual Review of Earth and Planetary Sciences 34, 325-354.

Church, M., Rice, S.P., 2009. Form and growth of bars in a wandering gravel-bed river. Earth Surface Processes and Landforms 34, 1433-1445. doi:10.1002/esp.1831.

Crosato, A, Mosselman, E., 2009. Simple physics-based predictor for the number of river bars and the transition between meandering and braiding. Water Resources Research 45, W03424. doi:10.1029/2008WR007242.

Day, G., Dietrich, W.E., Rowland, J.C., Marshall, A., 2008. The depositional web on the floodplain of the Fly River, Papua New Guinea. Journal of Geophysical Research 113, F01S02, doi:10.1029/2006JF000622.

Eaton, B.C., Millar, R.G., Davidson, S., 2010. Channel patterns: Braided, anabranching and single-thread. Geomorphology 120, 353-364.

Edmonds, D. A., Paola, C., Hoyal, D.C.J.D, Sheets, B.A., 2011. Quantitative metrics that describe river deltas and their channel networks, Journal of Geophysical Research 116, F04022. doi:10.1029/2010JF001955.

Federici, B., Paola, C., 2003. Dynamics of channel bifurcations in noncohesive sediments. Water Resources Research 39, 1162. doi:10.1029/2002WR001434.

Froese, D.G., Smith, D.G., Clement, D.T., 2005. Characterizing large river history with shallow geophysics: Middle Yukon River, Yukon Territory and Alaska. Geomorphology 67, 391-406. doi: 10.1016/j.geomorph.2004.11.011.

Fryirs, K.A., Brierley, G.J., Preson, N.J., Spencer, J., 2007. Catchment-scale (dis)connectivity in sediment flux in the upper Hunter catchment, new South wales, Australia. Geomorphology 84, 297-316.

Gupta, A. (Ed.), 2007. Large Rivers: Geomorphology and Management. Wiley, Chichester. 689pp.

Gurnell, A.M., Surian, N., Zanoni, L., 2009. Multi-thread river channels: A perspective on changing European alpine river systems. Aquatic Sciences 71, 253–265.

Happ, S.C., Rittenhouse, G., Dobson, G.C., 1940. Some principles of accelerated stream and valley erosion. Technical Bulletin 695, US Department of Agriculture, Wahington D.C. 133pp.

Harvey, A.M., 2002. Effective timescales of coupling within fluvial systems. Geomorphology 44, 175-201.

Heller, P.L., Paola, C., 1996. Downstream changes in alluvial architecture: an exploration of controls on channel-stacking patterns. Journal of Sedimentary Research 66**,** 297-306.

Hohensinner, S., Jungwirth, M, Muhar, S., Schmutz, S., 2011. Spatio-temporal habitat dynamics in a changing Danube river landscape 1812-2006. River Research and Applications 27, 939-955.

Hooke, J.M., 1995. Processes of channel planform change on meandering channels in the UK. In: Gurnell, A., Petts, G. (Eds.), Changing River Channels. Wiley, Chichester, pp. 87-115.

Hooke, J., 2003. Coarse sediment connectivity in river channel systems: a conceptual framework and methodology. Geomorphology 56, 79-94.

Hooke, J.M., Yorke, L., 2011. Channel bar dynamics on multi-decadal timescales in an active meandering river. Earth Surface Processes and Landforms 36, 1910-1928.

Hooke, R.LeB., Rohrer, W.L., 1979. Geometry of alluvial fans: effect of discharge and sediment size. Earth Surface Processes 4, 147-166.

Horn, J.D., Joeckel, R.M., Fielding, C.R., 2012. Progressive abandonment and planform changes of the central Platte River in Nebraska, central USA, over historical timeframes. Geomorphology 139-140, 372-383. doi: 10.1016/j.geomorph.2011.11.003

Huang, H.Q., Nanson, G.C., 2007. Why some alluvial rivers develop an anabranching pattern. Water Resources Research 43, W07441. doi:10.1029/2006WR005223.

Iriondo, M.H., Paira, A.R., 2007. Physical Geography of the Basin. In: Iriondo, M.H., Paggi, J.C., Parma, M.J. (Eds.), The Middle Paraná River. Springer-Verlag, Berlin, pp. 7-31.

Iriondo, M.H., Paggi, J.C., Parma, M.J. (Eds.), 2007. The Middle Paraná River. Springer-Verlag, Berlin. 382pp.

Jerolmack, D.J., Mohrig, D., 2007. Conditions for branching in depositional rivers. Geology GSA 35, 463-466. doi: 10.1130/G23308A.1.

Kleinhans, M.G., van den Berg, J.H., 2011. River channel and bar patterns explained and predicted by an empirical and physics-based method. Earth Surface Processes and Landforms 36, 721-738.

Kleinhans, M.G., Cohen, K.M., Hoekstra, J., Ijmker, J.M. 2011. Evolution of a bifurcation in a meandering river with adjustable channel widths, Rhine delta apex, The Netherlands. Earth Surface Processes and Landforms 36, 2011-2027. doi: 10.1002/esp.2222.

Kulemina, N.M., 1973. Some characteristics of the process of incomplete meandering of the channel of the upper Ob' River. Soviet Hydrology 6, 518-534.

Lane, S.N., 2006. Approaching the system-scale understanding of braided river behaviour. In: Sambrook Smith, G.H., Best, J.L., Bristow, C.S., Petts, G.E. (Eds.), Braided Rivers: Process, Deposits, Ecology and Management. International Association of Sedimentologists Special Publication 36, Blackwell, Oxford, pp. 107-135.

Latrubesse, E.M., 2008. Patterns of anabranching channels: the ultimate end-member adjustment of mega rivers. Geomorphology 101, 130-145. doi:10.1016/j.geomorph.2008.05.035.

Latrubesse, E.M., Franzinelli, E., 2002. The Holocene alluvial plain of the middle Amazon river, Brazil. Geomorphology 44, 241-257.

Latrubesse, E.M., Franzinelli, E., 2005. The late Quaternary evolution of the Negro River, Amazon, Brazil: implications for island and floodplain formation in large anabranching tropical systems. Geomorphology 70, 372-397.

Latrubesse, E.M., Stevaux, J.C., Sinha, R. 2005. Tropical rivers. Geomorphology 70, 187-206.

Leopold, L.B., Wolman, M.G., 1957. River channel patterns-braided, meandering and straight. U.S. Geological Survey Professional Paper 282B, pp. 39-85.

Lewin, J., Brewer, P.A., 2001. Predicting channel patterns. Geomorphology 40, 329-339.

Lewin J., Brindle, B.J., 1977. Confined meanders. In: Gregory K.J. (Ed.), River Channel Changes. Wiley, Chichester, pp. 221-233.

Luchi, R., Zolezzi, G., Tubino, M., 2010. Modelling mid-channel bars in meandering channels. Earth Surface Processes and Landforms 35, 902-917.

Luchsinger, H.M. 2006. The Late Quaternary landscape history of the middle Rio Negro valley, northern Patagonia, Argentina: its impact on preservation of the archaeological record and influence on Late Holocene human settlement patterns. Ph.D. Thesis, Texas A & M University, USA. 131pp.

Lunt, I.A., Bridge, J.S., 2004. Evolution and deposits of a gravelly braid bar and a channel fill, Sagavanirktok River, Alaska. Sedimentology 51, 415–432.

Makaske, B., 2001. Anastomosing rivers: a review of their classification, origin and sedimentary products. Earth-Science Reviews 53, 149-196.

Makaske, B, Smith, D.G., Berendson, H.J.A., de Boer, A.G., Nielen-Kiezebrink, M.F., Locking, T., 2009. Hydraulic and sedimentary processes causing anastomosing morphology of the upper Columbia River, British Colombia, Canada. Geomorphology 111, 194-205.

Meade, R.H., 2007. Transcontinental Moving and Storage: the Orinoco and Amazon Rivers Transfer the Andes to the Atlantic. In: Gupta, A. (Ed.), Large Rivers: Geomorphology and Management. Wiley, Chichester, pp. 45-63.

Meade, R.H., Bobrovitskaya, N.N., Babkin, V.I., 2000. Suspended-sediment and fresh-water discharges in the Ob and Yenisey rivers, 1960-1988. International Journal of Earth Sciences 89, 461-469.

Mertes, L.A.K., 1997. Documentation and significance of the periheic zone on inundated floodplains. Water Resources Research 33, 1749-1762.

Mertes, L.A.K., Dunne, T., Martinelli, L.A., 1996. Channel-floodplain geomorphology along the Solimões-Amazon River, Brazil. Geological Society of America Bulletin 108, 1089-1107.

Miall, A.D., 1985. Architecture-element analysis: a new method of facies analysis applied to fluvial deposits. Earth-Science Reviews 22, 261-308.

Miall, A.D.,1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology. Springer-Verlag, Heidelberg. 582pp.

Milliman, J.D., Syvitski, J.P.M., 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountain rivers. Journal of Geology 100, 525-544.

Mosselman, E., 2006. Bank protection and river training along the braided Brahmaputra-Jamuna River, Bangladesh. In: Sambrook Smith, G.H., Best, J.L., Bristow, C., Petts, G.E. (Eds.), Braided Rivers: Process, Deposits, Ecology and Management. Blackwell, Oxford, pp. 277-287.

Murray, A.B., Paola, C., 1994. A cellular model of braided rivers. Nature 371, 54-57.

Nanson, G.C., Croke, J.C.,1992. A genetic classification of floodplains. Geomorphology 4, 459-486.

Nanson, G.C., Huang, H., 1999. Anabranching rivers: divided efficiency leading to fluvial diversity. In: Miller, A., Gupta, A., (Eds.), Varieties of Fluvial Form. Wiley, Chichester, pp. 477-494.

Nanson, G.C., Knighton, A.D., 1996. Anabranching rivers: their cause, character and classification. Earth Surface Processes and Landforms 21, 217-239.

Neill, C.R., 1973. Hydraulic and morphologic characteristics of the Athabaska River near Fort Assiniboine. Report REH/73/3, Alberta Research Council, Highway River Engineering Division: Edmonton, 23 pp.

Neill, C.R., 1987. Sediment balance considerations linking long-term transport and channel processes. In: Thorne, C.R., Bathurst, J.C., Hey, R.D. (Eds.), Sediment transport in gravel-bed rivers. Wiley, Chichester, pp. 225-240.

Nicholas, A.P., Thomas, R., Quine, T.A., 2006. Cellular modelling of braided river form and process. In: Sambrook Smith, G.H., Best, J.L., Bristow, C., Petts, G.E. (Eds.), Braided Rivers: Process, Deposits, Ecology and Management. Blackwell, Oxford, pp. 137-151.

Nicholas, A.P., Sandbach, S.D., Ashworth, P.J., Amsler, M.L., Best, J.L., Hardy, R.J., Lane, S.N., Orfeo, O., Parsons, D.R.., Reesink, A.J.H., Sambrook Smith, G.H., Szupiany, R.N., 2012. Modelling hydrodynamics in the Rio Paraná, Argentina: An evaluation and inter-comparison of reduced-complexity and physics based models applied to a large sand-bed river. Geomorphology 169-170, 192-211. doi: 10.1016/j.geomorph.2012.05.014.

Nilsson, C., Reidy, C.A., Dynesius, M., Revenga, C., 2005. Fragmentation and flow regulation of the World's large river systems. Science 308, 405-408.

Orfeo, O., Stevaux, J., 2002. Hydraulic and morphological characteristics of middle and upper reaches of the Parana´ River (Argentina and Brazil). Geomorphology 44, 309-322.

Orfeo, O., Parsons, D., Best, J.L., Lutz, A., Zurita, A., 2009. The Paraná River: from Pleistocene to the Present. Conicet, Corrientes, Argentina, 155pp.

Paira, A.R., Drago, E.C., 2007. Origin, Evolution, and Types of Floodplain Water Bodies. In: Iriondo M.H., Paggi, J.C., Parma, M.J. (Eds.), The Middle Paraná River. Springer-Verlag, Berlin, pp. 53-81.

Paola, C. 1996. Incoherent structure: turbulence as a metaphor for stream braiding. In: Ashworth, P.J., Bennett, S.J., Best, J.L., McLelland, S.J. (Eds.), Coherent Flow Structures in Open Channels, Wiley, Chichester, 705–723.

Parker, G., 1976. On the cause and characteristic scales of meandering and braiding in rivers. Journal of Fluid Mechanics 76, 457-479.

Parker, G., 1978. Self-formed straight rivers with equilibrium banks and mobile bed. 2. the gravel river. Journal of Fluid Mechanics 89, 127-146.

Poi de Neiff, A., Neiff, J., Orfeo, O., Carignan, R., 1994. Quantitative importance of particulate matter retention by the roots of Eichhornia crassipes in the Paraná floodplain. Aquatic Botany 47, 213– 223.

Reinfelds, I., Nanson, G., 1993. Formation of braided river floodplains, Waimakariri River, New Zealand. Sedimentology 40, 1113-1127.

Rice, S.P., Church, M., Wooldridge, C.L., Hickin, E.J. 2009. Morphology and evolution of bars in a wandering gravel-bed river; Fraser river, British Columbia, Canada. Sedimentology 56, 709–736. doi: 10.1111/j.1365-3091.2008.00994.x.

Richards, K., Brassington, J., Hughes, F., 2002. Geomorphic dynamics of floodplains: ecological implications and a potential modelling strategy. Freshwater Biology 47, 559-579.

Rosgen, D.L., 1994. A classification of natural rivers. Catena 22, 169-199.

Sambrook Smith, G.H., Ashworth, P.J., Best, J.L., Lunt, I.A., Orfeo, O., Parsons, D.R., 2009. The sedimentology and alluvial architecture of a large braid bar, Río

Paraná, Argentina. Journal of Sedimentary Research 79, 629-642. doi: 10.2110/jsr.2009.066

Sandbach, S.D., Lane, S.N., Hardy, R.J., Amsler, M.L., Ashworth, P.J., Best, J.L., Nicholas, A.P., Orfeo, O., Parsons, D.R., Reesink, A.J.H., Szupiany, R.N. (2012). Application of a roughness-length representation to parameterize energy loss in 3-D numerical simulations of large rivers. Water Resources Research 48(12). doi 10.1029/2011WR011284.

Schumann, G., Matgen, P., Hoffmann, L., Hostache, R., Pappenberger, F., Pfister, L., 2007. Deriving distributed roughness values from satellite radar data for flood inundation modelling. Journal of Hydrology 344, 96-111. doi 10.1016/j.hydrol.2007.06.024.

Shiklomanov, I.A., Rodda, J.C. (Eds.), 2004. World Water Resources at the Beginning of the Twenty-first Century. Cambridge University Press, Cambridge. 452pp.

Sidorchuck, A.Y., Panin, A.V., Borisova, O.K., 2009. Morphology of river channels and surface runoff in the Volga River basin (East European Plain) during the Late Glacial Period. Geomorphology 113, 137-157.

Slingerland, R., Smith, N.D., 2004. River avulsions and their deposits. Annual Reviews Earth and Planetary Science 32, 257-285.

Smith, D.G., Smith, N.D., 1980. Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta. Journal of Sedimentary Petrology 50, 157-164.

Stevaux, J.C., Corradini, F.A., Aquino, S. 2012. Connectivity processes and riparian vegetation of the upper Paraná River, Brazil. Journal of South American Earth Sciences doi:10.1016/j.sames.2011.12.007.

Swanson, K.M., Watson, E., Aalto, R.E., Lauer, J.W., Dietrich, W.E., Apte, S., Bera, M., Marshall, A., Taylor, M., 2008. Sediment load and floodplain deposition rates: Comparison of the Fly and Strickland rivers, Papua New Guinea. Journal of Geophysical Research - Earth Surface 113(F1) F01S03. doi:10.1029/2006JF000623

Thorne, C.R.,1997. Channel types and morphological classification. In: Thorne, C.R., Hey, R.D., Newson, M.D. (Eds.), Applied Fluvial Geomorphology for River Engineering and Management. Wiley, Chichester, pp.175-222.

Tockner, K., Lorang, M.S., Stanford, J.A., 2010. River flood plains are model ecosystems to test general hydromorphic and ecological concepts. River Research and Applications 26, 76-86.

Törnqvist, T.E., Bridge, J.S., 2002. Spatial variation of overbank aggradation rate and its influence on avulsion frequency. Sedimentology 49, 891–905.

Valente, C.R., Latrubesse, E.M. 2012. Fluvial archive of peculiar avulsive fluvial patterns in the largest Quaternary intracratonic basin of tropical South America: the Bananal Basin, Central-Brazil. Palaeogeography, Palaeoclimatology, Palaeoecology 356-357, 62-74. doi:10.1016/j.palaeo.2011.1.10.002.

Van De Wiel, M.J., Coulthard, M.J., Macklin, M.G., Lewin, J., 2011. Modelling the response of river systems to environmental change: Progress, problems and prospects for palaeo-environmental reconstructions. Earth-Science Reviews 104, 167-185.

Vietz, G.J., Rutherford, I.D., Stewardson, M.J., Finlayson, B.L. 2012. Hydrodynamics and sedimentology of concave benches in a lowland river. Geomorphology 147-148, 81-101. doi: 10.1016/geomorph.2011.07.033

Warburton, J., Davies, T.R.H., Mandl, M.G., 1993. A meso-scale field investigation of channel change and floodplain characteristics in an upland braided gravel-bed river, New Zealand. In: Best, J.L., Bristow, C.S. (Eds.), Braided Rivers. Geological Society of London Special Publication 75, pp. 241-255.

Ward, J.V., Tockner, K., Arscott, D.B., Clarett, C., 2002. Riverine landscape diversity. Freshwater Biology 47, 517–539.

Yalin, M.S. 1971. Theory of Hydraulic Models, Macmillan, London, 266 pp.

Tables

Table 1: Nomenclature for river and floodplain depositional elements. The elements of alluvial exchange and deposition used in this paper are shown in Fig. 3.

Table 2: Big river character at selected reaches on 20 of the world's largest rivers (after Ashworth and Lewin, 2012).

Table 3: The four main hydraulic systems that characterise large rivers.

Table 4: Geomorphological and hydrological connectivity in large rivers and linkage with biological habitats.

Figure captions

Fig. 1. Contrasted anabranching patterns of (A) Ob (image taken on 7 July, 1999, flow up the page), (B) Jamuna (image taken on 19 February, 2000, flow down the page), and (C) Paraná (images taken on 15 April, 2003 and 8 April, 2003, flow down the page). Co-ordinates given on the images; note the scales of A and B are the same. Landsat imagery courtesy of the U.S. Geological Survey.

Fig. 2. The Amur River, Eastern Siberia (48^{o} 75′ N, 135^{o} 47′ E). Morphological components (1-8) are discussed in the text. Landsat imagery taken on 5 September 2002, courtesy of the U.S. Geological Survey.

Fig. 3. The elements of alluvial exchange (from Ashworth and Lewin, 2012). Elements comprise deposition on the floodplain (a-e), exchanges involving main channels (f-i) and deposition within them (h), or material input from tributaries (j).

Fig. 4. (A) The changing channel of the Paraná, 1905-2010, reproduced from historic and recent bathymetric surveys (data courtesy of Prof. M. Amsler, Dr R. Szupiany and Dirección Nacional de Vias Navegables, from Ashworth and Lewin, 2012). All data are reduced to the same common datum and the 18 km-reach is 25 km south-east of Santa Fe (31^{o} 37′ S, 60^{o} 42′ W), (B) Channel change on the Upper Paraná 1986 to 2008 in a reach 6 km west of Itati (27^{o} 16′ S, 58^{o} 14′ W). Images courtesy of U.S. Geological Survey. Label 1 = km-scale bar discussed in text.

Fig. 5. Main channel patterns in selected larger river reaches (See also Table 2) (from Ashworth and Lewin, 2012).

Fig. 6. The impact of stage on hydrological connectivity between main channels and floodplain: (A) Rio Paraná, Argentina, image taken on 29 January 2010, discharge = 25,590 $m^3 s^{-1}$; (B) Rio Paraná, image taken on 26 September, 2010, discharge = 11,488 $m^3 s^{-1}$, Label 1 = sinuous floodplain channel referred to in text; (C) River Ob, image taken at high flow on 30 May 2001, discharge = 12,900 $m^3 s^{-1}$; (D) River Ob, image taken at low flow on 2 August 2001, discharge = 8,720 $m^3 s^{-1}$. Images courtesy of U.S. Geological Survey. Co-ordinates given on the images.

Fig. 7. Types of geomorphological coupling in large rivers illustrated using examples from the Rio, Paraná, Argentina: (A-B) full channel-floodplain connectivity with active mid-channel bar sedimentation, infill of vegetated bar complexes (labelled F); (C-D) partial channel-floodplain connectivity with backwaters (labelled W), accessory channels (labelled S) and smaller bodies of open water in seasonally-replenished scroll ponds and old meander loops (labelled M).

Fig. 8. (A) Yukon River, Alaska (image taken on 1 October, 1999), (B) Rio Negro, Argentina (image taken on 16 January, 2003). Co-ordinates are given on the images. Pattern types (M meandering and B braiding) are shown together with mainstream (I), accessory (II), and tributary (III) channels. Three styles of palaeochannel appear on the Rio Negro alluvial plain: braided channels of probable mid-Holocene age (P1), a continuous meandering avulsive channel (P2) of late Holocene age (2500-2000 C^{14} years BP) and sets of truncated meander loops (P3) of >870 C^{14} yrs BP age (chronology from Luchsinger (2006)). The contemporary meander belt occupies the

southern portion of the 20-km wide valley and in places (label C) abuts the adjacent Patagonian Plateau bedrock. Images courtesy of U.S. Geological Survey.

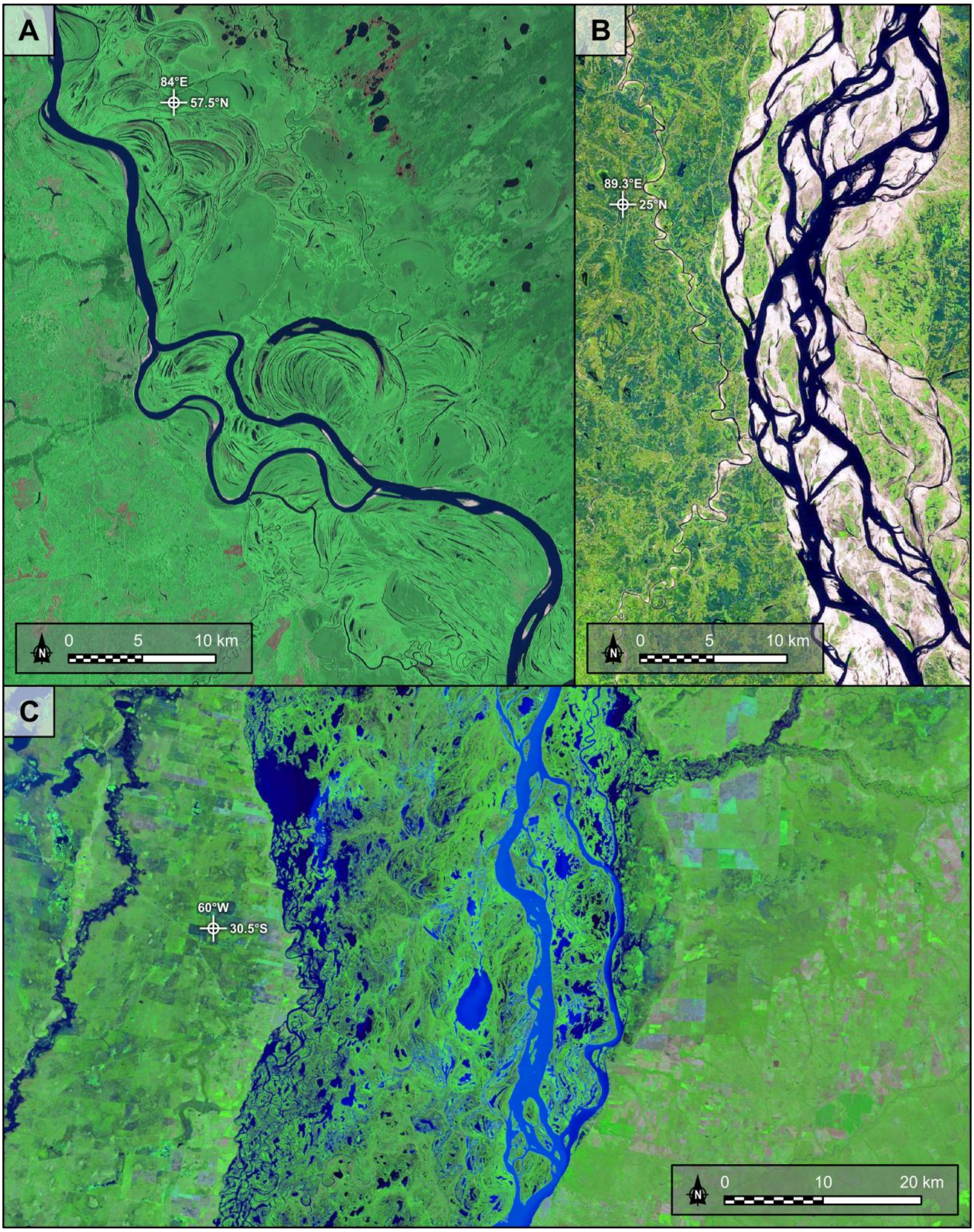
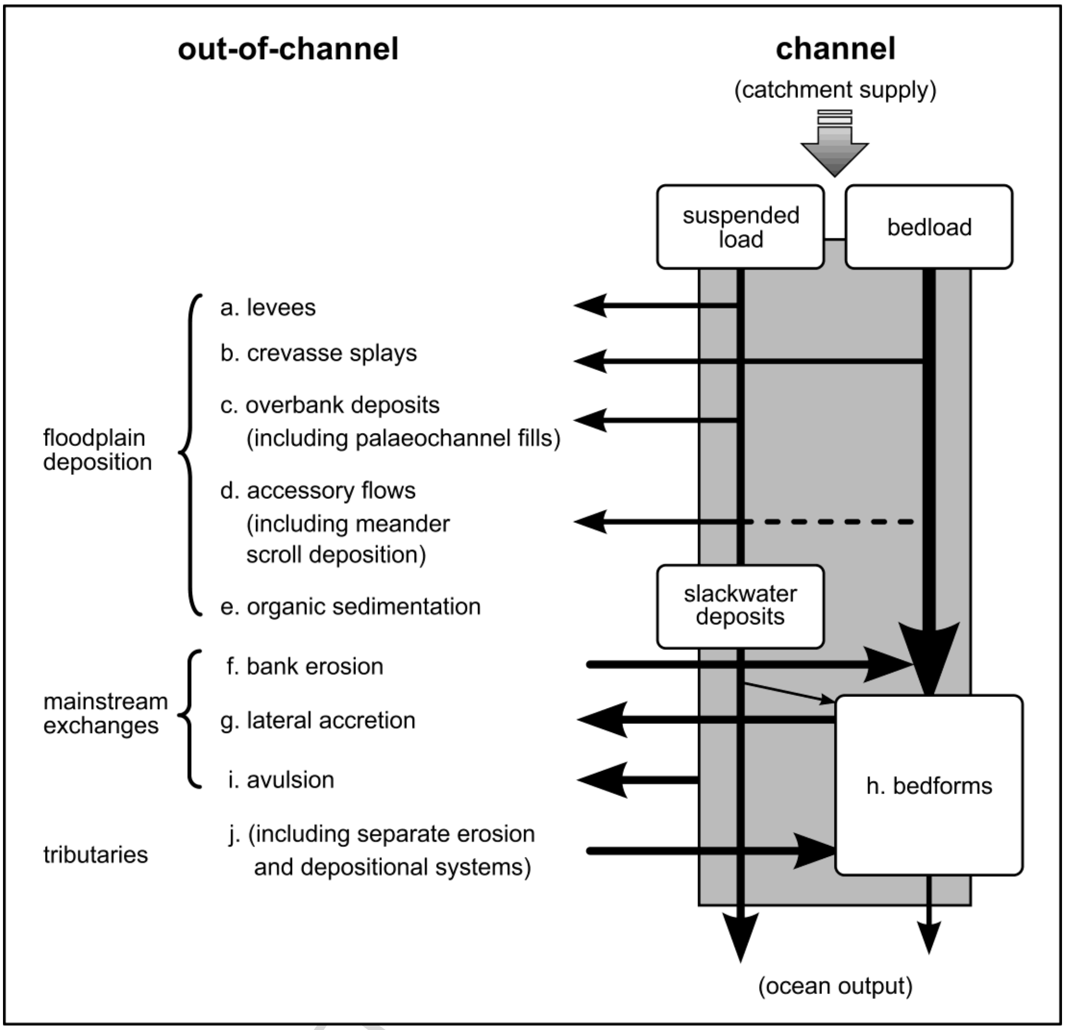


Fig. 1

Fig. 2



out-of-channel
channel
(catchment supply)
suspended load
bedload
floodplain deposition
a. levees
b. crevasse splays
c. overbank deposits
(including palaeochannel fills)
d. accessory flows
(including meander scroll deposition)
e. organic sedimentation
slackwater deposits
mainstream exchanges
f. bank erosion
g. lateral accretion
i. avulsion
h. bedforms
tributaries
j. (including separate erosion and depositional systems)
(ocean output)

Fig. 3

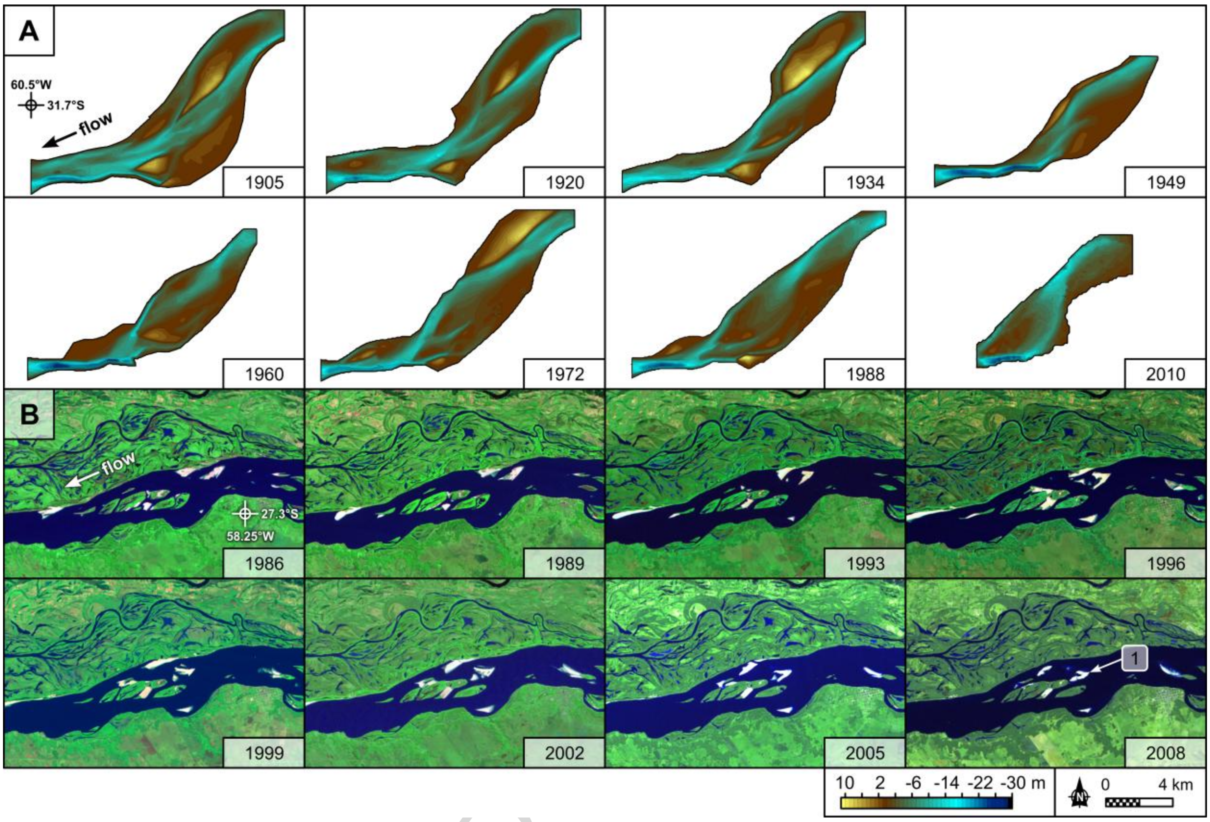

A
60.5°W
31.7°S
flow
1905
1920
1934
1949
1960
1972
1988
2010
B
flow
27.3°S
58.25°W
1986
1989
1993
1996
1999
2002
2005
2008
1
10 2 -6 -14 -22 -30 m
0 4 km

Fig. 4

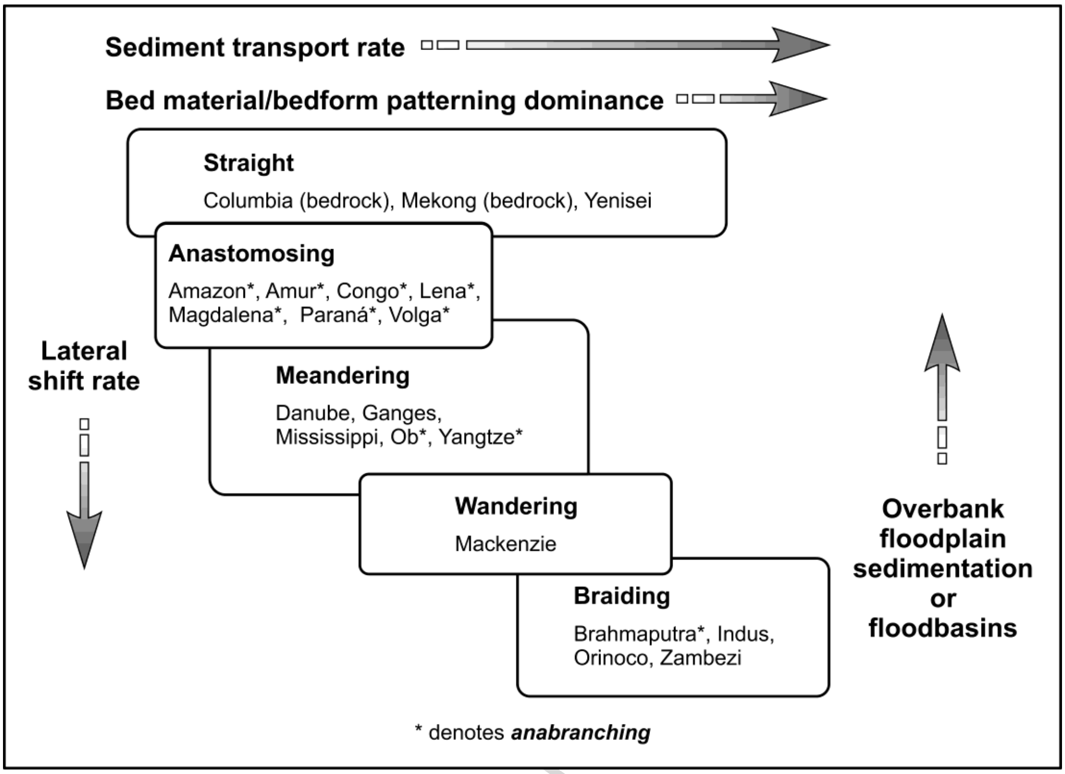

Sediment transport rate
Bed material/bedform patterning dominance
Straight
Columbia (bedrock), Mekong (bedrock), Yenisei
Anastomosing
Amazon*, Amur*, Congo*, Lena*, Magdalena*, Paraná*, Volga*
Lateral shift rate
Meandering
Danube, Ganges, Mississippi, Ob*, Yangtze*
Wandering
Mackenzie
Braiding
Brahmaputra*, Indus, Orinoco, Zambezi
Overbank floodplain sedimentation or floodbasins
* denotes *anabranching*

Fig. 5

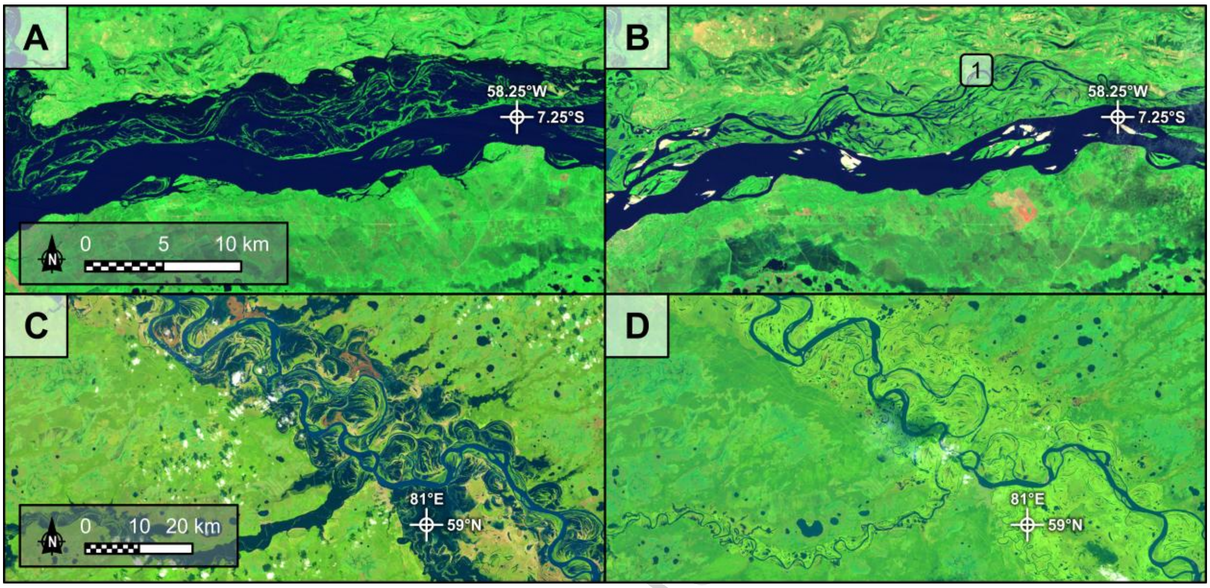

A
B
C
D
1
58.25°W
7.25°S
58.25°W
7.25°S
0 5 10 km
N
0 10 20 km
N
81°E
59°N
81°E
59°N

Fig. 6

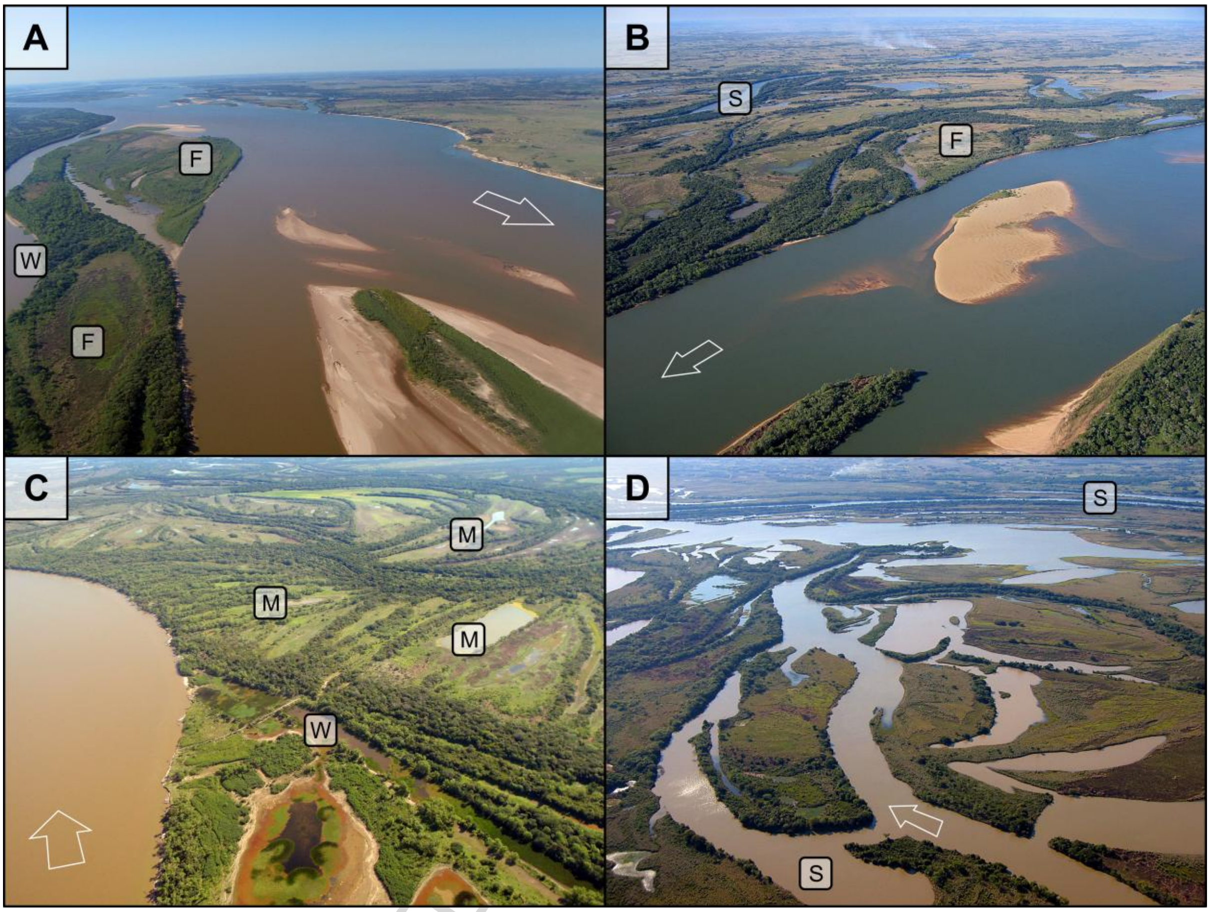


Fig. 7

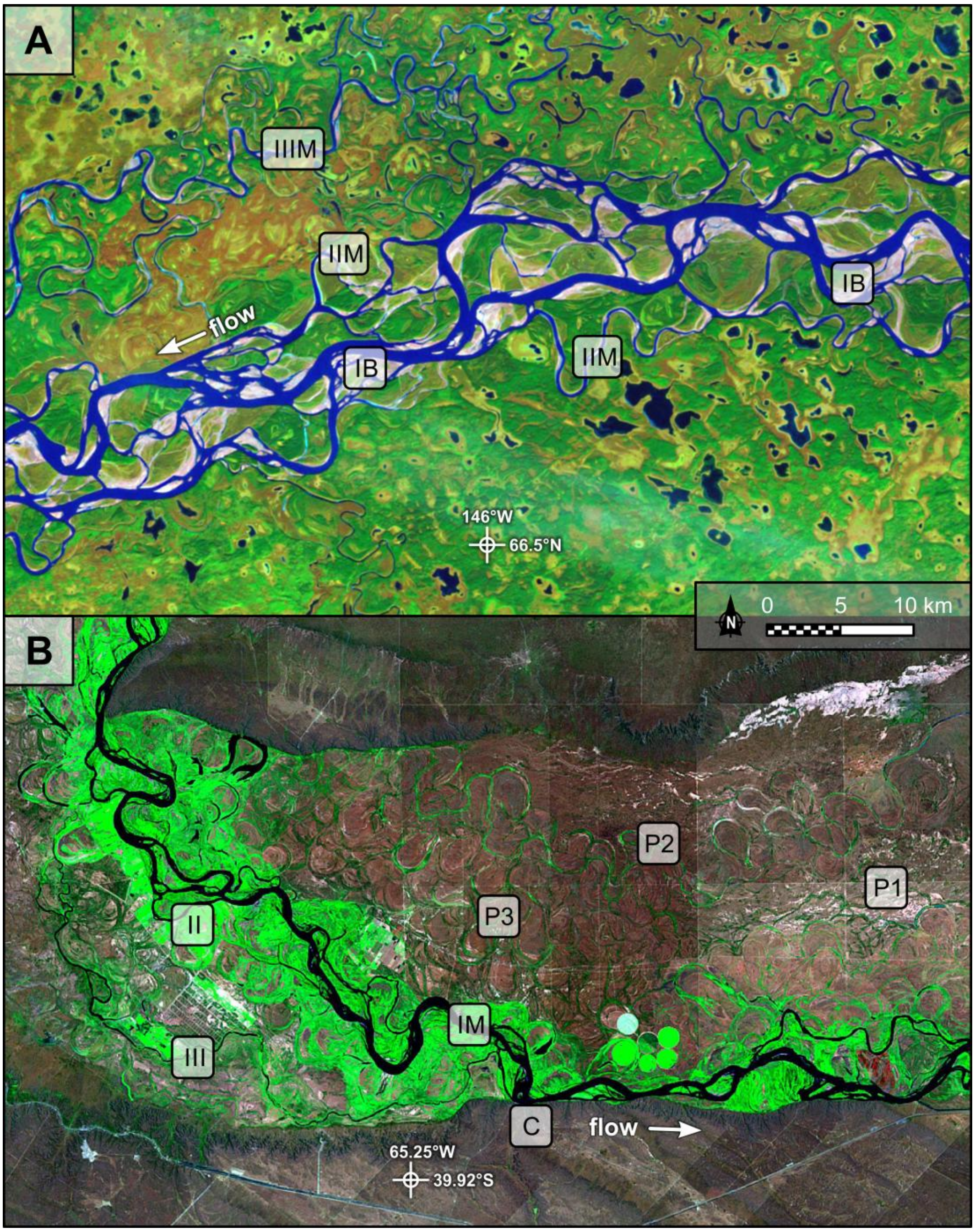

A
IIIM
IIM
flow
IB
IIM
IB
146°W
66.5°N
N
0
5
10 km
B
P2
P1
II
P3
IM
III
C
flow
65.25°W
39.92°S

Fig. 8

Table 1

Happ et al. (1940) deposits	Beerbower (1964) environmental elements	Miall (1985) architectural elements	Brierley (1991) morphostratigraphic elements	Nanson & Croke (1992) processes of floodplain formation (all 'accretions')
1. Channel-fill	1. Channel (a) floor (b) point bar (c) margin	1. Channels (CH)	1. Top stratum (a) sand-wedge (b) proximal (c) distal	1. Lateral point-bar
2. Vertical accretion	2. Crevasse channel	2. Gravel bars and bedforms (GB)	2. Ridge	2. Overbank vertical
3. Floodplain (splays)	3. Levee	3. Sandy bedforms(SB)	3. Chute channel	3. Braid channel
4. Colluvium	4. Channel bar, tops	4. Foreset macroforms (FM)	4. Bar platform	4. Oblique
5. Lateral accretion	5. Crevasse distributary	5. Lateral accretion deposits (LA)	5. Basal channel gravels	5. Counterpoint
6. Channel lag	6. Abandoned channel	6. Sediment gravity flows (SG)		6. Abandoned channel
	7. Floodplain (a) backswamp (b) swamp (c) lake (d) collection	7. Laminated sand sheets (LS)		
		8. Overbank fines (OF)		

Table 2

	Mean annual runoff [1] (10^9 m^3)	Reach location		Gradient (m km^{-1})[6]	Valley floor width (km)[7]	Mainstream character[2]	Channel width (km)	Sedimentation elements[3] Floodplain					Mainstream				Tribs	Surface waters[4]	Hydraulic system (Table 3)
								a	b	c	d	e	f	g	h	i	j		
Amazon	6246	2°33'S	66°30'W	0.10	50	*M/A	2.5	○	○	◉	◉	●	●	●	◉	◉	○	1,2,4	1,2,3(b)(i)
Congo	1292	2°09'N	21°36'E	0.14	10-26	*A	4.8+	○	○	○	○	○	○	●	○	○	○	-	2
Orinoco	1089	7°53'S	65°30'W	0.04	8	B	2.6	○	◉	◉	◉	◉	●	●	●	◉	○	1,2	3(a)
Yangtze (Changjiang)	872	30°37'N	117°13'E	-	15	*M/A	2.5	●	○	◉	◉	●	◉	◉	●	○	◉	1,2,3,4	1,2
Brahmaputra	574	25°50'N	89°39'E	0.22	20	*B	12.0+	○	◉	○	◉	○	●	●	●	●	◉	1	3(a)
Yenisei	572	65°16'N	87°56'E	-	9	S	2.4	○	○	○	●	●	◉	◉	●	○	○	1	2
Volga	560	57°07'N	47°18'E	0.08	18	*A	-	◉	○	◉	●	●	◉	◉	◉	◉	◉	1,2	3(a)
Zambezi [5]	546	17°57'S	35°30'E	0.22	9	*B	0.80	○	◉	◉	●	◉	●	●	●	◉	○	1,2	3(a)
Lena	512	62°42'N	129°49'E	0.06	14	*A	2.30	○	◉	○	●	◉	●	●	●	◉	○	1,2	2,3(b)(i)
Mississippi[5]	495	32°43'N	91°09'W	0.06	50+	M	1.50	●	○	●	○	◉	●	●	◉	◉	○	1,2	2
Mekong	466	14°00'N	105°53'E	0.46	10	*	1.80	(mostly bedrock)										-	4
Paraná	429	31°41'S	60°33'W	0.06	28	*A	2.20	◉	○	◉	●	●	◉	◉	●	◉	●	1,2,3,4	1,3(b)(i)(ii)
Ob	400	58°22'N	82°43'E	0.04	21	*M	0.90	○	○	◉	●	◉	●	●	◉	●	◉	1,2	3(a)
Ganges	380	25°24'N	83°10'E	0.08	10	M	1.00	○	○	◉	○	○	●	●	◉	○	○	-	2
Amur	324	48°48'N	135°46'E	0.36	11	*A/B	2.60	○	○	◉	●	◉	●	●	◉	○	◉	1,2,3,4	3(b)(i)(ii)
Mackenzie	306	64°38'N	125°03'W	0.38	6	*W	1.20	○	○	◉	◉	◉	●	●	●	◉	○	-	3(a)
Columbia	251	45°47'N	120°04'W	0.26	2	S	1.80	(mostly bedrock)										-	4
Indus	238	27°20'N	68°15'E	0.14	90+	*B/M	1.10	○	●	●	◉	○	●	●	●	●	◉	2	3(b)(ii)
Magdalena	238	8°55'N	74°29'W	-	25+	*A	0.70	●	◉	◉	●	●	○	○	○	◉	◉	2,3,4	1,3(a)
Danube	203	46°15'N	18°55'E	0.20	15	M	0.60	○	○	◉	○	◉	●	●	◉	○	◉	1,2	2

(1) From Milliman and Syvitski (1992) with unit adjustment; separate figures for Ganges and Brahmaputra from Shiklomanov and Rodda (2004)
(2) Main channels may be anabranching (*), anastomosing (A) or wandering (W). Single channels or sub-branches may be straight (S), actively meandering (M) or braided (B)
(3) Sedimentation elements (a-j) are given in Figure 3 (● dominant, ◉ present, ○ not significant)
(4) Surface waters may be in: 1 scroll ponds, 2 cutoff channels, 3 floodbasins (ponded between raised alluvial ridges or against valley-sides), 4 ponded tributary valleys
(5) Runoff adjusted for regulation as described in Milliman and Syvitski (1992)
(6) Gradients measured over 50 km on adjacent flooplain using GoogleEarth (- indicates so flat it is unquantifiable)
(7) Channel widths (+ including bars/islands) and valley floor widths (that may include low terraces) are locally very variable; figures give an approximate guide

Table 3

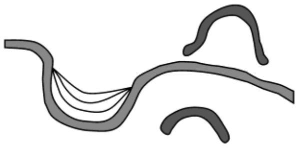
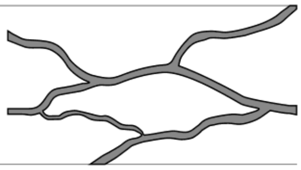
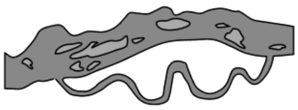
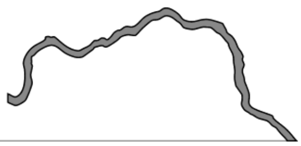
Hydraulic system	Characteristics	
1. Floodbasin prominent	The valley floor is dominated by ponded water, with limited overbank sedimentation from a relatively stable main channel Aggradation may involve organic fills or vertical accretion	
2. Main-channel dominated	The main channel generates bedforms or migrates producing lateral accretion deposits and abandoned channel fills Aggradation is dominated by channel belt sediments	
3. Plural sedimentation systems	Alluvial valley floor has several sedimenting channel systems: (a) equi-style Where divided (anabranching) channels are each of the same type, including meandering, braided and anastomosing	
	(b) contra-style (i) Accessory Where off-takes from the main channel or other internal drainages are of a different style to main channels, usually sinuous single channel rather than braided	
	(ii) Tributary Where tributary channels from sediment-rich sources dominate valley floor sedimentation	
4. Bedrock dominated	The channel is bedrock confined rather than being self-formed in alluvial sediments	

Table 4

	Geomorphological connectivity		Hydrological connectivity		Habitat
	High flow	Low flow	High flow	Low flow	
i. Main channel	●	localised	■	■	eupotomon [1]
sub- or side branch	●	○	■	■	parapotomon [1/2]
ii. Accessory channels	●	○	■	■	
iii. Tributary channels	●	◍	■	■	tributary [1]
iv. Internal drainages	◍	○	■	□	
v. Lake & pond environment	○	○	■	□	plesio- & palaeopotomon [2]
vi. Positive floodplain relief	◍ [3]	○	■	□	terrestrial ecosystems

Notes: Geomorphological connectivity involves sediment transfer, and is classified as high (●), moderate (◍), or low (○) activity. Hydrological connectivity involves active (■) or minimal (□) flow.

Habitats are largely as used in Hohensinner et al. (2011), Table 1, p. 943.

[1] indicates flowing water (lentic) environments,

[1/2] semi-lotic or semi-lentic one, and

[2] dominantly non-flowing (lotic) ones

[3] Positive floodplain relief elements may receive additional sediments during overbank flood flows, but also where connected floodplain channels are activated by water overspilling from sub-bankfull flows in the main channel