Braided river ecology

A literature review of physical habitats and aquatic invertebrate communities

Duncan Gray and Jon S. Harding

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Cover: The upper Clyde River, Canterbury, during autumnal low flows. Looking southeast towards Erewhon Station, with Watchdog Peak at the right.
Photo: Duncan Gray.

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ABSTRACT

A braided river is one that, over some part of its length, flows in multiple, mobile channels across a gravel floodplain. In New Zealand, many braided rivers remain in a relatively unmodified condition, but increasing demands for hydro-electricity generation, irrigation, gravel extraction and flood protection works are placing pressure on these systems. However, apart from a limited number of studies on the ecology of individual species or reaches, there has been little coordinated ecological research to assess the overall values and function of braided river ecosystems in New Zealand. This review summarises the international and New Zealand literature on braided rivers, with particular emphasis on benthic invertebrate ecology. Braided rivers typically experience short-term channel migration within the active bed and greater lateral channel migration across the entire floodplain in the longer term. Channel migration occurs because steep headwater tributaries supply highly variable discharges and mobile erodable substrates to the mainstem. Braided rivers typically possess extended floodplains, which may contain a mosaic of floodplain habitats ranging from highly unstable main-stem channels to stable spring complexes. Main channel aquatic invertebrate communities are frequently low in diversity and dominated by the leptophlebiid mayfly *Deleatidium* spp., but also chironomids and elmid beetles. In contrast, floodplain springs can have highly diverse communities rich in amphipods, mayflies, caddis, snails and chironomids. Groundwater and floodplain pond habitats also occur frequently and can contain several specialist taxa. Braided rivers and their floodplains are spatially complex, temporally dynamic habitats with high landscape- and reach-scale biodiversity values. The challenge facing managers is to protect this biodiversity within the context of increasing human demands on the rivers. This report highlights the particular threats and management issues associated with braided rivers in New Zealand and identifies areas where future research is required.

Keywords: Braided rivers, benthic invertebrates, geomorphology, springs, diversity, groundwater

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1. Introduction

1.1 THE SCOPE OF THIS REVIEW

The aim of this review is to summarise the literature available on braided rivers in New Zealand and overseas, with particular emphasis on our understanding of the diversity and structure of aquatic invertebrate communities in these ecosystems. The introductory section defines braided rivers and describes the location and condition of braided rivers. The review then considers the habitat template[1] and the physical characteristics of the floodplain habitats typically found within braided rivers, and the ecological patterns generated by this template. The biotic communities of typical floodplain habitats are presented. Finally, the threats, management issues and research gaps associated with braided rivers in New Zealand are discussed.

1.2 DEFINITION OF A BRAIDED RIVER

A number of definitions have been suggested to describe braided rivers. Most focus on the physical characteristics associated with multiple surface-flowing channels. For example:

> 'Braided rivers are characterised by having a number of alluvial channels with bars and islands between meeting and dividing again, and presenting from the air the intertwining effect of a braid.' (Lane 1957).
>
> 'A braided river is one which flows in two or more channels around alluvial islands.' (Leopold and & Wolman 1957).'

Historically, braided rivers have been described on the basis of the physical characteristics of the river reach under consideration. Leopold & Wolman (1957) suggested that numerous channel types can be identified within rivers, including braided, meandering and straight channels. One channel type may often be found within another such that further attempts at classification of the entire channel reach become difficult. Reinfelds & Nanson (1993) described a 'braided river floodplain' as a generally extensive, vegetated and horizontally bedded alluvial landform, sometimes composed of a mosaic of units at various stages of development, formed by the present regime of the river, occurring within or adjacent to the un-vegetated active river bed and periodically inundated by over-bank flow.

For the purpose of this review we define a braided river as one that at some point in its length flows in multiple, mobile channels across a gravel floodplain. There must be evidence of recent channel migration within the active bed of the river and of historical movements of the active bed across the floodplain. The lateral and vertical limits of the 'river' include the entire width of the floodplain and the saturated depths of the alluvial aquifer, within and across which the river moves as a single body of water.

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[1] The habitat template is the physical mosaic of habitats that occur in a river. The term template is used as the physical habitats are generally assumed to define the characteristics of the biological communities within them. Thus the biology sits upon and is defined by the physical template.

1.3 WHAT CONDITIONS CREATE BRAIDED RIVERS?

Leopold & Wolman (1957) proposed two primary controlling variables on channel pattern—discharge and slope—for which two rules are apparent. First, for a given discharge and bed material, there are threshold slopes between which channels will braid, and second, that the critical slope decreases with increasing discharge or decreasing sediment size. Both slope and bed material change naturally and predictably down the length of a river. In general, rivers are steeper in their headwaters and bed materials are coarser; however, as rivers flow away from their headwaters, slope decreases and bed materials become finer (Browne 2004). Consequently, channel form changes in a fairly predictable fashion downstream. Nevertheless, smaller-scale changes in slope and bed material, in conjunction with temporally variable changes in discharge, mean that braiding, and other channel patterns, can occur irregularly along the length of the river. A period of time with high discharges may produce a distinctly braided channel pattern, whereas a period of climatic stability, over months or even years, may produce a single, straight channel (Bridge 1993; Whited et al. 2007).

Geomorphologists have developed indices of channel type, which consider surface physical attributes including channel splitting and sinuosity, and the stability of floodplain bars and islands. Increasingly complex attempts at classifying channel types are summarised by Bridge (1993) and Sambrook Smith et al. (2006). However, more recently, research has highlighted the multi-dimensional nature of braided rivers and provides a more complete understanding of the role of the river and its floodplain within the greater catchment (Stanford & Ward 1988; Brunke & Gonser 1997; Woessner 2000). We now understand that braided rivers consist of much more than active surface channels, and that the river flows across an alluvial gravel bed, which may be many metres deep and possibly kilometres wide. Surface water flows over the top of the gravel, but also moves down vertically and horizontally though the gravels as groundwater. This groundwater, which may re-emerge in a spring or wetland, is the vertically connected component of the braided river. Despite most classification systems' preoccupation with surface characteristics, braided rivers are, in fact, three-dimensional ecosystems. They comprise a single body of water moving down the river corridor, and exert an influence far beyond the 'bank' of the active river. It is this multi-dimensional structure which makes braided rivers so important as physical and aesthetic phenomena, as well as diverse and complicated ecosystems.

Morphologically, rivers can be divided into two broad groups: those constrained by narrow valleys and terraces, and those unconstrained and flanked by a flood-plain (Schumm 2005). Braided rivers also depend upon two catchment-scale conditions. The first is a source of highly erodable bedrock, which forms the basis of gravel-dominated highly sinuous channels. This eroded material may be produced by several processes, but is usually the result of glacial activity, erosion of friable bedrock and active mountain building. Many braided rivers are found in areas that experience these erosional forces, notably parts of Canada, Alaska, the Himalayas and the South Island of New Zealand. The second catchment-scale condition is that almost all braided rivers are associated with steep mountain ranges, which have the capacity to create their own weather. For example, the Southern Alps of New Zealand are aligned perpendicular to the prevailing westerly air flow, resulting in orographic rain, which can occur at any time of year. So, rivers that are not laterally constrained by some geographical feature and that experience a high level of sediment input and high rainfall events may form an alluvial floodplain. Interactions between rainfall, sediment size and slope of the floodplain may create conditions that cause a river to form multiple sinuous channels across its floodplain. However, periods of discharge stability or anthropogenic constriction of the floodplain may shift the channel form away from braiding towards a single channel.

1.4 WHERE ARE BRAIDED RIVERS FOUND?

Braided rivers occur most frequently in arctic and alpine regions that have high precipitation and steep headwaters. However, they also occur in arid and Mediterranean climates subject to torrential rain, and in some tropical regions where there are monsoonal rains (Bravard & Gilvear 1996). Whilst the headwaters of many of the world's braided rivers may be relatively free from direct human modification, their lower reaches are frequently heavily impacted (Tockner & Stanford 2002). In fact, in most developed nations, few examples of non-impacted braided floodplain systems remain (Malmqvist & Rundle 2002: Tockner & Stanford 2002).

Dynesius & Nilsson (1994) estimated that, of the 139 largest rivers in Europe, the former Soviet Union, USA and Canada, 77% were moderately to strongly affected by flow regulation. Human degradation of river systems is a worldwide phenomenon (Benke 1990; Raven et al. 1998; Muhar et al. 2000; Pringle et al. 2000; Rosenberg et al. 2000; Brunke 2002; Young et al. 2004; Nilsson et al. 2005) and flow regulation and channelisation are recognised as particularly important issues in braided floodplain systems (Brunke 2002; Hauer & Lorang 2004; Hohensinner et al. 2004; Thoms et al. 2005). In Europe, human modification of rivers is so common that the Tagliamento River, in north-eastern Italy, is regarded as the only remaining morphologically intact braided river system (Tockner et al. 2003). The majority of extant unmodified systems in the northern hemisphere are concentrated in the extreme north of Alaska, Canada and Eurasia, away from centres of human development (Dynesius & Nilsson 1994). The majority of extant unmodified systems in the southern hemisphere are in New Zealand. Whilst many other alpine regions—such as the Himalayas and Andes—have rivers with braided reaches, the rivers are often severely degraded and published accounts of their ecology are scant (Garcialozano 1990; Gopal & Sah 1993; Wang et al. 2005; Habit et al. 2006).

Despite the paucity of unmodified river systems available for study, both Europe and North America have established centres of intensive research to investigate the function and landscape roles of floodplain systems (Stanford & Ward 1993; Ward & Stanford 1995; Tockner et al. 2003). Insights from these studies have supported a number of rehabilitation and restoration projects, particularly along central Europe's largest rivers (Hohensinner et al. 2004).

In New Zealand, numerous studies on the geomorphology of braided rivers have been published, and our physical braided river research continues to be at the forefront of such research internationally (Mosley 2001; Sambrook Smith et al. 2006). Furthermore, a considerable body of literature has been generated by catchment and regional water boards and regional councils, primarily as resource reports, draft management plans and water conservation/consent reports (e.g. NCCB 1983, 1986, 1991). However, apart from a limited number of studies on the ecology of individual species or reaches, little coordinated ecological research has taken place to assess the overall values and function of braided river ecosystems (Hughey et al. 1989; Sagar & Glova 1992; Reinfelds & Nanson 1993; Meridian Energy 2003; Gray 2005; but see O'Donnell & Moore 1983). Economic development, particularly demands for hydroelectric power generation and irrigation water are putting increasing pressure on New Zealand river systems (Young et al. 2004).

2. The habitat template: physical conditions within a braided river

2.1 GEOMORPHIC AND GEOLOGIC TEMPLATE

New Zealand sits atop a geologically active tectonic boundary resulting from the break-up of the ancient Gondwana supercontinent (Kamp 1992). Approximately 80 million years ago (mya), the Tasman Sea began to open, separating New Zealand from what would become Australia and Antarctica. About 60 mya, movement ceased and New Zealand has remained physically isolated ever since (Gibbs 2006). For the first 70 million years of this separation the climate is thought to have been warmer than at present and vegetation was similar to that now found in Australia and New Caledonia (Stevens 1981). At this stage, New Zealand comprised a series of low-lying islands, but about 8 mya the Pacific-Australian plate margin began to move again, lifting the seafloor and beginning the process of mountain building. Subsequent mountain building, volcanic activity, and periods of glacial growth and recession have produced our contemporary landscapes, particularly the major river valleys in the South Island alpine regions. Early Pleistocene (1.8 mya) glaciers were not restricted to the valley systems present today. The broad framework of modern watersheds was developed during the Ross and Porika glaciations (1–2 mya; Pillans et al. 1992). Two major glaciations—the Waimaunga and Otira—further modified these valleys. The brief glacial recessions are particularly well documented in the Waimakariri and Taramakau catchments, and culminated with the end of the second Poulter Advance about 13 000 years ago (Gage 1977). Similarly, the Würm glaciation in Europe and the Wisconsin glaciation in North America ended approximately 10 000 years ago. The most studied braided river systems in other countries are therefore of comparable age to those in New Zealand (Muller & Kukla 2004; Smith 2004).

During the last 10 000 years, New Zealand's braided rivers have been sculpted by fluvial processes augmented by discrete tectonic events. For example, Reinfelds & Nanson (1993) described the three predominant mechanisms in the development of the Waimakariri River's braided river floodplain. First, riverbed abandonment by lateral migration of the active river bed (usually in the lee of tributary fans and bedrock spurs), followed by aggradation during high-magnitude flood events and, finally, localised riverbed incision. In fact, several authors have described braided rivers as being in a state of 'dynamic stability' whereby (despite a high turnover of habitat) the proportions of each habitat type remain relatively constant over time (Arscott et al. 2002; Hauer & Lorang 2004; Latterell et al. 2006). However, over longer time scales (hundreds of years) it would be less accurate to view these rivers as being in a state of balance or equilibrium. For example, Korup (2004) used historical aerial photography and geomorphic, morphostratigraphic and dendrogeomorphic evidence from 250 landslides in south-western New Zealand to describe the channel-altering effects of landslides. At least 6% of landslides caused major avulsions (channel shifting) and it is likely that the characteristic instability of braided rivers is accentuated by sediment pulses (Hicks et al. 2004). The effect of these events upon terrestrial and aquatic floodplain habitats can be very dramatic. In 1967, the Gaunt Creek landslide caused the braided Waitangitoana River on the West Coast of the South Island to alter its course, from merging with the Whataroa River to flowing into the Okarito River catchment. The lower reaches of the Waitangitoana River are now predominantly fed by groundwater as opposed to surface runoff and, after the landslide, a large portion of the wetlands at the inflow of Lake Wahapo were buried under gravel. Goff & McFadgen (2002), Cullen et al. (2003) and Korup (2004) have documented evidence of several periodic seismic events that have caused river aggradation and driven vegetation destruction and channel instability throughout New Zealand.

2.2 CONTEMPORARY GEOLOGY AND GEOGRAPHY

An extensive desk-top mapping exercise by Wilson (2001) identified all the river systems that exhibit braiding within New Zealand. Overall, 163 river systems had braided reaches, with a total of 248 400 ha of braided river habitat occurring in 11 of New Zealand's 14 regions. Canterbury and the West Coast had the largest areas of braided river habitat, with 60% and 19% of the national total, respectively. Braided rivers occur on both coasts of the South Island but were restricted primarily to the east coast of the North Island (Fig. 1). Wilson (2001) also reported that North Island braided rivers have climatic conditions (temperature, solar radiation and humidity) similar to those in the northern South Island, and unlike those of the more southern regions of the island.

The majority of braided rivers in New Zealand drain lithologically unstable catchments predominantly of greywacke, mudstone or other sedimentary rocks, although some of the rivers in South Westland (such as the Landsborough and Arawata) are dominated by schist and gneiss. In the North Island, highest sediment production occurs in the East Cape region, where high rainfall, natural geologic instability and accelerated erosion (due to deforestation) contribute to high sediment yields (Mosley & Duncan 1991; Hicks et al. 2004). Sediment yields in the South Island are highest on the flanks of the Southern Alps and the yields in some rivers have been estimated to be among the highest in the world (Griffiths 1979).

High precipitation on the flanks of the Southern Alps in the South Island and on the Kaimanawa, Raukumara and Ruahine Ranges in the North Island contributes to the formation of braided rivers. Many of New Zealand's braided rivers also have glacial sources and snow-laden upper catchments, which also

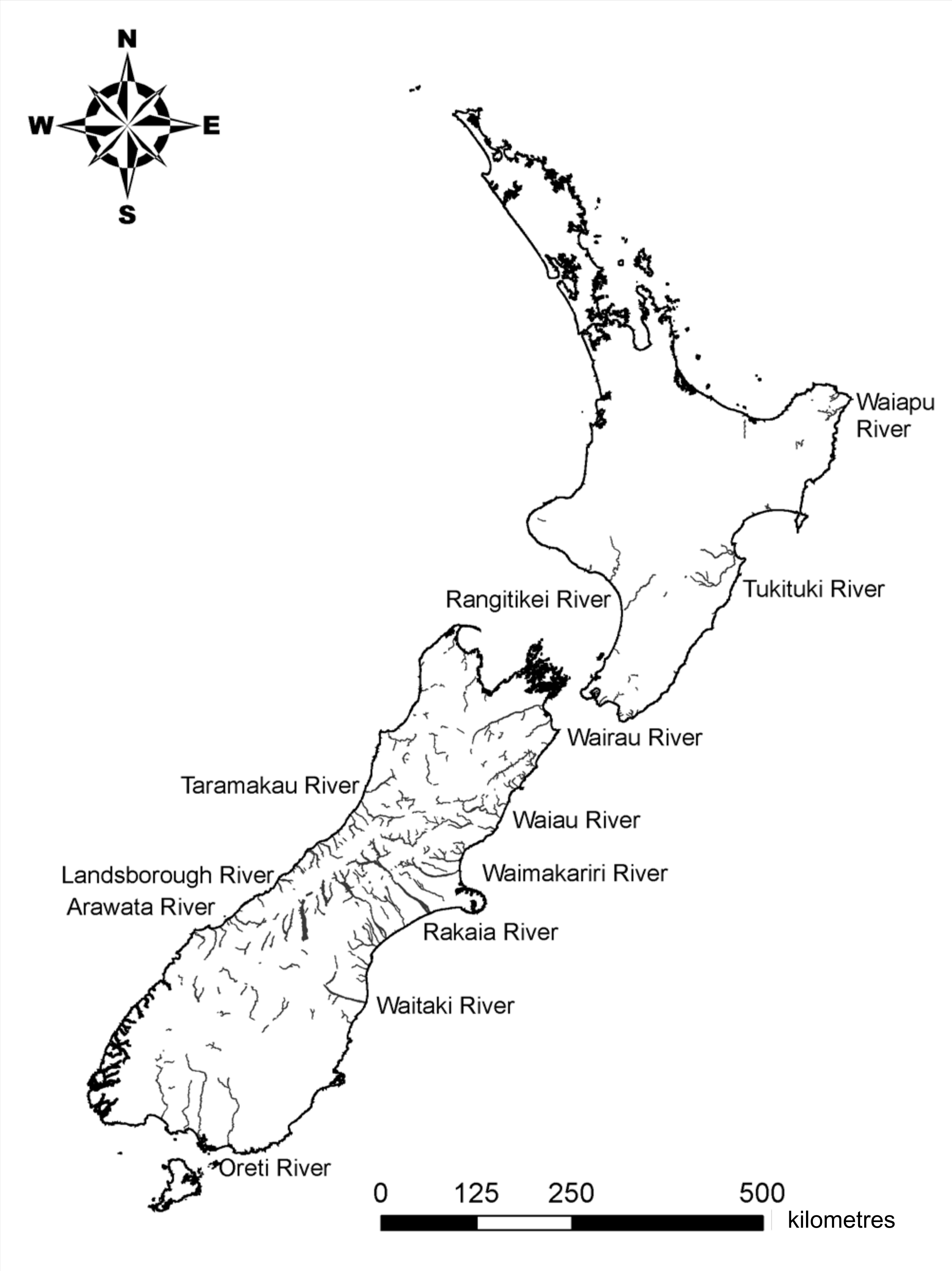

Figure 1. The braided reaches of the 163 braided rivers in New Zealand (New Zealand Land Resource Inventory). The locations of the larger rivers from each region have been labelled.

contribute to their volatile hydrologic regimes. The South Island's alpine rivers are characterised by large floods resulting from heavy rain along the Main Divide, often compounded by snow melt. Floods are common in spring and early summer. In contrast, flows are generally low in winter when water is locked in upper catchments as snow and ice, and in high summer and autumn when precipitation levels are low. Many South Island braided rivers experience extreme low flows during late summer and autumn. These seasonally-related water flow trends are common across braided rivers around the world. The Tagliamento in Italy and the Flathead in Montana, USA, have been similarly described as 'flashy pluvio-nival' (i.e. with flow characteristics dominated by rain and snow melt; Tockner et al. 2003; Hauer & Lorang 2004). In Switzerland, the braided Roseg River exhibits a distinct glacial-melt flow regime, which features strong seasonal flow patterns and a marked diel flow pattern during the summer melt period. These diel patterns are generally absent in New Zealand's braided glacial rivers, as any such patterns are usually masked by the high rainfall that also occurs during the melt season (McSaveney & Davies 1998).

2.3 CONTEMPORARY FLOODPLAIN HABITATS

Habitats found on braided river floodplains are physically unstable and have high turnovers. Despite this, biological communities survive because the relative proportion of each habitat in any particular floodplain remains roughly constant over time (Arscott et al. 2002; Hauer & Lorang 2004; Latterell et al. 2006). This means that although a particular habitat may be destroyed in one place, it will remain intact or be forming in others. Consequently, mobile taxa will persist within the floodplain, and form part of a meta-population within the river system (Begon et al. 1996). Furthermore, the existence of habitats in different successional stages provides a highly diverse mosaic of floodplain habitats, each with its own distinct biological communities. In New Zealand, Burrows (1977) reviewed the literature on riverbed vegetation of the upper Waimakariri River basin and suggested a time scale for the successional colonisation of riverbed features. Building upon his study, and using aerial photography from 1948 to 1986, Reinfelds & Nanson (1993) proposed that the upper Waimakariri River re-works its entire floodplain every 250 years, predominantly by lateral migration of the most active part of the braid (Fig. 2). Thus, floodplain habitats may be destroyed by high flows and channel movement on one side of the floodplain while other habitats are developing on the other side of the floodplain.

In a similar study in the upper Ashley River/Rakahuri in Canterbury, Warburton et al. (1993) observed the presence of stable bars and islands amongst the unstable materials, and noted that the active channel of the river was steadily migrating northwards. Mosley (1982a) made use of controlled water releases along the braided Ohau River in South Canterbury to estimate the effect of varying discharge from 26.5 m^3/s to 507 m^3/s on channel morphology. As discharge increased, the physical characteristics of existing channels changed, and new channels formed that were physically similar to the original channels. Mosley concluded that across the range of discharges the habitat types available remained proportionally relatively constant, and thus braided rivers may, in some respects, be morphologically more stable than single-thread rivers. More recent work has focussed upon riverbed turnover within the lower Waimakariri River. A combination of digital photogrammetry and LiDAR (Light Detection and Ranging

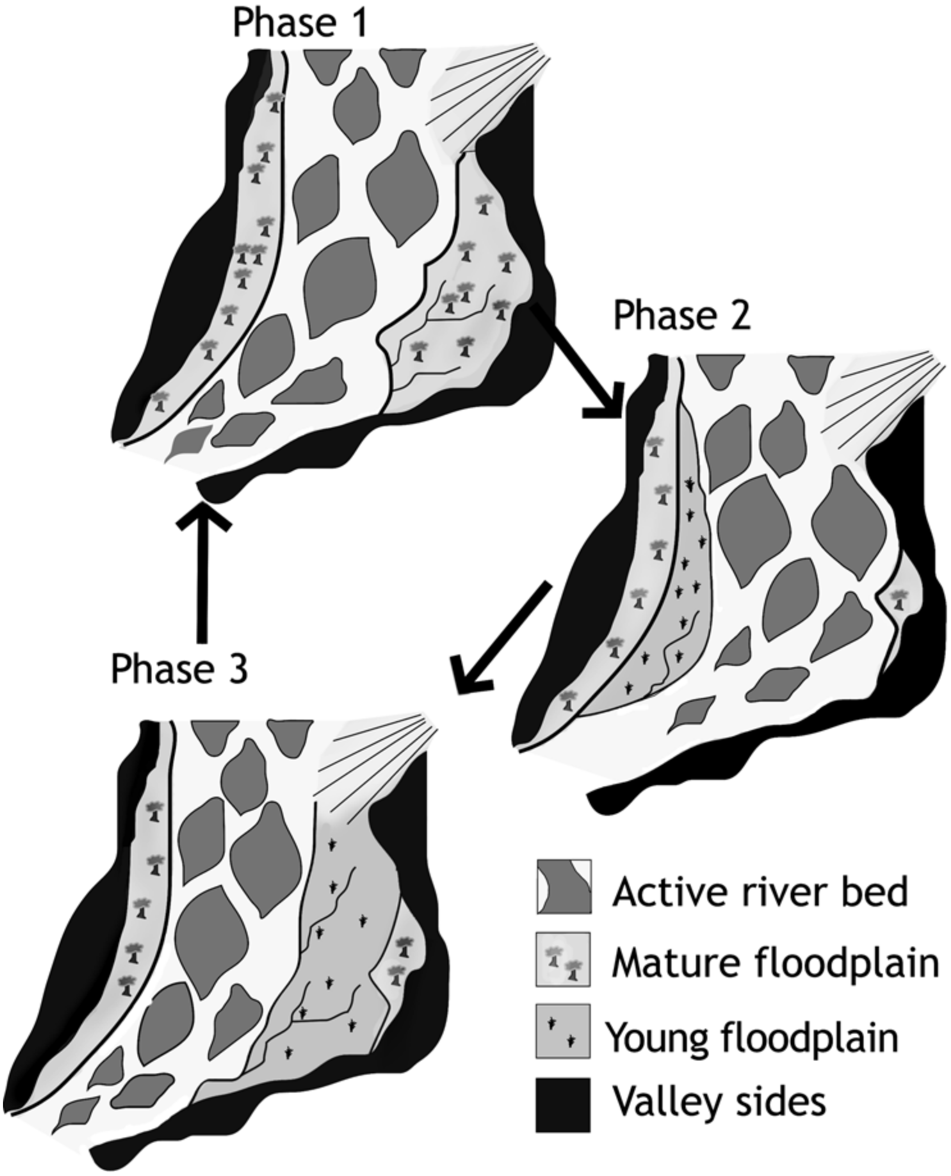

Figure 2. Floodplain re-working by lateral migration of braided channels. Adapted from Reinfelds & Nanson (1993).

or Aerial Laser Scanning) have been used to create 3-D models of the river bed which may be compared over time to investigate the influence of flooding on river morphology (Hicks et al. 2003; Lane et al. 2003; Westaway et al. 2003; Hicks et al. in press). Although it did not specifically focus upon in-stream habitat types, this recent research has shown that the lower Waimakariri River turns over two-thirds of its available floodplain annually (> 0.2 m vertical erosion or deposition) and would probably re-work its entire floodplain within 5 years. The most persistent areas of wetted habitat were those found within the dynamic braids. These were, therefore, the most physically disturbed of the aquatic habitats available. These findings highlight the potential ecological value of spatially minor, but more stable peripheral floodplain habitats. Temporal mapping of habitat types within New Zealand braided rivers has not been done to confirm habitat dynamics and the appropriateness of the shifting mosaic steady state model, although it is considered applicable to unmodified New Zealand systems (M.D. Hicks, pers. comm. 2007).

The role of large woody debris in structuring stream morphology is well documented in New Zealand and elsewhere (Gurnell et al. 2002; Hicks et al. 2004). In small New Zealand streams, large woody debris has been shown to influence channel morphology and pool formation, as well as providing important habitat for invertebrates in streams with otherwise unstable silt or pumice substrates (Hicks et al. 2004). Whilst the role of large woody debris has not been assessed in New Zealand's braided rivers, studies elsewhere indicate that wood may play an important role in large rivers (Gippel et al. 1996; Gurnell et al. 2000a; Van der Nat et al. 2003). In large rivers, wood has been associated with the creation and maintenance of bars and islands and sites for avulsion (channel shifting) and the formation of secondary channels. Pools form around embedded logs in response to flow diversion imposed by the root wad, and fine sediment accumulates downstream along the trunk (Gurnell et al. 2002). Many rivers in Europe suffered major deforestation of their riparian zones prior to the 16th century; however, investigations of woody debris accumulations in the mostly unmodified Tagliamento River, in Italy, have revealed the links between river morphology and riparian forest/woody debris. Wood storage within the active channel of the Tagliamento is spatially variable. Small quantities were found on the open gravel surfaces and intermediate quantities with mature islands, but large quantities were associated with pioneer or developing islands. The majority of this wood accumulated on bar crests, the point of formation for pioneer islands (Gurnell et al. 2000a; Gurnell et al. 2000b). Islands form in the lee of debris jams, as evidenced by the decreasing age of vegetation from upstream to downstream. The process of vegetated island development may also be accelerated if the woody debris is still alive and able to sprout (Gurnell et al. 2002). Furthermore, woody debris appeared to be more abundant in headwaters than in the lower reaches of rivers; thus, under natural vegetation conditions, a debris gradient occurs along the river. How this longitudinal gradient and the movement of wood downstream affects flow, habitat and the availability of carbon to food webs is poorly understood.

The condition and age of vegetation along a river's riparian corridor may substantially influence channel geomorphology, primarily by altering bank strength and flow resistance (Gran & Paola 2001). Numerous studies have linked channel properties such as width, depth and velocity to vegetation density in the riparian corridor (Graf 1978; Andrews 1984; Hey & Thorne 1986; Huang & Nanson 1997; Rowntree & Dollar 1999; Millar 2000), and vegetation type or density to channel form, e.g. braided or meandering (Mackin 1956; Brice 1964; Nevins 1969; Goodwin 1996; Gran & Paola 2001). However, in many developed regions throughout the world, riparian forests have been removed to create farmland. Since people arrived in New Zealand, much indigenous riparian forest has been removed and replaced with tussock grassland and pasture (Miller 2002). Subsequently, thousands of kilometres of stream and river banks have been re-planted with willows in order to prevent floods from damaging adjacent farmland (Miller 2006; Mosley 2004). Mosley (2004) suggested that rivers in New Zealand may be responding to increased riparian re-aforestation by narrowing and, for some lowland Canterbury rivers, this may represent a return to the stable anastamosing form they had prior to deforestation by Maori and European colonists.

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