The importance of 'moving targets' in assessing what is physically achievable and what we seek to achieve in river restoration practice.

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Key Points

- The shifting baseline of societal aspirations for river management targets ongoing improvement in river condition
- Insights from the past provide critical guidance for river restoration practices
- Future environmental conditions are likely to be different, such that rivers will have differing ranges of variability and evolutionary trajectories, with multiple (alternative) states possible in many instances
- Visions and goals of restoration should be viewed as 'moving targets', framed within an adaptive management ethos
- The river evolution diagram provides a conceptual tool that helps appraise 'moving targets' in relation to historical and likely future trajectories of adjustment.

Abstract

The shifting baseline syndrome asserts that what we measure against in environmental assessments is dependent upon the condition/state of ecosystems at a particular timeframe of reference. Although initially conceived in relation to measures of biodiversity, here we show how geomorphic considerations can use this concept to frame shifting terms of reference that define what is realistically achievable in restoration activities that address concerns for the physical structure and function of river systems. We demonstrate the use of the river evolution diagram as a generic tool that relates the historical range of variability to notions of naturalness, showing how understandings of evolutionary trajectories can be used to determine the best achievable condition for any given system. Given multiple alternative pathways of adjustment, and the potential for threshold-induced river change, restoration activities are most appropriately framed as 'moving targets'. Adaptive (flexible) management frameworks are required to communicate and facilitate adjustments towards uncertain futures in which surprises are inevitable.

Keywords

Fluvial geomorphology, shifting baseline, river evolution, restoration

Introduction: What are we trying to achieve in river restoration?

Effective river restoration activities view scientific considerations alongside socio-economic issues and cultural associations in determining what is desirable, what is realistically achievable, and how we set out to achieve clearly stated visions and associated goals. Proactive practices work with the type of river under consideration, its position within the catchment of concern, its present condition, and responses to prevailing (and likely future) drivers, pressures and stressors that impact upon its evolutionary trajectory. Such considerations must be clearly developed and communicated as part of visioning processes and the implementation of associated plans of action that express and engender what we seek to achieve. These are integral components of adaptive management.

In this paper we urge caution in the use of understandings of historical conditions and variability as a basis for river restoration efforts (Dufour & Piégay, 2009; Hiers et al., 2012). In worst-case scenarios, such re-restoration activities are an alternative form of 'command and control' practice, 'locking-in' river futures to a particular state or condition and process regime (Kondolf et al., 2006). Activities that recreate rivers that are 'fixed in place' are 'frozen in state/time' are likely to set path dependencies that are difficult to unpick and reframe, imposing significant constraints upon future management options and costs that must be met by future generations. As contemporary conditions are different, evolving in new ways, and shaping different landscape and ecosystem futures, we feel that river restoration plans and design should incorporate future variability through the use of flexible, open-ended and dynamic goals. As approaches to the physical management of stream channels evolve and encompass geomorphic principles of dynamism, it is important to highlight that prospective future adjustments may engender the adoption of a range of alternative future states (and behavioural regimes), such that there may be a range of acceptable outcomes. Surprising outcomes are inevitable in a complex, emergent world. Numerous challenges are faced in managing for such inevitabilities, for which the critical first step entails recognition of inherent uncertainties (e.g. Hillman and Brierley, 2008). Identifying ranges of variability, and placing constraints upon likelihood of prospective outcomes (and associated preferences and priorities) are vital issues to address (see Brierley and Cullum, 2012). Determination of thresholds of possible/potential concern provides insightful practical guidance with which to inform the proactive management of prospective futures (e.g. Gillson and Duffin, 2007).

This paper demonstrates the use of a simple conceptual tool (the river evolution diagram) to guide analyses of likely future trajectories and rates of river adjustment. We frame this contribution by building upon the shifting baseline concept that outline 'what is expected' for any given river system, striving to incorporate future variability into restoration planning and design by targetting the 'best achievable physical state' under prevailing and likely future conditions. In light of these understandings, we feel that effective restoration practices should not be framed in relation to notional benchmarks, reference conditions or endpoints, or 'historical ranges of variability' (Wohl, 2011); rather, vision statements and associated restoration goals should be framed as moving targets that reflect ranges of prospective future states and behavioural regimes (see Hughes et al., 2011, 2012).

Fluvial geomorphology and the shifting baseline syndrome

The shifting baseline syndrome asserts that what we measure against in environmental assessments is dependent upon the condition of a given system at a particular timeframe of reference. In its original use, this concept referred to changing expectations in the management of fish stocks, wherein seemingly healthy numbers at any given time may be a mere fragment of what has gone before (Pauly, 1995). Essentially, this highlights the importance of explicitly defining what we measure against in performing environmental assessments, relating what is observed (i.e. measured) to what is expected (i.e. the baseline). Although initially conceived in relation to measures of biodiversity, this concept can also be used to frame shifting terms of reference in geomorphic assessments of what is realistically achievable in river restoration.

Detailed reconstructions of past river adjustments and responses to disturbance events provide critical insights in analyses of prospective future pathways and rates of adjustment, helping to differentiate among multiple (alternative) states. Appraisals of reach sensitivity must be viewed in context of catchment-scale connectivity to assess the influence of stressors and limiting factors upon the trajectory of process-linkages and morphological responses. However, significant caution should be applied in using understandings of historical conditions and variability as a basis for restoration efforts, as contemporary conditions are different, evolving in new ways, and shaping different landscape and ecosystem futures (see Brierley & Fryirs, 2008). A future focus in restoration planning and design moves beyond efforts to reconstruct rivers as they were, 'working with' the inherent variability of 'natural' processes (e.g. Beechie et al., 2010; Kondolf, 2011) while recognizing that altered boundary conditions, modified catchment inputs and evolutionary trajectories fashion what is achievable into the future (Brierley & Fryirs, 2009; Fryirs et al., 2009). Such framings recognize explicitly that inherent uncertainties of a 'no analogue future' may bring about surprising outcomes and the emergence of novel ecosystems in some instances (Hobbs et al. 2009, 2013).

Key questions to address in assessing what is achievable through restoration interventions include: How far have the goalposts been shifted, with what consequences for what is achievable? Has human disturbance induced river change such that recovery to the type of river that previously existed is no longer possible? If recovery is possible, what is the best achievable state for that particular type of river? Alternatively, is change to a different type of river likely, and what is the best achievable state for that type of river? Can prospective threshold states and transitions be identified? The river evolution diagram (Brierley & Fryirs, 2005) provides a tool to address these questions.

Construction and use of the river evolution to assess prospective river futures

The long term evolution of river systems is fashioned by the interaction of flow, sediment and resistance elements in any given setting. As boundary conditions change, rivers evolve. The river evolution diagram places the contemporary capacity for adjustment of a river and its behavioural regime in context of the range of states that are possible in that setting (**Fig. 1**). Visual representations of the river (e.g. channel geometry and planform) can be placed atop this diagram, but for simplicity they are not included here (cf., Brierley & Fryirs, 2005). This conceptual tool can be used to assess 'what is expected' and 'what is achievable' in geomorphic terms for any given river system (see Fryirs et al. (2012) for a worked example).

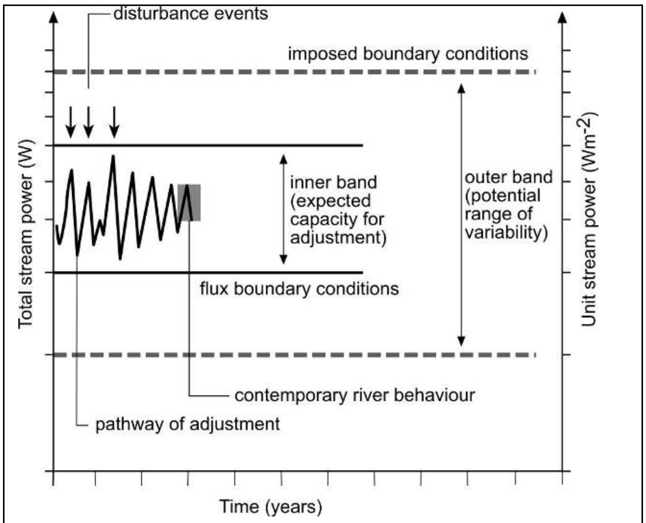

Figure 1 Basic components of the river evolution diagram (modified from Brierley & Fryirs, 2005).

For any given landscape and environmental setting, there is a '*potential range of variability*' within which differing types of river can form. Each type of river has its own behavioural regime, defined by its *expected capacity for adjustment* and characterized by its own *pathway of adjustment* (**Fig. 1**). Rivers change (evolve) from one type to another, within the potential range of variability that is evident in that particular location/setting. Adjustments to channel geometry and resistance elements along the valley floor fashion the use of available energy (i.e. the relationship between unit and total stream power). The outer band on the river evolution diagram is set by the range of total stream power conditions experienced by a reach over geological timeframes. This is a measure of the *imposed boundary conditions* within which the river operates (**Fig. 1**).

The channel adjusts to prevailing conditions to determine its width, and hence unit stream power. This is expressed on the river evolution diagram as the inner band of *flux boundary conditions*. The range of energy conditions set by the outer band determines the range of river morphologies that may operate in that setting. The position of the inner band within the outer band reflects channel adjustments to prevailing flux conditions. Adjustments around a *characteristic form*, and associated unit stream power conditions, are shown within the inner band on the diagram.

In framing the river evolution diagram, a critical distinction is made between river behaviour and river change. *River behaviour* reflects adjustments around a characteristic form, whereas *river change* reflects alteration to a different state, characterized by a different set of process-form relationships. If river change occurs, the river has a different behavioural regime with a different *expected capacity for adjustment*. The ease and frequency with which channels adjust their width and/or depth and planform attributes vary markedly for different types of river (cf., gorge, braided river, passive meandering river and swamps). The potential extent of adjustments (i.e. the *behavioural regime* of the river as indicated by the width of the inner band) is measured in terms of the range of formative unit stream powers that induce adjustments to river morphology, without resulting in river change. This conceptualization provides a platform to assess potential river responses to changes in stream power condition (outlined below).

Notable variation in the amplitude, frequency and shape of the pathway of geomorphic adjustment is evident for different types of river (Brierley & Fryirs, 2005). In essence, the *pathway of adjustment* is a visual representation of the morphologic and behavioural adjustments to on-going variability in the type, extent, and sequence of disturbance events on the one hand (i.e. impelling forces), and the capacity of the system to absorb change on the other (i.e. the effectiveness of response mechanisms as conditioned by resisting forces along the reach). This is manifest through adjustments to unit stream power under a range of formative flows. The timing and type of disturbance events are indicated on the river evolution diagram by arrows on the edge of the inner band. The shape of the pathway of adjustment varies in response to these disturbances.

In some instances alterations to prevailing flux boundary conditions (i.e. flow/sediment conditions and the nature/distribution of resistance elements on the valley floor) may result in *river change* where the formative processes that generate, sustain and adjust river morphology are fundamentally altered. These scenarios are depicted on the river evolution diagram by a shift in the position of the inner band, from Zones A or B, to Zone C on **Fig. 2**. Reaches now operate within a different inner band, with altered unit stream power conditions and capacity for adjustment. An accompanying transition in the pathway for adjustment marks a change in process-form associations along the valley floor. This shift in position may be accompanied by an *expanded* or *contracted capacity for adjustment* of the river (i.e.

the range of behaviour may be accentuated or suppressed). This is shown as widening or narrowing of the inner band (**Fig. 2a, b** respectively).

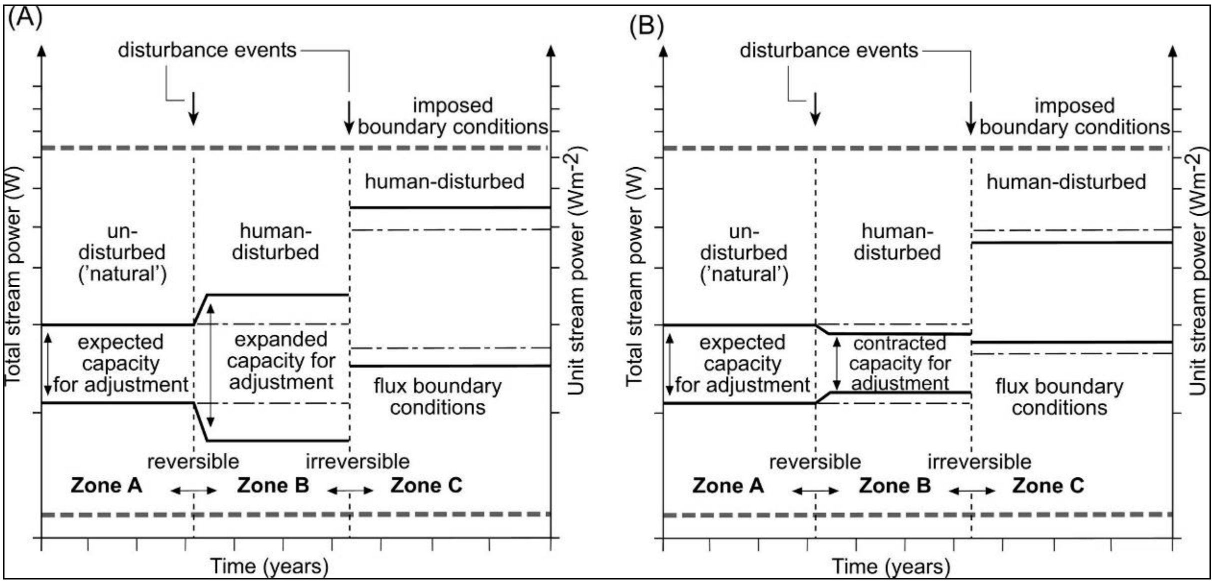

Figure 2 Expanding the complexity and uses of the river evolution diagram (modified from Brierley and Fryirs, 2005). Note that the imposed boundary conditions are the same as shown for Figure 1, such that geologic and climatic factors that influence the environmental setting are essentially set. The diagrams represent how disturbances have altered either the capacity for adjustment for a particular river type (shift from Zone A to B), or resulted in river change to a new river type (shift from Zones A/B to C). For simplicity, the pathway of adjustment shown on Figure 1 is not included here (different shapes would be evident in Zones A, B and C). (a) represents disturbance responses that have expanded the capacity for adjustment, (b) represents disturbance responses that have contracted the capacity for adjustment.

When *reversible adjustment* occurs, a fundamental shift in the type of river does *not* occur. This is represented by a shift from Zone A to Zone B in **Fig. 2**. The key defining attributes of the type of river remain unaltered in these instances, but other structural and functional attributes of the river may be modified. For example, a sand bed meandering river may have had a sinuosity of between 1.7 and 2.0 with cutoff formation occurring every 100 years, but the behavioural regime has been expanded such that channel sinuosity now ranges between 1.5 and 2.2, and cutoffs occur every 30 years. The key geomorphic structure of this type of river has not been altered, but the rate of adjustment has been accelerated, and the capacity for adjustment has expanded.

River change may take the form of a relatively simple, one-step transformation, or disturbance may set in train progressive adjustments around multiple states. In these instances, changes from the previous type of river may be *irreversible*. The key defining attributes of the type of river have changed, such that other structural and functional attributes are now evident for a different type of river. Using the example outlined above, if a sediment slug or a headcut passes through a sand bed meandering reach, the channel may straighten to a sinuosity of 1.1, altering channel and floodplain features and process-form interactions for what is now a low sinuosity sand bed river (represented by Zone C in **Fig. 2**). The geomorphic character and behaviour of this river has been fundamentally altered.

Spatial and temporal variability in forms, patterns and rates of direct and indirect human disturbance to river systems have altered river character and behaviour in many different ways and to variable extents. In some instances human activities have reduced (suppressed) the range of behaviour, elsewhere it has been expanded, and in other situations it has remained relatively consistent. Similarly, many human activities have simplified or homogenized river systems (e.g. impacts of flow regulation or channelization). Alternatively, in some instances relatively simple (homogenous) landscapes have been transformed into a complex assemblage of river features (e.g. Fryirs & Brierley, 2009). Across much of the world, multiple phases of activity can be discerned. This collective set of impacts fashions the historical range of variability of a river (e.g. Wohl, 2011) which sits atop natural variability (Brierley & Fryirs, 2005).

Building upon this conceptualization, individual and cumulative impacts of human disturbance can be shown on the river evolution diagram (**Fig. 2**) by (1) alterations to the position of the inner band within the outer band (i.e. how channel capacity and unit stream power has been altered if river change has occurred), and/or (2) the width of the band (contraction or expansion of the capacity for adjustment, and the behavioural regime of the river), and/or (3) the shape of the pathway of adjustment of the river (i.e. geomorphic adjustments of the channel that determine how energy is used). In this way, human disturbance is represented on the river evolution diagram as a change in river type, adjustments to the capacity for adjustment and behavioural regime of the river, or adjustments to the periodicity with which changes among various states take place on the pathway of adjustment. This conceptualization provides a platform to assess likely river futures, from which realistic target goals for geomorphic river structure and function can be assessed.

Moving targets as restoration goals for monitoring and evaluation

Recognizing that future environmental conditions are likely to be quite different to those experienced today, the river evolution diagram can be used to frame extensions of the shifting baseline concept, framing proactive and precautionary river management activities that incorporate appraisals of prospective future states wherein short-term goals are related to longer-term variability and environmental changes. Such endeavours strive to attain the best achievable state for any given system. In this framing, target conditions that guide management practices can be viewed as stepping stones along evolutionary trajectories of river systems, appraising success through monitoring and evaluation programmes along a 'moving scale of expectations', wherein what is considered appropriate today may not be considered appropriate in the future (Hiers et al., 2012). In this alternative view of a shifting baseline, what we measure against in determinations of river condition may change over time, as will the appropriateness of measures of river condition that are used to appraise the success of management interventions (c.f., Palmer et al., 2005, Fryirs et al., 2008).

Discussion and conclusion

Across much of the world, the shifting baseline of environmental expectations has moved towards increasingly positive aspirations. This reflects, among many considerations, changes in mindsets and approaches to river management practice in an era of river repair. Flexible and adaptable toolkits are required to underpin management applications that strive to 'work with nature', recognizing implicitly that inherent uncertainties will influence future trajectories of river adjustment. Catchment-specific considerations and the imprint of historical factors fashion what is achievable through restoration activities for any given system. The river evolution diagram provides a tool to appraise these relationships. In appraising river condition against a shifting baseline, we contend that aspirations for river futures should be framed in relation to the expected trajectory of the river, rather than a static assessment of some former condition. Prospectively, applications of these principles can support efforts to engender success in appropriately targeted restoration activities, enhancing societal and political support for future ventures and investment, thereby shifting the baseline of expectations further along the pathway towards improved river health. These geomorphic framings can be extended to consider risk assessments, identify threshold conditions, and to appraise ecosystem services, river values and the benefic-cost framings of river management activities in light of inherent uncertainties (Thorp et al., 2013).

Ultimately, river restoration activities reflect societal, institutional and political choices and deliberations. Efforts to conserve and improve river condition today are integral components of social and environmental justice programmes that seek to minimize the burden of costs for environmental repair, and the costs of outright loss, that may be experienced by future generations. Working with local communities to incorporate local knowledge and values is a critical component in the development of 'owned' management applications. Importantly, adoption of the scientific principles outlined in this paper have enormous implications for the effective governance of river systems, promoting the uptake of open-ended, proactive and enabling frameworks (see Gregory et al., 2011; Tadaki et al., 2014a, b).

Acknowledgements

We thank the editors and reviewer for helpful comments that improved the practical grounding of this paper. Gary Brierley gratefully acknowledges the support of a SRIP grant at the University of Auckland that facilitated his participation at 7ASM.

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