Towards defining geomorphic rarity and vulnerability; use of River Styles in High Ecological Value Aquatic Ecosystems (HEVAE).

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Key Points

- Rivers in New South Wales occur across a large range of geomorphic forms, derived from local geologic, lithologic and stream energy regimes
- The NSW River Styles database now catalogues 215 000 km of river reaches, allowing assessment of geomorphic rarity and threat across the State
- A number of river types are very limited in range, and are considered rare due to very limited distribution (uncommonness) or fragmentation, frequently hosting rare or threatened species
- Many river types remain vulnerable to future alteration, and require prioritisation for management actions

Abstract

Unlike in the field of ecology, defining geomorphic rarity of river systems has received relatively little attention. The fluvial geomorphology literature contains references to forms of rarity, denoting uncommonness (continental to basin scale rarity), unique geo-ecological relationships or vulnerability to alteration or destruction since European occupation of Australia. In this paper, we present a process to identify rarity in identified river forms defined using the River Styles Framework (Brierley and Fryirs 2005). A definition of geomorphic rarity for use in High Ecological Value Aquatic Ecosystems (HEVAE) has been made on the basis of: ***uncommonness*** meaning absolute rarity or endemism of a River Style, ***fragmentation*** where isolated remnants of a particular River Style occur, ***susceptibility*** where a River Style has a very low proportion of reaches in good condition or in moderate condition with rapid potential for geomorphic recovery, and ***vulnerability*** to alteration whereby geomorphic forms are under threat – directly or indirectly. Completion of NSW River Styles mapping now allows more detailed examination of risk to in-stream value matched to hydrologic stress modelling.

Keywords

Geomorphic rarity, riverine evolution, disturbance, high ecological value ecosystems

Introduction

The concept of rarity is well established in the ecological literature. Indeed, it may be argued that rarity drives ecological thinking (Jinping Yu and Dobson 2000). A number of categories of ecological rarity have been developed and debated for several decades (Rabbinowitz 1981, Flather et al 2007). Rarity also forms an element of discussion within geomorphic frameworks (e.g. Brierley et al 2002). The High Ecological Value Aquatic Ecosystems (HEVAE) framework (Aquatic Ecosystems Task Group 2012) describes geomorphic rarity as:

> The geomorphological processes of aquatic ecosystems conspicuously defines character. The kinds of features and processes under this criterion include:
>
> - geomorphic features of limited occurrence at the continental scale
> - geomorphic features that are vulnerable to threats
> - geomorphic features/processes important for evolutionary history
> - unusual hydrological features that are driven by geomorphology
> - extreme or unusual environmental conditions that affect the biota inhabiting the ecosystem (e.g. water chemistry or temperature) and to which the biota have adapted.

Rarity is a common term in ecological studies and by the NSW Scientific Committee under the NSW *Threatened Species Conservation Act 1995*. Rarity may mean a population or species that has very few members in existence over a continental or regional scale, or may refer to a population that is widely dispersed and vulnerable to local extinctions, and may be lost if threatening processes become cumulative (Flather et al 2007, Violle et al 2017). The central premises for rarity reflect vulnerability of highly specialised species that may not migrate to extinction, or whose habitat is remote, isolated or fragmented, or have been reduced in range and/or abundance due to habitat loss, predation by introduced species or pathogens.

However, defining geomorphic rarity is more difficult. No exact method to determine rarity exists. Different State jurisdictions have applied various metrics to determine rarity based on geomorphic variability and behavior or an inherent range of features across catchment, State or continental scales. Expert opinion is frequently relied on to inform rare geomorphic forms and occurrence (Clayton et al 2006). Other methods rely upon a single occurrence value, such as a 1% representation for a specific river type in a catchment (Lampert and Short 2004), or spatial analysis to determine fragmentation or outliers of general river forms or threatened habitats (Clayton et al 2006, Grove et al 2015, Macgregor 2011). These methods may adopt some thresholds to the methods used in the ecological literature, though at a very limited temporal scale – usually with no follow up monitoring to determine whether such unusual geomorphic forms persist or change over time.

The New South Wales government applied the HEVAE framework to support its assessment of likelihood of threat to geomorphic features that support target ecosystems or species (Healey et al 2018). The NSW River Condition Index framework adopts the FARWH approach (Alluvium Consulting 2011, Healey et al 2012), focusing on the 'physical form' index. This requires information on the range of fluvial geomorphologic forms present throughout New South Wales, the likely evolutionary history of geomorphic river types, their susceptibility to alteration or degradation, their geomorphic condition and the trajectory of geomorphic recovery or alteration which is occurring.

Similarly, defining rarity or threat requires an appropriate scale to identify commonness or rarity of a particular fluvial type. Similarities between ecological and geomorphological rarity appear when similar processes affect habitat diversity, required substrate or refuge, or water quality. Geomorphic rarity exists where rivers are formed within narrow boundaries of hydraulic regimes, lithology and slope, or where previously common geomorphic forms have been altered or destroyed. Geomorphic rarity may follow species rarity, falling generally within the following classes (Jinping Yu and Dobson 2010);

- **endemism**; an extremely limited total population size, occurrence or distribution, based on an appropriate scale,
- **fragmentation**, small, disconnected populations following destruction of sensitive geomorphic features, or introduction or extension of threatening processes across a catchment, region, State or continent,
- **vulnerability**; populations that are subject to threats based on external pressure or disturbance, including loss of highly specialized habitat needs or alteration of habitats

Rarity classification criteria - Endemism

To define rarity over a continental or multi-regional scale, a large, detailed and verified dataset must be available. That dataset must be reasonably comprehensive over an extended spatial area, and be available for interrogation, verification and ongoing monitoring to detect change.

The NSW River Styles database has compiled 215,750 km of river reaches into a set of catchment/basin scale maps and associated information, relating to geomorphic form, inherent fragility, geomorphic condition and recovery potential, using the River Styles Framework. Mapping coverage of all river basins in New South Wales was undertaken between 2000 to 2011, with a view to comparing rates of geomorphic change over decadal timescales. The River Styles dataset has been accredited for reporting to the Commonwealth

government (Hamstead 2010), and represents the most comprehensive foundation for ongoing investigation into geomorphic features, comparative condition and trajectories of change attempted in the State.

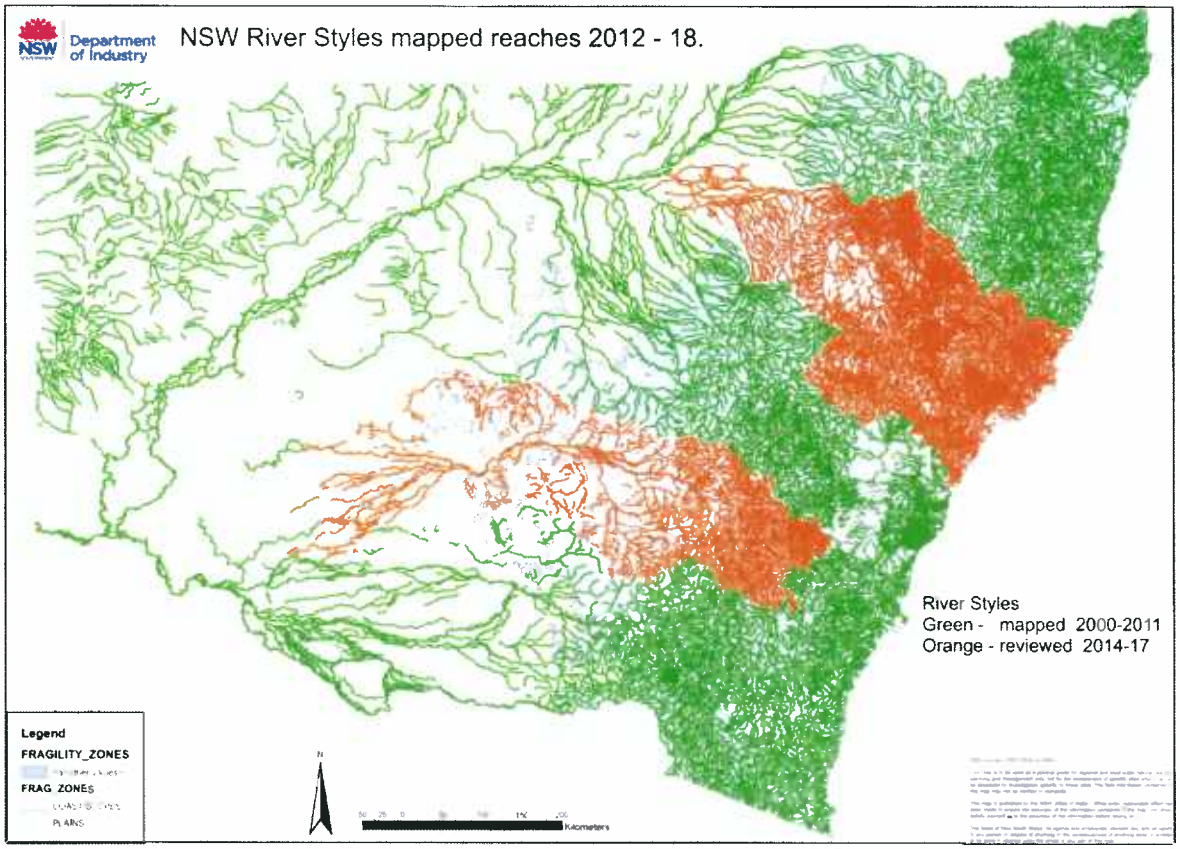

Figure 1 NSW River Styles. NSW Department of Industry – Crown Lands and Water Division. Green reaches were mapped to July 2011, while revised mapping to include 3rd order reaches occurred 2014-17.

The development of an assessment of rarity to the rivers that have been categorised across New South Wales requires a number of decisions. These include:

- thresholds at which rarity may be applied,
- spatial and temporal scales of assessment, mapping, evaluation and monitoring,
- indices to denote likelihood of alteration (sensitivity or fragility),
- association with or reliance by specific species or ecosystems that may be rare or threatened

Assigning rare classifications across a State-wide scale, based on a simple classification threshold for rarity due to uncommonness (endemism) creates a very large list of River Styles at over 50% of all identified river forms. One way to reduce the number and complexity of endemic geomorphic types is to collate only those represented in the majority of inland river basins or in at least three of four coastal regions across New South Wales. This may reduce the number of different types, but does not clarify the causes of endemism, or indicate whether threats to that particular form of river exist or may extend to become a significant threat to the style of river.

River Styles that have only short reach lengths by total river length may be dependent upon particular local lithology or a combination of local sediment source, gradients and specific stream power. For example, linear dune controls imposed on rivers in the north west of New South Wales have created several diverse river forms that are widespread in a small area of the State, while not represented in any other context. These include two distinctive River Styles; Laterally unconfined, dune controlled, chain of ponds and Laterally unconfined, dune

controlled, floodout. The only representative reaches of similar form identified elsewhere in the State are in very short sections of pinned rivers between linear coastal sand dunes.

Therefore, uncommonness requires a clear delineation of geological province, scale and representativeness to accurately define the likely presence of endemic river types. A representative list of highly sensitive River Styles assigned endemic, vulnerable and threatened status in inland New South Wales river basins is provided in Table 1.

Table 1 Endemic, vulnerable and threatened highly sensitive River Styles in inland NSW (by basin)

Group name – River Style	Endemic	Vulnerable	Threatened
LU CC Low sinuosity, gravel	L	BR, G, LMD	N, L, Murrum, LMD
LU CC Low sinuosity, sand	BR, G, CW, L	BR, G, CW, LMD	N, CW, L, Murrum, LMD
LU CC Meandering, fine grained	L	CW	CW
LU CC Meandering, gravel	BR, G, N, CW, Murrum, M	BR, G, N, CW, LMD	BR, L, Murrum, LMD
LU CC Meandering, sand	CW, L, Murrum, M	LMD	CW, L, Murrum, LMD
LU CC Wandering, gravel	N, LMD	Western	N, Western
LU CC Wandering, sand	N, L, Western	Western	N, Western
LU CC Lake delta	N, L		
PCVS Planform, low sinuosity, sand	G, M	LMD	BR, N, CW, L, Murrum, LMD
PCVS Planform, meandering, sand	N, CW, L, M	LMD	
PCVS Dune controlled, anabranching	LMD, Western	LMD	Western
LU DC Chain of ponds	BR, L, Murrum,	BR, G, CW, Murrum	BR, G, N, L, Murrum, LMD
LU DC Valley fill, fine grained*	G, N	BR, G, CW	BR, G, N, L
LU DC Valley fill, sand	BR, G, L, Murrum	BR, G, CW	BR, G, N, L, Murrum
LU DC Dune controlled, chain of ponds	LMD, Western		

BR – Border Rivers region (MacIntyre, Severn, Mole, Dumaresq, Tenterfield), G – Gwydir, N – Namoi, CW – Castlereagh, Macquarie, Bogan, L – Lachlan, Murrum – Murrumbidgee, M – Murray, LMD – Lower Murray Darling, Western – Barwon, Darling and all rivers west of the Barwon Darling.

*LU DC Valley fill, fine grained includes the former River Style – LU Channelised peat swamp.
LU = laterally unconfined valley setting, PCVS = partly confined valley setting, CC = continuous channel, DC = discontinuous channel

Rarity classification criteria – Fragmentation

Rivers in south eastern Australia have experienced varying levels of geomorphic impacts. Rivers that are deemed to be highly fragile (Simon 1995, Fryirs et. al. 2009) are likely to adjust rapidly when controlling elements are removed. A range of River Styles across New South Wales have become fragmented as adjoining reaches have incised or otherwise adjusted to alter from their 1790 state. This has caused remaining clusters of highly fragile River Styles to form in areas where either isolation or large State-managed areas, such as State Forests or National Parks provide protection to them.

Fragmentation is defined in this paper as a River Style where the Style is classed as having high sensitivity to alteration (Rustomji and Prosser 2001, Brierley and Fryirs 2005), and more than 25% of reach lengths are separated by two reach lengths between those reaches. This reflects the probability that the River Style was more common in the past, but has adjusted to become a different geomorphic form.

An example of a highly fragile, fragmented River Style is the chain of ponds. Three clusters of chain of ponds remain in New South Wales; Western (from Sturt National Park to Silverton), featuring large linear dune fields, Northern Pilliga sand outwash and the Mulwaree-Lake George-Tallaganda region in the NSW Southern Highlands. Fragmented chain of ponds are found across New South Wales, particularly on the New England Plateau, Dumaresq/Severn catchments on the New South Wales-Queensland border and Upper Lachlan and Upper Murrumbidgee catchments.

Identified reaches of chain of ponds, dune controlled chain of ponds and dune controlled anabranching River Styles are shown on Figure 2.

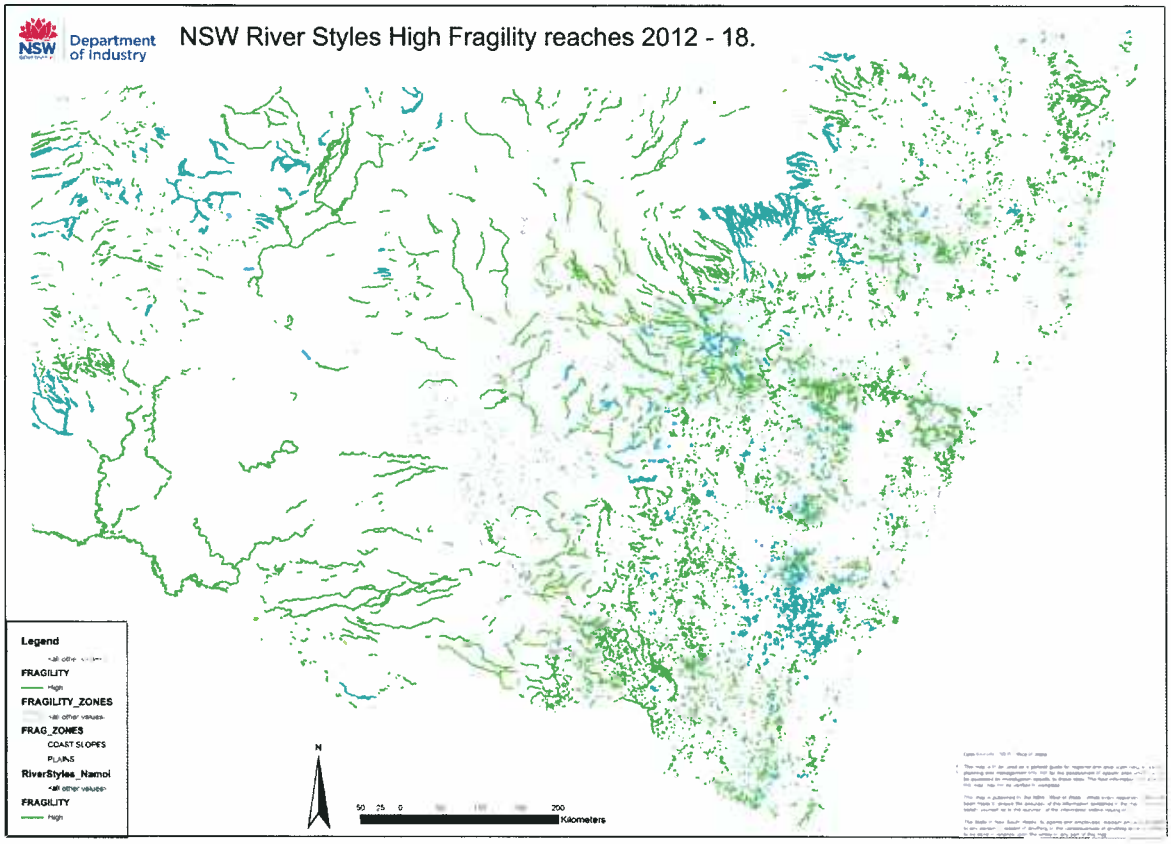

Figure 2. NSW River Styles. Mapped high fragility river reaches, including Chain of ponds, Dune controlled chain of ponds and Dune controlled, anabranching rivers (highlighted).

For example, the Southern Highlands chain of ponds and counterpart fragmented reaches on the New England Plateau are fragmented because areas where chains of ponds previously existed have been gullied since European settlement. The status and evolutionary history of chain of ponds located in the Pilliga outwash and on the New England Plateau remains largely unexplained, whereas the fragmentation of highly sensitive river forms on the Southern Highlands has been examined over a considerable period (Eyles 1977, Brierley and Munn 1997, Wasson et al 1998, Prosser et al 2001, Zierholz et al 2001, Olley and Wasson 2003, Hazell et al 2003, Mould and Fryirs 2017).

Rarity classification criteria – Vulnerability

Vulnerability is defined as rivers possessing moderate or high sensitivity to alteration and has a low proportion within River Styles Conservation or Rapid Recovery classes (Outhet and Young 2007); <10% for highly sensitive River Styles and <20% for moderately sensitive River Styles. This denotes the greater likelihood that highly sensitive rivers will adjust beyond their expected character and behaviour. Highly sensitive rivers are more likely to experience wide-scale adjustment, in planform, geomorphic attributes and bed material matrix, so that these River Styles are expected to form a larger proportion of vulnerable River Styles.

The concept of Threat

Threat represents the potential for a River Style, or a significant proportion of a specific River Style in a river basin, to adjust away from an intact or good condition towards an altered form. Identification of threat to a River Style includes an identified risk that physical disturbance or an adjacent threatening process, such as a bed knickpoint or sand slug, poses to a river form. The reaches that contain threatening process(es) are given

strategic priority in management. This is particularly necessary where fragmentation has been identified as common through any river basin, or where a State-wide assessment has been undertaken.

Threat may be indicated by several means:

- a River Style possessing high sensitivity has <10% of its river basin scale reach lengths in intact (Conservation) class,
- a River Style possessing moderate sensitivity has <2% of its river basin scale reach lengths in intact (Conservation) class,
- a River Style possessing high sensitivity has >25% of reaches within two reach lengths of Strategic reaches, or
- a River Style possessing moderate sensitivity has >50% of reaches within two reach lengths of Strategic reaches

The criteria used to identify threatened River Styles are based on known processes that threaten adjacent highly sensitive reaches, such as migrating bed incisions and/or sand slugs (Brierley and Murn 1997, Olley and Wasson 2003). Many of these types are both vulnerable and susceptible to immediate or short term change in a significant portion of their distribution. Where no current information is available, existing information on riverine geomorphic condition has been compiled for the assessment.

Discussion

The categorisation of river reaches across New South Wales into rarity and threat classes has been divided into river basins, for ease of assessment. At the same time, the HEVAE assessment is designed to support analysis of risk to instream value, and to inform Water Resource Plans under the Murray Darling Basin Plan. Therefore, data from the analysis of rarity and threat has only occurred at the scale of inland river basins, to date. Although preliminary collation of rare and threatened River Styles has been undertaken for coastal catchments in New South Wales, no comparative analysis of rarity has been undertaken. This should be conducted during 2018.

The fifteen River Styles identified in Table 1 are the most vulnerable river forms in inland NSW river basins. The collation of reach lengths and proportions to each rarity or threat category provides only a snap shot of the particular moment when the River Styles assessment occurred. The preliminary outcomes of this review indicates a slow increase in moderate to poor condition river reaches, largely due to increased riparian vegetation removal and physical disturbance of river channels by cattle. Further work must be undertaken to establish any trends in river condition or changes in the status of rare or threatened River Styles in inland New South Wales.

The correlation between rare River Styles and threatened species and ecosystems has not yet been fully examined. However, for example it is expected that links will occur between the distribution of threatened frogs and intact chain of ponds (Hazell et al 2004, Mo 2014) and species of threatened fish along lowland, laterally unconfined, low sinuosity gravel rivers in the Namoi Valley. To date, fish habitat assessments have predominately driven field investigations of geomorphic condition and recovery. Some programs are beginning to relate habitat recovery in areas where highly sensitive geomorphic forms have been developed, such as the northern New England region. The opportunities to focus on rare and/or threatened geomorphic forms to inform decision making processes have yet to be fully pursued.

Forecasting the likely extent and status of rare River Styles across New South Wales is complex and presents difficulties. As an example, land use activities such as protecting riparian and fringing vegetation, forms part of the objectives of protection to geomorphic diversity and riverine health. At the same time, removal of weed species, such as willows, is important to improving the integrity of riverine condition. The promulgation of collated datasets of rare and threatened geomorphic types, such as the NSW River Styles database, may lead to enhanced understanding of the complex nature of rivers across the State, and the need to protect geomorphic types that have become fragmented and vulnerable to degradation.

Conclusions

Destruction of many highly sensitive geomorphic types in New South Wales commenced shortly after European occupation. Today, many River Styles remain only in small, poor to moderate condition remnants on private land, and with strongholds remaining in public reserves. Some river types only exist in a narrow range of lithology, bed slope and unit stream power ranges. The recognition of rare riverine forms and understanding of their geomorphic evolutionary trajectories towards or away from recovery is essential to maintaining the diversity of rivers in New South Wales and protecting the species, ecosystems and human communities that depend upon them.

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