NEW ZEALAND JOURNAL OF ECOLOGY

FORUM

Braided rivers as a case for landscape-scale management

Holly A. L. Harris[1]*, Tara J. Murray[2], Jonathan D. Tonkin[1,3] and Angus R. McIntosh[1]

[1]Te Kura Pūtaiao Koiora | School of Biological Sciences, Te Whare Wānanga o Waitaha | University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand
[2]Te Papa Atawhai | Department of Conservation, PO Box 5244, Dunedin, New Zealand
[3]Te Pūnaha Matatini, Centre of Research Excellence in Complex Systems, New Zealand
*Author for correspondence (Email: holly.harris@pg.canterbury.ac.nz)

Published online: 29 August 2025

Abstract: Complex interactions between species, their environment, and people make species-specific management difficult and can lead to scale mismatches between management actions and ecological processes. However, taking a broader landscape-scale approach to management could help to avoid cascading negative effects of local-scale practices. Here, key lessons from ecological processes in a braided river highlight how landscape-scale management can benefit whole-ecosystem properties and species-specific persistence, and demonstrate the importance of considering the landscape context of ecological processes in conservation planning. Ultimately, we argue that a shift in thinking towards ecological processes at landscape scales will create more successful and cohesive management outcomes.

Keywords: braided river; conservation; landscapes; management; meta-ecosystem

Introduction

Ecosystems are complex, connected, systems where species, people, and the environment often interact in unpredictable ways. This complexity can result in unintended consequences when conservation strategies to manage threatened species, or the pressures affecting them, are initiated (Cruz et al. 2019; Fàbregas et al. 2021). As a result, conservation management strategies are not always effective. Additionally, management outcomes are often difficult to measure and frequently unreported (Kapos et al. 2009; McIntosh et al. 2018; Catalano et al. 2019). Taking a more flexible and adaptive approach where landscapes are managed to the scale of ecological processes that occur and resilience to future pressures is inbuilt could increase the chances of success for multiple conservation outcomes, from individual species to whole ecosystems (Gillson et al. 2013; Herse et al. 2022).

One of the biggest difficulties with conservation involves ecological scale mismatches. These mismatches between species' interactions with their environment and the scale of management may be avoided by considering the landscape and species contexts together (Cumming et al. 2017; Herse et al. 2020). For example, landscapes with high natural complexity and species that move between distinct local areas are likely to require a broader management approach than a homogenous landscape with low species movement and localised habitat requirements. Recognition of the importance of heterogeneity and the need for landscape-scale management due to its interactions with complexity and resilience has been increasing (Nyström & Folke 2001; Larkin et al. 2016; Cumming et al. 2017). However, despite their importance for ecological resilience, managing landscapes to match the scale of ecological processes is uncommon (Tockner & Stanford 2002; Herse et al. 2020).

Ecological processes, such as those affecting species persistence, often occur across both physical spatial scales and biological hierarchies, stimulating the development of ecological frameworks that represent spatial flows of energy, matter, and organisms within ("meta" system frameworks; e.g. Loreau et al. 2003; Leibold et al. 2004; Gounand et al. 2018) and across biological levels of organisation (e.g. spatial food-webs; Rooney et al. 2008). Macrosystem ecology shifts the focus from biological hierarchies to biological processes occurring within a hierarchical system across connected space (Heffernan et al. 2014; McCluney et al. 2014). In this way of thinking, the properties of an ecological system can be a product of both smaller-scale and broader-scale processes occurring within a landscape, allowing the integration of both spatial food webs and meta-systems ecology. The macrosystems framework is also useful to management because human activities generally occur within a macro-scale (Hefferman et al. 2014). Here, we refer to landscapes as areas within macrosystems (0.01–10^3 km^2; see McCluney et al. 2014) and use this macrosystems approach to emphasise how changes to local parts of a landscape can have effects on biodiversity, food webs, and species persistence across landscapes.

Management based at this landscape-scale could allow multiple ecosystem properties, such as the persistence of specific threatened species or improved biodiversity values, to be maintained within one broad conservation framework.

DOI: https://doi.org/10.20417/nzjecol.49.3608

Whilst funding and knowledge gaps often drive strategies toward individual population management, or blanket policy rules such as a fisheries quota, landscape-scale management will likely improve both species-specific conservation and the delivery of ecosystem services (Larkin et al. 2016; Cumming et al. 2017; Herse et al. 2020). This is particularly important when knowledge gaps limit the efficacy of species-specific conservation. Additionally, policy and law does not always align with best practice for conservation or management (see specific challenges and recommendations for braided river conservation and management below). Aligning the scale of management practice with ecological theory and updating legal frameworks accordingly will be key to effective conservation outcomes.

Here, we highlight key lessons from investigating the role of spatial heterogeneity in a complex river floodplain to advocate for landscape-scale contextual conservation management. Specifically, we address (1) the impact of landscape-scale heterogeneity on outcomes for biodiversity and whole-ecosystem properties, (2) how heterogeneity can aid and influence individual species' persistence, and (3) the importance of considering landscape context in conservation plans. We describe new knowledge of ecological processes in braided rivers to emphasise the difficulty of making fully informed management plans without context from broader spatial scales like landscapes. To avoid cascading negative effects through communities and food webs, highly connected, complex landscapes such as braided rivers require such approaches. We suggest this approach will not only benefit multiple ecological components but may also align with other management frameworks such as indigenous-led knowledge-based frameworks, thus allowing more cohesive management strategies between governing bodies.

Outcomes for biodiversity and whole-ecosystem values in heterogeneous landscapes

Preserving the natural spatial heterogeneity and temporal variability of landscapes will likely preserve both regional native biodiversity values and their persistence through time (Karaus et al. 2013; Peipoch et al. 2015; Milner et al. 2017). Heterogeneity contributes to regional biodiversity by enhancing co-existence in a landscape, reducing competition, and allowing re-colonisation after disturbances (Peipoch et al. 2015; Battisti et al. 2016; Harris 2024). These resilience mechanisms are particularly important in landscapes with strong spatial-temporal variability, such as braided rivers and intertidal zones (Cumming et al. 2017). In these complex landscapes, there are strong differences in the local physical environments and the species that reside within them driven by dynamic hydro-geomorphic processes (Hauer et al. 2016; Cumming et al. 2017). For example, in braided rivers large central gravel channels or major channels are flanked by smaller minor channels, and springs occur both in the central gravel part of the river floodplain and the wider more lateral areas where historic river channels may have run. Together the terrestrial and aquatic components of the braided river landscape are referred to as the braidplain (Gray et al. 2016; Harris et al. 2024). The mosaic of braidplain habitat creates the capacity for locally unique assemblages responding to local environmental conditions, and allows for complex species interactions across the different environment types, including recolonisation via dispersal from other parts of the landscape. We discuss these two processes next.

First, landscape heterogeneity supports high regional biodiversity, and simplification can lead to biodiversity loss (Peipoch 2015). Simplification of physical habitat is most associated with species loss due to the loss of specific niches (Peipoch et al. 2015; Larkin et al. 2016). For example, in braided rivers, different macroinvertebrate assemblages are found in lateral groundwater springs compared to those in gravel channels (Gray & Harding 2010; Karaus et al. 2013; Harris 2024). Additionally, lateral and mid-channel springs can support more disturbance-intolerant fish species such as salmonids (*Salmo* and *Oncorhynchus* spp.) and tuna (eels, *Anguilla* spp.). Springs, being the most lateral components of the braidplain, and embedded in the land least eroded by flooding, are typically highly affected by disturbance and are often the first components to disappear (Scarsbrook et al. 2007; Barquín & Scarsbrook, 2008). This local habitat disturbance and loss can be caused by combined anthropomorphic pressures from land encroachment, stock trampling, or flood mitigation plantings and plant invasion, or even lowered water tables from abstraction practices (Scarsbrook et al. 2007; Barquín & Scarsbrook, 2008). Loss of lateral floodplain complexity will likely result in the significant loss of whole-river biodiversity. This concept is consistent with general ecological theory that landscape heterogeneity contributes directly to biodiversity (Tilman 1982; Stein et al. 2014).

Second, whilst landscape simplification can cause the direct loss of biodiversity, loss of habitat complexity can also decrease biodiversity resilience and stability at emergent scales (temporal properties). In landscapes with highly connected species, movement facilitates recolonisation and compensatory dynamics because local environments fluctuate asynchronously (Karaus et al. 2013; Lamy et al. 2019; Larsen et al. 2019). For example, a study of macroinvertebrate assemblages across different aquatic habitats on Te Awa-a-Takatamira | the Cass River (Tekapo) found that local assemblages changed frequently through time, but the species composition across all three habitats meant that the same species were consistently found somewhere within the river landscape despite appearing and disappearing from local habitats through time (Harris 2024). Mayflies (Ephemeroptera) increased in mid-channel spring habitats in October and December then decreased in February, whereas in major channel habitats mayfly numbers were low in October to December then increased from February into May (Harris 2024). These compensatory dynamics between habitats are also true for total community biomass dynamics across local habitats within a braided river. Compensatory dynamics dampen whole-river variability and increase the capacity of a system, from species to populations to communities, to recover after localised disturbances, and so create more resilient landscapes (Nyström & Folke 2001; McCluney et al. 2014; Schiel et al. 2019).

Heterogeneity can aid and influence persistence of individual species

Species-specific conservation in New Zealand has traditionally occurred on a local scale. For example, weed control to protect the nesting habitat of a threatened bird may occur at local sites with short-term funding allocations despite processes of plant invasion often occurring at a much broader scale (such as water-driven dispersal throughout a river system) and over longer time scales (potentially multi-decadal; Hill et al. 2001). While there is a diverse array of conservation strategies being employed (e.g. predator-free landscapes such as the Perth-Whataroa catchment, and the Upper Rangitata River Ten Year Weed Plan), many strategies are still short term and localised, and encumbered by mismatches with legal definitions and directives. Shorter term or smaller-scale strategies can lead to mismatches between the scale of conservation management and the scale at which species interact with their environment (Cumming et al. 2017; see also Gurney 2022). Scale mismatches can be a particular issue with highly mobile species such as birds and diadromous fish, which transcend both traditional ecosystem boundaries and localised conservation efforts (e.g. Gurney 2022). Additionally, while local management is often applied to situations with landscape-scale ecological processes, the reverse can also be true where blanket rules reduce the ability for targeted local management (e.g. Herse et al. 2020). Local scale management is a crucial component of species conservation, but many species will also benefit from a contextual approach that accounts for the scale of species interactions with their environment, and thus the whole suite of ecological processes governing their persistence.

The first benefit of considering landscape contexts affecting mobile species (such as birds) is that resource availability can be better understood and conserved. For example, we expect that species feeding across heterogenous landscapes can have more consistent access to resources through time than landscape-constrained species (Rooney et al. 2008; Armstrong et al. 2021). This is particularly true in dynamic environments like braided rivers, where the availability of local food resources changes frequently with disturbances or physical environmental pressures. In these instances, local or specific food resources will disappear both in space and through time; however new resources become available because of asynchrony in spatially heterogenous locations. Predators able to take advantage of spatially and temporally dynamic food supplies will therefore benefit from differences in the timing of resource availability across a connected landscape. For example, spatial compensation affects the food resources of fish in Te Awa-a-Takatamira | the Cass River; although more resources are available during the summer than the winter, the existence of additional channel types provides more consistent availability of invertebrate prey than is provided by the major channels alone (Harris 2024). Additionally, mobile species utilise spatially varying resources in many different ways across a variety of spatial and temporal scales, including the exploitation of aquatic subsidies by predatory spiders, shifts in dietary regimes from aquatic to terrestrial with age in pohowera | banded dotterel (*Charadrius bicinctus*), and temporal shifts in generalist feeding based on availability in tarapirohe | black-fronted terns (*Chlidonias albostriatus*), e.g. from fish to lizards through the progression of the summer; Lalas 1977; Greenwood & McIntosh 2008; O'Donnell & Hoare 2009; Harris 2024). Such use of spatially distinct resources depends on spatial heterogeneity and the ability of species to move between local environments, resulting in landscape connectivity. With landscape simplification, resources may become more variable or be lost altogether, potentially destabilising the persistence of native birds, fish, and lizards, and the invertebrates they feed on.

The spatial heterogeneity of resources also provides mechanisms for whole food-web stability (McCann et al. 2005; Bellmore et al. 2015; Fig. 1). When predators connect

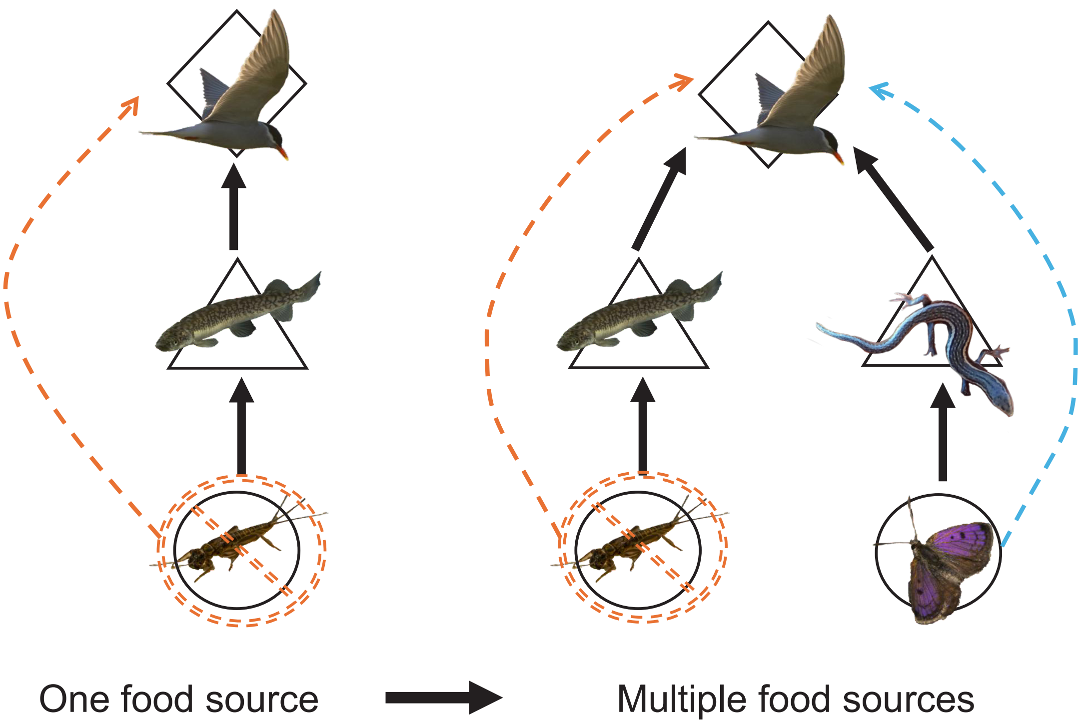

Figure 1. Two alternative food webs (depicted by shapes indicating trophic level and arrows indicating feeding interactions) show the consequences of multiple resource pathways when a resource at the bottom of the food web is removed during a stochastic event (orange 'not allowed' symbol). In a scenario with one resource from one area (left-hand food web) negative effects will propagate up the food chain and indirectly impact species at higher trophic positions (orange arrow), whereas when there are multiple food sources (right-hand food web) these negative effects will be counterbalanced by other feeding options (blue arrow). Photo credits: AR McIntosh and H Harris.

spatially distinct food sources within a landscape, individual consumer-resource interactions likely become weakened (McCann et al. 2005; Bellmore et al. 2015; Harris 2024). Weakened interactions enhance food-web stability by reducing the likelihood of cascading effects through food chains. Such cascading effects may be either top-down (e.g. predator over-feeding on a particular prey source) or bottom up (e.g. a prey species that has been limited by a disturbance subsequently restricting its predators) (McCann et al. 1998; Quévreux & Loreau 2022; Fig. 1). In a braided river, kōaro (*Galaxias brevipinnis*) could temporally reduce predation pressure on local invertebrate populations by moving between channels, while hunting spiders (e.g. *Dolomedes* spp. or Lycosidae) could reduce pressure on their terrestrial prey, such as moths or butterflies, by also catching emerging mayflies (Harris 2024). Spatial heterogeneity in this context works to moderate the strength of species interactions, thus potentially stabilising not only predator food sources but also naturally occurring oscillatory dynamics in populations (McCann et al. 2005; Bellmore et al. 2015).

Preserving space for natural landscape heterogeneity means there will be more spatial refuges for mobile species (Bellmore et al. 2015; Harris et al. 2024; McCabe et al. 2025). Flooding can reduce food sources by removing aquatic invertebrate biomass, and can wipe out bird nests and territories (Hughey 1998; Sanders & Maloney 2002; Harris 2024). In a large, unconstrained braided river there is typically enough space for the high flows to move through the braidplain without inundating the river from bank to bank, thus providing refuges for fish and maintaining some undisturbed foraging areas for birds (Fig. 2a). When rivers are constrained, flooding impacts become more significant and widespread relative to river area, potentially removing all food sources and predators alike, both homogenising and synchronising the system (Harris 2024; Fig. 2b). Allowing space within landscapes for natural variability and heterogeneity is therefore an important component of maintaining ecological resilience.

The importance of conservation plans considering landscape context.

Progress in understanding the ecology of complex landscapes such as braided rivers has increased significantly (Tockner et al. 2006; Gray et al. 2016; Hauer et al. 2016; O'Donnell et al. 2016). However, there are still significant knowledge gaps in our ability to apply conservation management at the right scale to ensure ecological resilience. In particular, the difficulty of finding rare species and understanding their requirements, resource use, and locations through time hinders targeted conservation efforts. For example, we know little about the flow requirements for forming habitat of the upland long-jaw galaxias (*Galaxias prognathous*) or the true invertebrate biodiversity specific to a given environment (Howard 2014; Murray & Anderson 2015; Eisenhauer & Hines 2021; Fig. 3). These uncertainties do not mean we cannot manage complex landscapes; rather we should manage them more conservatively. For example, in rivers, if the presence of a rare fish species is identified through broad detection methods such as eDNA, our lack of knowledge about the flow conditions, habitat formation, and resources the species requires should lead to more conservative minimum flow estimates. In this

a

b

c

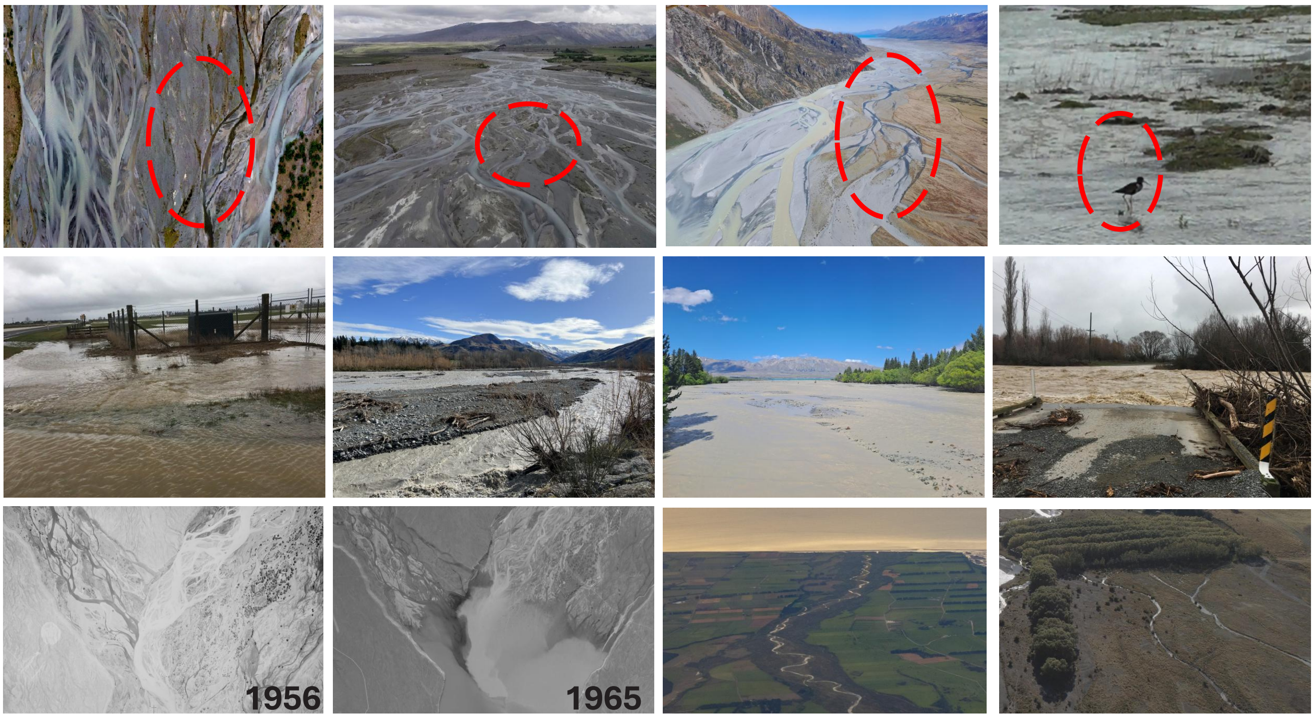

Figure 2. Rivers with more space relative to their flows (a) tend to have areas that remain intact during high flow events (circled in red) whereas large flood events in compressed rivers (b) caused by anthropomorphic management practices (c) tend to be more damaging. Areas that remain intact allow species refuges, recolonisation, and continuous species foraging (circled in red). Historic changes in land use can result in braided rivers transformed from highly heterogenous braidplain landscapes to areas swamped by water for dams or single channel rivers, often with ad hoc flood protection work in the form of tree planting. Photo credits: H Harris, I Barrett, K Whiting, AR McIntosh, and Land Information New Zealand (sourced from http://retrolens.com LINZ CC-BY 3.0).

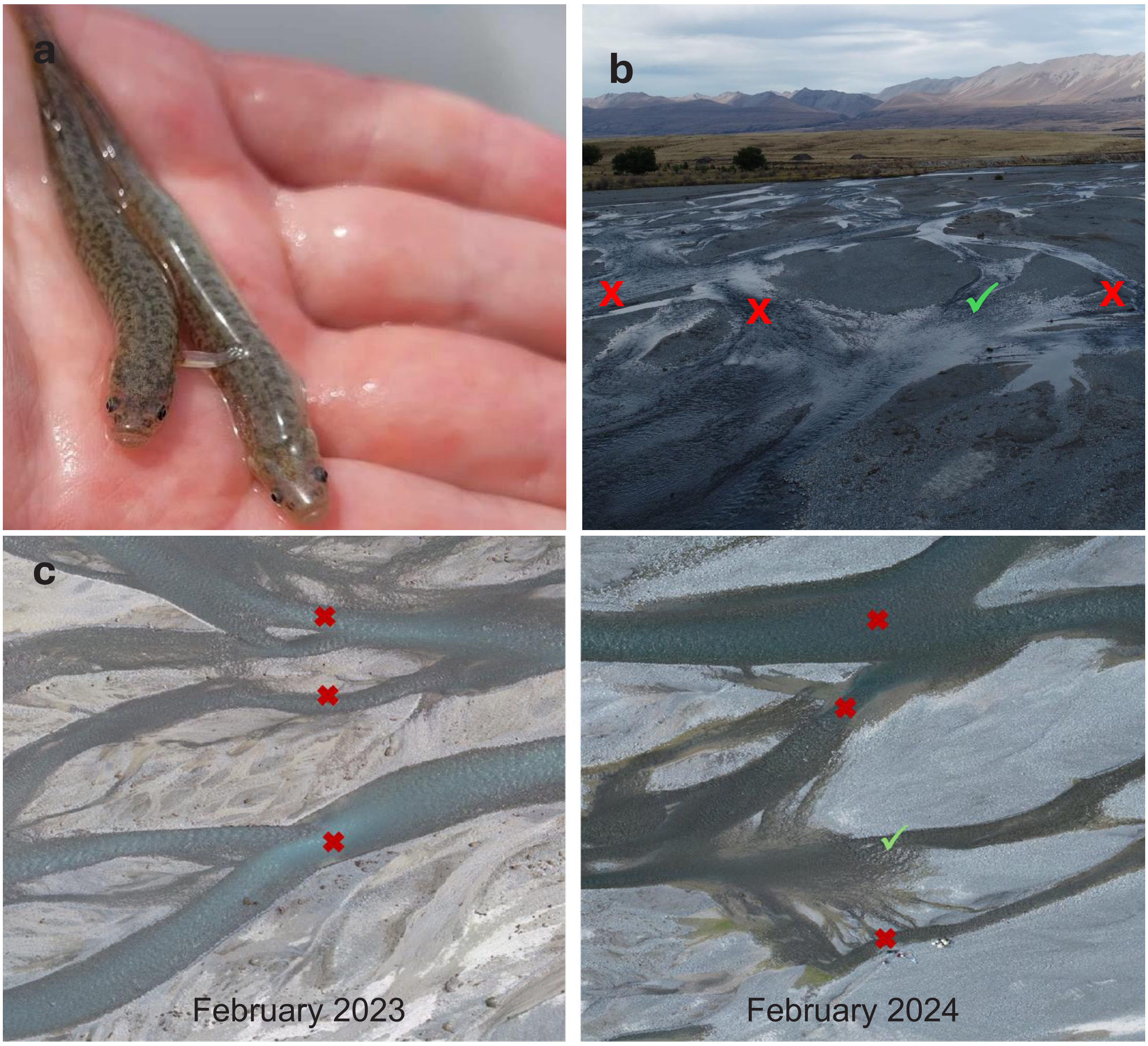

Figure 3. Sites on Te Awa-a-Takatamira | Cass River with upland longjaw (a) populations (identified with green ticks) are difficult to identify in the field (b) and change in location over time (c; left to right). Flow conditions and requirements for the formation of these habitats are largely unknown. Photo credits: N Boddy and H Harris.

example a more conservative management of macro-ecological, landscape-scale conditions such as flow will likely increase the protection of all the ecological processes associated with the persistence of rare species. Our increasing understanding of the complex interplay between landscape features and species persistence highlights the likelihood of local management decisions propagating across the landscape and through food webs (Gray et al. 2016; Hauer et al. 2016; Ward et al. 2023).

Landscape simplification and disturbance stressors will have compounding negative effects when species interactions and movement connect communities and food webs at large spatial scales (Harris 2024). Braided rivers in many parts of the world are following a trajectory of reduced braiding due to channelisation, damming, gravel mining, and flood protection works (Stecca et al. 2019). Reduced braiding will directly impact the mechanisms of resilience conferred by landscape heterogeneity but will also likely compound the effects of flooding because floods move through channels in a more concentrated manner, creating feedback cycles of disturbance (Gray et al. 2016; Harris et al. 2024; Fig. 2c). These compounding processes are particularly important to consider in a changing climate where rainfall extremes are predicted to increase, likely resulting in more extreme and potentially homogenising flood events (Srinivasan et al. 2021). Preserving the natural resilience of landscapes such as braided rivers by reducing the impacts of landscape simplification will be an important aspect of any conservation strategy incorporating climate change resilience (Gillson et al. 2013; Macinnis-Ng et al. 2021; Harris et al. 2024).

Specific challenges and recommendations for braided river conservation and management

Politicians

Politicians must balance many conflicting interests, but freshwater management at a national level is administered by the Ministry for the Environment and is typically directed through the National Policy Statement for Freshwater 2020 (NPSFW). The guiding principle of the NPSFW is Te Mana o Te Wai, which prioritises the health of water bodies and freshwater ecosystems (NPSFW 2020). However, the Resource Management Act (RMA) has led to a definition of riverbed (derived from common law) that ignores the complexity and special nature of braided river geomorphology and ecology, leaving the wider braidplain vulnerable and difficult to protect. To give effect to Te Mana o Te Wai, recognition that freshwater ecosystems are variable and dynamic, not static entities, must be incorporated into legislation. Rivers need room to create habitat heterogeneity within the landscape. Thus, braided rivers should be redefined at a national level to reflect this, and recommendations to councils should include recognising this variability. Recognising this need for natural variability at a national scale will not only increase our ability to give effect to Te Mana o Te Wai but may aid in reducing social risk from natural flooding events by removing the ability to build in designated floodplain areas (Chan et al. 2022). This recognition does not have to be to the exclusion of other activities, but requires that more weight be given to the configuration and spatial context of land-use practices such as flood protection works.

Planners

Regional Councils typically approach river management by fitting pre-existing practices into the RMA framework (Gray et al. 2018; McNeill 2016). Flood protection works, managed under The Soil Conservation and Rivers Control Act 1941, have traditionally been prioritised over preserving the natural character of rivers, despite subsequent direction to this effect in the RMA (Gray et al. 2018). Additionally, there have been significant land-use changes that correspond with encroachment onto braidplains and reductions in river habitat variability (Walker et al. 2003; Grove et al. 2015; Gray et al. 2018; Brower et al. 2024). These approaches to planning and resource use simplify riverine landscapes. Thus, wider landscape context needs to be taken into consideration with plans incorporating the perspectives of land managers, rivers engineers, and ecological processes (Gray et al. 2018). This may also allow for synergistic projects whereby flood mitigation or contaminant buffers such as wetlands can be combined with species and ecosystem conservation to increase landscape heterogeneity and floodplain restoration. Support from politicians on a science-based definition of braidplains would significantly improve the ability of planners to implement this approach.

Managers

There are many types of river managers, often bound by their own specific policy constraints, such as improving water quality, reducing flood risk, or improving the outlook for a specific species. However, with a broad-scale contextual approach, managing impacts of braided rivers and their contribution to biodiversity persistence could be improved. There are many factors contributing to braided river simplification (Habersack et al. 2007; Stecca et al. 2019, 2023), but removing a stop bank on one side of the river to restore more natural river movement and reduce flood risk is becoming a more common management option (Piegay et al. 2006; Beagley et al. 2023). Allowing rivers more room can additionally restore some habitat heterogeneity and hydrologic connectivity by restoring some river capacity for braiding (Piegay et al. 2006; Barlow & Ashmore 2024). However, it is likely this will have to occur concurrently with long-term planning to avoid river bed weed-invasion. Not only will this allow ecosystems to function in a more resilient manner but will likely provide additional buffers to property damage in a future of increased flooding and extreme events.

Conclusions

Understanding of the interactions between spatial complexity, resilience, and landscape-scale conservation management has grown significantly over the past two decades (Peipoch et al. 2015; Hauer et al. 2016). We have shown here that there are likely to be significant benefits to landscape-scale management for ecological outcomes in complex landscapes such as braided rivers and their braidplains. Ecological simplification of these threatened landscapes will have damaging effects on their biodiversity. Effects of simplification are likely to propagate through food webs, impacting the resilience of rare and threatened species that use these landscapes. An approach to management that incorporates landscape context and understanding of the impacts of ecological simplification may be more aligned with management frameworks such as Ki Uta Ki Tai (from the mountains to the sea; Tipa 2009; Crow et al. 2020). For example, many Māori communities recognise the importance of spatial heterogeneity within rivers, with some areas protected by tales of taniwha, and Ki Uta Ki Tai is a framework that requires a whole catchment understanding and scale of protection (Tipa 2009; Tipa et al. 2016; Crow et al. 2020). While challenges surrounding land-use practices, competing human interests, invasive species, and climate change remain, a shift in thinking towards a broad contextual understanding of the ecological processes involved at landscape scales could contribute to more successful and cohesive management outcomes for ecological processes and biodiversity in these landscapes.

Acknowledgements

Funding for this research was supplied by Environment Canterbury's Braided River Regional Initiatives Fund (Department of Conservation and Environment Canterbury), and the University of Canterbury Aho Hīnātore Scholarship. Thanks to Richard Maloney (Department of Conservation), and to the Freshwater Ecology Research Group (University of Canterbury), Linda Morris, Kim Doherty, and Nicole Lauren-Manuera for their technical support. Thanks to Jenny Ladley and University of Canterbury for the use of Mt John Field station. JDT is supported by a Rutherford Discovery Fellowship administered by the Royal Society Te Apārangi (RDF-18-UOC-007), and Te Pūnaha Matatini, a Centre of Research Excellence funded by the Tertiary Education Commission, New Zealand. Thank you to the three anonymous reviewers whose comments improved this manuscript. Finally, we acknowledge the iwi and hapu associated with the awa (river) we have been privileged to study.

Additional information and declarations

Author contributions: All authors contributed to conceptualisation. H. Harris wrote the first draft, and all authors contributed to subsequent drafts.

Funding: Braided Rivers Regional Initiatives Fund.

Data and code availability: N/A

Ethics: N/A

Conflicts of interest: there are no conflicts of interest to declare.

References

Armstrong JB, Fullerton AH, Jordan CE, Ebersole JL, Bellmore JR, Arismendi I, Penaluna BE, Reeves GH 2021. The importance of warm habitat to the growth regime of cold-water fishes. Nature Climate Change 11(4): 354–361.

Barlow V, Ashmore P 2024. River confinement and braiding loss in Canterbury region, Aotearoa New Zealand. Earth Surface Processes and Landforms 50(1): e6051.

Barquín J, Scarsbrook M 2008. Management and conservation strategies for coldwater springs. Aquatic Conservation: Marine and Freshwater Ecosystems 18(5): 580–591.

Battisti C, Poeta G, Fanelli G 2016. Heterogeneity, dynamism, and diversity of natural systems. In: Battisti C, Poeta G, Fanelli G eds. An introduction to disturbance ecology: A road map for wildlife management and conservation. Cham, Springer International Publishing. Pp. 1–6.

Beagley R, Davies T, Fuller I, Gardner M, Healey M, Williams G 2023. Future management of the Waiho River. Greymouth, Waiho Technical Advisory Group. 118 p.

Bellmore JR, Baxter CV, Connolly PJ 2015. Spatial complexity reduces interaction strengths in the meta-food web of a river floodplain mosaic. Ecology 96(1): 274–283.

Brower A, Hoyle J, Gray D, Buelow F, Calkin A, Fuller I, Gabrielsson R, Grove P, Brierley G, Louie AJS, Rogers J, Shulmeister J, Uetz K, Worthington S, Vosloo R 2024. New Zealand's braided rivers: The land the law forgot. Earth Surface Processes and Landforms 49(1): 10–14.

Catalano AS, Lyons-White J, Mills MM, Knight AT 2019. Learning from published project failures in conservation. Biological Conservation 238: 108223–108233.

Chan FKS, Yang LE, Mitchell G, Wright N, Guan M, Lu X, Wang Z, Montz B, Adekola O 2022. Comparison of sustainable flood risk management by four countries – the United Kingdom, the Netherlands, the United States, and Japan – and the implications for Asian coastal megacities. Natural Hazards and Earth System Sciences 22(8): 2567–2588.

Crow SK, Tipa GT, Nelson KD, Whitehead AL 2020. Incorporating Māori values into land management decision tools. New Zealand Journal of Marine and Freshwater Research 54(3): 431–448.

Cruz J, Windels SK, Thogmartin WE, Crimmins SM, Grim LH, Larson JH, Zuckerberg B 2019. Top-down effects of repatriating bald eagles hinder jointly recovering competitors. Journal of Animal Ecology 88(7): 1054–1065.

Cumming GS, Morrison TH, Hughes TP 2017. New directions for understanding the spatial resilience of social–ecological systems. Ecosystems 20(4): 649–664.

Eisenhauer N, Hines J 2021. Invertebrate biodiversity and conservation. Current Biology 31(19): R1214–R1218.

Fàbregas MC, Fosgate GT, Ganswindt A, Bertschinger H, Meyer LCR 2021. Unforeseen consequences of conservation management practices: Case study on herding rhino as an anti-poaching measure. Animal Conservation 24(3): 412–423.

Gillson L, Dawson TP, Jack S, McGeoch MA 2013. Accommodating climate change contingencies in conservation strategy. Trends in Ecology & Evolution 28(3): 135–142.

Gounand I, Harvey E, Little CJ, Altermatt F 2018. Meta-Ecosystems 2.0: Rooting the theory into the field. Trends in Ecology & Evolution 33(1): 36–46.

Gray D, Grove P, Surman M, Keeling C 2018. Braided rivers: natural characteristics, threats and approaches to more effective management. Christchurch, Environment Canterbury. 26 p.

Gray DP, Harding JS 2010. Spatial variation in invertebrate communities in New Zealand braided rivers. Science for Conservation 302. Wellington, Department of Conservation. 45 p.

Gray DP, Hicks M, Greenwood M 2016. Advances in geomorphology and aquatic ecology of braided rivers. In: Jellyman PG, Davie TJA, Pearson CP, Harding JS eds. Advances in New Zealand freshwater science. Wellington, New Zealand Freshwater Sciences Society and New Zealand Hydrological Society. Pp. 357 –378.

Greenwood MJ, McIntosh AR 2008. Flooding impacts on responses of a riparian consumer to cross-ecosystem subsidies. Ecology 89(6): 1489–1496.

Grove P, Parker M, Gray D, Behrens F 2015. Land use change on the margins of lowland Canterbury braided rivers, 1990-2012. Christchurch, Environment Canterbury. 22 p.

Gurney F 2022. Breeding movements and post-breeding dispersal of Black-fronted terns/Tarapirohe (*Chlidonias albostriatus*) in the Mackenzie Basin. Unpublished MSc thesis. Lincoln University, Lincoln, New Zealand.

Habersack H, Piegay H, Rinaldi M, Rinaldi M 2007. Gravel bed rivers 6: From process understanding to river restoration. Developments in earth surface processes Vol 11. Amsterdam, Elsevier Science & Technology. 817 p.

Harris HAL 2024. Untangling processes and mechanisms of stability in complex landscapes: lessons and applications for braided rivers. Unpublished PhD thesis. Te Whare Wānanga o Waitaha | University of Canterbury, Christchurch, New Zealand.

Harris HAL, Tonkin JD, McIntosh AR 2024. Mutli-scale ecological resilience in braided rivers. In: Thoms M, Fuller I eds. Resilience in riverine landscapes. Amsterdam, Elsevier. Pp. 157–175.

Hauer FR, Locke H, Dreitz VJ, Hebblewhite M, Lowe WH, Muhlfeld CC, Nelson CR, Proctor MF, Rood SB 2016. Gravel-bed river floodplains are the ecological nexus of glaciated mountain landscapes. Science Advances 2(6): e1600026.

Heffernan JB, Soranno PA, Angilletta MJ, Buckley LB Jr, Gruner DS, Keitt TH, Kellner JR, Kominoski JS, Rocha AV, Xiao J, Harms TK, Goring SJ, Koenig LE, McDowell WH, Powell H, Richardson AD, Stow CA, Vargas R, Weathers KC 2014. Macrosystems ecology: understanding ecological patterns and processes at continental scales. Frontiers in Ecology and the Environment 12: 5–14.

Herse MR, Lyver PO, Scott N, McIntosh AR, Coats SC, Gormley AM, Tylianakis JM 2020. Engaging indigenous peoples and local communities in environmental management could alleviate scale mismatches in social–ecological systems. BioScience 70(8): 699–707.

Herse MR, Lyver PO, Gormley AM, Scott NJ, McIntosh AR, Fletcher D, Tylianakis J 2022. A demographic model to support customary management of a culturally important waterfowl species. Ecology and Society 27(3): 14–28.

Hill RL, Gourlay AH, Barker RJ 2001. Survival of *Ulex* *europaeus* seeds in the soil at three sites in New Zealand. New Zealand Journal of Botany 39(2): 235–244.

Howard SW 2014. Flow-related threats to rare galaxiids in the upper Waitaki River. Unpublished PhD thesis. Te Whare Wānanga o Waitaha | University of Canterbury, Christchurch, New Zealand.

Hughey K 1998. Nesting home range sizes of Wrybill (*Anarhynchus frontalis*) and Banded Dotterel (*Charadrius bicinctus*) in relation to braided riverbed characteristics. Notornis 45(2): 103–111.

Kapos V, Balmford A, Aveling R, Bubb P, Carey P, Entwistle A, Hopkins J, Mulliken T, Safford R, Stattersfield A, Walpole M, Manica A 2009. Outcomes, not implementation, predict conservation success. Oryx 43(3): 336–342.

Karaus U, Larsen S, Guillong H, Tockner K 2013. The contribution of lateral aquatic habitats to insect diversity along river corridors in the Alps. Landscape Ecology 28(9): 1755–1767.

Lalas C 1977. Food and feeding behaviour of the Black-fronted tern, *Chlidonias hybrida albostriatus*. Unpublished MSc thesis, University of Otago, Dunedin, New Zealand.

Lamy T, Wang S, Renard D, Lafferty KD, Reed DC, Miller RJ 2019. Species insurance trumps spatial insurance in stabilizing biomass of a marine macroalgal metacommunity. Ecology 100(7): e02719.

Larkin DJ, Bruland GL, Zedler JB 2016. Heterogeneity theory and ecological restoration. In: Palmer MA, Zedler JB, Falk DA eds. Foundations of restoration ecology. Washington, DC, Island Press/ Center for Resource Economics. Pp. 271–300.

Larsen S, Karaus U, Claret C, Sporka F, Hamerlík L, Tockner K 2019. Flooding and hydrologic connectivity modulate community assembly in a dynamic river-floodplain ecosystem. PLoS ONE 14(4): e02719.

Leibold MA, Holyoak M, Mouquet N, Chase JM, Hoopes MF, Holt RD, Shurin JB, Law R, Gonzalez A 2004. The metacommunity concept: A framework for multi-scale community ecology. Ecology Letters 7(7): 601–613.

Loreau M, Mouquet N, Holt RD 2003. Meta-ecosystems: A theoretical framework for a spatial ecosystem ecology. Ecology Letters 6(8): 673–679.

Macinnis-Ng C, Mcintosh AR, Monks JM, Waipara N, White RS, Boudjelas S, Clark CD, Clearwater MJ, Curran TJ, Dickinson KJ, Nelson N, Perry GL, Richardson SJ, Stanley MC, Peltzer DA 2021. Climate-change impacts exacerbate conservation threats in island systems: New Zealand as a case study. Frontiers in Ecology and the Environment 19(4): 216–224.

McCabe CL, Matthaei CD, Tonkin JD 2025. The ecological benefits of more room for rivers. Nature Water 3: 260–270.

McCann K, Hastings A, Huxel GR 1998. Weak trophic interactions and the balance of nature. Nature 395(67040): 794–798.

McCann KS, Rasmussen JB, Umbanhowar J 2005. The dynamics of spatially coupled food webs. Ecology Letters 8(5): 513–523.

McCluney KE, Poff NL, Palmer MA, Thorp JH, Poole GC, Williams BS, Williams MR, Baron JS 2014. Riverine macrosystems ecology: Sensitivity, resistance, and resilience of whole river basins with human alterations. Frontiers in Ecology and the Environment 12(1): 48–58.

McIntosh EJ, Chapman S, Kearney SG, Williams B, Althor G, Thorn JPR, Pressey RL, McKinnon MC, Grenyer R 2018. Absence of evidence for the conservation outcomes of systematic conservation planning around the globe: a systematic map. Environmental Evidence 7: 22.

McNeill J 2016. Scale implications of integrated water resource management politics: lessons from New Zealand. Environmental Policy and Governance 26(4): 306–319.

Milner AM, Khamis K, Battin TJ, Brittain JE, Barrand NE, Füreder L, Cauvy-Fraunié S, Gíslason GM, Jacobsen D, Hannah DM, Hodson AJ, Hood E, Lencioni V, Ólafsson JS, Robinson CT, Tranter M, Brown LE 2017. Glacier shrinkage driving global changes in downstream systems. Proceedings of the National Academy of Sciences of the United States of America 114(37): 9770–9778.

Murray T, Anderson S 2015. Invertebrates of the Tasman River plain: Characteristics of the invertebrate community and analysis of sampling methods for biodiversity assessment. Wellington, Department of Conservation. 73 p.

Nyström M, Folke C 2001. Spatial resilience of coral reefs. Ecosystems 4(5): 406–417.

O’Donnell C, Hoare JM 2009. Predation of lizards by black-fronted terns (*Sterna albostriata*). Notornis 56: 167–168.

O’Donnell CFJ, Sanders M, Woolmore C, Maloney RF 2016. Management and research priorities for conserving biodiversity on New Zealand’s braided rivers. Wellington, Department of Conservation. 46 p.

Peipoch M, Brauns M, Hauer FR, Weitere M, Valett HM 2015. Ecological simplification: Human influences on riverscape complexity. BioScience 65(11): 1057–1065.

Piegay H, Grant G, Nakamura F, Trustrum N 2006. Braided river management: from assessment of river behaviour to improved sustainable development. In: Sambrook Smith GH, Best JL, Bristow CS, Petts GE eds. Braided rivers: process, deposits, ecology and management. Hoboken, John Wiley & Sons, Ltd. Pp. 257–275.

Quévreux P, Loreau M 2022. Synchrony and stability in trophic metacommunities: when top predators navigate in a heterogeneous world. Frontiers in Ecology and Evolution 10: 865398.

Rooney N, McCann KS, Moore JC 2008. A landscape theory for food web architecture. Ecology Letters 11(8): 867–881.

Sanders MD, Maloney RF 2002. Causes of mortality at nests of ground-nesting birds in the Upper Waitaki Basin, South Island, New Zealand: a 5-year video study. Biological Conservation 106(2): 225–236.

Scarsbrook M, Barquín J, Gray D 2007. New Zealand coldwater springs and their biodiversity. Science for Conservation 278. Wellington, Department of Conservation. 73 p.

Schiel DR, Alestra T, Gerrity S, Orchard S, Dunmore R, Pirker J, Lilley S, Tait L, Hickford M, Thomsen M 2019. The Kaikōura earthquake in southern New Zealand: Loss of connectivity of marine communities and the necessity of a cross-ecosystem perspective. Aquatic Conservation: Marine and Freshwater Ecosystems 29(9): 1520–1534.

Srinivasan R, Carey-Smith T, Macara G 2021. Trend analysis on frequency of New Zealand climate extremes. Weather and Climate 41(1): 18–29.

Stecca G, Zolezzi G, Hicks DM, Surian N 2019. Reduced braiding of rivers in human-modified landscapes: Converging trajectories and diversity of causes. Earth-Science Reviews 188: 291–311.

Stecca G, Hicks DM, Measures R, Henderson R 2023. Numerical modeling prediction of vegetation trajectories under different flow regimes in New Zealand braided rivers. Journal of Geophysical Research: Earth Surface 128(12): e2023.

Stein A, Gerstner K, Kreft H 2014. Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. Ecology Letters 17(7): 866–880.
Tilman, D 1982. Resource competition and community structure. Princeton, Princeton University Press. 296 p.
Tipa G 2009. Exploring indigenous understandings of river dynamics and river flows: a case from New Zealand. Environmental Communication 3(1): 95–120.
Tipa G, Harmsworth GR, Williams E, Kitson JC 2016. Integrating mātauranga Māori into freshwater management, planning and decision making. In: Advances in New Zealand freshwater science. Wellington, New Zealand Hydrological Society and New Zealand Freshwater Sciences Society. Pp. 613–637.
Tockner K, Stanford JA 2002. Riverine flood plains: Present state and future trends. Environmental Conservation 29(3): 308–330.
Tockner K, Paetzold A, Karaus U, Claret C, Zettel J 2006. Ecology of braided rivers. In: Samsbrook Smith GH, Best JL, Bristow CS, Petts GE eds. Braided rivers: process, deposits, ecology and management. Hoboken, John Wiley & Sons, Ltd. Pp. 341–354.
Walker S, Lee WG, Rogers GM 2003. Post-pastoral succession in intermontane valleys and basins of eastern South Island, New Zealand. Science for Conservation 227. Wellington, Department of Conservation. 75 p.
Ward CA, Tunney TD, McCann KS 2023. Managing aquatic habitat structure for resilient trophic interactions. Ecological Applications 33(3): e2814.

Received: 13 February 2025; accepted: 18 June 2025
Editorial board member: Anne Schlesselmann