Full Paper

Rob Rolls – Consequences of hydrological alteration for landscape-scale biodiversity

Testing predicted consequences of hydrological alteration for fish biodiversity at landscape scales

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Key Points

- Consequences of water resource development and climate fluctuations for river ecosystems are increasingly considered across landscape scales to inform delivery of environmental flows to support single species and entire assemblages
- To date, little research has considered how spatial variation in hydrology influences the degree to which assemblages of riverine organisms (e.g. fish) vary across spatial scales
- Connecting multi-species biodiversity responses to hydrology is necessary for landscape-scale water management to reflect the reality of biodiversity that varies at corresponding spatial scales

Abstract

Ecohydrology and environmental flow management are increasingly considering the consequences of hydrological alteration (e.g. dams, extraction) and events (e.g. drought, floods) for the ecosystem processes, population dynamics, and biodiversity that span large spatial extents. One hypothesis relevant to research and management is that spatial variation in hydrology positively affects spatial variation in ecological communities ('beta diversity'), and that water resource development and temporal variation in climate can alter spatial variation in hydrology, in turn influencing the degree to which communities differ across spatial scales. This project explored (i) how spatial variation in hydrology has been altered by water resource development and major climate fluctuations, and (ii) corresponding consequences for fish biodiversity at multiple spatial scales. Water resource development increased spatial variation in hydrological regimes both among and within rivers. Spatial variation in fish assemblages at both spatial scales was predominantly unrelated to spatial variation in modified flow regimes. Spatial variation in hydrology showed minor and inconsistent changes across scales associated with climate fluctuations. Variation in fish assemblages showed inconsistent, river-specific changes among contrasting hydrological periods. Inconsistent relationships between hydrology and beta diversity suggest that outcomes of water resource development and climate fluctuations for beta diversity are not broadly generalisable.

Keywords

beta diversity, drought, biotic homogenisation, biotic differentiation, hydrology, water resource development

Introduction

Ecohydrological research and environmental flow management are both increasingly considering how hydrology affects the structure and functioning of river ecosystems at broad spatial scales (Sharpe, 2018). Analyses done at fine scales (e.g. spanning individual sites to reaches of individual rivers) are useful for gaining local interest in the outcomes of altered hydrology and environmental flows, yet inadequately reveal the outcomes for ecosystems and biodiversity spanning larger spatial scales like river basins. Understanding multi-scaled responses to hydrology is necessary for environmental flows to achieve maximum ecological benefit and avoid risks of undesirable ecological outcomes at unmeasured spatial scales (Rolls et al., 2018).

Spatial variation in the composition of ecological assemblages, such as birds or riparian vegetation, is an aspect of ecosystems that has rarely been considered in assessments of water resource development and changes in hydrology due to climate fluctuations. In ecology, spatial variation in the composition of organisms among scales is termed 'beta diversity' (Anderson et al., 2011). Beta diversity provides a measure of the degree to which assemblages differ from one another within a specific region (e.g. a river basin or country). Beta diversity varies among regions, with some supporting assemblages that differ widely in composition whereas other regions support assemblages that are much more similar. There is a burgeoning literature related to the definitions, analysis, and conservation significance of beta diversity, yet the potential applications of this concept and empirical evidence to hydrological regime management have not yet been critically evaluated.

Multiple ecohydrological mechanisms drive freshwater beta diversity (see Rolls et al., 2018). Spatial variation in hydrological regimes is conceptualised to be a key driver of beta diversity, with locations that have highly variable hydrology predicted to support distinctly different assemblages (i.e. high beta diversity) compared to sites that have similar hydrology being occupied by similar assemblages (i.e. low beta diversity) (Figure 1). Spatial variation in hydrology can potentially be altered by water resource development or climate fluctuations (e.g. Poff et al., 2007), leading to potential changes in freshwater beta diversity.

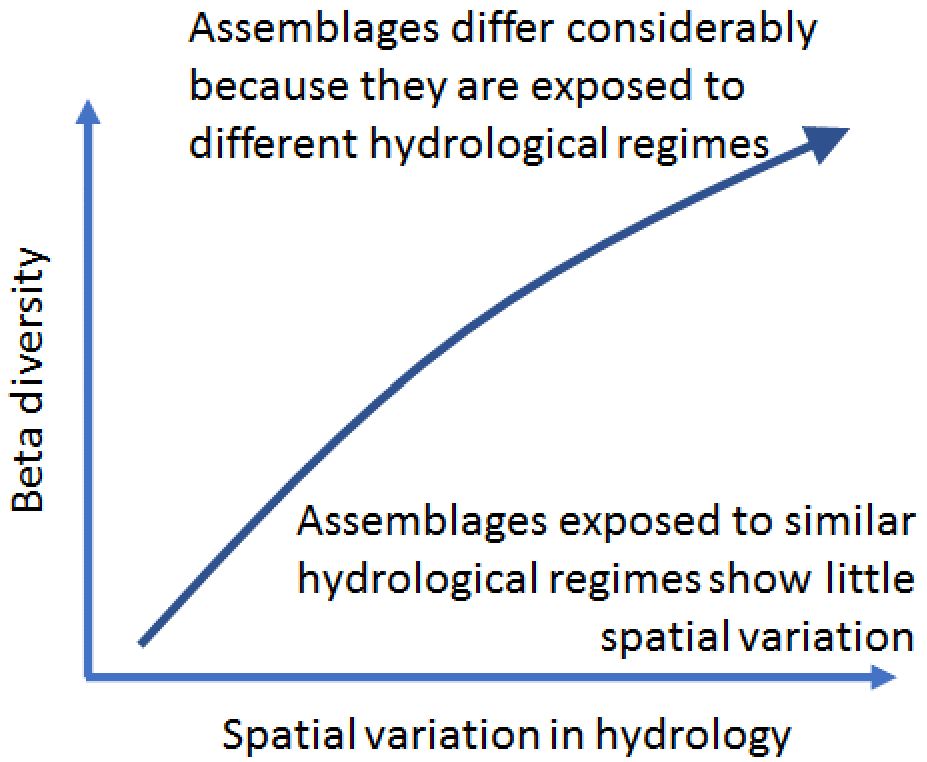

Figure 1. Predicted relationship between spatial variation in hydrology and beta diversity of riverine and riparian assemblages.

This paper briefly describes two case studies examining the relationships between spatial variation in hydrology and beta diversity of fish assemblages in the Murray-Darling Basin.

Case study 1: Consequences of hydrological alteration for beta diversity of fish assemblages at multiple spatial scales

Background: Effects of dam operation and extraction of water from rivers on spatial variation in hydrological regimes, and consequences for freshwater biodiversity, are widely predicted but seldom assessed empirically. While empirical research is limited, it is generally conceptualised that water resource development reduces spatial variation in hydrology among and with river systems (e.g. Poff et al., 2007). Even less evidence exists that tests how riverine beta diversity changes in association with altered spatial variation in hydrology in line with the predicted conceptual model (Figure 1). One of the major limitations to testing for changes in beta diversity associated with water resource development worldwide is absence of suitable data of ecological assemblages prior to hydrological alteration. This limitation necessitates careful and creative analyses of biodiversity datasets after hydrological change by water resource development has occurred.

Data and analyses: Time series data of modelled low-development (reference) and current regulated (modified) hydrological data from six lowland rivers in the Murray-Darling Basin were used to examine how spatial variation in hydrological regimes differed between hydrological scenarios. Additional data of fish assemblages from the same six rivers were sourced to test how beta diversity was linked with spatial variation in modified hydrological regimes.

Outcome: Spatial variation in hydrology among rivers was higher under the modified scenario than under the low-development scenario yet change in the magnitude of within-river (longitudinal) variation was inconsistent among rivers. Beta diversity among rivers was significantly associated with spatial variation in hydrology only in certain circumstances (native species assemblages in specific years). Within-river beta diversity varied among rivers yet was unrelated to longitudinal variation in modified hydrological regimes.

Considerable and significant beta diversity of fish assemblages among six lowland rivers of the Murray – Darling Basin suggests that complete homogenization has not occurred but detecting the true effects of water resource development are precluded by the absence of data prior to anthropogenic hydrological alteration. Overall, the lack of consistent relationships between the beta diversity of different components of the fish assemblage and hydrological dissimilarity suggest it may be simplistic to predict that beta diversity is driven by hydrological diversity per se. Instead, beta diversity may depend on the specific mix of hydrological regimes occurring across the spatial extent of interest, and how each regime favours or disadvantages particular species.

Case study 2: Temporal variation in relationships between hydrology and fish beta diversity during hydrological fluctuations in a climatically heterogeneous river basin

Background: Fluctuations in climate potentially alter spatial variation in hydrology among and within rivers, in turn influencing change in beta diversity in time. One possible scenario is that there may be a decline in beta diversity during specific climate scenarios if spatial variation in hydrology is reduced by drought. Most empirical work, however, is from research done in upland rivers spanning small spatial extents, with much less known of the consequences of hydrological variation for beta diversity across multiple spatial scales in lowland rivers.

Data and analyses: Monitoring data of river fish assemblages, coupled with hydrological and biophysical data, was used to test how fish beta diversity in lowland rivers of the Murray – Darling Basin (Australia) varied across spatial scales in response to hydrological fluctuations during and following the Millennium drought.

Outcome: Spatial variation in hydrology among rivers declined with increasing duration of hydrological drought before increasing during a return to above-average flows. Longitudinal hydrological variability did not show consistent changes between hydrological phases among rivers. Fish beta diversity among and within rivers showed variable, river-specific changes among hydrological periods.

Overall conclusions

Findings from these two case studies (i) fail to support predictions adopted by ecohydrological science that water resource development homogenises hydrological regimes, in turn causing biotic homogenisation (loss of beta diversity) in lowland rivers, and (ii) indicate that hydrological fluctuations occurring in the Murray-Darling Basin in the period analysed here did not cause significant or consistent homogenisation or differentiation of freshwater fish assemblages. Rather, inconsistent hydrology-beta diversity patterns found here suggest that mechanisms and outcomes of drought, flooding, and water resource development for variation in fish assemblage composition are context-specific and not broadly generalisable.

Do multi-species diversity patterns have relevance to monitoring ecological outcomes of hydrological alteration and environmental flows across landscape scales?

As planning and delivery of environmental flows is increasingly shifting towards broad spatial scales (e.g. across multiple river systems), beta diversity has some potential for informing environmental water management. Beta diversity of freshwater organisms is now a core theme in fundamental ecohydrology. However, the lack of work conceptualizing and translating how beta diversity can be used to assess human impacts and outcomes of restoration interventions (e.g. environmental flows) at broad spatial scales is an impediment for this wealth of fundamental knowledge to contribute to water management. Challenges to the incorporation of beta diversity in the planning and assessment of restoration interventions include (i) understanding the relevance of beta diversity to ecosystem functioning and biodiversity resilience, (ii) critical consideration of what magnitude of change in beta diversity is relevant to stakeholders, (iii) natural temporal variation in spatial beta diversity, (iv) the multiple ways beta diversity is considered and quantified (Anderson et al., 2011), and (v) the spatial scales over which change in beta diversity reflects true biodiversity loss. These challenges have the potential to be overcome by researchers and managers working together to translate this expanding aspect of ecohydrology in ways that matter to stakeholders and the public. Furthermore, while delivery of environmental flows is frequently focused on the requirements of single species (e.g. Stuart and Sharpe, 2020), the sheer number of species in need of consideration for support (sensu Franklin, 1993) by environmental flows means a multi-species, multi-scaled approach such as beta diversity may be an effective overarching framework for ecologically-appropriate water management.

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References

Anderson, M.J., Crist, T.O., Chase, J.M., Vellend, M., Inouye, B.D., Freestone, A.L., Sanders, N.J., Cornell, H.V., Comita, L.S., Davies, K.F., Harrison, S.P., Kraft, N.J.B., Stegen, J.C. & Swenson, N.G. (2011) Navigating the multiple meanings of β diversity: a roadmap for the practicing ecologist. Ecology Letters, 14, 19-28.

Franklin, J.F. (1993) Preserving biodiversity: species, ecosystems, or landscapes? Ecological Applications, 3, 202-205.

Poff, N.L., Olden, J.D., Merritt, D.M. & Pepin, D.M. (2007) Homogenization of regional river dynamics by dams and global biodiversity implications. Proceedings of the National Academy of Sciences of the United States of America, 104, 5732-5737.

Rolls, R.J., Heino, J., Ryder, D.S., Chessman, B.C., Growns, I.O., Thompson, R.M. & Gido, K.B. (2018) Scaling biodiversity responses to hydrological regimes. Biological Reviews, 93, 971-995.

Sharpe, A. (2018) Lifting our gaze: Improved environmental water management requires a landscape scale approach. Proceedings of the 9th Australian Stream Management Conference. Hobart, Tasmania.

Stuart, I.G. & Sharpe, C.P. (2020) Riverine spawning, long distance larval drift, and floodplain recruitment of a pelagophilic fish: A case study of golden perch (*Macquaria ambigua*) in the arid Darling River, Australia. Aquatic Conservation: Marine and Freshwater Ecosystems, 30, 675-690.