Policy brief
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Towards the sustainable management of rivers in the Anthropocene

Executive statement/Summary/Aim

This policy brief summarizes a recent perspective paper[1] that outlines that the spatial flows of organisms, material and energy across river networks need to be integrated to river management practices for improving their efficiency. We identify specific policy implications and provide guidance on how river management efforts could integrate such spatial flows to achieve international environmental and conservation targets.

Key messages

- Rivers are hotspots of biodiversity and provide essential ecosystem functions and services; however, they are heavily threatened globally notably due to increased fragmentation.
- Our understanding on how rivers are organized across spatial scales has progressed considerably over the past decades: the spatial flows of organisms, material and energy at the river-network scale are today recognised as vital for preserving population, community and ecosystem dynamics.
- However, most river conservation, restoration and biomonitoring practices and legislations focus on local-scale measures and actions.
- We suggest a range of metrics and assessment approaches that incorporate river-network processes to guide the management of river networks in the Anthropocene.

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The fragmentation of river networks

Fragmentation is the major driver of river connectivity loss[2] that is increasingly accentuated by global change and associated river channel drying. In addition to have severe local effects, fragmentation by dams and river drying also alter the network-scale flows of organisms, materials and energy and represent one of the major threats of the Anthropocene era[2]. Most river management practices – independently of the spatial scale at which they are implemented – are based on local assessments and actions. In contrast, our basic understanding of how biodiversity, ecosystem functions and services are organized across river networks has progressed substantially in the past decade and today recognises the importance of these network-scale flows. The increasing pressure of multiple threats calls for the need of a better integration of scale-dependent approaches to guide water management and conservation policies in a changing world.

The meta-system theory to integrating river-network processes into river management

In the meta-system theory, local- and regional-scale processes interact to influence the dynamics of environmental conditions and biota in a given landscape[3]. Local-scale processes consist in what drive local populations, communities and ecosystems dynamics. For example, the habitat preferences of a given species within a river reach and its biotic interactions with other species. Regional-scale processes consist in the flows of species, material and energy among localities of the landscape. For example, how organisms can move across the landscape. As such, sets of local populations, communities and ecosystems connected by regional flows of materials form, respectively, metapopulations, metacommunities and meta-ecosystems.

Fragmentation, by weirs, dams or drying, not only alters the local environments and biotic assemblages, but also disrupts the flows of water, organisms and resources[3]. Fragmentation has cascading effects from populations- to ecosystem-levels, thus altering the provision, flows and delivery of ecosystem services[4]. Fragmentation isolates populations by reduce gene flows, jeopardizing the long-term persistence of metapopulations due to genetic drift and inbreeding. Ultimately, this can lead to shrinking species ranges and to local or regional extinctions. Fragmentation alters metacommunity dynamics because reduced dispersal leads to shifts in local community composition, biological diversity patterns and biological interactions. This can alter associated ecosystem functions, such as terrestrial leaf litter decomposition, which is severely reduced in fragmentation contexts[5]. Integrating these regional processes has become crucial to guide effective river conservation, monitoring and restoration practices in the river networks of the Antropocene (Table 1).

Table 1. Examples of undesired management results when not considering regional-scale processes in river management.

Management problems	Example
Not achieving conservation targets	Habitats of an endangered fish species are protected but populations are isolated and subjected to inbreeding due to fragmentation.
Not achieving river restoration targets	Despite substantial habitat restoration of a river reach, recolonization from undisturbed colonist sources is impeded by fragmentation.
Failing of river biomonitoring methods at detecting anthropogenic impacts	Fragmentation prevent species from reaching their optimal habitat preferences so isolated sites show low richness and bad biomonitoring scores despite having good habitat quality.
Failing in maintaining ecosystem functions and ecosystem services	Not considering the sediment flows in river basin management contributes to river bank and coastal erosion.

Policy and management recommendations

We recommend different options to integrate river network-scale processes and enhance current methodologies under the implementation of major environmental and conservation policies (Table 2).

1. Conservation management

- Assess conservation status of species using methods and indicators able to assess their metapopulation structure (Table 2).
- Design protected areas to ensure the conservation of key sites (Table 1) that allows a good functional integrity of metapopulations and metacommunities.

2. Biomonitoring and restoration

- Develop or adapt biomonitoring methods integrating network-scale connectivity (eg fragmentation by dams, drying, and topographical barriers) and dispersal-related species traits (Table 2).
- Quantify fragmentation within a river network and its potential interactions with other stressors.
- Identify pivotal sites acting as sources of colonizers in the river network and obtain information on the dispersal capability of species to reach restored habitats.

3. Ecosystem-based management

- Include spatially-explicit measures of biogeochemical, hydromorphological and ecological processes across the river network (Table 2).
- Use spatial prioritization methods that integrate all biodiversity facets, ecosystem processes and services simultaneously to maximize their protection in a holistic way.

Table 2. Indicator metrics to monitor the achievement of environmental and conservation targets in the meta-system theory lens.

	Policies	Additional metrics/indicators	
Conservation/ restoration	European Biodiversity Strategy and Habitats Directive US Endangered Species Act Australia Environment Protection and Biodiversity Conservation Act	• Genetic diversity • Gene flow • Inbreeding • Hybridization • Species effective dispersal • Number and location of metapopulation key sites (eg refugia, dispersal routes) • Area and quality of metapopulation key sites • Connectivity between key sites (eg dendritic connectivity index)	(meta) population
Biomonitoring/restoration	European Water Framework Directive US Clean Water Act Australia Water Act	• Gamma species diversity • Beta and zeta species diversity • Species dispersal capability (eg using organisms' traits as a proxy for dispersal) • Species effective dispersal • Metacommunity key habitats area and quality (ie refugia, dispersal routes) • Connectivity between key habitats (eg dendritic connectivity index)	(meta) community
Ecosystem-based management/restoration	European Biodiversity Strategy	• Sediment monitoring at multiple locations • Leaf litter decomposition at multiple locations • Ecosystem metabolism at multiple locations • Food web structure at multiple locations • Riparian stocks (eg using remote sensing) • Number and location of hotspots of functioning (eg organic matter and nutrient processing) • Number and location of service-providing, service-connecting and service-benefiting areas	(meta) ecosystem and ecosystem services

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References/more information

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Link to the video: https://www.youtube.com/watch?v=dyyX9qhEFf8