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Functional Diversity of Freshwater Crustaceans Along Natural River Gradient Transitions

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Abstract: Crustaceans connect algae, detritus, and fishes in rivers, but their functional diversity is rarely investigated in relation to the natural gradient transitions that guide a river from its headwaters to its floodplains. This paper will consider how the functional diversity of crustaceans may be affected by natural gradient transitions in freshwater ecosystems and human impacts that may override them. Given the paucity of research on crustaceans, we have developed an evidence map based on the findings of twelve recent peer-reviewed papers on fishes, benthic macroinvertebrates, plankton and reef molluscs, and translating their results into a framework for crustaceans. Each source was coded by its main cause, which includes natural gradients, land use impacts, or river regulation/regime changes, as well as organism type. The literature corpus was provided rather than extracted from a formal systematic database search. Five sources were based on land use impacts, four sources on natural gradients, and three sources on river regulation/regime changes. Fishes and benthic macroinvertebrates were predominant in the corpus, representing nine out of twelve sources, while one source was about crustaceans. Nine of the 12 sources cited were written between 2020 and 2022. In light of this trend, a proposed path is one that involves four stages where trait filtering by gradient transition occurs, functional diversity reacts to this transition, and land use and regulation modify both. This model produces four hypotheses, including one that states functional diversity will be most sensitive to gradient transition at zone boundaries of the rivers and that regulation will have more influence on functional diversity than seasonal flow. Crustaceans need to be included in functional biomonitoring, and we provide a checklist and a research plan.

Keywords: Freshwater Crustaceans; Functional Diversity; River Gradients; Trait Filtering; Land Use; River Regulation; Biomonitoring.

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I. Rivers as Gradients, Crustaceans as Messengers

The river is not a single habitat but a series of habitats; the water moves from cold and shaded source waters to mid-stream waters where the stream broadens, then slows to lower streams before reaching the flood plains and lake shores. Each time the physical habitat changes, and so does the fauna able to cope in that habitat. Ecologists now characterize these changes both by counting the number of species present but also in terms of what the species do, that is, through functional diversity. For riverine macroinvertebrates on an elevation gradient, functional diversity was dependent upon elevation but surprisingly little impact of hydrological seasonality on these relationships was seen (Luo et al., 2022). In this instance, location within the gradient is paramount.

It is possible to test this hypothesis with crustaceans, which are seldom studied in this way. In a Neotropical lake, microcrustaceans were divided into functional groups on a horizontal gradient of colonization of macrophytes, demonstrating that the structure of the habitat alone can reorganize functional structure of a crustacean community (Coelho & Henry, 2021). The situation with rivers is similar since the structure will change from boulder structures to sand beds to vegetated banks moving downstream.

Natural gradients are not working in isolation. The effect of the type of land cover on a floodplain has influenced the biomass distribution of fish functional diversity in the Amazon River, while the land use change intensity has had an impact on the taxonomic and functional diversity of fish in a Neotropical floodplain (Arantes et al., 2019; Yofukuji et al., 2023). In a subtropical river network, different land use practices have resulted in varying levels of taxonomic and functional diversity of benthic macroinvertebrates (Liu et al., 2021). Some gradients can be very long. Reef molluscs have been studied

on a tropical-to-temperate gradient to describe the changes in functional diversity along the latitudinal gradient (Floyd et al., 2020).

The problem is that these studies involve different populations. For this reason, we ask ourselves three questions. What could be the effect of natural changes on functional diversity of crustaceans in the river? What kinds of anthropogenic factors can modify this pattern? And to what extent do existing data address both of these questions? We do not offer a new review here; we construct a pathway based on existing literature and assess the coverage of this literature along this pathway. The article adopts an unusual structure: lessons learned from other fields of science first, then the pathway, then coverage mapping methodology, results, and recommendations.

II. Pressures and Patterns Reported Across Related Groups

The six remaining studies reveal further information regarding the impacts of anthropogenic influences on aquatic ecosystems and demonstrate the existence of regional variation. After the regulation of rivers, it was shown that the composition of the fish community changes quickly and is accompanied by the disappearance of diversity and formation of the new community state (Perônico et al., 2020). Such results imply that river regulation does not only cause the reduction of the population size of organisms but also affects the composition of the community, leading to the replacement of one community state with another. At the same time, it was shown in northern Patagonia that the diversity of chironomids is affected not only by climatic conditions but also by site-specific factors (Motta & Massaferro, 2019). Such results show that it is necessary to take into account the environmental gradient as a combination of regional climate and local habitat conditions. Finally, it was also shown that the regulation of large tropical rivers causes the decrease in the taxonomic and functional diversity of phytoplankton (da Silva et al., 2020). As crustacean zooplankton relies on phytoplankton as a food source, such changes at the level of producers may affect their population size and functional diversity.

The impacts of anthropogenic activities like livestock grazing have also been demonstrated on freshwater biodiversity. It has been demonstrated that the presence of grazing impacted the taxonomic and functional diversity of benthic macroinvertebrates from six tributary streams of the eastern shore of Lake Hövsgöl in Mongolia (Yadamsuren et al., 2022). It means that livestock pressure on the stream banks can serve as an environmental driver in particular headwater and tributary systems. Also, there has been proposed a trait-based approach to assess the biodiversity of macroinvertebrates in Mongolian freshwater ecosystems based on their responses under various land use conditions (Yadamsuren et al., 2020). This approach is especially important for the evaluation of functional aspects of crustacean biodiversity since it is based on the ecological traits of organisms and their responses to environmental perturbations. Besides, there have been reported the impacts of changes in body size patterns and functional biomass on fish communities in a floodplain river system which were assessed as a regime shift (Bouska, 2020). Measurement of body sizes provides an easy and comparable method for assessment of ecological impacts and might be applicable for the assessment of functional impacts on crustacean communities.

In sum, there are three key lessons learned from these studies. Firstly, human impacts may result in discernible alterations not only in species structure and diversity but also in functional attributes (Perônico et al., 2020; da Silva et al., 2020; Bouska, 2020). Secondly, despite that all these studies consider a number of aquatic organism groups, crustaceans are relatively understudied among these organisms. Finally, natural environmental gradients and anthropogenic pressures are studied as independent variables; thus, their interaction remains largely unstudied. These scientific gaps form the basis for creating the conceptual pathway described below.

III. A Working Pathway from Gradient to Signal

The conceptual pathway shown in figure 1 includes three successive stages, one outcome, and two sets of modifiers. The first stage is referred to as gradient transition and relates to the passage of the river across

various ecological zones, such as headwaters and mid-reaches, lowlands, floodplains, and margins of lakes. Such ecological zones have unique environmental features, such as water flow, substrate composition, shade, food availability, and vegetation. Gradient of the river affects distribution of the characteristics of the aquatic communities. The second stage is called trait filtering and is about the effect of environmental conditions in ecological zones on the selection of traits. For crustaceans, such functional traits as body size, feeding habits, and habitat choice (open-water swimming, attachment to vegetation, and burrowing in sediments) can be considered. For example, variations in the number and distribution of macrophytes affect the composition of communities of microcrustaceans. The third stage is called functional diversity and reflects the characteristics of the filtered community in terms of functional richness, functional redundancy of species, and functional trait distribution.

The general result of this pathway will be the generation of an ecological monitoring signal through functional indicators. Functionals indicators are useful for ecological evaluation since they provide information about any structural or functional change in an ecosystem that cannot be detected using species abundance only. In addition to that, the pathway is also shaped by two classes of environmental modifiers. Land use practices, such as grazing and alteration of land cover, will affect mainly the trait filtering process through altering environmental conditions and resource inputs into aquatic ecosystems. Likewise, the processes of river regulation and ecological regime shift will affect the environmental filtering process and the community structure generated.

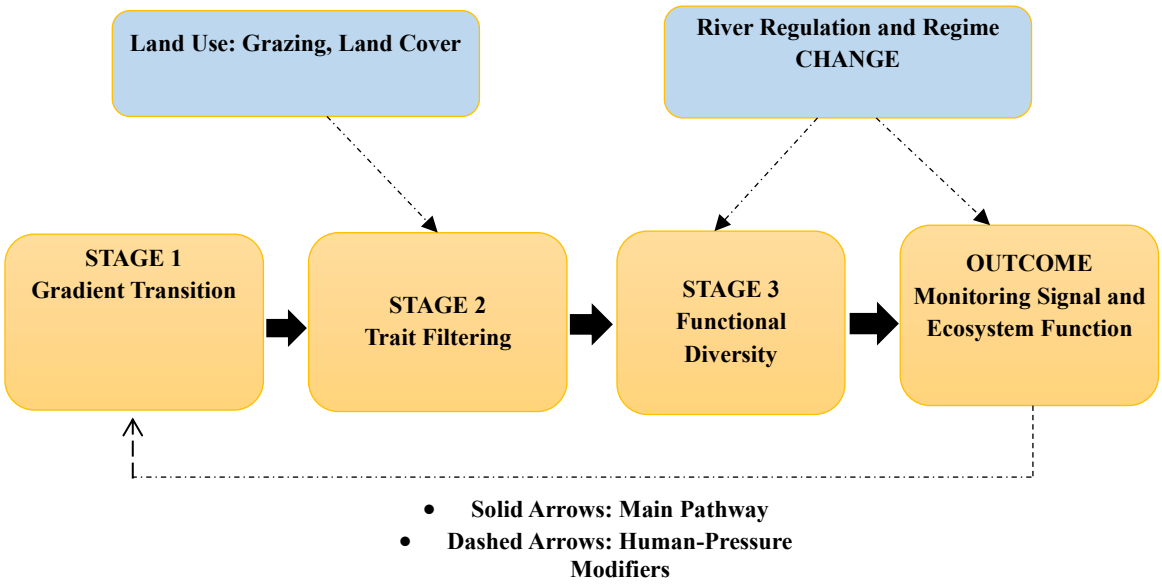


Figure 1: Conceptual Framework Illustrating the Influence of Natural Gradients, Habitat Trait Filtering, and Human-Induced Pressures on Functional Diversity and Ecosystem Function in Freshwater Ecosystems

The theory predicts four testable hypotheses for field study:

- **P1.** Functional diversity is predicted to change most dramatically between river zones and not gradually across the gradient.
- **P2.** Functional groups of crustaceans respond more to habitat structure (e.g., vegetation) than to season.
- **P3.** Intensity of land use will decrease functional richness/redundancy and will have its greatest impact on headwater and floodplain zones.
- **P4.** Regulation impacts on functional diversity will be greater than flow variation seasonality impacts.

IV. How Evidence Coverage Was Mapped

Coverage was evaluated using coding of the twelve papers included in the current review. This paper was given a corpus of sources. It does not result from systematic literature research, nor does it pretend to be complete.

A paper's title and the questions asked in it were examined, and it was given one category of primary drivers: natural gradients, land use, or river regulation and regime change. In addition, it was given one organism: fish, benthic macroinvertebrates (in particular, chironomids), plankton (zooplankton and phytoplankton), or reef molluscs. Finally, the publication year of the paper was noted. We have counted numbers of each, and studied which combinations of driver and organism were present and which were missing.

There are some limitations in this method. The corpus is too small, and coding was performed by a single researcher. Coding one primary driver may misrepresent those studies that consider several drivers. Some papers studying benthic macroinvertebrates may actually be studying crustaceans along with them, but it is not mentioned in the titles of those papers, and we code only what was stated in titles. The counts we get describe the corpus, not the whole field.

V. What the Evidence Map Shows

Figure 2 displays the spread of papers by the various environmental pressures. The papers were divided according to environmental pressures where land use pressure was the main focus in five papers, natural environment gradients in four papers, and river regulation or regime changes in three papers. These results suggest that land use pressure is the environmental pressure that is the most widely investigated in the review. As for the organisms, benthic macroinvertebrates were found in five papers and fishes in four papers, which amounts to nine of the twelve papers. Two papers dealt with plankton communities and one with reef molluscs. It should be noted that there was only one paper on crustaceans, dealing with microcrustaceans along a macrophyte gradient in a lake.

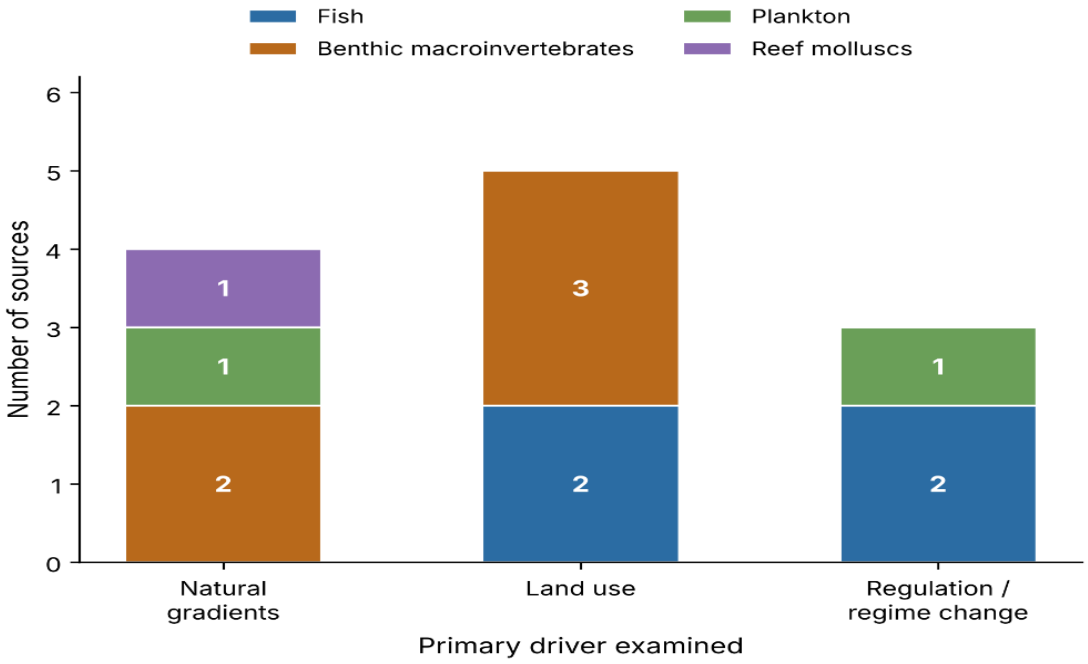


Figure 2: Number of Sources by Primary Driver Examined and Organism Timing

The way studies have been distributed in terms of organism groups and environmental drivers also exposes some critical research gaps. Fish studies looked at the effect of land use and river regulation, without considering the natural environmental gradients. On the other hand, studies conducted on macroinvertebrates looked at natural environmental gradients and land use, but did not look at river regulation. Studies done on planktons were split in half with half looking at natural environmental gradients and half at river regulation, while the one study on reef molluscs looked at a natural environmental gradient. It is significant to note that none of the sources considered have considered both natural environmental gradients and anthropogenic pressures together.

Interest has been recent. Five sources were published in 2020, two each in 2019, 2021 and 2022, and one in 2023, so nine of twelve fall between 2020 and 2022 (Figure 3).

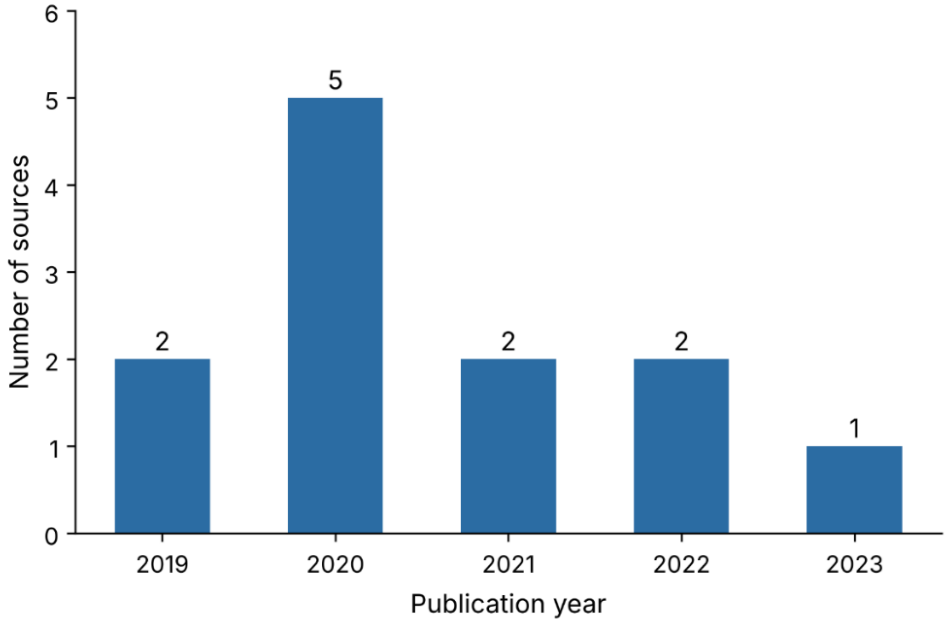


Figure 3: Distribution of Reviewed Research Publications Across Different Years (2019–2023)

The figure below shows the annual trend of research publications between 2019 and 2023. There were 12 sources of publications in the entire span of five years. The year 2020 saw the largest number of sources with five sources, implying a higher research trend in that year. Conversely, the year 2019, 2021, and 2022 had two sources each, whereas the year 2023 had one source. The trend shows that research had a relatively high concentration in 2020 and a gradual decrease in the following years.

VI. Reading the Pattern

The primary findings consist of two gaps. First, this is a taxonomic one, as crustaceans, in rivers varying from zooplankton to decapods, have no representation as an important group. Second, this is a conceptual gap, as natural gradients and human pressures are analyzed in separate studies, while the model described in figure 1 requires their interaction, as a pressure like grazing or regulation affects communities that have a gradient-driven structure.

The distribution of driving forces gives a practical conclusion. The land use is the most researched pressure, so the means of its evaluation must be well-developed. However, regulation is the least studied pressure, but all three sources describing it report clear changes in the community – reduction of fish diversity, loss of functional and taxonomic diversity of phytoplankton, and shifts in body size structure. If regulation leads to such changes in the other groups, then the crustaceans are not excluded, and the regulated parts of the river are ideal locations for testing P4.

There is another aspect to consider, which is what to measure. Taxonomic and functional diversity were measured in several sources, and this is relevant since these two types of diversity may change differently in time. The number of species in a community does not necessarily reflect its functional diversity, and vice versa. For crustaceans, body size is the characteristic that can be considered as the first step due to its availability and relevance to food consumption and predation risk. This is evident from body size patterns revealed in regime change study.

This approach has several limitations. First, it requires that characteristics of crustaceans are assigned consistently even within as different groups as zooplankton and decapods. There are also fewer trait databases for freshwater crustaceans than for insects. Second, the approach does not account for the continuous nature of gradient zones that can be observed in real rivers. Third, the approach distinguishes between land use and regulation as two independent modifiers although they co-occur in most catchments. Fourth, the map is based on only twelve sources and one coder. Hypotheses P1-P4 have been formulated but not proved or disproved.

VII. Conclusion

Six recommendations concerning the sampling of freshwater crustacean communities have been formulated. In the first place, the sampling sites should be set up along the transitions between river zones instead of their centers. The second recommendation refers to recording of habitat structure at each sampling site, since this parameter plays a key role in functioning of the crustacean functional guilds. The third recommendation concerns the need to study both taxonomic and functional features of the species (body size, feeding type, habitat) in the process of monitoring. The fourth one involves performing the joint analysis of taxonomic and functional diversity, since such approach enables distinguishing between changes due to species losses and those caused by ecological functions losses or changes. The fifth recommendation states that the monitoring programs should compare the reference sites with environmentally pressured sites within the same river zone to study the impacts of various activities such as livestock grazing, intensive land use, and river regulation. Finally, additional sampling efforts should be made in case of regulated river reaches since they remain poorly studied and characterized by significant community and ecological changes.

The main directions for future studies should be the following. Firstly, field investigations need to study crustacean communities, starting from zooplankton and ending up with macrocrustaceans, all the way along the entire river gradient, from the headwater areas to floodplains. Secondly, studies should include natural environmental gradients and at least one human disturbance impact to cover the main problem identified in the literature review. Finally, the creation of a database of functional traits for freshwater crustaceans is vital to conduct consistent comparison of results across various rivers and geographical areas.

The natural environmental transition occurs gradually, while anthropogenic actions lead to the sudden alteration of conditions. These processes have been studied by researchers in several organism groups, such as fish, insects, plankton and molluscs, yet the crustacean group has been paid little attention in the literature. Hence, a crustacean-oriented research programme aimed at studying the responses of crustacean communities in natural environmental transitions and comparing them with the patterns observed in environmental pressured parts of the river would fill the knowledge gap. Additionally, this approach will be very useful for river managers who want to create a reliable monitoring system based on functional traits.

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