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Influence of Submerged Habitat Complexity on Juvenile Fish Recruitment in Inland Water Systems

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Abstract: Juvenile fish require refuge, feeding and settlement areas, and in inland waters, these areas are typically comprised of submerged vegetation, wood, rock, or artificial structures. This paper considers the question of how the complexity of submerged habitats impacts juvenile fish recruitment in inland aquatic systems and where there is insufficient evidence. As there are very few papers focusing on inland recruitment in particular, we created an evidence map based on twelve recent articles found in peer-reviewed journals and related to lakes, rivers, coastlines, and reef systems, translating the results of their findings into the context of inland waters. Each paper was coded according to the system and the main focus of research. The corpus was provided and did not come from a systematic database search. There were five papers related to inland systems and five papers related to marine/coastal systems, with two papers being relevant to both categories. Although seven titles mentioned either recruitment or juveniles, only two of those were related exclusively to inland lakes. On the basis of such a trend, we advance a four-step model whereby the formation of structure leads to increased complexity, which in turn results in shelter, food, and recruitment signals, followed by juvenile survivorship and finally recruitment. Human influence and the landscape background serve as modifiers in our model. Four hypotheses can be tested as a result. The first one is that complexity will be important wherever there is little natural structure. Our list of topics and future research agenda includes recruitment rather than adult abundance.

Keywords: Juvenile Fish; Fish Recruitment; Habitat Complexity; Submerged Structure; Inland Waters; Aquatic Vegetation; Habitat Restoration.

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I. Nurseries Made of Structure

Each population of fish starts out as a cohort of juvenile fish. What happens to them—whether they develop into a fishery or not—largely hinges on their habitat settlement and what conditions they find there. In a temperate coastal system, a systematic study has looked into the impact of structure alteration on fish recruitment, whereby structure serves as the tool of manipulation for management (Macura et al., 2019). Structure can also be taken away. It has been shown that recreational boating degrades the important vegetation for fish recruitment, and this can happen on a highly trafficked shoreline without any apparent change to the naked eye (Hansen et al., 2019).

The process of recruitment is not only linked to physical shelter. The role of chemical stimuli in recruiting fish and habitat selection by juvenile fish differs from marine systems to freshwater systems (Bilodeau & Hay, 2022). It follows that for inland water bodies, one cannot apply lessons learned from the oceans. The inland fishery managers understand this issue. In North Central North America, there have been studies of the habitat requirements in relation to recruitment of walleye in inland lakes (Raabe et al., 2020). Where the natural habitat is unavailable, it can be created artificially. Artificial floating islands have been recommended for use in enhancing survival of juvenile fish in lakes (De Moraes et al., 2023).

It should be noted here that just the type of habitat may not be enough. Use of habitats by juvenile fish was seen to be more determined by the environment than the actual habitat (Bradley et al., 2019). This means that two reed beds in different lakes could bring out different results.

Questions about these strands are straightforward. Is there any association between more subaquatic complexity and greater number of young fish in freshwater systems, and under which circumstances? This is relevant to lake rehabilitation efforts, stock enhancement programs, and construction of manmade

structures. We do not introduce a new field survey. Rather, we try to build a conceptual framework based on previous studies and analyze how uniformly the existing research fills in this framework. This article uses an unorthodox approach in its structure. It starts by drawing conclusions from previous work, sets out a pathway, explains mapping of coverage, reports the results, and gives recommendations.

II. Evidence Gathered from Related Work

Another six studies shed more light on the interaction between habitat complexity and fish communities, considering different ecological aspects. Moving along the gradient of habitat structural complexity, fish alpha and beta diversity emphasized the significant impact of environmental filtering on the process of fish community formation (Cunha et al., 2019). This means that the habitat structure does not only lead to an increase in fish abundance but also impacts the species composition of a community, and it is especially critical for juvenile fish that have specific habitat needs. Moreover, studies conducted in a Neotropical River revealed that aquatic macrophytes impact the foraging efficiency, trophic niche width, and diet overlap of small fish (Quirino et al., 2022). It means that the aquatic vegetation can potentially impact feeding possibilities and resource consumption by young and small fish. Furthermore, it has been shown that macrophyte complexity impacts juvenile fish habitat selection in a marine habitat (Hinz et al., 2023).

In addition, the significance of habitat complexity within shallow lakes and ponds in terms of the benefits of complexity to ecology, threats to complexity, and possibilities for restoring habitat complexity have been reviewed (Meerhoff & de los Ángeles González-Sagrario, 2022). This review is especially pertinent for inland water bodies because it shows that habitat complexity serves as an important ecological asset and also a vulnerable habitat component. Moreover, a systematic review and meta-analysis assessed the effects of boat passage and mooring infrastructure on aquatic plants (Hansen et al., 2019; Sagerman et al., 2020). In combination with previous results indicating the impact of boating activity on fish recruitment, this information shows that recreational activity could slowly degrade vegetation and complexity needed for nursery habitats. Evidence from marine environments also proves that submerged structures serve as an important ecological structure. For example, submerged coral reef pinnacles contained higher fish richness and abundance as well as a unique fish assemblage in comparison with shallow emergent reefs (Galbraith et al., 2021). Although this study was conducted in marine environment, it shows that submerged structures at different depths may create specific fish communities.

The above findings lead to three main observations. First, habitat complexity affects the fish community composition, feeding habits, and habitat utilization by the juveniles (Cunha et al., 2019; Quirino et al., 2022; Hinz et al., 2023). Second, complex habitats are susceptible to human interference and may be challenging to restore once damaged (Meerhoff & de los Ángeles González-Sagrario, 2022; Sagerman et al., 2020). Third, despite the many studies that have established a relationship between habitat complexity and juvenile habitat utilization and recruitment, most of the information is from coastal and marine systems. Conversely, studies in the inland waters have been more concentrated on fish communities, feeding habits, and habitat restoration. Such information has led to an important knowledge gap which can form the basis of the theoretical framework shown below.

III. A Working Pathway from Structure to Recruitment

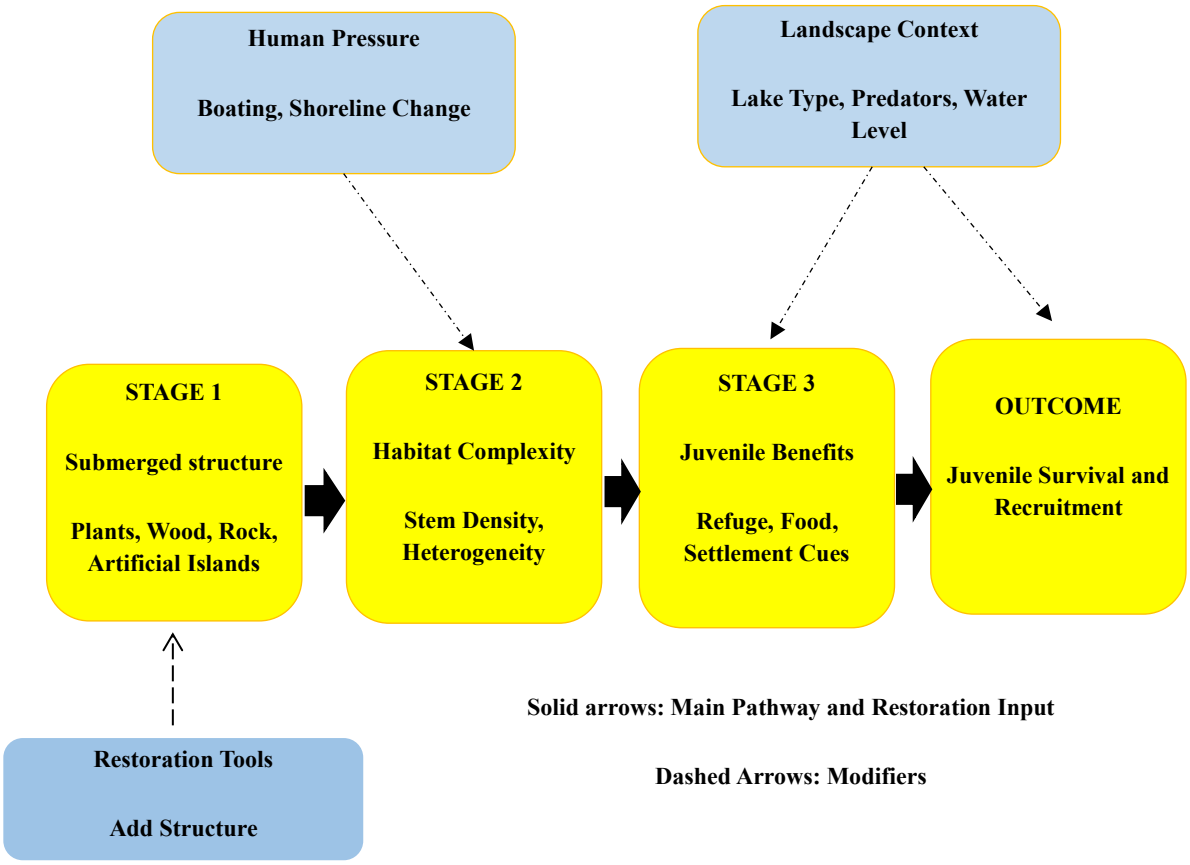


Figure 1: Conceptual Framework Illustrating the Influence of Habitat Structure, Environmental Context, and Human Pressure on Juvenile Survival and Recruitment

The pathway depicted in figure 1 comprises of three sequential steps, an outcome, two groups of modifiers, and a single management input. Step 1, submerged structure involves the presence of aquatic plants, wood, rocks, and artificial structures that comprise the physical structure of the habitat. In inland waters, the structure is dynamic in the sense that there is growth and death of aquatic plants coupled with fluctuations in water levels. Habitat complexity occurs in the second step when the physical structure creates varied stem densities, shapes, and both open and sheltered space. In other words, habitat complexity is not just a function of how much structure is available but how the structure is configured. In the third step, juvenile benefits, habitat complexity will offer shelter from predators, food and settlement cues. This is in effect, a number of pathways that could be adopted by habitat complexity for benefiting juveniles where the habitat could give one without offering the other two. The outcome of the entire process is increased juvenile survival and recruitment since the benefits provided by the habitat complexity will lead to increased survival chances of the young ones.

There are two types of modifying factors that influence the pathway. Human activities such as boating and shoreline alteration predominantly influence the first and second stages through modification and simplification of submerged habitat structures. The landscape setting that includes the lake type, predators, and changing water levels determines the third stage and the outcome through determining the ecological significance of the habitat structure within different environments. Artificial structures and other management actions are an input to the first stage since they increase the availability of submerged habitat structure.

This theoretical framework makes four predictions for testing in the field. First, the higher the juvenile numbers and survival rates, the more complex should the habitat be; yet these advantages of habitat complexity could be leveled off or reversed at very high vegetation densities, when dense vegetation might limit movements. Second, the advantages of habitat complexity would be more pronounced in those waterbodies that have low natural submerged structures. Third, the advantages of habitat complexity would depend on the environment, which implies that the same kind of structure can give rise to different recruitment results in different lakes in terms of predators, depth, and water level dynamics. Finally, additional structures, including artificial ones like floating islands, are expected to enhance habitat utilization by juveniles, but the results of recruitment improvement would depend on their ability to provide refuge or food or settlement cues.

IV. How Evidence Coverage Was Mapped

Coverage testing was performed using coding of the twelve references included in this essay. The collection of references was provided for this study. This collection is not the result of systematic search through databases and cannot be regarded as exhaustive.

Each of the references was coded in terms of the title and question addressed, as well as the system type (inland waters, marine/coastal waters or mixed/unspecified), and main research subject (complexity effects on fish use, assemblages or foraging; restoration/management; human impact on vegetation; synthesis of recruitment effects; settlement cues). Information on whether the title contained the term “recruitment” or “juveniles” and year of publication was also collected.

However, this coding method does have limitations. The body of work is small, and only one person did the coding. Categorizing the project according to only one focus allows researchers who do many things within one paper to simplify their work. However, although the paper might be considered a marine project, it could still apply to fresh water. A paper considered an inland project might not even discuss juvenile fish. We only coded what the title suggested, so the numbers represent this body of work and nothing else.

V. What the Evidence Map Shows

Types of Systems: Five sources each pertained to inland water and to marine or coastal water. Two sources covered both systems or were unspecified. Hence, half the sources in the corpus relate to the system of interest while the other half relates to the system used as a comparative framework.

Area of Research Focus: As seen from figure 2, five sources were related to the impact of complexity on fish utilization, assemblage, and foraging behavior. Three sources focused on restoration or management while two sources looked at the human impact on vegetation and one each studied the synthesis of recruitment effects and settlement cues.

Sources of Each Research Focus Area: Two out of the five sources dealing with the response of complexity focused on inland water while all three restoration or management sources were from inland water. None of the sources in inland water were related to human impacts on vegetation, recruitment effect, and settlement cues while all the marine or coastal sources provided the remaining research sources.

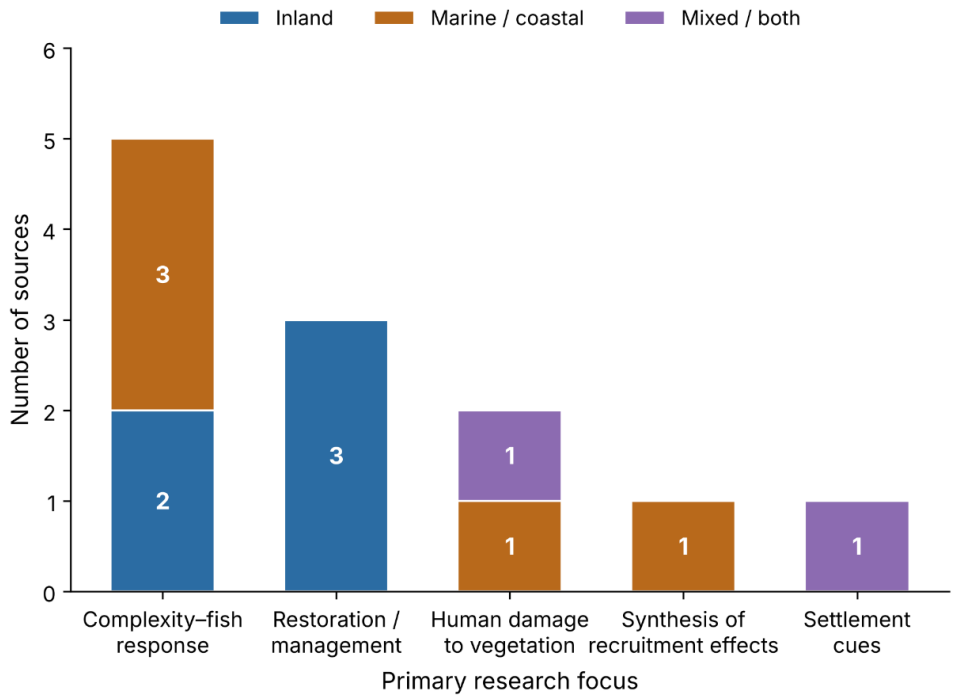


Figure 2: Number of Sources by Primary Research Focus and System Type

Recruitment and Juveniles: Seven of the twelve sources mention recruitment and/or juveniles. Of these, two dealt solely with inland waters. One source studied both marine and freshwater environments, while four others were marine or coastal. Sources about inland waters that do not mention recruitment and/or juveniles deal with assemblages, feeding, and restoration.

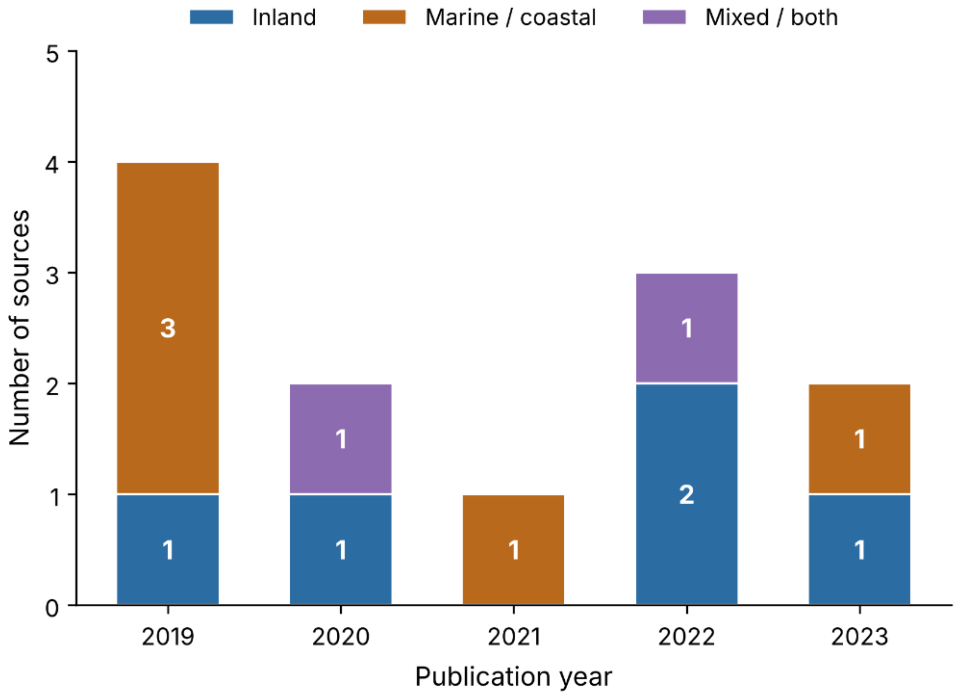


Figure 3: Number of Sources by Publication Year and System Type

Timing: Four sources were published in 2019, two in 2020, one in 2021, three in 2022, and two in 2023 illustrated in figure 3. Three out of four sources from 2019 were marine/coastal, while the remaining ones are either one or two sources for each subsequent year. Interest in this topic does not vary from year to year.

VI. Reading the Pattern

The key result is inconsistency between the research question and the data. The research question addresses juvenile fish and recruitment in inland water bodies. However, in this corpus, the studies addressing either recruitment or juveniles are almost all coastal/marine, while inland studies relate to assemblages, feeding habits, or restoration. There are inland data, but they have to be generalized through one step. Evidence that structural complexity modifies species composition or feeding habits does not mean evidence that it enhances recruitment.

Another result is that restoration is a well-researched inland topic. It is helpful as it indicates that there are means to restore ecosystems – for example, artificial floating islands; however, at the same time, the fast development of restoration may occur ahead of outcome-oriented evidence. Structural modification implies restriction of recruitment by structures. Therefore, this pathway presents a testable hypothesis (P2).

Another finding deals with context. According to the mixed-systems approach source on settlement cues and the two studies on habitat selection, the importance of structural complexity is defined by the senses and danger to which young fish are exposed. Thus, in the context of this study, landscape context is a modifier of the importance of complexity, and not an independent aspect. This suggests that two similar in terms of plant abundance lakes may provide unequal recruitment of fish.

There are some limitations of the pathway. Firstly, this pathway implies the comparability of structural complexity among plants, wood, rocks, and artificial structures; however, such metric does not exist. Secondly, this pathway distinguishes among three aspects (refuge, food, settlement cues), though they may share each other in reality. Thirdly, it implies the existence of pressure on structural complexity only (human activities); however, other pressures, for example, nutrient pollution, may affect recruitment directly. Finally, the evidence map includes twelve sources coded by one person, and all four hypotheses were not tested here.

VII. Conclusion

Six useful guidelines have been suggested to monitor and manage aquatic habitats. The recommendation is that recruitment must be assessed directly by taking samples of year-old fish and evaluating their survival rates without using adult fish catch or presence of a species only. Habitat complexity must be estimated by taking into account stem density, diversity in structure, and balance between sheltered and open habitats, rather than by measuring only the vegetation cover. The comparison of structured and unvegetated sites in the same water body will help to distinguish the impacts of habitat complexity. In addition, other environmental factors such as predators, water depth, water level changes, and the type of lake should be recorded at each study site. Protection of existing vegetation is recommended as the first step by reducing disturbances caused by boating and anchoring before installing the artificial habitat. Moreover, the restoration project should be considered as an experiment where use and recruitment of juvenile in structured and unstructured sites should be evaluated.

The future directions for research should be the following three. Firstly, the research should be carried out concerning the habitat complexity on the issues of juvenile survival and recruitment in freshwater systems. Secondly, the controlled experiment should differentiate the contribution of refugia, food, and recruitment cues to the development of juveniles. Finally, the research should be carried out on various types of lakes to see the role of environmental context on the issue of habitat and recruitment relationship.

The submerged habitat structures serve as important ecological elements used by young fish. However, such habitats face increasing destruction and degradation nowadays. The current paper shows that while

the link between the structure of submerged habitats and juvenile recruitment seems to be plausible ecologically, the corresponding studies have not been conducted sufficiently enough in the case of lakes and rivers. The currently available data describes how young fish use the habitat structures, obtain their food, and behave under the conditions of habitat degradation and restoration. Nevertheless, the direct connection between these issues and recruitment results was studied very poorly. Hence, special investigations concerning juvenile recruitment at different degrees of habitat complexity and environmental conditions should be made to fill the gap.

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