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Assessing the Contribution of Floating Vegetation Mats to Habitat Formation in Tropical Marshlands

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Abstract: Mats of floating vegetation are characteristic structural habitats within tropical marsh systems, where floating stems and leaves, along with submerged roots and entangled organic matter, give rise to a complex of microhabitats. The floating mats can serve as a refuge and source of food and substrata for aquatic invertebrates, as well as affecting the flow of water and processes of organic matter cycling in the vicinity. The role played by the structures could be affected if the mats are fragmented into isolated patches by drainage, changes in water level, physical disturbance, or invasive plant removal. In this paper, we will attempt to evaluate the contribution of floating vegetation to the creation of habitats, and establish an ecological context for the effects of fragmentation on the dispersal and colonization of aquatic invertebrates. Publications between 2014 and 2022 have been reviewed in the context of the structure of the vegetation, habitat heterogeneity, dispersal strategy, isolation of the patches, and wetland connectivity. Thus, fragmentation will have different impacts on different taxa, as aerial dispersal will be easier for mobile species than for taxa relying on aquatic transport or short-distance dispersal mechanisms. However, small patches may act as stepping stones when the appropriate distance, water flow, and habitat quality are available. The paper differentiates between theoretical expectations and experimental findings, and highlights the variables necessary to test the theoretical predictions, which include patch area, distance between patches, root abundance, water quality and invertebrate communities. The retention of a diverse but connected vegetation pattern in tropical marshes is suggested as a management principle.

Keywords: Floating Vegetation; Tropical Marshlands; Habitat Complexity; Wetland Fragmentation; Aquatic Invertebrates; Dispersal; Colonization.

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I. Introduction

Tropical marshes are constantly changing freshwater habitats influenced by periodic rainfall, varying water levels, sediment dynamics and abundant aquatic flora. They are home to a variety of biological communities and perform functions related to nutrient cycling, organic matter decomposition, water quality regulation and habitat formation. The ecological state of these ecosystems cannot be judged by the extent of open water surface and total plant coverage. The spatial configuration and structure of plant communities can result in different kinds of habitats with respect to shelter, food resources, oxygen supply, and organism access.

Floating mats are communities of floating and/or buoyant plants with their roots and stems, as well as organic debris attached to them. Depending on the species and hydrological regime, they can create rather homogeneous rafts or mosaic patches. Their submerged parts act as substrates for periphyton and provide shelter for tiny aquatic organisms. The upper layer of vegetation also acts as an interface between water and land habitats, with emergence of insects and interaction of the organisms on the water surface. Habitat formation due to macrophyte structure is a key determinant of aquatic invertebrate communities in wetlands and shallow-water ecosystems (Díaz-Valenzuela et al., 2016).

The functional value of a mat depends on its structure. The length of roots, number of branches, density of stems, biomass of plants, and volume of detritus held together affect the variety of space available for organisms. High structural complexity can lead to protection from predation and formation of low flow microhabitats, but the dense mat can hinder water exchange and promote low oxygen level under the mat. Thus, vegetation cannot be viewed as something always positive; it is influenced by the trade-off between providing the habitat and the local physical/chemical environment.

Vegetation in wetlands is subject to drainage, shore alterations, nutrient enrichment, water abstraction, mechanical removal and invasion by alien species. Such pressures can fragment previously continuous vegetation patches. Fragmentation results in reduced area of the habitat, greater distance between patches and change in pathways used by organisms. There are differences in the ability of invertebrates to cross gaps: adult aquatic insects have the opportunity to fly; larvae of insects, mollusks, and crustaceans are more dependent on water displacement.

The key issue to be addressed in this study is that of integrating habitat quality with habitat accessibility. An area may have complex root structures and plenty of food resources but poor colonization owing to its isolation from the source population. On the other hand, a comparatively smaller patch can aid landscape connectivity in case it serves as an intermediate habitat. The aims are to: (i) explore the habitat creation role of floating plant mats; (ii) explore the relationship between the vegetation structure and use of habitat by invertebrates; (iii) evaluate possible impacts of fragmentation on dispersal and colonization; and (iv) provide a field-based approach for marshland evaluation and management.

Review Approach and Scope

This paper represents a targeted narrative review and concept synthesis as opposed to a systematic review or experimental study. The evidence base will be limited to the years of publication requested for the manuscript – 2014-2022. The reviewed papers concern dispersal of macroinvertebrates in wetlands, associated communities in macrophytes, artificial floating vegetation, connectivity in wetlands, and invasion by floating plants. Papers have been included if they covered any of four areas of interest: (a) structural provision of habitat by aquatic vegetation; (b) colonisation and dispersal of aquatic invertebrates; (c) fragmentation and connectivity; and (d) management.

The presented synthesis is purposely conservative in its conclusions since there are variations across different ecosystems, plant species, scales, and methodologies. Evidence from constructed floating wetlands or temperate wetlands is used for understanding the mechanisms but not as direct transfer of effect size to tropical marshlands. The figures in the present manuscript are conceptual illustrations. Ordinal values and trend lines presented in them are illustrative and not observational, modeled, or derived from dataset results.

II. Floating Vegetation Mats as Habitat-Forming Structures

Structural Complexity and Microhabitat Availability

Floating mat habitat value is a result of the presence of above-ground vegetation cover, below-water roots, stems, surfaces, and detritus. Below-water roots not only add surface area but provide interstitial spaces that could be inhabited by small macroinvertebrates. Therefore, differences in root density and branching would generate significant variability in habitat availability despite similar total surface area of two floating mats.

Complexity of the vegetation itself might have an effect on the structure of macroinvertebrate assemblages through alteration of shelter sites, feeding surfaces, and local water flow regime. Macrophyte complexity and stream current velocity have been shown to affect the composition of epiphytic macroinvertebrate assemblages in lowland streams (Wolters et al., 2018). Although the difference between streams and marshes lies in their current velocity and channel shape, the underlying process remains valid for floating mats: vegetation structure influences the environment experienced by invertebrates. Microhabitats within wetlands could also harbor unique macroinvertebrate assemblages.

The structure of a floating mat must therefore be evaluated in addition to its coverage. Some useful parameters include root length per unit area, root biomass, stem density, vegetative height, perimeter of patch, detritus thickness and the proportion of exposed roots. Such parameters would make it possible to differentiate between a dense, well-branched mat and a sparse mat of equal surface area.

Food Resources and Trophic Support

Plant tissues and particulate organic matter offer surfaces for microbial colonization and breakdown. The periphyton that grows on roots and stems will allow scrapers and other grazer invertebrates to thrive, whereas the fine particulate organic matter can serve as a substrate for collectors and filter feeders. Shredders could possibly make use of decaying plant material, while the predators can take advantage of the concentrated prey in the root network. Thus, a floating mat can participate in multiple food chains rather than just providing physical refuge.

The significance of these mechanisms will depend on the plant type, quality of plant material, rate of decay, nutrient conditions, and oxygen levels. A lot of organic matter does not mean a high-quality habitat: the presence of too much organic matter increases microbial oxygen consumption, especially in standing water under dense vegetation. The monitoring process should involve the analysis of structural data along with dissolved oxygen content, temperature, pH, turbidity, and nutrients.

Refuge and Boundary Effects

Root masses reduce the ease with which the predators get into the narrow places and create refuges for young or non-swimming animals. The edge of the mat is a transitional area from open water to dense vegetation. This border area might be used by animals that inhabit both areas and will have higher water exchange than the center of the mat. The edge and center areas need to be analyzed separately when the goal of the research is the distribution of the community.

There is additional evidence that artificial floating islands and floating wetlands could be used by macroinvertebrates. One of the studies dedicated to macroinvertebrates associated with artificial floating islands in the Kshipra River proves the usage of such structures by aquatic organisms (Gleason et al., 2018). These systems do not resemble natural mats in the marshland, but they show the possibility that there is biological cover created through floating structures.

III. Vegetation Fragmentation, Dispersal and Colonization

Fragmentation as a Change in Habitat Configuration

Fragmentation affects both the quantity and pattern of habitat. An unbroken mat can be fragmented by physical break-up, boat activity, lowering of water level, waves or altered vegetation growth. The important attributes of the landscape include the size of patches, the number of patches, the ratio of the edges to the area, nearest neighbour distance and the connectivity through root systems or surface water. Fragmentation does not necessarily lead to significant loss of vegetation cover if the vegetation cover is simply redistributed as numerous isolated patches.

In terms of aquatic invertebrates, it will vary depending on whether the gap is a barrier or open space. The flying adult can cross open water and land while the larval stage may need to be connected to water or vegetation. Hydrological connections partially make up for the physical separation if the flow of water transports the organisms between the patches. Alternatively, barriers such as dry land, culverts or disconnected pools limit movement between the patches.

Dispersal Traits and Colonization

Dispersal abilities differ for various taxa and life history stages. While many insects living in the water have flying adults, there is a variation in their ability to fly, emergence times, and search for new habitats. Other animals either stay aquatic all their lives or depend on passive dispersal. Therefore, one and the same fragmentation pattern will positively influence the mobility of some taxa and negatively affect those animals that are poorly mobile.

The studies of metacommunities of wetland macroinvertebrates have demonstrated the importance of dispersal ability and type in spatial community turnover (Patrick et al., 2014). This confirms a trait-based

understanding of fragmentation when the ecological effect should be analyzed depending on the dispersal group and not just in terms of richness or abundance. Reduced connectivity will lead to a more dramatic effect in poor dispersers, while very mobile animals will be able to occupy disconnected patches. Insect colonization of Eichhornia floating meadows illustrates the importance of dispersal ability in accessing disconnected patches.

In addition, colonisation is contingent upon suitability of the habitat for establishment once the organism has arrived there. The site could well be accessible but unsuitable for colonisation if the root structure is insufficient, the sources of food are scarce, oxygen is unsuitable or predators abound. Thus, colonisation must be viewed in terms of a process consisting of arrival, survival and colonisation. Studies of artificial wetlands have investigated colonisation by macroinvertebrates in early successional stages (Kim et al., 2014).

Patch Networks and Stepping-Stone Functions

A cluster of small patches could serve as an integrated habitat network provided the distance between the patches falls within the movement abilities of the targeted species. Intermediate patches may lower the dispersal distance and offer temporary refuge or food. Floating wetlands created artificially have been suggested to serve as stepping stones which could enhance habitat connectivity for aquatic animals (Karstens et al., 2022). The effectiveness of such stepping stones will most probably depend upon the positioning, durability, vegetative structure and habitat connectivity of the patches.

Fragmentation should not be viewed simply as a dichotomy between intact and fragmented habitat, because the shape of the patches is important. A few small patches provide more edge habitat than one large patch, but they also leave organisms more isolated and more exposed to environmental variability. Whether fragmentation is good or bad will depend on the type of organism and the landscape in which it occurs.

Conceptual Synthesis and Graphical Presentation

The first chart illustrates how the various parts of a floating mat could serve for refuge, attachment, food, and microhabitat (Figure 1). The figures are ordinal representations meant to illustrate ecological functions; they do not indicate actual measured functions. This figure shows that there is no one part that can serve all functions. The submerged roots should be particularly useful for refuge and attachment, whereas detritus accumulation would serve as an actual resource for the food web.

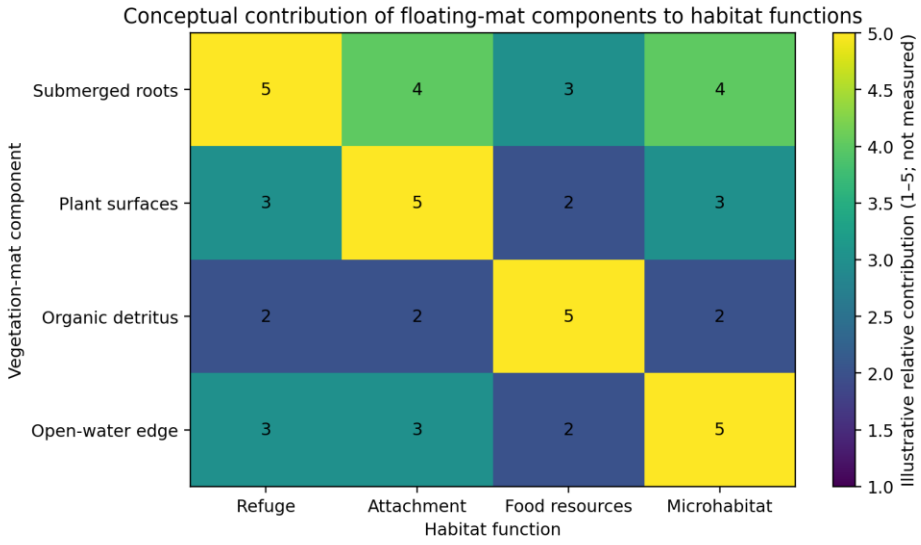


Figure 1: Conceptual Contribution of Floating-Mat Components to Habitat Functions

Figure 2 represents the predicted negative relationship between connectivity of vegetation and isolation of patches. The relationship is not based on a statistical fit but rather is hypothetical. In real-world situations, connectivity may be measured through distances between patches, hydrological connectivity, graph-based connectivity measurements, and landscape indices. The isolation index might have to be determined separately for different organisms due to differing dispersal distances of various organisms.

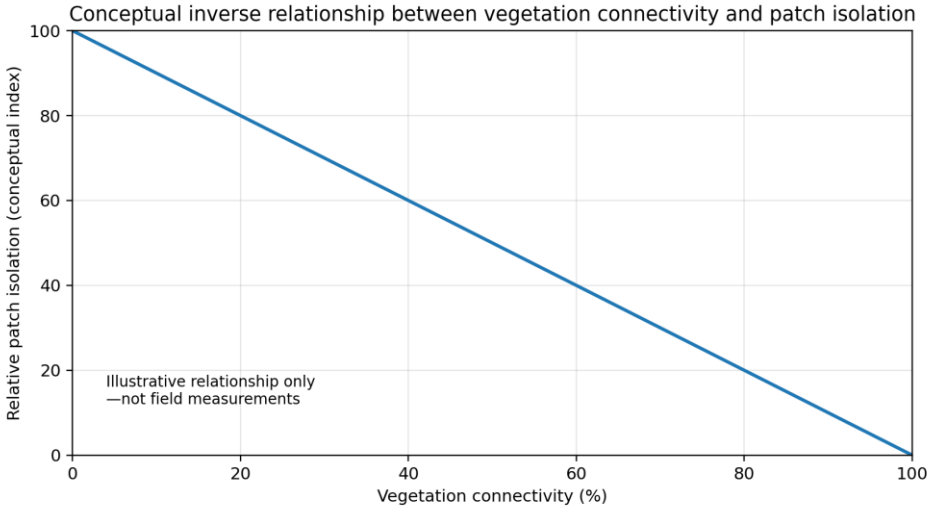


Figure 2: Conceptual Inverse Relationship between Vegetation Connectivity and Relative Patch Isolation. The Line is Illustrative and is not Based on Field Observations.

Figure 3 contrasts the predicted colonization potential of strong fliers, poor fliers, and water/aquatic dispersers with regard to three different types of vegetation connectivity. This ranking makes up the basis of a hypothesis that can be tested empirically; that is, less connectivity means more constraints on those species with limited possibilities to cross gaps. However, the ranking is not a general rule, and it needs to be verified.

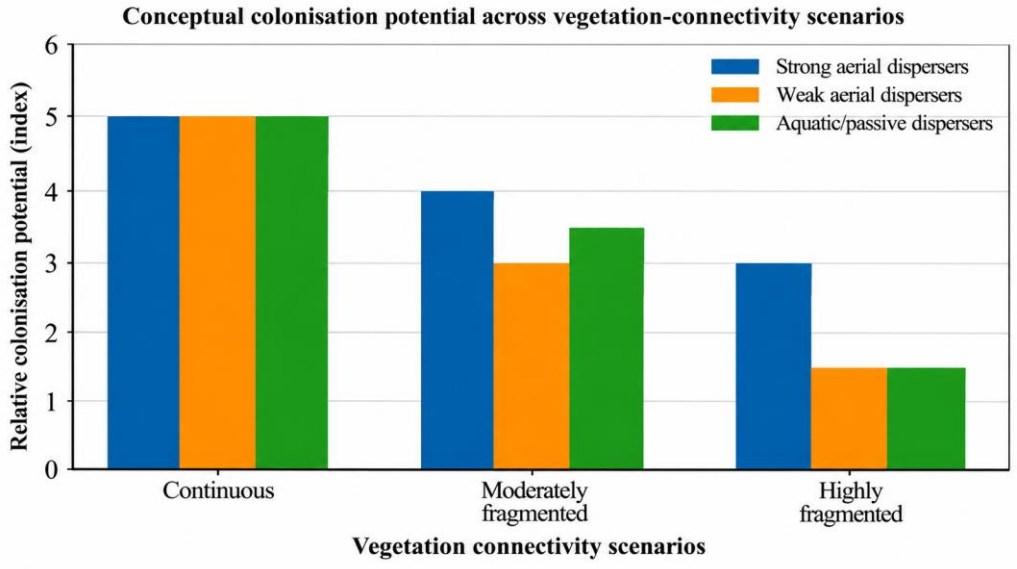


Figure 3: Conceptual Comparison of Colonization Potential Under Continuous, Moderately Fragmented and Highly Fragmented Vegetation Conditions. Scores are Illustrative, not Measured Data.

IV. Discussion

From the synthesis, it is evident that floating vegetation mats affect the aquatic invertebrate community via two connected parameters: habitat quality and accessibility in the landscape. Habitat quality depends on factors such as root morphology, surface area of plants, detrital inputs, oxygen environment and refuge presence. Accessibility is dependent on patch configuration, water flow, patch isolation and dispersal ability of organisms. Measures of the amount of vegetation can fail to capture these two aspects.

The connection between vegetation complexity and species diversity cannot be linear in all marshlands. Although increased vegetation complexity in the form of more complex roots may provide extra attachment sites and refuges, extremely dense vegetation will limit movement and cause low-oxygen levels. Just like the number of patches, while increasing edge habitat, it will also increase patch isolation.

Research in tropical and subtropical regions provides empirical evidence regarding the significance of vegetation structure and habitat characteristics in relation to macroinvertebrate assemblages. In this context, investigations into the complexity of macrophytes in a subtropical wetland have provided insights into the relationships between vegetation characteristics and macroinvertebrate community structure (Poi et al., 2021). The ecological implications of floating plants in terms of their invasive nature is another significant issue discussed in the context of wetlands with high coverage of floating vegetation (Kleinschroth et al., 2021).

The concept of fragmentation is also applicable in wetland landscapes in South Asia. Investigations into wetland connectivity and fragmentation with respect to the Haiderpur wetland complex in India provide the regional background for evaluating changes in wetland configuration (Singh et al., 2022). The long-term monitoring of aquatic macroinvertebrates in a Neotropical floodplain also provides an example of the significance of biological monitoring at wetlands (García-Ríos et al., 2022).

It is essential that the response variables are assessed on several scales. Patch scale assessment includes measurement of root density, plant biomass, detritus and water chemistry. Network scale assessment involves quantification of patch size, nearest neighbour distance and hydrological connectivity. Community scale assessment requires measurement of taxonomic diversity, abundance, functional feeding groups and dispersal traits. It is especially important to conduct sampling on repeated basis in tropical marshlands since hydrological variability can affect both the connectivity of vegetation and presence of aquatic habitats.

Conceptual model implies further development of the experimental design which will allow obtaining empirical data. It is necessary to conduct the experiment in several marshlands comparing continuously distributed, moderately fragmented and highly fragmented vegetation communities while controlling such variables as water depth, dissolved oxygen, nutrient status and plant identity. The sample must be taken separately for mat interior, edge and open water. Identification of invertebrates must be conducted at appropriate resolution in order to allocate their dispersal and functional traits.

The evidence base has some deficiencies. Research on constructed floating wetlands, streams, temperate wetlands, and tropical floodplains varies in terms of the ecosystem where studies were conducted. Hence, generalization needs to be done with caution. The current study is a narrative review and not a quantitative meta-analysis; it does not provide an estimated effect size of fragmentation. The suggested charts are purely illustrative.

Implications for Wetland Conservation and Management

Management should conserve the ecological function of natural floating vegetation while avoiding the formation of dense mats that would hinder water flow or displacement of other important habitats. Management should avoid unnecessary mechanical disturbance of natural mats, especially when the roots provide refuge to established invertebrate communities. Secondly, restoration should avoid homogenous vegetation coverage; there should be diversity in the size and placement of patches and corridors in the

ecosystem. Thirdly, where patches are far apart, strategically placed native floating vegetation could provide stepping-stone function.

Fourthly, invasions by alien floating plants require management through site-specific plans that take into consideration not only the spread of vegetation but also the habitat function of vegetation. Vegetation removal programs should avoid sudden disturbance that will eliminate the refuge habitat without offering an alternative. Finally, monitoring programs should incorporate biological indicators as well as remote sensing and vegetation mapping. Satellite or drone imaging could help in measuring the size and structure of patches and corridors, but it cannot replace ground-level observations of root structure, invertebrate communities and water quality.

A viable monitoring strategy would involve recording the vegetation cover, patch size, nearest neighbour distance, root density, oxygen levels, temperature, pH, conductivity, turbidity, and nutrients concentration. The invertebrates can be collected through standardized sweeping or sampling of substrate samples from within the vegetation, at the edge of the vegetation and at reference sites in open water. The sampling process should be done throughout both the wet and dry season.

V. Conclusion

Aquatic vegetation mats in tropical marsh ecosystems are of great importance as structures that facilitate habitat creation as they provide different microhabitats by virtue of leaves, roots and organic material. Such structures might serve as substrates, shelter and food for aquatic invertebrates and affect the water current in the area and organic matter decomposition. The ecological significance of these structures is determined not only by the presence of vegetation but also by the structure, water quality and distribution of vegetated patches. Fragmentation of such areas might decrease the continuity of habitats and increase the distances between the patches, thus affecting the ability of certain species to move from one patch to another due to the lack of aerial and aquatic dispersal ability. Other species might be able to cross the gap, while some weaker dispersers might need water currents or the presence of other intermediate patches. This framework for understanding has clearly shown that there is a need for assessment of the local structure of the habitat and landscape connectivity. The future studies in the field should aim at comparing vegetation mosaics seasonally, measuring patch configuration and root structure, and assessing the invertebrates according to their dispersion and feeding characteristics. In terms of management, the most sound method would be to ensure a mosaic of vegetation that is heterogeneous and well connected, preserving the natural root system, ensuring good water quality and preventing the invasion without destroying refuge habitats.

Declarations

Data availability: No new dataset was generated or analysed for this narrative review. The graphical values are illustrative conceptual scores and should not be interpreted as empirical data.

Ethics approval: Not applicable; no organisms were collected and no field experiments were conducted for this review.

Funding: No external funding was received.

Conflict of interest: Authors declare no conflict of interest.

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