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Ecological Significance of Rare Aquatic Plant Species in Maintaining Wetland Community Stability

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Abstract: Rare hydrophyte species are typically considered to be ornamental components of wetland communities for conservation purposes. This paper seeks to investigate whether the role played by rare hydrophyte species in promoting community stability is acknowledged in the existing wetland literature in different regions and in which aspects there is a lack of literature. Twelve recent studies in the form of peer-reviewed journal papers concerning saline, freshwater, urban, man-made, temporary, and permanent wetlands were carefully read and analyzed with respect to seven topics: habitat filtering, foundation plant species function, restoration, anthropogenic impact, climate and hydrology changes, fauna and ecosystem connectivity, and monitoring techniques. This reading leads us to the suggestion of a stability pathways framework where rare hydrophytes influence community stability through habitat filtering, functional complementarity, trophic function, water and sediment regulation, and recovery buffering, whereas land use, hydrology, and climate affect all pathways. It is evident from the evidence map that habitat filtering is the best-documented theme, while monitoring technologies are documented in only one paper. Out of the 12 papers, only one focuses on a rare or endangered plant community, while two others document foundation/key species in a community, and hence many of the claims made on rare plants are based on community-level studies or wildlife-related studies. It is proposed that rarity be viewed as a functional characteristic that needs testing, and that an adaptive management and monitoring process including aerial drone-based vegetation monitoring, hydrological data, and faunal indicators is outlined. The approach provides a useful method for wetland managers and planners to determine when protecting a rare plant also protects the plant community.

Keywords: Rare Aquatic Plants; Wetland Stability; Hydrophytes; Foundation Species; Wetland Restoration; Plant Community; Biodiversity Conservation.

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I. Why the Quiet Species Matter

The value of a wetland is rarely estimated by the presence of the smallest number of plant species. Tourists are able to see reed stands, floating plant mats, and open water surfaces, and the existence of the rarest species in small numbers remains unregistered. However, the maintenance of the community in a certain area depends on the ability of the community to cope with changes that include a dry season, nutrient loads, and a shift of land use without losing its unique characteristics. The role of rare species in this process remains more a statement than a proven fact.

In the study of the rare and endangered saline wetlands community that consists of Bolboschoenus maritimus in Southeastern Europe, the authors have shown the narrowness of the environmental niche where the community exists. This community is associated with certain physical and chemical parameters of water and soil (Ljevnaić-Mašić et al., 2020). Such communities should be considered not as a collection of species, but as a certain configuration that exists only in a unique combination of conditions.

A further argument can be derived from the literature regarding the role of foundation species in freshwater wetlands. According to Marazzi et al., such species affect the habitat structure and community assembly and require documentation and conservation (Marazzi et al., 2019). The issue is important for rarity since the species in question might be rare but structurally important; conversely, it may be rare and insignificant functionally. This issue is at the center of this paper.

A further argument in favor of the hypothesis can be provided by the literature concerning wetland restoration. According to Rodrigo, aquatic plants are not only the outcome but the means of restoration (Rodrigo, 2021). Therefore, if hydrophytes provide the means of wetland restoration, then the lack of specific plants at the early stages will create a bottleneck for the community formation process. Further, the problem of constructed wetlands can be raised. Zhang et al. assess whether the constructed wetlands can be wildlife refuges and consider the value of biodiversity conservation of the said refuges (Zhang et al., 2020). The refuges require specific communities providing food, cover, and nesting structure for the organisms in question.

Plant community pressure is well studied too. Wang et al. prove that land use change affects plant community features in wetlands of semi-arid regions (Wang et al., 2022). At the same time, Zheng et al. investigate the relationship between wetland plant communities and environmental factors in Tumen River basin of Northeast China (Zheng et al., 2019). These studies prove that the plant community reacts to the gradient which managers usually measure but cannot control. Rare species are positioned at the end of that gradient; hence, they are the first ones to react to any changes.

Each of the above-mentioned studies is characterized by one and the same disadvantage. All of them deal with plants, habitats or wetlands. However, only the first study investigates a rare plant community as its central subject of research. Other studies describe the environment of rare plants without focusing on the activity of the plants themselves. There is an obvious gap which needs to be filled. Through which mechanisms can rare aquatic plants affect the stability of communities?

This paper attempts to answer the question in three steps. The first step involves reviewing six more papers that consider wetlands in urban, faunal, restoration, dry land, pond, and monitoring perspectives. In the second step, all twelve papers are brought together to form a pathway model. In the third step, the level and strength of evidence for each pathway is mapped to show directions for fieldwork in the future.

II. Surveying the Terrain: What Related Studies Add

The six papers discussed above broaden the view of wetlands not simply as a matter of plant composition. The importance of wetlands to people, animal impacts on plants, restored vs. natural wetlands, the effects of climate on wetland hydrology, energy transfer from aquatic to terrestrial habitats, and monitoring of vegetation are among the topics addressed.

Urban Wetlands and the Cost of Neglect: Alikhani et al. explore the importance of urban wetlands from an ecological and cultural perspective (Alikhani et al., 2021). The key idea of the paper is that urban wetlands provide ecological services and cultural values, and that both aspects are related to each other. Wetlands that are valued by the local community will remain protected against drainage and filling. It follows that rare plants have an additional feature: survival of plants in urban wetlands depends on the recognition of their value by the local community. This makes rarity an aspect that cannot be understood based solely on ecological knowledge. It is also true that stability is a joint feature of the ecological community and the human environment.

Animals that Reshape Plant Habitat: Hood et al. explore whether beaver manipulation will sustain macroinvertebrate diversity in aquatic communities in terms of ecological trade-offs (Hood et al., 2021). Beavers modify flooding and thus either provide or block habitat for both plants and animals. This paper can be very helpful in this case since it illustrates how disturbance can create as well as eliminate habitat for a certain community, so a plant species preferred by one set of environmental conditions might be extinct under others. This work also illustrates how faunal engineer management might affect plants. Every framework for rare plants must incorporate faunal engineers into the system.

Building Wetlands and the Limits of Replacement: Spieles has a comparative review of construction, restoration, and integration of wetlands (Spieles, 2022). The relevance of the paper comes from its comparison of methods with varying levels of dependence on natural processes and engineering.

Constructed wetlands can achieve some of the desired goals of functional development such as water treatment but fail on others, specifically on the community composition, where rare plants are the most difficult to establish through natural processes. With the reliance on selected plant species for restoration practices, the rare end of the spectrum may not be achieved. This is seen as an extension of the restoration reviewed (Rodrigo, 2021).

Temporary Wetlands Under Global Change: Parra et al. look at the future of temporary wetlands in drylands in times of global change (Parra et al., 2021). Temporary systems go through phases of drying up and re-filling, and the plants in such systems are dependent on seed and propagule banks surviving the dry periods. This is a form of stability which is quite different from the one applied to permanent water bodies. In the latter case, the definition of stability is recovery ability after drying up and rare species with specific requirements become vulnerable if droughts are more frequent or prolonged. The paper also highlights the fact that stability is different from constancy.

Permanent Ponds and the Energy that Leaves the Water: Fehlinger et al. discuss the ecological function of permanent ponds in Europe via the diet connection between the terrestrial and aquatic environments through the emergence of insects (Fehlinger et al., 2023). Aquatic insects grow up in water bodies but eventually emerge and transfer energy to terrestrial organisms such as birds, bats, and spiders. Aquatic and emergent vegetation provides the environment for the growth of these insects. If a rare plant species provides habitat to a specific type of insect, then the loss of that plant would be devastating to a link that extends far beyond the edge of the pond.

Seeing Vegetation from above: Qin et al. utilized unmanned aerial vehicles to study the presence of species and the involvement of plateau pika in maintaining plant diversity on the northeastern part of the Qinghai-Tibetan Plateau (Qin et al., 2020). While it is an alpine grassland and not a wetland, the lesson carries over. The use of drone technology allows one to observe patterns in vegetation at such a small scale that links it with animal activities in ways that transects are unable to do. Rare aquatic plants that grow sporadically and are located in inaccessible locations may benefit from it.

What the Survey Adds: The importance of the survey. From all these papers, one can conclude that the stability of wetlands is based on social recognition, disturbance patterns defined by the activity of animals, restoration strategies, water resistance, energy flows across ecosystems and ability to monitor vegetation at an adequate scale (Alikhani et al., 2021; Parra et al., 2021; Qin et al., 2020). These are not focused on rare aquatic plants; however, their importance lies in the fact that they provide knowledge about the systems in which rare plants occur (Hood et al., 2021; Spieles, 2022; Fehlinger et al., 2023).

III. From Scattered Findings to a Stability Pathway Framework

From these twelve pieces of research, five possible roles that a rare aquatic plant may play in stabilizing its community can be identified. These roles are not proven effects but only hypotheses based on scientific literature. This is shown in figure 1.

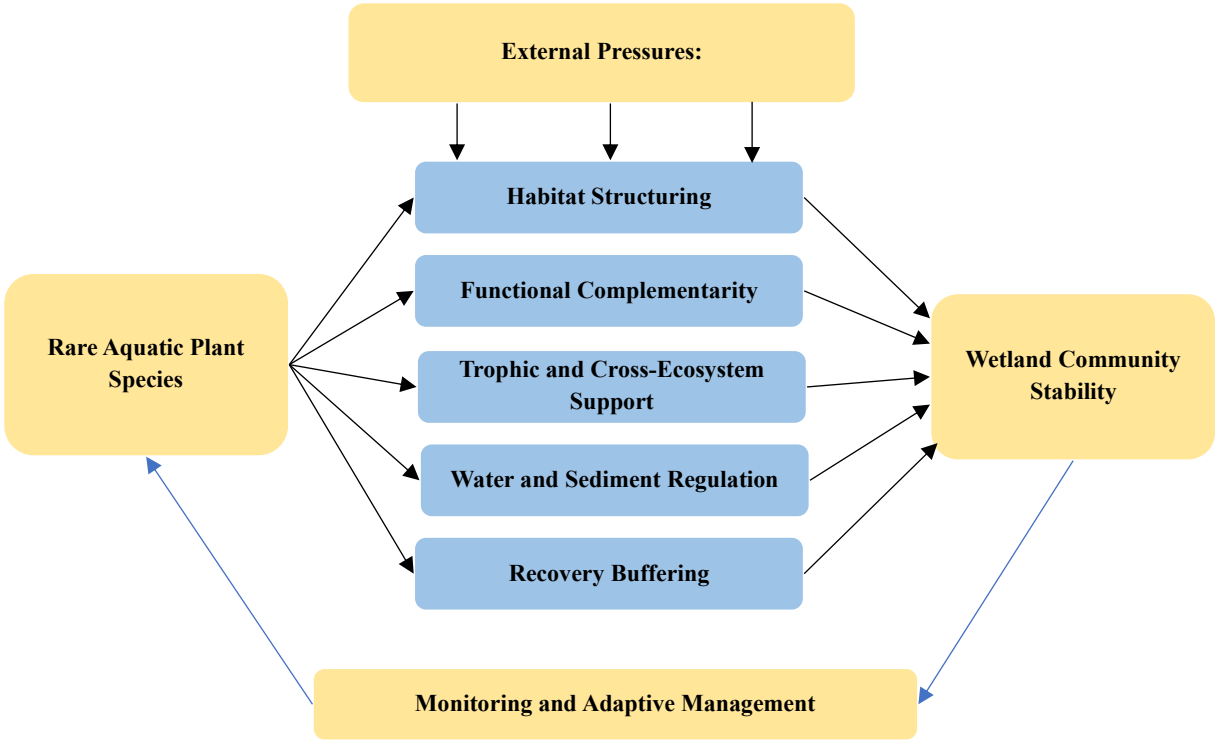


Figure 1: Conceptual Stability Pathway Framework

Habitat Structuring: Plants offer shelter, substratum and microclimate. In case a rare species has a growth habit that is not found in any other plant type, such as the tall emergent growth in a low-growing turf, or canopy-forming leaves of the floating type in an open water body, it provides variation in structure. This is clearly evident from the theory of foundation species and from the habitat specificity of plants.

Functional Complementarity: Community stability arises from the ability of different species to respond to disturbances, with some thriving while others struggle. Such species may occupy a unique niche relative to others, such as unique salinity, depth, and nutrient requirements. With changes in environmental conditions, these species could flourish and maintain community functions. This represents insurance for ecological processes, and is possible where the response traits of the species have been quantified.

Trophic and Cross-Ecosystem Support: Vegetation feeds and provides cover for invertebrates, which themselves provide food to vertebrates, as well as insects which emerge as a source of nourishment for terrestrial predators. The rare plant species that feed on a small range of invertebrates will be very important in relation to the fauna of the wetlands.

Water and Sediment Regulation: Aquatic plants assimilate nutrients and fix sediment, and restoration processes depend on these ecosystem services. Rare species possessing unique roots and rhizomes stabilize sediment in areas unsuitable for common species, such as the saline borders.

Recovery Buffering: Recovery buffering. Recovery occurs after disturbance due to plants already present in the community or from seed or propagule banks. In ephemeral wetlands this is the main source of recovery. A rare plant producing long-lived propagules might serve as a potential source of recovery even if few individuals of this species are found in a particular year.

Finally, two additional components complete the conceptual framework. First, external influences alter the functioning of all pathways. Changes in land use, urbanization, hydrology and environment may increase or decrease or even inhibit any of the five pathways. Second, monitoring and adaptive management make the loop closed. Observation of rare plants and their environments, ideally via remote means, allows

the manager to act and consequently modify the plant's environment. In this model rarity is not an independent pathway. Rather, it is an attribute determining the degree of functional redundancy of the species.

IV. How the Evidence was Read and Coded

It should be noted that the study is evidence mapping activity and not a field experiment and no field data have been collected for the purpose of this research. Twelve studies were selected and form a set of fixed number of studies. These studies were studied based on their objectives, the wetland context and the nature of their conclusion. Then each study was allocated to one or several themes which resulted out of this process. The seven themes which emerged out of this process were Habitat and Environmental Filtering; Foundation and Structural Plant Species; Restoration and Constructed Wetlands; Land use, Urban and Human Pressures; Fauna and Cross-Ecosystem Linkages; Climate and Hydrological Change; Monitoring Technology.

The second category of allocation was made independently in relation to the direct relevance of the evidence provided by the studies with regard to rare aquatic plants. Four categories were developed in this process. These were Focus on rare/ endangered plant community; Focus on foundation/key plant species; Context – wetland/community without species focus and Wildlife/Fauna-based evidence.

Here are two important cautions about the figures presented. First, the sample size is relatively small, and the articles were not identified via a systematic search, so the numbers only apply to the present sample and not the entire literature. Second, the coding was done by one person. These points are revisited in the final section. The counts should be seen as a clear summary of the distribution of the literature in question.

V. What the Evidence Map Shows

Where the Attention Falls: Figure 2 illustrates the number of studies on each theme, segregated into the introduction set and the survey set.

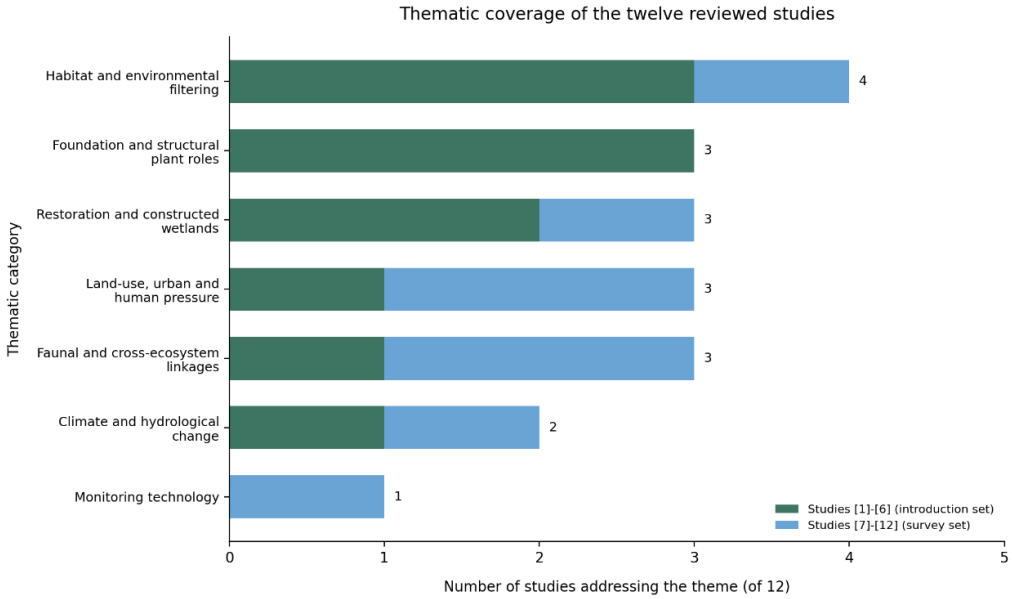


Figure 2: Thematic Distribution of the Twelve Reviewed Studies Across Major Research Areas

Habitat and environmental filtering is the most discussed topic; this topic is covered by four of the twelve papers. Three of them belong to the introduction set (focusing on plants and their environment), and one belongs to the survey set (hydrology being the filter in dryland wetlands). Foundation and structural plant

functions, restoration and construction of wetlands, human pressure and impacts on environment, and faunal relationships are also covered by three papers each. Introduction and survey set make different contributions. Plant-centered topics are mostly presented in the introduction set, while human pressure and faunal relationships are mostly discussed in the survey set. This is not surprising; the survey set was selected to increase the scope.

Climate and hydrology change is addressed by two papers, while monitoring technology by one. Monitoring technology is the least discussed topic, but this is the one which will provide field data required for the framework. Absence of this topic in the introduction set means that no introduction papers considered rare and foundation plants made use of remote sensing techniques.

How Directly the Evidence Speaks to Rare Plants: Figure 3 shifts the focus of the analysis from "what are the topics" to "how close is each article to the topic of this paper."

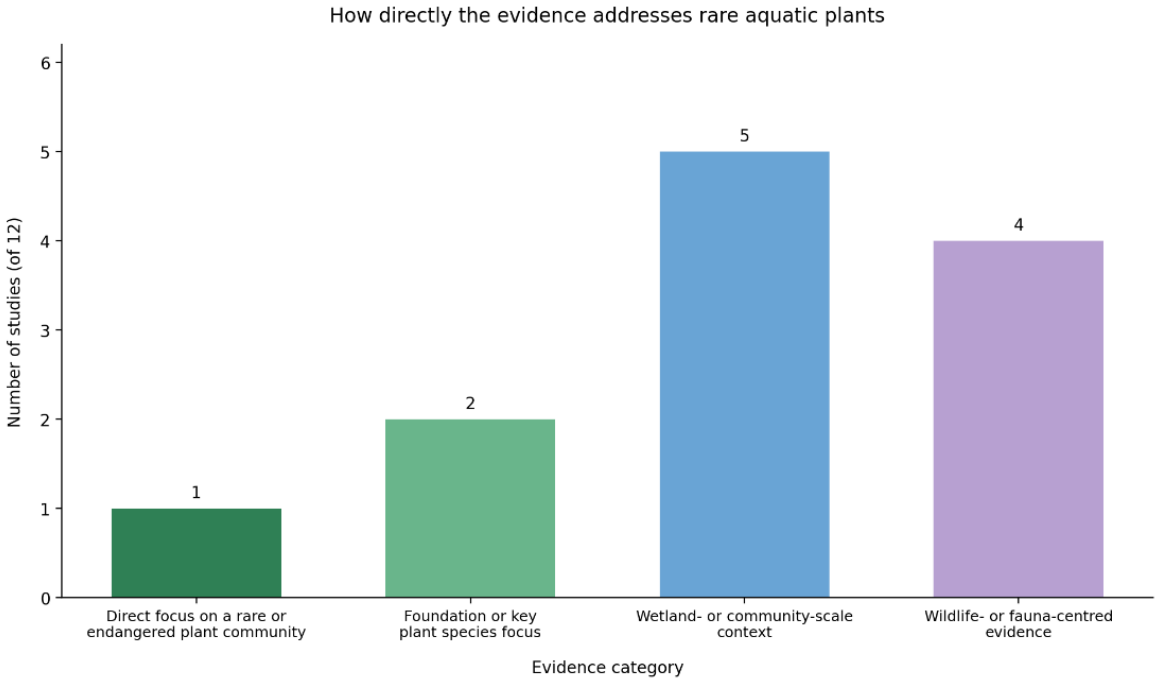


Figure 3: Distribution of Reviewed Studies According to Their Direct Focus on Rare and Endangered Aquatic Plant Communities

Only one paper deals explicitly with a rare or endangered plant community. Two are centered on a foundation or keystone plant species. Five papers offer wetland- or community-level context, while four of them focus on fauna. In other words, out of twelve studies, only three of them would support an assertion about rare plants directly, while the rest can only offer indirect evidence.

What this Means for Each Pathway: The five pathways are not equally supported by the literature. Habitat structuring has the most support, since it relies on the rare community study as well as the foundation species reasoning. Water and sediment regulation and recovery buffering are based on restoration and dryland studies, which focus on the functional role of aquatic vegetation in general but not of rare plants. Trophic and cross-ecosystem support are grounded in faunal studies where plants are treated as habitats rather than the objects of study. Functional complementarity is the least supported pathway, since it needs to show trait and response information of rare plants.

VI. Reading Between the Bars: What the Pattern Means for Wetland Management

The above pattern is not a flaw of individual studies; on the contrary, each of them was designed to address a specific question and does so quite successfully. What is important is how these studies can be perceived in aggregate to point out a certain gap in our knowledge and in the way research is organized to satisfy the needs of managers.

Rarity is a Signal for An Experiment Rather than a Judgment: First of all, the proposed framework allows us to distinguish between a rare species that performs functions easy to replace with other common species' functions and a rare species performing unique functions. There are three simple questions any manager can ask about a rare plant: Is there something about the plant's morphology or its rooting system which is missing in other species? Does it provide some kind of consumers (invertebrates for example) with special conditions to survive? Does it resist the disturbances in a manner useful for the whole community recovery? If one of these questions gets a positive answer – there are some more functions to protect.

Restoration Should Name its Rare Targets: If restoration efforts of wetlands that achieve functional success but fail to include the more unique vegetation types have an objective of including the more rare plants, then the objective must be stated, and a process needs to be outlined that will accomplish such a goal. Natural arrival in areas where no sources exist is not likely. This is particularly important for areas within urban environments, as isolation tends to be the rule of thumb.

Water Regime is the Master Variable: Water regimes are the key variables. Dryland and temporary wetlands have species presence dictated by hydrology, and changes in the hydrological environment through land use changes happen fast enough that their effect on the plant community is immediate. Management that preserves the water regime, therefore, preserves the environment that the rare plants need. Preservation of rare plants alone will not be successful, since the water regime will be ignored. The saline wetland community is a prime example, as it exists due to certain water and soil chemistry.

Animals are Part of the Answer: Beaver management and insect emergence are both examples of how animal management decisions have a profound impact on plant communities. Plant management decisions can affect fauna that feeds terrestrial predators in return.

A Monitoring Sequence that Fits the Gap: The limited evidence on monitoring implies a simple sequence. First, identify occurrences of the rare plants in fine-scale resolution by drone surveys, as used for studying vegetation diversity on the Qinghai-Tibetan Plateau. Second, link each occurrence with the hydrology and basic water and soil chemistry, as done for the saline wetlands and river basins. Third, identify faunal indicators, including macroinvertebrates and emerging insects, both in the presence and absence of rare plant. Fourth, compare the two sets to see if there is a difference between the communities that can support any of the five pathways. No new technology is needed for the sequence. The key is applying the old methods in one place and time.

Social Stability Matters Too: From the review of urban wetlands, we learn that wetland can persist only as long as it is tolerated by the community. Emphasizing the functional importance of the rare plants rather than rarity alone may provide better grounds for conservation.

VII. Limits of the Present Reading and Where to Go Next

There are four points to be kept in mind about this study. First of all, the set used here is rather small, and the sampling was not carried out systematically; hence the numbers presented in figures 2 and 3 apply only to these twelve studies and cannot be extended to represent the entire field of study. Second, the classification scheme used here is based on the perceptions of one person. Another reader would probably classify some of these studies differently, especially where they combine plant and animal aspects. Third, this framework is theoretical, having been constructed using the literature; it has not yet been validated with

the use of field data. Finally, the set covers diverse geographical regions and wetland types, from saline inland wetlands to alpine grassland.

Directions include several options. First, a field comparison between patches of wetland with and without a rare plant is useful as it could measure structure, invertebrates' community composition, nutrients and recovery from disturbance. Trait databases on rare hydrophytes would make it possible to test the functional complementarity mechanism altogether. Long-term drone-based observations would measure response of the rare plants patches to drying and wetting events in temporary wetlands. Systematic review of the literature on the matter with the help of the same coding scheme but a broader search strategy would reveal

VIII. Conclusion

Rare aquatic plants can be easily overlooked and difficult to research, as indicated by the existing literature. The twelve studies reviewed here cover the habitat, the pressure, the restoration techniques, the animal relationships and the tools of monitoring associated with rare plants, but only one is focused on the rare plant community itself. On the basis of this review we created a five-pathway approach, according to which rare plants can play a role in the stabilization of wetlands through the habitat structuring, functional complementarity, trophic support, water and sediment regulation and recovery buffering, all influenced by external pressures and monitored.

As seen from the evidence map, the five pathways approach seems to be quite plausible, but it is not sufficiently tested. The habitat filtering is sufficiently covered and the monitoring is poorly covered, so the next step in the development will be related to the measurement. Before accumulating the evidence, managers can make use of the three practical questions presented here in order to evaluate whether rare plants need to be protected because of their role in the community.

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