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Review

A bibliometric analysis of research on fish and floristic diversity: Trends and themes

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Abstract
Research on the relationship between fish and floristic diversity has been limited by narrow scopes, inconsistent methodologies, and geographic biases, resulting in fragmented insights. This study presents a comprehensive bibliometric analysis on the relationship between fish diversity and floristic diversity, spanning nearly six decades from 1965 to 2024. Using the Scopus database, 47 publications were identified based on the presence of the keywords "fish" and "floristic diversity" in article titles, abstracts, and keywords. The analysis reveals a gradual increase in publications over time, with notable peaks corresponding to heightened awareness of biodiversity conservation. The research themes identified include habitat provision, ecosystem resilience, impact of environmental change, and the role of invasive species. The study highlights the importance of integrating conservation strategies that protect both fish and plant diversity to maintain ecosystem health and resilience. The findings also point to regional and taxonomic specificity as critical areas for future research, particularly in climate change and habitat alteration. This bibliometric review provides valuable insights into the evolution of this field and identifies gaps and opportunities for further investigation. Therefore, the study underscores the critical interdependence between fish and floristic diversity within ecosystems, a relationship that both natural processes and anthropogenic influences have shaped over time. The findings suggest that conservation efforts must adopt a more integrated approach, recognizing the mutual dependencies between different forms of biodiversity. This approach will be essential for mitigating the adverse effects of human activities on ecosystems and ensuring the long-term sustainability of both fish and plant communities.

Keywords: bibliometric analysis; conservation strategies; ecosystem resilience; fish diversity; floristic diversity

1 | INTRODUCTION

The relationship between fish diversity and floristic diversity is fundamental to ecological research, carrying significant implications for biodiversity conservation and ecosystem management (Costa *et al.* 2019; Dinerstein *et al.* 2024). As ecosystems increasingly face pressures from anthropogenic activities, understanding the complex connections between these two forms of diversity is crucial for developing effective conservation strategies (Ricciardi *et al.* 2009). Fish and floristic diversity are intricately linked; plants provide essential habitats and resources for fish, while fish contribute to the maintenance and health of plant communities through processes like nutrient cycling and seed dispersal. This interdependence underscores the need for a holistic approach to conservation that considers the complex interactions between differ-

ent components of biodiversity (Donaldson 2002).

Recognizing the importance of this field, the present study employs a bibliometric analysis to explore the evolution of research on fish and floristic diversity from 1965 to 2024. This method allows for a comprehensive examination of how various factors, including anthropogenic pressures and conservation efforts, have influenced the dynamics of fish and plant populations over time. Such an approach is critical for understanding the impact of human activities on biodiversity, as demonstrated by studies linking human impacts to community changes in riverine ecosystems (Danet *et al.* 2024). By synthesizing the available literature, this research aims to highlight trends in species richness, shifts in community composition, and the effects of human activities on both fish and floristic diversity, emphasizing the necessity for integrative approaches in biodiversity conservation.

The study draws upon a diverse set of sources to capture the breadth of research in this domain. These include studies that explore the development of fish-based assessment indices tailored to specific regional contexts (Mostafavi *et al.* 2015), as well as research investigating the complex relationships between chemical contamination and the diversity of biological communities in rivers (Ricciardi *et al.* 2009; Mostafavi *et al.* 2015; Danet *et al.* 2024). The insights gained from these studies are particularly relevant in light of recent findings showing how variations in environmental conditions, often driven by human activity, can lead to significant shifts in fish community structures, which in turn affect associated plant diversity and overall ecosystem health (Danet *et al.* 2024).

Previous research on the relationship between fish and floristic diversity has been limited in scope, methodology, and geographic focus. Many studies have concentrated on specific ecosystems or individual species, leading to fragmented insights that do not capture the broader dynamics of biodiversity. Methodological inconsistencies, such as the use of qualitative approaches or localized surveys without standardized measures, have further complicated the comparison of findings across different studies. Additionally, much of the existing research has been geographically biased, focusing primarily on well-funded and accessible regions like North America and Europe, leaving other areas underrepresented.

Moreover, the literature on fish and floristic diversity has been dispersed across various disciplines, resulting in a fragmented body of knowledge. The absence of a systematic analysis of trends over time has limited the understanding of how these relationships have evolved, particularly in response to environmental changes and conservation efforts. This study addresses these gaps by conducting a bibliometric analysis of 47 documents from the Scopus database, covering the period from 1965 to 2024. The analysis aims to provide a comprehensive overview of the research landscape, identify trends and gaps, and offer insights to guide future studies and conservation strategies.

The primary objective of this article is to conduct a comprehensive bibliometric analysis of the research on the relationship between fish diversity and floristic diversity from 1965 to 2024. This study aims to identify key trends, themes, and gaps within the scientific literature, thereby providing insights into the evolution of this field. Additionally, the article highlights areas where further research is needed to inform and enhance conservation strategies that integrate fish and plant diversity for ecosystem resilience.

2 | METHODOLOGY

2.1 Research design

This study employed a bibliometric analysis approach to investigate the relationship between fish diversity and floristic diversity within scientific literature. Bibliometric analysis is a quantitative method used to measure the impact and evolution of scientific research by analyzing publications and citation patterns (van Eck and Waltman 2010). The goal of this methodology was to identify the scope and trends of research focusing on fish and floristic diversity, as captured in the Scopus database over a defined period (1965 and 2024).

2.2 Literature searching

The primary data source for this study was the Scopus database, a comprehensive and widely recognized bibliographic database covering a wide range of disciplines, including ecology, environmental science, and conservation biology. Scopus was chosen due to its extensive coverage of peer-reviewed literature, including articles, conference papers, and reviews, relevant to the study of biodiversity.

The search was conducted on 18 August 2024, using the Scopus database. The search terms used were "fish" and "floristic diversity," these keywords were required to be present in the article titles, abstracts, and keywords of the indexed documents.

The keyword “fish” is essential because it directly relates to the subject of the study, particularly if the research involves the ecological, biological, or environmental aspects of fish species. It is a broad term that captures the attention of researchers and practitioners interested in aquatic life, fisheries, and related environmental studies. Its simplicity and specificity make it a highly effective keyword for categorizing the research within relevant databases.

The keyword “floristic diversity” was selected to encapsulate the study's emphasis on the variety and richness of plant species within a specific area, particularly if the research investigates the interactions between plant life and the surrounding ecosystem, which may include

aquatic environments where fish are present. "Floristic Diversity" is a precise term that appeals to those studying biodiversity, conservation, and ecological interactions, making it a vital keyword for accurately targeting the intended academic audience.

This strategy was designed to capture publications that explicitly focused on the relationship between fish and floristic diversity, ensuring the results were highly relevant to the research question. The search was limited to documents published between 1965 and 2024, providing a comprehensive literature overview over nearly six decades. This timeframe was selected to capture the evolution of research in this area, from its early stages to the most recent developments.

Bibliometric data, including titles, abstracts, keywords, and references, were extracted from the selected publications. The extraction process involved downloading the metadata of each publication, which was subsequently imported into the visualization of similarity viewer (VOSviewer) (VOSviewer version 1.6.20; 2009–2023 van Eck & Waltman; Leiden University, The Netherlands), a specialized software for constructing and visualizing bibliometric networks (van Eck and Waltman 2010). VOSviewer was chosen for its ability to handle large datasets and clearly visualise complex relationships among terms within the literature. This network was based on the frequency of term co-occurrence within the selected publications. Terms that frequently appeared together were connected by edges in the network, with the strength of each connection indicating the level of co-occurrence (van Eck and Waltman 2014).

Next, VOSviewer employed its clustering algorithm to group related terms into clusters. Each cluster represented a group of closely related terms, highlighting specific research themes or topics within the field of floristic diversity conservation. The clusters were colour-coded to facilitate visual distinction and interpretation of different research themes. The software's ability to visually represent these relationships allowed an intuitive understanding of the main research areas and their interconnections (Waltman *et al.* 2010). Clusters of terms provided insights into the predominant research topics and their interconnections. This visualization helped identify key trends and emerging areas within the field (van Eck and Waltman 2010, 2014, 2017).

2.3 Inclusion and exclusion criteria

Only peer-reviewed journal articles, conference papers, and review articles were included in the search results (Table S1). This ensured that the study focused on high-quality, credible sources of information. Documents such as book chapters, editorials, and grey literature were excluded from the analysis to maintain the academic rigour of the study.

The search results were further refined by excluding duplicates and irrelevant documents. Irrelevant documents were those that, despite containing the search terms, did not directly address the relationship between fish diversity and floristic diversity. This step was necessary to ensure that the final dataset included only those studies that were pertinent to the research question.

2.4 Data extraction and analysis

After the search was completed, 47 documents were identified (Table S1). These documents were exported from Scopus into a bibliographic management software (i.e. VOSviewer) for further analysis. Key information such as publication year, authorship, journal title, and citation count was extracted. The abstracts and keywords of the selected documents were reviewed to verify their relevance to the study.

A descriptive analysis was conducted to identify trends in publication over time, including the distribution of articles by year, the most prolific authors, and the journals that published the most articles on the topic. Additionally, a keyword co-occurrence analysis was performed to identify common themes and topics within the literature and the relationships between different concepts related to fish and floristic diversity.

2.5 Limitations

The study's methodology is subject to certain limitations. Reliance on the Scopus database may have excluded relevant articles indexed in other databases, such as Web of Science or Google Scholar. The search terms may have also excluded studies addressing the relationship between fish and floristic diversity under different terminologies or within broader ecological contexts. Finally, excluding non-English publications could result in a language bias, potentially overlooking significant research conducted in non-English-speaking regions.

3 | RESULTS

A total of 47 papers were found based on the Scopus database (Table S1), involving 28 countries (Table S2), 104 keywords with the floristic-related (Table S3), and 29 keywords with the fish-related (Table S4). The results of this study (Figure 1) illustrate the co-occurrence and interconnections among academic keywords related to fish diversity, species diversity, floristic diversity, and broader ecological and conservation topics. Each node represents a keyword or concept, and the links between nodes indicate the strength of their association based on co-occurrence in academic literature.

3.1 Central concepts and clustering

Fish and species diversity (cyan cluster): Positioned centrally, this cluster highlights the map's core focus, reflecting the critical roles of fish and species diversity in ecological studies. The strong interconnections among these

terms suggest a high frequency of co-occurrence, indicating that these topics are central to discussions in related fields such as conservation, ecosystem management, and aquatic communities (Figure 1).

Biodiversity and conservation (green cluster): This cluster connects to various topics related to environmental change, species conservation, and broader biodiversity themes. The presence of terms like "climate change," "wetland," and "species conservation" indicates a focus on global environmental challenges and the need for conserving biodiversity across different habitats, including wetlands and other critical ecosystems (Figure 1).

Floristics and plant community (blue cluster): This cluster is prominently associated with floristic diversity and the composition of plant communities. Terms such as "native species," "invasive species," and "plant community" suggest a focus on the dynamics of plant species within ecosystems, particularly in relation to invasive species management and conservation efforts. The connection to regions like the United States and specific plant types, such as "grass", further highlights these studies' geographical and ecological context (Figure 1).

3.2 Regional and taxonomic focus (red and purple clusters)

South Africa and specific fish species (red cluster): This cluster is geographically focused on South Africa and includes terms like "Cape Floristic Region" and "Galaxiidae," indicating a strong focus on the phylogeography and conservation of fish species within this biodiversity hotspot. The presence of terms such as "haplotype," "mitochondrial DNA," and "population distribution" suggests a genetic and population-level approach to studying species in this region (Figure 1).

Birds and Argentina (purple cluster): The cluster labeled with terms such as "Aves," "Poaceae," and "Argentina" appears to focus on avian studies, particularly within the context of Argentina. Including "animalia" and "shrub" indicates a broader taxonomic and ecological scope, possibly encompassing studies of birds and plant species within these regions (Figure 1).

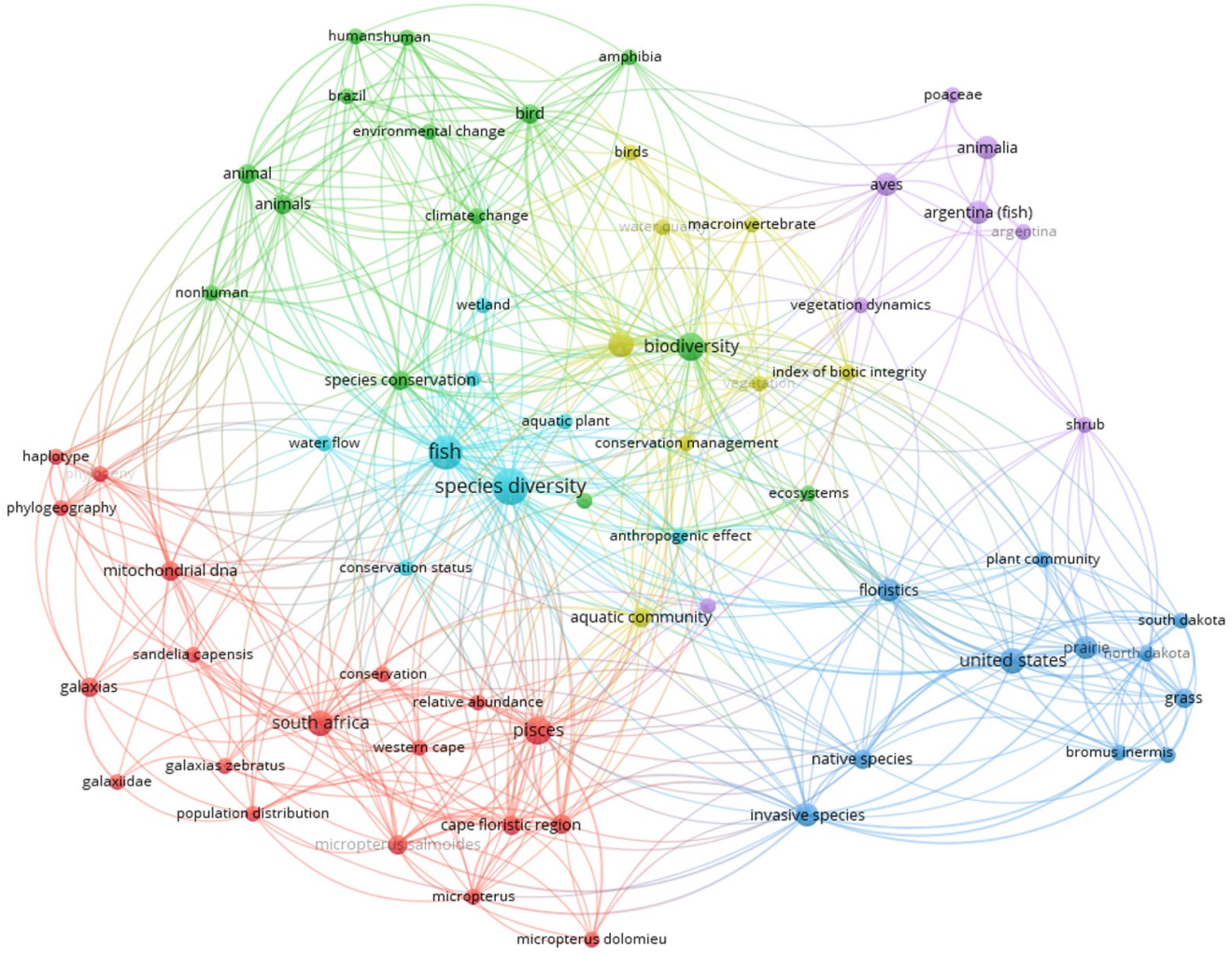

FIGURE 1 Visualization of similarity using VOSviewer based on 47 publications indexed in the Scopus database from 1964 to 2024 using the keyword “fish” and “floristic diversity” searched on 18 August 2024.

3.3 Environmental and conservation themes

Environmental change and conservation (green cluster): Keywords such as "climate change," "species conservation," and "wetland" emphasize the environmental challenges that affect species diversity and conservation efforts globally. This cluster reflects an interdisciplinary approach that integrates ecological, climatic, and conservation sciences to address the impacts of environmental changes on biodiversity (Figure 1).

Aquatic community and management (yellow cluster): Positioned centrally with strong links to both the cyan and green clusters, this cluster represents studies focused on aquatic ecosystems. The terms "aquatic plant," "conservation management," and "index of biotic integrity" suggest a focus on the assessment and management of aquatic communities, with an emphasis on maintaining ecosystem health and biodiversity (Figure 1).

3.4 Interdisciplinary and geographic connections:

The United States and grassland studies (blue cluster): This cluster focuses on grasslands and floristic studies within the United States. The presence of terms like "*Bromus inermis*" (a species of grass) and "South Dakota" suggests region-specific studies that explore the dynamics of native and invasive plant species in grassland ecosystems (Figure 1).

Linkages across clusters: The map also shows significant linkages across different clusters, indicating interdisciplinary connections between studies of fish diversity, floristic diversity, conservation management, and environmental change. The density and distribution of connections suggest a well-integrated research landscape where different ecological and conservation themes are interlinked (Figure 1).

4 | DISCUSSION

4.1 Centrality of fish and floristic diversity in ecological research

The prominent placement of fish and floristic diversity at the centre of the VOS map reflects their foundational roles in ecological research and their integral connections to a broad range of key concepts (Laureto *et al.* 2015; Pelletier *et al.* 2020). This central positioning underscores how both forms of diversity are essential for sustaining ecosystem functions and services, as they contribute to vital processes like nutrient cycling and primary productivity. These processes are crucial for ecological systems' overall health and resilience, highlighting the need for a comprehensive understanding of how fish and floristic diversity support ecosystem stability and adaptability (Laureto *et al.* 2015).

Furthermore, the maintenance of these ecosystem functions is significantly influenced by the functional diversity of species. Diverse traits among species can support multiple ecological roles, thereby promoting resilience against environmental disturbances. This underscores the necessity for conservation efforts beyond simply preserving species richness to encompass functional attributes critical for ecosystem health (Lyons *et al.* 2005; Laureto *et al.* 2015). The result's emphasis on fish and floristic diversity serves as a reminder that protecting these components is fundamental to sustaining the broader ecological functions on which many species, including humans, depend.

The centrality of fish and floristic diversity is also rooted in the critical interrelationships between these two components of biodiversity. The diversity of plant species provides essential habitats and resources for fish populations, illustrating the importance of preserving diverse flora to ensure that fish species can thrive. This interdependence reinforces the argument for a holistic approach to biodiversity conservation, which accounts for functional and phylogenetic diversity within these interconnected systems (Nyström and Folke 2001; Laureto *et al.* 2015). By recognizing the value of conserving both fish and plant species, conservation strategies can more effectively maintain the intricate web of interactions that define ecosystem functioning.

Studies indicate that species diversity plays a significant role in sustaining ecological processes, further reinforcing the need for integrated conservation strategies that prioritize biological diversity across multiple realms and scales (Naeem *et al.* 1999; Loreau *et al.* 2001; Humbert and Dorigo 2005; Beger *et al.* 2010; Laureto *et al.* 2015). The finding of these concepts highlights the complex and interwoven nature of ecological research, emphasizing that the preservation of biodiversity in both fish and plants is crucial for maintaining ecosystem integrity and resilience in the face of global environmental challenges.

Therefore, the central position of fish and floristic diversity in the results of this study reflects the increasing recognition of their importance in addressing global environmental challenges. As ecosystems face pressures from climate change, habitat loss, and pollution, understanding the relationships between fish and floristic diversity is critical for developing effective conservation strategies. Research in this area is essential for identifying ways to maintain ecosystem resilience and protect biodiversity in the face of these challenges. The centrality of these topics in ecological research highlights their relevance to both academic inquiry and practical conservation efforts.

4.2 Interconnectedness with conservation and ecosystem management

The interconnectedness between fish and floristic diversity has garnered increasing attention in the fields of conservation biology and ecosystem management (Chovanec

et al. 2003; Beger *et al.* 2010). This interaction pattern highlights the need for holistic conservation strategies beyond focusing on individual species to consider the complex relationships between different biological communities. These relationships are crucial for maintaining ecosystem processes and functions, making it essential to develop systematic conservation prioritization frameworks that account for connectivity across various habitats. Such frameworks are vital to ensure the persistence of both floral and fish species in the face of environmental changes (Beger *et al.* 2010).

Integrating ecological networks into conservation planning can significantly enhance the effectiveness of conservation actions by acknowledging and addressing the interactions among terrestrial, marine, and freshwater realms. This integrative approach is vital for the survival of certain species and the maintenance of ecosystem functions, particularly in ecosystems where the health of fish populations is closely tied to the diversity and integrity of plant communities (Beger *et al.* 2010). By recognizing the importance of these interactions, conservation efforts can be better targeted to preserve the complex web of life that sustains healthy ecosystems.

Research literature consistently suggests that preserving floristic diversity is a key factor in maintaining fish biodiversity and the overall health of aquatic ecosystems. Effective ecosystem management, therefore, requires a nuanced understanding of how environmental gradients and ecological dynamics contribute to biodiversity. This understanding emphasizes that the success of conservation strategies often hinges on fostering synergies between flora and fish populations, essential for achieving long-term ecological stability and resilience in freshwater environments (Ward 1998; Lyons *et al.* 2005). Such an approach is particularly important in biodiverse regions where local communities rely on aquatic resources for their livelihoods.

In regions with high biodiversity, the integration of conservation and sustainable fisheries management is critical for addressing both ecological and socioeconomic concerns. By fostering collaborations that align conservation goals with the needs of local communities, it is possible to create more sustainable and resilient ecosystems. This approach ensures that conservation efforts not only protect biodiversity but also support the livelihoods of those who depend on aquatic resources, leading to a more balanced and sustainable management of natural resources (Lyons *et al.* 2005; Phang *et al.* 2019).

Overall, the interconnectedness between fish and floristic diversity underscores the importance of adopting comprehensive conservation strategies that account for the complex interdependencies within ecosystems. By doing so, conservation efforts can more effectively protect biodiversity, maintain ecosystem functions, and support sustainable development, thereby contributing to the overall health and resilience of both natural and human communities.

Hence, the interconnectedness of fish and floristic diversity with ecosystem management underscores the need for an integrated approach to conservation that considers the interactions between different components of biodiversity. Effective ecosystem management requires a holistic understanding of how different species interact within an ecosystem and how these interactions contribute to overall ecosystem health. The results of this study suggest that research in this area often focuses on developing strategies that protect both plant and fish diversity, recognizing that these components are interdependent and that their preservation is essential for maintaining the integrity of ecosystems (Baron *et al.* 2002; Chapman *et al.* 2022; Meinam *et al.* 2023).

4.3 Regional and taxonomic specificity

The intricate relationship between fish and floristic diversity is crucial in maintaining local biodiversity, particularly in regions recognized as biodiversity hotspots (Kovalenko *et al.* 2019; Luo *et al.* 2022). This interdependence underscores the need for targeted conservation efforts that consider the specific ecological contexts of these areas, as they often face unique threats requiring tailored management strategies to protect endemic species and overall ecosystem health (Myers *et al.* 2000; Rodrigues *et al.* 2004; Moghanloo *et al.* 2023; Dinerstein *et al.* 2024). The increasing global threats to plant biodiversity, with many species classified as endemic and vulnerable, further emphasize the necessity for conservation initiatives that prioritize local ecological dynamics and the preservation of unique biological heritage (Moghanloo *et al.* 2023).

The distribution patterns observed, indicating a clustering of research focused on specific geographic regions and taxonomic groups, suggest that the interactions between fish and plant diversity are highly context-dependent (Myers *et al.* 2000; Moghanloo *et al.* 2023). In regions experiencing rapid environmental changes, such as developing countries, effective biodiversity conservation relies on understanding these localized interactions and implementing sustainable practices that protect aquatic species while ensuring the resilience of entire ecosystems (Belle *et al.* 2019). By leveraging genetic and ecological data, researchers can design more effective conservation strategies that address the specific needs of both fish and plant populations, ultimately contributing to the sustainability of these threatened ecosystems in the face of rapid change (Belle *et al.* 2019; Phang *et al.* 2019). Establishing synergies between fishing activities and ecosystem functioning can yield long-term benefits for both biodiversity conservation and local livelihoods, especially in regions where aquatic ecosystems are under significant pressure due to economic development and overexploitation (Phang *et al.* 2019).

Phylogenetic and genetic studies highlighted in the results of this study are crucial for understanding the mechanisms underlying the complex interactions between fish and plant diversity in biodiversity hotspots. Innovative methodologies, such as environmental DNA analysis and population genetics, enable researchers to uncover the intricate ecological roles that various fish species play within their habitats, thereby informing conservation efforts aimed at balancing biodiversity preservation with sustainable resource use in these sensitive environments (Donaldson 2002; Belle *et al.* 2019; Phang *et al.* 2019; Danet *et al.* 2024). These insights not only deepen our understanding of aquatic ecosystems but also stress the importance of integrating biodiversity conservation with sustainable fisheries management to ensure both ecological integrity and socio-economic stability in regions heavily reliant on aquatic resources for their livelihoods (Phang *et al.* 2019; Meinam *et al.* 2023).

Freshwater ecosystems are considered among the most imperilled habitat types worldwide, making it crucial to understand the specific interactions between fish and floristic diversity in biodiversity hotspots for developing effective conservation strategies (Myers *et al.* 2000; Gatti 2016; Cooke *et al.* 2024). Integrating research on genetic diversity and species interactions can help identify critical areas for conservation action and inform management practices that are adaptive to changing environmental conditions, thereby securing the sustainability of these rich yet vulnerable ecosystems for future generations (Belle *et al.* 2019). This approach enhances our understanding of the intricate web of interactions within these ecosystems and underscores the urgent need for comprehensive management frameworks that are scientifically informed and responsive to local community needs, particularly in light of growing pressures from anthropogenic activities and climate change (Cooke *et al.* 2024;).

Such frameworks should foster collaboration between researchers, policymakers, and local stakeholders to create sustainable practices that protect fish and plant diversity. By ensuring the long-term health and resilience of freshwater ecosystems, these frameworks can mitigate the threats posed by human activities and environmental shifts, preserving biodiversity and the well-being of communities that depend on these vital resources (Radinger *et al.* 2019).

Therefore, the taxonomic specificity of the results of this study underscores the importance of understanding the ecological roles of different species within an ecosystem. Different fish and plant species may play distinct roles in their ecosystems, and understanding these roles is essential for predicting how changes in biodiversity will affect ecosystem function. For example, some fish species may be key predators that help regulate the populations of herbivorous invertebrates, while certain plant species may be critical for stabilizing sediments and preventing erosion. The map's focus on specific taxa suggests that researchers are interested in understanding these ecological roles and how they contribute to ecosystems' overall health and stability (Humbert and Dorigo 2005; Daam *et al.* 2019; Radinger *et al.* 2019).

4.4 Impact of environmental change

The relationship between fish and floristic diversity has emerged as a key area of study in the context of global environmental changes, particularly climate change (Dudgeon 2010; Nyboer *et al.* 2021). These disruptions can lead to mismatches in the availability of critical resources, complicating the dynamics of food webs and potentially threatening the resilience of both fish and plant populations in diverse ecosystems (Nyboer *et al.* 2021). As species respond differently to climatic shifts, phenological mismatches may arise, undermining the stability of food webs, particularly in freshwater systems where fish depend heavily on the timing of aquatic plants for spawning and nursery habitats. This exacerbates threats to biodiversity and poses significant challenges to managing these ecosystems (Winder and Schindler 2004; Reid *et al.* 2018).

One of the most immediate consequences of climate change on the relationship between fish and floristic diversity is the alteration of habitats. Rising temperatures, changing precipitation patterns, and rising sea levels are transforming the environments supporting these species (Meinam *et al.* 2023). These habitat transformations threaten individual species' survival and disrupt existing ecological relationships, leading to shifts in community structure and function within aquatic ecosystems (Nyboer *et al.* 2021). For instance, as fish populations decline due to habitat changes, the overall health of aquatic ecosystems may suffer. The loss of key fish species could disrupt predator-prey interactions, further degrading the habitats that support a diverse array of plant life, and leading to a breakdown in the ecosystem's ability to maintain its functions (Reid *et al.* 2018).

Moreover, the decline in fish populations driven by climate change and habitat alteration can have cascading effects throughout the ecosystem. As these changes ripple through the food web, they can affect the abundance and distribution of plant species crucial for various aquatic organisms' survival (Trites *et al.* 2006). The degradation of these relationships can result in a loss of biodiversity, which in turn diminishes the ecosystem's resilience to further environmental changes (Reid *et al.* 2018). The intricate link between fish and floristic diversity thus becomes a focal point for understanding how climate change impacts biodiversity and ecosystem stability.

Additionally, the on-going pressures from overfishing and habitat degradation are likely to exacerbate the effects of climate change (Doney *et al.* 2012). These combined stressors pose significant challenges to the conser-

vation of biodiversity, the economic stability of fish-based economies, and the food security of communities that depend on these resources (Nyboer *et al.* 2021). As fish populations dwindle and habitats deteriorate, the livelihoods of people who rely on fishing and related activities are put at risk, highlighting the socio-economic dimensions of environmental conservation in the face of climate change (Elsler *et al.* 2021).

Hence, the relationship between fish and floristic diversity is increasingly being recognized as critical to maintaining ecosystem resilience in the face of climate change. Understanding and addressing the complex interactions between these components is essential for developing effective conservation strategies that protect biodiversity and support the communities that depend on healthy ecosystems. As global environmental changes continue to unfold, the need for integrated conservation approaches that consider ecological and socio-economic factors becomes ever more urgent.

Consequently, the impact of environmental change on the relationship between fish and floristic diversity underscores the need for adaptive conservation strategies. As environmental conditions continue to change, conservation efforts must be flexible and responsive to new challenges. The present results suggest that researchers are actively exploring ways to protect both fish and plant species in the face of these changes, such as by identifying climate refugia or developing restoration techniques that enhance ecosystem resilience. Understanding the relationship between fish and floristic diversity is critical for developing these strategies, as it provides insights into how ecosystems function and how they can withstand environmental change.

4.5 Role of invasive species and habitat alteration

The relationship between fish and floristic diversity is complex and dynamic, shaped by various factors, including invasive species and habitat alteration. Invasive species, in particular, can disrupt existing ecological interactions and alter nutrient cycles within these systems, leading to shifts in both fish and plant community structures (Meador *et al.* 2003; Powell *et al.* 2011; Su *et al.* 2023). This disruption often undermines biodiversity and ecosystem health, posing significant conservation and management challenges (Milardi *et al.* 2019). The mechanisms by which invasive species influence these ecological interactions can vary widely, making it essential for researchers to adopt a multifaceted approach to thoroughly study these impacts (Powell *et al.* 2011). Given the potential for significant long-term consequences on biodiversity and ecosystem function, such an approach is crucial for understanding and mitigating the effects of invasive species (Ehrenfeld 2010; Wainright *et al.* 2021).

The presence of invasive plant and animal species can profoundly affect the delicate balance of aquatic ecosystems, often leading to a decline in native species diversity. These invaders may disrupt trophic interactions and resource availability, exacerbating competition among native species and contributing to their decline. This, in turn, complicates efforts to restore affected ecosystems (Wainright *et al.* 2021). As invasive species alter their habitats' physical and biogeochemical dynamics, they can create environments less favourable for native species, resulting in diminished native biomass and potential local extirpation of sensitive taxa within the community (Mooney *et al.* 2009; Mooney 2010). The decline in native biodiversity affects ecosystem resilience and has significant implications for ecosystem services, such as water quality and habitat provision, which are crucial for maintaining healthy fish populations and diverse floristic communities (Milardi *et al.* 2019; Ceballos *et al.* 2020).

Understanding the specific pathways through which invasive species impact these interactions is critical for developing effective management strategies to mitigate their detrimental effects and restore ecological balance. Invasive species can alter habitat characteristics, such as nutrient cycling and energy fluxes, which may further exacerbate their negative effects on biodiversity by creating suboptimal conditions for native species. This highlights the interconnectedness of invasive species with other environmental factors in shaping community structure and ecosystem function (Powell *et al.* 2011; Wainright *et al.* 2021). Research indicates that the effects of invasive species can be both immediate and long-lasting, making it crucial for ecologists to monitor these dynamics over extended periods to fully understand their influence on native fish and plant communities, as well as the broader ecosystem processes that depend on these interactions (Dukes and Mooney 2004; Ehrenfeld 2010).

Moreover, invasive species often lead to cascading effects throughout the ecosystem. For example, when invasive species dominate, they can alter the composition of plant communities, affecting the availability of habitats and resources for native fish species. This can reduce the diversity and abundance of fish populations, which are integral to nutrient cycling and other ecosystem processes (Kiruba-Sankar *et al.* 2018). The interactions between invasive species and native biodiversity are complex and multifaceted, requiring a comprehensive approach to study and manage these dynamics effectively (Levin and Crooks 2011; Wainright *et al.* 2021).

Therefore, the relationship between fish and floristic diversity is deeply influenced by the presence of invasive species, which can disrupt ecological interactions, alter habitat characteristics, and undermine ecosystem resilience. The intricate ways invasive species interact with native communities underscore the need for on-going research and adaptive management strategies to mitigate their impacts and restore balance in affected ecosystems. By understanding and addressing these complex dynam-

ics, conservationists can better protect biodiversity and maintain the ecological functions that support both natural and human communities.

5 | CONCLUSIONS

The intricate relationship between fish diversity and floristic diversity plays a foundational role in the stability and resilience of coastal and freshwater ecosystems. This relationship is central to ecological research, as evidenced by its prominence in the present results, intersecting with a wide array of ecological and conservation-related concepts. The importance of these interactions cannot be overstated, as they underpin critical ecosystem functions such as habitat provision, nutrient cycling, and the maintenance of ecological balance. The health of fish populations is closely linked to the diversity of plant species within an ecosystem and vice versa, making the study and conservation of these relationships essential for sustaining biodiversity.

Conservation efforts that integrate the preservation of both fish and floristic diversity are crucial for maintaining ecosystem services and enhancing resilience to environmental change. The interconnectedness of these components highlights the need for a holistic approach to conservation that recognizes the interdependencies between different forms of biodiversity. By protecting and restoring diverse plant communities, it is possible to support the habitats and resources that are vital for fish populations, thereby contributing to the overall health and functionality of ecosystems. This integrated approach is particularly important in the face of global challenges such as climate change, habitat loss, and the spread of invasive species.

The impact of environmental change on the relationship between fish and floristic diversity underscores the urgency of adaptive conservation strategies. As climate change continues to alter habitats and disrupt ecological processes, understanding how these changes affect the interactions between fish and plants is critical for developing effective management practices. The present study reveals that this is a key area of research, focusing on identifying strategies that can mitigate the impacts of environmental change and preserve the resilience of ecosystems. The findings suggest that adaptive, region-specific conservation efforts will be necessary to address the unique challenges different ecosystems face and protect the biodiversity critical for their survival.

Invasive species and habitat alteration further complicate the relationship between fish and floristic diversity, posing significant threats to both. The disruption caused by invasive species can lead to the loss of native biodiversity and the degradation of ecosystems, making it imperative to manage these threats through targeted restoration and management efforts. The present study indicates that researchers are actively exploring solutions to these challenges, emphasizing the importance of restoring native plant communities and controlling invasive species to preserve the delicate balance between fish and floristic diversity. These efforts are essential for maintaining the ecological integrity of ecosystems and ensuring their ability to support diverse plant and fish species.

In conclusion, the relationship between fish and floristic diversity is a cornerstone of ecological research and conservation. The present findings illustrate the centrality of this relationship within the broader context of biodiversity, ecosystem management, and environmental change. As ecosystems face increasing pressures from human activities and climate change, understanding and preserving the interactions between fish and floristic diversity will be critical for sustaining biodiversity and maintaining the health and resilience of ecosystems. Future research and conservation efforts must continue to prioritize these relationships, adopting integrated, adaptive strategies that address ecological systems' complex and interdependent nature.

CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of the study will be made available on a reasonable request from the corresponding author.

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