

DOI:10.12923/2353-8627/2025-0015

Czasopismo indeksowane
na liście MNiSW - 70 pkt.

Aquatic Biodiversity and Mental Health: Lack of Association Evidence from Empirical Studies and Global Research Trends

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Abstract

Introduction: Aquatic biodiversity plays a crucial role in maintaining ecological balance, supporting ecosystem services, and enhancing human well-being. This study aimed to assess global research trends and empirical evidence on the relationship between aquatic biodiversity and mental health outcomes, while identifying thematic gaps and emerging areas of inquiry.

Materials and methods: A bibliometric analysis was conducted using the Web of Science Core Collection (2014–2025) and analysed in R with Bibliometrix (Biblioshiny). From an initial 19,320 records, 159 highly cited original research articles were screened using the Rayyan systematic review platform, resulting in 10 eligible studies that directly examined human mental health in relation to aquatic biodiversity or blue space quality.

Results: The study results show that research at this intersection remains limited, with mental health often treated as a secondary or indirect aspect within broader ecological or sustainability frameworks. Emerging but underexplored topics include emotional exhaustion, depression, and stress linked to the degradation of aquatic ecosystem and water insecurity. Content analysis of the 10 studies revealed no direct quantitative evidence linking measured aquatic biodiversity to mental health outcomes. Instead, perceived environmental quality and visible wildlife presence consistently predicted higher well-being and more frequent engagement with aquatic environments, suggesting that perceived biodiversity may serve as a key intermediary for psychological benefits.

Conclusions: These findings underscore the need for longitudinal, interdisciplinary research that integrates ecological metrics with psychological assessments. Strengthening collaboration among environmental scientists, psychologists, and public health experts will be essential to establishing an evidence-based frameworks linking aquatic biodiversity with mental health.

Keywords: biodiversity, sustainability, aquatic environment, mental health, bibliometric analysis

Streszczenie

Wstęp: Różnorodność biologiczna środowiska wodnego odgrywa kluczową rolę w utrzymaniu równowagi ekologicznej, wspieraniu usług ekosystemowych i poprawie jakości życia ludzi. Celem niniejszego badania była ocena globalnych trendów badawczych i dowodów empirycznych dotyczących związku między różnorodnością biologiczną środowiska wodnego a zdrowiem psychicznym, a także identyfikacja luk tematycznych i nowych obszarów badań.

Materiał: Przeprowadzono analizę bibliometryczną przy użyciu bazy danych Web of Science Core Collection (2014–2025) i przeanalizowano ją w programie R z wykorzystaniem Bibliometrix (Biblioshiny). Spośród początkowych 19 320 rekordów, przy

użyciu platformy do przeglądu systematycznego Rayyan, wybrano 159 często cytowanych oryginalnych artykułów naukowych, co dało 10 kwalifikujących się badań, które bezpośrednio dotyczyły zdrowia psychicznego człowieka w odniesieniu do różnorodności biologicznej środowiska wodnego lub jakości przestrzeni wodnej.

Dyskusja: Wyniki wskazują, że badania w tym obszarze są nadal ograniczone, a zdrowie psychiczne często traktowane jest jako kwestia drugorzędna w kontekście ekologii i zrównoważonego rozwoju. Niewystarczająco zbadane pozostają tematy takie jak wyczerpanie emocjonalne, depresja i stres wynikające z degradacji ekosystemów wodnych i braku bezpieczeństwa wodnego. Analiza 10 badań nie potwierdziła bezpośredniego związku ilościowego między zmierzoną różnorodnością biologiczną a zdrowiem psychicznym. Jednak postrzegana jakość środowiska i obecność dzikiej przyrody konsekwentnie wiązały się z wyższym dobrostanem, co sugeruje, że subiektywnie odbierana różnorodność biologiczna może pośredniczyć w korzyściach psychologicznych.

Wnioski: Wyniki te podkreślają potrzebę przeprowadzenia długoterminowych, interdyscyplinarnych badań, które integrują wskaźniki ekologiczne z ocenami psychologicznymi. Wzmocnienie współpracy między naukowcami zajmującymi się ochroną środowiska, psychologami i ekspertami ds. zdrowia publicznego będzie miało zasadnicze znaczenie dla ustanowienia opartych na dowodach ram łączących różnorodność biologiczną środowiska wodnego ze zdrowiem psychicznym.

Słowa kluczowe: zdrowie psychiczne, zrównoważony rozwój, różnorodność biologiczna, środowisko wodne, analiza bibliometryczna

1. Introduction

Aquatic biodiversity refers to the diverse life forms in, including freshwater habitats (e.g., lakes, rivers, wetlands) and marine ecosystems (e.g., oceans, seas) [1]. It encompasses a wide range of organisms, from fish and shellfish to microscopic plankton and aquatic plants, all of which contribute to the health and functioning of water ecosystems. While "biodiversity" broadly refers to the variety of life on Earth [2], aquatic biodiversity specifically focuses on the organisms that inhabit aquatic environments, highlighting the unique roles water plays in supporting life.

Biodiverse aquatic environments like rivers, lakes, and coastal areas, often known as "blue spaces" (environments where water is a prominent feature), are used as recreational and therapeutic spaces and are associated with reduced stress, improved mood, and enhanced mental well-being [3-7]. Mental health in this study refers to the absence of mental illness, while mental well-being refers to the positive states of one's mental health, characterised by proper functioning. The loss of aquatic resources can exacerbate mental health issues by impacting livelihoods, food security, and access to clean water, which are social determinants of mental health [8,9]. Whereas access to healthy waterscapes, for instance, can improve mental health by reducing anxiety and restoring cognitive resources, and can offer therapeutic benefits through activities like walking and relaxation, which can increase psychological resilience [10]. However, current issues include the challenge of studying these effects. A key challenge is the lack of quantification and clear identification of measures or indicators that directly demonstrate an association between aquatic biodiversity

and positive mental health outcomes [10-13]. Research need to move beyond general links to specifically measure the relationship between the degraded aquatic environment and psychological distress.

Understanding the relationship between aquatic biodiversity and mental health requires integrating ecological, psychological, and psychiatric perspectives. Beyond the presence of water, the biodiversity and ecological quality of aquatic environments appear central to their restorative potential. According to the Biophilia Hypothesis, humans possess an innate affinity for diverse living systems, therefore contact with biodiverse aquatic habitats may evoke fascination, positive emotions, and calmness [14-16]. The Attention Restoration Theory and Stress Recovery Theory further explain how complex natural environments restore attentional capacity and promote physiological recovery from stress [17-21]. Together, they explain how complex natural environments, which are often high in "soft fascination" and low in threat, are restorative, improving both cognitive functioning and physiological/emotional states [21]. Beyond individual responses, the Blue Space Framework links ecological quality to the mental health of population-level, demonstrating that proximity to natural, biodiverse water bodies is associated with lower psychological distress, including lower rates of depression and stress [3,22-24]. From an ecosystem services perspective, aquatic biodiversity contributes to cultural and psychological value through recreation, beauty, and meaning, thereby reinforcing environmental identity and place attachment, which in turn protects against mental ill-health [25-27]. Biological pathways proposed in environmental psychiatry and psychoneuroimmunology

also suggest that biodiverse environments may regulate stress physiology and immune balance [28–30]. Together, these frameworks suggest that ecologically rich aquatic systems promote mental health through a range of mechanisms, including affective, cognitive, social, and biological factors, positioning biodiversity conservation as both an ecological and a public mental health priority.

This study, therefore, aims to examine whether there is empirical evidence supporting a significant relationship between aquatic biodiversity and mental health. It synthesises current findings to determine the extent to which the diversity and ecological quality of aquatic environments contribute to psychological well-being, stress reduction, and the prevention of mental disorders. Bibliometric analysis will identify research trends, key themes, and knowledge gaps in publications connecting aquatic biodiversity and mental health. A review of the literature in this area will provide an understanding of the psychological benefits and risks associated with aquatic biodiversity, offering insights into the ecosystem-mediated impacts on mental health. By combining quantitative and qualitative insights, the study will highlight the role of aquatic biodiversity in promoting well-being, provide targeted recommendations where necessary, and inform future research and conservation efforts.

2. Methodology

2.1 Bibliometric Analysis

2.1.1 Data Sources and Search Strategy

A bibliometric analysis was conducted using the Web of Science (WoS) database to identify research trends and patterns at the intersection of aquatic biodiversity and mental health. The keyword search string used was: (“aquatic biodiversity” OR “biodiversity loss” OR “aquatic environments” OR “blue spaces” OR “ecosystem services” OR conservation OR “water-based therapy”) AND (“mental health” OR “mental disorders” OR stress OR anxiety OR mood OR “stress reduction” OR “mood improvement”). The search was restricted to documents in the English language. It included articles, review articles, proceeding papers, early access publications, book chapters, editorial materials, data papers, meeting abstracts, letters, and book reviews. Excluded were retracted publications, corrections, and reprints. Since aquatic biodiversity is not a standalone field but rather embedded in biodiversity studies in general, it was decided to include all the results of our search for our analysis to get a more comprehensive overview of the intersecting fields.

Figure 1. PRISMA flowchart of article selection

2.1.2 Data Extraction and Preprocessing

Metadata, including the full records and references,

was extracted for analysis. The timeframe was set from 2014 to 2024 to reflect a decade of relevant research covering the emergence and development of studies linking biodiversity and mental health. Data were processed using the bibliometrix package in R, while R-Biblioshiny was employed for data analysis and visualisation [31]. An updated search using the search string was carried out with a timeframe from the 1st of January 1, 2014, to the 12th of October, 2025. A total of 159 Highly Cited original research articles in English from the Web of Science Core Collection were selected for content analysis. Focusing on highly cited papers ensures the inclusion of studies with the greatest scientific impact, methodological robustness, and conceptual influence. This approach also provides a feasible and representative subset for in-depth analysis, as screening and appraising all 19,320 initial records would be impractical and resource-intensive within the study’s scope and timeframe. The records were then uploaded to Rayyan (an AI-powered systematic review platform) [32] and screened using the following exclusion criteria:

1. Non-human studies, including the exclusion of human-derived cell lines/models
2. Non-original research studies, including the exclusion of meta-analysis and systematic reviews
3. Studies not directly or indirectly related to the aquatic environment/aquatic biodiversity
4. Studies without specific or generalised mental health effects of the aquatic environment/biodiversity

The full text of the final records was then analysed for both qualitative and quantitative contents where relevant to address our study aim.

2.2 Literature search

A further comprehensive literature search, utilising PubMed and Google Scholar, provided contextual insights and supported the bibliometric findings. The same search keywords used in the bibliometric analysis were applied. The inclusion criteria encompassed studies exploring the relationship between aquatic biodiversity and mental health. Sources included systematic reviews, meta-analyses, observational studies, conference papers, policy documents, reports, relevant webpages, blog posts, and published books or sections. The analysis synthesised insights from diverse sources to draw conclusions and provide recommendations. The combination of quantitative bibliometric findings with qualitative review insights aimed to ensure a holistic understanding of the topic.

3. Results and analysis

Table 1 provides a summary description of the analysis. The analysis spanned a decade (2014–2024) and

included 19,320 documents sourced from 4,516 sources, including journals, books, and conference proceedings. The annual growth rate of publications in this domain was 36.25%, reflecting a rapid increase in research interest. On average, documents were 3.97 years old and received 18.72 citations per document, indicating high engagement and relevance of these fields. The dataset included a total of 934,252 references, demonstrating the depth and breadth of the research. The dataset contained 47,917 keywords provided by authors and 36,922 Keywords Plus (index keywords automatically generated by Web of Science). These keywords highlight the thematic diversity and focus areas in the research context. A total of 72,279 authors contributed to the dataset, with 800 authors involved in single-authored documents. Single-authored documents accounted for 863 publications, while most were the result of collaborative efforts, with an average of 5.71 co-authors per document. Notably, 34.55% of the documents were the result of international co-authorship, emphasizing the global nature of research in this domain. The dataset comprised various publication types, dominated by 16,458 articles, followed by 1,645 review articles. Document types included book chapters (218), proceedings papers (434), editorial materials (78), and early access articles (294). Other types of publications, such as book reviews (2), data papers (8), and meeting abstracts (7), were less frequent but added diversity to the dataset. This variety underscores the multifaceted approach to studying the intersection of aquatic biodiversity and mental health.

The number of articles published annually (Figure 2) on the relation of aquatic biodiversity and mental health has shown a consistent upward trend from 2014 to 2023, reflecting the growing interest in this research area. The slight dip observed in 2024 may be attributed to incomplete data for the year. This growth indicates the expanding recognition of the importance of aquatic biodiversity in mental health studies.

The average number of citations per year (Figure 3) demonstrates fluctuations over the study period, peaking around 2018 and declining afterwards. This pattern suggests a strong initial impact of publications in the intersecting field, followed by a possible shift in research focus or the natural ageing of highly cited documents. The decline in citations may also reflect the fact that 'aquatic biodiversity' has rarely been examined as a distinct research focus. Instead, it is often subsumed under broader studies on the relationship between overall biodiversity and mental health.

Table 1. Summary of information from the bibliometric analysis.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2014:2024
Sources (Journals, Books, etc)	4516
Documents	19320
Annual Growth Rate %	36,25
Document Average Age	3,97
Average citations per doc	18,72
References	934252
DOCUMENT CONTENTS	
Keywords Plus (ID)	36922
Author's Keywords (DE)	47917
AUTHORS	
Authors	72279
Authors of single-authored docs	800
AUTHORS COLLABORATION	
Single-authored docs	863
Co-Authors per Doc	5,71
International co-authorships %	34,55
DOCUMENT TYPES	
article	16458
article; book chapter	218
article; data paper	8
article; early access	294
article; proceedings paper	97
book review	2
editorial material	78
editorial material; book chapter	7
editorial material; early access	2
letter	4
letter; early access	1
meeting abstract	7
proceedings paper	434
review	1645
review; book chapter	31
review; early access	34

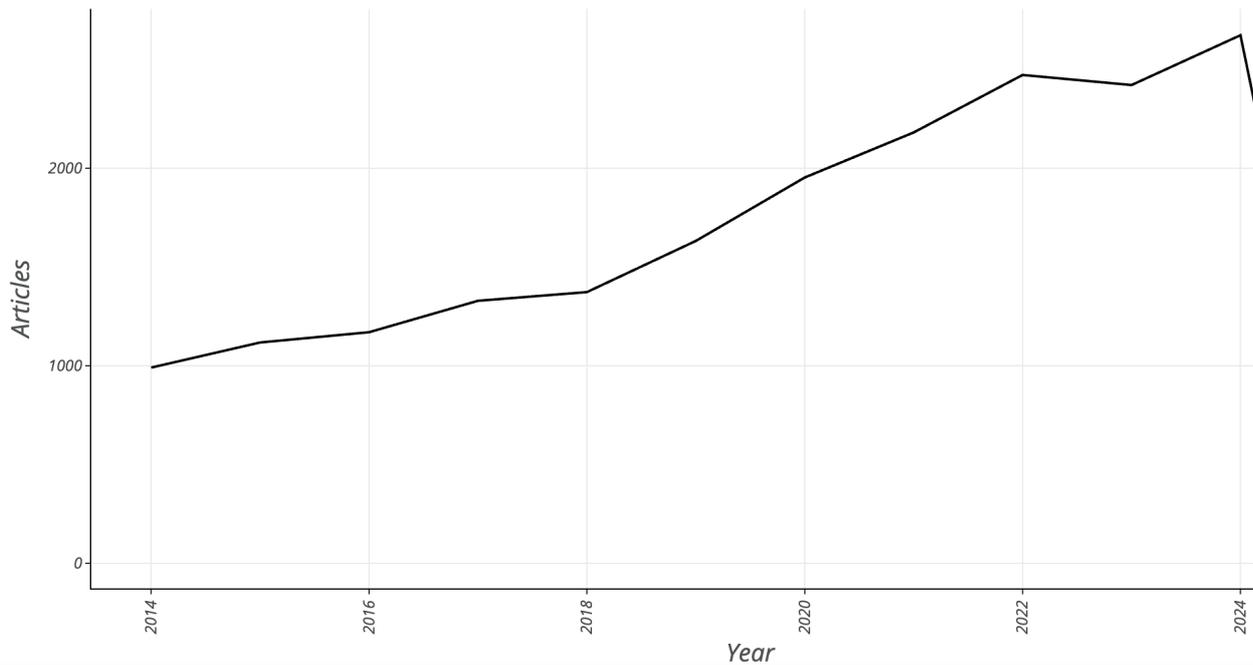


Figure 2. Annual scientific publications.

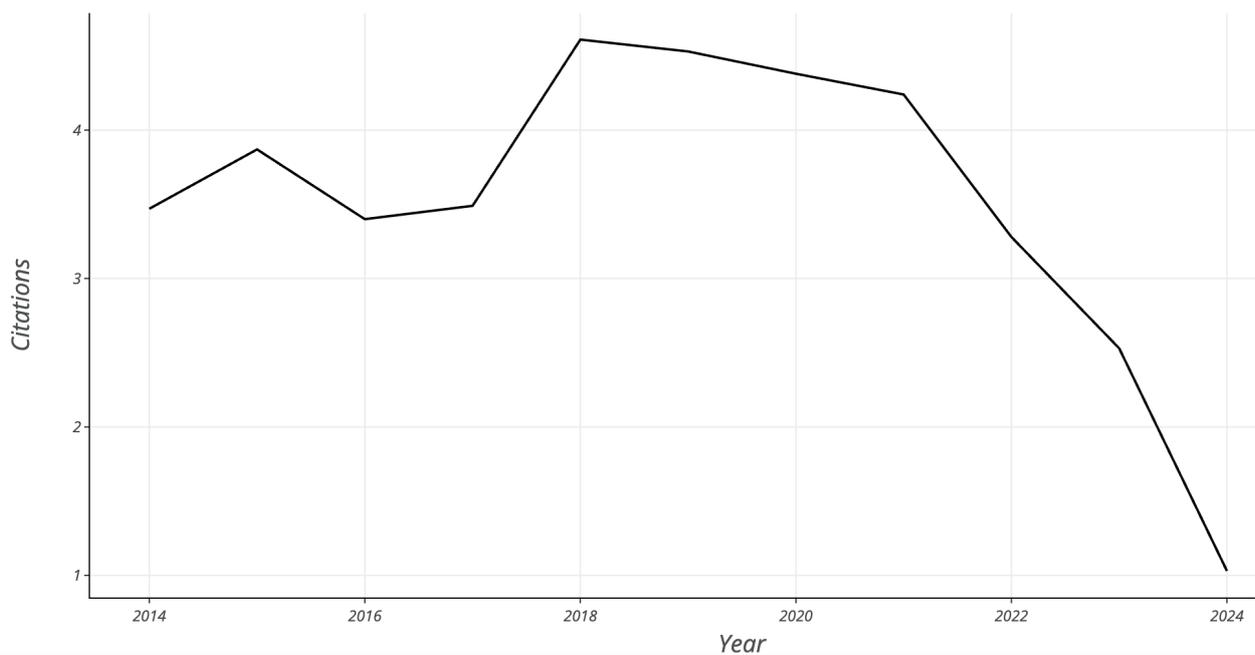
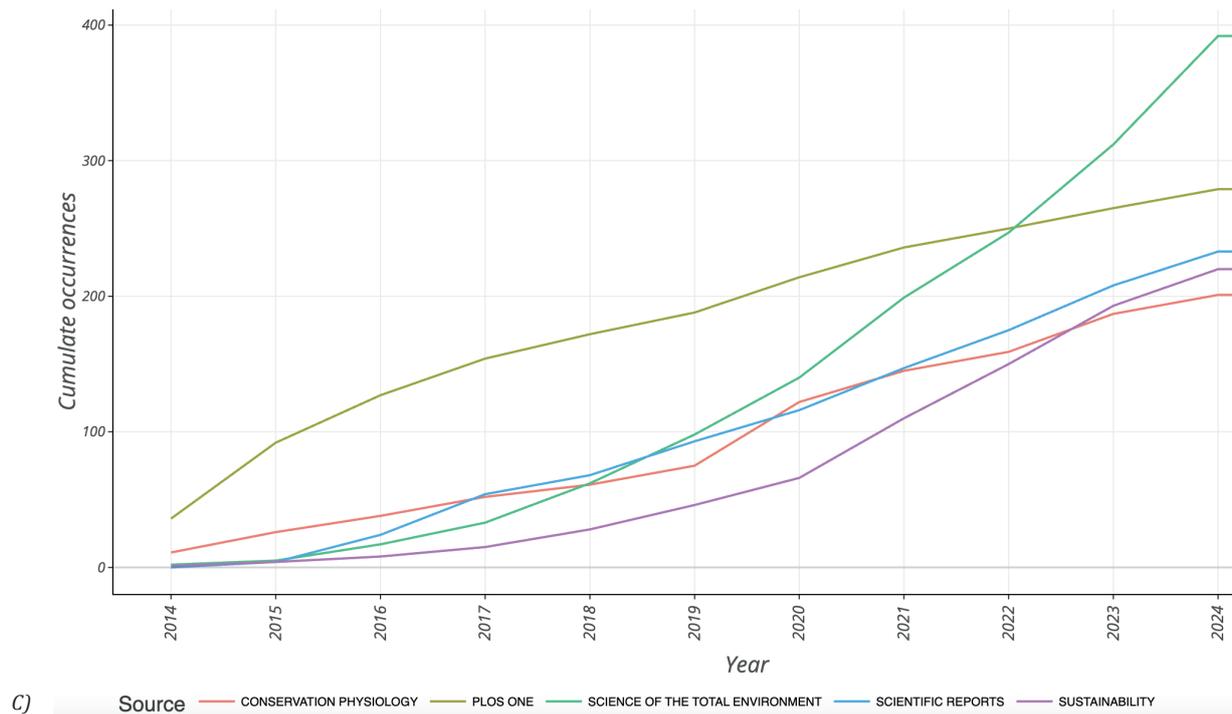
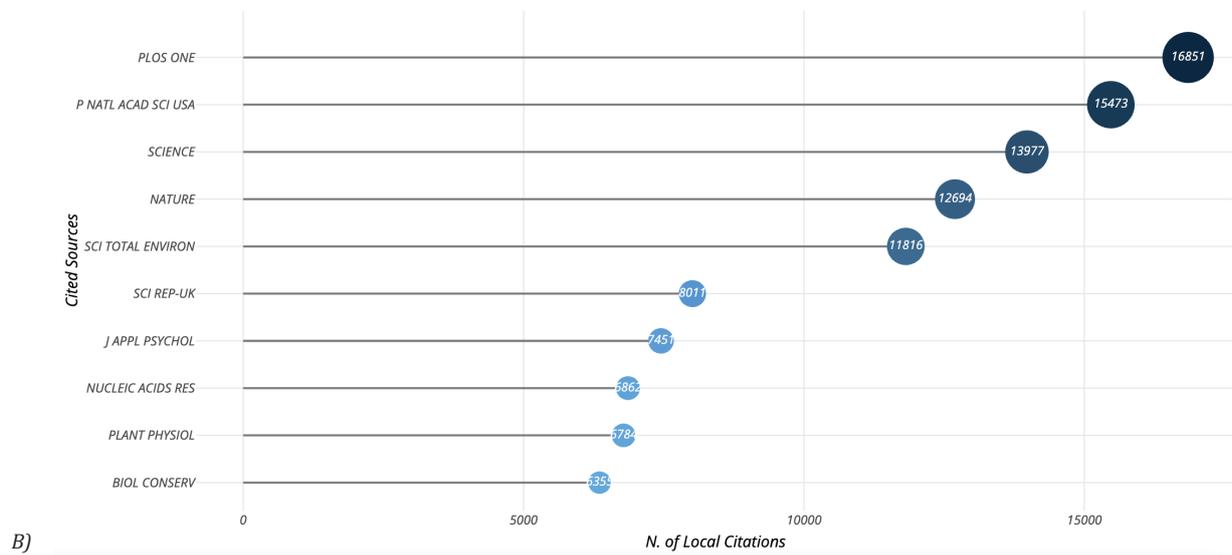
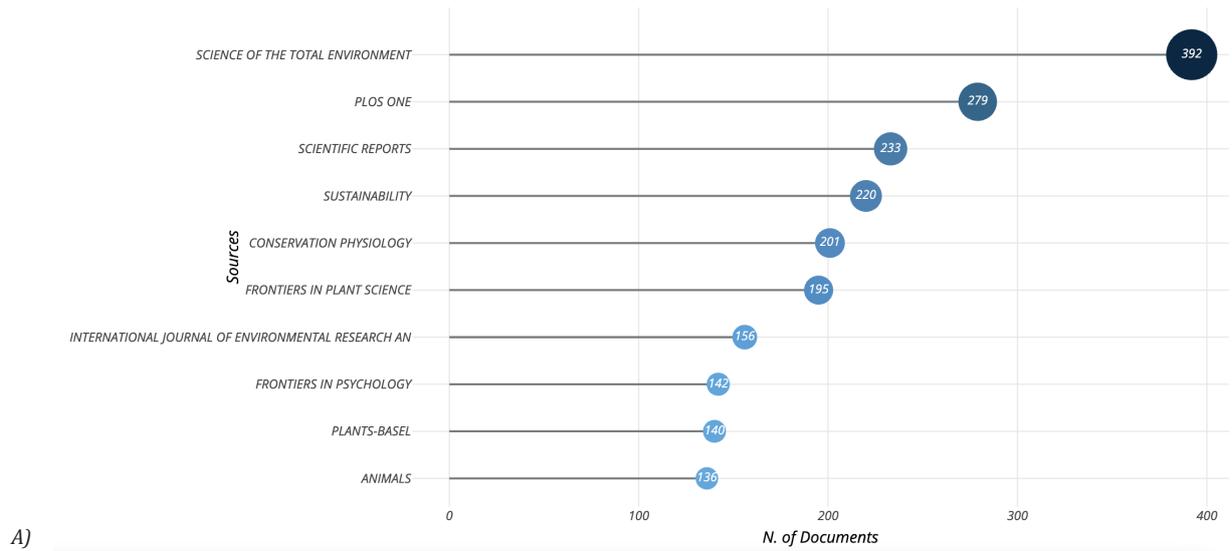


Figure 3. Average citation per year.

The source analysis (Figure 4A) identified Science of the Total Environment, PLOS ONE, and Scientific Reports as the top publication outlets, reflecting the multidisciplinary focus of studies linking aquatic biodiversity, environmental science, and mental health. Country-level analysis (Figure 4D) showed that China, the USA, and India were the leading contributors, with China producing the highest number of publications and exhibiting strong international collaboration. Keyword mapping and temporal trends (Figures 4E–4F) revealed that terms such as “biodiversity,” “climate change,” and

“conservation” dominated the field, while “mental health,” “stress,” and “resilience” appeared less frequently but demonstrated steady growth in recent years. Network analysis (Figure 4G) revealed that “conservation” and “climate change” formed the most central nodes, with “stress,” “ecosystem services,” and “resilience” serving as bridges between the environmental and mental health domains. The global collaboration network (Figure 4H) showed dense intercontinental linkages, highlighting the field’s highly interconnected and interdisciplinary nature.



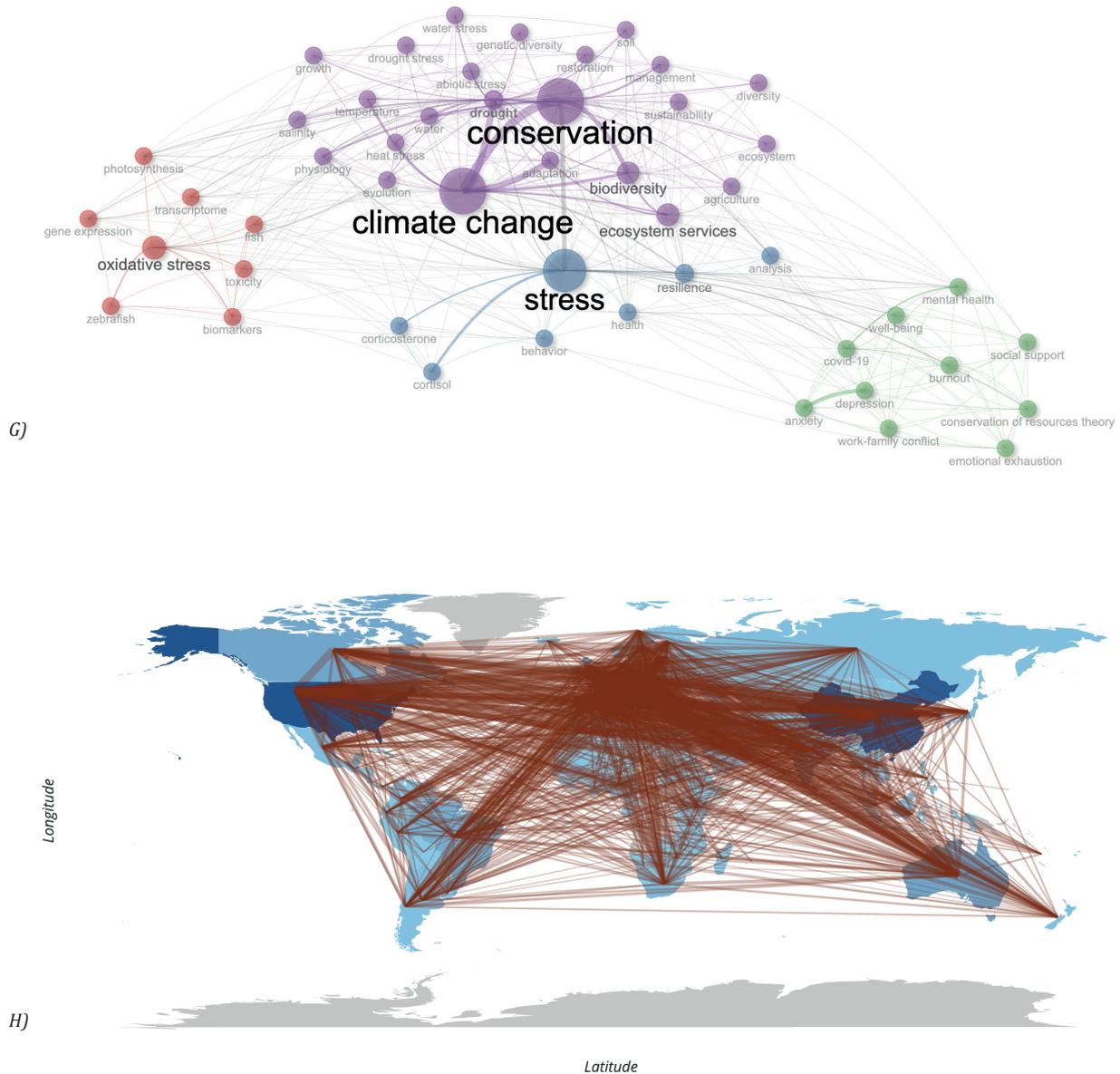


Figure 4. Global research landscape linking aquatic biodiversity and mental health. (A) Top scientific journals; (B) Most cited journals; (C) Cumulative publication trends; (D) Leading author countries and collaboration types; (E) Keyword co-occurrence word cloud; (F) Temporal trends in keyword frequency; (G) Keyword co-occurrence network; (H) Global collaboration network among contributing countries.

Table 2 presents a synthesis of ten original research studies identified through content analysis of 159 highly cited papers on aquatic biodiversity and mental health. The table summarises study design, strength of evidence, population characteristics, and whether

aquatic biodiversity was measured directly or inferred through perceived or ecological indicators, highlighting the methodological diversity and evidence gaps in this emerging field.

	Study Type	Strength of evidence	Study population	Quantitative Indicators Measured	Qualitative/ Perceived Indicators Measured	Measurements or Descriptions of Aquatic Biodiversity	Ref.
1	Cross-sectional survey / Natural experiment	Moderate (Context-Specific/ Correlational)	Adults who participated in an online self-report survey. 5,218 used for Hypothesis 1 (from 9 countries). A subsample of 3,403 respondents from Spain (under strict Level 1 lockdown) was used for Hypothesis 2	Depression/ Anxiety Symptoms: Measured using the 4-item Patient Health Questionnaire (PHQ-4) screening scale, which yields a composite score (0-12) for psychological distress. Mood/Emotions: Self-assessment of emotions (e.g., happy, sad, angry, fearful, etc.) pre- and during lockdown, based on Plutchik's wheel of emotions, classified into seven core emotions	Perceived Coping: Respondents' self-assessed perception of the extent to which contact with outdoor nature helped them to cope better with the lockdown situation (Likert scale 1-5).	Indirect. Focus on on exposure to "blue-green spaces".	[33]
10	Qualitative study (In-depth interviews, including walking interviews)	Strong (Qualitative)	Community-dwelling older adults. 27 participants initially interviewed (T1), with 19 participating in a second round (T2). Ages ranged from 65 to 86 years	None (The study methodology was entirely qualitative).	Mental Wellbeing: Broadly explored in terms of self-reported experiences, including feelings of renewal, rejuvenation, and restoration. Spiritual Connection/ Contemplation: The tranquility of blue spaces was valued as a place to relax, contemplate, and connect spiritually.	Wildlife Mention (Qualitative): One participant mentioned seeing seals and herons near the Seawall (a seaside walking trail) and noted, "It's beautiful". Blue Space Definition: Blue space is defined broadly as aquatic environments, both natural and urban, encompassing oceans, lakes, rivers, and smaller features like fountains and streams.	[34]
2	Cross-sectional survey (Large international survey)	Moderate to Strong (High Generalizability/ Correlational)	Adults. 16,307 participants in the final analytical sample	Positive Well-being: Measured using the World Health Organisation's 5-item Wellbeing Index (WHO-5) (scored 0-100). Mental Distress: Indicated by a WHO-5 score of < 28. Medication Use: Self-reported use of doctor-prescribed medication for depression (binary: yes/no). Self-reported use of doctor-prescribed medication for anxiety (binary: yes/no).			

3	Cross-sectional population-based survey / Ecological study	Weak/ Inconclusive	Adults. 8,793 participants whose residential address was successfully geocoded	Self-perceived general health (dichotomized: 'less than good' vs. 'not less than good'). Perceived risk of poor mental health: Measured using the General Health Questionnaire (GHQ-12) (dichotomized at a score of ≥ 3). Perceived depression and/or anxiety (binary: yes/no). Visits to mental health specialists (psychiatrist and/or psychologist during the last year; binary: yes/no). Intake of medication: Self-reported use of tranquilizers or sedatives, antidepressants, or sleeping medication in the last two days (binary: yes/no for each).	None explicitly measured in the study population, though the authors explored social support as a mediating indicator using the Duke-UNC Functional Social Support (DUFSS) total score (11-55).	Indirect. Access to blue spaces was defined as the presence or absence of blue space (inland and non-inland water bodies) within a 300m buffer, derived from the CORINE Land Cover 2006 (CLC2006) database.	[35]
4	Cross-sectional survey	Strength: Moderate (Correlational/ Perceptual)	Adult Hong Kong residents. The sample consisted primarily of older adults (80% were >50 years old). 1,000 participants completed the survey	Self-reported general health (single-item SF1, dichotomised into 'Good' vs. 'Not good'). Subjective Wellbeing: Measured using the World Health Organisation's 5-item Wellbeing Index (WHO-5) (0-100 score, dichotomised into 'High wellbeing' ≥ 50 vs. 'Low wellbeing' <50). Risk of Depression: A sensitivity check used the WHO-5 threshold of < 28. Recalled Wellbeing from a specific visit: A composite score derived from four items representing positive/negative experiential wellbeing, eudaimonic wellbeing, and evaluative wellbeing (dichotomised as 'High' vs. 'Low' recalled wellbeing, mean score ≥ 6).	None explicitly described as qualitative data; measures of perceived environmental quality (e.g., perceived safety, presence of wildlife) were treated quantitatively (Likert scales).	Direct. Aquatic biodiversity is addressed through a perception-based quality indicator: Participants were asked to rate the "presence of wildlife" at their nearest blue space on a seven-point scale. The authors mention that, in the coastal areas of Hong Kong, the most common species visible from above the waterline would be marine birds and black kites. The study found that the perceived presence of wildlife (ORadj = 1.7) was associated with a greater likelihood of high recalled wellbeing from a single visit.	[36]

5	Cross-sectional population-based study / Multilevel regression modeling	Moderate (Methodologically Novel/ Correlational)	Elderly people aged 60 or above. 1,190 individuals in the final dataset	Depressive Symptoms: Assessed using the self-rated, shortened Geriatric Depression Scale (GDS-15), which ranges from 0 (no symptoms) to 15 (severe symptoms). Robustness tests also used a binary classified GDS-15 score (above 8 = depressed).	None	Indirect. The study primarily measures streetscape blue space as a proportion (ratio of blue space pixels to total pixels) detected via deep learning on Tencent Street View images. Examples of blue space objects identified by the network include rivers, lakes, fountains, waterfalls, and swimming pools. The study also used the Normalised Difference Water Index (NDWI), which quantifies water surfaces based on surface reflectance.	[37]
6	Experimental study	High (Causal/ Experimental)	Seventy adults who had no current or past diagnosis of neurologic or psychiatric disorder. 60 individuals were included in the final analysis (30 in the nature group, 30 in the urban group)	Anxiety (State): Assessed using the 20-item State-Trait Anxiety Inventory (STAI). Rumination: Assessed using the Rumination-Reflection Questionnaire (RRQ) (Rumination scale). Positive Affect (State) and Negative Affect (State): Assessed using the 20-item Positive and Negative Affect Schedule (PANAS).	None	Indirect. The study involved walks in either a nature environment or an urban environment.	[38]
7	Ecological study (Cross-sectional)	Moderate (Policy Relevant/ Ecological)	The general population of Great Britain. The study used aggregated data (ecological study) derived from the 2011 Census. Data covers 96.4% of the English population	Good Health Prevalence: Age/sex standardised percentage of people reporting good/very good health (derived from the 2011 UK Census). Bad Health Prevalence: Age/sex standardised percentage of people reporting bad/very bad health (derived from the 2011 UK Census).	None, as this was a cross-sectional ecological study using aggregated secondary data.	Direct. Wildlife/ Biodiversity Indicator: Bird species richness (number of different species observed) was used as an indicator of local biodiversity. These data, sourced from the Bird Atlas 2007–11, were allocated to geographical units (LSOAs/ DZs) using areal interpolation. Although bird species richness is a general	[39]

						ecological indicator, it is explicitly associated with some findings for the coastal and saltwater categories. Water Quality: Surface (primarily river) water quality data were used as a general indicator of landscape quality, measured via ecological status ratings (High, Good, Moderate, Poor, and Bad) based on biological, chemical, and hydrological measures under the European Water Framework Directive. Aquatic Land Cover Types: Land cover types relevant to aquatic environments measured as percentage LSOA area coverage include "saltwater" (largely formed of estuaries) and "freshwater".	
8	Controlled experiment (Neuro-imaging/ Behavioral)	High (Causal/ Mechanistic)	Thirty-eight healthy participants (adults) with no current or past diagnosis of neurologic or psychiatric disorder. 38 participants recruited; 31 used for perfusion analysis; 37 used for rumination analysis. Mean age was 26.6 years	Rumination: Self-reported levels of rumination using the Rumination portion of the Reflection Rumination Questionnaire (RRQ). Neural Activity/ Physiological Correlate: Regional cerebral blood flow (rCBF) in the subgenual prefrontal cortex (sgPFC), measured via the neuroimaging method arterial spin labeling (ASL) (milliliters of blood per 100 g tissue per minute).	None	Indirect. The study compared 90-minute walks in a nature setting versus an urban setting.	[40]

9	Descriptive case study / Cross-sectional survey	Weak (Descriptive/ Subjective)	Users/ visitors of urban and peri-urban natural areas. 346 valid responses	Importance of visiting natural areas during COVID-19 (Likert-style scale measuring subjective importance/value).	Mental health benefits such as stress reduction and rumination reduction are mentioned in the discussion as effects sought by people.	Direct. Specific Wildlife Mention: One of the key reasons respondents gave for visiting the natural areas was "birding". General Ecosystem Descriptions: The natural areas studied (25 parks and areas in and around Burlington, Vermont) are described generally by their ecosystems, which include peatlands, swamps, wetlands, and open waters. Unpublished Species Data: The study refers to an "Unpublished raw data" source called "Database of species living in UVM's Natural Areas", but the specific contents of this database (aquatic species) are not detailed in the provided excerpts.	[41]
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5. Discussion

5.1 Insights from the study findings

The bibliometric analysis highlights a significant growth in research at the intersection of aquatic biodiversity and mental health, with a significant increase in the number of publications from 2014 to 2023. Despite the growth in the number of publication, citation rates are declining, likely reflecting the limited statistical significance and modest scientific impact. This trend underscores the growing recognition of the ecological and the psychological importance of water ecosystems. However, mental health remains a secondary focus compared to broader ecological themes such as biodiversity, climate change, and conservation. Key terms like "biodiversity" and "climate change" dominate the discourse, while "mental health" and "stress" show more modest but consistent growth. Conserved aquatic biodiversity offers diverse psychological benefits, including stress reduction, enhanced well-being, and resilience [10,42,43]. These benefits are mediated by ecosystem services such as clean water access, climate regulation, nutritional support, and cultural and spiritual opportunities [44,45]. The most prominent

psychological risk of biodiversity degradation is heightened stress and mental health deterioration caused by water contamination, resource scarcity, and ecosystem instability. The analysis of journals and keyword co-occurrence reveals that conservation, ecosystem services, and resilience are central themes bridging ecological and psychological dimensions. Emerging topics such as "water stress," "resource conservation," and "burnout" are underrepresented, highlighting the need for further exploration of how ecosystem services intersect with mental health, particularly in the context of resource scarcity and socio-environmental pressures. This is important because resource scarcity and environmental pressures can disrupt ecosystem services and exacerbate mental health challenges [46]. Mental health-specific topics like anxiety, depression, and well-being are also underdeveloped, reflecting the need for targeted research in this area. While the short-term benefits of ecosystem services on mental health are well-documented, there is limited research on the long-term psychological impacts of biodiversity conservation, especially in urbanised or degraded environments. The field remains fragmented, with limited collaboration between environmental

scientists, psychologists, and public health experts, hindering a holistic understanding of how ecosystem services mediate mental health outcomes.

The primary objective of this study was constrained by a notable absence of direct quantitative data. Across the ten reviewed studies for content analysis, no direct empirical associations were identified between measured indices of aquatic biodiversity (such as species richness, fish or invertebrate diversity, or ecological complexity) and individual mental health outcomes. Instead, the available evidence primarily relies on proxy indicators of environmental quality and subjective perceptions of biodiversity within blue space settings.

The strongest and most consistent evidence derives from perceptual studies linking the subjective experience of wildlife to improved psychological outcomes. For instance, perceived wildlife presence predicted higher recalled well-being ($OR_{adj} = 1.7$) among older adults visiting urban blue spaces in Hong Kong and was also associated with more frequent voluntary engagement with these environments [36]. Qualitative studies further reinforce this finding that participants consistently describe the visual and aesthetic experience of wildlife, such as observing herons, seals, or aquatic birds, as a meaningful source of restoration and emotional relief [33,34]. These findings collectively suggest that perceived biodiversity acts as a psychologically salient cue, shaping restorative and affective responses to aquatic environments.

Evidence from objective ecological measures remains sparse and inconsistent. Across the ten reviewed studies for content analysis, no direct empirical associations were identified between measured indices of aquatic biodiversity such as species richness, fish or invertebrate diversity, or ecological complexity and individual mental health outcomes. A large-scale ecological study in the United Kingdom of Great Britain identified a positive association between bird species richness [39], a general proxy for biodiversity that often encompasses aquatic and coastal species, and population-level reports of good health [47–50]. In contrast, surface water quality, used as an ecological indicator, was inversely associated with health outcomes, implying that such generalised indicators may capture broader environmental or socioeconomic conditions rather than direct psychological mechanisms [39]. This inconsistency highlights the methodological challenges of inferring mental health effects from population-level ecological data, particularly when individual exposure or perception measures are lacking.

More robust and consistent evidence exists for the psychological benefits of blue space exposure itself, independent of biodiversity metrics. Frequent

recreational use and intentional visits to coastal or inland waters are consistently associated with higher subjective well-being, reduced stress, and improved restoration [22]. However, these benefits are largely attributed to experiential mechanisms, including relaxation, physical activity, and social engagement, rather than ecological diversity [36]. Objective measures, such as proximity to water or satellite indices (e.g., normalised difference water index - NDWI), show weaker or inconclusive relationships [37], suggesting that exposure alone is insufficient without considering perceived environmental quality or engagement.

5.2 Future Studies and Research Gaps

Despite these clear benefits, this study highlights significant gaps in understanding the intersection between aquatic biodiversity and mental health. To address the fragmented nature of research in aquatic biodiversity and mental health, fostering interdisciplinary collaboration is crucial to ensure the synthesis of evidence that is currently lacking.

1. **Underrepresentation of Mental Health in Research:** The bibliometric analysis indicates that mental health-related themes, such as "anxiety," "depression," and "stress," remain secondary compared to broader ecological topics like "biodiversity," "climate change," and "conservation." While these connections are increasingly recognised, there is a lack of direct studies exploring the specific mental health outcomes of the aquatic biodiversity conservation.
2. **Emerging but Underexplored Topics:** Themes such as "water stress," "resource conservation," "emotional exhaustion," and "burnout" are underrepresented in current research. These areas hold significant potential for exploring the links between biodiversity conservation and mental health, particularly in terms of resource scarcity and socio-environmental pressures.
3. **Limited Evidence on Long-Term Impacts:** Current research primarily focuses on the short-term benefits of ecosystem services. Understanding on how aquatic biodiversity conservation influences mental health outcomes over the long term is limited.
4. **Fragmented Interdisciplinary Collaboration:** There is a lack of integration between environmental science, psychology, and public health disciplines. This fragmentation limits the ability to fully understand how ecosystem services mediate mental health outcomes and develop holistic approaches for addressing these challenges. Cross-disciplinary research hubs should be established

that bring together psychologists, ecologists, public health experts, and policymakers to co-develop research agendas. Regular interdisciplinary workshops, conferences, and symposia could facilitate knowledge exchange and the formation of collaborative networks. Joint publications in interdisciplinary journals and the development of policy briefs could further enhance collaboration by aligning research outputs with actionable policy objectives.

5. Use of innovative technology: digital platforms, tools, and artificial intelligence (AI) should be leveraged for collaboration, data sharing and analysis to break down geographical barriers and streamline contributions from diverse fields.
6. Resource mobilisation: Funding bodies should prioritise grants that mandate cross-disciplinary partnerships, encouraging innovative research at the intersection of aquatic biodiversity and mental health.

5.3 Implications for Policy and Practice

Given the limited empirical evidence currently available on direct links between aquatic biodiversity and mental health, policy recommendations should be framed cautiously while still recognising the potential for co-benefits. Conservation strategies can be designed to remain ecologically sound while exploring opportunities to support mental well-being. Urban and regional planning may consider incorporating well-managed blue spaces as part of broader environmental quality initiatives, not as proven mental health interventions, but as components that may enhance overall environmental experiences for communities.

Education and outreach programs can focus on fostering general environmental stewardship and awareness of the indirect ways in which healthy ecosystems contribute to societal resilience. Support for local and regional conservation projects can emphasise demonstrable ecological outcomes while leaving open the possibility of ancillary social benefits. At the international level, aquatic biodiversity can continue to be aligned with the Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 14 (Life Below Water), while acknowledging that evidence for explicit mental health pathways remains insufficient and under investigation.

Addressing existing gaps (mainly in the form of a lack of empirical evidence) requires a more focused and interdisciplinary research approach. Future studies should:

1. Investigate direct links between aquatic biodiversity and specific mental health outcomes,

such as stress reduction, anxiety mitigation, and mental disorders (bipolar disorder, unipolar disorder, schizophrenia, sleeping disorder, eating disorder, etc.).

2. Explore emerging themes, such as water stress and resource scarcity, particularly in vulnerable regions.
3. Foster collaboration between environmental scientists, psychologists, and public health experts to develop comprehensive frameworks that integrate biodiversity conservation and mental health strategies.
4. Expand research efforts to underrepresented regions, ensuring that the benefits of aquatic biodiversity conservation are understood and accessible globally.

The study highlights the psychological benefits of aquatic biodiversity, including stress reduction and mood enhancement, but the specific mechanisms underlying these effects remain underexplored. Future research should investigate biological pathways, such as how exposure to 'blue spaces' influences neurochemical processes like cortisol regulation and dopamine production. Psychosocial mechanisms, including how interactions with biodiverse aquatic environments foster a sense of connection, relaxation, and resilience, also warrant exploration. Experimental studies using physiological markers (e.g., heart rate, cortisol levels) alongside psychological surveys could provide a comprehensive understanding. Interdisciplinary research that integrates environmental science with neuroscience and psychology would deepen insights into the ecosystem-mediated mental health benefits.

5.4 Promising concepts of the use of water in mental health

Water is the most important component of aquatic biodiversity. It is essential for life, serving as a critical habitat that supports aquatic organisms by providing the necessary conditions, such as proper temperature, oxygen levels, and cleanliness, for species to thrive and sustain their ecosystems. Below, are presented several promising concepts that can be considered in research and policy.

1. Beneficial microorganisms or molecules that out-compete pollution/disease-causing microbes and enhance water bodies' physical appearance, such as color, which can stimulate and calm the mind, and reduce stress and anxiety. Microbes can enhance water quality by outcompeting harmful species and breaking down pollutants [51,52], while calming colors like blue and green in aquatic environments promote stress reduction [53–55]. Cleaner water creates a visually appealing and calming

environment with its clear appearance and pleasant blue or green hues as a result of reduced algae and pollutants, combined with the health benefits of a balanced microbiome. Further research is needed to see if specifically introducing beneficial microbes can directly influence the color of water in a way that promotes mental well-being.

2. The sounds of water help with fall asleep and can be used to manage sleeping disorders. Various studies have shown that natural sounds, including rain and water flow, improve sleep quality by masking environmental noise, lower stress and promote feelings of calmness [56–60]. In the study by Williamson et al. from 1992, listening to ocean sounds significantly improves sleep depth or quality and overall sleep experience, contributing to better mental health outcomes [61]. The study by Yang et al. from 2018 found that indoor water sounds reduced annoyance and enhanced perceptions of pleasantness, calmness, and naturalness [62]. The sound of water and the water environment can also influence neurotransmitters in the human body and help with stress response and management. This is especially important in stress-related mental disorders. Research has found that water sounds have a stress-reducing effect [63] indicated by low cortisol levels in humans [58], and sound exposure in rodents caused an increase in the level of dopamine [64], which plays a role in memory, mood, sleep, learning, concentration, movement and other body functions. However, more research is needed on the specific effects of water sounds and water environments on individual neurotransmitters, which are still not well understood.
3. Water can play a supportive role in the treatment of eating disorders. Water with electrolytes could be used for rehydration purposes. Dehydration is common in eating disorders, especially in those with Anorexia Nervosa [65]. The study by Solmi et al. conducted in 2024 found that people with eating disorders who also had electrolyte problems were more likely to die (15.7% versus 5.6% of those without) and face serious health issues, including more hospital stays (60.5% versus 47.4% of those without), kidney problems (10.4% versus 3% those without for acute issues, 12.3% versus 4.3% of those without such problems for chronic issues), fractures (7.0% versus 4.0% in those without such problems), and bowel blockages (3.6% versus 1.4% in those without problems) [66]. Electrolyte-enhanced water can support eating disorder treatment by addressing dehydration, restoring electrolyte balance for organ function, and encouraging fluid

intake in individuals hesitant to hydrate [67,68]. Water also plays an important role in transporting nutrients throughout the body, including the brain, which dehydration can negatively impact [69].

6. Limitations and strengths of the study

The present study provides a novel and comprehensive synthesis of the emerging relationship between aquatic biodiversity and mental health, combining bibliometric analysis and systematic review to integrate insights from ecology, psychology, and public health. Drawing from over 19,000 records, it offers a robust overview of global research trends (2014–2024) and highlights key interdisciplinary linkages and research gaps. However, the analysis is limited by the scarcity of direct empirical studies ($n = 10$), methodological heterogeneity, and the predominant reliance on perceived rather than measured biodiversity. Dependence on the Web of Science database, specific keywords, and Highly Cited Papers may have led to omissions, and publication bias could favour studies with positive outcomes. Additionally, the focus on pristine environments restricts generalizability to urban or degraded settings. Despite these constraints, the study establishes a valuable foundation and roadmap for future longitudinal, ecologically grounded, and interdisciplinary investigations into the ecosystem-mediated effects on mental health.

7. Conclusions

This study examines the existence/absence of empirical evidence on the role of aquatic biodiversity in maintaining both ecosystem integrity and human mental well-being. Although the current evidence does not establish (or weakly establishes) a direct empirical relationship between measured aquatic biodiversity and mental health, consistent findings link perceived environmental quality and visible wildlife presence with improved psychological outcomes and greater engagement with aquatic environments. These findings indicate that perceived biodiversity may influence mental states, but they do not confirm a causal or measurable relationship with actual aquatic biodiversity. Major research gaps remain, including the limited use of standard biodiversity metrics, the lack of mental health -related endpoints, and the absence of longitudinal or experimental designs. Addressing these gaps will require coordinated interdisciplinary research. In the absence of stronger evidence, any policy integration of aquatic biodiversity and mental health should be approached cautiously and framed as exploratory rather than evidence-based.

Ethical Statement

Ethical approval is not necessary for this study, as it is a bibliometric/evidence analysis.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

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Otrzymano: 15.09.2025

Zrecenzowano: 08.10.2025, 24.11.2025

Przyjęto do publikacji: 15.01.2026