Macrophytes in Natural and Artificial Wetlands: A Review of Their Adaptability and Resilience

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Abstract

Introduction: Macrophytes are aquatic plants that have been the subject of further study in various fields. They currently play a fundamental role in the absorption of carbon dioxide from the atmosphere. In response, research into this ecosystem service has been promoted.

Methods: This article presents a review of recent research on these species, using a bibliometric analysis of 113 Scopus documents; delving deeper into the scientific discourse surrounding these organisms and their relationship with greenhouse gases GHG. Using tools such as VOSviewer, a detailed view of the characteristics and evolution of the research field is offered. Several research directions are identified, including the application of artificial wetlands as sinks, wastewater treatment in climatological terms, carbon absorption in natural wetlands and the factors that influence it.

Resultados y Conclusions: In conclusion, the analysis shows a trend in recent years towards the search for efficient alternatives for carbon fixation and to counteract the devastating effects of climate change. The countries with the greatest research contribution were China and the United States, which are currently major emitters of GHG. From this, the recommendation is derived to carry out large-scale studies, as well as the inclusion of other databases so that the bibliometric analysis on this subject has greater coverage. These results offer valuable information for researchers who address this subject, significantly enriching the understanding of this crucial and urgent field.

Keywords: Macrophytes, Greenhouse Gases, Bibliometrics, VOSviewer, Carbon Dioxide, Wetlands

1. Introduction

Climate Change (CC) is one of the most pressing global concerns for both developing and developed countries, exacerbated by increasing emissions of Greenhouse Gases (GHGs) that contribute to the rise in the planet's temperature, with Carbon Dioxide (CO_2) being the largest contributor (López-Pacheco y otros., 2021). Reducing these gases has become a goal of the United Nations, which has recommended implementing measures to lower their concentrations. This will provide a key contribution to achieving the

sustainability pursued by the 17 objectives of the 2030 Agenda established in 2015 (Naciones Unidas, 2018).

Despite the above, it is proposed that one of the mechanisms to achieve results in addressing climate change (SDG 13) involves the sustainable use of Ecosystem Services (ES), including climate regulation, which is globally relevant (Yan y otros., 2023). As mitigation alternatives, the Paris Agreement of 2015, ratified in 2019, highlights the importance of protecting GHG sinks or reservoirs as part of the process to achieve the goals set forth in this treaty. It emphasizes the balance that should exist between these ecosystems and anthropogenic activities, which are the primary causes of atmospheric emissions.

In recent years, macrophytes found in wetlands have received significant attention due to the adverse consequences of the use of aquatic ecosystems, such as wetlands. This has led to the excessive growth of these organisms, prompting their removal through various methods. However, this practice generates negative impacts on ecosystems, and conversely, these organisms can fulfill important functions within the system (Haroon & Abd Ellah, 2021)(Harpenslager y otros., 2022). It is important to note that the harms caused by the overpopulation of these species compete with the benefits associated with them, such as ES, which are often overlooked in decision-making regarding resource management (Thiemer y otros., 2021).

In the context of some macrophytes in wetlands, consulted research has shown that some invasive species, such as Eichhornia crassipes, can play an important role in the biogeochemical carbon cycle, reducing GHG emissions. It has been observed that waters with proliferation of this species experienced a significant reduction in emissions compared to open waters. However, it has also been found that carbon storage in biomass depends on various factors, including the species present, climate, and other parameters s (Attermeyer y otros., 2016; Arellano, Meza, Miranda y Camaño, 2013; Maldonado y Aparicio, 2021).

Therefore, it is important to highlight the significance of conducting a bibliometric analysis on topics of great environmental relevance, such as this global phenomenon. This approach allows us to identify weaknesses, highlight key aspects, and understand trends related to this issue (Huang y otros., 2023).

Methodology

Data Collection

This article uses the Scopus database as a reference (https://www.scopus.com/). A bibliographic review was conducted, and a canonical equation was established using ChatGPT based on the keywords macrophytes and greenhouse gases. This approach detected 175 articles related to the topic. The search period was specified (2011-2024), filters were applied to display documents in all languages, and the information was delimited by including keywords in English such as aquatic plants, carbon cycles, carbon sequestration, among others, resulting in 113 documents. The resulting equation was: TITLE-ABS-KEY (macrophytes) AND TITLE-ABS-KEY (greenhouse AND gases) AND PUBYEAR > 2010 AND PUBYEAR < 2024 AND (LIMIT-TO (EXACTKEYWORD , "Macrophyte") OR LIMIT-TO (EXACTKEYWORD , "Greenhouse Gas") OR LIMIT-TO (EXACTKEYWORD , "Greenhouse Gases") OR LIMIT-TO (EXACTKEYWORD , "Wetlands") OR LIMIT-TO (EXACTKEYWORD , "Carbon Dioxide") OR LIMIT-TO (EXACTKEYWORD , "Wetland") OR LIMIT-TO (EXACTKEYWORD , "Climate Change") OR LIMIT-TO (EXACTKEYWORD , "Macrophytes") OR LIMIT-TO (EXACTKEYWORD , "Carbon") OR LIMIT-TO (EXACTKEYWORD , "Organic Carbon") OR LIMIT-TO (EXACTKEYWORD , "Vegetation") OR LIMIT-TO (EXACTKEYWORD , "Biomass") OR LIMIT-TO (EXACTKEYWORD , "Greenhouse Gas Emissions") OR LIMIT-TO (EXACTKEYWORD , "Carbon Sequestration") OR LIMIT-TO (EXACTKEYWORD , "Carbon Cycle") OR LIMIT-TO (EXACTKEYWORD , "Photosynthesis") OR LIMIT-TO (EXACTKEYWORD , "Plants") OR LIMIT-TO (EXACTKEYWORD , "Greenhouse Gas Emission") OR LIMIT-TO (EXACTKEYWORD , "Eichhornia Crassipes") OR LIMIT-TO (EXACTKEYWORD , "Aquatic Macrophytes") OR LIMIT-TO (EXACTKEYWORD , "Aquatic Plant") OR LIMIT-TO (EXACTKEYWORD , "Plant") OR LIMIT-TO (EXACTKEYWORD , "Greenhouses Gas") OR LIMIT-TO (EXACTKEYWORD , "Global Change") OR LIMIT-TO (EXACTKEYWORD , "Gases") OR LIMIT-TO (EXACTKEYWORD , "Climate") OR

LIMIT-TO (EXACTKEYWORD , "Aquatic Plants") OR LIMIT-TO (EXACTKEYWORD , "Carbon Cycling") OR LIMIT-TO (EXACTKEYWORD , "Aquatic Ecosystems") OR LIMIT-TO (EXACTKEYWORD , "Aquatic Ecosystem") OR LIMIT-TO (EXACTKEYWORD , "*Azolla*").

Bibliometric Analysis Tools

The resulting search data were exported in RIS format and uploaded to the Mendeley platform for reference management. The VOSviewer software was used to generate visual representations that allowed for the analysis of the nationality of the main authors, highlighted key terms, temporal evolution of word frequency, and emerging topics. The visualizations created by VOSviewer present various elements organized by topic using different colors; the size of the circles reflects the frequency of the element, and the distance between the circles indicates their relationship. To begin the graphical representation, a minimum threshold of 5 occurrences was set for a keyword. Out of the 1,735 keywords analyzed, 11 met the threshold. Irrelevant and repeated words were discarded, resulting in a total of 22 keywords.

Keyword Analysis

Co-occurrence Analysis

The co-occurrence Analysis displays 22 high-frequency keywords within the research field of macrophytes and greenhouse gases, classified into four groups differentiated by colors. It is evident that the largest nodes with the most connections (links) are macrophytes (69 occurrences), greenhouse gases (59 occurrences), wetlands (36 occurrences), and carbon dioxide (37 occurrences), making these the most relevant keywords in the dataset. From this, it is identified that the words macrophytes and greenhouse gases have a closer relationship, as indicated by the proximity of their nodes and their inclusion in the same cluster. It is also evident that in the most recent research (from 2019 onwards), these two terms are the most relevant.

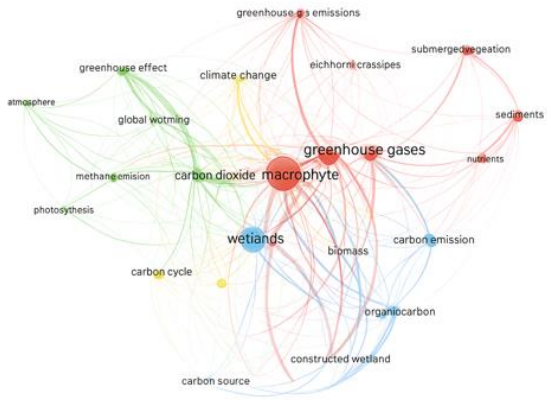

Figure 1. Keyword Co-occurrence Map

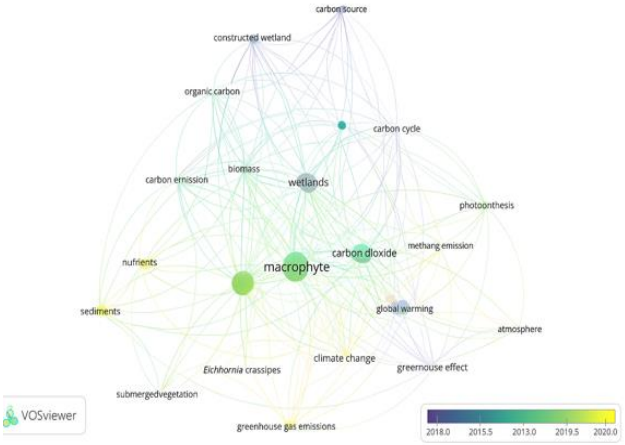

Figure 2. Keyword Heat Map

The grouping provided by the software served as a basis for summarizing the directions of the research that has been conducted and the sets of keywords corresponding to the four clusters.

Table 1. Keyword Grouping

CLUSTER	NODOS
1	n=7 Eichhornia crassipes, greenhouse gas emissions, greenhouse gases, macrophytes, nutrients, sediments, submerged vegetation.
2	n=6 Atmosphere, carbon dioxide, global warming, greenhouse effect, methane emissions, photosynthesis.
3	n= 5 Carbon emissions, carbon source, artificial wetland, organic carbon, wetlands.
4	n=4 Biomass, carbon cycle, carbon sequestration, climate change

Cluster 1 (Red Color)
This was the group with the highest number of nodes (7), featuring the keyword Macrophytes, which obtained the highest total link strength (TLS) score (224). It had the strongest link with the greenhouse gases node.

Cluster 2 (Green Color)
This group consisted of 6 terms, with the keyword carbon dioxide showing the highest total link strength (137) and 37 occurrences. This group is primarily related to the node corresponding to greenhouse effect.

Cluster 3 (Blue Color)
This cluster is composed of 5 items, with wetlands having the highest total link strength (137). This term is strongly related to artificial wetland, followed by carbon emission with link strengths of 12 and 6, respectively.

Cluster 4 (Yellow Color)
This group is represented by 4 nodes, with the term climate change having a total link strength of 57, followed by biomass, carbon sequestration, and carbon cycle with TLS values of 2, 3, and 4, respectively. This indicates that these terms have similar values, suggesting that they are closely related concepts to the phenomenon of climate change and are strongly interconnected.

Discussion
Countries

The 111 articles were published in 15 countries worldwide, with a publication range varying between 6 and 30 publications.

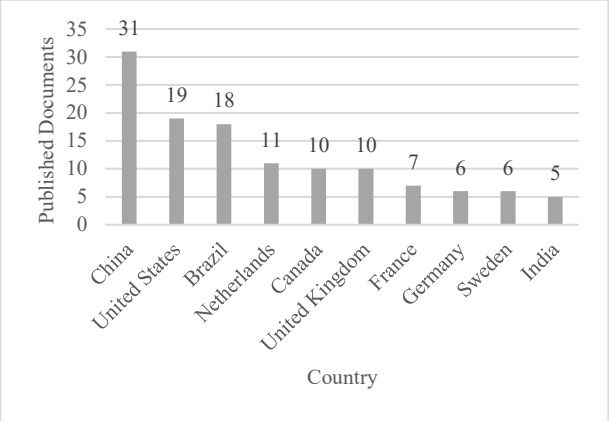

Figure 3. Documents Published by Country

China is the country with the highest number of publications, followed by the United States. This can be attributed to the fact that China has emerged as one of the world's largest carbon emitters, contributing nearly one-third of global carbon emissions in 2019 (Friedlingstein y otros., 2020). Additionally, within the framework of its national economic and social development plan, China values the promotion of sustainable and low-carbon development as a crucial component (Lee y otros., 2024).

Publication Trends
Based on the Scopus database, 3 articles related to the topic were published in 2011, and by 2023, there were 13 publications, indicating a 33.33% increase **Figure 4**. It could be said that this is a trending topic, attributable to the emergence of the 2030 Agenda, which outlines the Sustainable Development Goals (SDGs), including addressing climate change (SDG 13). The global goal is to reduce total emissions to 2 metric tons of CO_2-equivalent per capita by 2050 (Franco y otros., 2022). It is proposed that one of the mechanisms to achieve results involves the sustainable use of Ecosystem Services (ES), including climate regulation (Yang y otros., 2020), where we can affirm that wetlands are important carbon sinks (Malerba y otros., 2022).

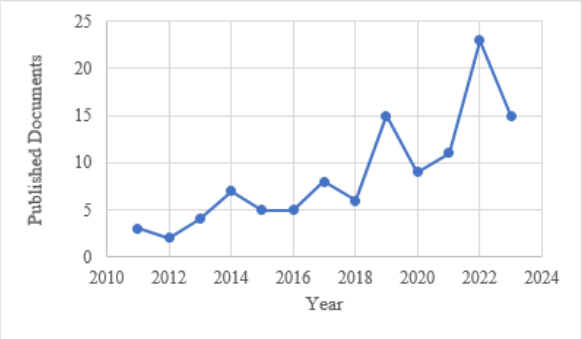

Figure 4. *Publication Trends by Year*

On the other hand, an analysis of the Scopus database revealed that the earliest research focused on the use of macrophytes in wetlands for the removal of water pollutants such as nitrogen and volatile compounds (Lévesque y otros., 2011; Reid & Jaffé, 2012), while the most recent research centers on how global warming reduces the photosynthesis of macrophytes, even in moderate scenarios, i.e., less severe global warming projections (Carriel y otros, 2023), affecting the carbon sequestration capacity of these species. This is attributable to the evolution of this topic over time, as the direct impact of human activities on climate change, with global repercussions on extreme weather events, is undeniable. Although the Intergovernmental Panel on Climate Change (IPCC) has been active since 1988 in initiatives to mitigate climate change, the results so far have been unsatisfactory. Challenges have been highlighted from the United Nations Framework Convention on Climate Change (UNFCCC) to the Paris Agreement, with the cornerstone of international consensus being the urgency to reduce anthropogenic greenhouse gas (GHG) emissions (Chen & Kong, 2023).

Interactions Between Macrophytes, Greenhouse Gases, and Environmental Factors: Influence of Nutrients and Sediments

It is important to note that Cluster 1 is associated with the influence of macrophytes on greenhouse gas emissions, such as Eichhornia crassipes, Azolla, and others, both submerged and floating. The node "nutrients" is related to the fact that organisms like Eichhornia crassipes tend to concentrate in eutrophic water bodies because there is a large amount of nutrients available in the water. However, aquatic systems with high and excessive levels of nutrients, such as those receiving wastewater or agricultural runoff, can function as critical zones for GHG emissions, regardless of the predominant plant species (Aben y otros, 2022**).** Similarly, this species can exacerbate eutrophication by increasing nutrient loads, reducing available oxygen, and contributing to GHG emissions. Although it captures carbon during its growth phase, its role as a carbon sink is limited and temporary compared to other species due to its high decomposition rate (Ribaudo y otros, 2023).

Additionally, this keyword is also associated with research by Fujibayashi et al. (2020), who analyzed the effects of emergent macrophytes on water quality, organic carbon characteristics in sediments, and GHG emissions in a eutrophic lake, specifically Lake Hachiro in Japan. Their findings suggest that the reintroduction of emergent macrophyte communities in littoral areas could improve water quality. In contrast, Ribaudo et al. (2014) conclude that a shallow lake environment with high biomass of submerged aquatic weeds (Egeria densa) may be subject to hypoxic conditions (low oxygen levels) and nutrient release, which could alter the ecological balance and water quality. Similarly, Theus et al. (2023) mention that the high density of submerged macrophytes, such as Ceratophyllum demersum, increases GHG emissions (CO_2 and CH_4) in shallow freshwater bodies. This is also due to the decomposition of biomass, which enriches the sediment with organic matter and favors anaerobic processes. In this regard, considering the plant physiology of these species, a review by Ali et al. (2019) reveals that emergent macrophytes, especially plants with fine root systems, exhibit highly efficient structures and symbiotic associations, removing nitrogen, phosphorus, and toxic heavy metals (including cadmium, chromium, copper, nickel, lead, vanadium, and zinc) to a greater extent compared to plants with more robust roots.

On the other hand, another keyword in this group is "sediments," as one of the processes influencing GHG emissions is decomposition, which is related to sediments in these natural systems. Dos Santos et al. (2017) describe that methane production in sediments increases when there are decomposing macrophytes with high carbohydrate levels. In contrast, in areas with lower carbohydrate levels, methane generation is lower. Another study analyzes two methane regulators: acetate and sulfate in sediments in two areas of a wetland (limnetic and littoral), concluding that acetate is useful for increasing methane production in areas

with less available carbon, while sulfate serves to reduce methane production, especially in areas already low in sulfate. This is useful for understanding the behavior of aquatic ecosystems in the presence of these compounds, helping to anticipate and manage methane emissions in the context of climate change (Dos santos y otros, 2019). On the other hand, Da Cunha-Santino and Bianchini (2013) argue that sediments are the primary setting where the transformation of organic matter into carbon gases occurs under anaerobic conditions, and their dynamics are modulated by factors such as temperature and the composition of plant remains.

Macrophytes and the Greenhouse Effect: Carbon Sequestration and Its Ambivalent Implications

Cluster 2 focuses on carbon sequestration through the photosynthetic process carried out by macrophytes and its relevance in counteracting the phenomenon of global warming (Nag y otros, 2023; Gremmen y otros., 2023). El crecimiento de las macrófitas emergentes y flotantes se ve favorecido por el incremento de CO2, ya que utilizan este gas como fuente de carbono (Dhir,2015). It has been recorded that floating plants like Azolla, due to their high growth rate, contribute to reducing atmospheric carbon dioxide concentrations, as evidenced in the Eocene (Hamdan & Houri, 2022). Additionally, Attermeyer et al. (2016) demonstrated that global carbon emissions (CO_2 + CH_4) in areas covered by water hyacinths (Eichhornia crassipes), an invasive species, were 57% lower than in water bodies without vegetation. This suggests that an increase in the expansion of water hyacinths and other floating plants could influence GHG emissions, which in turn could affect carbon balances. However, other macrophytes with high invasive potential, such as Salvinia auriculata Aublet, produce CO_2 and, to a lesser extent, methane (CH_4) during decomposition, especially under conditions of rising temperatures (Bianchini & Da Cunha, 2016).

Similarly, Björk et al. (2023) concluded that macrophyte remains in flooded beach environments have a considerable impact on methane emissions, which could increase significantly with rising global temperatures. However, when these remains accumulate away from water, emissions are reduced to almost zero. In fact, some wetlands, due to various factors, contribute significantly to GHG emissions. Evidence of this is explained in the research of Desrosiers et al. (2022), who evaluated CO_2 and CH_4 levels in a lake with emergent macrophytes (Typha latifolia and Brasenia schreberi), finding that these gases are typically higher in vegetated areas compared to those without vegetation. However, the most notable variations between different habitats were observed in CH_4 emissions, where vegetated areas recorded total CH_4 emissions that were one or two orders of magnitude higher than those in non-vegetated littoral and pelagic environments.

Similarly, the node "global warming" is related to the research of Audet et al. (2017), who mention that heat waves increase GHG emissions, especially CO_2, CH_4, and N_2O, due to the acceleration of metabolic processes. However, the author notes that this effect varies: in environments with high nutrient concentrations, the impact on CO_2 is lower, suggesting that nutrients can mitigate the effects of heat. In contrast, in low-nutrient areas, the reduction of macrophytes is associated with an increase in CO_2 emissions, including a reduction in the plant biomass present in the water body.

Constructed Wetlands and the Carbon Cycle

Cluster 3 suggests that the research focus is on the application of constructed wetlands with macrophyte communities as a possible alternative to offset carbon emissions. Some studies have concluded that these structures, which have traditionally been used for water treatment, are effective in reducing GHGs. They also show that these treatments emit fewer GHGs compared to traditional treatments like activated sludge, making floating plant treatments a promising alternative for improving wastewater quality in an environmentally sustainable manner (Casas Ledón y otros, 2017;Hendriks y otros, 2023). In fact, over the past two decades, there has been increased interest in studying the ecological benefit of carbon sequestration provided by these artificial ecosystems (Mander y otros, 2014;Badiou y otros, 2019). This is also corroborated by the most cited document (236 citations) in the database, titled "Greenhouse gas emission in constructed wetlands for wastewater treatment: A review." Another study analyzed the capacity of different floating and submerged macrophytes to remove nutrients from wastewater treatment plant effluents (WWTP), capture CO_2, and reduce GHG emissions (CH_4 and N_2O), concluding that floating macrophytes (Azolla filiculoides and Lemna minor) stood out for their high efficiency in removing nitrogen and phosphorus, as well as

capturing more CO_2 and emitting fewer GHGs, achieving a net absorption of these gases. In contrast, submerged macrophytes (Ceratophyllum demersum and Callitriche platycarpa) showed less growth in the effluents and a more limited contribution to nutrient removal and CO_2 capture (Hendriks y otros,2023).

On the other hand, Hamdan and Houri (2022) concluded in their research that controlled ponds provide environmental and economic benefits, offering a viable alternative for reducing carbon footprints through the cultivation of Azolla. This approach not only contributes to CO_2 sequestration but also has a low environmental impact compared to current industrial practices, while generating biomass that can be used in various industries. Thus, Azolla cultivation presents itself as a sustainable and commercially viable solution for mitigating the effects of climate change and promoting a greener economy.

Macrophytes and Their Behavior in Wetlands

Cluster 4 consists of documents describing the ecosystem service of carbon sequestration, which is part of the carbon cycle as a defense mechanism against climate change. It is evident that wetlands contribute to combating this effect, although this depends on certain environmental conditions (Dhir, 2015; Sheng y otros, 2015; Nag y otros, 2017). One influential factor is water depth, which has significant implications for GHG fluxes (Morin et al., 2022). Despite the above, it is important to clarify that some studies have described wetlands as carbon sources, and this is generally due to spatiotemporal variability in the ecosystem's environmental variables (Li y otros, 2022). That is, depending on the flow dynamics of other GHGs, it is analyzed that while wetlands can act as carbon sinks, they can also act as methane sources (Dos Santos Fonseca y otros, 2017; Oliveira Junior y otros, 2021; Wang y otros., 2023). On the other hand, macrophytes have also been studied in the field of water quality improvement. It has been demonstrated that in wetlands with harmful algal blooms, the flocculation, clogging, and incubation of submerged macrophytes achieve a removal rate of over 98%, also favoring the reduction of methane emissions and carbon production. In contrast, the biomass of submerged macrophytes is formed from inorganic carbon, derived from a fraction of the CO_2 produced in the aquatic environment, and consequently, oxygen is delivered to the sediment-water interface (Ai et al., 2019).

The "climate change" node is initially related to how this global phenomenon is causing more frequent and severe floods in various regions of the planet. Research such as that by Blackburn and Stanley (2020) mentions that during floods, concentrations and fluxes of gases such as carbon dioxide and methane increase, accompanied by changes in factors such as increased turbidity, dissolved organic carbon, reduced dissolved oxygen, and macrophyte cover. The reduction in macrophyte cover is one of the factors that could be linked to increased GHG emissions. On the other hand, Dhir (2015) describes how climate change, through variations in temperature, precipitation, nutrients, and salinity, impacts aquatic vegetation, especially macrophytes and seagrasses. These changes affect their physiology, growth, and reproduction, also influencing other ecosystems. In wetlands, rising temperatures intensify evaporation and reduce productivity. Similarly, Davidson et al. (2015) describe that the increase in temperature due to climate change affects shallow lakes, creating a critical state regarding GHG emissions, significantly contributing to the release of gases such as CO_2 and methane. It has been shown that temperature plays a role in these processes, but the availability of nutrients in the water is even more crucial. It has been observed that when nutrients are scarce and temperatures are high, macrophytes grow more, which is beneficial in reducing the emission of these gases.

Regarding the "carbon cycle" node, it has been shown that macrophytes are essential in wetlands, playing a crucial role in the carbon cycle. While they grow, they capture carbon, and when they die, their organic matter decomposes in the water, releasing gases such as CO_2 and CH_4. Based on this, Borges et al. (2019) describe that the connection of these ecosystems with rivers facilitates the transport of this carbon to the river system, maintaining high levels of these gases in the water. Thus, macrophytes significantly contribute to CO_2 and CH_4 emissions, making wetlands an important source of GHGs in river ecosystems through the decomposition and drainage of organic matter, the direct release of CO_2 into the water, and hydrological exchange that transfers dissolved carbon. Another mechanism by which wetlands tend to emit GHGs such as methane (CH_4) and nitrous oxide (N_2O) is through the presence of nanoparticles in wetlands that affect soil denitrification. However, in soils with macrophytes such as Typha minima, the negative

impact is reduced, as these plants act as buffers, minimizing the inhibition of denitrification and keeping GHG emissions under control (He et al., 2022).

To understand the dynamics and evolution of knowledge in this specific field, the thematic area with the highest number of documents (81 articles) corresponds to **environmental science**. In this category, shows that some of the research focuses on the role of both artificial and natural wetlands in absorbing carbon from the Earth's atmosphere. However, the field of study is much broader, as confirmed by the bibliometric analysis, with research associated with phytoremediation for contaminated waters, such as the study titled "Efficiency of nitrogen, phosphorus, and heavy metal removal associated with swine wastewater using aquatic macrophytes," which proposes the idea that a constructed wetland system designed to directly treat contaminants in livestock wastewater could implement a combination of three aquatic macrophytes, including E. dulcis, T. domengensis, and L. obtusifolium (Chung & Ha, 2023).

Table 2. Systemic Analysis of the Environmental Science Thematic Area

TITLE	AUTHORS	COUNTRY	METHODOLOGY	CONCLUSIONS
An appraisal of carbon capture and sequestration in few selected wetlands of West Bengal	Subir Kumar Nag, Bandana Das Ghosh, U. K. Sarkar & B. K. Das	**INDIA** **One is part of the East Kolkata Wetlands, while the other two wetlands are floodplain lakes: Mathura and Bhomra**	The research in three different wetlands analyzed physicochemical parameters and carbon content in water, sediments, and macrophytes from five sampling points per wetland, comparing carbon accumulation with arable uplands.	The analyzed wetlands showed significantly higher carbon accumulation than the reference uplands, with Bhomra and Mathura storing between 243% and 378% more carbon.
A comparison of water quality and greenhouse gas emissions in constructed wetlands and conventional retention basins with and without submerged macrophyte management for storm water regulation	**Pascal Badiou, Bryan Page, Lisette Ross**	**CANADÁ** City of Winnipeg (Manitoba, Canadá)	The study evaluated CO_2 emissions in 10 stormwater basins (4 untreated and 6 with vegetation removal) and 5 urban wetlands with vegetation over 22 weeks, comparing variations based on treatment and basin type.	The study recorded higher CO_2 emissions in constructed urban wetlands (UCW) and lower emissions in treated stormwater basins (CSRB). After treatment, CO_2 emissions increased in all basins, and GHG fluxes began to differ due to higher CH_4 fluxes in treated CSRB, related to macrophyte removal. UCWs are highlighted as an effective alternative for stormwater management, improving water quality and reducing GHGs.
Life-cycle greenhouse gas emissions assessment and extended exergy accounting of a horizontal-flow constructed wetland for municipal wastewater treatment: A case study in Chile	**Yannay Casas Ledón, Ariel Rivas, Daniela López, Gladys Vidal**	**CHILE**	The study analyzed GHG emissions and resource consumption in a horizontal subsurface flow constructed wetland (HSSF) designed to treat wastewater from 700 people, evaluating the impact of macrophytes Phragmites australis and Schoenoplectus californicus, as well as the influence of seasonality on GHG emissions and environmental remediation costs.	The results highlight that constructed wetlands are an effective environmental engineering option for mitigating climate change and reducing resource consumption in wastewater treatment in Chile. GHG emissions per person from a horizontal subsurface flow constructed wetland (HSSF) are four times lower than those from the traditional activated sludge technique.

CO_2 sequestration by propagation of the fast-growing *Azolla* spp.	Hamdan Z. Hamdan & Ahmad F. Houri	**LÍBANO**	The theoretical study assessed the feasibility of using Azolla to mitigate the annual increase of 18.9 billion tons of CO_2, through a hypothetical design of 1-hectare ponds, calculating the required cultivation area based on its CO_2 absorption capacity.	Each 1-hectare pond can retain 21,266 kg of CO_2 annually. To offset the annual increase in CO_2, 1,018,023 km² of crops would be needed, equivalent to one-fifth of the Amazon rainforest.
Water Hyacinth's Effect on Greenhouse Gas Fluxes: A Field Study in a Wide Variety of Tropical Water Bodies	Ernandes S. Oliveira Junior, Tamara J. H. M. van Bergen, Janne Nauta, Andrea Budiša, Ralf C. H. Aben, Stefan T. J. Weideveld, Célia A. de Souza, Claumir C. Muniz, Jan Roelofs, Leon P. M. Lamers & Sarian Kosten	**BRAZIL**	The study analyzed 22 tropical water systems in the Amazon and Pantanal, measuring physicochemical parameters, CH_4 and CO_2 concentrations, and Global Warming Potential (GWP).	Water hyacinth beds are highly efficient in absorbing GHGs, with an average rate of 7.69 g of CO_2/m^2/day. Their impact on GHG fluxes depends on water depth and biomass density, while open water areas emit CO_2 significantly.

Conclusions

This report presents the findings of a bibliometric analysis encompassing 111 articles on carbon capture by macrophytes in wetlands, published between 2011 and 2023. The evaluation was conducted using tools such as VOSviewer. The results indicated that China, the United States, Canada, and Brazil stood out as the main contributors in this field. Additionally, during the evaluated period, there was a noticeable increase in interest, scientific collaboration, and public engagement in areas related to this topic.

Specifically, academics have played a fundamental role in driving interdisciplinary research on greenhouse gases across various thematic areas. Among these areas, research proposing alternatives to GHG emissions stands out, through a sustainable strategy: biological carbon sequestration by hydrophytic plant species. One of the limitations in conducting the bibliographic analysis was the exclusive use of the Scopus database. For this reason, it would be pertinent to use diverse datasets that may include more related research, such as Google Scholar, Springer, among others. These would allow for an evaluation in other languages, such as Spanish, thereby broadening the scope of associated research.

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