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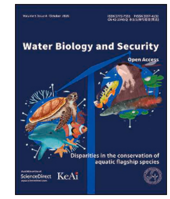

Research Article

Use of aquatic organisms as flagship species in selecting priority areas for conservation

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ABSTRACT

Flagship species are widely used to garner support for conservation, but the selection of these taxa often overlooks ecological, social, and cultural criteria, which may limit the effectiveness of conservation efforts in priority areas. Furthermore, this approach often fails to adequately reflect the importance of ecosystems. A notable example is the undervaluation of aquatic environments, which are frequently neglected or assessed using terrestrial groups whose characteristics and requirements do not necessarily align with the specific demands of these ecosystems. In light of this, we conducted a scientometric analysis to map the scientific literature on the use of aquatic organisms as flagship species for selecting priority conservation areas, highlighting global trends and gaps. A total of 400 articles published between 1997 and 2024 were analyzed from the Scopus and Web of Science databases. The highest number of articles published was in 2021 ($n = 46$; 11.5 %). Australia ($n = 49$) and Brazil ($n = 34$) were the countries most frequently studied. The most frequently researched areas were marine/coastal protected areas (43.75 %) and unprotected natural areas (42.50 %). More than 80 % of the flagship species belonged to the phylum Chordata, with notable representation from Actinopterygii (bony fishes; 43.58 %) and Mammalia (20.18 %). The most commonly used taxon selection criteria were "conservation status" (57.17 %) and "charisma and emblematic value" (15.80 %). Despite the representation of marine ecosystems (58.63 %), freshwater habitats such as rivers (16.78 %), lakes (4.96 %), and streams (4.26 %) remain underrepresented. The most frequently employed research methods and response metrics were "abundance and density" (39.04 %) and "monitoring and observation" (38.32 %). We identified a significant bias favoring marine ecosystems and charismatic taxa, neglecting freshwater habitats and less visible but ecologically important groups. We emphasize the need to diversify conservation strategies by adopting more inclusive approaches that encompass the full range of aquatic biodiversity and habitats, particularly those that are underrepresented. Such diversification is essential for strengthening public policies and practices aimed at protecting critical ecosystems and ensuring global environmental sustainability.

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1. Introduction

The conservation of biodiversity and ecosystem services is one of the most critical challenges of our time, particularly given the intensification of anthropogenic threats to ecosystems worldwide (Pulido-Chadid et al., 2023). One prominent example of the strategies that have been developed to address this challenge is the use of flagship species (charismatic, threatened, or culturally or ecologically significant organisms) to attract attention and resources for the protection of priority areas. This approach has gained global recognition in recent decades (Lecina-Diaz et al., 2019; McGowan et al., 2020). For example, the use of grizzly bears in Yellowstone National Park is an emblematic case (Rehm, 2018). These species not only symbolize the need for conservation but also act as catalysts for direct actions, mobilizing greater public support and funding (McGowan et al., 2020).

Despite the success of this strategy in terrestrial ecosystems, its application in aquatic environments, including both freshwater and marine systems, remains disproportionately limited or underrepresented in the selection of priority areas (Kalinkat et al., 2017; Carrizo et al., 2017). This is particularly concerning given the accelerated degradation of aquatic ecosystems due to pollution, deforestation, overfishing, and the impacts of climate change, which threaten the integrity of water resources and the food webs they sustain (Azevedo-Santos et al., 2019; Nabout et al., 2023; Sousa et al., 2024). These ecosystems play critical roles, including regulating water quality, cycling nutrients, sequestering carbon, facilitating trophic flows between aquatic and terrestrial ecosystems, and supporting global biodiversity, underscoring the urgent need for more inclusive and representative conservation strategies (Cole et al., 2007; Lecina-Diaz et al., 2019; Valentim et al., 2024; Sayer et al., 2025).

Although the international community has established formal commitments under the Convention on Biological Diversity to prevent extinctions, many aquatic targets set for 2020 remain unmet (Mitrotta, 2020). This includes *Aichi* Targets 6 (sustainability of fisheries), 11 (protection of species at risk of extinction), and 14 (conservation of aquatic ecosystems) (Pollom et al., 2024). The Sustainable Development Goals (SDGs) play a central role in the global conservation agenda; however, most environmental targets focus on marine ecosystems, particularly in SDG 14, “Life Below Water” (Tickner et al., 2020). Although SDG 15, “Life on Land”, includes targets for the protection of freshwater ecosystems (Ishtiaque et al., 2020), these habitats, which host extraordinary biodiversity, provide essential ecosystem services (Sayer et al., 2025), and serve as a means of livelihood for millions of people, still receive insufficient attention (Momblanch et al., 2022; Lynch et al., 2023). While marine ecosystems are much larger in area, freshwater systems support more than 10 % of all known species, including approximately one-third of vertebrates and half of all fishes, despite occupying less than 1 % of the Earth's surface (Strayer and Dudgeon, 2010). Notably, about 24 % of freshwater animal species are threatened with extinction (Sayer et al., 2025).

According to the most recent report by the United Nations Educational, Scientific and Cultural Organization (United Nations EducationalScientific and Cultural Organization, 2024), approximately 70 % of the potable water extracted from freshwater systems such as rivers, lakes, and streams is used in agriculture, about 20 % goes to industry, and around 12 % is used for domestic purposes. Freshwater ecosystems are the most vulnerable due to their direct dependence on the surrounding landscape, which is often altered by human activities either through direct changes in water bodies, such as dam construction, or changes in the adjacent terrestrial ecosystems (Da Silva et al., 2024a; Chícharo et al., 2006). These changes result in the reduction of riparian vegetation that protects watercourses, increased pollutant inflow, and a decrease in both the flow and quantity of water available in their channels (Da Silva et al., 2024a), significantly undermining the potential for achieving holistic and effective conservation of aquatic ecosystems (Tickner et al., 2020; Momblanch et al., 2022). Consequently, the risk of losing species and ecosystem functions provided by these environments and organisms increases as anthropogenic pressures intensify (Azevedo-Santos et al., 2021), making freshwater ecosystems the most threatened on Earth (Abell et al., 2008).

Some aquatic species have been widely used as flagships in conservation programs due to their visual appeal and popularity. Notable examples include sea turtles, which draw global attention to the preservation of marine ecosystems (Carrizo et al., 2017), manatees, a conservation symbol for coastal and estuarine areas (Kalinkat et al., 2017), European otters, which promote the protection of rivers and wetlands in Europe (Stahl et al., 2020), and the freshwater pearl mussel, which highlights the importance of conserving clean, free-flowing freshwater ecosystems (Geist et al., 2023).

In South America, the hawksbill turtle (*Eretmochelys imbricata*), grey and pink dolphins (*Sotalia fluviatilis* and *Inia geoffrensis,* respectively), and fishes such as the goliath grouper (*Epinephelus itajara*) are iconic species symbolizing conservation efforts (Reis et al., 2016; Hayes et al., 2016; Da Silva et al., 2023). In Brazil, the ICMBio Monitora Program (*Instituto Chico Mendes de Conservação da Biodiversidade*) includes aquatic insects like dragonflies (Odonata) to assess the quality of Amazonian streams and enhance the sustainable management of conservation areas through in situ conservation strategies, such as community-based ecotourism using Odonata as key organisms (Oliveira-Junior et al., 2022; Da Silva et al., 2024a; Guerrero-Moreno et al., 2024). These initiatives demonstrate the potential of aquatic flagship species to mobilize public interest, but much remains to be done to expand their impact and benefit local populations.

Expanding the use of aquatic organisms as flagship species can play a decisive role in mobilizing public support and funding directed towards the conservation of these critical ecosystems (Verissimo et al., 2011; Sousa et al., 2024). Including a greater diversity of flagship species can not only diversify conservation strategies but also facilitate the achievement of global goals, such as the United Nations Sustainable Development Goals and *Aichi* Targets, which emphasize the importance of preserving biodiversity and aquatic ecosystems (Stahl et al., 2020; Nabout et al., 2023).

Organizing and analyzing existing studies on flagship species in aquatic ecosystems is essential to identify patterns and gaps that can aid in promoting conservation and mobilizing collective support (Li et al., 2024). This type of analysis can also uncover characteristics that make particular species more effective as flagships and highlight underrepresented ecosystems, thereby guiding conservation efforts more strategically (Guerrero-Moreno and Oliveira-Junior, 2024a, 2024b). This study addresses this gap through a scientometric approach, compiling and consolidating knowledge about the use of aquatic organisms as flagship species in selecting priority areas for conservation. This approach provides a comprehensive perspective, identifying successful cases and challenges in the implementation of strategies on a global scale (Oliveira-Junior et al., 2022; Guerrero-Moreno and Oliveira-Junior, 2024a).

We conducted a scientometric analysis to map the scientific literature and explore the use of aquatic organisms as flagship species in the selection of priority areas for conservation, including studies that mention species with flagship characteristics even if these have not been directly used in the selection process, highlighting trends and gaps in the research. To achieve this, we addressed seven questions: (i) what is the temporal distribution of scientific publications? (ii) what is the geographic distribution of the studied areas? (iii) what are the protection levels of the studied areas? (iv) which taxonomic levels are most commonly used and what is the conservation status of the most cited species? (v) what are the described characteristics of the species cited as flagships? (vi) what types of aquatic ecosystems do these species inhabit? and (vii) what methods are used in the studies? This type of analysis will provide essential information to clarify the research context and will serve as a foundation for directing future conservation efforts toward the areas that need it the most.

2. Materials and methods

2.1. Search and selection process

To explore the use of aquatic organisms as flagship species in selecting priority areas for conservation, we conducted a comprehensive literature review of scientific articles published in two primary databases: Scopus (Elsevier) and Web of Science (WoS) (Clarivate Analytics). These databases were selected due to Scopus' broad coverage of indexed journals and the area-specific specialization offered by WoS (Guerrero-Moreno and Oliveira-Junior, 2024b). This combination ensures a comprehensive representation of the scientific literature across multiple disciplines (Zhu and Liu, 2020). Keywords were selected based on synonyms found in the literature for aquatic organisms, flagship species, and priority areas. The search strategy adopted in both databases was: (flagship species OR iconic species OR symbolic species OR representative species OR charismatic species OR conservation symbol species OR emblematic species) AND (aquatic OR freshwater OR marine) AND (conservation priorities OR conservation areas OR conservation units).

2.2. Inclusion and exclusion criteria

During the search, reviews, conference proceedings, and book chapters were excluded, limiting the search exclusively to peer-reviewed scientific articles, as they represent the most reliable source for literature reviews (De Oliveira et al., 2019). During the initial, non-restricted document search, the oldest scientific article on the topic identified was published in 1997. Based on this finding, we defined the temporal scope of the study from 1997 to 2024. This timeframe ensures the inclusion of all relevant literature, starting with the first published article found on the topic. The search was conducted on November 19, 2024, to encompass the most significant number of possible articles.

We did not restrict the search to a specific domain area, as this is a multidisciplinary topic. This allowed us to obtain a larger volume of records, ensuring global representation. We did not include a linguistic criterion. Although there is ongoing debate regarding the impact of a linguistic criterion in scientometric analysis, we chose to include publications regardless of the language, as this allows for a more comprehensive identification and synthesis of relevant evidence, considering that publications in different languages may offer unique contexts and perspectives (Walpole, 2019). Taking this perspective into account, our study includes 16 publications in languages other than English (7 in Spanish, 5 in Chinese, 2 in French, 1 in Portuguese, and 1 in Russian). We utilized English translation support to extract information from these articles.

2.3. Data integration and cleaning

The searches in the Scopus and WoS databases resulted in 763 and 509 articles, respectively, which were downloaded in CSV format for consolidation. We used RStudio (version 4.3.1) to merge the data and automatically remove duplicates, obtaining a final database of 768 documents. RStudio was chosen for its robustness in statistical analyses, its ability to merge databases, its practical statistical algorithms, and its provision of strong bibliometric analyses (Aria and Cuccurullo, 2017). The initial search across two distinct databases ensured a comprehensive coverage, thereby mitigating the risk of omitting relevant data. The subsequent merging process in RStudio was carefully executed to standardize entries and minimize merging errors. We manually reviewed the articles to eliminate remaining duplicates, as variations in references may be undetectable by the software (Guerrero-Moreno and Oliveira-Junior, 2024b). Our final file was used to analyze the title, abstract, keywords, and materials and methods to identify studies that could answer our seven questions. Only articles related to the theme were included. After this rigorous process, we had 400 articles left for detailed analysis (Fig. 1).

We then classified the information contained in the articles by protection levels of study areas, the characteristics of the species cited as flagships and methods used, each described below.

- Protection levels of the study areas: (a) reserves: including studies in any type of reserve, such as biological reserves, extractive reserves, or sustainable development reserves; (b) national parks: articles on national parks typically follow a more restrictive protection model; (c) marine/coastal protected areas: studies explicitly conducted in protected areas located in marine or coastal zones, including marine reserves, coastal conservation units, or multiple-use marine protected areas; (d) sanctuaries: includes wildlife sanctuaries or protected areas established to safeguard specific species or critical habitats; (e) private protected areas: includes studies exploring protected areas managed by private actors, such as individual landowners, foundations, or companies; and (f) unprotected natural areas: refers to studies conducted in natural environments that do not have any formal protection or conservation status.
- Characteristics of species cited as flagship species: (a) conservation status: articles that highlight the conservation status of a species, focusing on factors indicating species decline, such as extinction risk, vulnerability, population decrease, or global assessment criteria, primarily based on the IUCN (International Union for Conservation of Nature) Red List of Threatened Species; (b) ecology and function: documents discussing the ecological and functional roles of species

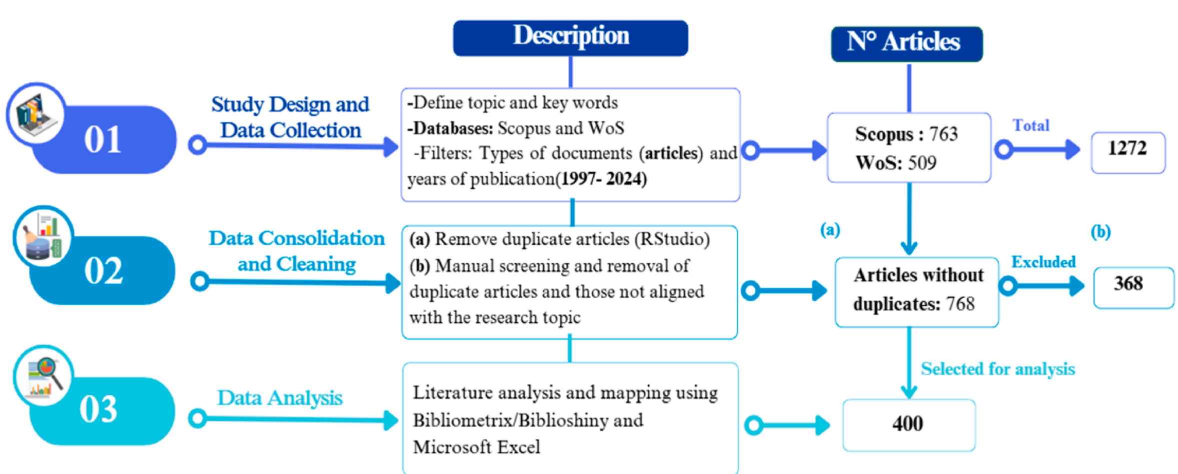

Fig. 1. General illustration of the methodology used to search, consolidate, clean, and analyze data from articles on the use of aquatic organisms as flagship species in the selection of priority areas for conservation conducted on November 19, 2024. Databases used: Scopus and Web of Science.

in ecosystems, including keystone species, ecosystem engineers, or those providing essential ecosystem services, such as maintaining biodiversity, trophic balance, or habitat regeneration; (c) charisma and emblematic value: studies emphasizing the charismatic or emblematic characteristics of species that attract public attention or have cultural and symbolic relevance; (d) economic and cultural value: research examining the economic and cultural significance of aquatic organisms, including those utilized in rituals, sacred species, species involved in tourism activities, and commercially exploited species; (e) endemism and uniqueness: studies focused on species with a restricted geographic distribution or unique characteristics that render them ecologically or genetically important; (f) bioindicators and monitoring: studies that use species as bioindicators of environmental health, or to monitor habitat changes, water quality, or climate impacts, including sentinel species important for conservation and environmental management efforts; (g) anthropogenic impacts: articles addressing the impacts of human activities, such as overexploitation, climate change, anthropogenic pressure, or environmental degradation, on flagship species and their habitats; this category focuses on the documented consequences of human actions on species viability and ecosystem integrity, rather than the quantitative assessment of populations, and includes issues related to species vulnerability due to human actions; and (h) representative species: studies highlighting species as representative of larger groups or as substitutes in biodiversity studies, including umbrella species, conservation target species, and those considered models for ecosystem analysis.

- Study methods: (a) abundance and density: articles that assess variation in abundance and density of organisms, including population estimates and species presence–absence data; (b) distribution and richness: studies that focused on analyzing the spatial distribution or species richness in different geographical areas, including approaches such as identifying Key Biodiversity Areas and analyzing geographic occurrence patterns; (c) genetics and phylogeny: this also includes the identification of genetic diversity, DNA studies, or evolutionary analyses; (d) modelling: using statistical and predictive modelling techniques to understand ecological patterns or predict future environmental impacts; (e) monitoring and observation: documents that involve direct observation, population monitoring, or environmental data collection, including techniques such as remote sensing data collection, field sampling, or continuous monitoring for environmental assessment; (f) chemistry and pollutants: analyzing chemical and physical parameters of the environment, including the measurement of pollutants and chemical compounds that affect environmental quality and ecosystem health; (g) review and database analysis: articles that analyze scientific literature and existing databases; and (h) ethnographic methods: employing qualitative and participatory research approaches, including interviews and participant observation, to capture local ecological knowledge, cultural values, or social perceptions related to aquatic species and ecosystems; unlike categories focused on ecological or chemical assessments, ethnographic methods emphasize human dimensions of conservation, such as traditional practices, beliefs, and community-based management.

2.4. Data analysis

To analyze the temporal distribution of research, we used a Pearson's correlation coefficient (r) to assess the association between the variables 'year' and 'number of articles.' The value of r ranges from −1 (strong negative correlation) to 1 (strong positive correlation). In order to identify geographic scientific production patterns, we created a choropleth map that shows the 10 most studied countries in blue, with red outlined circles indicating the number of articles on the topic. The remaining results were represented through histograms and frequency graphs. For all analysis, we used RStudio software and the Bibliometrix/Biblioshiny packages (version 4.1.4).

3. Results and discussion

3.1. Temporal distribution of scientific publications

There has been an increase in the number of articles focusing on the use of aquatic organisms as flagship species in selecting priority areas for conservation in recent years. This was evidenced by a strong positive correlation between the years and the number of publications (r = 0.920, 95 % confidence interval = 0.837–0.960, $p < 0.001$), indicating a consistent increase in the number of publications over the years. The 95 % confidence interval for the correlation coefficient was calculated as [0.837, 0.960], confirming the robustness of the observed correlation (Fig. 2/Table S1).

The analysis of the temporal distribution of scientific publications using aquatic organisms as flagship species reveals three distinct phases. Initially, between 1997 and 2006, scientific production was limited, with annual output represented by few or no articles published. This period reflects the early stage of applying the flagship species concept to aquatic ecosystems, alongside a predominant focus on the conservation of terrestrial ecosystems (Kalinkat et al., 2017; Carrizo et al., 2017; Jarić et al., 2020). Methodological challenges may have also contributed to the low production, as tools like Geographic Information Systems (GIS) and advanced modelling techniques were not widely available for free (Turner, 2003; Costa et al., 2010), nor were they commonly applied to aquatic ecosystems. It is important to note that the concept of flagship species was introduced in the 1980s by Mittermeier (1986), emphasizing charismatic species as practical tools for promoting conservation, focusing on terrestrial ecosystems.

Between 2007 and 2016, there was a gradual increase in scientific production, culminating in 22 studies published in 2015 and 2016. This rise coincided with a period of advances in global conservation policies, including the implementation of the Convention on Biological Diversity and the initiation of discussions related to the Sustainable Development Goals (Mitrotta, 2020; Tickner et al., 2020). Simultaneously, growing concern over the degradation of aquatic habitats caused by deforestation, pollution, and climate change began to attract the attention of the scientific community (Reid et al., 2019; Kumar et al., 2022). In this context, aquatic organisms, such as macrophytes (Lukman et al., 2023), dragonflies (Da Silva et al., 2024a; Guerrero-Moreno et al., 2024), fishes (Peiffer et al., 2024), and bivalves (Tan et al., 2022), began to be recognized not only as indicators of environmental quality but also as charismatic species, with the potential to engage the public, mobilize resources for conservation, and simultaneously generate income for local populations. In some cases, flagship species have also driven the creation of multiple captive breeding stations, as seen in freshwater pearl mussel conservation efforts (Geist et al., 2023).

Starting in 2015, a phase of sharp growth began, peaking at 46 publications in 2021. This increase can be attributed to the consolidation of the Sustainable Development Goals (SDGs), especially SDG 14, which emphasizes the conservation of life below water (Tickner et al., 2020). Events such as the United Nations Decade on Biodiversity (2011–2020) and preparations for the Decade of Ocean Science for Sustainable Development (2021–2030) also stimulated research focused on aquatic ecosystems (Ferrier, 2020; Waltham et al., 2020; Zhao, 2021). During this period, technological advances, such as the use of environmental DNA (eDNA) and ecological niche modelling, facilitated more detailed and accessible analyses, promoting global scientific collaborations (Elith and Leathwick, 2009; Taberlet et al., 2012). Additionally, the 13th Conference of the Parties (COP13) of the Convention on Biological Diversity, held in Cancun (Mexico) in December 2016, saw significant participation from various sectors and an increase in public attention on biodiversity, with approximately 10,000 participants including representatives from member countries, observer countries, international organizations, and other stakeholders (Gobierno de

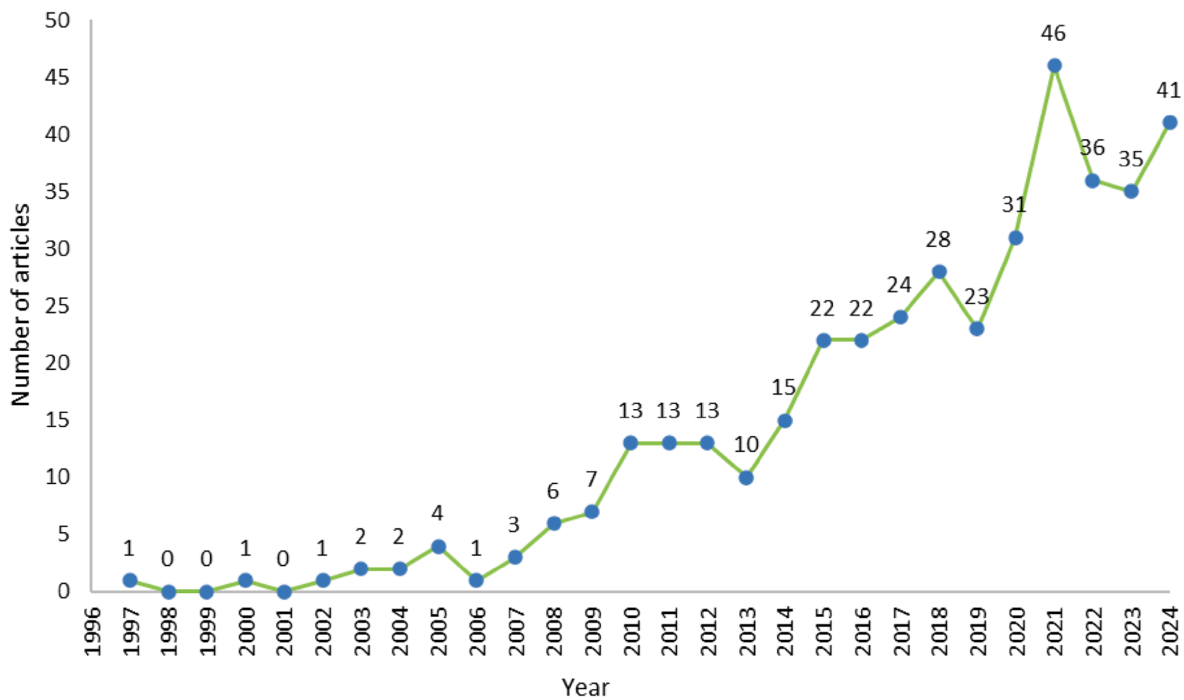

Fig. 2. Annual scientific production on the use of aquatic organisms as flagship species in the selection of priority areas for conservation. Databases used: Scopus and Web of Science.

México, 2016).

The year 2021 marks a milestone with the highest number of publications. This peak can be attributed to a combination of factors, including increased global discussions on climate change driven by COP26 (Martin et al., 2021; Wang et al., 2022). One potential consequence of these discussions is a growing awareness of the vulnerability of aquatic ecosystems such as coral reefs, wetlands, and polar regions, which are among the most immediately and visibly affected by climate change (Hoegh-Guldberg et al., 2017; He et al., 2024; Klein et al., 2024). As a result, conservation agendas and public campaigns increasingly began to include iconic marine and freshwater aquatic species, linking biodiversity loss to broader climate change narratives (Kalinkat et al., 2017; Jarić et al., 2025). Additionally, 2021 marks the beginning of more concrete debates on the Global Biodiversity Framework, which culminated in 2022 with the Kunming–Montreal agreement. This agreement aimed to catalyze, facilitate, and accelerate urgent and transformative actions by governments, along with the participation of society as a whole, to halt and reverse biodiversity loss (Joly, 2022).

Although there is a slight reduction in the number of publications after 2021, likely due to the impact of the COVID-19 pandemic (Da Silva et al., 2024b), many researchers focused their efforts on analyzing existing data and completing projects that were previously shelved during this time (Aviv-Reuven and Rosenfeld, 2021; Pires et al., 2021). This likely contributed to the scientific output remaining higher compared to previous periods. This stabilization could reflect a reorganization of research priorities or economic challenges faced by global science in the post-pandemic period (Riccaboni and Verginer, 2022). Nonetheless, the continued high production underscores the growing interest in utilizing aquatic organisms as flagship species, thereby solidifying their scientific and strategic relevance (Kalinkat et al., 2017).

3.2. Geographical distribution of the areas studied

We found studies that focused on the use of aquatic organisms as flagship species in the selection of priority areas for conservation across different countries and regions (Table S2). Among them, Australia ($n=49$) had the highest number of studies, followed by Brazil ($n=34$) and the USA ($n=33$) (Table 1/Table S2).

This prominence of Australia can be attributed to a combination of ecological, scientific, and political factors which position the country as a global leader in environmental research and conservation practices. Australia's aquatic biodiversity is widely recognized, exemplified by the Great Barrier Reef, the largest coral reef system in the world and a UNESCO World Heritage site (Richards and Day, 2018). Moreover, its freshwater and coastal ecosystems host a high proportion of endemic species, many of which are increasingly threatened due to climate change, human activities, and the introduction of invasive species (Kingsford et al., 2017).

Another essential aspect to highlight is the role of Australian Indigenous peoples in environmental conservation. These ethnic groups, including those from the Torres Strait Islands, have managed their lands for tens of thousands of years through traditional practices that integrate the stewardship of values, resources, histories, and cultural practices related to their territories (Larson et al., 2019; Loomis, 2000). Recognizing this contribution, the Australian Federal Government developed several funding programs, such as the Indigenous Land and Sea Management Programs (Hill et al., 2012). A notable example is the Yawuru Nagulagun Marine Park, located in the northwest of Western Australia, a unique and biodiverse habitat that is also valued for its cultural

Table 1
The 10 most studied countries concerning the use of aquatic organisms as flagship species in the selection of priority areas for conservation. Databases used: Scopus and Web of Science.

Countries	Number of articles
Australia	49
Brazil	34
USA	33
China	30
Spain	28
France	23
Italy	19
Mexico	19
South Africa	18
United Kingdom	17

importance, which is co-managed by the Yawuru Indigenous people and the Department of Biodiversity, Conservation and Attractions (D'Cruz et al., 2022).

Australia's prominence is also attributed to the central role of its public policies and the established research infrastructure for conservation (Fitzsimons et al., 2024a). Initiatives like the Reef 2050 Plan demonstrate the government's commitment to protecting its marine ecosystems (Commonwealth of Australia, 2015), while institutions such as James Cook University lead studies integrating conservation and sustainable management (Macgregor, 2015). Furthermore, Australia's ability to attract international scientific collaborations enhances the relevance and impact of its academic output (Da Silva et al., 2024b). While these factors legitimately position Australia as a global leader in conservation, the concentration of studies conducted in that country also highlights the geographic disparities that exist in the scientific literature. These inequalities are deeply rooted in structural inequities such as unequal access to research funding, limited visibility in academic publications, and limited participation in global scientific networks, which restrict the representation of other megadiverse regions such as Southeast Asia, South America, and Africa (Adhiambo et al., 2023).

Brazil was the second most researched country, reflecting its unparalleled aquatic biodiversity, the socioeconomic relevance of its ecosystems, and its growing role in scientific production focused on conservation (Da Silva et al., 2024b; Guerrero-Moreno et al., 2024). The country is home to the largest and most preserved tropical rainforest on the planet, the Amazon (Levis et al., 2024), and the largest river basin in the world around the Amazon River (Nian et al., 2024), along with other globally significant aquatic systems such as the Pantanal (Penatti et al., 2015) and coastal mangroves (Aragón and Clüsener-Godt, 2024). These ecosystems sustain a high diversity of species, many of which are endemic, and play a crucial role in ecological, economic, and cultural balance (Jézéquel et al., 2020; Junk et al., 2014).

Some Brazilian aquatic organisms, such as the Amazon river dolphin [*Inia geoffrensis* (Blainville, 1817)] and the arapaima [*Arapaima gigas* (Schinz, 1822)], stand out as potential flagship species, not only because of their ecological uniqueness but also due to their popular appeal, which can help raise environmental awareness (Nogueira et al., 2020; Silva et al., 2023). Furthermore, Brazil's aquatic ecosystems are crucial for the livelihoods of local communities, providing resources such as food, water, and support for economic activities, including fishing and sustainable tourism (Da Silva et al., 2024a, 2024b; Guerrero-Moreno et al., 2024). However, these ecosystems face significant pressures due to deforestation, dam construction, illegal mining, agriculture, livestock farming, overfishing, pollution, and climate change, which have severely impacted on health of aquatic systems (Latrubesse et al., 2017).

Despite these challenges, Brazil has implemented important conservation initiatives, such as the National Action Plan for Threatened Species (Silva et al., 2023), and regulatory milestones, such as the Biodiversity Law (Law No. 13,123/2015), which aim to protect the country's natural wealth (Brazil, 2015). However, obstacles such as instability in research funding, changes in governmental priorities, and the fragmentation between science and public policies limit the effective implementation of these initiatives (Ferreira et al., 2014; Da Silva et al., 2024b; Guerrero-Moreno and Oliveira-Junior, 2024a) and may even lead to the discontinuation of established and successful programs.

Although Brazil has a high level of academic production, certain regions within the country remain underexplored, representing significant gaps in aquatic conservation efforts (Junk et al., 2014). A comparison with Australia reveals notable differences: while Brazil has more biodiversity, it faces structural and economic challenges that hinder the integration of science and practice, whereas Australia benefits from more consolidated conservation policies and a robust research infrastructure (Fitzsimons et al., 2024a).

The United States had the third highest number of articles, a ranking attributed to its advanced research infrastructure and well-established conservation policies (Börk, 2024; Da Silva et al., 2024b). Additionally, recent efforts to increase scientific funding (Kreier, 2022) may further strengthen this position. The increase in financial support aims not only to enhance technological competitiveness but also to advance strategic areas, such as environmental conservation (Tollefson and Van Noorden, 2024). With a highly developed research infrastructure, the United States has the capacity to develop advanced technologies for monitoring and protecting aquatic ecosystems, enabling more effective conservation policies (Guerrero-Moreno and Oliveira-Junior, 2024a, 2024b). These investments also demonstrate a commitment to balancing environmental sustainability with global competitiveness, consolidating biodiversity as a strategic priority in its scientific and technological agenda (Kreier, 2022). However, it is important to highlight that, although these three countries account for the highest number of studies, the total number of studies conducted, both in these countries and elsewhere, is still low when compared to the vast biodiversity potential they harbor and the global relevance of the issue. However, it is important to acknowledge that during the Trump administration, federal science and environmental policies were significantly weakened, often reducing funding and support for conservation research, demonstrating that robust infrastructure alone does not guarantee continuity or effectiveness in conservation efforts (Devictor, 2025; Desikan et al., 2023; Webb and Kurtz, 2022). These fluctuations underscore the importance of long-term political commitment to maintain the effectiveness of conservation strategies over time.

3.3. Protection levels of the study areas

There was a predominance of studies in marine/coastal protected areas (43.75 %) and unprotected natural areas (42.50 %), while types of areas traditionally associated with formal conservation, such as reserves (6.50 %), national parks (4.75 %), sanctuaries (1.75 %), and private protected areas (0.75 %), present significantly lower values (Fig. 3).

This pattern reflects a concentration of efforts in marine and coastal environments, possibly driven by their high visibility and economic importance, especially for sectors such as tourism and fisheries (Gössling et al., 2018; Lachs and Oñate-Casado, 2020; Treviño et al., 2022). However, this approach often neglects the protection of freshwater ecosystems, which are also fundamental to environmental sustainability and human well-being.

On the other hand, the high representation of unprotected natural areas suggests a growing concern for these vulnerable ecosystems, which are often more exposed to anthropogenic pressures such as deforestation, pollution, and urbanization (van Genuchten, 2024). Such studies are essential for identifying priority areas for conservation and justifying the implementation of new protected areas (Zhang and Li, 2022). However, a reliance on studies in unprotected areas also highlights significant gaps in environmental policies and aquatic ecosystem management, particularly in countries with limited scientific infrastructure or regulatory frameworks (Schiemer et al., 2024). Additionally, recent studies highlight that type localities, which serve as the original reference sites for species descriptions, are often overlooked in the designation of protected areas, despite their importance for biodiversity conservation (Azevedo-Santos and Ottoni, 2025). The low frequency of studies in reserves, national parks, and sanctuaries suggests an underutilization of these locations as research targets (Giehl et al., 2017; Martínez-Vega and Rodríguez-Rodríguez, 2022). This underrepresentation may be related to logistical constraints, such as limited funding opportunities, restricted transportation infrastructure, or bureaucratic challenges that hinder research implementation in certain regions (Fowler, 2002; Hoffmann, 2022). It may also reflect a geographic bias in scientific sampling and publication trends, which tend to favor more visible, accessible, or institutionally supported areas (Stegmann et al., 2024). This pattern is concerning, as protected areas are known to play a critical role in conserving threatened species and maintaining ecosystem services (Ma et al., 2024). The comparison with unprotected areas

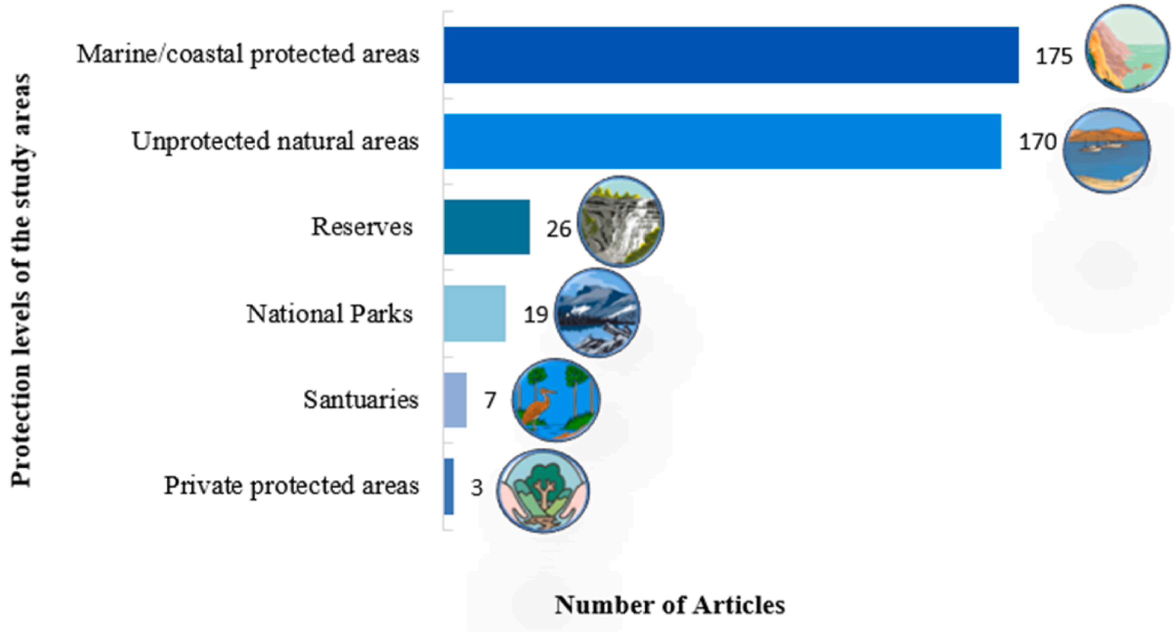

Fig. 3. Protection levels of the study areas cited in publications on the use of aquatic organisms as flagship species in the selection of priority areas for conservation. Databases used: Scopus and Web of Science.

highlights the need to assess the effectiveness of existing conservation areas should be assessed and public policies strengthened that encourage research in these regions (Sousa et al., 2024), as well as expanding these areas when necessary.

Finally, the extremely low representation of private protected areas (0.75 %) highlights that they face additional challenges. Although these areas have the potential to complement public conservation networks, especially in high biodiversity regions with significant land use, they face barriers such as lack of formal recognition, restricted access, and absence of economic incentives for their maintenance and study (Hoffmann, 2022; Hansen et al., 2024), which often discourages landowners from preserving these areas. This highlights the pressing need for targeted policies that value and integrate these areas into global conservation planning (Carter et al., 2008).

3.4. *Most studied aquatic organisms*

We found that most studies focused on the phylum Chordata, representing more than 70 % of the taxa (Fig. 4). This contrasted with the lower frequency of studies involving phyla such as Arthropoda (8.42 %) and Cnidaria and Mollusca (5.55 %).

This trend reflects a well-documented taxonomic bias in the

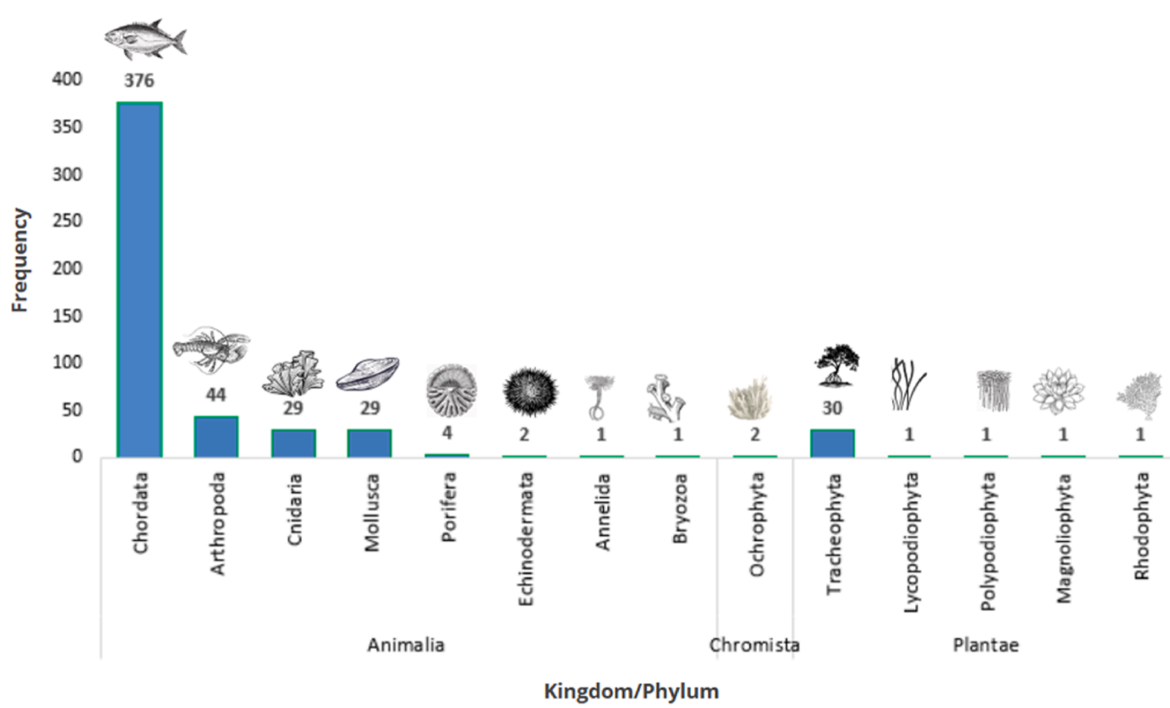

Fig. 4. The kingdoms and phyla used as aquatic flagship species. Several of the studies mentioned more than one taxon. Databases used: Scopus and Web of Science.

literature that favors charismatic vertebrates in conservation research (Gerlach et al., 2014). This preference can be attributed to factors such as phylogenetic proximity to humans, visibility, charisma, and the emotional appeal of these species, which facilitate public engagement and the mobilization of financial resources (Polgar and Jaafar, 2018; McGowan et al., 2020; Miralles et al., 2019). For instance, mammals like cetaceans and iconic birds like the wandering albatross (*Diomedea exulans*) are often chosen as conservation symbols, whereas less visible groups, including invertebrates and plants, remain underrepresented (Gerlach et al., 2014). Previous studies on terrestrial and general flagship species have similarly reported taxonomic biases, particularly favoring mammals and birds due to their visual appeal and public engagement potential (McGowan et al., 2020; Lundberg and Arponen, 2022). This practice presents significant limitations in representing patterns of species richness and threats to other taxa, as the distributions and challenges faced by well-studied taxonomic groups rarely align with those of less visible yet equally critical groups, like invertebrates (Donaldson et al., 2017; Wosnick et al., 2021). Despite their ecological importance, there is a lack of studies and public awareness regarding invertebrates with high levels of endemism and habitat specificity (De León et al., 2020; Perera et al., 2021), compounded by the misconception that their abundance negates the need for conservation efforts (Horwitz et al., 1999). Additionally, the general lack of understanding about the importance of invertebrates and their ecosystem services, which are essential for biodiversity conservation and functioning, exacerbates this issue. This bias in the selection of target groups can lead to conservation gaps, leaving critical areas for global biodiversity neglected (Rodrigues et al., 2005; Guerrero-Moreno and Oliveira-Junior, 2024b; Barouillet et al., 2024).

In the context of aquatic ecosystems, many organisms perform essential ecological functions and have the potential to serve as flagship species for conservation but are often overlooked due to their lower visibility and public appeal (Kalinkat et al., 2017). Aquatic insects from the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), as well as Odonata, are widely recognized as effective bioindicators of water quality, reflecting the health of aquatic ecosystems (Tubić et al., 2024; Oliveira-Junior and Juen, 2019). Recent studies highlight that the presence and abundance of EPT are positively correlated with environmental quality, making them ideal candidates to represent the need for aquatic habitat conservation (El Yaagoubi et al., 2024). However, their potential as flagship species for developing in situ conservation initiatives, such as entomotourism, remains underutilized (Guerrero-Moreno and Oliveira-Junior, 2024b). Similarly, aquatic macrophytes provide habitat, food, and refuge for various aquatic species while contributing to ecological stability and nutrient cycling (Thomaz, 2023). They are bioindicators due to their sensitivity to environmental changes, such as pollution and shifts in water quality, reflecting ecosystem conditions. Utilizing them as flagship species could enable the monitoring of anthropogenic impacts and support conservation strategies for freshwater aquatic biota as a whole. This potential is strengthened when aligned with integrative frameworks that promote knowledge co-production, ecosystem connectivity, and supportive policies and funding mechanisms (van Rees et al., 2025; Nagel et al., 2025).

When analyzing the distribution of classes within the phylum Chordata (Fig. 5), we found that Actinopterygii (bony fishes) were the most represented, accounting for 43.58 % of studies, followed by the classes Mammalia (20.18 %), Aves (14.22 %), and Chondrichthyes (cartilaginous fishes; 10.09 %).

The predominance of bony fishes can be attributed to their economic, ecological, and cultural significance, especially in marine ecosystems, where they play key roles as food sources, ecological indicators, and symbols of sustainability (Bak et al., 2023). Fish species such as the bonefish (*Albula vulpes* (Linnaeus, 1758)) hold ecological, economic, cultural, and charismatic value, being an integral part of the local diet and a source of income for populations living in the so-called Family Islands, excluding the urban centers of Nassau (New Providence) and Freeport (Grand Bahama, as well as important components of the coastal trophic system (Adams et al., 2021).

On the other hand, the classes Mammalia and Chondrichthyes, which include species such as cetaceans, sharks, and rays, highlight the central role of charismatic species in conservation (Mazzoldi et al., 2019; Hani, 2020; Li et al., 2024). These organisms, exemplified mainly by species such as bottlenose dolphins (*Tursiops truncatus* (Montagu, 1821)), Eurasian otters (*Lutra lutra* (Linnaeus, 1758)), whale sharks (*Rhincodon typus* (Smith, 1828)), and reef manta rays (*Mobula alfredi* (Krefft, 1868)), have been extensively mentioned in the scientific literature due to their charisma, wide global distribution, ecological importance, IUCN status (Table 2). These species serve as effective flagships, drawing attention to the protection of threatened marine habitats and other critical issues, such as plastic pollution, overfishing, vessel traffic, and noise pollution (Hart et al., 2013; Erbe et al., 2019; Godley et al., 2020). For a comprehensive list of species mentioned as flagships in the reviewed articles, please refer to Table S3.

Previous studies indicated that species with a concerning conservation status, such as Vulnerable (VU) or Endangered (EN), are more likely to be chosen as flagships (Home et al., 2009; Smith et al., 2012). In this context, marine turtles and cetaceans exemplify how threatened and charismatic species can serve as catalysts for the conservation of broader marine ecosystems (Polgar and Jaafar, 2018). However, within the top 20 flagship species used in the selection of priority areas, it is evident that a majority of these species have a low-risk conservation status or are classified as Least Concern (LC). This highlights that the choice of flagship species is not always driven solely by conservation status but also by other factors such as endemism, ecological role, and spiritual, aesthetic, or cultural value (Qian et al., 2020), which will be further discussed in Section 3.5.

Another important observation was the underrepresentation of other taxonomic groups, such as Cnidaria, Mollusca, Tracheophyta, and Rhodophyta. Despite their crucial roles in maintaining aquatic ecosystems, these groups received less visibility in conservation strategies. For instance, aquatic plants such as seagrasses (*Posidonia oceanica* (Linnaeus) Delile, 1813 and *Zostera marina* Linnaeus, 1753) and the grey mangrove (*Avicennia marina* (Forsskål) Vierh., 1906) perform essential ecological functions, including sediment stabilization and carbon sequestration, yet remain underutilized as flagship species (Dahl et al., 2016; Kalinkat et al., 2017; Dajam et al., 2024). Tropical and subtropical seagrass meadows exhibit some of the highest primary productivity rates globally (Rasheed et al., 2008) and serve as critical food sources for endangered species such as the green sea turtle (*Chelonia mydas* (Linnaeus, 1758))and the dugong (*Dugong dugon* Müller, 1776) (Valentine and Duffy, 2007; Coles et al., 2015). Similarly, invertebrates like corals, including the staghorn coral (*Acropora millepora* (Ehrenberg, 1834)), Mediterranean coral (*Cladocora caespitosa* (Linnaeus, 1767)), red gorgonian (*Paramuricea clavata* (Risso, 1826)), and smooth cauliflower coral (*Stylophora pistillata* (Esper, 1797)), as well as mollusks such as the freshwater pearl mussel, horse mussel (*Modiolus modiolus* (Linnaeus, 1758)), and small giant clam (*Tridacna crocea* (Lamarck, 1819)), play vital roles as ecosystem engineers and water filters (Gutiérrez et al., 2003; Geist, 2010; Wild et al., 2011). However, these groups face challenges related to their limited visual appeal, which reduces their visibility and inclusion in conservation strategies as flagship species (Lewis, 2006). Despite this, species such as the freshwater pearl mussel (*M. margaritifera*) have attracted considerable conservation attention and funding. This is exemplified by extensive captive-breeding programs established in at least 16 European countries, which have proven effective in supporting the recovery of declining wild populations (Geist et al., 2023).

These findings raise critical questions about the representativeness of biodiversity in conservation approaches based on flagship species (McGowan et al., 2020). Concentrating efforts on charismatic vertebrates may result in gaps in the protection of ecosystems and of less visible, yet equally important, functional groups (Darwall et al., 2011).

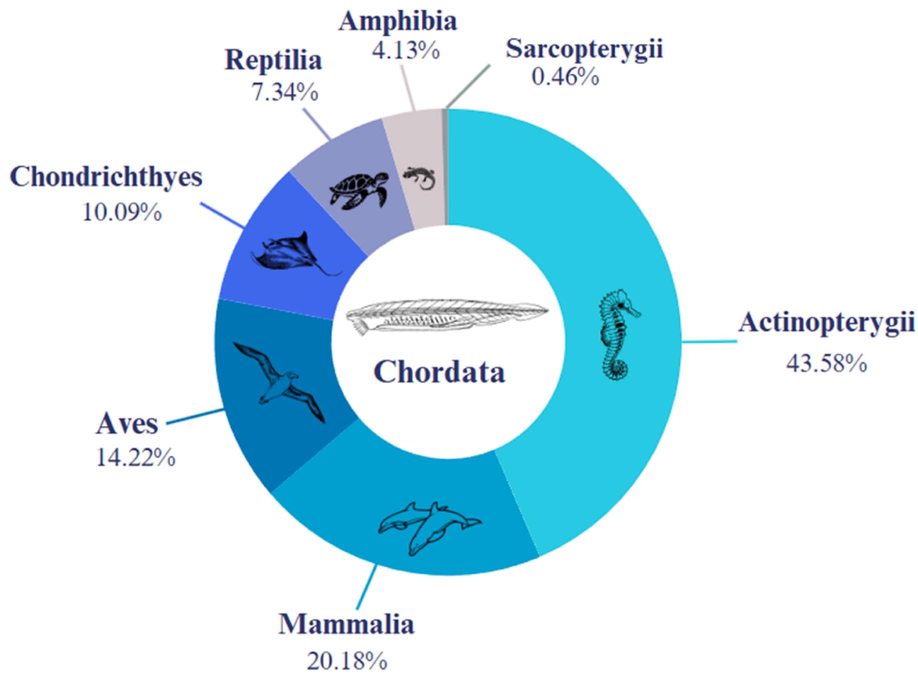

Fig. 5. Classes to which the flagship species of the phylum Chordata belong. Databases used: Scopus and Web of Science.

Table 2
Top 20 flagship species used in the selection of priority areas for conservation.

Kingdom	Phylum	Class	Common Name	Scientific Name	Frequency	IUCN Status	
Animalia	Chordata	Reptilia	Loggerhead sea turtle	*Caretta caretta* (Linnaeus, 1758)	12	Vulnerable	VU
Animalia	Chordata	Mammalia	Common bottlenose dolphin	*Tursiops truncatus* (Montagu, 1821)	12	Least Concern	LC
Animalia	Chordata	Reptilia	Green sea turtle	*Chelonia mydas* (Linnaeus, 1758)	11	Endangered	EN
Animalia	Chordata	Mammalia	Eurasian otter	*Lutra lutra* (Linnaeus, 1758)	8	Near Threatened	NT
Animalia	Chordata	Reptilia	Olive ridley sea turtle	*Lepidochelys olivacea* (Eschscholtz, 1829)	7	Vulnerable	VU
Plantae	Tracheophyta	Monocots	Neptune grass	*Posidonia oceanica* (Linnaeus) Delile, 1813	7	Least Concern	LC
Animalia	Chordata	Reptilia	Hawksbill sea turtle	*Eretmochelys imbricata* Linnaeus, 1766	6	Critically Endangered	CR
Animalia	Chordata	Actinopterygii	Short-snouted seahorse	*Hippocampus hippocampus* (Linnaeus, 1758)	6	Data Deficient	DD
Animalia	Chordata	Actinopterygii	Bumphead parrotfish	*Bolbometopon muricatum* (Valenciennes, 1840)	5	Vulnerable	VU
Animalia	Chordata	Mammalia	Dugong	*Dugong dugon* (Müller, 1776)	5	Vulnerable	VU
Animalia	Chordata	Actinopterygii	Long-snouted seahorse	*Hippocampus guttulatus* Cuvier, 1829	5	Data Deficient	DD
Animalia	Chordata	Mammalia	Humpback whale	*Megaptera novaeangliae* (Borowski, 1781)	5	Least Concern	LC
Animalia	Chordata	Actinopterygii	Mediterranean monk seal	*Monachus monachus* (Hermann, 1779)	5	Endangered	EN
Animalia	Chordata	Chondrichthyes	Whale shark	*Rhincodon typus* Smith, 1828	5	Endangered	EN
Animalia	Chordata	Mammalia	Indo-Pacific humpback dolphin	*Sousa chinensis* (Osbeck, 1765)	5	Near Threatened	NT
Animalia	Chordata	Mammalia	Reef manta ray	*Mobula alfredi* (Krefft, 1868)	4	Vulnerable	VU
Animalia	Chordata	Mammalia	Spotted seal	*Phoca largha* (Pallas, 1811)	4	Least Concern	LC
Plantae	Tracheophyta	Monocots	Eelgrass	*Zostera marina* (Linnaeus, 1753)	4	Least Concern	LC
Plantae	Tracheophyta	Magnoliopsida	Grey mangrove	*Avicennia marina* (Forsskål) Vierh, 1906	3	Least Concern	LC
Animalia	Chordata	Mammalia	Common dolphin	*Delphinus delphis* (Linnaeus, 1758)	3	Least Concern	LC

It is essential to adopt complementary approaches, such as the use of multiple flagship species and biodiversity indicators that include less-studied organisms (Gerlach et al., 2014).

3.5. Characteristics described of the flagship species

Analysis of the characteristics attributed to aquatic species used as flagships in the selection of priority areas reveals patterns that reflect contemporary priorities for biodiversity conservation (Fig. 6).

The predominance of the "Conservation Status" category (57.17 %) suggests that the scientific community and environmental managers have prioritized threatened species as flagships. This approach aligns with IUCN guidance, which identifies extinction risk as an important factor to consider when planning and prioritizing conservation strategies, particularly in response to anthropogenic pressures and environmental degradation (Gerlach et al., 2014). Threatened species, such as the Hawksbill sea turtle (*Eretmochelys imbricata,* Linnaeus, 1766), which is listed as Critically Endangered, and the West Indian manatee (*Trichechus manatus,* Linnaeus, 1758), classified as Vulnerable, have been used as flagships for the protection of coastal and mangrove habitats, highlighting the impact these species have on resource mobilization and public awareness (Normande et al., 2023). However, the IUCN Red List is subject to a taxonomic bias due to the scarcity of established taxonomist specialists for diverse and less-studied taxa, particularly in Neotropical regions (New and Samways, 2014; Duffus et al., 2023). This is relevant because the IUCN Red List is a widely recognized tool used by the public and policymakers and can play a crucial role in decision-making and global conservation efforts (Betts et al., 2020).

The second most cited category, "Charisma and Emblematic Value" (15.80 %), highlights the role of species with high visual or symbolic appeal in social awareness. Studies demonstrate that charismatic species, such as the short-snouted seahorse (*Hippocampus hippocampus* Linnaeus, 1758) or the European otter (*Lutra lutra*), have a high potential to engage communities, as they function as umbrella species (species whose conservation provides protection to a large number of coexisting species) when used to promote conservation initiatives (Leoncini et al., 2022; Bifolchi and Lodé, 2005). Moreover, the charisma of these species not only stimulates conservation campaigns but also generates economic opportunities through ecotourism (Guerrero-Moreno and Oliveira-Junior, 2024b). Despite their importance, it is crucial to

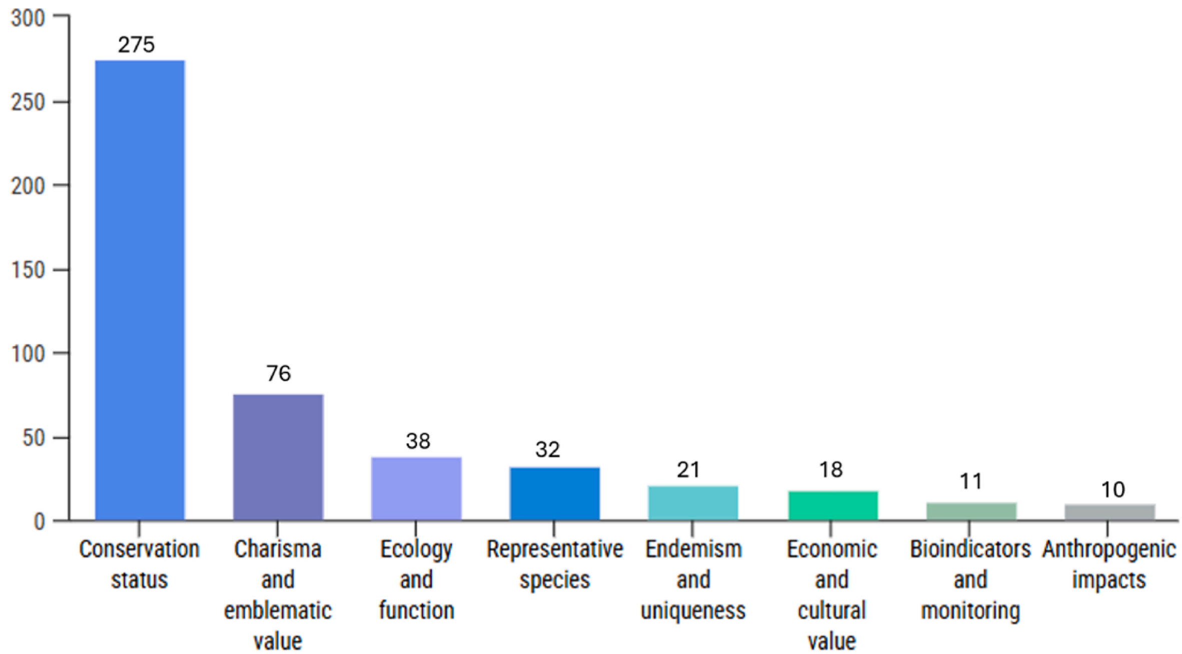

Fig. 6. Characteristics attributed to aquatic species used as flagships in the selection of priority areas for conservation. More than one characteristic of flagship species was described in each article. Databases used: Scopus and Web of Science.

highlight that the selection of charismatic species as a conservation criterion overlooks taxa that have lower aesthetic value or lack iconic characteristics. Less visible species, such as invertebrates, fungi, and plants, play crucial roles in ecosystems, contributing to processes like nutrient cycling, decomposition, and pollination (Cardoso et al., 2011; Noriega et al., 2018). This limited approach generates a bias in biodiversity protection, neglecting the complexity and interdependence between different components of ecosystems (Ripple et al., 2017). To overcome this challenge, it is essential to make them "visible" by adopting strategies that integrate the functional value of species, such as approaches based on ecosystem services, and raising public awareness about the importance of lesser-known species for environmental balance.

The categories "Bioindicators and Monitoring" (2.29 %) and "Anthropogenic Impacts" (2.08 %) showed relatively low frequencies. This may reflect an underutilization of aquatic species in environmental monitoring programs, despite their great potential for assessing water quality and detecting early changes in ecosystems (Da Silva et al., 2024a). For example, bivalve mollusks, such as mussels, are widely recognized as indicators of aquatic ecosystem health but have not received the same attention as charismatic species (Vereycken and Aldridge, 2023).

The category "Ecology and Function" (7.90 %) emphasizes the importance of considering the functional role of species in ecosystems (Correia and Lopes, 2023). Key species, such as apex predators, play crucial roles in maintaining ecological balance and regulating biotic communities (Pongen, 2024). However, the lower frequency of this category compared to "Conservation Status" suggests that the functional aspects of species are still underexplored in the selection of aquatic flagships (Aune et al., 2018). Additionally, "Economic and Cultural Value" (3.74 %) also had low use, despite being fundamental in areas where communities directly depend on aquatic species for their livelihood (Aswani and Hamilton, 2004). Species like the red-head parrotfish (*Bolbometopon muricatum* Valenciennes, 1840) and the arapaima (*Arapaima gigas*), widely exploited for local and sustainable fishing by both Indigenous and non-Indigenous communities, exemplify how the economic and cultural value associated with traditional ecological knowledge can be integrated into conservation efforts (Aswani and Hamilton, 2004; Santana et al., 2020).

The category "Endemism and Uniqueness" (4.37 %) demonstrates the importance of species with restricted distributions and unique characteristics for biodiversity conservation. Endemic species, such as Neptune grass (*Posidonia oceanica* (L.) Delile, 1813), the Mediterranean monk seal (*Monachus monachus* Hermann, 1779), and the proteus (*Proteus anguinus* Laurenti, 1768), have attracted significant attention due to their uniqueness and critical conservation status (Bizjak-Mali et al., 2018; Cañada, 2024; Zhuang et al., 2024). Finally, the intersection between different categories deserves attention. Species that have high vulnerability, charisma, and ecological function are particularly effective as flagship species, as they encompass the aspects that maximize public engagement and conservation impact (McGowan et al., 2020). The use of such species can optimize the selection of priority areas, ensuring greater success in the implementation of protection measures (Croteau and Mott, 2011). Our results suggest that the most frequently utilized characteristics reflect a focus on threatened and charismatic species, with opportunities to expand the use of other traits, such as functional roles and economic value. Incorporating these dimensions can enhance conservation strategies and contribute to more comprehensive protection of aquatic ecosystems.

3.6. Types of aquatic ecosystems inhabited by the selected species

We found a focus on marine ecosystems, which represented 58.63 % of the studies, while freshwater ecosystems, such as rivers (16.78 %), lakes (4.96 %), and streams (4.26 %), were underrepresented considering their importance (Fig. 7).

This disparity reflects a historical and scientific bias in favor of more visible and charismatic environments, such as seas and oceans, often associated with marine megafauna and issues of global economic relevance, such as fisheries and tourism (Gerlach et al., 2014; Gössling et al., 2018; Polgar and Jaafar, 2018). However, this emphasis creates a critical gap in the understanding and protection of freshwater ecosystems, which harbor disproportionately rich biodiversity and play essential ecological roles that are increasingly under threat (Darwall et al., 2011; Reid et al., 2019; Tickner et al., 2020).

While the focus on the marine environment aligns with the objectives of SDG 14, which explicitly prioritizes the conservation of seas and oceans (Tickner et al., 2020), it overlooks freshwater biodiversity, which does not have a dedicated goal within the global sustainability agenda (Darwall et al., 2011). Although SDG 15 ("Life on Land") includes references to freshwater ecosystems, its central focus lies on terrestrial biodiversity, leaving inland aquatic environments underrepresented (Ishtiaque et al., 2020). On the other hand, SDG 6 ("Clean Water and Sanitation") addresses freshwater from the perspective of water services and sanitation, without directly considering biodiversity conservation in these environments. Thus, ecosystems like rivers, lakes, and streams remain underrepresented in global policies, despite being vital for environmental balance and the ecosystem services that sustain human life and biodiversity (Carrizo et al., 2017; Kramer et al., 2023).

This underrepresentation is alarming, especially considering those freshwater ecosystems harbor about 10 % of known species, despite occupying less than 1 % of the Earth's surface (Strayer and Dudgeon, 2010; Tockner, 2021), and that freshwater is essential for human survival. The accelerated degradation of these habitats due to pollution, climate change, deforestation, and dam construction intensifies the global biodiversity crisis (Tickner et al., 2020). Furthermore, our analysis revealed that areas like groundwater (0.24 %) and mangroves (1.18 %), which are crucial for climate regulation, carbon sequestration, and the stability of coastal and riverine ecosystems, receive little attention in scientific studies focused on the conservation of flagship species (Rose et al., 2023).

Therefore, it is evident that the seas dominate conservation attention and resources and that freshwater ecosystems are being neglected, despite their vital importance. Recent research reinforces this conclusion, highlighting that freshwater ecosystems are facing a global biodiversity crisis and require interdisciplinary approaches that integrate science, public policy, and social engagement to ensure their effective conservation (Ottoni et al., 2023; Azevedo-Santos and Ottoni, 2025). To ensure a truly holistic conservation approach, it is imperative to balance efforts between these environments, recognizing the relevance of freshwater ecosystems in maintaining biodiversity and providing ecosystem services essential for the survival of both humanity and the planet.

3.7. Methods used in the studies

We found a predominance of "Abundance and density" (39.04 %) and "Monitoring and observation" (38.32 %) methods, reflecting a traditional and descriptive approach in studies on the conservation of aquatic species (Fig. 8).

Although these methodologies are essential for establishing population baselines and understanding ecological dynamics, their prevalence suggests a potential limitation in adopting more advanced approaches, such as predictive modelling and genetic analyses (Thompson et al., 2021; Johnston et al., 2022). The low utilization of "Modeling" methods (8.56 %) is particularly concerning, given their potential to predict habitat changes and anticipate future impacts from anthropogenic and climatic pressures (Kumari et al., 2024), as well as reduce knowledge gaps related to species distribution, as they can model the predicted biodiversity in a specific region. This gap may be attributed to the lack of technological infrastructure and professional training in certain regions, underscoring a significant barrier to advancements in conservation (Riccaboni and Verginer, 2022; Fitzsimons et al., 2024a, 2024b).

The underutilization of "Genetics and Phylogeny" (6.95 %) is also noteworthy, as these methods are fundamental for understanding the genetic resilience of populations and identifying evolutionary important lineages (Hoban et al., 2020). However, implementing these analyses often faces financial challenges, as highlighted by studies on the high costs of sequencing and genomic analysis, which limit their application to well-funded research groups (Payne et al., 2018). This economic barrier may restrict the ability to incorporate relevant genetic information into management and conservation plans, compromising the effectiveness of long-term strategies (Laikre et al., 2020). Similarly, the

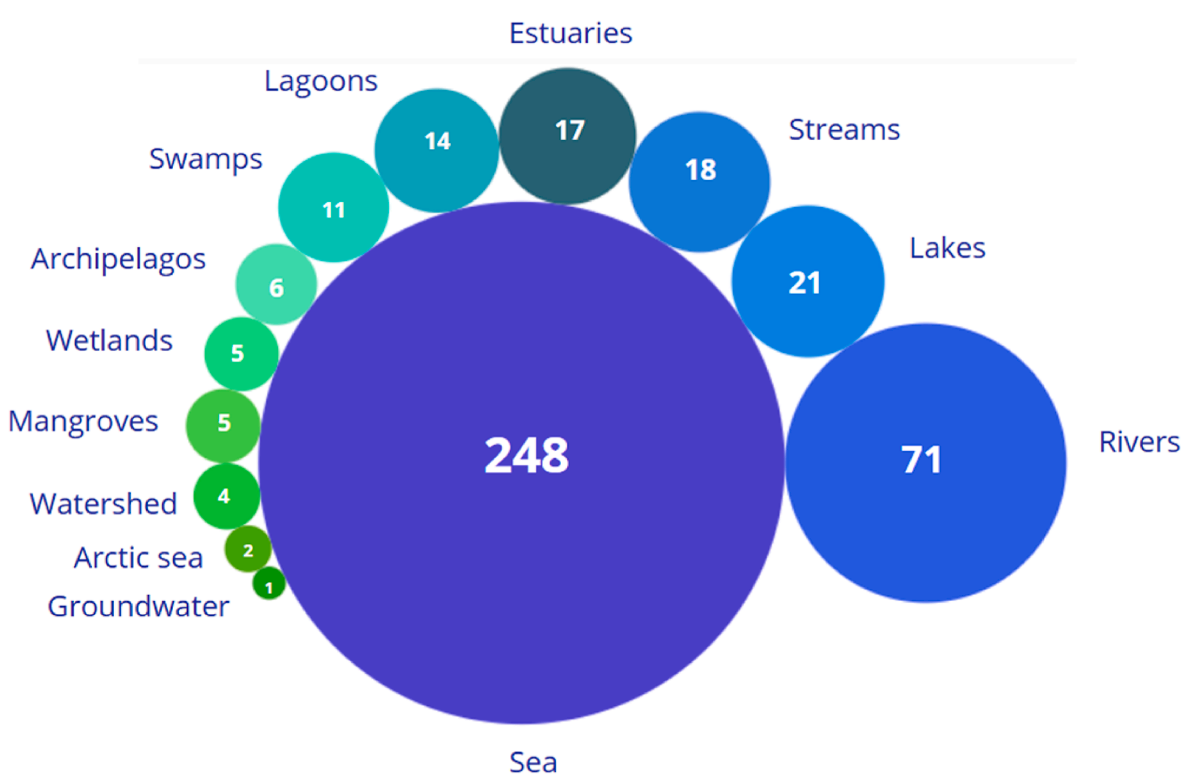

Fig. 7. Types of aquatic ecosystems inhabited by flagship species. More than one type of aquatic ecosystem was described in each article. Databases used: Scopus and Web of Science.

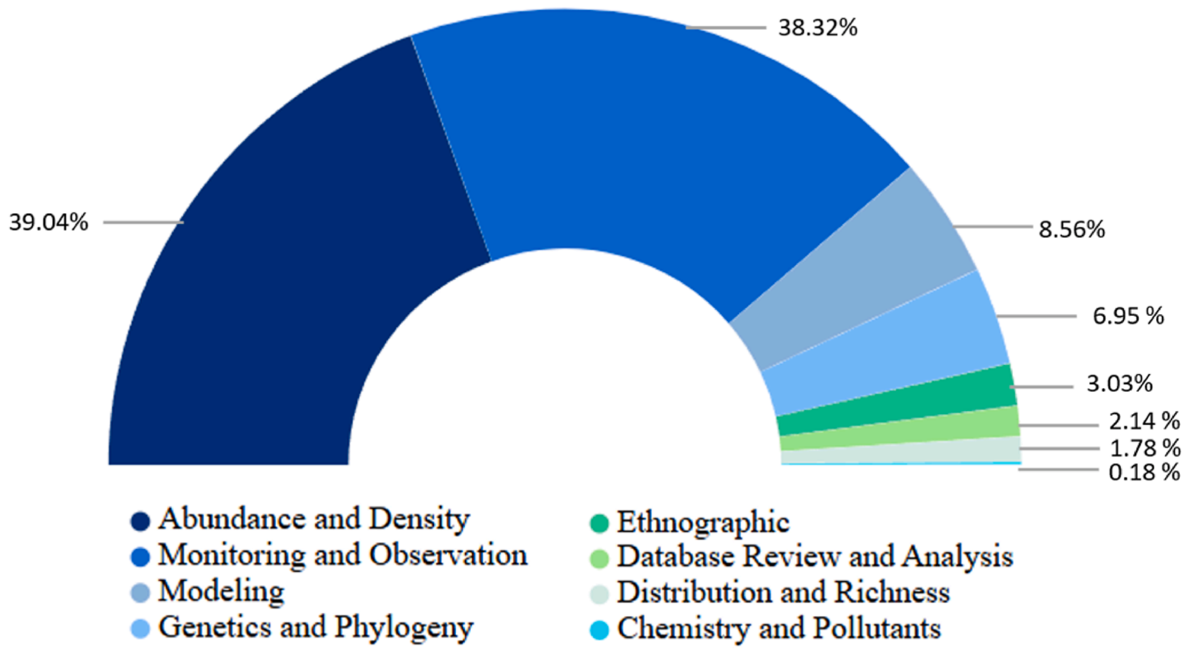

Fig. 8. Methods used in research on aquatic species that are flagships in the selection of priority areas for conservation. More than one method was mentioned in each article. Databases used: Scopus and Web of Science.

low frequency of "Ethnographic" (3.03 %) reflects a disconnect between science and local knowledge. This disconnection overlooks the valuable contributions of traditional communities to conservation, which could enhance social acceptance and the effectiveness of initiatives (Da Silva et al., 2024b; Guerrero-Moreno et al., 2024; Levis et al., 2024).

The underrepresentation of methods focusing on "Distribution and Richness" (1.78 %) and "Chemistry and Pollutants" (0.18 %) raises concerns about critical gaps in understanding biodiversity hotspots and assessing the impacts of pollutants on aquatic ecosystems (Margules and Pressey, 2000; Malaj et al., 2014; Jézéquel et al., 2020). While the former provides essential information for prioritizing conservation areas, the latter is indispensable for understanding and mitigating the growing threats to water resources that are becoming increasingly frequent.

These results underscore the pressing need to diversify and balance the methodologies employed in conservation studies. While traditional approaches are essential, they must be complemented by more advanced and integrative methods, such as modelling, genetics, and chemical impact analyses, to address the complex challenges affecting aquatic ecosystems (Hampton and Parker, 2011; Hoban et al., 2020). Additionally, integrating ethnographic methods can create a bridge between science and society, fostering more inclusive and effective conservation strategies (Levis et al., 2024). To achieve effective conservation, it is essential to invest in technological infrastructure, scientific training, social engagement, and policies that promote the application of a broader range of methodological approaches. This is the way forward to transforming data into impactful actions and ensuring the sustainable protection of global aquatic ecosystems.

4. Conclusions

This study revealed a growing scientific interest in using aquatic organisms as flagship species in conservation, highlighting temporal trends, geographic and taxonomic gaps, and critical research areas. Although the increase in scientific production over the last decades demonstrates advances in the understanding and application of the concept of flagship species in aquatic ecosystems, the results also highlight significant challenges, such as the predominance of studies in marine environments and the underrepresentation of freshwater ecosystems, as well as the disproportionate focus on charismatic vertebrates compared to other taxonomic groups.

The integration of advanced methodologies, such as genetic analyses and predictive modelling, along with the increased use of less visible but ecologically crucial species, can fill existing gaps, promoting a more inclusive and practical conservation approach. Furthermore, the involvement of local communities, the incorporation of traditional knowledge, and the engagement of society as a whole are essential strategies to align conservation efforts with socio-economic and cultural needs. For the future, it is necessary to balance research efforts across diverse types of aquatic ecosystems and taxa, promoting a comprehensive view that integrates biodiversity and ecosystem services into conservation planning, while prioritizing geographically underrepresented regions, especially those with high biodiversity and vulnerability.

We conclude that the use of aquatic organisms as flagship species not only represents a powerful tool for public and political mobilization, but also a strategic path to achieve global goals, such as the SDGs and Aichi Targets. However, the success of this approach depends on coordinated actions that combine science, governance, and social engagement, consolidating the conservation of aquatic ecosystems as a global priority.

5. Limitations and future perspectives

We employed a rigorous scientometric methodology to analyze the existing scientific literature on the topic, but it is also important to recognize the limitations inherent to this approach. The accuracy of the results may depend on the databases consulted. While Web of Science and Scopus are widely recognized databases frequently used in scientometric analysis, there is a risk that relevant articles indexed in other specialized or regional databases were not found in our search. Furthermore, the exclusion of reviews, conference proceedings, or book chapters may have left out conceptual or methodological contributions related to the use of aquatic organisms as flagship species. By focusing exclusively on peer-reviewed scientific literature, the approach becomes more robust, yet it may overlook sociocultural and ecological nuances in understanding the role of these species in prioritizing conservation areas in different contexts. This study reinforces the relevance of using aquatic organisms as flagship species in ecosystem conservation, providing a detailed overview of global trends and challenges. However, the complexity of the topic requires ongoing and integrated efforts to enhance practical application and expand the impact of conservation strategies. Some perspectives include broadening the focus to a greater diversity of aquatic organisms, such as invertebrates, plants, fungi, algae, and microorganisms, which play essential ecological functions and are still underexplored in conservation research. Additionally, strengthening technological approaches, such as the use of environmental DNA (eDNA, predictive modelling, and remote sensing monitoring, can contribute to understanding biodiversity patterns and forecasting future impacts, while still recognizing that traditional approaches remain important.

The integration of traditional knowledge and the active participation of local communities are also essential to align conservation strategies with social and cultural realities, fostering a more inclusive connection between science and society. The combination of studies addressing local, regional, and global scales is equally crucial to aligning the specific needs of ecosystems with global objectives, such as the Sustainable Development Goals and Aichi Targets, which are key to the future of our planet.

Strengthening public policies and governance can enhance financial and strategic support for the conservation of aquatic ecosystems. The creation of incentives to protect areas that are not yet formally conserved will help strengthen the global conservation network. Another important perspective is to expand research efforts to regions with high biodiversity that are still underrepresented, such as Southeast Asia, Africa, and South America, ensuring greater representativeness and effectiveness in conservation strategies. By adopting these perspectives, it is expected that the integration of scientific and social approaches will advance, creating a more promising scenario for the protection of aquatic ecosystems and the biodiversity they support. These efforts are crucial for meeting global conservation demands and ensuring the sustainability of interactions between humanity and nature.

CRediT authorship contribution statement

Mayerly Alexandra Guerrero-Moreno: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Everton Cruz da Silva:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Fernando Abreu Oliveira:** Writing – original draft, Formal analysis, Data curation. **Ana Caroline Leal Nascimento:** Methodology, Data curation. **Thaisa Sala Michelan:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis. **Karina Dias-Silva:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Maria Alexandra Teodósio:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis. **James Ferreira Moura Jr:** Writing – review & editing, Formal analysis. **José Max Barbosa Oliveira-Junior:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis. **Leandro Juen:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing 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.

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Appendix A. Supplementary data

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