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Acoustic and behavioral responses of the American manatee (*Trichechus manatus*) to anthropogenic disturbances: an integrative systematic and bibliometric review

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Abstract

The American manatee (*Trichechus manatus*) faces increasing anthropogenic threats in its habitat. In this integrative review, we synthesize current knowledge on the behavioral and acoustic responses of manatees to anthropogenic disturbances, including tourism activities, environmental noise, and port operations. Our literature search identified 40 studies published between 2000 and 2025 that investigated the responses of Florida (*T. manatus latirostris*) and Greater Caribbean (*T. manatus manatus*) manatees to anthropogenic impacts. Results show that manatees adjust their behavior in response to disturbances, including changes in movement, activity patterns, and habitat use. Acoustic responses include alterations in vocalization duration and rate. Most studies were conducted in Florida, USA, on Florida manatees, whereas the Greater Caribbean manatee was more extensively studied in Brazil, Mexico, and Belize. We identified important gaps, such as the lack of studies on the impact of recreational aquatic tourism and direct human interactions, especially in Central and South America. Addressing these gaps is crucial to improve conservation and management strategies for the American manatee.

Keywords:
bioacoustics; conservation; ethology; environmental stressors; sirenians

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Introduction

The American manatee (*Trichechus manatus*), also referred to as the West Indian manatee, is one of the four extant species of the order Sirenia. This order comprises three species within the family Trichechidae - the American manatee (*T. manatus*), the Amazonian manatee (*T. inunguis*), and the African manatee (*T. senegalensis*) - and one species within the family Dugongidae, the dugong (*Dugong dugong*) (Domning & Hayek, 1986). The American manatee is classified as Vulnerable on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species, based on the most recent assessment, which reflects a declining population primarily driven by anthropogenic impacts and habitat loss (Deutsch & Morales-Vela, 2024). Sirenians play an important ecological role as large aquatic herbivores, influencing vegetation structure, nutrient cycling, and ecosystem productivity (Aragones et al., 2012). They are also considered flagship species, as their charismatic nature attracts public attention and fosters support for the conservation of their habitats (Normande et al., 2026). Manatees also provide cultural, social, and recreational services, particularly through their role in community-based tourism (Coutinho et al., 2025).

Within this species, two subspecies are recognized: the Greater Caribbean manatee (*Trichechus manatus manatus*), also known as the Antillean manatee, and the Florida manatee (*Trichechus manatus latirostris*), which differ in their geographic distributions

and conservation contexts (Lima et al., 2021; Mignucci-Giannoni et al., 2024). The Florida manatee occurs primarily in the Florida Peninsula and adjacent coastal waters of the southeastern United States (Cloyed et al., 2025), whereas the Greater Caribbean manatee is distributed throughout the Caribbean basin, including the Gulf of Mexico, Central America, and extending to the northern and northeastern coasts of South America (Luna et al., 2008; Alves et al., 2016; Edwards et al., 2026; Normande et al., 2026).

The Florida manatee is currently listed as Threatened by the United States Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2025). In contrast, the Greater Caribbean manatee occurs across a broad geographic range and exhibits a wide but fragmented distribution which, combined with uneven research and monitoring efforts across its range, has resulted in limited knowledge of its population status in many regions (Edwards et al., 2026). Although conservation status may vary regionally, the most recent IUCN Red List assessment classifies this subspecies as Endangered (Deutsch & Morales-Vela et al., 2024). In Brazil, it was recently reclassified as Critically Endangered under MMA Ordinance No. 1.704 of June 16, 2026 (Ministério do Meio Ambiente e Mudança do Clima, 2026).

Despite their ecological importance and conservation status, both subspecies of the American manatee are increasingly exposed to anthropogenic disturbances, though the types and intensities of these impacts vary across their respective geographic ranges (Bonde & Flint, 2017). For the Florida manatee, the main threats are associated with watercraft traffic, particularly vessel collisions (Runge et al., 2017; Combs-Hintze et al., 2025; Hostetler et al., 2025), which represent one of the leading causes of mortality. Historical mortality records documented 1,212 manatee deaths in Florida between 1976 and 1991, with human-related causes, particularly watercraft-related mortality, identified as important factors affecting population viability (Marmontel et al., 1997). More recent assessments indicate that anthropogenic mortality continues to be a major conservation concern for the species, influencing recovery trajectories despite population increases in some regions (Runge et al., 2017). In addition, habitat degradation and declining water quality have reduced the availability of seagrass, the primary food resource for Florida manatees, contributing to the recent Unusual Mortality Event (UME) in Florida (Allen et al., 2024). The Greater Caribbean manatee, however, is exposed to a broader and more heterogeneous set of anthropogenic pressures (Castelblanco-Matínez et al., 2012; Meirelles et al., 2018). Historically, overhunting and habitat modification have contributed to population declines across its range (Domning, 1982). Currently, habitat loss remains one of the major threats, often leading to calf strandings (Balensiefer et al., 2017; Meirelles et al., 2024; Normande et al., 2026). Additional pressures include boat collisions and increasing human disturbance associated with coastal development and tourism activities (Borges et al., 2007; Alves et al., 2013; Campos et al., 2023; Coutinho et al., 2023; Galves et al., 2023).

In addition to threat documentation, assessing behavioral responses to anthropogenic disturbances is critical for understanding the vulnerability of the American manatee. Like all extant sirenians, the American manatee is a fully herbivorous aquatic mammal (Marsh et al., 2011); the species exhibits behavioral traits shaped by its dependence on shallow coastal habitats, where aquatic vegetation is abundant (Marsh et al., 2011; Keith-Diagne et al., 2022). Consequently, manatees spend much of their time foraging on food resources in nearshore environments and are also strongly associated with areas that provide access to freshwater sources (Favero et al., 2020; Keith-Diagne et al., 2022). Their postural behavior is characterized by slow swimming speeds, frequent surfacing to breathe, and prolonged periods of feeding and resting (Hartman, 1979; Attademo et al., 2020). Tactile signals are particularly important in low-visibility environments, facilitating conspecific interactions and environmental perception (Lucchini et al., 2023). Similarly, vocal communication plays an important role in maintaining mother-calf cohesion (Umeed et al., 2023). Manatees produce single-note vocalizations that vary significantly across subspecies and geographic locations (Brady et al., 2023; Reyes-Arias et al., 2023), as well as among individuals, sex, and age groups (Sousa-Lima et al., 2008; Umeed et al., 2018; 2022). Umeed et al. (2022) identified four categories of vocalizations, two of which included different variants.

These behavioral characteristics, combined with the intense human use of their habitats, increase their susceptibility to anthropogenic disturbances (Alves et al., 2013; Littles et al., 2019), including vessel collisions, entanglement in fishing gear, and disturbances associated with coastal development and tourism (Reinert et al., 2017; Rycyk et al., 2018; Ponnampalam et al., 2022). Despite the frequency and diversity of these interactions, significant gaps remain in the understanding of sirenian behavioral responses to anthropogenic pressures. Given these vulnerabilities, advancing knowledge of acoustic and behavioral responses is essential for better identifying existing gaps and guiding targeted research and conservation actions, particularly in regions where information remains scarce.

This study presents an integrative literature review that synthesizes current scientific knowledge on the behavioral and acoustic responses of the American manatee to anthropogenic disturbances, including tourism activities, environmental noise, and port operations. Additionally, this review seeks to identify existing knowledge gaps and highlight research priorities that may help improve management strategies and, consequently, the conservation of one of the most threatened aquatic mammals in the world. To achieve this goal, we: (a) characterized the scientific production by identifying the numbers and type of publications (*e.g.*, articles, theses, dissertations, and book chapters) addressing behavioral and acoustic responses of the American manatee to anthropogenic disturbances; (b) identified which subspecies has been most frequently investigated; (c) analyzed the temporal trends in scientific publications; (d) mapped the geographic distribution of the studies conducted on the subspecies; (e) identified and categorized types of anthropogenic disturbances reported in the literature; and (f) compiled and categorized the manatee's behavioral and vocal responses described in the studies.

Methods

A systematic literature review was conducted to gather studies from 2000 to 2025 that investigated the behavioral and vocal responses of the Greater Caribbean subspecies of the American manatee to anthropogenic disturbances. The literature search

and study selection followed a PRISMA-style approach to improve transparency and reproducibility (Fig. 1). We used Google Scholar and Web of Science platforms. To Google Scholar, we applied a combination of keywords: *Trichechus manatus* behavior boats, *Trichechus manatus* manatee watching, *Trichechus manatus* behavioral responses, *Trichechus manatus* tourism, *Trichechus manatus* anthropogenic factors, *Trichechus manatus* vocalization, *Trichechus manatus* vocal repertoire, *Trichechus manatus* vocal response.

For Web of Science platform we used the following searches: ("*Trichechus manatus*" OR "*Trichechus manatus manatus*" OR "*Trichechus manatus latirostris*") AND (behavior* OR behavioral OR response* OR reaction* OR change*), ("*Trichechus manatus*" OR "*Trichechus manatus manatus*" OR "*Trichechus manatus latirostris*") AND (tourism OR "manatee watching" OR boat* OR vessel* OR traffic OR anthropogenic OR disturbance* OR noise), ("*Trichechus manatus*" OR "*Trichechus manatus manatus*" OR "*Trichechus manatus latirostris*") AND (vocal* OR acoustic* OR sound* OR call* OR communication), ("*Trichechus manatus*" OR "*Trichechus manatus manatus*" OR "*Trichechus manatus latirostris*") AND (vocal* OR acoustic* OR sound* OR communication) AND (noise OR boat* OR vessel* OR traffic OR anthropogenic OR disturbance*).

No language restrictions were applied during the search. Studies published in any language were considered eligible if they met the inclusion criteria. However, all studies retrieved and included in the review were published in English or Portuguese. All records retrieved from the database searches were initially screened based on their titles and abstracts. Publications that clearly did not meet the scope of the review were excluded at this stage. The remaining studies were subsequently assessed through full-text reading, and their eligibility was determined according to the predefined inclusion and exclusion criteria described below.

Publications were included if they focused on the Florida or the Greater Caribbean manatee subspecies of the American manatee, and/or addressed postural behavior and/or acoustic responses of manatees associated with anthropogenic interactions. We included scientific articles, dissertations, theses, and book chapters published from 2000 to 2025. Graduate theses and dissertations were included when they met the predefined eligibility criteria and were considered as independent records when they provided distinct information relevant to the objectives of this review.

Studies were excluded when they met one or more of the following criteria: when the study focused on other sirenian species (Amazonian manatee, African manatee, dugong) without including the American manatee, if the study addressed topics unrelated to behavioral or acoustic responses to anthropogenic disturbances, and when the publication did not contain primary research data. Studies conducted in captive environments were included only when they assessed behavioral or acoustic responses to specific anthropogenic stimuli. Descriptive studies of general behavior in captivity, without explicit evaluation of human-induced disturbance, were excluded.

After an extensive search, information from the selected studies was compiled into a spreadsheet containing the following information: author, year of publication, journal, subspecies, study design, study setting (wild or captive), study location, anthropogenic impact, and reported behavioral and vocal responses.

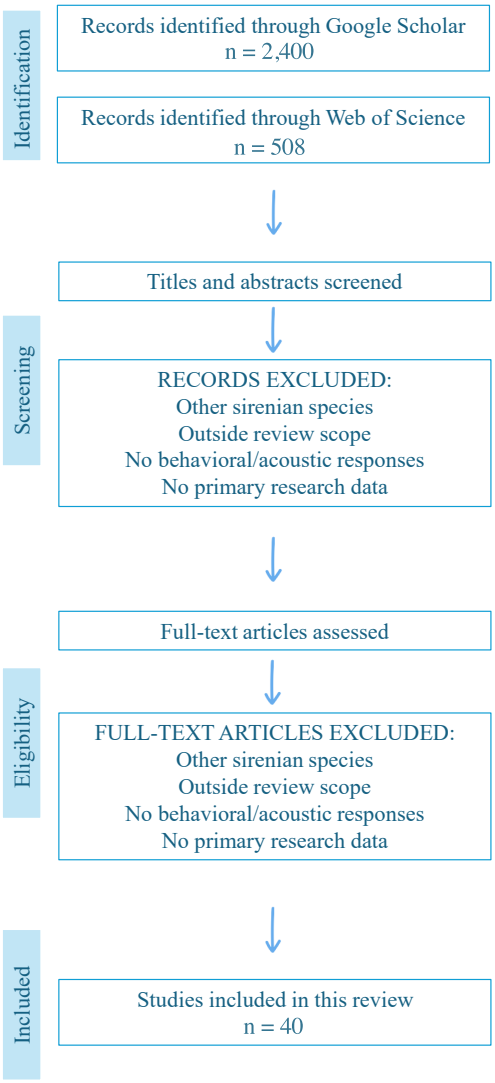


Figure 1. PRISMA-style flow diagram summarizing the literature search, screening, eligibility assessment, and study selection process adopted in this integrative systematic and bibliometric review. **Note:** Google Scholar screening was limited to the first 30 pages of results for each search strategy because subsequent records became increasingly unrelated to the scope of the review. Duplicate records identified across search strategies and databases were removed during the screening process.

As multiple keyword combinations and databases were used, some publications appeared repeatedly across different search results. In such cases, records already included in the data extraction spreadsheet were not added again to avoid duplication.

Anthropogenic impacts and reported behavioral and vocal responses were extracted from each study and systematically classified. Behavioral responses were grouped into predefined categories based on similarities in response type, and an ethogram was developed. Vocal responses were also identified and categorized. The frequency of each response category was quantified based on the number of studies in which it was reported.

To map the geographic distribution of studies conducted on the subspecies of the American manatee, we used ArcGIS 10.4 (Environmental Systems Research Institute, 2016). For each selected study, we recorded the country and, whenever available, the specific locality where the research was conducted (*e.g.,* beach, river mouth, or protected area), and retrieved its geographic coordinates from Google Earth. These coordinates were then plotted as points on the maps, representing the locations where the studies were conducted. Finally, we assigned the number of publications involving these subspecies to circles on the maps, such that larger circles indicate more studies conducted in that country and location. Two maps (Figs 3, 4) were generated: one showing the distribution of studies by country/region and another showing the specific study localities. In both maps, orange circles represent studies on the Florida manatee, whereas pink circles represent studies on the Greater Caribbean manatee.

Results

The search yielded 40 documents, which are listed in Supplementary Material 1 for transparency and further analysis. The most frequent type of document was peer-reviewed article (including articles, reviews, and short communications; n = 31, 77.5%), followed by master's theses and doctoral dissertations (n = 9, 22.5%). Of these, a smaller proportion corresponded to doctoral dissertations (n = 3, 33.3%). No book chapters met the inclusion criteria.

Most reviewed studies focused on the Florida manatee (n = 24, 60%), followed by Greater Caribbean manatee (n = 15, 37.5%), and one study addressed both taxa (n = 1, 2.5%). The number of publications showed an overall increasing trend over time, with a marked rise after 2000-2004, followed by a relatively stable pattern, and a slight increase in the most recent period. When analyzing the subspecies separately, studies on the Greater Caribbean manatee showed a clear increasing trend over time, whereas research on the Florida manatee peaked in 2005-2009 and subsequently declined and stabilized in latter periods (Fig. 2).

Geographically, studies on the Greater Caribbean manatees were distributed across multiple countries within the species' range, including Brazil (n = 6), Mexico (n = 3), Belize (n = 3), Puerto Rico (n = 2), and Panama (n = 1), whereas studies on the Florida manatee (n = 24) were conducted in Florida, USA, where this subspecies predominantly occurs. One study addressed the American manatee without specifying the subspecies or study location (Raoult et al., 2020). Overall, research on the Greater Caribbean manatee is more geographically dispersed, reflecting its broader distribution, although it remains unevenly distributed across countries (Fig. 3).

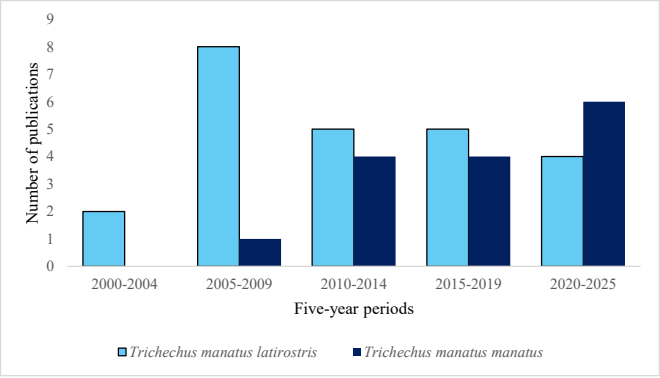


Figure 2. Temporal distribution of publications addressing vocal and postural responses of American manatee (*Trichechus manatus*) subspecies to anthropogenic factors across five-year periods.

Regarding study locations, a total of 59 records were identified across the documents included in this review, comprising 27 for Florida manatee and 32 for Greater Caribbean manatee. The number of locations exceeded the total number of studies, as some investigations were conducted across multiple sites. For Florida manatees, all study sites were located in Florida (USA), consistent with the known geographic distribution of this subspecies. Locations included Charlotte Harbor National Estuary, Crystal River National Wildlife Refuge, and Sarasota Bay. In contrast, Greater Caribbean manatee study locations were more widely distributed, encompassing coastal, estuarine, and freshwater environments across the Caribbean, Central America, and northeastern Brazil, including sites such as Quintana Roo, Corozal, Jobos Bay, and the Mamanguape River estuary. This reflects the broader distribution range of this subspecies (Fig. 4).

Anthropogenic impacts reported in the studies were grouped into seven main categories according to their primary source of disturbance. All impacts associated with watercraft (*e.g.*, vessel presence, vessel traffic, vessel noise, and vessel collisions) were classified under the broader category of vessel-related impacts. Vessel-related impacts were the most frequently reported (n = 23; 41.8%). Within this category, studies investigated manatee responses to approaching vessels, primarily focusing on behavioral (postural) changes. These include comparisons of manatee behavior under vessel presence and control conditions (absence of boats) (King & Heinen, 2004; Nowacek et al., 2004), as well as assessments of manatees' behavioral changes during vessel approaches using Digital acoustic recording tags (DTAGs) and Argos-linked GPS tags (Rycyk et al., 2018). Vessel-traffic studies focused on manatee behavior in areas with regular boat activity, rather than direct interactions with approaching vessels. For example, Campos et al. (2023) evaluated manatee behavioral patterns in areas with vessel traffic, examining their responses to ongoing anthropogenic activities, and Barton (2006) evaluated manatee behavior in areas with intense boat traffic.

Studies addressing vessel noise, in turn, employed experimental approaches, such as boat-noise playbacks, to evaluate changes in behavioral state and respiration rates (Miksis-Olds et al., 2007a), and used passive acoustic monitoring to detect feeding-related sounds (*e.g.*, chewing) under noisy and control conditions (Burke, 2019). Additionally, studies have examined variation in manatee vocal activity in relation to the presence of boat noise, including changes in vocalization rates (Brady et al., 2023). Furthermore, vessel noise has been shown to acoustically mask manatee tonal vocalizations, particularly by overlapping with their peak frequency range (Rivera-Chavarría et al., 2015). Studies examining vessel collisions have investigated the probability that manatees avoid watercraft strikes by examining their diving behavior (Edwards et al., 2016) and their response time relative to vessel speed (Rycyk et al., 2018).

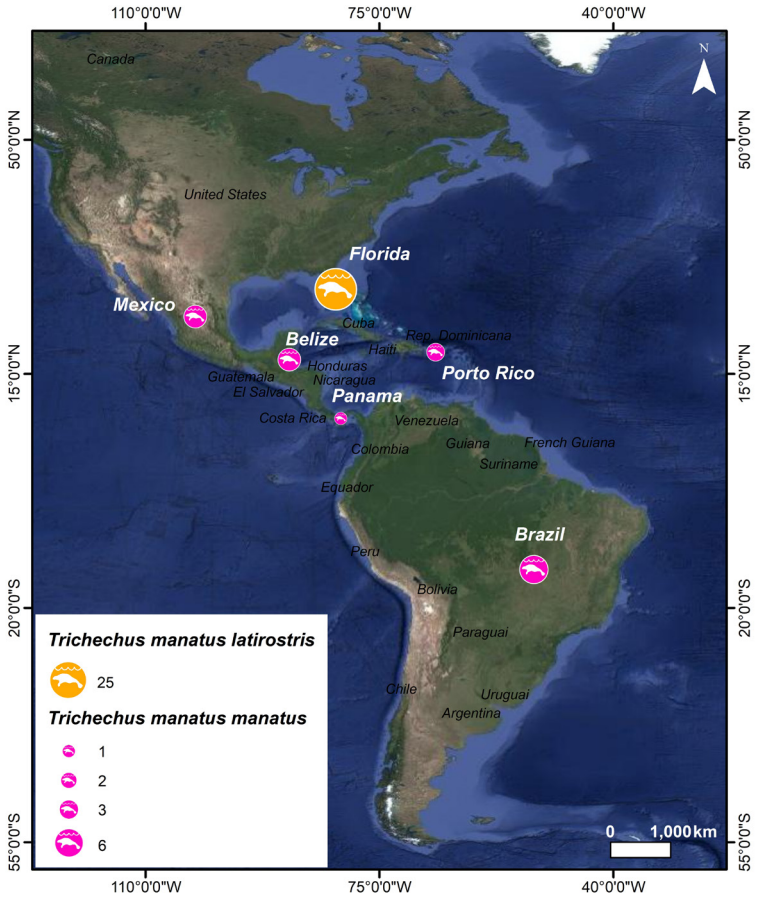


Figure 3. Geographic distribution of studies included in this review addressing vocal and postural responses of Florida manatee *Trichechus manatus latirostris* and Greater Caribbean manatee *Trichechus manatus manatus* to anthropogenic disturbances, according to country, from 2000 to 2025. Circle size represents the number of publications conducted in each location.

The second most frequent category of impact was elevated background noise levels (n = 8; 14.5%), encompassing studies that examined how manatees modify vocalization usage and structure in response to increased ambient noise (Miksis-Olds & Tyack, 2009), as well as studies investigating the effects of elevated sound levels on manatees' postural behaviors (Miksis-Olds & Wagner, 2011; Parks et al., 2020). In addition, some studies have shown that variations in ambient noise levels can affect manatees' ability to detect approaching vessels and manatee vocalizations (Rycyk et al., 2022). Other studies addressed manatee distribution as a function of noise level (Miksis-Olds et al., 2007a; Tellechea et al., 2013).

Studies addressing habitat degradation (n = 7; 12.7%) examine how changes in habitat structure and environmental conditions, often driven by anthropogenic factors, affect manatee behavior, primarily in terms of occurrence patterns (Viragh, 2012; Grissett, 2014; Littles et al., 2019). This category also includes studies addressing the effects of invasive species, which were considered as drivers of habitat degradation due to their potential to alter ecological interactions and habitat conditions. These studies examined how the presence of non-native fishes may influence manatee behavior and habitat use (Nico et al., 2009; Gibbs et al., 2010).

Coastal human activity (n = 5; 9.1%) includes studies investigating the effects of ongoing human activities in coastal environments, such as fishing and shoreline use, on manatee behavior and habitat use (Berger, 2007; Alves et al., 2013). Tourism activities such as scuba diving, snorkeling, kayaking, in-water interaction, and swimming with manatees were included in the category in-water human presence (n = 5; 9.1%), which also comprised two studies involving in-water researcher presence during data collection (King & Heinen, 2004; Harms-Tuohy & Tuohy, 2017; Coutinho et al., 2023; Slone et al., 2023; Umeed et al., 2023).

Studies of captive manatees (n = 4; 7.3%) examined the effects of time in captivity on animal behavior (Anzolin et al., 2014; Mercadillo-Elguero et al., 2014; Heiman, 2016; Ramos et al., 2023), while studies using unmanned aerial systems (UASs) (n = 3; 5.5%) assessed the effects of this technology on manatee postural behavior (Ramos et al., 2018; Raoult et al., 2020; Landeo-Yauri et al., 2021).

Some studies addressed multiple types of anthropogenic impacts simultaneously; therefore, individual studies were assigned to more than one impact category when applicable, assigned to more than one impact category when applicable, resulting in a total of 55 recorded impacts across 40 studies.

Studies reported a range of manatee responses to anthropogenic disturbances, classified into six behavioral categories and three vocal-acoustic categories. Behavioral responses were dominated by movement/locomotor responses (n = 21; 36.8%), followed by

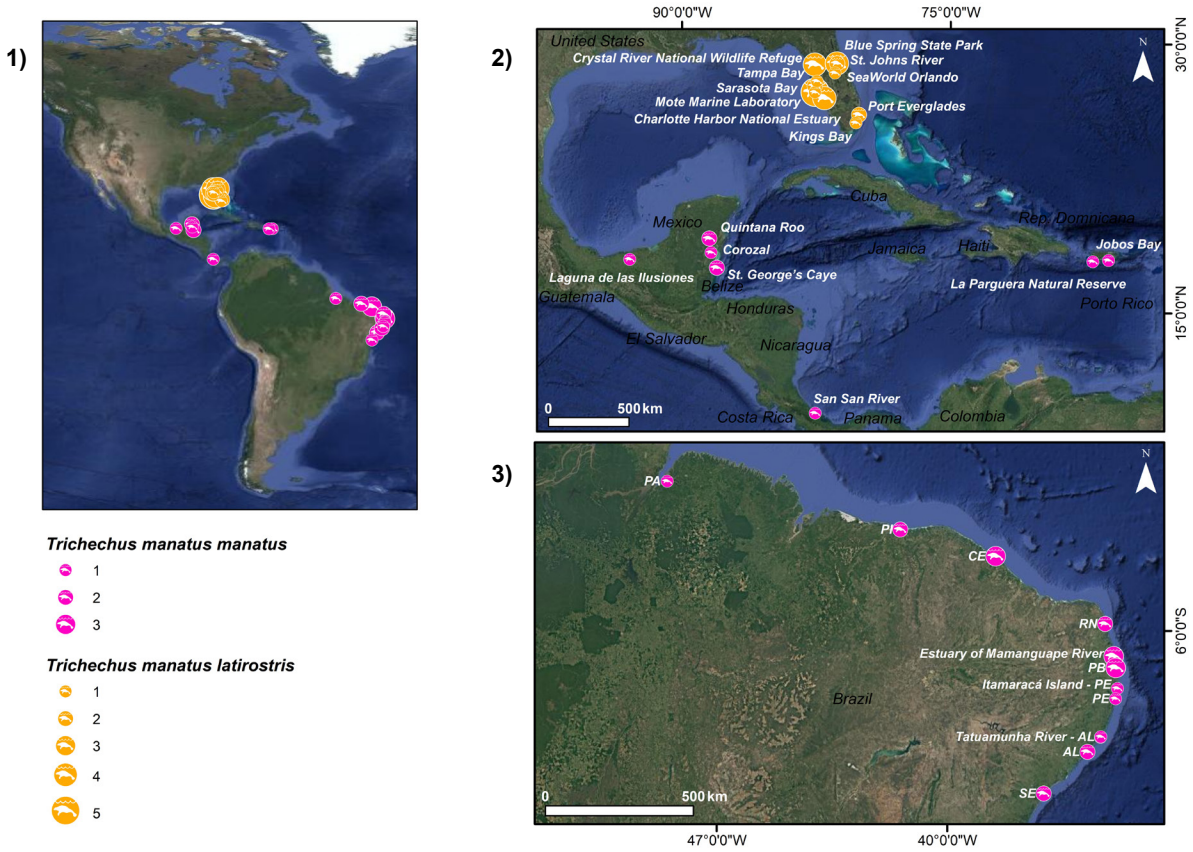


Figure 4. Geographic distribution of specific study localities included in this review addressing vocal and postural responses of Greater Caribbean manatee *Trichechus manatus manatus* and Florida manatee *Trichechus manatus latirostris* to anthropogenic factors. Circle size represents the number of publications conducted in each locality. Panel 1 includes an overview of the study localities for both subspecies. Panels 2 and 3 include detailed names of the localities within Florida and the Caribbean region and the tropical South Atlantic Ocean region, respectively.

activity/behavioral state changes (n = 12; 21.1%) and disturbance-related behaviors (n = 12; 21.1%). Spatial displacement/habitat use responses were also frequently reported (n = 11; 19.3%), and neutral responses were rare (n = 1; 1.8%). Behavioral categories and their respective definitions are detailed in the ethogram (Supplementary Material 2).

Movement/locomotor responses were the most frequently reported behavioral category. These responses encompassed immediate modifications in body movement, orientation, and locomotor patterns in response to anthropogenic stimuli. Reported behaviors included changes in orientation, characterized by alterations in body heading, roll, or pitch in response to approaching boats (Rycyk, 2013; Rycyk et al., 2018), and depth-related displacement, with individuals in shallow waters orienting towards deeper areas, such as navigation channels, in response to approaching vessels (Nowacek et al., 2004). Changes in swimming speed were also observed, typically involving increases in locomotor velocity during disturbance events; for example, manatees increased swimming speed or altered their trajectory when encountering boats in canal systems (Barton, 2006). Changes in fluking behavior were also reported, as reflected in alterations in tail-beat patterns, with manatees exhibiting changes in fluking behavior before and after watercraft noise events (Dombroski, 2023). Diving behavior was also examined in relation to collision risk, with one study assessing how manatee submergence patterns influence their vulnerability to vessel strikes (Edwards et al., 2016). Avoidance responses include directed movement away from a disturbance source to increase distance from the stimulus, such as fleeing or terminating interactions. Such responses were observed during vessel disturbance, with manatees moving away from approaching boats and toward deeper water, as noted previously (Nowacek et al., 2004). Similarly, avoidance behaviors were reported in response to aerial disturbance, with individuals fleeing from their original positions or moving beneath submerged structures during flights (Landeo-Yauri et al., 2021).

Following movement/locomotor responses, the next most frequently reported category was activity/behavioral state changes. This category encompasses changes in activity patterns and behavioral states, including modifications within ongoing behaviors and transitions between behavioral states in response to anthropogenic stimuli. Studies conducted in captive and semi-captive settings reported changes in feeding behavior, including alterations associated with human-managed conditions. For example, manatees exhibited anticipatory behaviors prior to feeding events, such as increased vocal activity (Ramos et al., 2023), and strong dietary preferences for provisioned food, with limited consumption of natural forage (Mercadillo-Elguero et al., 2014). There were also variations in feeding activity in response to anthropogenic disturbance (*e.g.*, vessel noise), including

changes in chewing rate or duration (Burke, 2019). Changes in activity patterns were observed, for example, in response to drone flights, with manatees exhibiting increased activity levels during and after exposure (Landeo-Yauri et al., 2021). Transitions between behavioral states were also reported in this category; for example, manatees shifted from bottom resting and nursing to milling and swimming in the presence of swimmers (King & Heinen, 2004).

Disturbance-related behaviors were also frequently reported. This category encompasses behaviors directly associated with disturbance or interaction with anthropogenic stimuli, including agitation-related responses to biological disturbances, such as interactions with invasive fish species, as well as direct engagement with humans. For example, manatees were reported to approach or interact with humans, engaging with swimmers or maintaining proximity to people (King & Heinen, 2004; Coutinho et al., 2023). Changes in respiration rates were also observed, reflecting physiological responses to disturbance (Miksis-Olds et al., 2007b).

Another category of behavioral responses to anthropogenic disturbances involved spatial displacement, habitat use, shifts in space use, displacement to different areas, and spatial association with anthropogenic activities. Manatees tended to use protected (no entry) sanctuaries when the number of swimmers and boats increased in open areas (King & Heinen, 2004). Changes in habitat use were also evident, with manatees modifying their spatial use in response to anthropogenic structures and disturbances, including altered use of areas associated with power plants and bridge environments (Viragh, 2012; Tellechea et al., 2013). Some studies reported the presence of manatees near anthropogenic activities, suggesting spatial association with features such as boats and coastal development (Berger, 2007; Alves et al., 2013).

Neutral responses were the least frequently reported behavioral category and denoted the absence of observable behavioral changes in response to anthropogenic stimuli. For example, manatees continued to engage in natural behaviors despite human presence, showing no apparent avoidance or disturbance (Campos et al., 2023).

A smaller subset of studies investigated manatees' vocal-acoustic responses to anthropogenic disturbances, with only six studies addressing this aspect. These studies described changes in vocal behavior in response to anthropogenic noise – increased call duration, increased/decreased call rates (Miksis-Olds & Tyack, 2009; Brady et al., 2023), as well as the occurrence of acoustic masking under elevated background noise conditions (Rivera-Chavarría et al., 2015; Rycyk et al., 2022).

Discussion

Despite the growing interest in manatee research, the number of studies addressing behavioral and acoustic responses to anthropogenic disturbances remains relatively limited. The available literature is largely concentrated on the Florida manatee. This pattern likely reflects differences in sampling intensity, funding opportunities, and access to research technologies across the species' range. Long-term monitoring programs and greater research infrastructure are more established; these factors have enabled more extensive investigations and the application of advanced monitoring techniques in some regions. Consequently, the apparent predominance of studies on the Florida manatee should be interpreted in light of differences in research effort rather than as evidence of differences in the occurrence or importance of anthropogenic disturbances between species. Despite this heterogeneity, our results indicate a consistent increase in the number of publications on the Greater Caribbean manatee over time, suggesting growing research interest throughout its distribution.

Overall, scientific production has increased since the early 2000s, suggesting a growing recognition of the importance of understanding manatees' behavioral responses to human-induced impacts. However, this growth appears to have stabilized in recent years, which may reflect the diversification of research efforts across a wider range of topics, including genetics, acoustics, distribution, and ecological aspects.

The geographic distribution of studies addressing vocal and postural responses of the American manatee to anthropogenic disturbances reveals a clear pattern of uneven research effort across the species' range. While studies on the Florida manatee are concentrated exclusively in Florida, reflecting both the limited distribution of this subspecies and the strong infrastructure in the United States (Cloyed et al., 2025), research on the Greater Caribbean manatee is more geographically dispersed, but unevenly distributed. Brazil had the most studies, followed by Mexico and Belize. This pattern is consistent with previous bibliometric analyses on the Greater Caribbean manatee, which reviewed literature regarding this subspecies without restriction of the research topic and found Brazil and Mexico as leading contributors to research on this subspecies (Castelblanco-Martínez et al., 2023). It is important to note that the patterns reported here pertain specifically to studies of vocal and postural responses to anthropogenic disturbances and do not necessarily reflect the overall distribution of manatee research across regions.

At a finer scale, the distribution of study locations also highlights this pattern. For the Florida manatee, research is concentrated on well-established sites in Florida (*e.g.*, Crystal River Wildlife Refuge – King & Heinen, 2004; Berger, 2007; Heiman, 2016; Slone et al., 2023; Charlotte Harbor National Estuary – Rycyk, 2013; Rycyk et al., 2018; Burke, 2019). Greater Caribbean manatee studies are distributed across a wider range of localities, including coastal, estuarine, and freshwater environments (*e.g.*, Alves et al., 2013; Landeo-Yauri et al., 2021). These locations are often associated with areas where long-term monitoring programs are already established, such as protected areas (*e.g.*, Barra do Rio Mamanguape Environmental Protection Area, Brazil – Campos et al., 2023). In addition, some of the studied sites are areas of intense human activity, including tourism hotspots and areas with heavy vessel traffic, prompting investigations into manatees' behavioral responses to anthropogenic disturbances (*e.g.*, King & Heinen, 2004; Coutinho et al., 2023).

Anthropogenic impacts reported in the literature are dominated by vessel-related disturbances, the most frequent category. This impact is particularly evident in studies conducted in Florida, where a substantial body of research has focused on Florida manatee response to vessel presence (*e.g.*, Nowacek et al., 2004), traffic (*e.g.*, Barton, 2006), and associated noise (*e.g.*, Rycyk et al., 2022). The prominence of this topic may reflect both the intensity of boat activity within Florida manatee habitats (Slone

et al., 2023) and the greater availability of research infrastructure (vessels for monitoring) and technological resources (Digital acoustic recording tags (DTAGs), and Argos-linked GPS tags) (*e.g.*, Rycyk et al., 2018).

Elevated background noise also emerges as a relevant category of impact, influencing manatees' postural behaviors (Miksis-Olds & Wagner, 2011; Parks et al., 2020) and reducing their ability to detect approaching vessels, thereby increasing their collision risk (Rycyk et al., 2022). This relationship highlights the close connection between noise and vessel-related disturbances, the most frequently reported impact category, reinforcing the importance of studies on background noise as a significant anthropogenic impact on manatee populations.

Studies addressing habitat degradation indicate that manatees tend to modify their occurrence patterns in response to changes in habitat structure and environmental conditions, often avoiding or reducing the use of degraded areas (*e.g.,* Grissett, 2014; Littles, 2019). Interestingly, we also identified studies on the influence of invasive species, which were included in this category as described above, highlighting how non-native fishes may directly interact with manatees, potentially increasing disturbance and activity levels (Nico et al., 2009; Gibbs et al., 2010). Coastal human activity, such as fishing and shoreline use, represents a broader category of disturbance and was often investigated in combination with other impacts, such as vessel traffic and habitat degradation (Alves et al., 2013; Ramírez-Jiménez et al., 2017; Littles et al., 2019; Campos et al., 2023). Only one study addressed coastal human activity as an isolated factor (Berger, 2007). The limited number of studies suggests that these impacts remain underexplored, particularly regarding the postural and vocal responses of manatees to this kind of pressure.

Tourism-related activities, grouped here under in-water human presence, were represented by relatively small number of studies. This limited representation led to the inclusion of a range of activities, such as scuba diving, snorkeling, kayaking, and direct in-water interactions, within a single category. Given the well-established nature of manatee-related tourism, including swim-with-manatee programs in Florida and the widespread occurrence of manatee watching in northeastern Brazil, a higher number of studies would be expected. Notably, even in Florida, where research efforts are more extensive most studies have focused on vessel-related impacts rather than direct in-water human interactions. In Brazil, recent evidence indicates that manatee-related tourism is broadly distributed and overlaps with the subspecies' occurrence (Coutinho et al., 2023). Despite this, studies addressing how tourism influences manatees' postural and vocal behaviors remain scarce.

The limited number of studies investigating manatees' behavioral responses to captivity contrasts with the substantial number of individuals currently maintained in *ex situ* settings worldwide, many of whom are involved in rehabilitation or long-term management programs (Castelblanco-Martínez et al., 2025). This gap suggests that captive environments remain underexplored for advancing knowledge of manatees' postural behavior. Regarding the effects of UASs, this remains an emerging area of research, and the increasing use of this technology suggests that further studies on manatee behavioral responses are warranted.

The diversity of behavioral responses identified in this review reflects manatees' capacity to adjust their behavior in response to different types of anthropogenic disturbances. Overall, responses were predominantly associated with changes in movement and activity patterns, indicating that behavioral adjustments commonly involve modifications in locomotion, orientation, and general activity. These movement-related responses may include avoidance behaviors when individuals actively increase their distance from disturbance sources, however, differences in terminology and behavioral criteria among studies may limit direct comparisons across responses. The predominance of movement-related responses is influenced by the type of disturbance most frequently investigated. Given that vessel-related impacts were the most commonly reported and that a large proportion of studies were conducted in Florida (*e.g.*, Nowacek et al., 2004; Miksis-Olds et al., 2007b; Rycyk, 2013; Rycyk et al., 2018), behavioral responses largely reflect how Florida manatees react to vessel presence, and adjustments in movements and position, such as changes in swimming speed, depth, and orientation, appear to be the primary response to approaching vessels and boat traffic. In addition, vessel-related studies provide evidence that factors such as vessel speed and type, as well as the behavioral state of the manatee at the time of anthropogenic exposure, can influence the nature and intensity of the animal's responses (Nowacek et al., 2004; Miksis-Olds et al., 2007b; Rycyk et al., 2018).

Following this, activity/behavioral state changes also represented a prominent category of response. These responses indicate that manatees frequently adjust their behavioral states and/or modify their ongoing behaviors in response to disturbances, rather than only modifying their movements. Transitions between behavioral states are classic responses, with individuals shifting from resting or nursing to more active states such as milling, in the presence of anthropogenic stimuli (King & Heinen, 2004; Miksis-Olds & Wagner, 2011). Such changes suggest that disturbance may reduce time allocated to essential behaviors, redirecting it toward more energetically demanding activities.

Disturbance-related behaviors highlight the complexity of these responses and raise concerns regarding the effects of human activities. These include direct interactions with humans (Coutinho et al., 2023) and the tendency of manatees to terminate such interactions (King & Heinen, 2004), suggesting that these encounters may be perceived as stressful. Spatial displacement and changes in habitat use indicate that manatees may respond to disturbance by redistributing themselves within the environment, often seeking areas that provide refuge or reduce exposure to anthropogenic activities (King & Heinen, 2004; Slone et al., 2023). This pattern highlights the importance of protected areas, such as no entry sanctuaries, to manatee conservation (Marsh & Morales-Vela, 2012; Herrejón et al., 2020; Allen et al., 2024). Avoidance and flight responses, although less frequently reported, suggest that manatees can actively distance themselves from disturbance sources when necessary (Borges et al., 2007; Ramos et al., 2018). However, the relatively low frequency of these responses reinforces the idea that manatees tend to rely on subtle adjustments, such as movement and positioning, rather than on more pronounced avoidance or escape behaviors. Neutral responses were less frequently reported among the reviewed studies, suggesting that most research has focused

on situations in which behavioral adjustments were observed following anthropogenic disturbances. However, the absence of an observable behavioral change does not necessarily indicate a lack of disturbance perception, as remaining in a suitable or safe location may represent an appropriate response strategy under certain conditions.

Concerning manatees' acoustic responses to anthropogenic impacts, although a limited number of studies have pointed the vocal behaviors or communication adaptations of manatees directed towards disturbances, the available evidence suggests that anthropogenic noise alters manatee acoustic behavior by leading to changes in call duration and call rates when comparing manatees' vocalizations in noisy/less noisy conditions (*e.g.*, O'Shea & Poché, 2006; Miksis-Olds & Tyack, 2009; Brady et al., 2023), and addressing the occurrence of acoustic masking and its consequences in manatee vocal communication (*e.g.*, Rivera-Chavarría et al., 2015; Rycyk et al., 2022).

Overall, this review highlighted a wide range of anthropogenic impacts on manatees, as well as a diverse suite of behavioral responses, demonstrating the species' sensitivity and behavioral plasticity in the face of human disturbances. The findings also underscore the importance of expanding research in Central and South America, as well as pointing out important gaps, particularly regarding the effects of in-water recreational tourism and direct human interactions, including the potential of habituation to swimmers and close-range human presence, and the lack of studies identifying manatees' responses to coastal human activities. In addition, there is a notable lack of studies addressing behavioral responses under *ex-situ* conditions and limited information on vessel-related impacts affecting the Greater Caribbean manatee. Future research should prioritize these topics, while also expanding long-term behavioral monitoring across different populations and integrating behavioral, acoustic, and ecological approaches to better understand manatee responses to increasing anthropogenic pressures. Such efforts will provide a stronger scientific basis for conservation planning, mitigation measures, and evidence-based management across different habitats, conservation contexts, and regions with unequal research capacity.

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Supplementary material

Supplementary Material 1- Characteristics of the scientific literature included in the integrative systematic and bibliometric review on acoustic and behavioral responses of the American manatee (*Trichechus manatus*) to anthropogenic disturbances (2000 – 2025).

Supplementary Material 2 - Ethogram of behavioral responses of the American manatee (*Trichechus manatus*) to anthropogenic disturbances identified in the documents included in the integrative systematic and bibliometric review.