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Conservation challenges and emerging threats to the West Indian manatee (*Trichechus manatus*) in Florida and Puerto Rico

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Abstract

Sirenians are experiencing unprecedented anthropogenic threats around the globe due to habitat destruction, interaction with fisheries, collisions with watercrafts, and climate change. Although the West Indian manatee (*Trichechus manatus*) has been protected by law for the past five decades, significant threats persist in the United States. In 2017, the US Fish and Wildlife Service (USFWS) downlisted the West Indian manatee from Endangered to Threatened under the Endangered Species Act of 1973 (ESA). Here, we provide an overview of the current conservation status of manatees in US waters, particularly in Florida and Puerto Rico. In recent years, there has been a marked increase in manatee mortalities in the US. The sources of these mortalities are relatively well known, particularly collisions with watercrafts. However, other sources have recently emerged and constitute threats of increasing concern, particularly resource depletion due to seagrass loss and emerging diseases. Recommendations for future research are proposed to improve our understanding of the magnitude of the threats affecting manatees in the US, and support management decisions and conservation actions.

Keywords:
emerging diseases, seagrass decline, sirenians, unusual mortality events, watercraft collisions

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Introduction

Sirenians are experiencing unprecedented anthropogenic threats around the globe. Specific threats are unique to the regions inhabited by sirenians, and often relate to habitat destruction, interaction with fisheries, collisions with vessels, and climate change. Two subspecies of the West Indian manatee (*Trichechus manatus*) are found in the United States and its territories and commonwealths: the Florida manatee *(T. m. latirostris*), endemic to the southeastern continental US, and the Antillean manatee (*T. m. manatus*) that occurs around the Puerto Rico archipelago, including the US Virgin Islands (Lefebvre et al., 2001; Self-Sullivan & Mignucci-Giannoni, 2012). The West Indian manatee is classified as Vulnerable throughout its range on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Deutsch, 2008; Self-Sullivan & Mignucci-Giannoni, 2008). In the US, the West Indian manatee is listed as Threatened under the Endangered Species Act (ESA) of 1973, which provides a framework for protecting endangered species and their habitat. Manatees in the US are also protected by the Marine Mammal Protection Act of 1972, which prohibits the capture, harassment, killing, and collection of marine mammals in the US. In 2017, the US Fish and Wildlife Service (USFWS) reclassified the status of both subspecies from Endangered to Threatened under the provisions listed in the ESA after analyses of available scientific data (USFWS, 2017).

While manatees are still protected under federal, state, territorial and commonwealth laws, there are growing concerns that multiple threats affecting both subspecies remain inadequately addressed, and that new, poorly understood threats have been emerging (*e.g.,* Allen et al., 2022; Landsberg et al., 2022), particularly over the past decade. The most recent abundance estimate of manatees in Florida was 9,790 individuals (95% Bayesian credible interval, 8,350–11,730) in 2021–2022 (Gowan et al., 2023). However, over

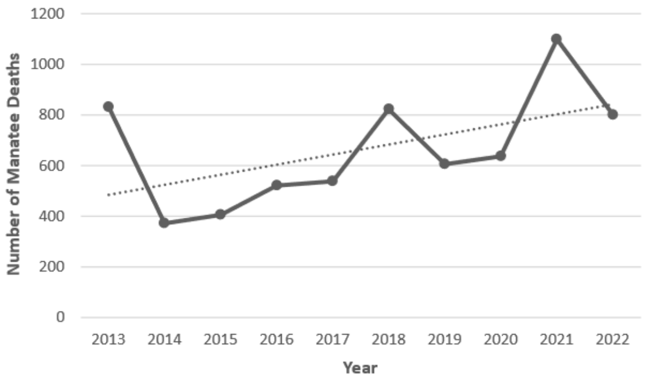

Figure 1. Number of manatee (*Trichechus manatus latirostris*) deaths observed in the state of Florida between 2013 and 2022 (source: FWC, 2023a).

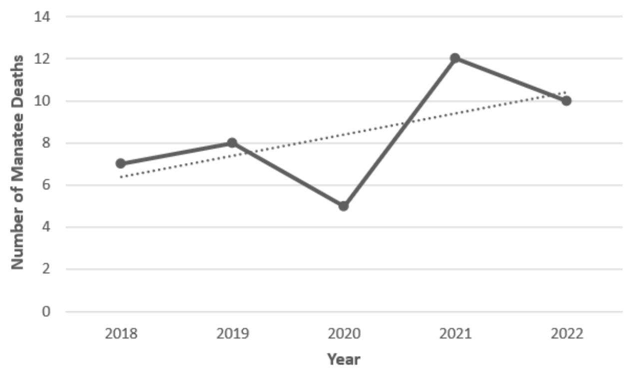

Figure 2. Number of manatee (*Trichechus manatus manatus*) deaths observed in Puerto Rico between 2018 and 2022 (source: USFWS, unpubl. data).

the past 10 years, a steady rise in annual manatee deaths has been recorded (Fig. 1), with 538 individuals recovered in 2017, 824 in 2018, 607 in 2019, and 637 in 2020 (FWC, 2023a). Although not every single manatee mortality is detected, based on abundance estimates in 2021–2022, the proportion of these manatee deaths represents from 4.59%–6.44% to 7.02%–9.87% of the population. There was a 10-year average of 663.20 ± 224.91 (SD) fatalities per year, representing 5.65%–7.94% of the population. In 2021, Florida manatees reached their highest-ever annual observed mortality, with 1,100 carcasses recovered (9.38%–13.17% of the population), exceeding the previous record of 830 (7.08%–9.94% of the population) from 2013. In 2022, this number declined, but remained high, with another 800 manatee deaths reported (6.82%–9.58% of the population) (FWC, 2022, 2023a). Current mortality trends may not be sustainable for the long-term survival of this subspecies.

In Puerto Rico, aerial survey data collected 2010–2014 generated an abundance estimate of 312–535 individual manatees (Collazo et al., 2019). In 2013, the highest annual observed mortality for manatees in Puerto Rico reached 16 deaths (2.99%–5.13% of the population). Since 2013, annual observed mortality has remained high, and has increased in recent years (Fig. 2). Puerto Rico has experienced a 10-year average of 9.20 ± 3.29 (SD) deaths per year (1.72%–2.95% of the population) (USFWS, unpubl. data). Although population abundance and annual mortality data have limitations, this situation raises important concerns about the long-term survival of manatees in Puerto Rico.

The West Indian manatee is a *K*-selected species producing one offspring every one to three years (Beck, 2022). Previous studies suggest that the population size of manatees is increasing in Florida (Runge et al., 2004; Hostetler et al., 2018; Gowan et al., 2023) and Puerto Rico (Mignucci-Giannoni et al., 2018), although rates of increase are low. Today, there is a need to reexamine population abundances and dynamics considering the latest increases in observed mortality rates. Annual mortalities represent a substantial percentage of the population of manatees remaining in Florida and Puerto Rico (Table 1), and the long-term survival of this species could be compromised if anthropogenic mortalities remain high. Newly identified threats, such as resource depletion causing malnutrition in Florida, and the increase of registered watercrafts and collisions in Puerto Rico indicate that manatees in US waters are facing both continued and emerging challenges.

Collisions with Watercraft

Collisions with watercraft remain the leading cause of direct, human-related mortalities among manatees in the US, both in Florida and in Puerto Rico (Mignucci-Giannoni et al., 2000; Bonde et al., 2012; Bassett et al., 2020; USFWS, unpubl. data). Typically, watercraft collisions account for 20–25% of reported annual mortalities in Florida (Calleson & Frohlich, 2007; Runge et al., 2017) and 16.3–29.8% of reported annual mortalities in Puerto Rico (see Supplementary Material 1) (Mignucci-Giannoni et al., 2000; USFWS, unpubl. data). Most manatees bear scars from sublethal collisions with watercrafts. A recent study (Bassett et al., 2020) conducted in Florida between 2007 and 2016 examined 3,786 manatee carcasses and reported that 96% of adults, 70% of subadults, and 34% of calves experienced watercraft-related injuries. In addition, 25% of adults had been struck on ≥ 10 occasions, and five manatee carcasses showed evidence of collision on more than 40 occasions (Bassett et al., 2020). The prevalence and severity of sublethal injuries is correlated to human population densities and vessel traffic, with manatees showing fewer injuries in less populated areas, and a higher occurrence of watercraft-related injuries along the west coast of Florida than along the east coast (Bassett et al., 2020). While manatees often survive, watercraft-related mortalities remain a major issue that has received limited attention. Recently, in Puerto Rico, there has been a rise in the number of personal watercrafts (PWCs, commonly referred to as jet skis) which can traverse shallower areas and narrow mangrove channels at higher speeds than traditional watercrafts. Injuries from these types of watercrafts have been increasingly observed during necropsies over the past two decades (Mignucci-Giannoni et al., 2000; Caribbean Manatee Conservation Center, unpubl. data).

To address the watercraft collision issue, speed zones have been enacted in Florida's coastal counties to mitigate interactions, but not in Puerto Rico. The implementation of slow-speed zones allows greater time for the boat operator to react to manatees and reduces the severity of injuries if a manatee is struck (Calleson & Frohlich, 2007; Rycyk et al., 2018; Udell et al., 2019). Manatees are known to respond to oncoming vessels by changing their orientation, depth, and diving behavior, which suggests that slower boats give more time to manatees avoid vessels (Rycyk et al., 2018). Slow-speed zones contribute to reduce the risk of collision with manatees by 51.5%–70.0% (Udell et al., 2019). However, boaters usually demonstrate low levels of compliance

Table 1. Estimated annual observed mortality of West Indian manatee *Trichechus manatus* populations in Florida and Puerto Rico between 2013 and 2022 (FWC, 2023a; USFWS, unpubl. data). The population size estimate for Florida was 8,350–11,730 in 2021–2022 (Gowan et al., 2023) and 312–535 between 2010–2014 in Puerto Rico (Collazo et al., 2019).

10-Year Mortality Rates of Manatees in the United States							
FLORIDA				PUERTO RICO			
Pop. Estimate	No. Mortalities	Min. % of Pop.	Max % of Pop.	Pop. Estimate	No. Mortalities	Min. % of Pop.	Max % of Pop.
8,350–11,730#				312-535*			
Year				Year			
2013	830	7.08	9.94	2013	16	2.99	5.13
2014	371	3.16	4.44	2014	11	2.06	3.53
2015	405	3.45	4.85	2015	6	1.12	1.92
2016	520	4.43	6.23	2016	10	1.87	3.21
2017	538	4.59	6.44	2017	7	1.31	2.24
2018	824	7.02	9.87	2018	7	1.31	2.24
2019	607	5.17	7.27	2019	8	1.50	2.56
2020	637	5.43	7.63	2020	5	0.93	1.60
2021	1,100	9.38	13.17	2021	12	2.24	3.85
2022	800	6.82	9.58	2022	10	1.87	3.21
10-Yr. Mean ± SD	663.20 ± 224.91	5.65	7.94	10-Yr. Mean ± SD	9.20 ± 3.29	1.72	2.95

#from Gowan et al., 2023 and FWC, 2023a, 2022a

*from Collazo et al., 2019 and USFWS, unpubl. data.

to slow-speed zones. For example, along the Florida Gulf coast, Gorzelany (2004) reported only 63% compliance with speed zones in Sarasota County and 58% in Lee County. Even lower levels were reported in the St. Johns River, where only 45% of boaters complied with slow-speed zones (Jett et al., 2013). Reevaluation of current slow-speed zones in Florida and the implementation of slow-speed and no-entry zones in Puerto Rico would be practical to reduce the likelihood of watercraft strikes in important manatee habitats. Strict enforcement of speed-zones by law enforcement and greater penalties for non-compliance could have a positive influence on boater compliance rates. However, the number of law enforcement entities on the water is likely constrained, particularly because of limited resources and personnel. In Puerto Rico, in addition to marking areas of common manatee presence as slow-speed zone areas, there is a need to designate specific areas as no-entry zones (refuges). Slow speed zone considerations would also be useful, as well as restricting operation of PWCs in important manatee habitats.

Loss of Seagrass

The loss of seagrass ecosystems threatens coastal ecosystems worldwide (Waycott et al., 2009). Food limitation due to the decline of seagrass is an emerging threat that manatees are facing in the Indian River Lagoon (IRL) along Florida's Atlantic coast (see Allen et al., 2022; FWC, 2023b). This area is presently experiencing the consequences of continued harmful algal blooms (HABs) which have resulted in a significant decline of seagrass meadows (Lapointe et al., 2015, 2020, 2023; Morris et al., 2021, 2022). HABs within the lagoon are driven by anthropogenic nutrient input from septic, agricultural, and stormwater runoff from urban land uses (Lapointe et al., 2015, 2020, 2023; Brewton & Lapointe, 2023). Beginning in 2011, a major HAB caused a greater than 50% decline in seagrass throughout the lagoon (Morris et al., 2021, 2022). HABs create hypoxic conditions (Lapointe et al., 2015, 2020), increasing turbidity and low light conditions that block out the sunlight needed by photosynthetic seagrass (Morris et al., 2021, 2022). These conditions have persisted for consecutive years, resulting in a regime shift from seagrass- to phytoplankton-dominated primary production (Phlips et al., 2015, 2021; Allen et al., 2022). In the winter of 2020–2021, an unusual mortality event (UME) began along the east coast of Florida, with over 1,000 manatee deaths recorded (FWC, 2022, 2023b; NOAA, 2023); this UME was still ongoing at the time this manuscript was written. The FWC reported that 582 carcasses in the winter of 2020–2021 and 457 in the winter of 2021–2022 exhibited signs of emaciation due to malnutrition (FWC, 2023b). The analysis of stomach contents from manatee carcasses collected in the IRL between 1977–1989 showed that manatees primarily consumed seagrass (61.7%), followed by macroalgae (28.4%); conversely, stomach contents collected in 2013–2015 showed a 44.9% decline of seagrass consumption and a 74.3% increase in macroalgae consumption (Allen et al., 2022). The long-term health and population-level consequences of this dietary shift remain poorly understood, but the extensive consumption of macroalgae might prevent manatees from fulfilling their energetic requirements. Landsberg et al. (2022) investigated an earlier UME in the IRL (2012-2019), finding that mortalities occurred due to clostridiosis (toxic effects from *Clostridium difficile*) and hypothesized that a low-fiber diet (macroalgae) may have caused gastrointestinal lesions providing a route for clostridial infection. Future research should investigate the influence of forage quality and selection on energy intake by manatees and how it could affect individual fitness and survival.

Because marine mammals are large organisms with high energetic requirements, dietary shifts in some species have the potential to lead to decreasing body condition and fitness, reducing individual survival and overall population decline (Rosen & Trites, 2000; Osterblom et al., 2008). This increasing mortality due to malnutrition as exhibited in the IRL could be more widespread throughout the distribution range of manatees, as eutrophication similarly impacts submerged aquatic vegetation and seagrass meadows in other regions of Florida such as Biscayne Bay (Caccia & Boyer, 2007; Lirman et al., 2014; Millette et al., 2019), Caloosahatchee River and Charlotte Harbor (Doering et al., 2006; LaPointe & Bedford, 2007), Florida Bay (Hall et al., 2016; Cole et al., 2018; Gilbert et al., 2021), and Tampa Bay (Beck et al., 2022;

Morrison et al., 2023). There is a need for concerted efforts to restore seagrass meadows and limit existing sources of nutrients (*e.g.,* nitrogen and phosphorus) entering Florida's waterways. It also becomes critical to address the issue of septic tank leakage along the coasts of Florida, as human waste remains the main source of anthropogenic nutrients entering the IRL (Lapointe et al., 2020, 2023; Brewton & Lapointe, 2023) and other areas.

Closure of Power Plants

Manatees in subtropical latitudes need warm water to regulate their body temperature and avoid cold-induced stress and mortality. When temperatures decrease in Florida, manatees typically migrate to warm water sources at power plants (warm water outputs used to cool power generation sources), passive thermal basins, and natural artesian springs (Laist et al., 2013; Sattelberger et al., 2017). The presence of power plants along the Florida coastline has allowed manatees to expand their range further north, but animals have become dependent upon such warm water sources during cooler winter months (Laist & Reynolds, 2005; Laist et al., 2013). Power plants supply thermal refuges for significant numbers of manatees when water temperatures decrease and lessen the potential for manatee mortalities related to cold-stress syndrome (Laist & Reynolds, 2005; Laist et al., 2013). A study found that 48.5% of manatees counted across Florida during winter months depend on power plant outputs for warmth, with manatees in the Southwest Florida and Atlantic Coast subpopulations relying on power plants more heavily than others (Laist et al., 2013). Although positive for the environment, outdated power plants are being replaced by more efficient power generating stations, while some are being closed entirely, which can pose adverse consequences for manatees (Laist & Reynolds, 2005).

The modernization, improved optimization, and closure of power plants will negatively affect manatees in their ability to find necessary warmth during cool, winter months. More efficient power plants create less warm-water output, reducing space for manatees needing to use these warm-water sources; closures will completely remove these warm-water sources. As global impacts of climate change increase the potential for more extreme weather events, the loss of these warm-water sources will be detrimental for manatees. Alternative options to these reductions or losses in warm-water resources will be essential for supporting manatee populations during the winter.

Climate Change

Climate change can affect manatees directly and indirectly. The increasing frequency of cold fronts and extreme weather events (*e.g.,* hurricanes) will increase the risk of mortalities (Edwards, 2013; Marsh et al., 2017; Hardy et al., 2019). The direct climate-related impacts and threat of increased frequency and duration of cold fronts in Florida are worsened by the closure of power plants which will reduce or eliminate the number of available refuge sites for manatees. Climate change is also related to the increasing occurrence and severity of harmful algal blooms (HABs) (Marsh et al., 2017; Gobler, 2020). HABs are directly impacting manatees through direct toxic effects (*e.g.,* red tide) (Landsberg et al., 2014; Walsh et al., 2015; Marsh et al., 2017) and indirectly by increasing seagrass mortality and decline (Lapointe et al., 2015, 2020; Phlips et al., 2015, 2021; Morris et al., 2021, 2022; Allen et al., 2022). Climate warming in tropical and subtropical ecosystems will most likely accelerate the decline of seagrass, particularly in south Florida and in Puerto Rico. However, in the southeastern continental US, the colonization of warm coastal temperate ecosystems by tropical and subtropical seagrass species will likely affect the distribution of the Florida manatee. There remain gaps in our understanding of the synergistic effects of climate change on sirenians in general, including in the Gulf of Mexico and in the wider Caribbean region where changes have already been detected (Cloyed et al., 2022).

Emerging and Unknown Pathogens

There is a rising threat of new and unknown pathogens among marine mammal populations (Bossart, 2007; Bossart et al., 2012; Sulzner et al., 2012; Bossart & Duignan, 2018; Mignucci-Giannoni et al., 2022). In Florida, there are preliminary, unpublished reports of manatees suffering from unknown conditions due to bacterial, fungal, or viral sources (*e.g.,* Vorbach et al., 2017). In Puerto Rico, there is an increasing prevalence of toxoplasmosis (Fig. 3), leptospirosis, and other infections possibly due to runoff of pathogens from land sources (*e.g.,* feral cat feces) that has been observed in pathologic findings from necropsies (Bossart, 2007; Bossart et al., 2012; Mignucci-Giannoni et al., 2022). This has resulted in 10–15% of annual manatee mortalities (see Supplementary Material 1) in Puerto Rico between 1980 and 2022 (Mignucci-Giannoni et al., 2000; USFWS, unpubl. data). Declining environmental conditions and the impact of climate change can worsen the effects of naturally occurring diseases and promote the exposure of manatees to new pathogens (Harvell et al., 2002; Lafferty, 2009; Sanderson & Alexander, 2020). Identifying the causes, effects, and prevalence of new and emerging sources of disease in manatees is of key importance. Additionally, finding methods to clinically treat these conditions will be critical, particularly in Puerto Rico, as the population of Antillean manatees is small and geographically isolated (Lefebvre et al., 2001).

Figure 3. A stranded Antillean manatee *Trichechus manatus* tested positive and died from toxoplasmosis in Puerto Rico, photo by A.A. Mignucci-Giannoni.

Invasive Species

Invasive species are affecting a wide range of terrestrial and marine ecosystems around the globe (Molnar et al., 2008; Gallardo et al., 2016). Manatees in Florida and Puerto Rico are facing two distinct types of invasive species, and the full extent of their influence is currently unknown.

Figure 4. A resting Florida manatee *Trichechus manatus latirostris* in a spring with eight invasive armored catfish *Pterygoplichthys disjunctivus* on its dorsum, photo by A.C. Allen.

Important freshwater habitats in Florida, particularly springs, have seen an influx of both invasive fish and plant species. Disturbance of manatees by invasive armored catfish (*Pterygoplichthys disjunctivus*) has been recorded (Fig. 4), where these fish feed on the epibionts that grow on manatees (Nico, 2010; Nico et al., 2009). These interactions have been shown to elicit negative reactions from manatees as they attempt to dislodge the fish (Nico et al., 2009). Harassment from catfish can cause disruption of resting and foraging activities, and cause manatees to leave these sources of warm-water during winter months, thus exposing them to acute, cold temperatures. Additionally, as the populations of these invasive catfish grow (Nico et al., 2009, 2012), increasing interactions with manatees should be expected and should be investigated.

Halophila stipulacea is a species of seagrass native to the western Indian Ocean and the Red Sea but has been introduced into the Mediterranean and tropical western North Atlantic (Ruiz & Ballantine, 2004). This invasive seagrass has spread throughout the Caribbean since the early 2000s and has now been established in Puerto Rico and the Virgin Islands (Ruiz et al., 2017; Willette et al., 2014, 2020), but has not yet been recorded in Florida. Other megaherbivores such as the green turtle (*Chelonia mydas*) in the southeastern Caribbean exhibit a range of responses to the presence of *H. stipulacea* (Becking et al., 2014; Christianen et al., 2018; Whitman et al., 2019). Thus, in Bonaire, Guadeloupe, and Martinique in the Lesser Antilles, green turtles have a significant preference for native seagrass species such as *Thalassia testudinum* and *Syringodium filiforme* and tend to avoid consuming *H. stipulacea* and the areas colonized by this species (Christianen et al., 2018 Siegwalt et al., 2022; Whitman et al., 2019). The current importance of *H. stipulacea* in the diet of Antillean manatees is unknown. However, in Jobos Bay, Puerto Rico, manatees have opportunistically been observed consuming it (A. Dieppa, Jobos Bay National Estuarine Research Reserve, pers. comm., 1 August 1, 2023). *H. stipulacea* is a rapid colonizer with high seed production, and has been shown to replace native seagrass, particularly *T. testudinum*, *S. filiforme*, *Halodule wrightii*, and endemic *Halophila* spp. (Winters et al., 2020). By removing rhizomes or extensively cropping leaf canopies, manatees have the potential to facilitate the spread of invasive *H. stipulacea* in the Caribbean region. Presently, there is no information on the impact of *H. stipulacea* on habitat use and trophic interactions of manatees in Puerto Rico. Other exotic plant species such as *Hydrilla* sp. and water hyacinth (*Pontederia crassipes*) are increasing in abundance in waterways in Florida and in inland lakes and channels in Puerto Rico. These invasive plants are known to be consumed by manatees. Although the importance of these plants in the manatee diet are not well known, they can supply a plentiful and economic resource to feed rescued manatees in rehabilitation settings (Allen & Keith, 2015), including the use of *H. stipulacea* for rehabilitating manatees in Puerto Rico (Mignucci-Giannoni, 2019). Future research should investigate interactions between manatees and invasive plant species, such as *H. stipulacea*, and assess the role that manatees might have in facilitating or reducing the spread of these species. If invasive plants are consumed by manatees, there is a need to further understand the energetic impact that their consumption will have.

Other Threats

Other threats to manatees occur in the waters of Florida and Puerto Rico. Marine debris of various sizes and sources causes problems for manatees when ingested (*e.g.*, intussusception, gastrointestinal impaction, peritonitis); abandoned fishing gears (lines, hooks, nets, and traps) and other large debris can also cause entanglement, injuries, and mortalities (Beck & Barros, 1991; Reinert et al., 2017). Manatees are also exposed to a range of other contaminants. Persistent organic pollutants (POPs) such as hydrocarbons, organochlorines, and organohalogens (Ames & Van Vleet, 1996; O'Shea et al., 1984); per- and polyfluoroalkyl (PFAs) such as perfluorononanoic, carboxylic, and sulfonic acids (Griffin et al., 2021; Palmer et al., 2019); and heavy metals (O'Shea et al., 1984; Siegal-Willott et al., 2013; Stavros et al., 2008; Takeuchi et al., 2016) have been found in high concentrations in manatee tissues. The health risk that these contaminants pose on manatees is not well known.

Habitat loss and degradation also pose a significant risk to manatees (Castelblanco-Martínez et al., 2012; Runge et al., 2017). With over 22 million people, Florida is the third most populous U.S. state, representing over 6.5% of the country's entire population, and is one of the fastest growing states in the country (EDR, 2023; U.S. Census Bureau, 2019, 2020). Nearly 1,000 people move to Florida every day (EDR, 2023). Development on near critical manatee habitats (Castelblanco-Martinez et al., 2012; Marsh et al., 2017; Packard & Wetterqvist, 1986) and the consumption of natural resources such as fresh water could pose a significant risk to manatees and aquatic habitats (Bulleri & Chapman, 2010; Rubec et al., 2021; Tsou & Matheson, 2002). Between 1845 and the late 1990s, Florida lost nearly half of its wetland habitats (Dahl, 2005). Coastal development has fragmented submerged aquatic vegetation (Santos et al., 2015), and Florida residents consume over 6 million gallons of freshwater per day (Marella, 2015), which will rise with a growing population. Additionally, increasing disturbance from tourism and recreational activities, like wildlife viewing activities, fishing, and boating, may have potential negative impacts on manatees (Allen et al., 2014). Manatees in the U.S. are exposed to multiple, cumulative impacts throughout their range, and major efforts will be required to reduce threats on both Antillean and Florida manatees to ensure their future survival.

Research Recommendations

Manatees in Florida and Puerto Rico face multiple threats, including some that have been well documented, while others remain poorly understood. Additional research is necessary to inform policy makers and support management decisions and conservation actions that target manatees and their habitats. We propose the following recommendations for future research:

1. Analyze the dynamics of manatee morbidity and mortality (both in Florida and Puerto Rico) to identify anthropogenic impacts, both in space and time. This will have to be accompanied by a more systematic assessment of the cause of death of manatees.

2. Continue to monitor manatee abundance, distribution and movements through aerial surveys and telemetry studies, and expand assessments and monitoring programs to areas where research efforts have historically been limited.

3. Identify sources of anthropogenic nutrient input (*e.g.,* nitrogen and phosphorus) into coastal watersheds and investigate methods to improve water quality and reduce the effects and duration of harmful algal blooms.

4. Evaluate the continued threat from watercraft collisions and identify more effective methods to mitigate their impacts.

5.Determine the effects and prevalence of emerging diseases (*e.g.,* toxoplasmosis), particularly associated with growing feral cat populations in Puerto Rico, and what effect legacy and emerging contaminants have on the health of manatees.

6. Investigate the feeding ecology of manatees and the drivers of food selection, particularly considering macrophyte community changes, both in Florida and Puerto Rico.

7. Assess the impacts of invasive species (*e.g.,* fish, seagrass) on forage selection and habitat use of manatees.

8. Model the effects of climate change on the distribution, behavior and ecology of manatees using existing time-series data (mortality, distribution, and abundance survey data from multiple regions).

Conclusion

Here, we reviewed the most significant threats that manatees are facing in Florida and Puerto Rico, where growing human populations are expected to increase the severity of these threats. Today, there is an urgent need to better understand their magnitude and to mitigate these impacts. Along with research, community outreach is also critically needed, both in Florida and Puerto Rico, to address and educate people through bringing awareness about the threats that manatees are facing. A detailed assessment of public perceptions towards conservation measures (*e.g.,* increase of slow-speed zones and creation of no-entry zones to reduce watercraft collisions, reduction of anthropogenic nutrients) is also recommended, along with outreach campaigns that will incentivize the public to change attitudes (*e.g.,* boating practices, water consumption, fertilizer use). Additionally, it would be appropriate for the USFWS to conduct a comprehensive review of the current status of manatees in the US as required by the ESA, with consideration of emerging threats.

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Supplementary material

Supplementary Material 1 - Annual manatee mortality data for Puerto Rico (1980-2022). Source: CMCC, USFWS, PRDNER