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Marine turtles, umbrella species undergoing recovery

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Marine turtles inhabit various coastal and marine ecosystems and play significant ecological roles throughout their life cycles. Because of the significant overlap with other species at risk in their geographic ranges, the successful conservation of marine turtles also protects numerous co-occurring species, a phenomenon known as the "umbrella species effect." Since several marine turtle populations have shown positive trends, suggesting incipient recovery, it is expected that their umbrella characteristics will coevolve as their populations grow and expand. Recognizing the considerable potential of marine turtles as umbrella species, we advocate for promoting this concept and explicitly integrating it into management and recovery programs. This approach would facilitate concurrent benefits not only for marine turtles but also for other species and their associated habitats. To achieve this goal, we analyzed the conservation status of marine turtles in the Gulf of Mexico and Western Caribbean within the framework of the legal regulations. Additionally, we reviewed the current challenges in marine turtle recovery in the framework of ecological restoration, while also aiming to target and encourage their utilization as umbrella species.

KEYWORDS

population recovery, ecological restoration, management investment, operational ecology, strategic planning

1 Introduction

Given the intensive human extractive activities in our marine and coastal habitats, such as oil industries and fisheries, environmental assessments by regulatory authorities and interested private entities (operating corporations, financing groups, and insurers) require access to reliable information on marine ecosystems (Golf Coast Ecosystem Restoration

Task Force, 2012). There are noteworthy examples of multinational and multi-institutional monitoring initiatives (e.g. GEOBON, OBIS-SEAMAP) that provide this necessity (Halpin et al., 2009; Navarro et al., 2017). Endangered and vulnerable indicator species become the focal point of management, conservation, and restoration efforts that promise the highest returns while incurring no losses and yielding net gains for biodiversity and ecosystems (Gilby et al., 2017; Zhang et al., 2020).

Umbrella species are taxa with such an extensive habitat requirements that management and restoration efforts targeted at them are predicted to benefit co-occurring species (Simberloff, 1998). Consequently, conserving these species offers protection to a broad array of co-occurring species (Roberge and Angelstam, 2004), and are valuable to support restoration actions (Mekonnen et al., 2022). These species represent an opportunity to maximize mitigation, compensation, and restoration efforts, promoting the protection and amelioration of habitat quality and viability of other co-occurring species of interest, yielding the greatest benefits to impacted ecosystems.

Endangered marine turtle species, hawksbills (*Eretmochelys imbricata*), green turtles (*Chelonia mydas*), loggerheads (*Caretta caretta*), Kemp's ridleys (*Lepidochelys kempii*), and leatherbacks (*Dermochelys coriacea*), are of significant ecological importance because of their roles on habitat and community maintenance and connectivity, among others, as we describe further (Wallace et al., 2011; Valverde and Holzwart, 2017). They inhabit critical basins, including the Gulf of Mexico (GoM), where extensive extractive activities (oil extraction, fisheries) and other threats (hurricanes, tourism, chemical pollution) are frequent (Aleksa et al., 2018; Hart et al., 2018; Gradzens and Shaver, 2020; Iverson et al., 2020; Uribe-Martínez et al., 2021).

As top predators inhabiting various habitats throughout their life cycles, marine turtles are a recognized natural umbrella species, exerting influence on the structure and function of their ecosystems through both inter and intraspecific interactions (Kalinkat et al., 2017; Hazen et al., 2019). These interactions encompass several aspects, for example, maintenance of strong competitor species on coral reef ecosystems (Goatley et al., 2012), including sponges (León and Bjorndal, 2002); promotion of carbon sequestration in seagrass meadows (Johnson et al., 2020), which is important for mitigating CO_2 levels in the environment; contribution to nutrient flow, nesting females enhance nutrient flow between marine and terrestrial ecosystems by introducing organic matter to beaches when they lay their eggs, benefiting dune plant communities (Hannan et al., 2007). Other biological features that confer umbrella species status to marine turtles include their wide geographic distribution which implies a broad utilization of multiple coastal, neritic, and oceanic habitats throughout their lifetimes, long dispersal and migration movements that connect ecosystems (Plotkin, 2003), and all the interactions they engage during their prolonged life histories.

Exposure to natural and anthropogenic disturbances can disrupt their population dynamics and hinder their ability to fulfill their ecosystem functions efficiently (Bjorndal and Bolten, 2003; Gaus et al., 2019). Therefore, efforts to facilitate the recovery of marine turtles and enhance the ecological health of their habitats contribute to management strategies aimed at mitigating significant adverse changes and maintaining the health and resilience of oceans, and are expected to also benefit other key species and ecosystems (Fleishman et al., 2000; Roberge and Angelstam, 2004; Goatley et al., 2012; Bjorndal et al., 2017; Wildermann et al., 2018; Almpanidou et al., 2019; Dickson et al., 2022; Mekonnen et al., 2022).

Recently, Calderon-Aguilera et al. (2021) and Wabnitz et al. (2010) placed marine turtles at the highest levels of the marine trophic webs they assessed, describing several positive and negative interspecific interactions of marine turtles with ecologically and economically important species. The latter supports the fact that marine turtles play a multifaceted role in ecosystem dynamics and functions, and their presence in turn has far-reaching effects on the viability of the ecosystems they inhabit, making them pertinent umbrella species (Eckert and Hemphill, 2005; Hannan et al., 2007; Rousso et al., 2015; Cárdenas and Lew, 2016; Johnson et al., 2020; Mortimer et al., 2021; Scott et al., 2021; Wulf, 2021; Ashford et al., 2022; Guzmán-Hernández et al., 2022; Liceaga-Correa et al., 2022; Li et al., 2023).

From this perspective, it is strategic to formally introduce into management and mitigation discussions how the recovery or restoration efforts of umbrella species, such as marine turtles, contribute to better focus decision-making, restoration, and conservation planning, to maximize the returns on investments. In this context, we summarized and presented some highlights on (i) the legal framework and conservation status of marine turtles in the Gulf of Mexico (GoM) and Western Caribbean, as well as some indicators of their conservation status and how these provide a positive cascading effect onto habitat management, (ii) how marine turtle restoration is taking place, along with some ecological and management implications, and (iii) how appropriate management and restoration actions regarding marine turtles as umbrella species are expected to increase the benefits of public and private investments.

The analysis presented in this article primarily focuses on marine turtle populations in the GoM and Western Caribbean due to the authors' expertise; however, the analysis of ecological management and the umbrella species approach is applicable to other regions because it is based on their geographic coexistence with other species and their habitats, as well as their intra and interspecific ecological interactions they have, and we will present some examples from other regions.

2 Legal framework and cascading habitat management

The seven marine turtle species are included in the Red List of Threatened Species (three under Vulnerable category, two Critically endangered, one Endangered, and one Data deficient, Table 1) (Seminoff, 2004; Webb, 2008; Mortimer and Donnelly, 2008; Wallace et al., 2013; Casale and Tucker, 2017; Wibbels and Bevan, 2019). In Mexico, marine turtles are protected by the Mexican Official Norm NOM-059-SEMARNAT-2010 (DOF, 2019), which lists all species inhabiting Mexican territory as Endangered.

TABLE 1 Main characteristics for each marine turtle species, as well as the Red List of Ecosystems they occupy and the Priority Marine Sites they inhabit in the southern Gulf of Mexico.

Marine turtle species (IUCN Red List global status)	Prey species	Predator species	Other spatiotemporal coincident species	Occupied habitats	Occupied IUCN Ecosystems	Key species in "Priority Marine Sites"	References
Hawksbill turtle (*Eretmochelys imbricata*) (Critically endangered)	Sponges, lobsters, octopuses, sea urchins	Tiger shark	Mollusks, crustaceans, fishes, echinoderms	Coral reefs, sargassum rafts, rocky reefs, coastal lagoons, mangroves	Marine Shelf Biome, Pelagic Ocean waters biome	Anchovy, mangroves, birds, crocodiles, among others	van Dam and Diez, 1998; Heithaus et al., 2008; Goatley et al., 2012; Keith et al., 2020.
Green turtle (*Chelonia mydas*) (Endangered)	Mainly Seagrasses and/or marine algae	Tiger shark	Mollusks, crustaceans, fishes, seagrasses	Shallow, nearshore and reef areas of abundant seagrass and algae	Marine Shelf Biome, Pelagic Ocean waters biome	Anchovy, mangroves, crocodiles, among others	Musick and Limpus, 1997; Heithaus et al., 2008; Keith et al., 2020; Howell and Shaver, 2021.
Loggerhead turtle (*Caretta caretta*) (Vulnerable)	Primarily benthic invertebrate, mollusks, crabs, decapods, bivalves, gastropods	Tiger shark	Corals, invertebrates, birds, marine mammals	Coral reefs, nearshore ecosystems	Marine Shelf Biome, Pelagic Ocean waters biome	Elkhorn coral (*Acropora palmata*), brain coral (*Meandrina meandrites*), seagrasses	Plotkin et al., 1993; Heithaus et al., 2008; Ernst and Lovich, 2009; Keith et al., 2020.
Kemp's ridley turtle (*Lepidochelys kempii*) (Critically endangered)	Primarily based on crabs, and occasionally includes clams, shrimp, jellyfish, and some fish species	Bull shark	Mollusks, crustaceans, fishes, marine mammals	Shallow bays with sandy and/or muddy bottoms	Marine Shelf Biome, Pelagic Ocean waters biome, Anthropogenic marine biome	Marine mammals	Metz, 2004; Miller, 2017; Keith et al., 2020; Reyes-López et al., 2021
Leatherback turtle (*Dermochelys coriacea*) (Vulnerable)	Gelatinous zooplankton prey, primarily jellyfishes	Tiger shark occasionally	Sponges, corals, fishes, reptiles, seagrasses	Along physical oceanic boundaries that aggregate prey in the open ocean and coastal habitats	Marine Shelf Biome, Pelagic Ocean waters biome	Elkhorn coral (*Acropora palmata*), brain coral (*Meandrina meandrites*)	Hays et al., 2006; Heithaus et al., 2008; Aleksa et al., 2018; Sasso et al., 2021

The International Union for Conservation of Nature (IUCN) has also published a Red List of Ecosystems, many of which are inhabited and critical for maintaining the life cycle of marine turtles (Keith et al., 2020) (Table 1). Also, in the southern GoM, in Mexican waters, the National Commission for Biodiversity Knowledge in Mexico (CONABIO, in Spanish) has defined Priority Marine Sites (PMS), which harbor high marine biodiversity under distinct levels of threat (CONABIO et al., 2007). Marine turtles occupy several of those threatened ecosystems listed by IUCN and the PMS (Table 1), interacting with numerous key species (Liceaga-Correa et al., 2022). Any conservation and management action implemented on those sites targeting marine turtles is expected to integrally benefit the ecosystem.

The co-occurrence of marine turtles with other species of ecological (also Endangered) and economic interest (for fisheries and tourism) has been documented, highlighting their relevance as umbrella species for management, conservation, and restoration strategies (Gradzens et al., 2014; Hammerschlag et al., 2015; Hays et al., 2019). Knowing about such interactions helps management planning and restoration actions targeting marine turtles that could benefit other relevant species, making resource investment more effective and efficient. One key interspecific interaction is predation; marine turtle preys (seagrasses, jellyfish, lobsters, octopuses, crabs, and sponges) also have important ecosystem functions, and as they are essential food sources for endangered marine turtles, their management and conservation relevance scale up (Hamann et al., 2010) (Table 1).

Since 1986, 16 sanctuaries on marine turtle nesting beaches in Mexico were designated as natural protected areas (DOF, 2022). These sanctuaries serve as refuges for protecting, conserving, rewilding, developing, and controlling the nesting habitats of marine turtles in Mexico. This designation recognizes that these areas host a significant richness of flora and fauna, including species and habitats with restricted distribution, and encompass topographic units that require protection. Notably, this includes dune vegetation and mangrove communities (also Threatened and protected in Mexico; DOF, 2003; DOF, 2019) because they are vital for the marine turtle life cycle during nesting, foraging, and

development stages. Most of those sanctuaries are adjacent to high and very high ecological integrity areas (Figure 1) (CONABIO, 2018), as well as high and extreme restoration priority sites (CONABIO, 2016). These sanctuaries also enforce administrative rules regarding public usage of these areas, primarily permitting only scientific research, conservation efforts, ecological restoration, and low-impact non-extractive activities. These management actions focused on conserving marine turtle populations have legal conservation status with cascading effects benefiting the flora and fauna species that share these habitats with marine turtles, even when marine turtles are not nesting, as the administrative rules persist (Comisión Nacional de Áreas Naturales Protegidas, 2018). Also, given the interactions between marine turtles with dune vegetation and mangroves, specific management actions about connectivity and fluxes are expected to be considered in the conservation programs of those natural protected areas (Comisión Nacional de Áreas Naturales Protegidas, 2018).

Marine turtles have also influenced management and conservation actions for their in-water habitats, such as coral reefs and the extensive Caribbean seascapes they inhabit. Chevis et al. (2017) argued for the implementation of conservation measures on coral reefs in Belize due to the presence of hawksbill turtles, as these turtles significantly impact the ecological integrity of the coral reefs. Additionally, Eckert and Hemphill (2005) emphasized the importance of considering the use of the Caribbean by marine turtles when analyzing management actions in this vast basin. These examples illustrate how these species strongly influence the ecosystems they inhabit.

3 Recovery of marine turtles and some implications

Ecological restoration discipline has scarcely focused on the recovery of fauna populations and their interactions (SER, 2004; McAlpine et al., 2016; Palmer et al., 2016); however, a singular interest in recovering endangered marine species, their critical habitats, and their ecological functions has constantly increased in the last decades (Bayraktarov et al., 2016; UNEP, 2021); acknowledging fauna as a key ecosystem element that facilitates a balanced recovery of ecosystem functions (Volis, 2019). Umbrella species may maximize management and restoration efforts and investments, increasing the likelihood of recovery of many associated species that may be in critical condition.

Marine turtles are an excellent example of umbrella species because they have a top-down cascading influence on populations of other species that share the same habitat. This influence is associated with their cohabitation in areas where other threatened species are present; therefore, the implemented restoration, and management actions amplify their ecosystem benefit. Additionally, a positive influence arise from the ecological functions performed by viable and healthy marine turtle populations, which, in turn, benefit other species by maintaining the habitat where they coexist.

Marine turtles occupy various marine ecosystems throughout their life history, such as lagoons, mangroves, coastal dunes, and oceanic habitats. They play a role in attracting management actions that benefit other species through cohabitation and ecological interactions, facilitating an umbrella cascade effect, and making them strategic target species for an integrated biodiversity management and restoration approach (Bjorndal et al., 2011; Webb, 2012; Oliver et al., 2015; Bayraktarov et al., 2016; DWH NRDA Trustees, 2016; Molinos et al., 2016; Guzmán Hernández et al., 2019; Hays et al., 2019; Open Ocean Trustee Implementation Group, 2019; Frasier et al., 2020; Ashford et al., 2022).

For instance, concerning conservation and restoration policies, the recovery plans for marine turtles in several countries (such as Antigua and Barbuda, Aruba, Mexico, Panama, Trinidad and Tobago, to name a few) emphasize the need to protect and restore dune vegetation communities, mangroves, coral and rocky reefs, seagrasses, and sandy

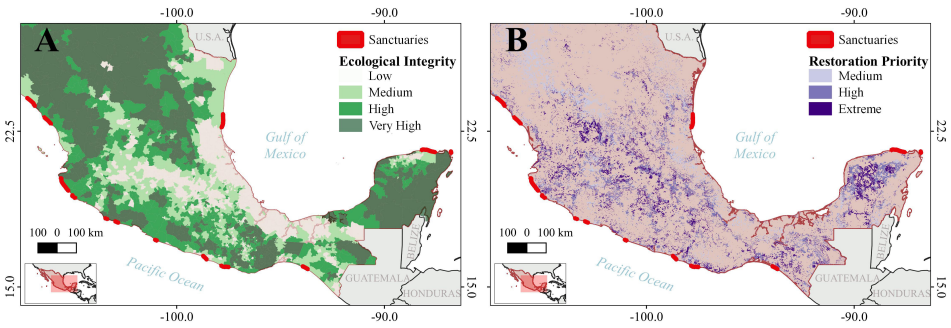

FIGURE 1
Geographic distribution of the 16 marine turtle sanctuaries in Mexico with conservation status for nesting habitats (Comisión Nacional de Áreas Naturales Protegidas, 2023). Ecological Integrity **(A)** measures the ecological value of ecosystems, aiming for sustainable development based on a set of ecological features (human impact, self-organization, trophic mobility, and stability) of the species and their habitats (CONABIO, 2018). Restoration priority **(B)** evaluates the biological value of significant areas and in terms of these results, identifies the extent of required restoration actions that will ensure the persistence of their biodiversity, ecological functions, and ecosystem services in the long term. These evaluations guide Mexico's actions to accomplish Goal 15 of the Aichi Convention (CONABIO, 2016).

beaches (Fuller et al., 1992; Barmes et al., 1993; Ruiz et al., 2007; WIDECAST, 2010; SEMARNAT, 2018a; SEMARNAT, 2018b; SEMARNAT, 2018c; SEMARNAT, 2018d; SEMARNAT, 2020). These plans also aim to strengthen the economic resilience of coastal communities to improve their welfare and facilitate the understanding and conservation of marine turtle species. These solutions were established in those public policy instruments under the influence of the marine turtle umbrella effect due to their interactions with socio-environmental components and their cohabitation.

Successful marine turtle restoration programs have also been documented (Mazaris et al., 2017; Godley et al., 2020), and one of the species with outstanding results is *C. mydas*, with some examples of effective population recovery in the Gulf of Mexico (Fuentes et al., 2013; Piacenza et al., 2016; López-Castro et al., 2022; Del Monte-Luna et al., 2023). *C. mydas*, considered an umbrella species, has led to the discovery of previously unknown seagrass meadows (Hays et al., 2018) and highlights the positive interactions between turtles and seagrasses (Christianen et al., 2011; Atwood et al., 2015; Johnson et al., 2020), as well as the connectivity benefits provided by green turtles for seagrass meadows (Patrício et al., 2022). However, this success also poses new challenges for lower trophic communities, and a potential imbalance in restoration actions could lead to significant ecological impacts as rapid green turtle populations recovery is impacting the viability of some seagrass meadows because of the higher foraging intensity on them (Murdoch et al., 2007; Fourqurean et al., 2010; Heithaus et al., 2014; Molina-Hernández and van Tussenbroek, 2014; Ramesh et al., 2018; Esteban et al., 2020; Christianen et al., 2021; Gulick et al., 2022).

As we implement robust, synchronized monitoring strategies for the different populations' vital signs and the performance of management actions (Halpern et al., 2008; Love et al., 2017) for marine turtles and other species, we will gain more robust empirical understanding of how the umbrella species effect operates. Meanwhile, significant baseline knowledge regarding the spatiotemporal distribution of marine turtles has been established, particularly in the Gulf of Mexico, over the past 15 years (e.g., Cuevas et al., 2008; Girardt et al., 2009; Shaver et al., 2013; Cuevas et al., 2020; Gradzens and Shaver, 2020; Hart et al., 2020; Iverson et al., 2020; Evans et al., 2021; Cuevas et al., 2022).

Marine turtles' populations recovery will make their intra and interspecific interactions more intense and extended, reaching levels and spaces that we may not have been previously recorded. The later examples show how the recovery of an umbrella species provokes benefits (protect blue carbon stocks, fertilize vegetal communities) and impacts on communities associated with habitats that marine turtles occupy (may degrade seagrass resilience and viability). These cases may be understood as ecological cascades (Polis et al., 1997) implied by the umbrella effect of marine turtles.

4 Discussion

The need to integrate fauna recovery actions has become more evident as they drive vital ecological processes and functions (Cristescu et al., 2013), and are fundamental for ecosystems' stability and health (see Hannan et al., 2007; and Guzmán-Hernández et al., 2022 for a discussion). Fauna species are crucial elements for ecosystem restoration, particularly those classified as umbrella species, as they strongly contribute to the recovery of associated species and ecosystem functionality. This represents a significant challenge that requires important efforts and investment (Cross et al., 2020) to promote the recovery of the composition, structure, and functions of habitats based on previous conditions before degradation or a specific reference time to realize the optimal dynamics of ecosystems.

Nevertheless, it may still be controversial whether an umbrella species can effectively promote the conservation of associated species (Caro and O'Doherty, 1999). Andelman and Fagan (2000) and Roberge and Angelstam (2004) emphasized the need for deeper empirical assessments demonstrating the benefits of adopting the umbrella species approach. We acknowledge the need for generating further examples of the umbrella effect afforded by the conservation efforts on marine turtles, and admit that there have been cases where biased restoration actions may have disrupted ecological interactions in some ecosystems. Nevertheless, we have presented robust examples that illustrate how management, conservation, and restoration actions targeting the recovery of marine turtle populations benefit other flora and fauna species and human communities due to the interspecific linkages that marine turtles establish. We believe that sufficient empirical knowledge supports the management approach based on marine turtles as umbrella species, as recognized and implemented in public policy instruments in several countries.

In this regard, it is undeniable that high trophic level species influence numerous lower ecological interactions among species that are directly and indirectly associated with umbrella species, such as marine turtles. Therefore, an approach based on marine turtles opens a window of opportunity to contribute to a better understanding (Zacharias and Roff, 2001) and implementing management, conservation, and restoration actions that also benefit other coastal (dune vegetation, mangroves) and marine species (corals, seagrasses, nesting marine birds). Furthermore, they have the potential to serve as indicators of marine conservation issues, thereby promoting the protection of critically important areas (Eckert and Hemphill, 2005; Frazier, 2005).

Management, including conservation and restoration actions are context-dependent processes. We do not imply that all the successful actions to restore marine turtle populations will be equally effective for all the species they interact with, but they can establish a fertile context for facilitating the implementation of other actions. The umbrella species approach is expected to broaden the benefits of actions, and when accompanied by specific restoration actions directed at other key ecosystem components, it can synergistically enhance their recovery. Public policy instruments (recovery plans) are already implicitly operationalizing the umbrella property of marine turtles, as they promote benefits to other flora and fauna species. They exemplify how regulatory authorities and interested private entities (such as operating corporations, financing groups, and insurers) may direct investments from mitigation, compensation, and Biodiversity

Action Plans (IFC, 2019) to maximize regional socio-environmental benefits.

Finally, questions about the restoration approach for marine fauna species, including marine turtles, remain as knowledge gaps. What reference condition should be used to set the restoration goal for a population? Do our ecosystems have the capacity to sustain recovered populations at the expected level? How can we balance and link management actions to integrally attend to species and their critical habitats? While we have important advances in ecological knowledge on key ecological and economic interest species, there are still planning tasks in terms of integrally attending to the conservation and restoration needs of species and their habitats. This includes an adaptive model that permits the modulation of actions as the ecosystem components respond to management so we can foster a balanced recovery of the entire ecosystem.

Author contributions

SG-F: Conceptualization, Data curation, Formal Analysis, Investigation, Writing – original draft. JT-C: Conceptualization, Data curation, Formal Analysis, Investigation, Writing – original draft. VG-H: Conceptualization, Supervision, Validation, Writing – original draft. FA-G: Conceptualization, Supervision, Validation, Writing – review & editing. PH-R: Data curation, Formal Analysis, Investigation, Writing – review & editing. PG-R: Supervision, Validation, Writing – review & editing. AU-M: Conceptualization, Project administration, Supervision, Writing – review & editing. EC: Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Writing – original draft.

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Conflict of interest

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