The Azores: A Mid-Atlantic Hotspot for Marine Megafauna Research and Conservation

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The increasing public perception that marine megafauna is under threat is an outstanding incentive to investigate their essential habitats (EMH), their responses to human and climate change pressures, and to better understand their largely unexplained behaviors and physiology. Yet, this poses serious challenges such as the elusiveness and remoteness of marine megafauna, the growing scrutiny and legal impositions on their study, and difficulties in disentangling environmental drivers from human disturbance. We argue that advancing our knowledge and conservation on marine megafauna can and should be capitalized in regions where exceptional access to multiple species (i.e., megafauna 'hotspots') combines with the adequate legal framework, sustainable practices, and research capacity. The wider Azores region, hosting EMHs of all key groups of vulnerable or endangered vertebrate marine megafauna, is a singular EMH hotspot on a migratory crossroads, linking eastern and western Atlantic margins and productive boreal waters to tropical seas. It benefits from a sustainable development model based on artisanal fisheries with zero or minor megafauna bycatch, and one of the largest marine protected area networks in the Atlantic covering coastal, oceanic and deepsea habitats. Developing this model can largely ensure the future integrity of this EMH hotspot while fostering cutting-edge science and technological development on megafauna behavior, biologging and increased ocean observation, with potential major impacts on the Blue Growth agenda. An action plan is proposed.

Keywords: mid-Atlantic ridge, seamounts, essential habitat, vulnerable species, pelagic predators

INTRODUCTION

Marine megafauna, a broad definition for large marine vertebrates including marine mammals, reptiles, birds and large fishes, has captivated human mind since pre-historic times. The petroglyphs and bone carvings depicting whale hunting, the leviathanic scenes in classical art (many inspired in biblical episodes), the sacred nature of sharks, turtles or whales in many cultures, the profusion of Hollywood movies and TV documentaries featuring fearsome or tender sea giants, all of these are cultural manifestations of a genuine human fascination for these creatures. Today, their iconic role

and charismatic nature gained a new momentum, as they embody the contemporary challenge of saving wild animals from mass extinction caused by an unsustainable human development model. The increasing public perception that most marine megafauna species reached a threatened or endangered conservation status, in spite of their great ecological as well as economic value for fisheries and ecotourism, renders them a unique flagship role both for conservation research and citizen science.

This contemporary paradigm represents an unprecedented push to investigate megafauna, including the discovery of the habitats essential for their survival, gauging their individual and population responses to exploitation, shipping, climate change or pollution, or understanding the many behaviors, physiology and motivations behind the migrations, feeding, mating and other vital functions throughout their lives that are still unknown or remain largely unexplained (e.g., Hays et al., 2016). Yet, as obvious as it can be, this strategic scientific move faces serious challenges.

First, the elusiveness and remoteness of many marine megafauna species make them hard and costly to access and to study in detail. The good news here is that the use, performance and sophistication of electronic tagging devices have increased substantially, and appropriate statistical tools to make sense of the wealth of data retrieved from these equipments have now been developed, allowing observation/measuring of behavior of free-ranging organisms with a detail and accuracy that we would only dream of a couple of decades ago (e.g., Hussey et al., 2015; Hays et al., 2016). This change was also accompanied by an increasing capacity to collect and analyze large volumes of oceanographic and remote sensing data at the scales needed to understand the environment in which these animals live in (e.g., Druon et al., 2016; Braun et al., 2019; Chambault et al., 2019). Second, the growing scrutiny and legal rules imposed to the handling and study of threatened megafauna, including the publication of results, requires proven high-standards in research, especially with respect to captivity facilities and at-sea procedures (e.g., tagging and restraining, mitigation of behavioral disruption due to human presence). Third, although the same can be arguably said about other animal groups, it is almost impossible to find situations without some sort of potential human interference on megafauna's individual behavior, given the high sensitivity to human activities (including research) brought about by their general characteristics (large size, high mobility, increased sensory capacities). Thus, it becomes very hard to disentangle the key effects of environmental drivers from human disturbance and, consequently, our capacity to forecast those effects and devise appropriate conservation measures.

There are, however, some areas around the globe where the conditions under which megafauna subsist may be considered less stressful (as opposed to the fable concept of more pristine), as they profit from environmentally sustainable developmental models, adopted rules and cultural behaviors. Arguably, these areas should be broadly favorable from the megafauna conservation biology and research perspectives. Advancing our scientific knowledge and conservation progress on marine megafauna can and should also be capitalized in regions where an

exceptional access to multiple species (i.e., megafauna research 'hotspots') combines with the existing adequate legal framework, know-how and research infrastructure. Areas fulfilling the three conditions could, therefore, be targeted for research. In this paper, we argue that the wider Azores region (mid-north Atlantic) is one of such areas, and discuss possible strategies and measures toward achieving that goal.

A MID-ATLANTIC HUB FOR OCEANIC MEGAFAUNA

The Azores (Portugal) is the most remote oceanic archipelago in the north Atlantic, distancing about 1,400 and 2,000 km from continental Europe and north America, respectively. It represents a sub-area of Portugal's Economic Exclusive Zone (EEZ) of around 1 million km^2, one the largest in the European Union. This group of nine volcanic islands and the numerous seamounts surrounding it sits right on the mid-Atlantic ridge at a triple (tectonic plate) junction, and was formed by the high eruptive activity in this region. In climatological-oceanographic terms, the Azores represent an ecotone: its otherwise temperate geographic location is tuned for a subtropical hint by the north Atlantic subtropical gyre via the southeastern branch of the Gulf stream (the Azores current) and its eddies flowing through the southern part of the region (Santos et al., 1995; Caldeira and Reis, 2017). This unique blend of a dynamic oceanography interacting with high seafloor complexity in the middle of the north Atlantic basin is thought to provide the particular conditions which attract oceanic vertebrate megafauna.

The Azores hosts one of the highest cetacean biodiversity in the world, with 24 species of toothed and baleen whales sighted regularly in the region (**Table 1**). It includes a mix of resident species (e.g., bottlenose and Risso's dolphins), species that are present year-round (e.g., sperm whales, common and striped dolphins, pilot whales, *Mesoplodon* beaked whales), and seasonal visitors (baleen whales, Atlantic spotted dolphin, northern bottlenose whale) (Silva et al., 2014). A common trait seems to be the exceptional access to cetacean prey which are available either seasonally (e.g., the krill and baitfish upon which baleen whales and dolphins feed during their spring and summer visits, respectively) or year-round (e.g., the deep-sea squid fed upon by sperm whales – Clarke et al., 1993 – or the mesopelagic prey targeted by dolphins, beaked whales, pelagic sharks or swordfish – Clarke et al., 1995, 1996). Some year-round or seasonal visitors also use the region as a nursery, namely sperm whales, common and spotted dolphins (Silva et al., 2014).

It also represents an important ornithological transition between tropical and temperate regions. Although not ranking as high in number of nesting species than other archipelagic regions such as the Orkneys or Cabo Verde, ten seabird species (six procellariiformes and four charadriiformes) use the Azorean islands and islets as a primary nesting area (**Table 1**). The region holds 100% of the world's breeding population of Monteiro's storm petrel (Bolton et al., 2008), almost 75% of Cory's shearwater, up to 33% of Barolo shearwater and nearly half the European breeding population of roseate tern

TABLE 1 | Resume of the conservation status, pressures and proposed actions for each of the four groups of marine megafauna occurring in the Azores.

	Cetaceans	Seabirds	Sea turtles	Sharks and Large Predatory Fishes
Total no. Species	24	10 (nesting)	5	79
Conservation (no. species)				
IUCN Cr/En/Vu/DD (global assessments)	0/2/2/8	0/0/1/0	2/2/1/0	1/2/20/15
EC Birds/Habitats Directive Annex I or II/IV	1/24	9/0	2/3	
CITES Annexes I/II	8/16	0/0	5/0	6/13
CMS Bonne Annex I/II	5/6	0/2	5/5	18/0
Pressures in the Azores (intensity/actions)				
Target fisheries	Null Maintain legal protection	Null Maintain legal protection	Null Maintain legal protection	Null Maintain legal protection
Fisheries bycatch	Low Maintain fishing regulations and low-impact gears	Low Maintain fishing regulations and low-impact gears	Medium Ban higher-impact gear (pelagic longlines) Use of circle-hooks Implementation of legislation/code of conduct for mandatory release of by-caught animals/avoid hotspots and proper handling	Medium Ban higher-impact gear (pelagic longlines, gillnets) Use of circle-hooks and nylon leader Implementation of legislation/code of conduct for mandatory release of by-caught animals/avoid hotspots and proper handling
Prey depletion	Low R&D on trophic interactions and habitat requirements	Low R&D on trophic interactions and habitat requirements	Low R&D on trophic interactions and habitat requirements	Low R&D on trophic interactions and habitat requirements
Contaminants	Low R&D on contaminant levels and impacts	Low R&D on contaminant levels and impacts	Low R&D on contaminant levels and impacts	Low R&D on contaminant levels and impacts
Litter	Low R&D on litter impact	High Enforce anti-littering legislation Continue education, awareness and clean-up campaigns	High Enforce anti-littering legislation Continue education, awareness and clean-up campaigns	Low R&D on litter impact
Anthropogenic noise	Medium implement stricter permitting processes and stringent regulations for seismic surveying	Not assessed R&D on impacts of noise	Not assessed R&D on impacts of noise	Not assessed R&D on impacts of noise
Light from land	Null	High Implement regulations to reduce disturbance from light sources	Null	Null
Non-indigenous species	Null	High Control/eradication of NIS predators at nesting sites	Null	Not assessed R&D on impacts of NIS (via trophic interactions)
Boat collision	Medium Improved understanding of distribution patterns of large whales and collision risk	Null	Low R&D on distribution patterns of turtles and collision risk	Low R&D on distribution patterns of whale shark and collision risk
Human presence	Medium Tighten and enforce whale-watching legislation	Medium Tighten and enforce non-disturbance legislation	Low R&D on impacts of human presence (whale-watching)	Low Implementation of legislation/code of conduct for shark-diving R&D on impacts of shark-diving

Cetaceans, seabirds, and seaturtle information adapted from Saavedra et al. (2018).

(BirdLife International, 2019), the most oceanic population of this species globally. Studies have also revealed that breeding adults and their reproductive success depend on the epi- and mesopelagic feeding resources around the Azores (Monteiro et al., 1996; Granadeiro et al., 1998; Magalhaes et al., 2008; Amorim et al., 2009; Neves V. et al., 2012; Neves V.C. et al., 2012; Paiva et al., 2018).

Four out of seven species of sea turtles occur in Azorean waters (**Table 1**). The area is used as a prime oceanic juvenile (growth) habitat by the loggerhead turtle population nesting in south-eastern United States (Bolten et al., 1993, 1998) and is along the

migratory corridor during oceanic leatherback turtle migrations between feeding and nesting areas (e.g., Fossette et al., 2010). The region's oceanic and ecotonic position favors the blooming along the year of a wide range of gelatinous organisms (Lucas et al., 2014), the main staple of sea turtles in the open ocean (e.g., Frick et al., 2009; Dodge et al., 2011).

Large bony and cartilaginous fishes are another key component of the megafauna ensemble occurring in the region, including six tropical and temperate tuna, five billfishes/spearfishes, five sun/moon fishes, three large groupers (one endemic to Macaronesia) and over 60 species of benthic and

pelagic sharks and rays (Porteiro et al., 2010; Das and Afonso, 2017) (**Table 1**). In the case of tuna/billfishes and pelagic/deepsea sharks, this represents a relatively high diversity (e.g., Das and Afonso, 2017). Some are mostly visitors during the warmer season, i.e., June to November (e.g., tropical tuna and billfishes, mobulid rays, whale shark), but others apparently use the area throughout their lives (e.g., groupers, several deepwater sharks, Afonso et al., 2011; Reid et al., 2019) or as a long-term nursery ground for juvenile growth (e.g., blue, smooth hammerhead and tope sharks, Afonso et al., 2014b).

Collectively, these taxa constitute by far the most vulnerable and protected group of animals occurring in the region, including the terrestrial realm (**Table 1**). 80, 29, and 17% of the sea turtles, sharks/fishes and marine mammals that occur in the region are classified as Critically Endangered, Endangered or Vulnerable by the International Union for the Conservation of Nature (IUCN), respectively, and a large number of cetaceans and sharks/fishes are still Data Deficient (**Table 1**). Their catch, trade and use as well as their disturbance and habitat degradation is strictly forbidden by national and international laws and conventions including the EU Common Fisheries Policy (CFP), Natura 2000 and Marine Strategy Framework (MSFD) Directives, the Convention for Biological Diversity (CBD), the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) and the Convention on Migratory Species of Wild Animals (CMS). Nearly all of the large fishes including sharks are of commercial interest worldwide. Large groupers, tuna and most elasmobranchs are IUCN redlisted, protected by international law (e.g., CITES, CBD) and managed tightly by regional marine fisheries organizations, namely the International Council for Exploration of the Sea (ICES) and the International Commission for the Conservation of Atlantic Tunas (ICCAT), in some cases forbidding their catch and trade globally (e.g., mobulid rays, hammerhead and thresher sharks) or in the northeast Atlantic (e.g., most deepwater sharks) (**Table 1**).

In short, the Azores hosts multiple essential megafauna habitats (EMH) for the north Atlantic populations of all four key groups of vulnerable/endangered marine megafauna combined (marine mammals, seabirds, sea turtles, fishes), be them feeding, mating, spawning, pupping, or even resting grounds during their large scale migrations. In addition, documented large-scale migrations, from both Azorean and non-Azorean-based tracking studies, directly connect these EMH in the Azores to the eastern and western north Atlantic and/or to the arctic waters and the tropical/equatorial regions at the individual spatial ecology level of several whales (Silva et al., 2013; Prieto et al., 2014, 2017), seabirds (González-Solís et al., 2007; Neves et al., 2015; Ramos et al., 2015), turtles (Bolten et al., 1998), sharks (Afonso et al., 2014a; Thorrold et al., 2014; Vandeperre et al., 2014) and tuna/billfishes (Druon et al., 2016) (**Figure 1**).
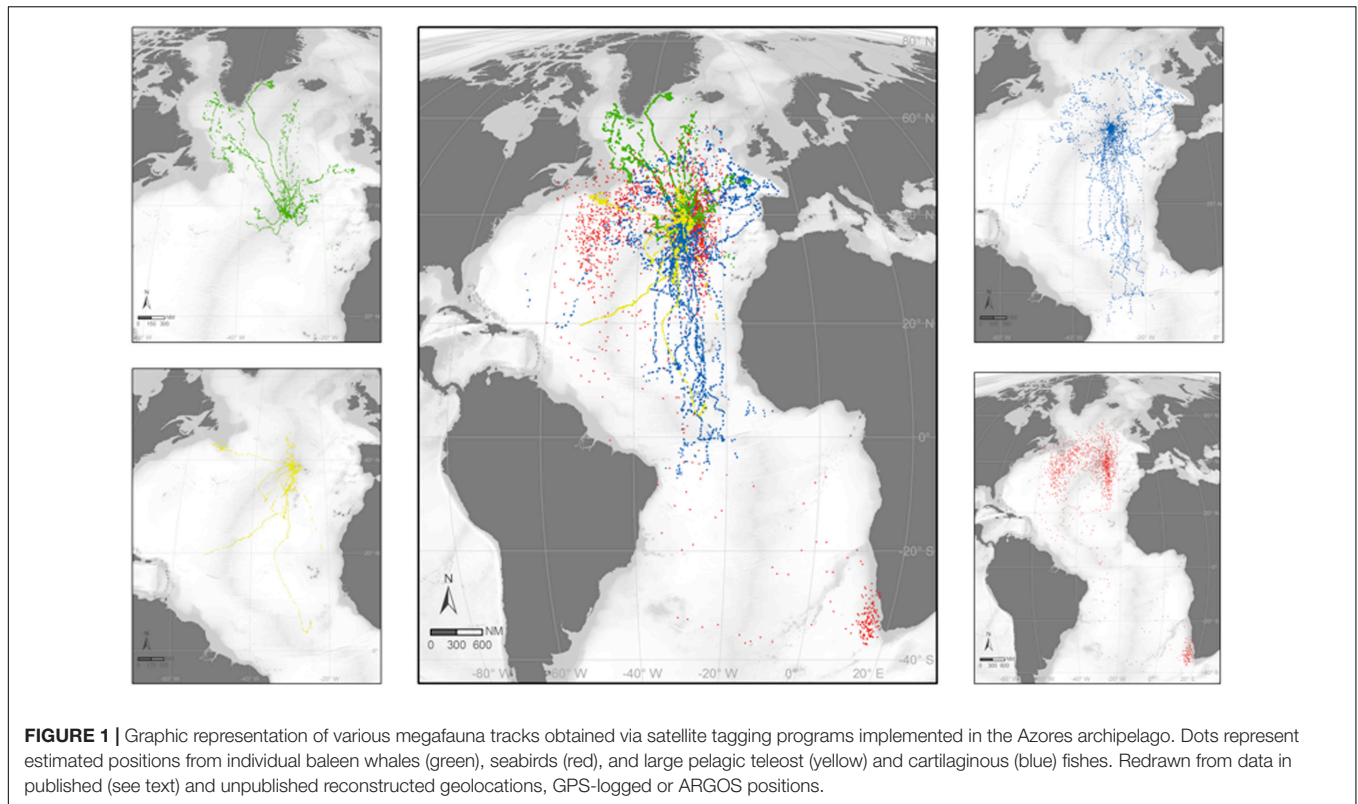
From the broader Atlantic scale perspective, the wider Azores emerge as a singular multispecies oceanic EMH hotspot on a migratory crossroads, linking the eastern to western basin margins as well as the cold productive boreal waters to the tropical and equatorial seas. Yet, we still lack the basic knowledge of the population dynamics, spatial ecology and fine-scale behavior for most of these species, and therefore ignore the full extent of the region's role (and any other region, for that matter) for marine megafauna conservation. Nevertheless, it is clear that the relevance of this Atlantic hotspot results from (1) the diversity of meso- and local scale EMH hotspots located in Azorean island shores, adjacent deepsea and open ocean, some of which are concurrently utilized by multiple species, and (2) the valuable resources (food, shelter, mates, nests) they offer for the survival of the resident and visiting megafauna.

HARNESSING MEGAFAUNA TO SPEARHEAD AN INTEGRATED MARINE CONSERVATION, RESEARCH AND DEVELOPMENT STRATEGY

Marine megafauna populations face rising menaces at the broad scale of their ocean basin distribution and movements including: (1) the targeted or accidental capture by longlining and purse-seining industrial fishing (e.g., Bolten et al., 1998; Ferreira et al., 2001; Amandè et al., 2011; Filmalter et al., 2013); (2) the degradation of their habitat due to chemical, noise and light pollution (Halpern et al., 2008; Fontaine et al., 2011; Peng et al., 2015; Rodríguez et al., 2017; Romagosa et al., 2017), to introduced predators and diseases (e.g., Fontaine et al., 2011; Hermosilla et al., 2016; Neves et al., 2017) or to traffic (Tournadre, 2014); (3) the effects of climate change such as rising sea temperatures (Sundby et al., 2016) and the expansion of oxygen minimum zones (Stramma et al., 2012) which may lead to physiological stress, reduced foraging opportunities or higher parasite loads, and to the subsequent reduction of their physiological condition and reproductive success. These threats are recognized in current European (MSFD and N2000) and global (CBD, Ramsar, Convention for the protection of the marine environment of the northeast Atlantic OSPAR) policies, which tie signatory countries including Portugal to establishing effective protection measures and rigorous scientific monitoring programs.

The global oceans already support few areas of wilderness and even less so in the northern hemisphere and the Atlantic Ocean (Jones et al., 2018). The wider Azores region is one area where those threats, taken together, are less severe and with a slower annual change in the north Atlantic (Halpern et al., 2008, 2019). The region hosts a small (1/4 million) human population and promotes a sustainable development model, with ecotourism now being the fastest growing sector. Fisheries are essentially artisanal and, although the Azores was once an arena for whaling, there is no taking of cetaceans, seabirds or turtles for decades. A moratorium put in place by the European Commission in 2005 as a result of the region's previous policies (independent of the EU CFP) bans all trawling inside the Azores EEZ (Probert et al., 2007). Tuna are an important fishery but caught exclusively using one-by-one line fishing. The bottom hooks-and-lines fishery by-catches very small elasmobranch quantities compared to continental fisheries (Torres et al., 2016; Fauconnet et al., 2019). Industry is very small in scale, and direct sources of human pollution considered to be of minor concern. There are also conservation

FIGURE 1 | Graphic representation of various megafauna tracks obtained via satellite tagging programs implemented in the Azores archipelago. Dots represent estimated positions from individual baleen whales (green), seabirds (red), and large pelagic teleost (yellow) and cartilaginous (blue) fishes. Redrawn from data in published (see text) and unpublished reconstructed geolocations, GPS-logged or ARGOS positions.

policies and best practice programs implemented by the region that target or benefit megafauna: The Azores has one of the largest and more diverse networks of marine protected areas (MPAs) in Europe and the Atlantic, covering a mix of coastal, oceanic and deep-sea habitats (including several seamounts and pelagic seabird foraging areas), although many still require specific regulations and proper enforcement (Abecassis et al., 2015); whale and shark watching are limited to legally defined carrying capacities and codes of conduct are broadly followed by operators; several public and civil environmental education and impact mitigation programs are now well established, such as the annual rescue campaign of seabird fledglings (Fontaine et al., 2011), the marine litter cleaning events, and the catch-and-release in big-game fishing.

Yet, the region's megafauna also faces some threats locally. The most evident is the high by-catch of pelagic sharks and sea turtles in the EU pelagic longlining occurring within Azorean waters (Pham et al., 2013; Afonso et al., 2014b) (**Table 1**). The increasing marine traffic and noise produced by international cargo vessels, inter-island fast ferries and whale-watching vessels are also a potential problem to cetaceans and other marine megafauna (Romagosa et al., 2017). Documented areas of megafauna aggregation, such as the cetacean ground south of Pico and Faial islands and the of large pelagic fishes aggregations on the summits of the Princess Alice, Condor and Formigas banks, still lack effective protection even when already declared as an MPA (Abecassis et al., 2015; Afonso et al., 2018). Marine litter is, as elsewhere, a growing and pervasive problem all way up to megafauna (Pham et al., 2014).

We argue that the current international-to-local push for an integrated conservation approach and full implementation of a sustainable development model in the Azores, where sustainable harvest levels based on low impact gear and effort may subsist with ecotourism, can support the future integrity of this EMH hotspot. This model could also have major impacts in promoting an innovative Blue Economy agenda leveraged on R&D, where hybrid research programs based on new technological developments could foster cutting edge science on megafauna behavior and biologging, and vice-versa. Some already existing examples demonstrate the feasibility of developing this concept (e.g., Fontes et al., 2018a,b). Importantly, it could promote substantial opportunities for studying and testing the ecosystem approach to the management of marine resources and the understanding of ecosystem-level impacts of climate change. The multispecific nature of this megafauna hotspot also renders it an added opportunity in that it allows the concurrent study of both patterns and processes and the transversal hypothesis testing involving evolutionarily contrasting species, thus partially overcoming the traditional limitation of understanding those mechanisms using single-species approaches.

Thus, the Azores fulfills the three major conditions to qualify as an area of priority for research and development on megafauna conservation biology. The strategic centrality of the region, its exceptional access to multiple megafauna species and hotspots very close to harbor, and its historical low levels of (artisanal) fisheries impact, pollution, and reduced habitat degradation when compared with most other regions, turn it into a realistic opportunity with substantial gains and few, if any, downsides.

AN ACTION PLAN

In order to promote and materialize this vision, we propose an integrated action plan.

Fist, this plan should ensure the long-term survival of effective measures already in place, including an unequivocal political commitment to enforce and periodically reassess current management and conservation measures. On the legal side, these measures include the maintenance of the current legal conservation status of most megafauna species (cetaceans, seabirds, turtles, some elasmobranchs) as well as their associated protection actions (e.g., protection and restoration of seabird nesting sites, mandatory release of listed turtle and shark species), the maintenance of the trawling ban and the prohibition of high impact tuna fishing practices in the region, or the maintenance of the broad protection status of some offshore areas, including seamounts (**Table 1**).

Second, the region should adopt new and expand existing protecting measures when necessary in order to ensure an effective contribution to the conservation of megafauna populations. Among the most obvious are a set of measures to protect pelagic and coastal sharks, which currently have little protection, including the banning of shark landings and gears with higher shark by-catch (i.e., pelagic longlining and coastal gillnetting) and the adoption of best practices to release sharks and turtles in surviving conditions (**Table 1**). Both these fisheries have a minor social-economic impact in the Azores as they contribute a very small fraction to the landings and the number of employments (Carvalho et al., 2011; Pham et al., 2013). Fifteen coastal countries in the Atlantic, Indian, and Pacific Oceans have already opted to ban commercial shark fishing altogether, and have laws that prohibit the possession, trade or sale of sharks and shark products (Ward-Paige and Worm, 2017). Another would be a set of measures targeting cetaceans, such as tightening and effectively enforcing the whale watching codes of conduct and legislation, establishing stringent regulations to reduce noise (including seismic surveying) and the risk of ship strike in areas of high cetacean concentration. Finally, the region should establish no-take MPAs in areas known to serve as multispecific EMHs. The very few currently existing no-take areas in the Azores are all coastal and very small in size (Abecassis et al., 2015; Afonso et al., 2018) and, consequently, have very little, if any, impact on megafauna populations. This measure could be easily achievable by updating the current legislation and zoning of some partially protected MPAs that are known to host multiple megafauna, such as the Condor, D. João Castro, Formigas and Princess Alice seamounts.

Third, this plan requires an ambitious research agenda that can ensure the acquisition of relevant knowledge from local to global scales in support of megafauna conservation while effectively promoting R&D. For example, a thorough multidisciplinary investigation of where those multispecific hotspots are located (patterns) and why they are important (processes) for diverse megafauna is needed in order to better understand what would be the sites of priority for full protection, and what would be the relative contribution of creating a

'megafauna sanctuary' to the populations' health. However, achieving that goal will take several years to decades, even in a relatively well studied area such as the Azores. This agenda should thus focus on ensuring an adequate level of multidisciplinary research infrastructure and funding for the next decade in the region. Essential to the feasibility and broader benefits of this agenda is to be anchored on international collaborations and partnerships that can ensure state-of-the-art scientific and technological developments.

Such an action plan could benefit not only many highly migratory megafauna populations that live and depend on the broader Atlantic Ocean basin, but also leverage the Azores and its marine megafauna as a case study for global environmental awareness of the stakeholders and the wider public about the urgent need for an effective ecosystem approach to marine management. It can serve as a flagship political program to change practices, techniques, policies and options while promoting ocean literacy that help revert the problems menacing marine conservation.

DATA AVAILABILITY STATEMENT

The datasets for this study will not be made publicly available since the data has not yet been published. The data used in the broad mapping presented in **Figure 1** is part of a separate publication and will be available once finalized.

AUTHOR CONTRIBUTIONS

PA designed the study and drafted the manuscript. All other authors improved the draft and critically reviewed the manuscript. PA, MS, and MM provided additional data for **Figure 1**. FV produced the re-analysis and mapped the data on **Figure 1**.

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