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Editorial

Conservation science for marine megafauna in Europe: Historical perspectives and future directions

1. Marine megafauna at risk

A broad range of marine species have been named as marine megafauna, however providing a precise definition of this term is difficult. It is not a taxonomically defined group, as it includes sea mammals, birds, reptiles, large fish and elasmobranchs (Fig. 1). Overall, marine megafauna species are large vertebrates that depend on marine resources for their food. These mobile species are generally at the top of their trophic food webs and have none or few predators. From the tiny storm-petrel to the gigantic blue whale, this group is biologically diverse and brings together species which cannot be strictly defined by morphological or physiological similarities. Rather, our perception of marine megafauna as a coherent group is based on ecological similarities and shared conservation issues. These species are exposed to similar threats and generally show limited resilience due to their intrinsic life history traits such as low fecundity rates and high longevity. Consequently, they share common conservation challenges (e.g. Hooker and Gerber, 2004; Lascelles et al., 2014).

The conservation of marine megafauna intrinsically deserves particular attention. First, these species can be exposed to intense and cumulative pressures. Over-exploitation, incidental catches, high contaminant burdens, entanglement in or ingestion of macro- and micro-litter, underwater noise, collisions, global environmental changes and reductions in the availability of food resources are widespread pressures shared by several or all the taxa constitutive of marine megafauna. Consequently, many marine megafauna populations currently have a critical conservation status (Lascelles et al., 2014). Moreover, the low fecundity and long generation time often limit the capacity of collapsed populations to quickly recover. The recovery process typically takes decades in cetaceans, petrels or sharks; and their current conservation status often results from pressures of the last century cumulated with current pressures (e.g. Baker and Clapham, 2004: Lotze et al., 2011).

Beyond species themselves, marine megafauna are a key element of many marine conservation strategies. Including some of the most charismatic marine species, large marine vertebrates are generally used as flagships to mobilize society at large on conservation issues. Moreover, they can function as umbrella species due to their large home ranges and high trophic level. Indeed, conservation measures focusing upon marine megafauna often benefit lower trophic level species, positively impacting marine habitat protection (Hooker and Gerber, 2004). They also have the potential to act as sentinel species and inform the ecological status of other less visible compartments of marine ecosystems (Simberloff, 1998; Zacharias and Roff, 2001).

2. Species-, site- and threat-based conservation instruments

Because many of the pressures marine megafauna face involve catches, whether accidental or not, early conservation actions most often consisted in taking reduction measures. With reference to marine megafauna this was the core objective of, for example, grey seal conservation in the UK (1912), the moratorium on commercial whaling worldwide (1986) or the recovery plan for Atlantic Bluefin tunas (2007) adopted by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Whilst there has been a gradual increase in the number of protected seabird and marine mammal species within individual Member States in Europe, large fish and elasmobranchs have generally been treated as natural resources. As such, the latter can be harvested and are rarely listed as protected: for example, the European sturgeon and the basking shark were only listed on CITES Appendix II in 1975 and 2003, respectively. The main provision of these conservation instruments was typically to prohibit capture, killing and trade of the considered species. More recently, species-based legislations have also aimed to reduce disturbance and habitat degradation (Dolman et al., 2011).

Maintaining the integrity of habitats that are critical for the maintenance of marine megafauna is among the main goals of marine protected areas (MPAs, Hooker and Gerber, 2004). Early protected areas for marine megafauna were typically terrestrial, and dedicated to the protection of habitats specifically used by seabirds and pinnipeds when resting or breeding on land (*e.g.*, *Sept-Îles* Archipelago seabird natural reserve, France, 1912; Moffen walrus reserve, Svalbard, 1983; ICES, 2011). Truly marine MPAs have only been recently identified in coastal or semi-enclosed areas (*e.g.*, Moray Firth, United Kingdom 1991; Wadden Sea, Germany 1999) and in the open sea (*e.g.*, PELAGOS sanctuary 1999; Irish whale and dolphin sanctuary, 1991; ICES, 2011). The size, management rules and governance of these MPAs are varied. Initially, small protected areas with strong exclusion rules for some or all human activities were enforced in sites deemed critical for key biological functions of one or a few species of interest. More global conservation goals were later agreed in international fora, *e.g.* the Aichi target 11 of at least 10% of marine habitats worldwide to be protected by

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Fig. 1. Marine Megafauna. From upper left to lower right panel: Leatherback turtle (*Dermochelys coriacea,* credits: C. Dars), Grey seal (*Halichoerus grypus*, credits: G. Dorémus), Basking shark (*Cetorhinus maximus*, credits: G. Gautier), European storm-petrel (*Hydrobates pelagicus*, credits: O. van Canneyt), Short-beaked common dolphin (*Delphinus delphis*, credits: G. Gautier) and Sunfish (*Mola mola,* credits: O. van Canneyt).

2020 (Convention on Biological Diversity, 2010). Achieving such goals requires the designation of large to very large multipurpose MPAs (Wilhelm et al., 2014). Little or no initial restrictions to human activities are usually put in place when establishing such MPAs, but all key stakeholders are expected to settle on management rules in a participative manner (*e.g.* Marine Natural Parks, 2011; Wells et al., 2016). When willingness, manpower, or funding is low, the risk is high that these MPAs become paper parks (Rife et al., 2013); but the participative approach to their management has become mandatory for their public acceptability (McCauley, 2008). Besides, the consistency between MPA size and the extent of marine megafauna movement patterns or the definition of their conservation unit remains a challenge: as large as these new MPAs can be, they often encompass just a fraction of the distribution or home range of many marine megafauna populations (Wilhelm et al., 2014).

EU regulations have provided powerful tools for the implementation of species- or site-specific conservation policies for marine megafauna. The Bird Directive (2009/147/EC) and Habitat Directive (92/43/EEC) both include provisions for the protection of species, the designation of sites and the monitoring of man-induced incidental mortalities. These directives have initially been implemented on land, and later at sea. Transferring the concepts and practices initially developed for terrestrial habitats and species into marine systems proved problematic, notably for mobile species and pelagic habitats, since the locations of both the animals and their habitats can change over various time scales. However, EU directives also provided the framework for the development of a network of MPA: taken as a whole, the Natura 2000 network can be viewed as a partial answer to the issue of MPA size relative to marine megafauna distribution patterns.

Threat-based approaches provide a different framework than site-based ones for marine megafauna conservation. They include a variety of regulations and agreements dealing with the planning and management of a range of both maritime and, in instances where effects may propagate to marine ecosystems, land based activities. This includes the extraction of marine biological and mineral resources, all terrestrial activities known to export energy or waste to the ocean; as well as transport, recreation, military and research activities at sea. Many different local, regional or global bodies can be involved in the development and implementation of these regulations. For example, the decisions of a local code of conduct for the whale-watching industry, the EU Common Fishery Policy and the International Maritime Organisation can affect marine megafauna species conservation status by regulating activities that can impact these animals. Typically, these instruments implement threat-based management regulations within part or all of their area of competence. It can be noted that the existence of management regulations across a spatially delineated area of implementation are the two basic attributes of MPAs. Although threat-based instruments and MPAs are often presented as conceptually distinct, they actually represent two end points across a continuum of spatial management tools.

The recent EU Marine Strategy Framework Directive (MSFD) unites the mitigation of pressures (threat-based approaches; Programmes of Measures; Environmental Objectives) with the monitoring of conservation status (species- and site-based approaches; Programmes of Monitoring; Good Environmental Status: GES) in an ecosystemic approach conducted at a large spatial scale in European waters (defined as Marine Regions, and further divided into Marine Sub-Regions, Fig. 2). The MSFD explicitly invites Member States to implement the directive in an integrated way across national boundaries. The implementation of these diversified management tools largely relies on 'best available' science, either to provide reference situations, to monitor current status of populations or ecosystems or to predict the effect of candidate management options or mitigation measures.

3. Overcoming scientific challenges

Although scientific interest in marine megafauna has been historically strong, approaches to its study at ecologically relevant scales are fairly recent. One obvious reason boils down to problems of measurement and accuracy/reliability, which in the marine environment are required at a scale commensurate with the high mobility and usually low density of marine megafauna. Marine ecosystems are vast, dynamic, heterogeneous and inter-connected in ways that make measurements of important state variables challenging. The seemingly simple question of marine megafauna distribution, for example, is complicated by imperfect detection: even in suitable habitats, a species may not be sighted during a survey because it may be unavailable to detection (e.g. a diving species) or observation conditions are poor (e.g. low visibility, high Beaufort sea state). Specific data collection designs (e.g. line transect surveys with distance sampling protocol; Katsanevakis et al., 2012) are thus required. Failure to account for imperfect detection will generally result in greater risks of sub-optimal management because of biased estimates of abundance or flawed inferences on true distribution (Katsanevakis et al., 2012; Monk, 2014).

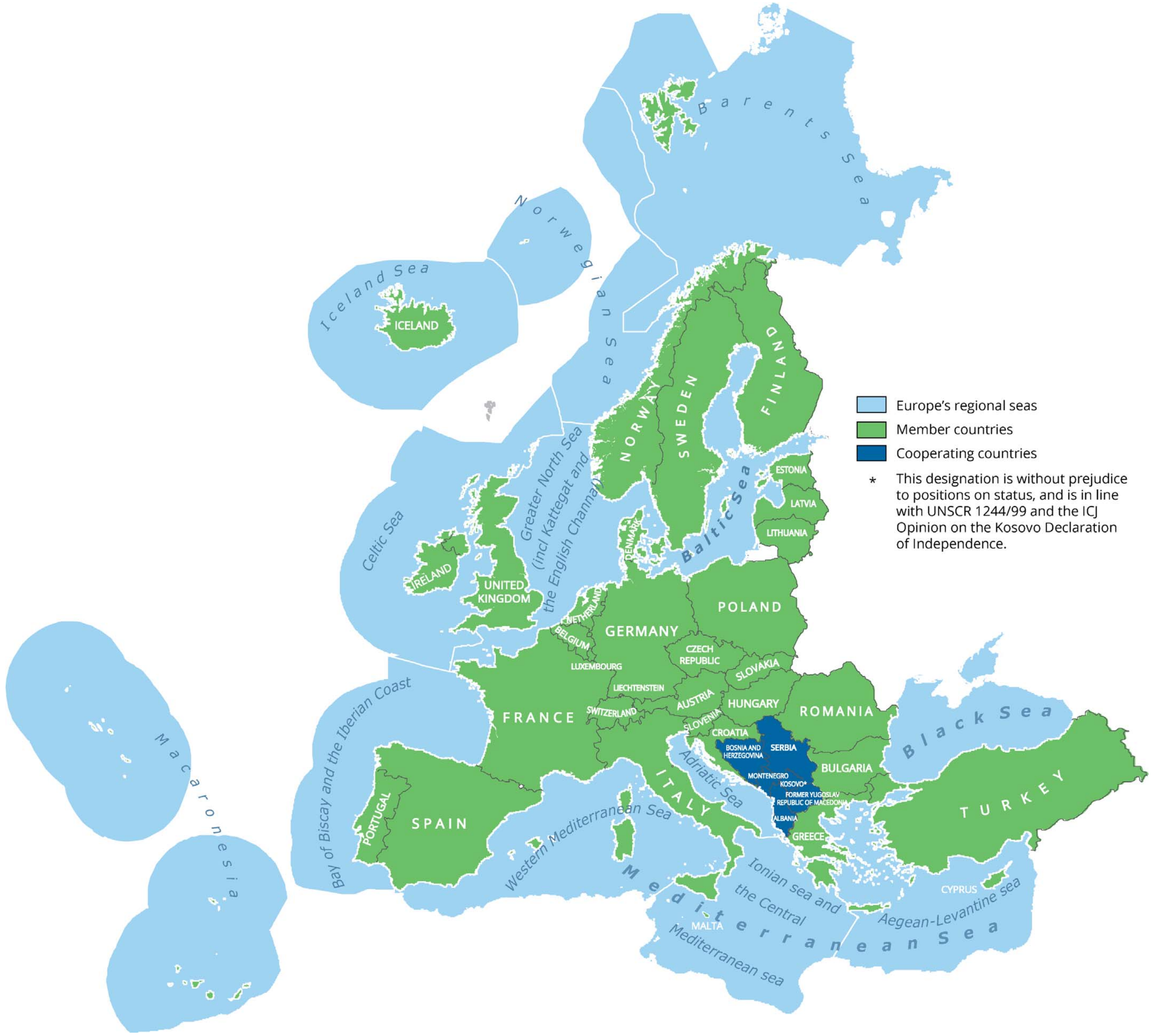

Fig. 2. Marine regions as identified by the European Marine Strategy Framework Directive (source: http://www.eea.europa.eu/about-us/countries-and-eionet/marine-regions).

A second complication stems from the measurement, at an adequate and relevant spatio-temporal scale, of oceanographic processes explaining the occurrence and abundance of marine megafauna (Forney, 2000). These limitations have been progressively addressed with the rapid advancement of remote-sensing of the environment from satellites: accurate, fine-scale data describing the physical, chemical and biological environment of surface waters are readily and easily available nowadays, and can be correlated to marine megafauna data using sophisticated, yet accessible, statistical methods (Edgar et al., 2016). An important pro of recent state-of-the-art methodologies is their ability to distinguish between measurement (observation) errors and process variability (King, 2014), and to allow in the latter, non-linear relationships with environmental drivers (Forney, 2000). These statistical techniques are generic enough to accommodate both traditional data collected via ship-based or aerial surveys, and data derived from electronic devices such as Global Positioning System tags, passive acoustic devices or Time-Depth Recorders. Technological advances in the miniaturization of electronic tags also opened new venues for fine-scale investigations into the in-situ behavior of marine megafauna (Bestley et al., 2009; Pirotta et al., 2015; Labrousse et al., 2017). It is difficult to over-emphasize the tremendous progresses that technological and methodological innovations have enabled over the past decades with respect to the study of marine megafauna at the scale of whole ecosystems (e.g. Block et al., 2011).

Whilst the first investigations into predicting the habitats of mobile species were limited in spatial scope and environmental information (Forney, 2000), current studies can both span large marine ecosystems and routinely incorporate dynamic and physiographic variables (*e.g.* Mannocci et al., 2015). Modern research, with its heavy focus on predictions (including hind-, now- and fore-casts), thus integrates a wide panel of data to reveal the habitats of marine megafauna over large areas (Guisan et al., 2013). Future investigations will most certainly go a step further, and integrate in the same model whole communities (Warton et al., 2015) and mechanistic approaches (Talluto et al., 2016) to refine predictions. Marine megafauna provide in fact a striking and concrete illustration of the synergistic interplay between technological innovations and advanced modelling. This synergy opens the door to ecosystem-based management which is the cornerstone of current conservation policies (Long et al., 2015). Despite

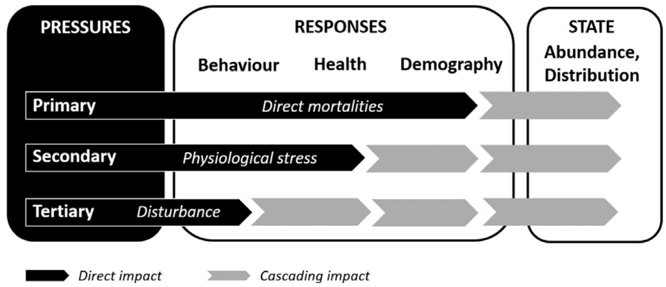

Fig. 3. Typology of pressures based on their effects on marine megafauna.

tremendous scientific progress, the conservation and management of marine megafauna have not necessarily kept apace with the wealth of new results.

4. The challenges of scale and integration

A common result across increasingly sophisticated studies is the importance of oceanographic spatio-temporal heterogeneity in driving marine megafauna habitats, and the importance of connectivity between these habitats (Block et al., 2011). This result alone highlights the severe limits of traditional state-based and fixed-boundary management articulated around arbitrary inside/outside dichotomies (Song et al., 2017). Ecosystem-based approaches, such as the EU MSFD, promote management around ecological, rather than politico-legal boundaries. While transboundary collaboration holds many promises for efficient conservation of mobile species (Kark et al., 2015), many challenges remain to its implementation. For example, in the European Union, the MSFD vows to promote regional cooperation between member states sharing the same marine ecosystems (Marine Regions or Marine Sub-Regions). Yet the regional level has no legal basis in EU treaties (van Hoof, 2015). While the MSFD suggests a pivotal role of Regional Sea Conventions (*e.g.* the OSPAR and Barcelona conventions), there is much “institutional ambiguity” arising from uncertainty in the legal mechanisms by which supra-national conflicts will be handled and adjudicated; or from uncertainty in the division of responsibilities between the national, regional, European and international levels (van Leeuwen et al., 2012). Operational actors, here the scientists, are thus left to organize their work at the relevant scales by promoting data sharing, mutual training, joint project or integrated monitoring.

Integrating pressures in quantitative modelling is one of the remaining challenges for marine megafauna conservation. While the list of threats and pressures impacting marine megafauna is already long (e.g. Hooker and Gerber, 2004; Lascelles et al., 2014), new threats are being unveiled faster than previous ones can be resolved. Threats and pressures are generally categorized according to the human activities at their origin, but rarely according to their effects on marine megafauna populations. We suggest a typology of pressures defined on their mechanism of action on the organisms: primary, secondary and tertiary pressures (Fig. 3). Primary pressures cause direct additional mortality such as accidental and intentional catches or collisions. Population modelling can predict the effect of such direct removals on population dynamics (*e.g.* Barbraud et al., 2008; Mannocci et al., 2012; Wade, 1998). Secondary pressures induce physiological stress that negatively impacts the health or condition of animals. Chemical contamination or food shortage directly affect individual energy budgets or reproductive and immune performances, and ultimately population dynamics. Bioenergetics modelling or individual-based models attempt to integrate the effect of such secondary pressures on individual fitness. However, scaling up the effects of secondary pressures from individual fitness to population dynamics is challenging (*e.g.* Goutte et al., 2014; Rosen and Trites, 2000). Tertiary pressures, such as noise exposure or disturbance, trigger behavioural responses that generally drive animals to less favourable habitats or disrupt on-going vital biological activities. Such disturbance generated by tertiary pressures can have cascading effects on population dynamics (*e.g.* Bejder et al., 2006; Ellenberg et al., 2006), but we are still far from being able to integrate these effects into management scenarios. Finally, marine megafauna species are rarely exposed to a single pressure. A major challenge for the future is to estimate the cumulative and synergistic effects of multiple pressures. Developing a common currency to gauge the impact for all three categories of pressures would be a major step in resolving these issues.

Past and current human pressures may combine in determining today's marine megafauna distributions and abundance (*i.e.* conservation status), resulting in a mismatch between predicted densities from conventional habitat modelling and the actual species distribution. Some favourable habitats where spatial modelling predicted high densities of marine megafauna can be under-populated either because of the effect of past pressures, which have reduced population size, or because of the effect of current pressures, which have induced a distributional shift. Conversely, some less favourable habitats may be over-populated compared to predicted densities due to such shifts caused by tertiary pressures. A future challenge for marine spatial conservation is to incorporate intensities of past and present human activities as environmental predictors in habitat modelling (Di Marco and Santini, 2015).

5. Overview of the topical issue on “European Marine Megafauna”

In recent years there has been a considerable increase in research effort devoted to marine megafauna conservation, and notably in ecosystemic and management-oriented approaches. Because societal demand for such an outlook was dramatically reinforced by the recent implementation of the MSFD, we found it extremely timely to gather recent research on marine megafauna in a topical issue of Deep-Sea Research Part II. This topical issue is composed of twenty-six papers, with the large majority dealing with marine mammals and seabirds and a handful dealing with large fish and marine turtles.

Distribution patterns and abundance estimation remain critical for many species, especially rare or cryptic species. Rogan et al. (2017) offered baseline estimates for five species of deep-diving cetaceans in the North-East Atlantic. Jungblut et al. (2017) capitalized on several ship-based trans-equatorial transects to investigate seabird distribution pattern change along a latitudinal gradient in the Atlantic Ocean. Laran et al. (2017a, 2017b) and Pettex et al. (2017a, 2017b) documented seasonal variations in abundance for, respectively, the cetacean and seabird community of the Channel, Bay of Biscay and North-western Mediterranean Sea. Importantly, these studies documented patterns in the little studied winter season. Panigada et al. (2017) documented not only seasonal but also yearly variations in abundance for cetacean species in the Pelagos Sanctuary and other regions around Italy where a decline in fin whale (*Balaenoptera physalus*) abundance may have occurred. In the Tyrrhenian sea, Lauriano et al. (2017) provided a fishery-independent abundance estimate for a commercially exploited species, the swordfish (*Xiphias gladius*). Except the surveys of Rogan et al. (2017) and Jungblut et al. (2017), which were ship-based, all other surveys used aircrafts to collect data on marine megafauna.

Habitat modelling and distribution mapping of marine megafauna represent another well-covered topic among contributions to the special issue. Prieto et al. (2017) and Baines et al. (2017) both looked at large whales' habitat in the North Eastern Atlantic: the former around the Azores and the latter in the Porcupine Seabight in the Celtic Seas. Pennino et al. (2017) studied, among other species, fin whales in the Western Mediterranean Sea. All these studies evidenced the importance of primary productivity and submarine topography in predicting whale habitat. Lambert et al. (2017a, 2017b) and Virgili et al. (2017) investigated the habitats of cetacean, seabird and coastal bird species in the Channel, Bay of Biscay and Western Mediterranean Sea to highlight important seasonal variability in habitat use. Similarly, the fine-scale studies of Cox et al. (2017) and Benjamins et al. (2017) on Harbour Porpoise (*Phocoena phocoena*) foraging activity both stressed the importance to account for spatio-temporal heterogeneity in habitat use. Ortega and İsfendiyaroğlu (2017) showed with a combination of land-based and ship-based surveys how the habitat of the vulnerable Yelkouan shearwaters (*Puffinus yelkouan*) shifted from the cold and shallow coastal waters to the deep pelagic waters of the Black Sea between the breeding and non-breeding season. Bauer et al. (2017) studied the distribution and behaviour of the Atlantic Bluefin Tuna (*Thunnus thynnus*) in the North-western Mediterranean Sea to identify the importance of productivity and mesoscale activity levels in driving the foraging grounds of this economically lucrative species. Michelot et al. (2017) examined how the European Shag (*Phalacrocorax aristotelis*) used benthic habitats for foraging at different times of the year in relation with its energetic constraints and reproduction.

This topical issue provides thus new robust data on abundance and distribution of marine megafauna and, consequently, brings insights for creating future relevant MPAs or evaluating the relevance of existing MPA networks. In the English Channel, Bay of Biscay and north-western Mediterranean Sea, Lambert et al. (2017c) assessed for instance the existing network of MPAs along the French Atlantic and Mediterranean coasts using model-based marine megafauna distribution. While this network appeared relevant for coastal seabird species, Lambert et al. (2017c) identified shortcomings for offshore seabird species in the Bay of Biscay and for cetaceans both in the Bay of Biscay and in the Mediterranean Sea. Delavenne et al. (2017) performed a sensitivity analysis; they evaluated the impact of using different sources of data (i.e. from encounter rates in 40×40 km grid cells to densities predicted by kriging or habitat modelling) on the identification under MARXAN of important cetacean and seabird areas in the perspective of designating offshore Natura 2000 sites. As illustrated by Pérez-Roda et al. (2017) tracking data can likewise inform MPA effectiveness. After deploying Global Location Sensing loggers on breeding Balearic shearwaters (*Puffinus mauretanicus*), Pérez-Roda et al. (2017) highlighted the relevance of the current design of conservation areas in Spain and Portugal for this highly mobile species. Along the French coast of the English Channel, Vincent et al. (2017) monitored grey and harbour seals (respectively, *Halichoerus grypus* and *Phoca vitulina*) at the southern limit of their range. Seals tracked from haulout sites in France mostly remained within the limits of Nature Reserves or Special Areas of Conservation, thereby stressing the relevance of the existing network of MPAs both for hau-lout and foraging. Moreover, this long-term monitoring of colonies showed a significant increase of seals at haul-out sites in France since 1990, suggesting notably grey seal movements from the southwest British Isles and the North Sea.

Marine megafauna has been under growing environmental and anthropogenic pressures. Distribution and habitat preferences can inform on actual or future exposure of marine megafauna to these pressures. Cañadas and Vázquez (2017) used a two decades-long dataset on the common dolphin (*Delphinus delphis*) to project its distribution under the effect of sea warming. An increase in sea surface temperature would reduce the suitable habitat for common dolphins in the Alboran Sea. Azzellino et al. (2017) evidenced changes in cetacean distribution over the last 25-years from at-sea surveys and strandings in the Ligurian Sea. These changes correlated with a decrease in ecosystem productivity, and may also be linked to fishery activities and marine traffic. Finally, Darmon et al. (2017) analyzed visual observations of both sea turtles and marine debris from aircrafts to provide a risk assessment for litter ingestion or entanglement. These authors thus identified major risk areas for leatherback turtles (*Dermochelys coriacea*) in the Bay of Biscay and for loggerhead turtles (*Caretta caretta*) in the North-western Mediterranean Sea.

Because ecologically meaningful limits are often labile in the marine environment, because marine megafauna use these habitats at large spatial scales and because past and current pressures combine in multiple yet hardly quantifiable ways, research and management efforts bound to political boundaries seldom can provide an appropriate response to actual knowledge and conservation needs. By illustrating these challenges in multiple ways, the present topical issue is an invitation to further develop active regional co-operation in the understanding of the underlying processes and the design of conservation strategies.

Acknowledgements

Although not exhaustive, the present topical issue on European Marine Megafauna provide a large selection of biological models, study areas and methodologies, and it is our pleasure to acknowledge the efforts of all authors in this endeavour. The edition of the present special issue was funded by Agence Française pour la Biodiversité (AFB). *Observatoire PELAGIS* is mostly supported by the French Ministry in charge of the environment (MEEM) and AFB. We are also grateful to editors-in-chief John D. Milliman and Javier Arístegui, and all reviewers who contributed to make this topical issue possible.

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