Trends in cetacean research in the Eastern North Atlantic

Abstract

1. Cetaceans are considered ecosystem engineers and useful bioindicators of the health of marine environments. The Eastern North Atlantic region is an area of great geographical and oceanographic complexity, that favours ecosystem richness and, consequently, cetacean occurrence. Although this occurrence has led to relevant scientific research on this taxon, information on composition of this research remains unassessed.
2. We aim to quantify the evolution of research on cetaceans, highlighting the main focuses and trends in the Eastern North Atlantic.
3. This study considers 380 peer-reviewed publications between 1900-2018. For each paper, we collected publication year, research topics and regions, and species studied. We assessed differences among regions with distinct cultural and socio-economic landscapes, and between coastal and oceanic habitats. To evaluate the growth of scientific production, we fitted a General Additive Model to the time series of paper numbers.
4. Although research in this region has been growing, the results show relatively little research output in Northern African and coastal regions within the study area. Moreover, except for four studies done in high seas, research was restricted to a few miles around the coast of main islands, leaving offshore regions less well surveyed. There was less research on genetics, acoustics, and behaviour. Most papers focused on the Azores and Canary Islands, and mostly involved bottlenose dolphins (*Tursiops truncatus*), common dolphins (*Delphinus delphis*), and sperm whales (*Physeter macrocephalus*). Species considered Endangered or Near Threatened are objects of only 10% of the studies.
5. We suggest a greater research focus on beaked whales in Macaronesia, as well as collaborative efforts between research teams in the region, by sharing data sets, and aiming to produce long-

term research. Moreover, a Delphi method approach, based on rounds of questionnaires answered by experts, could be attempted to identify priority research for cetaceans in these important areas.

Keywords: Cetaceans, systematic review, Macaronesia, Portuguese Exclusive Economic Zone, Northwest Africa

Wordcount: 9983 words

Introduction

Cetaceans play a significant role in marine ecosystems functioning due to their relatively large body size and to the high trophic position of many species (Bowen 1997). Some whales recycle nutrients by releasing faecal plumes near the surface after deep water feeding, supplying fertilizers to primary producers in the surface ocean (Roman et al. 2014). Cetacean carcasses that sink to bathyal and abyssal areas become 'whale fall' providing unique habitats to a myriad of organisms in an otherwise energy-poor seafloor, and serve as hot spots for specialized fauna and as stepping stones for hydrothermal vent organisms (Smith et al. 2015). Some species also transport nutrients across different latitudes when migrating between highly productive high-latitude feeding grounds, and low-latitude calving areas (Smith 2013, Roman et al. 2014). Moreover, many species are apex predators, feeding on a wide variety of fish and cephalopods, and thus bioaccumulate contaminants, serving as useful bioindicators of the health and status of the marine environment (Kucklick et al. 2011). Responding to fluctuating prey populations due to pressures from climate change and human exploitation, cetacean species across the world are exhibiting changes in their distribution and abundance patterns (Tulloch et al. 2019, Wild et al. 2019). Finally, cetaceans are widely distributed in all oceans, occupy a wide number of strikingly different ecological niches (Ballance 2018), and present diverse demographics and population dynamics (Wade 2018); as such, they are likely to present very different conservation needs among species, populations and throughout their distributional range.

This study is focused between latitudes 42°N and 13°N in the eastern North Atlantic, including mainland Portugal, Morocco, Mauritania and Senegal, and the Macaronesia archipelagos that include the Azores, Madeira, Canaries, and Cape Verde. Hereafter the study region will be referred to as 'Eastern North Atlantic' (Figure 1, Correia et al. 2019).

The Eastern North Atlantic is a very diverse region with regards to geomorphology, climate, oceanography, and ecology. It presents great geomorphological complexity, including large number of seamounts (Morato et al. 2008, Kvile et al. 2014), diverse seafloor morphology, and a rugged coastline along Iberia and North Africa (Valdés & Déniz-González 2015, Perán et al. 2016). This region encompasses the East and West North Atlantic Subtropical Gyral (NAST-E and NAST-W, respectively), Canary Coastal (CNRY), and North Atlantic Tropical Gyral (NATR) Longhurst biogeochemical provinces (Longhurst 2007). It comprises coastal, as well as oceanic warm-temperate and oceanic subtropical habitats (Beaugrand et al. 2019). The Macaronesia archipelagos' climate is influenced by the Canary Current (to the east), the North Equatorial Current (to the south), and the Azores Current (to the north) (Mason 2009). During late spring and summer, the Portuguese NW Iberian coast is characterized by prevailing northerly winds due to the presence of the Azores high-pressure system, which favours a coastal upwelling system of cold and nutrient-rich waters. This increases primary production in the area, which sustains large stocks of economically important exploitable species (Fraga 1981). Additionally, the NW African coast is also characterized by a strong upwelling system creating local phytoplankton blooms that fuel the entire trophic chain, including marine mammals and seabirds (Cushing 1971, Cropper & Hanna 2014). Moreover, the Africa sub-Saharan region is endowed with a variety of coastal ecosystems, such as estuaries, coral reefs, mangrove forests, wetlands, and dunes, providing not only services to coastal communities (i.e., coastal stabilization from severe weather and sea level rise, and regulation of water quality and quantity), but also to the environment (i.e., higher biodiversity, and spawning habitat for many aquatic species) (Carrere 2009).

Marine mammals' populations have been affected directly by human activities around the world such as direct hunting, fisheries bycatch, habitat destruction, ship-strikes, acoustic and chemical pollution, unregulated whale watching activities, overexploitation of prey resources, and the effects of warming oceans (Parsons 2012, Weir & Pierce 2013). The Eastern North Atlantic region is also subject to considerable threats and pressures on cetacean biodiversity. For instance, in the Canary Islands, 18% of cetacean deaths were explained by human impacts, mainly as a result from collision with vessels, with the most affected species being the sperm whale (Riera et al. 2014, Fais et al. 2016). In Madeira Island, the ship strike risk is apparently not alarming, but as vessel traffic increases, so does the negative impact on cetaceans (Cunha et al. 2017). In the Portuguese coast, high concentrations of heavy metals have been found in the livers of common and bottlenose dolphins (Zhou et al. 2001, Carvalho et al. 2002). Disturbance from whale watching in the Azores may cause detrimental effects to sperm whale social units that are regular visitors and spend long periods off these islands, with potential effects on the population dynamics (Boys et al. 2019). Additionally, the rate of dolphin bycatch in the pole-and-line tuna fishery in the Azores has varied considerably between years, and while dolphins caught were reported to be released alive, the fate of these released individuals is unknown (Cruz et al. 2018). Dolphins by-catch by artisanal fishers has also been documented in Cape Verde (Lopes et al. 2016). Despite the urgency in conserving these habitats and animals, information on various aspects of cetacean ecology and biology is scarce and scattered across the region (Correia et al. 2015, Valente et al. 2019).

Bibliometric analysis, a field of research that examines bodies of knowledge within and across disciplines (Norton 2000), has been widely used to evaluate different research topics (e.g. methods, publishing outlets, authors' collaborations) in most fields of expertise (Holden 2005). Systematic reviews are a powerful way of synthesizing all relevant studies on a topic and involve a detailed and comprehensive plan and search strategy developed a priori, to reduce bias (Uman 2011). Efforts to compile chronologically and/or analytically the available information on cetaceans in the Eastern North Atlantic have been partially attempted for single species (Prieto et al. 2012) or in some sub-regions (Valente et al. 2019). However, to the best of our knowledge, an overview of the research carried out on cetacean species in the wider area of the Eastern North Atlantic is lacking. Such wide-ranging and extensive bibliographic research can verify the progress in cetacean research made in the past century related to this biologically important area, thereby identifying trends and gaps to guide future research.

Aims

This study aims to: (i) undertake a bibliometric analysis to quantify the evolution of research on cetaceans in the Eastern North Atlantic; (ii) summarize the state of knowledge about cetaceans in this area and, by reviewing historical data, compare regions with distinct cultural and socio-economic landscapes and coastal and oceanic habitats, to identify research patterns and gaps; and (iii) highlight where the focus of research on cetaceans has been between 1900-2018, identifying trends and research difficulties as a contribution to improved management policies in this area.

Methods

This study is a systematic survey of scientific publications involving cetacean species occurring in the Eastern North Atlantic, including coastal and oceanic regions of mainland Portugal, Morocco, Mauritania, Senegal and around the archipelagos of Azores, Madeira, Canaries, and Cape Verde (Fig. 1).

The search period was 1900–2018, and the search terms were "cetaceans", "whales", "dolphins", and names of the regions included in the study area, using Thompson's ISI Web of Science, Scopus and Google Scholar platforms. For the latter, only the first 15 result pages were included, since prior *ad hoc* testing showed that after the 10th page there was a negligible chance of finding further relevant publications. After 1980, the analysis was restricted to peer-reviewed literature, but before 1980, technical reports were also included due to a considerable smaller body of work and difficulties in assessing peer-review status. To ensure that all 2018 publications were included, literature was surveyed until the end of the first semester of 2019. To increase coverage, we applied a "snowball" technique (Almeida-Filho et al. 2003), in which the reference section of available publications was used as a source for the identification of new papers. Papers unavailable on the internet were requested to the first author and/or co-authors through ResearchGate website or via email. Older publications (1900-1960) were kindly provided by the Jean Monnet University (St. Étienne, France).

The information retrieved from each publication was compiled in Excel and then imported into the R program (R Development Core Team 2019), including: first author, title, year, journal title, study region, topics covered (i.e., anatomy, taxonomy, ecology, behaviour, acoustics, genetics, conservation and human interactions, adapted from Brito and Sousa (2011); related topics described in Appendix S4), and taxa studied. Each species global and local conservation status were obtained from the International Union for the Conservation of Nature (IUCN) (Appendix S5).

The study investigated research output between regions with distinct cultural and socio-economic landscapes. We compared "European regions" (mainland Portugal, archipelagos of Azores, Madeira and Canaries) with "North African regions" (Morocco, Mauritania, Senegal and Cape Verde Islands). To assess differences in research output between coastal *versus* oceanic habitats, we grouped areas as follows: coastal – mainland Portugal, Morocco, Mauritania, Senegal; and oceanic – archipelagos of Azores, Madeira, Canary and Cape Verde Islands. We compared regions based on topography, political boundaries, and countries' economy. We considered the regions comprising islands to be "oceanic habitats" due to their narrow island shelves, conferring close proximity to pelagic habitats (Woodroffe 2014).

A General Additive Model (GAM, Poisson distribution, logarithm link function) was fitted to the number of papers per year. A Change-point analysis was implemented to detect significant changes in the quantity of published papers through time. Analyses were conducted using R 3.6.1 software (R Development Core Team 2019).

Results and Discussion

This review covers issues related to habitat (coastal vs. oceanic regions) and socio-economic and cultural traits (European vs. North African regions), based on the number of papers published throughout time, on selected topics and species conservation status. We identified 380 scientific publications on cetacean species conducted in the Eastern North Atlantic from Portugal to Senegal, including the oceanic archipelagos of the Macaronesia biogeographic region, during the period between 1900-2018. Paper publication dates ranged from 1913 to 2018. Results are complemented with supplementary material covering topics not discussed at length here, such as leading authors and journals publishing on cetaceans in the study area. To the best of our knowledge, this constitutes the first bibliometric analysis on cetaceans taking an all-species and multi-habitat approach in the study region, providing information on trends of past research, helping to direct future research.

Temporal evolution of research across regions within the Eastern North Atlantic

Prior to the 1990s, research output on Eastern North Atlantic cetaceans was scarce. The GAM and the change-point analysis revealed a significant growth in research output, especially since 2005 (r^2: 0.897; $P < 0.001$; Fig. 2), when it started to grow exponentially. However, a closer look reveals heterogeneity in the number of publications throughout the years within and between the studied regions (Table 1, Fig. 4).

North African *versus* European regions

Cetacean research was relatively scarcer in Northern African regions (n=136), than in European regions (n=340). The largest number of studies came from the Azores (n=124), followed by the Canary Islands (n=95). The least studied regions were Morocco (n=20), Cape Verde (n=35) and Mauritania (n=37). The latter stabilized its research output since 1990, with eight papers per decade (Appendix S17). Fewer papers have investigated the cetacean fauna of Morocco and Senegal - with less than five and ten papers per decade, respectively. Nonetheless, both regions showed an increased research output during the 1950s and 1960s, especially in the fields of anatomy and taxonomy, utilizing stranded animals (e.g., Cadenat 1954), when compared with later years. After that period, however, research has declined in these two countries. According to Price's Law, if scientific output on a subject does not follow exponential growth, either the field has reached a saturation point, which is clearly not the case, or not enough resources have been allocated to research (Price 1951). In the case of the coastal countries of northern West Africa, the boost in the 1950s, followed by the lower output on cetacean research during the last 20 years, is likely due to their independence processes from European countries. Morocco became independent from France and Spain in 1956, while Senegal and Mauritania obtained their independence from France in 1960 (Nugent 2012). The French nationality of the authors likely explains the considerable increase in research output during the 1950s, and its subsequent decrease. Upon independence, these African countries not only had no socio-economical conditions to continue scientific research (Olukoshi 2001), but also underwent societal reorganization. Interestingly, in 2009, Morocco announced an increase of its science and technology investment to finance restoration and construction of laboratories, and training courses for researchers (Sawahel 2009, Kushnir 2019). This can create a window of opportunity for cetacean research in the near future.

The results for Cape Verde are somewhat different. Research has been steadily increasing since the 1980s, with previous little research output (n=2). Historically, small levels of information on the biodiversity of cetaceans from Cape Verde area have been obtained mainly from strandings, anecdotal sighting accounts, and accidental catches in fishing operations (by-catches) (e.g., Reiner et al. 1996, Hazevoet et al. 2010). Cape Verde became independent from Portugal in 1975 and, although it showed overall low levels of research output, the country has not seen a decrease in research after independence, in contrast to other North African countries in this study. In the 1960s and 1970s the overall scientific output in peer-reviewed journals by Portugal was negligible, numbering in the low hundreds and being two orders of magnitude below that of France, for example (Lemarchand 2016, Powell & Dusdal 2017). That fact translates the very low investment in science by Portugal in the study period (Heitor & Horta 2013), and probably explains why the data does not show any relevant cetacean-related scientific production in Cape Verde prior to the independence. Instead, the feeble, but steady, research growth recorded for Cape Verde was fostered by international cooperation and tourism development that took place after the independence. Researchers from the National Institute of Fisheries Development in Cape Verde, and the Institute of Tropical Scientific Research in Portugal, have been collecting information on cetacean distribution (both from directed sightings and monitoring strandings) in the Cape Verde region since the beginning of the 2000's, resulting in a considerable increase in publications in this area (Hazevoet et al. 2010). Additionally, several environment-related international organizations now operate in Cape Verde, such as Maio Biodiversity Foundation (since 2010) and BIOS.CV (since 2012). Moreover, the growing popularity of Cape Verde as a holiday and whale-watching destination contributed to the increased number of reported opportunistic observations, particularly on the islands of Sal and Boavista (Hazevoet et al. 2010). Indeed, whale-watching tour boats have been used as platforms to conduct research activities such as estimating abundance and studying the spatio-temporal distribution of humpback whales (Van Waerebeek et al. 2013, Ryan et al. 2014).

In contrast with the North African countries, for mainland Portugal and the archipelagos of Madeira, Azores, Canary Islands, research has been steadily increasing since the 1980s, with previous little research output (mainland Portugal n=1, Madeira n=5, Azores n=2, Canary Islands n=2). The European regions considered in this study showed a clear growth in cetacean-related research over the study period, with most of the contribution coming from the three Portuguese regions, which can in part be explained by the larger number of Portuguese regions included in the study. The Portuguese regions encompass the entire national territory, representing a stable population of ca. 10 million people since the 1990s (Instituto Nacional de Estatística; https://www.ine.pt: accessed 02 April 2019).

In contrast, Spain is only represented by the Canary Islands, with a population varying from 1.5-2.2 million people between 1990 and 2019 (3.8-4.7% of the Spanish population, Instituto Nacional de Estatística, https://www.ine.es: accessed 02 April 2019).

Compared to the other European regions, the research in Madeira apparently lagged some years. Although the Madeira Archipelago has almost ideal year-round weather conditions for cetacean observation, this region presented a lower number of published papers on cetaceans. Commercial whaling activities ended in Madeira and the Azores in 1981 and 1984 respectively (Brito 2008). While the Azores showed a boost in cetacean research in the post-whaling period, Madeira only saw a clear increase in publications after 2010. It is difficult to pinpoint a single reason for that difference. Research groups in small regions such as Madeira, the Azores and the Canary Islands tend also to be small, which can slow down publication output. Scientific production can also be affected by group dynamics and competition (Fochler et al. 2016), which will be more noticeable in regions or fields where the number of researchers is reduced. Also, Madeira and Azores are Portuguese autonomous regions with own local research and development (R&D) priorities and policies, which can influence the effort devoted to specific research fields. Regardless, after the year 2010, Madeira saw an increase in cetacean-related publications, which is now in line with the other European regions.

Our results indicate a change point in 2005 regarding the cetacean-related publications in the entire study area. Interestingly, a similar pattern showing a significant increase in peer-reviewed publications on mammalian carnivores in the mid-2000s was observed in Portugal (Bencatel et al. 2018). Due to the low contribution of the North African regions, and greatest weight of Portugal within the European regions in this study, it is likely that a large part of the growth of cetacean-related research reported here might be explained by factors influencing Portugal. Perhaps not surprisingly, gross expenditure in R&D as a function of gross domestic product, as well as the number of researchers per capita, started to see a drastic increase in Portugal in 2005 (Heitor & Horta 2013). That growth is partly a result of access to international funds and international cooperation ensuing the integration in the European Union (EU) in 1986, as well as restructuring of the national R&D policies to converge with the EU (Heitor & Horta 2013).

Another relevant aspect was the creation and process leading to implementation of the EU Directive 92/43/EEC (Habitats directive) and Directive 2009/147/EC (Birds directive). The Habitats and Birds directives set up the Natura 2000 network, comprised by special areas of conservation (for natural habitats) and special protection areas (for birds) and designated by each member state, fostering investment in key under-represented research areas, including in marine sciences (Abecasis et al. 2015, Kati et al. 2015). Abecasis et al (2015) reported a significant increase in the number of marine-related peer-reviewed publications in the Azores, stemming from the increase in marine conservation research projects in the region during the 2000s, related to the creation and management of Natura 2000 sites and other marine protected areas. It is likely that the Natura 2000 network implementation acted as an incentive for cetacean-related research in the four European regions. This research then continued after the Natura 2000 process, fuelling the exponential growth reported here.

Coastal *versus* Oceanic regions

There was also a clear difference between research output from Coastal and Oceanic regions. Oceanic regions (*i.e.*, areas around the Macaronesia islands) were more frequently represented in the literature (n=303) than coastal ones (n= 174).

It is well known that marine species diversity is positively influenced by habitat heterogeneity (Downing 1991), and it has been shown that in offshore oceanic waters, biodiversity and endemism increase in the vicinity of islands (Costello et al. 2017). The physiography of oceanic islands and seamounts create multiple habitats that harbour species with differing preferences and create conditions for primary and secondary production enhancement and entrapment (Genin 2004). These oceanographic processes lead to the formation of higher productivity spots, creating complex food webs that inevitably attract apex predators, such as cetaceans (Cañadas et al. 2002, Genin 2004).

The Macaronesia archipelagos host multiple cetacean species, either year-round or seasonally, with strikingly distinct ecologies (Silva et al. 2003, 2014, Carrillo et al. 2010, Hazevoet et al. 2010, Freitas et al. 2012). The narrow island shelves allow the co-occurrence of species with coastal and pelagic habits, increasing the opportunities to work with different species and reducing logistical costs. For example, deep diving species such as sperm and beaked whales are seldom seen over the continental shelf, which hinders their study in most areas of the Atlantic (MacLeod & Mitchell 2006). However, they are relatively common near the Macaronesia archipelagos, enabling sustained research over medium- to long-term periods (e.g., Prieto et al. 2013, Boys et al. 2019). In contrast, the continental shelf along the coastal regions in this study can stretch tens of kilometres into the sea, limiting the occurrence of deep diving species close to shore and increasing logistical costs associated with the study of these animals (Kiszka et al. 2007, Viddi et al. 2010). Not surprisingly, most studies in the coastal regions tend to be focused on species with more coastal habits (e.g., Augusto et al. 2011), although efforts at studying cetaceans off the continental shelves have been increasing, especially using platforms of opportunity (e.g., Correia et al. 2015).

Although we considered oceanic regions in this review to be areas surrounding islands, this nomenclature does not mean that research was necessarily conducted in high seas. Given anthropogenic impacts and the non-sustainable use of marine resources that are increasingly affecting offshore areas, there is growing urgency for the management of high seas. However, conservation efforts (such as the creation of Marine Protected Areas, MPAs) have been focused largely on coastal regions (Hooker & Gerber 2014). Since the logistic requirements for monitoring offshore waters are very challenging (Kiszka et al. 2007, Viddi et al. 2010), published data are mainly restricted to a few hotspots in this area, located within the Portuguese Exclusive Economic Zone, where most data collection is limited to a few miles from the coast of the Azores and Madeira archipelagos (e.g., Silva et al. 2003, Alves et al. 2018). Exceptions include four studies done in high seas in this area; 1) Boisseau et al. (1999) used yachtsmen sailing from the Caribbean to the Azores; 2) Doksæter et al. (2008) had a dedicated research ship to study the distribution and feeding ecology of dolphins along the Mid-Atlantic Ridge between Iceland and the Azores; 3) Correia et al. (2015) considered cargo ships as platforms of opportunity; and 4) Jungblut et al. (2017) used a dedicated research ship on latitudinal transfer expeditions through the Atlantic Ocean. Expanding the range of MPAs and study areas in marine research is challenging, but a much-needed task for both decision-makers and the scientific community (Correia et al. 2015).

Socio-economic effects also seem to contribute to the differences between Coastal and Oceanic regions. Of the Coastal regions considered, all but mainland Portugal belong to North African countries, which were shown to have a lower cetacean-related scientific output, in great part attributable to socio-economic factors. Conversely, only one of the Oceanic regions (Cape Verde) is from North Africa. Thus, the lower scientific production in the Coastal regions evidenced in our results is probably also an effect of the socio-economic constraints to cetacean research acting on the North African countries.

Distribution of research by species and topics in the Eastern North Atlantic

<u>Species</u>

The most studied cetacean species in the Eastern North Atlantic were bottlenose dolphins (*Tursiops truncatus*, n=117), common dolphins (*Delphinus delphis*, n=103), sperm whales (*Physeter macrocephalus*, n=96), short-finned pilot whales (*Globicephala macrorhynchus*, n=66), Atlantic spotted dolphins (*Stenella frontalis*, n=66), striped dolphins (*Stenella coeruleoalba*, n=57), fin whales (*Balaenoptera physalus*, n=56), Risso's dolphins (*Grampus griseus*, n=55), and Cuvier's beaked whales (*Ziphius cavirostris*, n=50, Figure 5). Moreover, species listed as Least Concern in the IUCN Red List were more frequently studied (n=62%) than species exhibiting higher concern status. Endangered or Near Threatened cetacean species are involved in only 10% of the studies conducted (Figure 6; see also Table 2 and 3).

We identified 35 cetacean species in the publications analysed in this study, however three stand out as the most frequent, accounting for 25% of all references: the bottlenose dolphin, the common dolphin, and the sperm whale. There are probably multiple reasons for this.

The bottlenose dolphin is a widespread species that occurs in all of the regions in the study area, and has resident populations in at least some of them (Silva et al. 2009, Augusto et al. 2011, Tobeña et al. 2014, Dinis et al. 2016). As they are often associated with coastal habitats having become one of the most studied cetacean species worldwide (Wells & Scott 2009). The bottlenose dolphin is one of two cetacean species considered as priority under the EU Habitats Directive, which has elicited a great effort in studying that species across the EU (Nykänen et al. 2019).

As with the bottlenose dolphin, common dolphins are abundant and wide-spread in coastal and pelagic habitats (Perrin 2009). As apex predators, they are important components of their ecosystems (Kenney et al. 1997). The common dolphin is one of the most commonly sighted oceanic dolphins off Macaronesia archipelagos and an important component of these insular marine ecosystems (Reiner et al. 1996, Carrillo et al. 2010, Quérouil et al. 2010, Silva et al. 2014). Furthermore, common dolphins are one of the cetaceans most affected by bycatch mortality in the North Atlantic, further motivating research (Cruz et al. 2018).

Unlike the dolphin species above, the sperm whale is a deep-diver and is seldom found in waters <1000 m, especially over the continental shelves (Whitehead 2009). The species is common in the Macaronesia archipelagos (Moore et al. 2003, Freitas et al. 2004, Carrillo et al. 2010, Silva et al. 2014) and, as such, these islands are important for its study. Moreover, the species was targeted by whaling operations for a long period, with relevant catches in the Azores and Madeira archipelagos (Brito 2008, Prieto et al. 2013). This fostered some of the early research work in these regions, especially in the case of the Azores (e.g., Clarke et al. 1993), and yielded data that still support current research (Vieira & Brito 2009, Prieto et al, 2013). The species is also targeted by whale watching operations, raising questions about impacts at individual and population levels, and leading to resource allocation to the study of the species, as well as the whale watching activity and its management (e.g., Vieira et al. 2018).

The other species that are represented in our results are probably a reflection of the cetacean diversity of the study region and combine results from directed (projects or surveys with pre-designed sampling protocol) and opportunistic research, including strandings, opportunistic sightings and encounters (Perrin 2009, Wells & Scott 2009).

Research topics

We identified research in all eight main topics considered (Table 1, Fig. 3). In general, ecology-related topics received most attention (n=141). This is not surprising, given the vast and diversified list of ecology-associated topics included (Appendix S4). Azores has been the stage of most papers on ecology (n=59), human interactions (n=34), taxonomy (n=27), and behaviour (n=21), but topics related to genetics (n=15) or acoustics (n=15) were less common. It is noteworthy that, with 59 records, the Azores holds more than twice the number of records under ecology than any of the other regions. Ecology is also the modal topic within the Azores.

About a third (33.8%) of the research outputs were focused on anatomy and taxonomy. Although not presented here, our results show that many of the early works were related to species records accounts and strandings descriptions, with anatomical and pathological information, that fall in those two research topics. When considering only the North African regions, Anatomy and Taxonomy have an even higher importance (53.5%), evidence of a more opportunistic rather than focused approach to cetacean research in those regions (e.g., Cadenat 1954). Senegal had a high scientific contribution on taxonomy (n=24) and anatomy (n=24), but none on acoustics or genetics, and only one paper on behaviour. Cape Verde has contributed mostly to ecology (n=17), with only one study on behaviour and genetics (n=1), and none on acoustics. In Morocco, studies have been focused on ecology (n=11) and taxonomy (n=10) but had very low research output for all other topics.

The same pattern applies for Mauritania (ecology n=18; taxonomy n=13) and for Madeira (ecology n=25, taxonomy n=17).

The Canary Islands mostly contributed with work on cetacean anatomy (n=36) and human interactions (n=36), with a low contribution on genetics (n=7), taxonomy (n=9), and behaviour (n=13). Among regions, either the Azores or the Canary Islands had always the highest number of records for any given research topic (Azores: taxonomy, ecology, behaviour, genetics; Canary Islands: anatomy, acoustics, conservation, human interactions). From our results alone it is difficult to interpret these findings as a result of a certain level of specialization on a given topic, focused research goals, or a combination of those (which is more likely). However, it is apparent that these two archipelagos have been devoting a considerable effort in researching several aspects of cetacean life and conservation and are at the forefront of cetacean research within the study region.

The two topics that had the least records were acoustics and genetics with 43 and 30 records, respectively. There may be a number of reasons for that. One reason may have to do with our method: acoustics and genetics, along with conservation, have the least associated topics which naturally restricts the number of publications that can be assigned to each of them. On the other hand, studies under those topics involve specialized equipment and skills, that are not widely available and may have high associated costs, with many recent developments, hindering their historical widespread use. However, conservation studies do not necessarily involve specialized resources and can, in many cases, be based on existing data.

Not surprisingly, the most studied species in each topic were almost invariably the bottlenose dolphin, the common dolphin, and the sperm whale, although for acoustics and genetics, one or two of those species were replaced by others.

Final considerations

Bibliometric analysis has increasingly been used to explore the proportion of published research of a specific field of study (Kochin & Levin 2004), or to evaluate research trends (Bini et al. 2005). This is the first review quantifying the number of extant cetacean species and their ecology, focused in the Eastern North Atlantic. This wide geographical and economically diverse area showed a high diversity with 35 species, corresponding to approximately 1/3 of all described cetaceans. Finding research patterns over time helps identifying knowledge gaps, allowing to prioritize future research, and to improve ecosystems' management.

Other papers have analysed cetacean research trends globally. However, the methodology, study area, time span, and species were distinct from ours, making it difficult to compare results. For example, Rose et al (2011) demonstrated that modern cetacean research is focused on conservation-related topics, representing a shift from previous basic biological and ecological studies. Although our review found a biology-related research focus in earlier years, the same was not observed for ecological research, nor was an accentuated focus on conservation research observed in recent years. This may be a consequence of a change in what is considered a conservation topic. For instance, those authors considered many acoustic papers to fall within the conservation category. In addition, differences might be due to different time spans, which could mask some temporal trends. On the other hand, Hill and Lackups (2010) found that only 3.2% of the papers analysed covered conservation, ecology or environmental topics. However, they only focused on cetacean species cared for by humans at some point during captivity's documented history', leaving out conservation studies done on free-ranging cetaceans (such as baleen whales and beaked whales).

Nevertheless, and in spite of the different approaches to analyse research trends over the past 20 years and the allocation of limited resources, growing environmental concerns have prioritized scientific research and the allocation of funds to identify critical questions that need to be answered to support conservation issues (Sutherland et al. 2009, 2011). Under this framework, Parsons et al (2015) presented a list of priority questions for global cetacean conservation, in which geographic, cultural, and economic contexts were taken into account, as attempted here.

Among other topics, a priority for conservation was how to best supervise populations and key activities (such as development projects, industry, fisheries, and tourism). Cetacean populations are subject to many pressures, and this is particularly important in the Azores, Madeira and Canary Islands, where anthropogenic activities are growing at a fast pace. Moreover, understanding how to manage the lack of data on many cetacean species to better address gaps on information useful for conservation, was another problem identified in our review and also reported by Parsons et al. (2015). In this particular region, beaked whales are common (Aguilar de Soto et al. 2017), but little is known about them (Hooker et al. 2019). Thus, allocating research resources to these species could lead to relevant findings to help their conservation.

Not mentioned in Parsons et al. (2015) list is the importance of long-term studies. As pointed out by Lindenmayer et al. 2012, such studies are important for providing key insights in ecology, environmental change, natural resource management and biodiversity conservation, and this needs to be emphasized to resource managers and policy makers. However, long-term ecological studies have been scarce due to financial constraints since they usually exceed government administrations time span and funding cycles. As such, ecologists and field biologists should join efforts in an open and collaborative way, maintaining publishing outlets for empirical field-based ecology and sharing of their long-term data sets (Lindenmayer et al. 2012). In our dataset, only a limited number of studies utilized long-term datasets, using whaling or fisheries observer programs data and not necessarily analysing temporal trends (Brito 2008, Silva et al. 2009, 2014, Prieto et al. 2013). In contrast, we verified the segregation of topics studied in the two most explored regions for cetacean research (Azores and the Canary Islands).

Given the special ecological importance of the study area, we suggest a strategy similar to that of Ijsseldijk et al. (2018), to coordinate resources and research agendas. Here, expert opinions were exploited through a two-round Delphi approach that aimed to "identify current knowledge gaps, predict future threats and suggest useful conservation indicators to guide research and monitoring of harbour porpoises". The Delphi method is a questionnaire-based research approach that allows experts to collectively address complex problems. Several rounds of questionnaires are sent out to a group of experts, and the anonymous responses are aggregated and shared with the group, and each round is followed by a feedback round (Mukherjee et al. 2015). The Delphi method is especially powerful on assessing complex issues with poor data and has been used previously in a range of fields, such as tourism and medicine. Although, the use of this method in conservation studies and ecological management is still uncommon (Mukherjee et al. 2015), by defining research priorities its applicability could guide research focus and management efforts of cetacean populations. Thus, we suggest the application of that method to identify priority research for cetaceans in our study region, and to foster collaborative efforts among the region's research teams, dataset-sharing and development of long-term research programs.

Conflict of Interest

The authors declare no conflicts of interest.

References

Abecasis RC, Afonso P, Colaço A, Longnecker N, Clifton J, Schmidt L, Santos RS (2015) Marine conservation in the Azores: evaluating marine protected area development in a remote island context. *Frontiers in Marine Science*, 2.

Aguilar de Soto N, Martín V, Silva M, Edler R, Reyes C, Carrillo M, Schiavi A, Morales T, García-Ovide B, Sanchez-Mora A, Garcia-Tavero N, Steiner L, Scheer M, Gockel R, Walker D, Villa E, Szlama P, Eriksson IK, Tejedor M, Perez-Gil M, Quaresma J, Bachara W, Carroll E (2017) True's beaked whale (*Mesoplodon mirus*) in Macaronesia. *PeerJ* 7 (5): e3059.

Almeida-Filho N, Kawachi I, Pellegrini Filho A, Dachs JNW (2003) Research on health inequalities in Latin America and the Caribbean: bibliometric analysis (1971–2000) and descriptive content analysis (1971–1995). *American Journal of Public Health* 93 (12): 2037–2043.

Alves F, Ferreira R, Fernandes M, Halicka Z, Dias L, Dinis A (2018) Analysis of occurrence patterns and biological facts of cetaceans based on long-term and fine-scale data from platforms of opportunity: Madeira Island as a case study. *Marine Ecology* 39: e12499.

Augusto JF, Rachinas-Lopes P, Santos ME (2011) Social structure of the declining resident community of common bottlenose dolphins in the Sado Estuary, Portugal. *Journal of the Marine Biological Association of the United Kingdom* 92 (8): 1773-1782.

Ballance LT (2018) Cetacean ecology. In: Würsig B, Thewissen JGM, Kovacs, KM (eds) *Encyclopedia of Marine Mammals*, 3rd edition, 172-180. Academic Press, Cambridge, Massachusetts, EUA.

Beaugrand G, Edwards M, Hélaouët P (2019) An ecological partition of the Atlantic Ocean and its adjacent seas. *Progress in Oceanography* 173: 86-102.

Bencatel J, Ferreira CC, Barbosa AM, Rosalino LM, Álvares F (2018) Research trends and geographical distribution of mammalian carnivores in Portugal (SW Europe). *PLOS ONE* 13(11): e0207866.

Bini LM, Diniz-Filho JAF, Carvalho P, Pinto MP, Rangel TFLVB (2005) Lomborg and the litany of biodiversity crisis: what the peer-reviewed literature says. *Conservation Biology* 19: 1301–5.

Boisseau O, Prieto R, Nicholson D, Gordon J (1999) An Atlantic cetacean survey using yachtsmen: a pilot study. *Arquipélago. Life and Marine Sciences* 17A: 101-107.

Boys RM, Oliveira C, Pérez-Jorge S, Prieto R, Steiner L, Silva MA (2019) Multi-state open robust design applied to opportunistic data reveals dynamics of wide-ranging taxa: the sperm whale case. *Ecosphere* 10 (3): e02610.

Bowen WD (1997) Role of marine mammals in aquatic ecosystems. *Marine Ecology Progress Series* 158: 267-274.

Brito C (2008) Assessment of catch statistics during the land-based whaling in Portugal. *Marine Biodiversity Records*, 1: e92.

Brito C, Sousa A (2011) The Environmental History of Cetaceans in Portugal: Ten Centuries of Whale and Dolphin Records. *PLoS ONE* 6 (9): e23951.

Cadenat J (1954) Echouage d'un cachalot sur les côtes du Sénégal. *Notes Africaines* Dakar 64: 119-121.

Cañadas A, Sagarminaga R, Garcia-Tiscar S (2002) Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. *Deep-Sea Research Part I* 49: 2053–2073.

Carrere R (2009) African Mangroves: Their Importance for People and Biodiversity. *Nature & Faune* 24 (1): 3–7.

Carrillo M, Pérez-Vallazza C, Álvarez-Vázquez R (2010) Cetacean diversity and distribution off Tenerife (Canary Islands). *Marine Biodiversity Records* 3: E97. doi:10.1017/S1755267210000801

Carvalho ML, Pereira RA, Brito J (2002) Heavy metals in soft tissues of *Tursiops truncatus* and *Delphinus delphis* from west Atlantic Ocean by X-ray spectrometry. *The Science of the Total Environment* 292: 247–254.

Clarke MR, Martins HR, Pascoe P (1993) The diet of sperm whales (*Physeter macrocephalus* Linnaeus 1758) off the Azores. *Philosophical Transactions of the Royal Society of London B* 339: 67-82.

Correia AM, Gil Á, Valente R, Rosso M, Pierce GJ, Sousa-Pinto I (2019) Distribution and habitat modelling of common dolphins (*Delphinus delphis*) in the eastern North Atlantic. *Journal of the Marine Biological Association of the United Kingdom* 1–15.

Correia AM, Tepsich P, Rosso M, Caldeira R, Sousa-Pinto I (2015) Cetacean occurrence and spatial distribution: Habitat modelling for offshore waters in the Portuguese EEZ (NE Atlantic). *Journal of Marine Systems* 143: 73–85.

Cropper TE, Hanna E (2014) An analysis of the climate of Macaronesia, 1865–2012. *Internationnal Journal Climatology* 34: 604-622.

Cruz MJ, Machete M, Menezes G, Rogan E, Silva MA (2018) Estimating common dolphin bycatch in the pole-and-line tuna fishery in the Azores. *PeerJ* 6: e4285.

Cruz MJ, Menezes G, Machete M, Silva MA (2016) Predicting Interactions between Common Dolphins and the Pole-and-Line Tuna Fishery in the Azores. *PLoS ONE* 11(11): e0164107.

Cunha I, Freitas L, Alves F, Dinis A, Ribeiro C, Nicolau C, Ferreira R, Gonçalves JÁ, Formigo N (2017) Marine traffic and potential impacts towards cetaceans within the Madeira EEZ. *Journal of Cetacean Research and Management* 16: 17–28.

Cushing DH (1971) Upwelling and the Production of Fish. *Advances in Marine Biology* 9: 255–335.

Dinis A, Carvalho A, Alves F, Nicolau C, Ribeiro C, Kaufmann M, Cañadas A, Freitas L (2016) Spatial and temporal distribution of bottlenose dolphins, *Tursiops truncatus*, in the Madeira archipelago, NE Atlantic. *Arquipelago. Life and Marine Sciences* 33: 45-54.

Doksæter L, Olsen E, Nøttestad L, Fernö A (2008) Distribution and feeding ecology of dolphins along the Mid-Atlantic Ridge between Iceland and the Azores. *Deep-Sea Research II* 55: 243–253.

Downing JA (1991) Biological heterogeneity in aquatic ecosystems. In Kolasa J, Pickett STA (eds) *Ecological Heterogeneity*. New York, NY: Springer New York, 160-180.

Fais A, Lewis TP, Zitterbart DP, Álvarez O, Tejedor A, Aguilar Soto N (2016) Abundance and Distribution of Sperm Whales in the Canary Islands: Can Sperm Whales in the Archipelago Sustain the Current Level of Ship-Strike Mortalities? *PLoS ONE* 11(3): e0150660.

Fraga F (1981) Upwelling off the Galician coast, northwest of Spain. In: Richards F (ed) *Coastal Upwelling,* 176-182. American Geophysical Union, Washington

Fochler M, Felt U, Müller R (2016) Unsustainable Growth, Hyper-Competition, and Worth in Life Science Research: Narrowing Evaluative Repertoires in Doctoral and Postdoctoral Scientists' Work and Lives. *Minerva* 54 (2): 175-200.

Freitas L, Dinis A, Nicolau C, Ribeiro C, Alves F (2012) New records of cetacean species for Madeira Archipelago with an updated checklist. Boletim do Museu Municipal do Funchal 62 (334): 25-43.

Freitas L, Dinis A, Alves F, Nóbrega F (eds) (2004) *Cetáceos no Arquipélago da Madeira*. Machico, Portugal: Museu da Baleia do Machico.

Genin A (2004) Bio-physical coupling in the formation of zooplankton and fish aggregations over abrupt topographies. *Journal of Marine Systems* 50: 3–20.

Hazevoet CJ, Monteiro V, López P, Varo N, Torda G, Berrow S, Gravanita B (2010) Recent data on whales and dolphins (Mammalia: Cetacea) from the Cape Verde Islands, including records of four taxa new to the archipelago. *Zoologia Caboverdiana* 1 (2): 75-99.

Heitor M, Horta H (2013) Science and technology in Portugal: From Late awakening to the challenge of knowledge-integrated communities. In: Neave G, Amaral A (eds) *Higher education in Portugal 1974-2009: A nation, a generation.* Springer Netherlands, 179-226.

Hill H, Lackups M (2010) Journal publication trends regarding cetaceans found in both wild and captive environments: what do we study and where do we publish? *International Journal of Comparative Psychology* 23: 414–534.

Holden G, Rosenberg G, Barker K (2005) Tracing thought through time and space: A selective review of bibliometrics in social work. *Social Work in Health Care* 41 (¾): 1-34.

Hooker SK, Aguilar de Soto N, Baird RW, Carroll EL, Claridge D, Feyrer L, Miller PJO, Onoufriou A, Schorr G, Siegal E, Whitehead H (2019) Future Directions in Research on Beaked Whales. *Frontiers in Marine Science* 5: 514.

Hooker SK, Gerber LR (2014) Marine reserves as a tool for ecosystem-based management: the potential importance of megafauna. *Bioscience* 54 (1): 27–39.

IJsseldijk LL, ten Doeschate MTI, Davison NJ, Gröne A, Brownlow AC (2018) Crossing boundaries for cetacean conservation: Setting research priorities to guide management of harbour porpoises. *Marine Police* 95: 77-84.

Jungblut S, Nachtsheima DA, Boos K, Joiris CR (2017) Biogeography of top predators – seabirds and cetaceans – along four latitudinal transects in the Atlantic Ocean. *Deep-Sea Research Part II* 141: 59–73.

Kati V, Hovardas T, Dieterich M, Ibisch PL, Mihok B, Selva N (2015) The challenge of implementing the European network of protected areas Natura 2000 29 (1): 260-270.

Kenney RD, Scott GP, Thompson TJ, Winn HE (1997) Estimates of prey consumption and trophic impacts of cetaceans in the USA Northeast Continental shelf ecosystem. *Journal of Northwest Atlantic Fishery Science* 22: 155-171.

Kiszka J, Macleod K, Van Canneyt O, Walker D, Ridoux V (2007) Distribution, encounter rates, and habitat characteristics of toothed cetaceans in the Bay of Biscay and adjacent waters from platform-of-opportunity data. *ICES Journal of Marine Science* 64: 1033–1043.

Kochin BF, Levin PS (2004) Publication of marine conservation papers: is conservation biology too dry? *Conservation Biology* 18: 1160–2.

Kucklick J, Schwacke L, Wells R, Hohn A, Guichard A, Yordy J, Hansen L, Zolman E, Wilson R, Litz J, Nowacek D, Rowles T, Pugh R, Balmer B, Sinclair C, Rosel P (2011) Bottlenose dolphins as indicators of persistent organic pollutants in the western North Atlantic Ocean and northern Gulf of Mexico. *Environmental Science & Technology* 45 (10): 4270-7.

Kushnir I (2019) Economy of Northern Africa. Independently Published, 72 pp.

Kvile KØ, Taranto GH, Pitcher T, Morato T (2014) A global assessment of seamount ecosystems knowledge using an ecosystem evaluation framework. *Biological Conservation* 173: 108-120.

Lemarchand GA (2016) The scientific productivity and the dynamics of self-organizing networks: Ibero-American and Caribbean countries (1966–2013). In Horta H, Heitor M, Salmi J (eds) *Trends and Challenges in Science and Higher Education.* Springer International Publishing, 29-46.

Lindenmayer DB, Likens GE, Andersen A, Bowman D, Bull CM, Burns E, Dickman CR, Hoffmann AA, Keith DA, Liddell MJ, Lowe AJ, Metcalfe DJ, Phinn SR, Russell-Smith J, Thurgate N, Wardle GM (2012) Value of long-term ecological studies. *Austral Ecology* 37: 745-757.

Longhurst AR (2007) Chapter 9 – The Atlantic Ocean. In: Longhurst AR (ed), *Ecological Geography of the Sea (Second Edition)*. Burlington: Academic Press, 131-273.

Lopes K, Passos L, Rodrigues JG, Koenen F, Stiebens V, Szekely T, Dutra A (2016) Sea Turtle, Shark, and Dolphin Bycatch Rates by Artisanal and Semi-Industrial Fishers in Maio Island, Cape Verde. *Chelonian Conservation and Biology* 15(2): 279–288.

MacLeod CD, Mitchell G (2006) Key areas for beaked whales worldwide. *Journal of Cetacean Research and Management* 7 (3): 309-322.

Mason E (2009) High-resolution modelling of the Canary Basin oceanic circulation. PhD thesis, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain.

Moore MJ, Steiner L, Jann B (2003) Cetacean surveys in the Cape Verde Islands and the use of cookiecutter shark bite lesions as a population marker for fin whales. *Aquatic Mammals* 29: 383-389.

Morato T, Machete M, Kitchingman A, Tempera F, Lai S, Menezes G, Pitcher TJ, Santos RS (2008) Abundance and distribution of seamounts in the Azores. *Marine Ecology Progress Series* 357: 17-21.

Mukherjee N, Huge J, Sutherland WJ, McNeill J, Van Opstal M, Dahdouh-Guebas F, Koedam N (2015) The Delphi technique in ecology and biological conservation: applications and guidelines. *Methods in Ecology and Evolution* 6 (9): 1097-1109.

1097–1109, https://doi.org/10.1111/2041-210X.12387

Norton MJ (ed; 2000) Introductory concepts in information science. Information Today, Inc, Medford, NJ.

Nugent P (2012) *Africa since Independence*. London, United Kingdom: MacMillan Education UK.

Nykänen M, Louis M, Dillane E, Alfonsi E, Berrow S, O'Brien J, Brownlow A, Covelo P, Dabin W, Deaville R, de Stephanis R, Gally F, Gauffier P, Ingram SN, Lucas T, Mirimin L, Penrose R, Rogan E, Silva MA, Simon-Bouhet B, Gaggiotti OE (2019) Fine-scale population structure and connectivity of bottlenose dolphins, *Tursiops truncatus*, in European waters and implications for conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29 S1: 197-211.

Olukoshi A (2001) West Africa's political economy in the next millennium: Retrospect and Prospect, 48. CODESRIA, Senegal.

Parsons ECM (2012) The Negative Impacts of Whale-Watching. *Journal of Marine Biology*, DOI: 10.1155/2012/807294.

Parsons ECM, Baulch S, Bechshoft T, Bellazzi G, Bouchet P, Cosentino AM, Godard-Codding CAJ, Gulland F, Hoffmann-Kuhnt M, Hoyt E, Livermore S, MacLeod CD, Matrai E, Munger L, Ochiai M, Peyman A, Recalde-Salas A, Regnery R, Rojas-Bracho L, Salgado-Kent CP, Slooten E, Wang JY, Wilson SC, Wright AJ, Young S, Zwamborn E, Sutherland WJ (2015) Key research questions of global importance for cetacean conservation. *Endangered Species Research* 27: 113–118.

Perán AD, Pham CK, Amorim P, Cardigos F, Tempera F, Morato T (2016) Seafloor characteristics in the Azores region (North Atlantic). *Frontiers in Marine Science* 3: (204).

Perrin WF (2009) Common Dolphins. In: Perrin WF, Würsig B, Thewissen JGM (eds) *Encyclopedia of Marine Mammals (2nd ed.)*. New York, USA: Academic Press, 255-259.

Price D (1951) Quantitative measures of the development of science. *Archives Internationales d'Histoire des Sciences* 14: 85–93.

Prieto R, Janiger D, Silva MA, Waring GT, Gonçalves JM (2012) The forgotten whale: a bibliometric analysis and literature review of the North Atlantic sei whale Balaenoptera borealis. *Mammal Review* 42 (3): 235-272.

Prieto R, Pham CK, Brito C, Morato T (2013) Biomass removal from shore-based whaling in the Azores. *Fisheries Research* 143 (0): 98-101.

Powell JJW, Dusdal J (2017) The European center of science productivity: Research universities and institutes in France, Germany, and the United Kingdom. In: Powell JJW, Baker DP, Fernandez F (eds) *The Century of Science*. International Perspectives on Education and Society Emerald Publishing Limited, 55-83.

Quérouil S, Freitas L, Cascão I, Alves F, Dinis A, Almeida JR, Prieto R, Borràs S, Matos JA, Mendonça D, Santos RS (2010) Molecular insight into the population structure of common and spotted dolphins inhabiting the pelagic waters of the Northeast Atlantic. *Marine Biology* 157: 2567-2580.

Reiner F, dos Santos ME, Wenzel FW (1996) Cetaceans of the Cape Verde Archipelago. *Marine Mammal Science* 123: 434-443.

Riera R, Becerro MA, Stuart-Smith RD, Delgado JD, Edgar GJ (2014) Out of sight, out of mind: Threats to the marine biodiversity of the Canary Islands (NE Atlantic Ocean). *Marine Pollution Bulletin* 86(1-2): 9-18.

Roman J, Estes JA, Morissette L, Smith C, Costa D, McCarthy J, Nation JB, Nicol S, Pershing A, Smetacek V (2014) Whales as marine ecosystem engineers. *Frontiers in Ecology and the Environment* 12: 377–385.

Rose NA, Janiger D, Parsons ECM, Stachowitsch M (2011) Shifting baselines in scientific publications: A case study using cetacean research. *Marine Policy* 35: 477–482.

Ryan C, Wenzel FW, Suárez PL, Berrow SD (2014) An abundance estimate for humpback whales *Megaptera novaeangliae* breeding around Boa Vista, Cape Verde Islands. *Zoologia Caboverdiana* 5 (1): 20-28.

Sawahel W (2009) 'Morocco to boost investment in science'. SciDev, 9 June. https://www.scidev.net/global/funding/news/morocco-to-boost-investment-in-science.html (Accessed: 28 October 2019)

Silva MA, Prieto R, Magalhães S, Cabecinhas R, Cruz A, Gonçalves JM, Santos RS (2003) Occurrence and distribution of cetaceans in the waters around the Azores (Portugal), Summer and Autumn 1999–2000. *Aquatic Mammals* 29 (1): 77–83.

Silva MA, Magalhães SM, Prieto R, Santos RS, Hammond PS (2009) Estimating survival and abundance in a bottlenose dolphin population taking into account transience and temporary emigration. *Marine Ecology Progress Series* 392: 263-276.

Silva MA, Prieto R, Cascão I, Seabra MI, Machete M, Baumgartner MF, Santos RS (2014) Spatial and temporal distribution of cetaceans in the mid-Atlantic waters around the Azores. *Marine Biology Research* 10 (2): 123-137.

Smith CR, Glover AG, Treude T, Higgs ND, Amon DJ (2015) Whale-fall ecosystems: recent insights into ecology, paleoecology, and evolution. *Annual Review of Marine Science* 7: 571-596.

Smith LV, McMinn A, Martin A, Nicol S, Bowie AR, Lannuzel D, van der Merwe P (2013) Preliminary investigation into the stimulation of phytoplankton photophysiology and growth by whale faeces. *Journal of Experimental Marine Biology and Ecology* 446: 1–9.

Sutherland WJ, Adams WM, Aronson RB, Aveling R and others (2009) One hundred questions of importance to the conservation of global biological diversity. *Conservation Biology* 23: 557−567.

Sutherland WJ, Fleishman E, Mascia MB, Pretty JP, Rudd MA (2011) Methods for collaboratively identifying research priorities and emerging issues in science and policy. *Methods in Ecology and Evolution* 2: 238−247.

Tobeña M, Escánez A, Rodríguez Y, López C, Ritter F, Aguilar N (2014) Inter-island movements of common bottlenose dolphins *Tursiops truncatus* among the Canary Islands: online catalogues and implications for conservation and management. *African Journal of Marine Science*, 36(1): 137–141.

Tulloch VJD, Plagányi E, Brown C, Richardson AJ, Matear R (2019) Future recovery of baleen whales is imperiled by climate change. *Global Change Biology* 25: 1263–1281.

Uman LS (2011) Systematic Reviews and Meta-Analyses. *Journal of the Canadian Academy of Child and Adolescent Psychiatry* 20 (1): 57–59.

Valdés L, Déniz-González I (2015) Oceanographic and biological features in the Canary Current Large Marine Ecosystem. Paris, France: IOC-UNESCO.

Valente R, Correia AM, Gil A, Garcia LG, Sousa-Pinto I (2019) Baleen whales in Macaronesia: occurrence patterns revealed through a bibliographic review. *Mammal Review* 49 (2): 129-151.

Van Waerebeek K, Djiba A, Krakstad J, Bila ASO, Bamy IL, Almeida A, Mbye EM (2013) New evidence for a South Atlantic stock of humpback whales wintering on the Northwest African continental shelf. *African Zoology* 48 (1): 177–186.

Viddi FA, Hucke-Gaete R, Torres-Florez JP, Ribeiro S (2010) Spatial and seasonal variability in cetacean distribution in the fjords of northern Patagonia, Chile. *ICES Journal of Marine Science* 67: 959–970.

Vieira J, Santos C, Silva F, Lopes F (2018) When watching replaces hunting: An analysis of customer participation and satisfaction with cetacean-watching in the Azores. *Ocean & Coastal Management* 160: 86-92.

Vieira N, Brito C (2009) Past and recent sperm whales sightings in the Azores based on catches and whale watching information. *Journal of the Marine Biological Association of the United Kingdom* 89 (5): 1067-1070.

Wade PR (2018) Population dynamics. In: Würsig B, Thewissen JGM, Kovacs, KM (eds) *Encyclopedia of Marine Mammals*, 3rd edition, 763-770. Academic Press, Cambridge, Massachusetts, USA.

Weir CR, Pierce GJ (2013) A review of the human activities impacting cetaceans in the eastern tropical Atlantic. *Mammal Review* 43: 258–274.

Wells RS, Scott MD (2009) Common Bottlenose Dolphin. In: Perrin WF, Würsig B, Thewissen JGM (eds) *Encyclopedia of Marine Mammals*, 2nd ed. New York, USA: Academic Press, 249-255.

Whitehead H (2009) Sperm whale Physeter macrocephalus. In: Perrin WF, Würsig B, Thewissen JGM (eds) *Encyclopedia of Marine Mammals*, 2nd ed. New York, USA: Academic Press, 1091-1097.

Wild S, Krützen M, Rankin RW, Hoppitt WJE, Gerber L, Allen SJ (2019) Long-term decline in survival and reproduction of dolphins following a marine heatwave. *Current Biology* 29: 225–240.

Woodroffe CD (2014) The rock coasts of oceanic islands. Geological Society, London, Memoirs: 40 (1): 247-261.

Zhou JL, Salvador SM, Liu YP, Sequeira M (2001) Heavy metals in the tissues of common dolphins *Delphinus delphis* stranded on the Portuguese coast. *The Science of the Total Environment* 273: 61-76.

Figures' headings

Figure 1. Study area.

Figure 2. Number of peer-reviewed papers on cetaceans published per year in Central Northeast Atlantic from 1900-2018. A General Additive Model was fitted to the data (r^2: 0.897; $P < 0.001$). The red dashed line represents the year in which the evolution of published papers had a significant turning point (via the Change-Point Analyses).

Figure 3. Research output on cetaceans per topic.

Figure 4. Research output on cetaceans per region.

Figure 5. Cetacean species studied in the Central Northeast Atlantic and the number of papers involving these species. Codes of species are specified in the Appendix S3 of the supplementary material.

Figure 6. Percentage of studied species according to their IUCN (global) statuses. LC=Least Concern, VU=Vulnerable, NT=Near Threatened, EN=Endangered, CR=Critically Endangered, DD=Data Deficient.

Tables and tables' headings

Table 1. Number of publications per topic on cetaceans in each region from 1900-2018.

	Anatomy	**Taxonomy**	**Ecology**	**Behaviour**	**Acoustics**	**Genetics**	**Conservation**	**Human interactions**
Madeira Archipelago	11	17	25	9	1	7	6	8
Azores Archipelago	26	27	59	21	15	15	19	34
Mainland Portugal	20	21	29	12	9	14	11	24
Canary Islands	36	9	28	13	23	7	23	36
Cape Verde Islands	9	17	17	1	0	1	3	9
Morocco	6	10	11	1	1	1	1	2
Senegal	24	24	11	1	0	0	6	4
Mauritania	12	13	18	2	1	2	2	5
Total	116	103	141	55	43	30	60	99

Table 2. Summary of the most studied species in each region, and number of papers in which the species were studied (n).

	Top studied species
Madeira Archipelago	*Delphinus delphis* (n= 19)
	Tursiops truncatus (n=16)
	Globicephala macrorhynchus (n=14)
Azores Archipelago	*Physeter macrocephalus* (n=48)
	Delphinus delphis (n=34)
	Tursiops truncatus (n=31)
Mainland Portugal	*Tursiops truncatus* (n=32)
	Delphinus delphis (n=28)
	Phocoena phocoena (n=13)
Canary Islands	*Ziphius cavirostris* (n=30)
	Globicephala macrorhynchus, Mesoplodon densirostris (n=29)
	Tursiops truncatus (n=28)
Cape Verde Islands	*Megaptera novaeangliae* (n=18)
	Physeter macrocephalus, *Globicephala macrorhynchus* (n=8)
	Tursiops truncatus, *Stenella frontalis*, *Steno bredanensis*, *Balaenoptera physalus* (n=7)
Morocco	*Tursiops truncatus*, *Orcinus orca*, *Delphinus delphis* (n=8)
	Ziphius cavirostris, *Sotalia teuszii*, *Phocoena phocoena*, *Globicephala melas*, *Megaptera novaeangliae*, *Balaenoptera acutorostrata* (n=5)
	Stenella frontalis, *Stenella coeruleoalba*, *Physeter macrocephalus*, *Pseudorca crassidens*, *Globicephala macrorhynchus*, *Grampus griseus*, *Balaenoptera physalus* (n=4)
Senegal	*Tursiops truncatus* (n=17)
	Sotalia teuszii (n=16)
	Orcinus orca (n=14)
Mauritania	*Sotalia teuszii*, *Phocoena phocoena* (n=12)
	Tursiops truncatus (n=11)
	Delphinus delphis (n=10)

Table 3. Summary of the most studied species for each topic, number of papers in which the species were studied for specific topics, and total of papers per topic.

	Anatomy	Taxonomy	Ecology	Behaviour	Acoustics	Genetics	Conservation	Human interactions
Most studied species	*T. truncatus* (n=35)	*D. delphis* (n=41)	*T. truncatus* (n=52)	*T. truncatus* (n=17)	*M. densirostris* (n=10)	*D. delphis* (n=10)	*T. truncatus* (n=24)	*P. macrocephalus* (n=34)
	D. delphis (n=33)	*T. truncatus* (n=32)	*D. delphis* (n=46)	*P. macrocephalus* (n=11)	*T. truncatus* (n=7)	*T. truncatus* (n=6)	*D. delphis* (n=20)	*D. delphis, T. truncatus* (n=29)
	P. macrocephalus (n=29)	*P. macrocephalus* (n=28)	*P. macrocephalus* (n=38)	*D. delphis* (n=9)	*G. macrorhynchus* (n=6)	*S. frontalis* (n=5)	*P. macrocephalus* (n=15)	*S. frontalis* (n=19)
Least studied species	*D. capensis* (n=0)	*D. capensis, M. mirus, S. clymene* (n=2)	*M. mirus* *n=0*	*S. clymene, S. attenuata, S. longirostris, P. phocoena, M. mirus, M. bidens, K. sima, F. attenuata, D. capensis* (n=0)	*S. clymene, S. attenuata, S. teuszii, S. longirostris, S. bredanensis, P. electra, M. bidens, L. hosei, K. sima, K. breviceps, F. attenuata, D. capensis, M. novaeangliae, E. glacialis, B. edeni* (n=0)	*S. clymene, S. attenuata, S. longirostris, S. bredanensis, P. electra, P. crassidens, M. europaeus, M. densirostris, M. bidens, L. hosei, K. sima, K. breviceps, H. ampullatus, F. attenuata, E. glacialis, B. edeni, B. acutorostrata, B. musculus, O. Orca, G. griséus, S. teuszii* (n=0)	*S. clymene, S. attenuata, S. longirostris, F. attenuata, D. capensis, P. electra* (n=0)	*D. capensis* (n=0)
	S. attenuata, (n=1)	*S. attenuata,* (n=5)	*D. capensis* (n=1)	*M. europaeus, S. teuszii, P. electra, K. breviceps, G. melas, B. acutorostrata, B. edeni, M. novaeangliae, B. musculus, H. ampullatus* (n=1)	*P. phocoena, M. mirus, P. crassidens, O. orca, H. ampullatus, G. melas, B. musculus, B. acutorostrata* (n=1)	*Z. cavirostris, M. mirus, D. capensis, M. novaeangliae, B. physalus, B. borealis* (n=1)	*M. mirus, K. sima, L. hosei, B. musculus* (n=1)	*S. clymene, P. electra* (n=1)
	M. mirus (n=2)	*F. attenuata, B. edeni, L. hosei* (n=7)	*K. sima, M. bidens, S. attenuata, F. attenuata* (n=4)	*E. glacialis, O. orca, L. hosei, B. physalus* (n=2)	*S. coeruleoalba, M. europaeus* (n=2)	*P. macrocephalus* (n=2)	*M. bidens, B. edeni, P. crassidens* (n=2)	*S. attenuata, M. mirus, F. attenuata* (n=2)
Total of papers	116	103	141	55	43	30	60	99