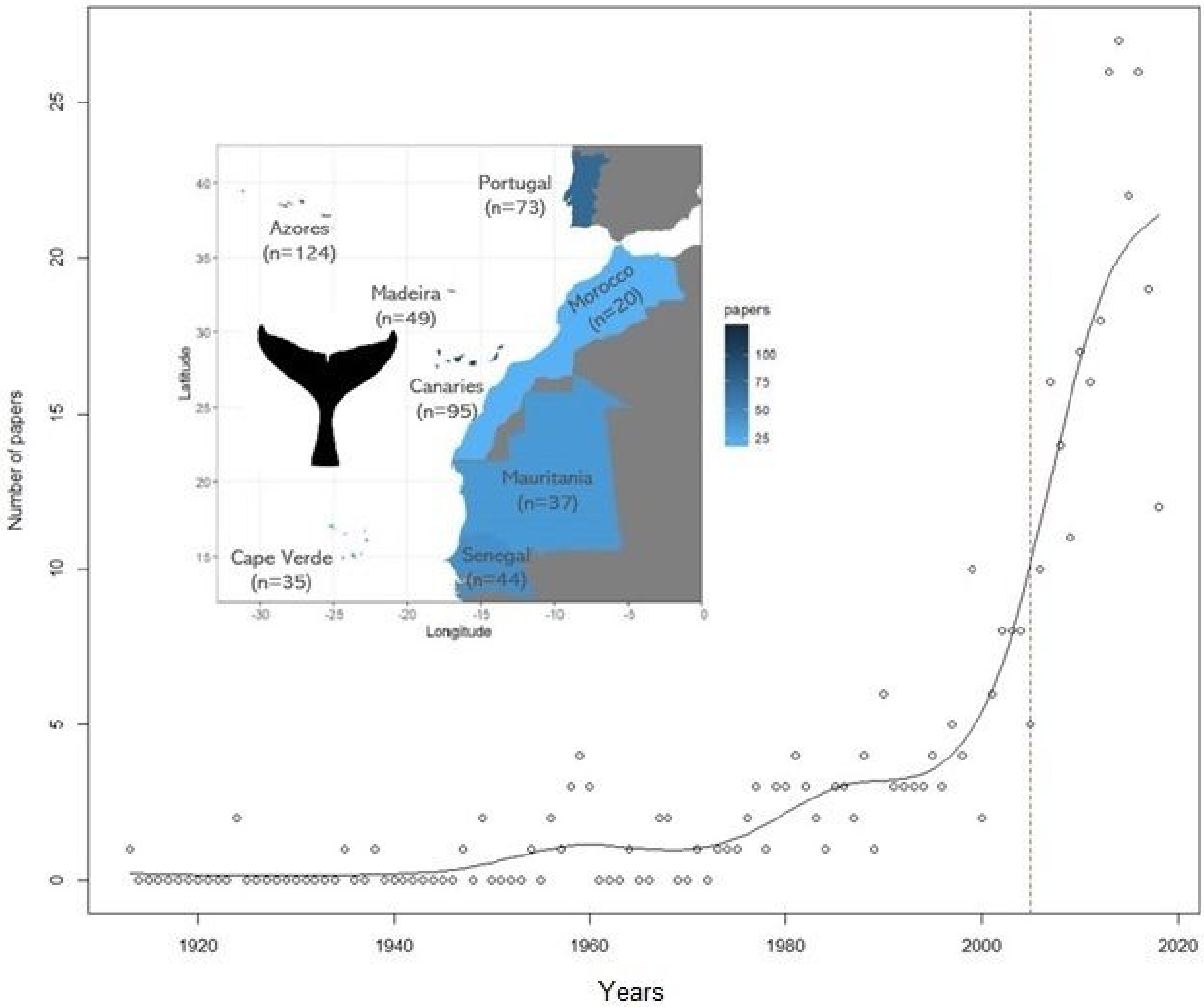
Trends in cetacean research in the Eastern North Atlantic



Graphical Abstract: Number of peer-reviewed papers on cetaceans published per year from 1900-2018 in Eastern North Atlantic Ocean, including, mainland Portugal, Morocco, Mauritania, Senegal, and the islands of Cape Verde, Canaries, Madeira and Azores. The dashed line marks the year in which the evolution of published papers had a significant turning point, 2005. In the map, darker coloured countries represent higher number of published papers on cetaceans.

REVIEW

Trends in cetacean research in the Eastern North Atlantic

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ABSTRACT

1. Cetaceans are considered ecosystem engineers and useful bioindicators of the health of marine environments. The Eastern North Atlantic 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 the composition of this research has not been assessed.
2. We aimed to describe and quantify the evolution of research on cetaceans in the Eastern North Atlantic, highlighting the main focal areas and trends.
3. We considered 380 peer-reviewed publications between 1900 and 2018. For each paper, we collected publication year, research topics and regions, and species studied. We assessed differences among regions with distinct socio-economic landscapes, and between coastal and oceanic habitats. To evaluate the changes in scientific production over time, we fitted a general additive model to the time series of numbers of papers.
4. Although research in this region has been increasing, the results show relatively little research output in North African and coastal regions within the study area. Moreover, except for four studies, research was restricted to a few miles around the coast of the main islands, leaving offshore regions less well surveyed. There was little research on genetics, acoustics, and behaviour. Most papers were focused on the Azores and Canary Islands, and mostly involved *Tursiops truncatus*, *Delphinus delphis*, and *Physeter macrocephalus*. Species considered Endangered or Near Threatened were the subjects of only 10% of the studies.
5. We suggest a greater research focus on beaked whales (Ziphiidae) 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 questionnaires answered by experts, could be attempted to identify priority research for cetaceans in these areas.

Keywords: cetaceans, Eastern North Atlantic, Macaronesia, Northwest Africa, Portuguese Exclusive Economic Zone, scientific production, systematic review

INTRODUCTION

Cetaceans play a significant role in marine ecosystem functioning due to their relatively large body size and due 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 fertilisers to primary producers in the ocean surface (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 specialised fauna and as stepping stones for hydrothermal vent organisms (Smith et al. 2015). Some cetacean 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 they may 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 throughout 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 large 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 geographic ranges.

This study is focused between latitudes 42°N and 13°N in the Eastern North Atlantic, including waters off mainland Portugal, Morocco, Mauritania and Senegal, and the Macaronesia archipelagos that include the Azores, Madeira, Canaries, and Cape Verde. The study region is referred to as the 'Eastern North Atlantic' (Fig. 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 numbers of seamounts (Morato et al. 2008, Kvile et al. 2014), diverse seafloor morphology, and a rugged coastline in Iberia and North Africa (Valdés & Déniz-González 2015, Perán et al. 2016). This region encompasses the East and West North Atlantic Subtropical Gyral, Canary Coastal, and North Atlantic Tropical Gyral biogeochemical provinces (Longhurst 2007). It comprises coastal habitats, 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 north-west Iberian coast is characterised 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 important and economically exploitable fish species (Fraga 1981). Additionally, the Northwest African coast is characterised 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 sub-Saharan African region is endowed with a variety of coastal ecosystems, such as estuaries, coral reefs, mangrove forests, wetlands, and dunes, providing ecosystem services not only to coastal communities (e.g., coastal stabilisation 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).

Populations of marine mammals 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 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; the most affected species was the sperm whale *Physeter macrocephalus* (Riera et al. 2014, Fais et al. 2016). In Madeira, the ship strike risk is apparently not alarming, but as vessel traffic increases, so does the negative impact on cetaceans (Cunha et al. 2017). Along the Portuguese coast, high concentrations of heavy metals have been found in the livers of bottlenose dolphins *Tursiops truncates* and common dolphins *Delphinus delphis* (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 (Thunnini tribe) 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). Dolphin 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 synthesising all relevant studies on a topic, by employing a detailed and comprehensive plan and search strategy developed *a priori*, to reduce bias (Uman 2011). Chronological and analytical compilations of 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 progress in cetacean research made in the past century related to this biologically important area, thereby identifying trends and gaps to guide future research.

We aimed to: 1) undertake a bibliometric analysis to quantify the evolution of research on cetaceans in the Eastern North Atlantic; 2) summarise 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, in order to identify research patterns and gaps; and 3) highlight where the focus of research on cetaceans has been between 1900 and 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; we used the 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 tenth 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 considerably 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 May 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 from the authors through the 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 a spreadsheet and then imported into the R program (R Development Core Team 2019). We collected data including: first author, title, year, journal title, study region, topics covered (in the categories: anatomy, taxonomy, ecology, behaviour, acoustics, genetics, conservation and human interactions; adapted from Brito and

Sousa 2011; related topics are described in Appendix S1), and taxa studied. Each species' global and local conservation status (Red List category) was obtained from the International Union for the Conservation of Nature (IUCN; Appendix S2).

We investigated research output, based on where the study took place, 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). Similarly, to assess differences in research output between coastal *versus* oceanic habitats, taking account the location of the studied areas, we grouped areas as follows: coastal habitats – mainland Portugal, Morocco, Mauritania, Senegal; and oceanic habitats – 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 (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 socio-economic and cultural traits (European vs. North African regions) and habitat (coastal vs. oceanic habitats), based on the number of papers published throughout time, on selected topics and species conservation status. We identified 380 scientific publications on cetacean species in the Eastern North Atlantic from Portugal to Senegal, including the oceanic archipelagos of the Macaronesia biogeographic region, during the period 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 (Appendices S5 – S41). 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, and helping to direct future research.

Temporal evolution of research in the Eastern North Atlantic

Prior to the 1990s, research output on Eastern North Atlantic cetaceans was scarce. The general additive model and the change-point analysis revealed a significant increase in research output, especially since 2005 (r^2: 0.897; $P < 0.001$; Fig. 2), when research output started to grow exponentially. However, a closer look reveals heterogeneity in the number of publications throughout the years within and between the regions studied (Table 1, Fig. 3).

European versus North African regions

Cetacean research was scarcer in North African regions (n=136) than in European regions (n=340). Regarding study areas used, 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 stabilised its research output since 1990 at eight papers per decade (Appendix S3). Only a few papers cover the cetacean fauna of Morocco and Senegal: fewer 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, utilising stranded animals (e.g., Cadenat 1954), when compared with later years. After that period, 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 to be 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' research entities may explain the considerable increase in research output during the 1950s, and independence may explain its subsequent decrease. Upon independence, these African countries not only experienced unsuitable socio-economical conditions for the continuation of scientific research (Olukoshi 2001), but also underwent societal reorganisation. In 2009, Morocco announced an increase in its science and technology investment to finance the restoration and construction of laboratories, and training courses for researchers (Sawahel 2009, Kushnir 2019). This may 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 little previous research output (n=2). Historically, limited information on the biodiversity of cetaceans from Cape Verde area was 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). This suggests that there was very low investment in science by Portugal in the study period (Heitor & Horta 2013), and probably explains why the data do not show any relevant cetacean-related scientific production in Cape Verde prior to independence. Instead, the feeble, but steady, increase in research recorded for Cape Verde was fostered by international collaboration and tourism development that took place after 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 by monitoring strandings) in the Cape Verde region since 2000, resulting in a considerable increase in publications in this area (Hazevoet et al. 2010). Additionally, several environment-related international organisations now operate in Cape Verde, such as Maio Biodiversity Foundation (since 2010) and BIOS.CV (since 2012). The growing popularity of Cape Verde as a holiday and whale-watching destination has 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 *Megaptera novaeangliae* (van Waerebeek et al. 2013, Ryan et al. 2014).

In contrast with the North African countries, in 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 increase 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, research in Madeira apparently lagged by some years. Although the Madeira Archipelago has almost ideal year-round weather conditions for cetacean observation, this region has 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 are 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 priorities and policies, which can influence the effort devoted to specific research fields. Regardless of this, after the year 2010, Madeira saw an increase in cetacean-related publications; it is now in line with the other European regions.

Our results indicate a change point in 2005 regarding cetacean-related publications in the entire study area. 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 increase in cetacean-related research reported here is explained by factors influencing Portugal. Perhaps not surprisingly, gross expenditure in research and development 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 increase is partly a result of access to international funds and international co-operation ensuing integration in the European Union (EU) in 1986, as well as restructuring of the national research and development 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 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 and 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 habitats

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

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, Carrillo et al. 2010, Hazevoet et al. 2010, Freitas et al. 2012, Silva et al. 2014). The narrow island shelves allow the co-occurrence of species with coastal and pelagic habits, increasing opportunities to work with different species and reducing logistical costs. For example, deep-diving species such as sperm whales *Physeter macrocephalus* and beaked whales (Ziphiidae) 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 time 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 that anthropogenic impacts and the non-sustainable use of marine resources 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) have been focused largely on coastal regions (Hooker & Gerber 2014). Since the logistics of 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, and 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 the 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 Marine Protected Areas and study areas in marine research is challenging but is 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 habitats. Of the coastal habitats 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 habitat regions (Cape Verde) is from North Africa. Thus, the lower scientific production in coastal habitats evidenced in our results is probably also an effect of the socio-economic constraints to cetacean research acting on the North African countries.

Research on cetacean species

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; Fig. 4). Moreover, species in the Least Concern category in the IUCN Red List were more frequently studied (*n*=62%) than species in categories of greater conservation concern. Endangered and Near Threatened cetacean species are involved in only 10% of the studies conducted (Fig. 5 see also Tables 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 it is often associated with coastal habitats, the bottlenose dolphin has 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 the species throughout the EU (Nykänen et al. 2019).

Like bottlenose dolphins, common dolphins are abundant and widespread 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 is 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, the common dolphin is 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 deep, especially avoiding the continental shelves (Whitehead 2009). The species is common in the waters around the Macaronesia archipelagos (Moore et al. 2003, Freitas et al. 2004, Carrillo et al. 2010, Silva et al. 2014), so 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 exploitation fostered some of the early research 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 to 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 research (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. 6). In general, ecology-related topics received most attention (n=141). This is not surprising, given the vast and diverse list of ecology-related topics included (Appendix S1). The Azores was the location 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 (34%) 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 stranding descriptions, with anatomical and pathological information, that fall in those two research topics. When considering only the North African regions, anatomy and taxonomy are even more important (54%), evidence of an opportunistic rather than a focused approach to cetacean research in those regions (e.g., Cadenat 1954). Senegal had high numbers of scientific contributions on taxonomy (n=24) and anatomy (n=24), but none on acoustics or genetics, and only one paper on behaviour. Researchers in Cape Verde contributed mostly towards ecology (n=17), with only one study on behaviour and genetics (n=1), and none on acoustics. In Morocco, studies were focused on ecology (n=11) and taxonomy (n=10); there was very little 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).

Researchers in the Canary Islands mostly contributed towards work on cetacean anatomy (n=36) and human interactions (n=36), with low contributions on genetics (n=7), taxonomy (n=9), and behaviour (n=13). Among regions, either the Azores or the Canary Islands had the highest number of records for every 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; they could be the result of a certain level of specialisation on a given topic, focused research goals, or a combination of those (which is more likely). However, it is apparent that researchers in these two archipelagos have devoted a considerable effort towards 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 lowest numbers of records were acoustics and genetics, with 43 and 30 records, respectively. This may be related to our method: acoustics and genetics, along with conservation, had the lowest number of associated topics, which naturally restricted the number of publications that could be assigned to each of them. Also, studies on acoustics and genetics involve specialist equipment and skills that are not widely available and may have high associated costs alongside many recent developments, hindering their historical widespread use. However, conservation studies do not necessarily involve specialised 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.

CONCLUSIONS

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 papers on 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 one third of all described cetacean species. Finding research patterns over time helps us to identify knowledge gaps, allowing researchers to prioritise future research and improve ecosystem management.

Other researchers 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 we 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 changes in what is considered a conservation topic. For instance, Rose et al (2011) 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. Hill and Lackups (2010) found that only 3.2% of the papers analysed covered conservation, ecology, or environmental topics. However, they focused only on cetacean species cared for by humans at some point during the documented history of captivity, leaving out conservation studies done on free-ranging cetaceans, such as baleen whales (Mysticeti) and beaked whales (Ziphiidae).

Despite the different approaches taken to analyse research trends over the past 20 years and the allocation of limited resources, growing environmental concerns have led to prioritisation of scientific research and to 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 defining how best to monitor cetacean populations and key human activities (such as development projects, industry, fisheries, and tourism). Cetacean populations are subject to many pressures, and this is particularly important in waters around 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 in order to address gaps in information that is useful for conservation was another problem identified in our review, and also reported by Parsons et al. (2015). In this particular region, beaked whales, such as True's beaked whale *Mesoplodon mirus*, 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.

The importance of long-term studies is not mentioned by Parsons et al. (2015). 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 emphasised 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-spans and funding cycles. Therefore, ecologists and field biologists should join efforts in an open and collaborative way, maintaining publishing outlets for empirical field-based ecology, and sharing their long-term data sets (Lindenmayer et al. 2012). In our dataset, only a limited number of studies utilised long-term datasets. Those that did used mainly observational data from whaling or fisheries and did not necessarily analyse temporal trends (Brito 2008, Silva et al. 2009, Prieto et al. 2013, Silva et al. 2014). 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 on harbour porpoises *Phocoena phocoena* 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 address complex problems collectively. 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 for 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 for cetacean populations. Thus, we suggest the application of the Delphi method to identify priority research for cetaceans in our study region, foster collaborative efforts among the region's research teams, and encourage dataset sharing and the development of long-term research programs.

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Figures' headings

Fig. 1. The Eastern North Atlantic study region, between 42°N and 13°N, includes the coastal waters of Portugal, Morocco, Mauritania and Senegal, and the Macaronesia archipelagos that include the Azores, Madeira, Canaries, and Cape Verde.

Fig. 2. Number of peer-reviewed papers on cetaceans in the Eastern North Atlantic published per year from 1900-2018. A General Additive Model was fitted to the data (r^2: 0.897; $P < 0.001$). The vertical dashed line represents the year in which the evolution of published papers had a significant turning point (identified via change-point analysis).

Fig. 3. Research output on cetaceans, published 1900-2018, per region in the Eastern North Atlantic.

Fig. 4. Cetacean species studied in the Eastern North Atlantic and the number of papers published 1900-2018 on each species. Species codes are specified in Appendix S4.

Fig. 5. Percentage of cetacean species in the Eastern North Atlantic in each International Union for Conservation of Nature (IUCN) Red List category (global), and percentage of peer-reviewed papers published 1900-2018 covering species in each IUCN category. CR=Critically Endangered, DD=Data Deficient, EN=Endangered, LC=Least Concern, NT=Near Threatened, VU=Vulnerable.

Fig. 6. Research output on cetaceans in the Eastern North Atlantic, published 1900-2018, per topic.

Tables and tables' headings

Table 1. Number of publications on cetaceans per topic in each region, published 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 the numbers of papers in which the species were studied (*n*).

	Most-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, the numbers of papers in which the species were studied for specific topics, and total numbers 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 number of papers	116	103	141	55	43	30	60	99

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

Appendix S1. Description of main and related topics used in the review. Adapted from Brito and Sousa (2011).

Appendix S2. Species and IUCN conservation status (Global and local)

Appendix S3. Number of papers per decade in Mauritania.

Appendix S4. Code, species and common name of the studied cetaceans.

Appendix S5. Top five first authors, and numbers of papers as first-authors.

Appendix S6. Top five journals.

Appendix S7. Study regions' rankings according to United Nations and World Bank.

Appendix S8. Number of publications between 1900-2018 in the Central Northeast Atlantic on cetaceans.

Appendix S9. Collaborative network among regions. The lines represent cooperation between two regions and its width refers to the frequency of collaboration. Cooperation was considered valid whenever two regions were researched together in one published paper.

Appendix S10. Supporting table for Appendix 8 on the Network collaboration between studied regions.

Appendix S11. Number of papers per decade in Madeira island.

Appendix S12. Number of papers per decade in Azores.

Appendix S13. Number of papers per decade in mainland Portugal.

Appendix S14. Number of papers per decade in Canary Islands.

Appendix S15. Number of papers per decade in Cape Verde.

Appendix S16. Number of papers per decade in Morocco.

Appendix S17. Number of papers per decade in Senegal.

Appendix S18. Number of papers dedicated to each cetacean species studied in Madeira.

Appendix S19. Number of papers dedicated to each cetacean species studied in Azores.

Appendix S20. Number of papers dedicated to each cetacean species studied in mainland Portugal.

Appendix S21. Number of papers dedicated to each cetacean species studied in Canary Islands.

Appendix S22. Number of papers dedicated to each cetacean species studied in Cape Verde.

Appendix S23. Number of papers dedicated to each cetacean species studied in Morocco.

Appendix S24. Number of papers dedicated to each cetacean species studied in Senegal.

Appendix S25. Number of papers dedicated to each cetacean species studied in Mauritania.

Appendix S26. Number of papers dedicated to each cetacean species studied in European regions (mainland Portugal, and archipelagos of Azores, Madeira and Canaries).

Appendix S27. Number of papers dedicated to each cetacean species studied in North African regions (Morocco, Mauritania, Senegal and Cape Verde).

Appendix S28. Number of papers dedicated to each cetacean species studied in Oceanic regions.

Appendix S29. Number of papers dedicated to each cetacean species studied in Coastal regions.

Appendix S30. Number of papers dedicated to each cetacean species studied for Anatomy.

Appendix S31. Number of papers dedicated to each cetacean species studied for Taxonomy.

Appendix S32. Number of papers dedicated to each cetacean species studied for Ecology.

Appendix S33. Number of papers dedicated to each cetacean species studied for Behavior.

Appendix S34. Number of papers dedicated to each cetacean species studied for Acoustics.

Appendix S35. Number of papers dedicated to each cetacean species studied for Genetics.

Appendix S36. Number of papers dedicated to each cetacean species studied for Conservation.

Appendix S37. Number of papers dedicated to each cetacean species studied for Human interactions.

Appendix S38. Percentage of species occurring in each IUCN status (global), and percentage of peer-reviewed papers published in each IUCN category, in European regions (mainland Portugal, and archipelagos of Azores, Madeira and Canaries).

Appendix S39. Percentage of species occurring in each IUCN status (global), and percentage of peer-reviewed papers published in each IUCN category, in North African regions (Morocco, Mauritania, Senegal and Cape Verde).

Appendix S40. Percentage of species occurring in each IUCN status (global), and percentage of peer-reviewed papers published in each IUCN category, in Coastal regions (Morocco, Mauritania, Senegal and Portugal).

Appendix S41. Percentage of species occurring in each IUCN status (global), and percentage of peer-reviewed papers published in each IUCN category, in Oceanic regions (Azores, Madeira Island, Canary Islands, and Cape Verde).

Figures

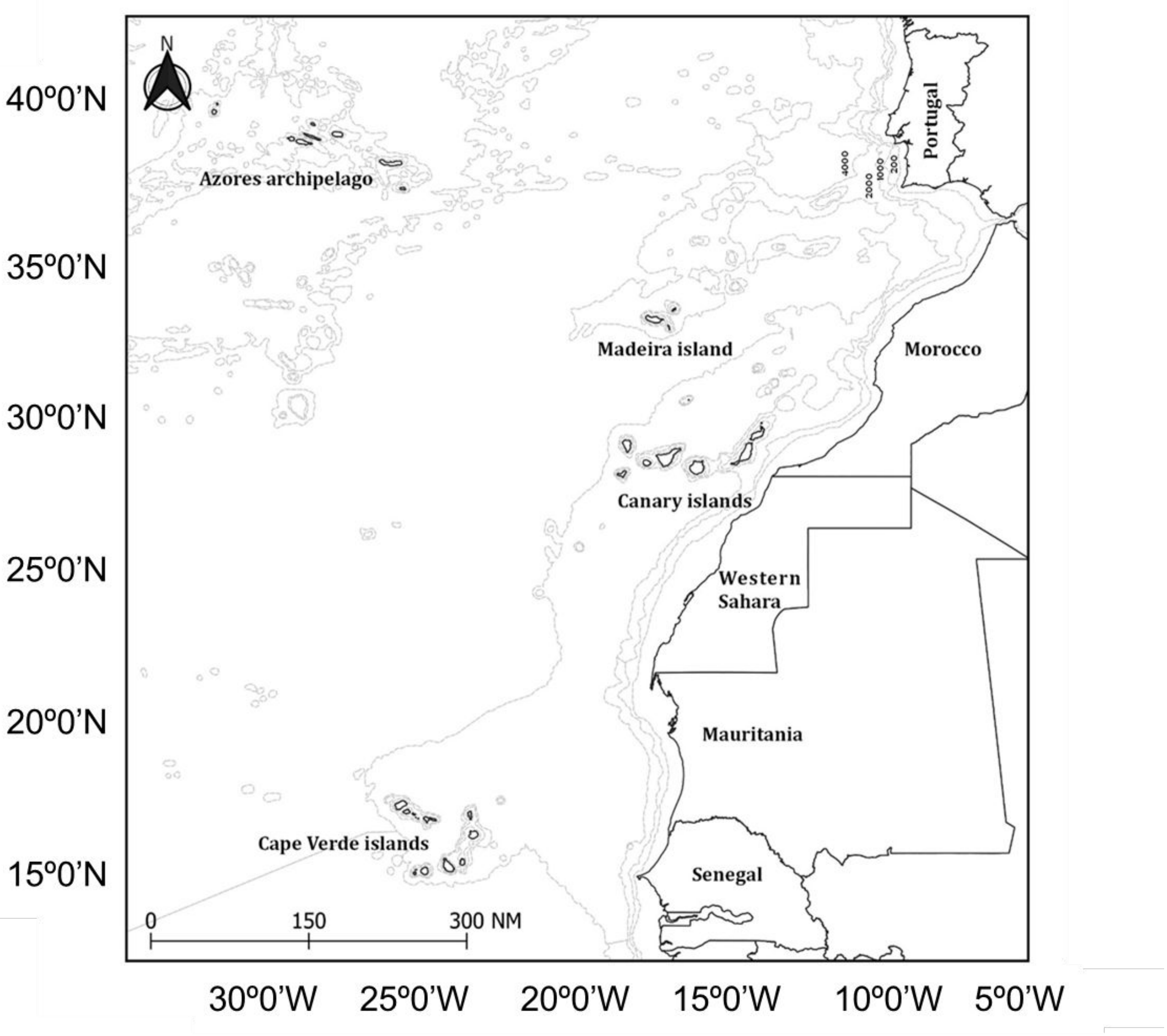
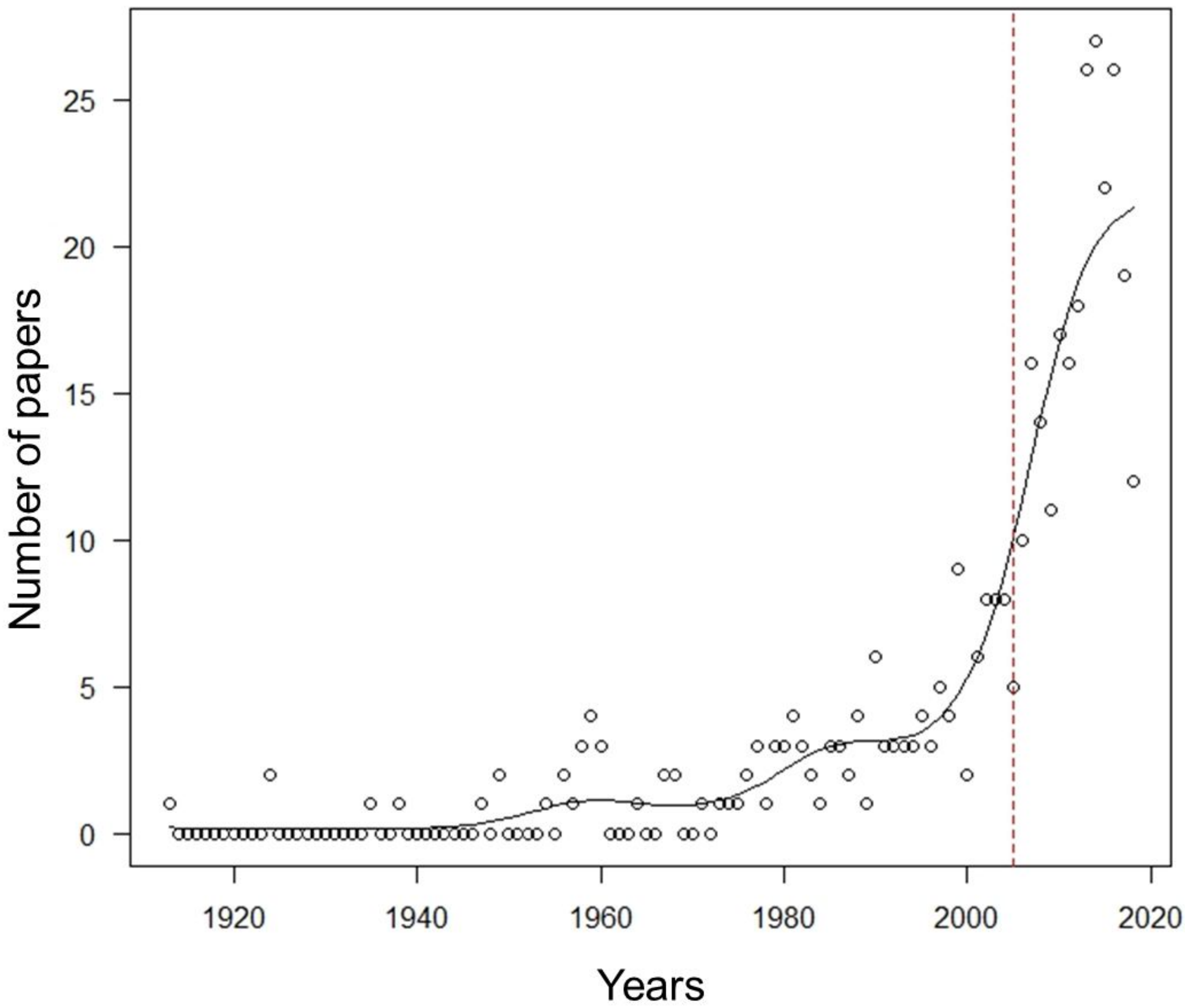


Figure 1.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1940
1960
1980
2000
2020
Years

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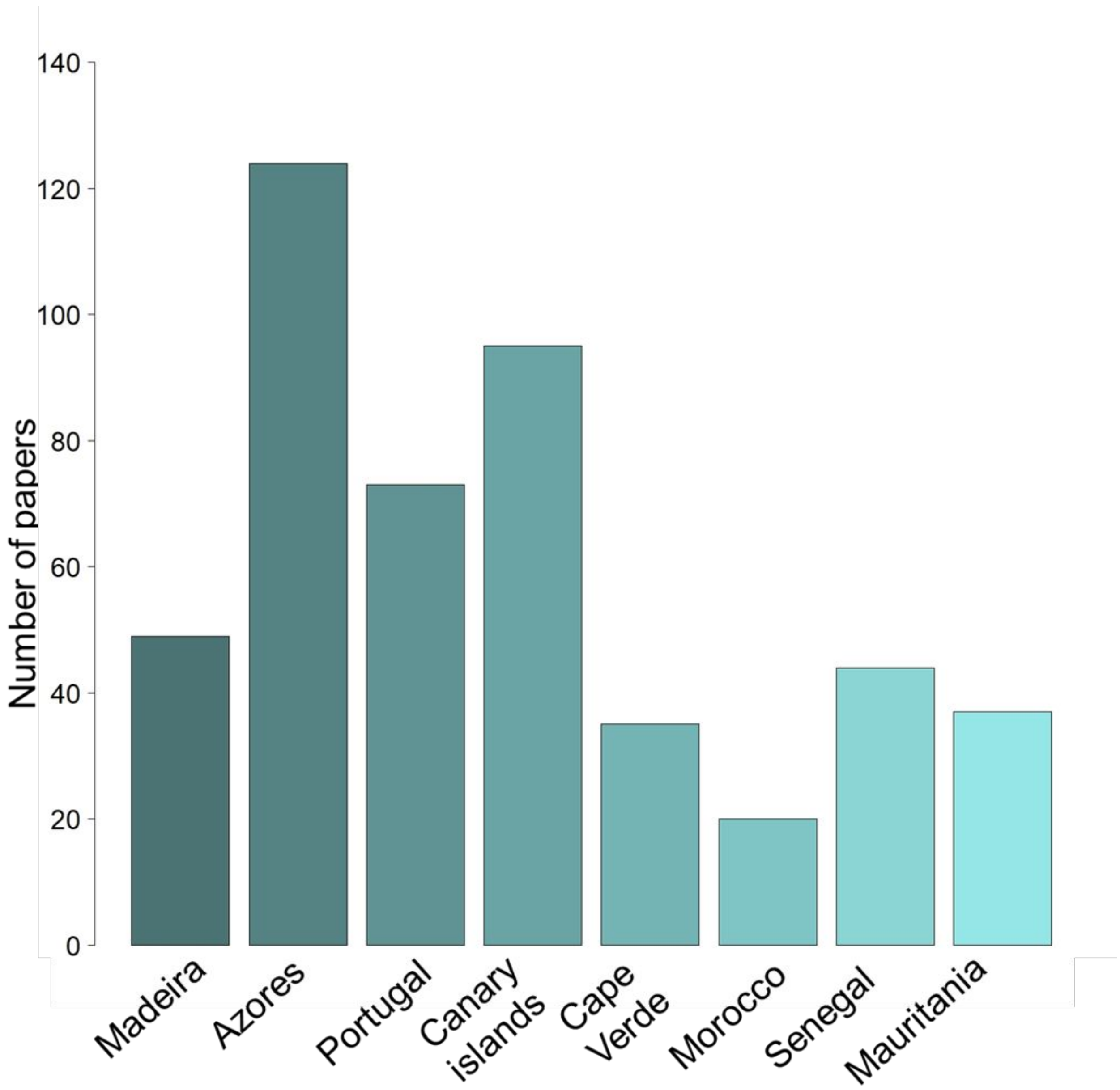
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Madeira
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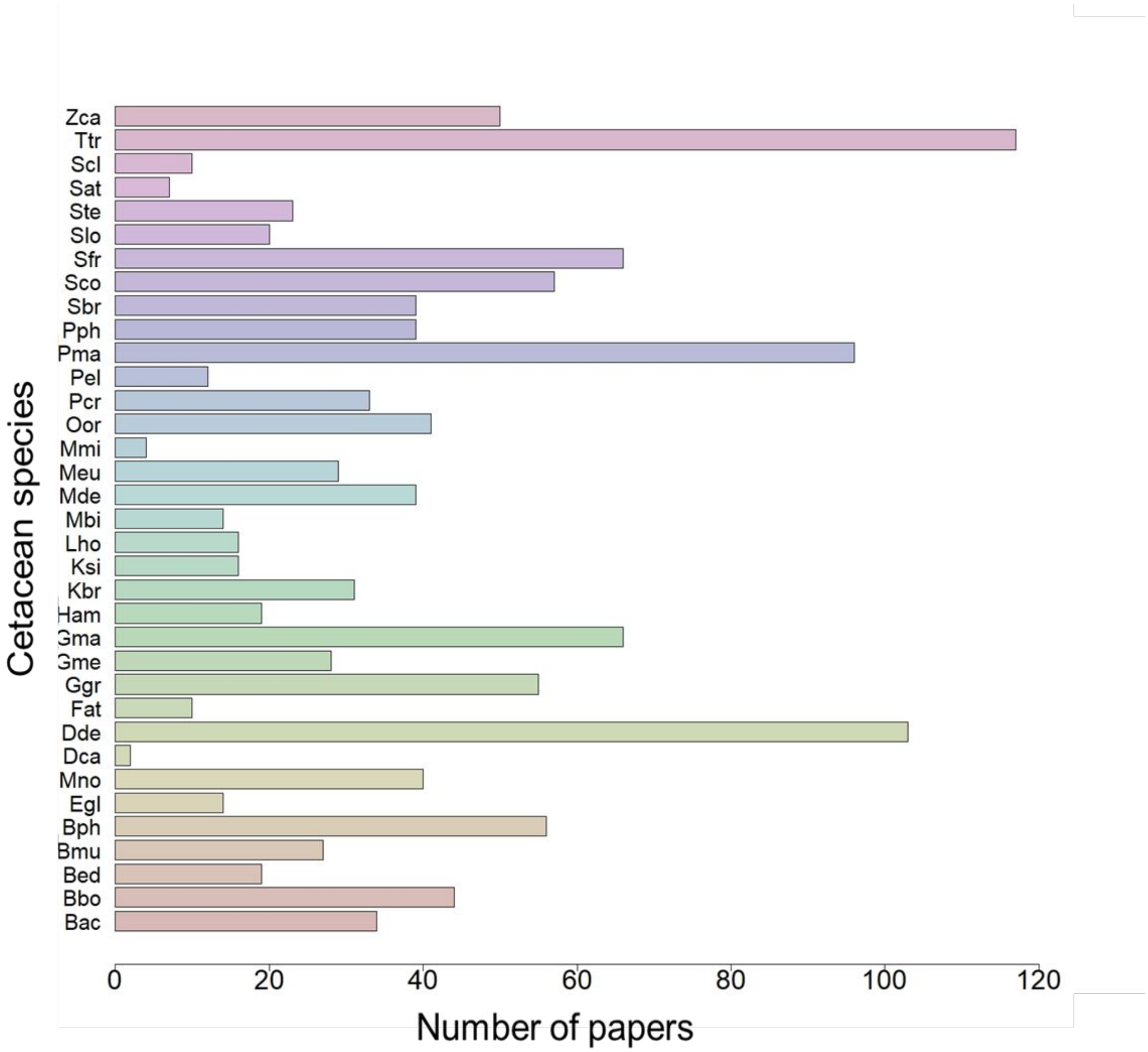
Portugal
Canary islands
Cape Verde
Morocco
Senegal
Mauritania

Figure 3.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Mbi
Lho
Ksi
Kbr
Ham
Gma
Gme
Ggr
Fat
Dde
Dca
Mno
Egl
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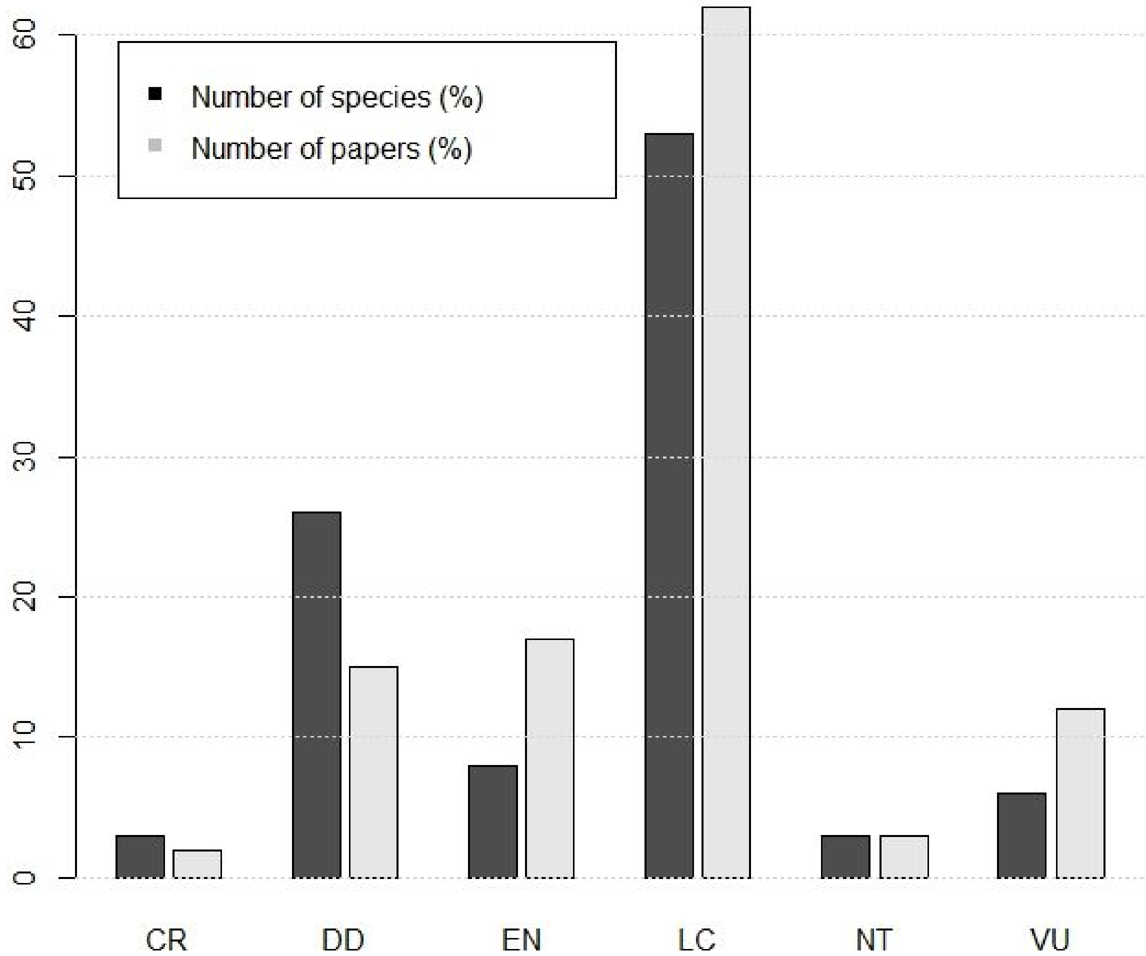
80
100
120
Number of papers

Figure 4.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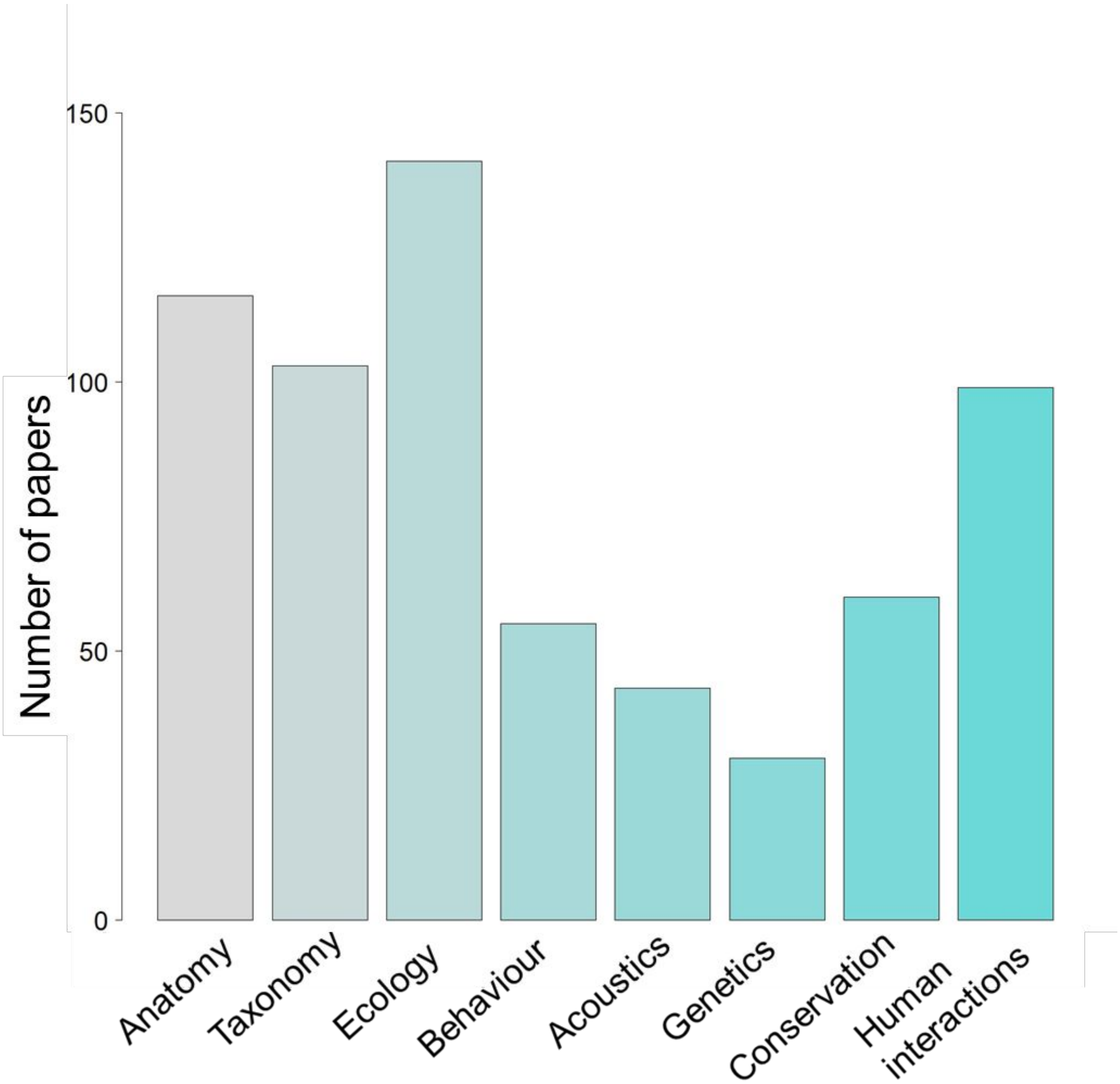
DD
EN
LC
NT
VU

Figure 5.


Number of papers
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Anatomy
Taxonomy
Ecology
Behaviour
Acoustics
Genetics
Conservation
Human interactions

Figure 6.