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Challenges and conservation potential of shark-diving tourism in the Macaronesian archipelagos

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ABSTRACT

Macaronesia is formed by some of most isolated oceanic islands of the Atlantic Ocean. This region is typically heavily exploited by fisheries; however, in recent years, marine wildlife tourism has become popular and a shark-diving industry has emerged, potentially presenting an alternative for the sustainable use of sharks. Combining a literature review with interviews with dive operators conducting shark encounters in the Macaronesian archipelagos, we provide an overview of the challenges and conservation potential of shark-diving tourism for these territories. Owing to the regular presence of important shark species for tourism and the growth of the scuba-diving industry, shark-diving has potential to expand over the region. Yet, the overlap between European industrial fishing pressure and shark populations, coupled with the unregulated recreational and artisanal fishing sector in the Canary Islands and Cape Verde, may jeopardize the sustainability of the shark-diving industry. However, the economic benefits for local communities directly and indirectly produced by shark-diving tourism suggest local benefits, fostering stronger shark conservation in Macaronesia.

1. Introduction

Historically, sharks were generally considered an incidental catch in fisheries targeting other more valuable species [1]; however, in recent decades the global demand for shark products has progressively increased, shifting the capture of sharks from bycatch to target taxa in many fisheries [2]. Sharks are caught by fishing fleets from all over the world, with an estimated catch of up to 100 million individuals per year [3]. In 2015 the global market for shark products was estimated to generate roughly USD \$1 billion traded annually [2]. Yet, poor regulation of shark fisheries, including the common practice of shark-finning in the High Seas [1,4,5], has triggered a precipitous worldwide decline of many shark populations [3,6]. Due to overfishing, sharks are currently accepted worldwide as a group for priority conservation [6], with 20% of the nearly 500 known shark species in the Red List of the International Union for Conservation of Nature – IUCN threatened with extinction [7].

Whereas there are numerous fisheries management tools utilized to prevent shark overexploitation, effective implementation of these

approaches is restricted to few species and in developing countries with strong fisheries management systems in place [8,107]. Unfortunately, effective fisheries management is the exception, not the rule for most regions around the world [9], and in light of these challenges, new economic perspectives, which may allow a more sustainable use of sharks are now being considered, such as shark-diving touristic industry. This type of non-consumptive use of sharks, first developed in the late 20th century [10], has been growing in popularity and today is a global phenomenon [11]. In recent years, sharks have become important attractions in many dive sites around the world, contributing to local, regional and national economies in North America, Central and South America, Europe, Greater Caribbean, Oceania, North Africa and Middle East, Asia and Indonesia and Southern and Eastern Africa [10–16]. Observing these animals in their natural habitat either from boats or underwater with snorkel or scuba gear is a niche sector in the rapidly developing marine tourism market [17]. Aside from producing positive changes in tourist knowledge, attitudes, and conservation behaviors [18, 109] and making significant contributions to national economies, the revenues from this industry may support the livelihood of local

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communities, and support conservation strategies and management [19, 20].

Shark-diving tourism has also seen an increase in academic attention. A review by Gallagher et al. [18] found that, until 2014, 47 original research articles focusing on some aspect of the shark-diving tourism industry were published, with 47% of these studies consisting of socio-economic analyses conducted at many scales. These studies generally concluded that, where shark-diving tourism is viable, the economic benefits from shark conservation are potentially larger than what can be achieved by fisheries exploiting the same resources [12,19,

21,111]. For example, Cisneros-Montemayor et al. [21] estimated the global value of shark-diving industry to be around USD \$ 314 million in 2011, directly supporting around 10,000 jobs. While the accuracy of these estimates has been a source of debate (see [22]), many studies have demonstrated that shark-based tourism has driven shifts in the socio-economic importance of sharks from a fisheries product to a more valuable non-consumptive resource in many tourist destinations around the world [18]. Therefore, identifying and assessing new potential sites for shark-diving tourism development is strongly encouraged in the greater literature [10,21], particularly in those regions experiencing

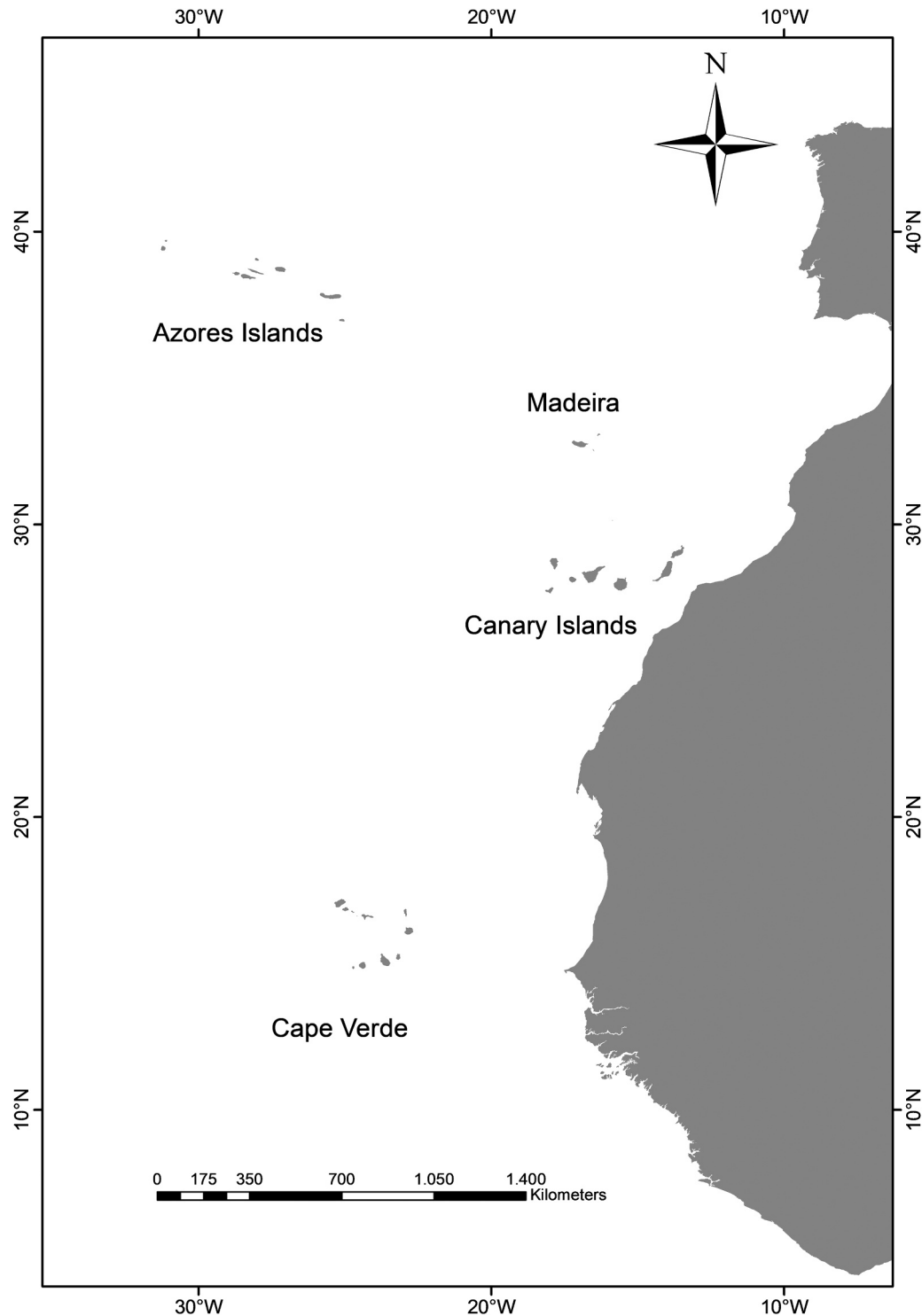


Fig. 1. Geographic position of the archipelagos and islands of Macaronesia.

significant shark populations declines due to overfishing, such as in the Northeast Atlantic [23]. However, despite these declines, only around 10% of the scientific studies published on shark-diving tourism have focused on the Atlantic Ocean [18], despite the high number of shark-diving operations in this region [11] and to date no study has focused on the NE Atlantic in particular.

In the present study, we address this gap by mapping and contextualizing the opportunities, both current and potential, for shark-diving tourism within the Macaronesian archipelagos (the Azores, Madeira, Canary Islands and Cape Verde). This biogeographic region contains some of the highest rates of marine biodiversity in the North-East Atlantic Ocean [24], whereby species from diverse geographic areas meet [25]. It is particularly characterized by the presence of highly migratory pelagic shark species with moderate to high risk of extinction such as blue shark (*Prionace glauca*) [26] and shortfin mako shark (*Isurus oxyrinchus*) [27], together with other highly threatened demersal species such as angel shark (*Squatina* spp.) [28]. This region is also a hotspot for commercial fishing activities from small to large scale fleets, which pose significant risks to these species [29–31]. Here we summarize the challenges of the shark-diving industry in the Macaronesian archipelagos based on the analysis of the shark-related activities in the regional context, namely fisheries and tourism, and present the perspectives and opportunities for potential expansion of this market.

2. Methods

2.1. Study area

Macaronesia is a biogeographic region whose area extends from the North-East Atlantic to the Central-East Atlantic Ocean, encompassing five archipelagos, in decreasing order of latitude: the Azores, Madeira, Salvages, Canary Islands and Cape Verde (Fig. 1). With a total land area of approximately 15,000 km² Macaronesia includes 40 islands > 1 km² stretching from 14.8°N (Brava, Cape Verde) to 39.7°N (Corvo, Azores) and from 13.4°W (Roque del Este, Canary Islands) to 30.9°W (Flores, Azores) [32]. Summing the land surface, the Exclusive Economic Zone (EEZ) and the Extended Continental Shelf (ECS), the total area of the Portuguese Autonomous Regions of Azores and Madeira (including Salvages islands), the Spanish Autonomous Community of Canary Islands and the Republic of Cape Verde, is 2467,622 km², divided into 131 municipalities [33]. As part of the territory of European Members states despite being remotely detached from the European continent, the Azores, Madeira and Canary Islands are considered European Outermost Regions (ORs) [34].

2.2. Tourism in the Macaronesian archipelagos

The structure of the economy in Macaronesia is oriented towards services where tourism has a significant role, especially in Madeira and the Canary Islands [33]. Tourism is the main economic activity in the Canary Islands with roughly 15 million visitors a year, accounting for approximately 31% of total Gross Value Added (GVA) and 35% of total employment [36]. For Madeira, tourism is also the most important sector of the regional economy accounting to almost 21% of GVA and 20% of employment [37]. The tourism industry in the Azores is far less well developed than those of Madeira or the Canary Islands, but this activity has been progressively gaining popularity [34]. Akin to the Azores, Cape Verde tourism activity is nascent; however, it is gaining in significance, especially coastal tourism [37]. This industry accounts for 50% of the services sector, which represented about 70% of Gross Domestic Product (GDP) in 2016 [38]. Overall, coastal tourism shows great potential all around the Macaronesian Region specifically those activities that take advantage of the marine environment and its resources and the coastal culture such as whale and bird watching, recreational fishing tourism and marine gastronomy, among others [37].

2.3. Shark fisheries in the Macaronesian archipelagos

Fishing is an ancestral practice in Macaronesia, traditionally artisanal and subsistence with the use of vessels with less than 12 m in length [33]. This sector has shown a decreasing trend in number of vessels and fishers in the ORs due to the reduction of fleets and fleet capacities established by the European Union (EU), in order to maintain a sustainable balance between fishing capacity and fishing opportunities [39]. Yet, fisheries in the region still suffer from lack of effective monitoring and surveillance, making it difficult to deter illegal fishing [37]. Against this backdrop, sharks are common bycatch in many fisheries, from multinational industrial companies to artisanal fishers, including demersal trawls, longlines, or gillnets, and some species are specifically targeted and heavily fished by international large-scale fleets [40]. Domestic shark fisheries also exist in Macaronesia and have traditionally exploited small bottom-living coastal sharks and, more recently, deep-water sharks [30,40–43]. Industrial longlines land most of the shark catch; however, the impact of the local sector on regional stocks of sharks is usually underestimated [44]. According to Food and Agriculture Organization (FAO), the major shark fishing entities on these waters are Spain, France, the UK and Portugal [23]. Spain is the third-highest shark catching country in the world and one of the largest producers and exporters of shark fins - mostly to East and Southeast Asian markets [2]. Moreover, Spain is the main trader of shark meat in Europe and is responsible for importing and exporting most of shark fins and shark meat in the region [5].

According to EUROSTAT data on shark catches by EU fleets in the Atlantic, 69% and 72% of Spanish and Portuguese surface longline Atlantic catches, respectively, are comprised of sharks, mainly blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*) [45]; however, shark catches from both countries are poorly documented and generally underreported [42]. A recent global analysis of shark habitat use and fishing activity found that industrial fisheries in the North Atlantic overlap with nearly 80% of the space use of blue sharks, which exhibit moderate densities in the Macaronesian Region [31]. Other species such as threshers (*Alopias* spp.), silky (*Carcharhinus falciformis*), hammerhead (*Sphyrna* spp.), and oceanic whitetip (*Carcharhinus longimanus*) sharks are also regularly caught [46]. The majority of Atlantic shark catches from Spanish, Portuguese and UK longliners are landed in the harbors of St. Vincent and Mindelo in Cape Verde, and Vigo and Las Palmas in Spain [45]. The Spanish ports of Vigo and Las Palmas in the Canary Islands are the European centers for the shark fin trade [5] and major entry points to the EU market for illegal shark products [47].

Shark fisheries occurring in Macaronesia are mainly controlled by the European Union fisheries management, under the EU Common Fishery Policy (CFP) and the fisheries partnership agreement with Cape Verde. Spain, France and Portugal pay to West-African countries for access rights to exploit fish stocks from their EEZ, and a budgetary support for implementing the Sustainable Fishery Policy (SFP) [48]. The most relevant Regional Fisheries Management Organization (RFMO) for the Macaronesian Region shark catches is the International Commission for the Conservation of Atlantic Tunas (ICCAT). This organization, concerned with the oceanic, pelagic, and highly migratory elasmobranchs, requires contracting parties to annually report catch data for each shark species caught in association with the fisheries ICCAT manages [5]. However, the lack of species-specific statistics from EU shark fisheries, landings, markets and trade [42], underreporting to the ICCAT Secretariat [5] and little monitoring of what is actually caught, particularly in Cape Verdean waters [29], remain some acknowledged problems. In Table 1, we summarized the principal shark-fishing regulations concerning the Macaronesian archipelagos.

2.4. Data collection

We collected qualitative and quantitative data about shark-related activities in Macaronesia from a broad bibliographic review and

Table 1
Historical overview of shark fishing regulations on the Macaronesian waters.

Shark fishing regulations on the Macaronesian waters	
2003	Council Regulation (EC) 1185/2003 on the removal of fins of sharks on board vessels established a general prohibition of the practice of shark finning.
2005	The EU banned the use of trawls and gillnets in waters deeper than 200 m in the Azores, Madeira and Canary Island areas in order to protect deep-water sharks. Portuguese dogfish (<i>Centroscymnus coelolepis</i>), leafscale gulper shark (<i>Centrophorus squamosus</i>), and kitefin shark (<i>Dalatias licha</i>) are managed under TACs (total allowable catches) in the Azorean waters.
2013	The EU established a strict no finning regulation for all vessels in European Union waters and all European Union-registered vessels, mandating that all sharks be landed with fins still attached to their bodies.
2014	The new European Common Fisheries Policy introduced a discard ban and landing obligation for pelagic species.
2015	According to the Council Regulation (EU) 2015/104, most of the sharks listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora – CITES Appendix I, such as white shark (<i>Carcharodon carcharias</i>), basking shark (<i>Cetorhinus maximus</i>), and species listed under Appendix II, such as the porbeagle (<i>Lamna nasus</i>) and all hammerheads (<i>Sphyrna spp</i>) may not be fished, retained on board, transhipped or landed by any EU vessels.
2016	Under the Council Regulation (EU) 2016/72, the EU also included in these terms the angel shark (<i>Squatina squatina</i>) in European waters, and oceanic whitetip shark (<i>Carcharhinus longimanus</i>), silky shark (<i>Carcharhinus falcaformis</i>), bigeye thresher sharks (<i>Alopias superciliosus</i>) and hammerhead sharks of the Sphyrnidae family (except for the <i>Sphyrna tiburo</i>) in the ICCAT convention area.
2019	Three species of angel shark (<i>Squatina squatina</i> , <i>Squatina aculeata</i> and <i>Squatina oculata</i>) have been registered by the Spanish Ministry for Ecological Transition in the Spanish Catalog of Threatened Species, under the category of Endangered Species. Any action taken with the purpose of killing, capturing, persecuting, disturbing or trading with them and any action that destroys or deteriorates their habitat or breeding areas is prohibited.

documental analysis on the following subjects: shark-based tourism, shark fisheries and shark conservation. For this purpose, we used peer-reviewed publications, published PhD theses, government, NGO and newspaper reports, internet websites, UN databases and personal enquiries. Peer-reviewed publications were selected from the Science Citation Index Database (Web of Science) and Google Scholar using the keyword searches “sharks in Macaronesia”, “sharks in Azores”, “sharks in Madeira”, “sharks in Canarias” and “sharks in Cabo Verde”.

From September to December 2019, we conducted interviews with diving operators in each archipelago of Macaronesia in order to understand the scale and potential about the shark-diving activity they provide. Prior to this, we identified and quantified all the official diving centers in the region through online search on the websites of national and regional authorities from Macaronesia and also performed an online search to identify non-official diving centers. We used the keyword searches “diving centers in Azores”, “diving centers in Canarias”, “diving centers in Madeira” and “diving centers in Cabo Verde”. We included in our analysis those companies with an official website advertising different scuba-diving activities.

Then, we identified diving centers specifically advertising shark encounters as an associated service. The criteria used to select these companies included: (a) a banner on the website homepage featuring a shark image and/or text advertising a shark encounter and (b) operations directly promoting and pricing a specific shark encounter. Moreover, we also include in our analysis those companies mentioning sharks on their websites as part of the attractions of a given diving or snorkeling activity.

After we identified and quantified all the diving centers providing shark encounters in the Macaronesian archipelagos, we attempted to contact all of them and were successful in obtaining reply from 30% to 40% in each archipelago. The criteria used to identify those companies to be interviewed included: (a) conduct specific shark-diving operations; (b) be official diving centers and (c) include diversity in terms of geographic distribution, seniority and size of the operations. Thought the interviews, we quantified the scope of their operation through the

following parameters: (a) number of years providing scuba-diving activities; (b) number of operations per year; (c) % of shark encounters operations; (d) price of shark-diving or shark encounters operations; (e) shark species observed; (f) frequency of shark observation and (g) seasonality. We also included an open-ended question about the potential of shark-diving tourism in each archipelago.

Since there are limited data available from the official sources, we used the *Sea Around Us* – research initiative database (<http://www.seaaroundus.org>) to elicit the volume of shark catches in the Exclusive Economic Zones (EEZ) of the Macaronesian archipelagos. We also collected the total landed values of sharks in order to compare the revenues generated from shark fisheries and shark-diving tourism. This information was gathered with the aim of understanding the scale of shark fisheries in the region and how this could affect to potential expansion of shark-diving industry.

3. Results

3.1. Bibliographic review and documental analysis

Our review revealed 53 published shark-related studies in terms of fisheries, tourism and conservation in the Macaronesian archipelagos from 2003 to 2019 (Supplementary data). This list includes original research articles (26 studies); technical reports (14 studies); published theses (5 studies); books (3 studies); chapters (3 studies) and conference papers (2 studies). Most of the studies focused on the Azores Islands (49%), followed by Macaronesia and the Canary Islands with 12 and 10 studies, respectively. Fisheries comprised the majority of studies (58%), whereas 25% were focused in shark-diving tourism. Of all the studies focused in tourism, approximately 77% occurs in the Azores Islands. Despite the shark-diving industry in the Azores is still in its infancy [49], it is not surprising that this archipelago dominates the literature, as this is the most popular shark-diving destination in Macaronesia. From this review, we synthesized the primary information related to shark-diving tourism industries for each of the archipelagos within the Macaronesia below.

3.2. Overview of tourism and shark-diving in the Macaronesian archipelagos, as synthesized from our literature review

3.2.1. Azores

The Azores is an emerging touristic destination for marine-related activities such as sailing, surfing, whale and dolphin watching and, more recently, scuba-diving and shark-diving [50]. Shark-diving operations in the Azores began in 2011 [51] and in 2014 the estimated revenues generated by this industry were around 2 million Euros (~2250,000 USD). Shortfin mako sharks (*Isurus paucus*) and blue sharks (*Prionace glauca*) are the principal attractions of this diving experience, which is operated only in Faial and Pico Islands [49]. The dives are conducted offshore, in waters with depths of about 200 m and use chum buckets to lure the sharks [52]. Usually, divers do not directly interact with the sharks but hold on to weighted lines to avoid being carried away by the currents [51].

Swimming with whale sharks (*Rhincodon typus*), either with snorkel or scuba gear, is another shark-based tourism activity offered in the Azores, mainly near the island of Santa Maria [51]. Since 2008 there has been an increase in frequency of whale sharks probably due to change in migratory patterns as a result of a possible change in water conditions [50,53,54]. Bentz et al. [51] observed that local fishers of Santa Maria cooperate with the dive centers informing when a whale shark was sighted in exchange of the economic benefits from the presence of snorkelers.

3.2.2. Canary Islands

The Canary Islands are a very popular tourist destination for scuba divers. In 2009 there were 84 official diving centers distributed across

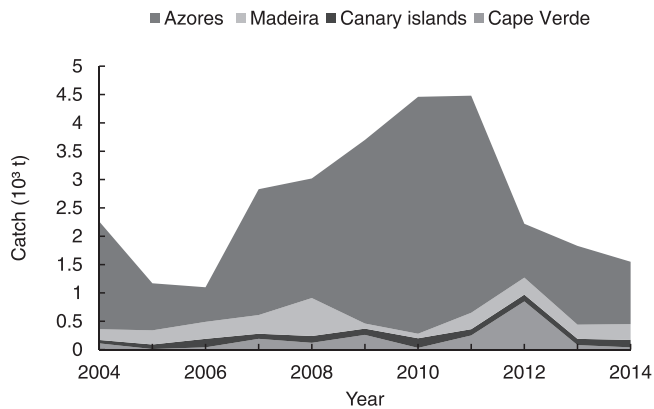


Fig. 2. Sharks and rays (commercial groups) catches in the Exclusive Economic Zones of the Azores, Madeira, Canary Islands and Cape Verde between 2004 and 2014.

Source: Adapted from the *Sea Around Us Database* (2021).

the archipelago [55]. The most popular islands for diving are El Hierro, Fuerteventura, Gran Canaria, Lanzarote and Tenerife [56]. According to De la Cruz Modino et al. [55], sharks and rays are a main attraction of diving tourism in the archipelago, and in 2009 were responsible for generating one-third of their total economic revenues of the industry. These authors estimated elasmobranch diving in the Canarian Archipelago to generate € 17.7 million (around USD \$24.6 million) in 2009, supporting 429 jobs [55]. Demersal elasmobranch species are often sighted and the angel shark, in particular, is one of the most commonly encountered species by recreational scuba divers [30]. It is also possible to sight whale sharks (*Rhincodon typus*), hammerhead sharks (*Sphyrna zygaena*) and smalltooth sand tiger (*Odontaspis ferox*), but these sightings are sporadic [55].

3.2.3. Cape Verde

Diving is one of the main tourist attractions in Cape Verde due to the relatively lightly impacted tropical marine environment by anthropogenic factors [57]. Sal Island is the most popular destination for diving, while there are no socioeconomic data on Cape Verde's diving industry, there are at least six dive centers operating in the Santa Maria Bay, which is a major tourism destination (Dive-report, 2016). The most recent validated check-list of coastal fish from the Cape Verde Islands [58] lists a total of 315 fish species, of which 22% are elasmobranchs (sharks, rays and skates). The most frequently shark species observed in Cape Verde's coast are: nurse shark (*Ginglymostoma cirratum*), dusky shark (*Carcharhinus obscurus*), lemon shark (*Negaprion brevirostris*), smooth hammerhead (*Sphyrna zygaena*), tiger shark (*Galeocerdo cuvier*), Galapagos shark (*Carcharhinus galapagensis*), whale shark (*Rhincodon typus*) and sand tiger shark (*Carcharias taurus*), among others [58]. One of the most popular tourist attractions in Cape Verde is the observation of lemon sharks in Shark Bay (Santa Maria, Sal Island) either from shore or as an in-water activity.

Table 2

Summary table of diving centers in the Macaronesian archipelagos from internet search.

Macaronesian archipelago	Number of diving centers	Number of diving centers advertising specific shark encounters	Number of diving centers advertising general shark encounters
Azores Islands	58	8	4
Madeira	13	0	0
Canary Islands	145	1	108
Cape Verde	12	0	8
Total	228	9	120

3.2.4. Madeira

Madeira is experiencing a steady increase in marine-based activities such as whale watching, scuba-diving, surfing, body boarding, wind-surfing, stand up paddling, recreational fishing, underwater archaeology, among others [37]. However, we found no evidence of shark-diving activities being advertised or carried out despite the presence of various species of elasmobranchs in this archipelago [59].

3.3. Shark-diving industry profiles in the Macaronesian archipelagos

We identified 228 diving centers in the Macaronesian archipelagos of which ~64% are located in the Canary Islands (145 companies), followed by the Azores Islands and Madeira with 58 and 13 companies, respectively (Table 2). We found that 129 companies advertised shark encounters, of which 120 consisted on general shark encounters and 9 on specific shark encounters. General shark encounters were defined as those encounters where sharks are not the main attraction of diving activities. The majority of companies advertising general shark encounters were located in the Canary Islands (108 companies), followed by Cape Verde and the Azores with 8 and 4 companies respectively. Regarding those companies that advertised specific shark encounters, 8 were located in the Azores and 1 in the Canary Islands. Madeira was the sole archipelago where shark encounters were not advertised.

We obtained information to assess the shark-diving industry potential in the region based on the interviews conducted with 26 dive operators advertising shark encounters in the Macaronesian archipelagos: 2 dive centers from the Azores (~20%); 21 dive centers from the Canary Islands (~20%) and 3 dive centers from Cape Verde (~35%). We also contacted 2 dive operators from Madeira; however, they could not offer any information about shark encounters since these were unreported. Most of respondents selected (1 per company) were dive guides between 30 and 40 years old, with more than 5 years working in each dive center. In some cases, we interviewed the owners of these companies, which allow us to gather a wider information about the subject of research. We summarized our results in Table 3 and 4.

Overall, we found that the Azores is the only archipelago where it is possible to undertake specific shark-diving activities, mainly in Faial and Pico Island. Some dive centers in Santa Maria Island also provide opportunistic shark encounters such as snorkeling with whale sharks. Blue sharks are the main attraction of shark-diving operations in the Azores, which occurs only during summer season (from July to September). According to local dive operators, shark-diving activities represent less than 5% of total dive operations per year. The operators identified the regular occurrence of blue sharks and the international recognition of the dive spot as the principal strengths of the operation.

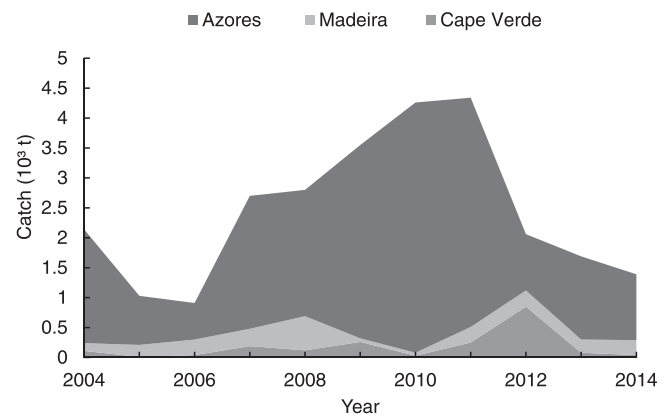


Fig. 3. Sharks (>90 cm) catches in the Exclusive Economic Zones of the Azores, Madeira and Cape Verde between 2004 and 2014. Catch data from the Canary Islands is lacking since this information was not available.

Source: Adapted from the *Sea Around Us Database* (2021).

Table 3
Shark-diving industry profiles in the Macaronesian archipelagos.

	Number of years providing scuba- diving activities	Number of dive trips per year per company	% of shark-dive operations* or general shark encounters** per year per company	Cost (€) of a shark dive trips* or general shark encounters**	Shark species observed	Frequency of shark observation	Seasonality
Azores Islands	17 ± 7	1250 ± 1060	3.38 ± 1.9*	172.5 ± 3.5*	Blue shark and mako shark	From to 1–6 blue shark per immersion, normally 2–3. Mako shark is quite rare to observe in the last years	From June to October
Canary Islands	15.2 ± 11.1	2045 ± 1403	8.47 ± 14.8**	45.13 ± 6.7**	Angel shark in most of the islands. Smalltooth sand tiger in El Hierro. Others: hammerhead shark, tope shark and blue shark	Gran Canaria: 1–3 angel sharks per immersion. Fuerteventura: until 20 angel sharks per immersion, normally 3–4. Lanzarote: 1–3 angel sharks per immersion. Tenerife: 2–4 angel sharks per immersion. El Hierro: 2–3 smalltooth sand tigers per immersion	Angel shark: November-June in Gran Canaria, November to March in Fuerteventura and Tenerife, October-May in Lanzarote. Smalltooth sand tiger: June-November in El Hierro
Cape Verde	12.75 ± 11.9	1400 ± 583	10.75 ± 10.3**	65 ± 16.8**	Lemon shark, nurse shark, black tip shark, whale shark, hammerhead shark, sand tiger shark, Galapagos shark, thresher shark, tiger shark and milk shark	Lemon shark, nurse shark and blacktip shark are the most abundant species. From 1–8 nurse sharks. In average 2–3 nurse sharks per immersion	Generally, between April-December. Nurse shark: whole year. Thresher shark: April. Whale shark: September-November

Note: Madeira was not included in the table since shark encounters were not reported as stated in our results.

However, the operators also expressed major concerns regarding overfishing and its potential threat to the shark-diving industry and highlighted the need of implementation of marine protected areas and/or shark sanctuaries.

The Canary Islands is the archipelago with the most developed scuba-diving industry in Macaronesia accounting the largest number of diving centers in the region (145 companies) and the highest number of diving operations per company (2045 trips on average per year). Although one company in the Canary Islands advertised “diving with angel sharks” on its website, we verified that these encounters are only opportunistic. Angel sharks are the most observed species in these islands, mainly in Gran Canaria, Lanzarote, Fuerteventura and Tenerife, during winter and spring season. Although the majority of Canarian dive operators supported the development of a shark-diving industry in this archipelago, a few of them disapproved it. The principal strengths mentioned were: well-established scuba-diving industry in the European market and high probability of angel shark sightseeing. However, most of the operators indicated legal barriers established by local authorities as the main obstacle for developing a shark-diving industry. All the operators advocate for implementation of marine protected areas and/or shark sanctuaries and to raise public awareness of ecological and economic benefits of shark-diving tourism.

Cape Verde is the less developed archipelago in terms of scuba-diving industry with only 12 diving centers. However, this sector is growing fast as the number of companies has doubled in recent years. Despite shark-diving industry is non-existent, local dive operators pointed out that sharks in Cape Verde are sighted in roughly 10% of scuba-diving operations. Moreover, they reported that more than 50% of dive tourists come to Cape Verde expecting to encounter sharks. Operators highlighted principal strengths as the diversity and regular presence of shark species in their waters and optimal conditions for diving during most of the year. However, they noted that overfishing is the main threat for the development of a shark-diving industry. They also expressed the need for better surveillance and monitoring of existent marine protected areas and increasing public awareness of the ecological and economic benefits of shark-diving tourism.

3.4. Volume of shark catches and landed value in the Macaronesian archipelagos

The total volume of commercial elasmobranchs catches between 2004 and 2014 in the Macaronesian archipelagos EEZ was 28,620 t with a total landed value estimated to be over USD \$ 808.6 million. The Azores EEZ had the highest quantity with a total 22,360 t and landed value in order of USD \$ 763 million. These were followed by Madeira with 3030 t (USD \$ 27.9 million), Cape Verde with 1980 t (USD \$ 16.6 million), and finally the Canary Islands with 1250 t (USD \$ 1.1 million). There is a clear decreasing trend of shark catches in all the archipelagos since 2011, with some indication of stabilization in the volume caught since 2013 (Fig. 2). This may be partially explained by the reduction of number of vessels in the Macaronesian waters and other regulations established by the European Common Fisheries Policy (CFP) for controlling the shark fishing such as the reduction of quotas and the prohibition of retention of certain sharks and rays species. Reported data on catches of large species of sharks in the Canary Islands is limited [60], however, the reconstructed catches of sharks greater than 90 cm displayed a decreasing trend, similar to that found in commercial shark and ray species (Fig. 3).

4. Discussions

4.1. Potential for expansion of the shark-diving industry in the Macaronesian archipelagos

Scuba-diving tourism is a well-established activity in all the Macaronesian archipelagos; however, shark-diving tourism is still largely

undeveloped. The Azores stands out as the sole archipelago in Macaronesia offering specialized shark-diving operations. While shark-diving activities represent less than 5% of the total annual dive operations in the Azores, in 2014 this sector was estimated to generate more than USD \$2 million [49] and according to the dive operators it has experienced an increasing trend since then. In Cape Verde and the Canary Islands, sharks are one of the main attractions of some scuba-diving operations; however, dive operators in both archipelagos stated that these encounters are mainly opportunistic. In 2009, De la Cruz et al. [55] intended to estimate revenues generated by elasmobranch diving in the Canary Islands; however, this study was mostly focused on sighting of rays and may have not reflect the economic value of sharks as an attraction in Canarian diving industry, thus a detailed evaluation of economic benefits associated with shark-diving in this archipelago is necessary.

Despite the small number of specialized shark-diving operations in Macaronesia, the shark-diving industry has the potential to expand in the Azores and to become a specialized market in the archipelagos where it is still inexistent. Shark divers worldwide are drawn to dive spots where sharks can be encountered on a consistent basis and observed at close range, preferably in clear waters [10]. As observed in our results, these elements are present in the Macaronesian Region. Many popular species for shark-diving can be found regularly or frequently in most of the archipelagos, these include blue sharks, shortfin makos and whale sharks in all the Macaronesian waters, lemon and nurse shark in Cape Verde or angel shark in the Canary Islands (Table 5, [30,31,49,50,58]). The established shark-diving industry operating in the Azores suggest that regular and reliable encounters can support operations at least for pelagic species (i.e. blue and mako sharks) in offshore environments. Regular coastal shark-diving operations are likely to be logistically less challenging; however, these can potentially face challenges due to lower abundance of sharks due to fishing pressure.

Each of the archipelago in Macaronesia has particular features to develop shark-diving activities. In the Azores, dive operators stressed that aside from the current shark-diving spots there are other potential areas where shark-diving operations could take place given the abundance of blue sharks on their waters. Also, while swimming with whale sharks is opportunistic in all Macaronesian archipelagos, the Azores is the European dive destination with highest probability to encounter them during their seasonal migrations [50]. The Canary Islands is the only place in the Northeast Atlantic where angel sharks may be sighted regularly [30]. Since 2019, these sharks are under stricter legal protection in the archipelago. According to local dive operators, angel sharks can be observed mostly during winter season, and recreational scuba divers have opportunistic encounters with them in approximately 10% of the overall dives conducted annually, indicating that shark-diving could be advertised as a seasonal activity. Cape Verde, as home of high diversity of warm-water marine species [57], and characterized by the regular presence of coastal sharks [58], offers a high probability of shark observations, even from the shore. According to Cape Verdean operators, sharks are opportunistically observed in roughly 10% of the total number of general dive operations per year; however, they highlighted that this proportion was considerably higher in previous years. Additionally, some dive operators in the Canary Islands and Cape Verde indicated that it would be possible to develop a shark-diving industry using chumming to lure pelagic shark species, such as blue and mako shark, similarly to Azorean operations.

Other important elements considered for the selection of shark-diving spots worldwide are infrastructure and accessibility [10]. In the Macaronesian archipelagos, tourism is a crucial economic sector [33,34, 36–38], which led to the rapid development of new infrastructure, accommodation and facilities in coastal areas. Also, these small islands are well served with flights from Europe, Africa, and the Americas, thus, becoming attractive for both international visitors and tourism investors. Coastal recreational activities such as scuba diving are major

Table 4

Conclusions from the open-ended question about the potential of shark-diving industry in the Macaronesian archipelagos.

Azores Islands	Canary Islands	Cape Verde
Current situation		
Shark-diving industry is an emerging activity in the Azores Islands. General diving tourism is growing up fast in the region.	There is no shark-diving industry in Canary Islands. Dive tourism is a well-established industry in the archipelago.	There is no shark-diving industry in Cape Verde. Some marine tourism companies provide shark-watching activities from the shore since the abundance of lemon sharks.
Strengths and Opportunities		
This activity has potential to expand as new dive spots for shark-diving operations can be explored.	Angel shark is the specie with highest potential for develop shark-dive operations owing to high rate of encounters with dive tourists in most of islands during winter season. This activity would need to be well prepared and duly regulated. Diving with smalltooth sand tiger sharks in El Hierro is not every year activity but its popularity has increased in the last years. These operations are regulated in order to avoid negative impacts. Dive operations with blue shark and mako shark could be developed in the Canary Islands as occur in the Azores.	There is a great potential for this activity as the diverse and regular presence of shark species on their waters, non-aggressive species and well visibility for diving. A shark-diving industry using chumming could be developed similarly to Azores if it is well prepared.
Weakness and Threats		
Shark-diving operations only occur during 3 months per year. Impact by fisheries and insufficient number of marine protected areas are the main concerns.	Angel shark sightseeing is not guaranteed; existent legal barriers; endangered status of the specie and possible touristic impact on shark behavior.	The number of shark populations has diminished due to overfishing from international fleets. There are local conflicts with dive centers probably since only foreigners own all diving centers.
Measures required		
The creation of a shark sanctuary and international marketing will be a big contribute to Azorean diving.	Implementation of marine protected areas and/or shark sanctuaries and awareness of ecological and economic benefits of shark-diving tourism to local authorities.	Better surveillance and control of marine protected areas are needed. Shark sanctuary could be a solution.
Note: Madeira was not included in the table since shark encounters were not reported as stated in our results.		

tourist attractions with a great potential for growth [37]. Although official data of the economic contribution of scuba-diving industry to the regional tourism sector are lacking, our results revealed that 228 companies provided diving activities in the archipelagos of Macaronesia in 2019, which means a large expansion on the number of dive centers in recent years, particularly in the Azores (27 companies in 2014) and Cape Verde (6 companies in 2016) [61,88]. Furthermore, the occurrence of the main shark species broadly coincides with peak tourist seasons in the Azores and the Canary Islands, while in Cape Verde these can be observed practically the whole year.

Shark-diving tourism industry in Macaronesia is thought to serve as a means of transitioning local economies from unsustainable to sustainable non-consumptive uses of marine resources as occurs in other parts of the world [18,62]. However, since the economies of these territories are highly dependent on the marine resources [48], shark-diving tourism operations are very likely to interact with fisheries.

Prohibitions placed on fishing sharks to protect local dive sites may create significant issues for coastal communities [10], therefore it is necessary to implement strategies that will assure the sustainable use of sharks while safeguarding and integrating the local communities. Such approach has been successfully adopted in other popular shark-diving destinations [19,63]. For example, community levies paid by the shark-diving industry to adjacent fishing communities could be further explored and a mean of financial compensation not to fish at specific shark-diving spots in Macaronesia [63]. Other profits from the presence of shark tourists, such as the demand for local fish, could also make local fisher encouraged to support the shark-diving tourism [19]. Evidences of cooperation between local fishers and diving centers generating mutual benefits have already been found in the Azores [51].

4.2. The impact of shark fisheries on the expansion of the shark-diving industry in the Macaronesian archipelagos

Many of the shark species targeted by the diving industry are heavily fished by North Atlantic fisheries by national and foreign fleets [40]. Thus, the potential expansion of shark-diving tourism in Macaronesia is likely to be jeopardized by pelagic industrial fisheries as both industries are competing for the same targets species. Spanish and Portuguese longline fleets are the largest shark fisheries in the Macaronesian Region [45], and Spain is one of the largest producers and exporters of shark fins worldwide [2]. Shark catches are mostly compounded of large amounts of pelagic species such as blue shark and mako shark [42], which are the principal tourist attractions of the Azorean shark-diving operations and potential species for shark-diving industry expansion in Macaronesia. According to the qualitative information obtained from our interviews with the Azorean dive operators, there has been a decrease in the number of shark sightings in the last decade, which they attribute to fishing pressure. Declines in abundance of sharks can result in a substantial reduction in the demand for dive trips and economic losses not only to the dive industry, but also to the broader local tourism market [64].

The impact of small-scale and recreational fisheries on shark populations is also a major concern since coastal sharks are the main target species for a dedicated shark-diving industry in Cape Verde and the Canary Islands. In Cape Verde, an overall reduction of biodiversity of local marine species has been reported to be caused by unregulated fishing practices [65], and according to local operators, this has decreased the number of shark sightings in recent years. Significant bycatch of smooth hammerhead, tiger shark, and mostly lemon and nurse sharks by artisanal and semi-industrial fishers comprised [41,43], all potential target species for tourism, has been reported in this region. However, shark catch from small-scale fleets remains largely unreported [29], which suggests that the impact of this sector on shark populations is largely underestimated. In the Canary Islands shark landings are severely underreported [60]. Information gathered by researchers show that angel sharks, the most popular shark species for recreational divers, are incidentally caught by recreational and artisanal fishers [30]. A study found that sharks and rays composed roughly 38% of total catch in weight in artisanal trammel net fisheries, of which angel shark represented more than 50% [66]. Moreover, the increasing fishing effort from recreational fisheries, as a result of the excessive number of active licenses and unreported catches, suggests this sector has a strong negative impact on angel shark populations [67].

Although there has been a decrease of the shark catches in Macaronesia since 2011 and signs of stabilization in the last decade, the lack of effective monitoring, management and surveillance to improve catch reporting, halt overfishing and poaching represent major threats for shark populations in the region [5,29,40,42,45,47,59,68,69]. The fishing pressure coupled with the intrinsic vulnerability of some shark species makes urgent the need for more effective shark conservation measures [42]. Torres et al. [49] stressed that decision makers should ensure that shark fishing is sustainable implementing comprehensive

management plans in the region; however, in practice this objective is far from achievable in most places around the world [8]. Moreover, as new shark-diving sites are discovered and advertised, there is some evidence that these areas can become a target for the exploitation of sharks, e.g. bull sharks in Mexico or Caribbean Reef sharks in the Bahamas [18].

4.3. Conservation potential of shark-diving tourism in the Macaronesian archipelagos

Despite yet not fully quantified for all the archipelagos in Macaronesia, the socioeconomic revenues of shark-diving tourism may present a robust argument for enhancing shark conservation policies in the region. For example, in the Azores 1101 t of sharks and rays catches were landed in 2014 with a total landed value estimated in USD \$ 8.2 million (Sea Around Us, 2021). This value represented around four times the total economic value of the Azorean shark-diving industry in the same year (USD \$ 2.2 million, [49]). However, the total landed value of blue shark and shortfin mako shark in the Azorean local market was estimated to be over USD \$ 20,000 [40]. This suggests that most of the revenues from shark catches were captured by distant-water fleets, and that this industry brings little economic benefits locally when compared to the local emerging shark diving industry that rely on the same pelagic species. With the potential expansion of the shark-diving industry in Macaronesia, this activity could generate comparable annual revenues to those yielded by shark fisheries, with potentially larger benefits for the local economy and community, as it has been demonstrated elsewhere [19]. In 2014, for example, the Azores received 1280 tourists to engage in shark-diving activities [49]. Assuming the average tourist expenditure estimated in Torres et al. [49] remains the same and similar shark landings over time, a four-fold increase in the Azorean shark-diving industry would potentially result in larger annual revenues than the total landed value of sharks and rays fished within Archipelago. However, the widespread overfished status and severe declines of oceanic shark populations [70] will inevitably result in decrease in catches in the near future, also potentially reducing the overall landed value and revenues from fishing sharks. Thus, alternative non-consumptive uses of shark populations, such as shark-diving tourism, should be preferred from a socio-economic and conservation perspective and is likely to increasingly represent an attractive strategy.

Direct revenues, income and employment generated directly and indirectly through shark-diving industry have influenced a shift in the socio-economic importance of sharks from fisheries products to non-consumptive resource in many tourist destinations around the world [18,19,63]. Further, the financial benefits from shark-based tourism can promote the protection of sharks and/or their habitats through

conservation strategies and management [19,20]. Indeed, the number of Marine Protected Areas (MPAs) around shark-diving locations is growing worldwide together with very large shark-specific marine reserves in countries where shark-diving tourism contributes significantly to the nation's GDP such as Palau or Bahamas [18,19]. Additionally, there is evidence that dive tourists are more willing to pay to support the enforcement of marine protected areas for shark conservation in dive destinations where they have experienced shark-diving activities [14, 20,49].

Marine Protected Areas are a widely used tool for the protection of biodiversity and are increasingly advocated as a strategy for protecting or restoring shark and ray populations worldwide [71,72]. However, given some of the shark species found in the Macaronesian waters are highly migratory, MPAs would likely only protect individuals for part of their life cycle [73]. According to Hernandez (2010), a larger-scale conservation plan including the entire main corridor of the Canary Current, from the Azores to Cape Verde, as a great sanctuary for highly migratory oceanic species is feasible. As an example, The Ligurian Sea Sanctuary, based on an agreement between three states and including areas located outside the respective national jurisdictions, is a marine sanctuary based on an international agreement [74]. Considering the rapid decline of many shark populations in the North Atlantic [3,6] and signs of significant overfishing in the Canary Current Marine Ecoregion [75], supra-regional control measures could be implemented to reduce shark-fishing mortality. A similar call for regional MPAs to protect highly-migratory species was recently announced in the Caribbean, which shares many similarities in terms of regional connectivity as the Macaronesian Region [72].

Shark-diving tourism may also serve as a potential instrument and platform for the implementation of citizen science initiatives to improve monitoring and understanding of shark populations in the region [18]. Recreational scuba divers in the Canary Islands, for example, collaborated with researchers for assessing the abundance and distribution of angel sharks in the archipelago through registering their encounters with this critical endangered species [56]. According to Azorean dive operators, dive companies consistently share information about shark encounters with the Department of Oceanography and Fisheries (DOP) at University of Azores since both target the same species (i.e., blue sharks). This cooperation allows them to better understand the areas where sharks can be found generating mutual benefits. Furthermore, shark-based tourism operations and marine science expeditions can also serve as deterrents for illegal or environmentally harmful activities such as poaching [18].

Although shark-diving tourism has proved to be a potential driver of conservation benefits, it is worth considering its limitations. While many studies have shown the financial contribution of shark-diving industry

Table 5

Distribution, habitat, exploitation status and current human use of potential species for shark-diving in the Macaronesian archipelagos.

Shark species	Macaronesian Archipelagos	Habitat	Exploitation Status (IUCN)	Fisheries	Tourism
Blue shark (<i>Prionace glauca</i>)	All waters	Oceanic	Near Threatened	Targeted and bycatch	Shark-diving in the Azores
Short fin mako (<i>Isurus oxyrinchus</i>)	All waters	Oceanic	Endangered	Targeted and bycatch	Shark-diving in the Azores
Whale shark (<i>Rhincodon typus</i>)	All waters	Oceanic	Endangered	Bycatch	Scuba-diving in the Azores and Cape Verde
Smooth hammerhead (<i>Sphyrna zygaena</i>)	All waters	Oceanic	Vulnerable	Bycatch	Scuba-diving in Cape Verde
Angel shark (<i>Squatina squatina</i>)	Canary Islands	Coastal	Critically Endangered	Bycatch	Local scuba-diving
Smalltooth sand tiger (<i>Odotaxis ferox</i>)	Canary Islands	Pelagic	Vulnerable	Data deficient	Local scuba-diving
Lemon shark (<i>Negaprion brevirostris</i>)	Cape Verde	Coastal	Near Threatened	Bycatch	Local scuba-diving
Nurse shark (<i>Ginglymostoma cirratum</i>)	Cape Verde	Coastal	Data deficient	Bycatch	Local scuba-diving
Black tip shark (<i>Carcharhinus limbatus</i>)	Cape Verde	Coastal	Near Threatened	Targeted and bycatch	Local scuba-diving
Sand tiger shark (<i>Carcharias taurus</i>)	Cape Verde	Coastal	Vulnerable	Data deficient	Local scuba-diving
Tiger shark (<i>Galeocerdo cuvier</i>)	Cape Verde	Reef	Near Threatened	Bycatch	Local scuba-diving

to several regions [10–16], economic estimations may be inaccurate [22] or based on limited information (e.g. [55]). Also, the shark-diving tourism industry focuses only on a limited number of species, while more than a hundred species are threatened with an elevated risk of extinction [6]. Furthermore, shark conservation can still occur without the advent of shark-diving tourism, while the latter relies on the creation and enforcement of appropriate management regimes and the provision of alternative sources of income to local communities [64].

4.4. Challenges for the potential expansion of shark-diving tourism in the Macaronesian archipelagos

Since a large number of shark encounters in Macaronesia are opportunistic in nature, a basic understanding of shark movement patterns and behavior from the region is required [10]. As highly migratory species move seasonally, shark-diving operations could only occur for a few months per year, therefore the annual benefits of a shark-diving industry based on these species would be lower than those aggregated for longer periods. Providing a significant fraction of conservation incentives to local fisher communities against this backdrop seems to be more difficult to achieve [21]. A regular payment throughout the year, potentially subsidized by governments, would be necessary if tourism can prove to be an essential activity for socioeconomic development.

Establishing a large-scale conservation plan for highly migratory species may contribute to the expansion of the shark-diving industry in Macaronesia. However, this would require a cohesive management strategy across the countries involved with individual jurisdictional and management requirements, which could present a significant challenge. In order to promote and achieve this vision, a shark conservation agenda would need to be included in the Summit of the Archipelagos of Macaronesia. This biannual meeting was formed in 2010 through a joint declaration of the State governments of Cape Verde, Spain, Portugal and the regional governments of the Azores, Canary Islands and Madeira, to foster a common approach to global challenges such as preservation and protection of the marine environment and tourism development [33]. The Marine and Maritime Cluster of Macaronesia is another platform that could also be used to coordinate a set of protective measures targeting oceanic and coastal sharks and the regional expansion of the shark-diving industry. This joint action program formed by institutional, business and scientific-technological actors of the Macaronesian archipelagos is focused on fostering the sustainable economic growth and employment in the maritime sector of the Atlantic Ocean area of Macaronesia [33].

Conflicts between dive operators and local population in Cape Verde and legal barriers established by local authorities in the Canary Islands were reported by dive operators. In the Canary Islands this could be partially explained by the lack of public awareness of ecological benefits and economic inclusion from shark-diving tourism. Hence, a higher dissemination of the potential benefits of establishing a shark-diving industry would be necessary. In Cape Verde, for example, all companies were exclusively run by foreigners, thus the lack of incentive for the local communities to engage with the industry represents a challenge and needs to be addressed. Gallagher et al. [18] have contended that in cases where community-based management is not in place, there is higher potential for poaching and resistance to the shark-diving industry from the local communities. Encouraging local communities in Cape Verde to have a leading role in the potential shark-diving industry could ensure that the business revenues generated may be translated into important socio-economic benefits (e.g. [76,77]).

Finally, any growth of the shark-diving industry in Macaronesia needs to be regulated and monitored to assure minimal negative impact to the marine life, habitats but also to the local human communities. For example, the coastal angel sharks are critically endangered species, as such diving operations targeting these sharks in the Canary Islands follows guidelines that aim to reduce the impact on the animals and that have been established in collaboration by local operators, marine

scientists, managers and community. For oceanic sharks such as blue sharks or mako sharks, chumming may provide the only alternative for reliable encounters in Macaronesia, thus guidelines and regulations of this practice need to be particularly robust and enforced to assure safety of divers and well-being of the animals. In the Azores, the shark-diving industry is already limited to legally defined carrying capacities and codes of conduct established by the Regional Government in 2012 [51], which are broadly followed by tourism operators [78]. With the potential development of the industry across Macaronesia these regulations need to be standardized in terms of restrictions across the archipelagos in order to ensure the coordinate management of shark-diving tourism and an effective regional cooperation for shark conservation.

5. Conclusions

Shark-diving tourism is considered to be a potential non-consumptive alternative of use of shark species. This industry, which can generate economic benefits for communities in different parts of the world, could be further developed in the Macaronesian archipelagos. However, the primary species targeted by the diving industry are also threatened by commercial and recreational fisheries. In particular, pelagic and migratory species overlap with Spanish and Portuguese industrial fisheries across all Macaronesian waters, while coastal species are being exploited by recreational and artisanal fisheries in the Canary Islands and Cape Verde. Although there may be some small operations that can persist on a local level, developing a robust industry that can provide incentives to local fishers for supporting diving activities requires to establish a regional policy to safeguard sharks. Increasing public awareness of the importance of sharks for ocean health, and, most critically - disseminating the ecological and economic benefits of shark-diving operations to local authorities of each archipelago is the first stage in this process. It is also necessary to strengthen management and effective monitoring of shark (and fisheries in general) catches by local and foreign fleets operating in the Macaronesian waters, coupled with the creation of large-scale protected areas over the region.

Sharks are widely distributed throughout the world's oceans and therefore shark-diving tourism has a large potential for expansion. For those places who share a regional connectivity, the Macaronesia could provide a comparable case study as there are different levels of industry development between the archipelagos. Nevertheless, the recognized potential benefits of shark-diving tourism are not directly applicable to all coastal destinations; therefore, a prior assessment of the potential benefits that may result from establishing a shark-diving industry in specific locations is essential for achieving sustainable and socio-economic goals.

Further research is needed to obtain more clarity on the potential for long-term benefit of shark-diving activities in Macaronesia. To accomplish this, the most important knowledge gaps needing filling are data on the abundance and distribution of shark populations in the Macaronesian waters, socioeconomic valuations of the potential shark-diving industry in each archipelago, updated data on the shark fisheries from North-East Atlantic to the Central-East Atlantic Ocean, and assessments of the local communities' perceptions and social inclusion in the shark-diving tourism industry.

CRedit authorship contribution statement

Pedro G. González-Mantilla: Conceptualization, Formal analysis, Investigation, Project administration, Funding acquisition, Visualization, Writing - original draft. **Austin J. Gallagher:** Conceptualization, Formal analysis, Methodology, Writing - review & editing, Supervision. **Carmelo J. León:** Conceptualization, Project administration, Supervision, Validation. **Gabriel M.S. Vianna:** Conceptualization, Formal analysis, Methodology, Writing - review & editing, Supervision.

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Conflict of Interest

No potential conflict of interest was reported by the authors.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2021.104632](https://doi.org/10.1016/j.marpol.2021.104632).

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