SUSTAINABLE FISHERIES GROUP
UNIVERSITY OF CALIFORNIA SANTA BARBARA

Economic Valuation of Marine Ecosystem Services in the Azores

Azores Economic Valuation

Economic Valuation of Marine Ecosystem Services in the Azores developed by the Sustainable Fisheries Group. Prepared December 2019 for the Blue Prosperity Coalition.

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BLUE PROSPERITY COALITION

Executive Summary

Marine biodiversity sustains a range of ecosystem services that contribute substantially to the wealth and general well-being of people in the Azores. The purpose of this report is to identify the most important services provided by the marine ecosystems in the Azores and quantify their economic value. We broadly group these services into revenue-generating and non-revenue-generating services, and use the best available methods from the literature to quantify their value. We also utilize primary literature and expert knowledge to: 1) qualitatively assess the likely impact of the implementation of fully protected Marine Protected Areas (MPAs) on the value of each service as a "strong benefit", "moderate benefit", or "variable/minimal effect" and 2) provide a "low", "medium", or "high" uncertainty score to the value estimate for each service given data availability and quality.

We estimate the total annual 2017 value of revenue-generating marine ecosystem services in the Azores to be between €55 - 99 million, and the annual value of non-revenue-generating services to be €11 - 14 million (Table 1). The two revenue-generating services, fisheries (€31.7 million) and marine tourism (€23.5 - 67.0 million), are roughly equivalent in value. Availability of data on the number of tourists and revenue generated per tourist are variable across each subsector of the marine tourism industry, resulting in the larger range of estimated value. The non-revenue-generating services include the value of research and education, the intrinsic value of marine ecosystems in the Azores now ("existence value") and to future generations ("bequest value"), and the "option value" of developing novel pharmaceutical and biotechnology products derived from marine ecosystems in the future.

Our qualitative assessment of the predicted effect on the estimated service values from

Table 1. The marine ecosystem services included in our analysis and their estimated annual value (2017€).

Category	Service	Subsectors	2017€ (millions of euros)
Revenue-generating	Fisheries	Demersal, Pelagic, Coastal, Recreational	31.7
	Marine Tourism	Hospitality, Whale Watching, Diving, Sport Fishing, Sailing/Yachting, Cruise Ship	23.5 - 67.0
Non-revenue-generating	Research/Education	–	3.0
	Existence/Bequest	–	0.2 - 2.1
	Med./Biotech. Option Value	–	7.9 - 8.4

the implementation of fully protected MPAs is presented in Figure 1. We find that the demersal, coastal, and recreational subsectors of the fisheries service and the diving, whale watching, and sport fishing subsectors of the marine tourism industry could benefit considerably from well-designed MPAs in the Azores. Together, these services make up 45 - 74% of the total estimated value of the revenue-generating services. The value of several services including the pelagic fishery, hospitality industry, and the existence and bequest value have a more indirect relationship with the creation of an MPA network and may only benefit minimally if at all. Finally, the potential synergy between MPAs and the sailing/yachting and the cruise ship subsectors is difficult to estimate because revenue generated from the cruise trip and sailing/yachting industry is likely largely attributed to the location of the Azores, a perfect stop for boats crossing the Atlantic, and less dependent on the quality of the marine ecosystem provisioning those services.

There are fundamental differences and uncertainties associated with quantifying value for revenue- and non-revenue-generating ecosystem services that may make these estimates not directly comparable. Thus, we highlight where additional data would improve the accuracy of our estimations and reduce uncertainty, specifically:

- Estimates of total landings from recreational shore-based fishing and collecting by hand
- Tourism revenue generated by food service and non-traditional accommodation sectors
- Updated estimates of the total number or percentage of tourists that participate in each marine tourism activity and direct tourist expenditures on those activities
- Updated survey data reflecting the attitudes of Azorean residents towards the marine environment, including quantitative estimates of existence and bequest values

These results estimate baseline economic values of ecosystem services, and how current and potential future threats may affect these values, which can be used to inform natural resource management decisions in the Azores and make the tradeoffs between conservation and development more explicit.

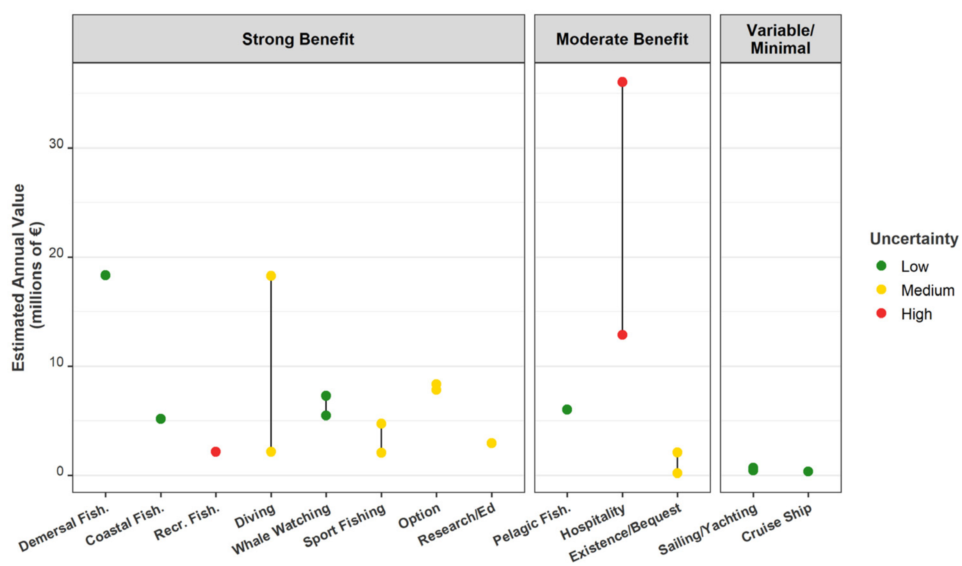

Figure 1. Estimated economic value (millions of 2017 euros) of the marine ecosystem services (or subsectors) of the Azores, grouped by the predicted effect of fully protected MPAs on their value. Two connected points are used to denote when a range of values were calculated. The color of the point indicates the uncertainty score assigned to that service based on data availability and quality (see *Methods Overview* section for more information).

In addition to the current marine sectors we have valued, we have identified four emerging marine sectors with potential future economic value in the Azores: aquaculture, seabed mining, blue carbon sequestration, and deep-sea submersible tourism.

Development of aquaculture in the Azores has the potential to generate significant economic activity, diversify seafood production, and reduce pressure on wild populations. Areas suitable for offshore aquaculture have been identified across the Azores and the first farms culturing invertebrates, macroalgae, and finfish have been proposed for development on the islands of Terceria, Faial, and Sao Miguel.

Expeditions to the deep-sea in the Azores are currently offered to scientists for research expeditions to explore the Azores unique and diverse deep-sea habitats. In the future, technological advances and lower input costs could catalyze a deep-sea submersible tourism.

The Azores has been identified as an area where ocean mining could potentially be developed because of the polymetallic nodules, crusts, and massive sulphides containing copper, cobalt, gold, silver, and platinum located within the seabed. While ocean mining could provide and economic opportunity for the regional economy, environmental impacts should be carefully evaluated before this sector is pursued.

"Climate change mitigation" is an ecosystem service that is underpinned by oceanic carbon sequestration and is sometimes included in economic valuations of marine ecosystems. The economic value of deep-sea carbon sequestration was not included in our analysis because the carbon markets in Europe are still being developed and do not currently include a mechanism to generate revenue from natural carbon sinks like the ocean. Using a model of blue carbon ocean stocks and the social cost of carbon carbon market, we estimate the economic value of the global benefit of blue carbon sequestration in the Azores could be up to €12.7 billion.

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Introduction

Ecosystem services are provided by the natural environment and either directly or indirectly benefit human populations. These services are underpinned by a wealth of biodiversity. Degradation of the natural environment and loss of this biodiversity threatens the continued provisioning of services essential for human health, livelihood, and survival[1,2]. However, each ecosystem service provides different value to humans, and each may be facing a different suite of threats. Thus, evaluating and considering the impact of policy decisions on these services can help guide sustainable development[3,4]. Quantifying the importance of a healthy ecosystem is challenging because ecosystems provide many different types of benefits that are often measured using different metrics (e.g., species biodiversity, climate regulation, and fisheries revenues).

Ecosystem service valuation, or estimating the quantitative value of ecosystem services to humans in a common unit (e.g., money, energy, time), is an approach that has been widely utilized to weigh the relative importance of diverse ecosystem services[2]. While valuing these ecosystem services in common units is complicated and fraught with uncertainty, the alternative of failing to quantify these benefits often obviates them from decision-making, which can result in adoption of polices that are unsustainable or sub-optimal[3,5]. Therefore, economic valuation is a critical step in planning as it provides policy makers with a framework for identifying and informing tradeoffs of different conservation and development scenarios that may impact the natural environment and the services it provides.

In this report, we present an economic valuation of ecosystem services provided by the marine environment surrounding the Azores, an archipelago of volcanic islands in the North Atlantic Ocean, which is an autonomous region of Portugal. We identify and present qualitative descriptions of a suite of marine ecosystem services in the Azores and provide quantitative estimates of direct economic benefits generated through revenue-generating services (such as fisheries and marine tourism) and indirect and/or non-use benefits generated through non-revenue-generating services (such as research and existence value). The objective of this report is to compile and analyze the best available information on marine ecosystem services in the Azores, with the ultimate goal that this information be utilized by the Azorean Government, stakeholders, and policy-makers to inform conservation and development policies in the region.

The Azores

General Description

The Azores is an archipelago of nine volcanic islands in the North Atlantic Ocean roughly 1,500 km west of mainland Portugal. The islands are situated along 600 km of the Mid-Atlantic Ridge and separated into three geographic groups: the western islands (Flores and Corvo), the central islands (Faial, Pico, Sao Jorge, Graciosa, and Terceira), and the eastern islands (Sao Miguel and Santa Maria) (Figure 2). The Azorean Exclusive Economic Zone (EEZ) (0-200 nm offshore) is slightly under one million km^2 and constitutes one of the largest EEZs in the European Union (Figure 3). The vast EEZ supports the blue economy of the region, contains unique underwater features and habitats, and is a hotspot for marine biodiversity[6]. Given the remote geographic location and relatively young age of the island chain, the Azores is considered an important area for research[7], conservation, and trade[8].

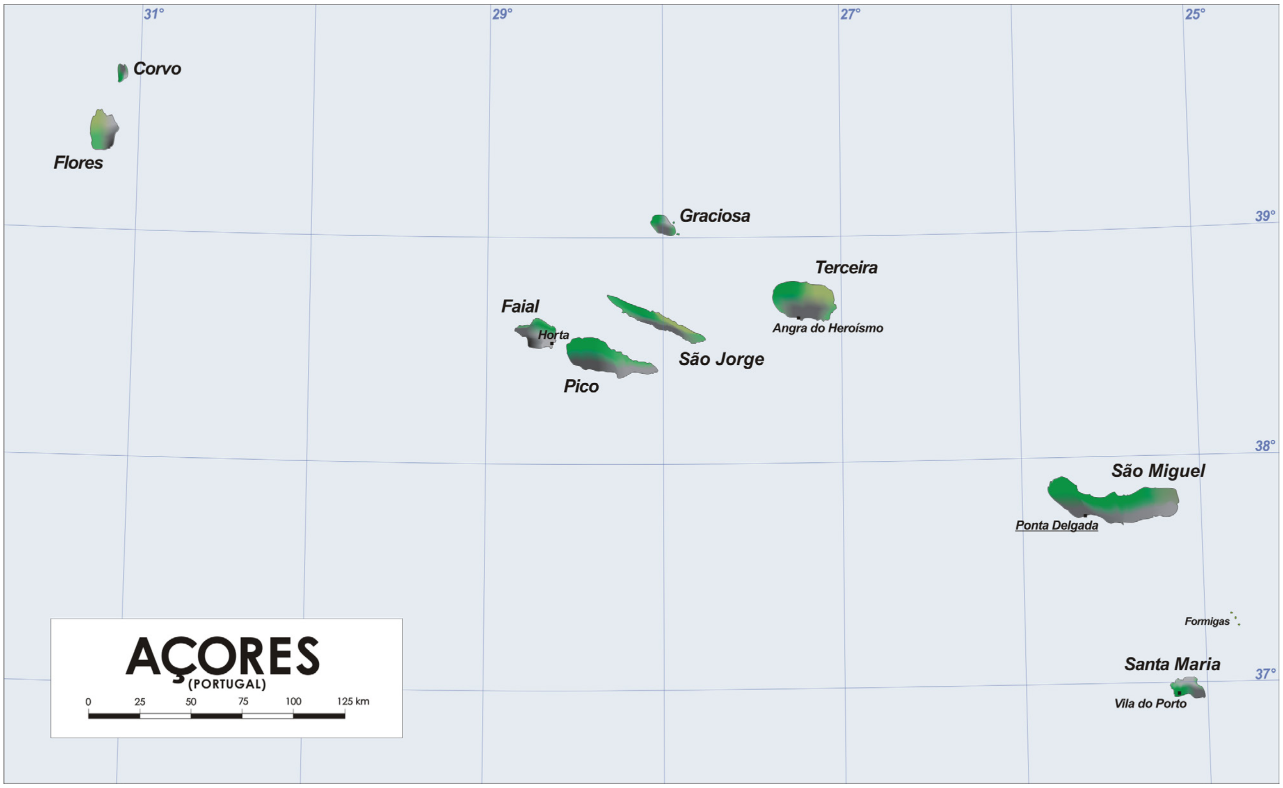

Figure 2. Map of the Azores[13].

The Azores is home to approximately 244,000 residents[9]; São Miguel and Terceira are the most densely populated islands. The archipelago's GDP was €4.1 billion in 2017[10] and is based mainly on agriculture, fisheries, and tourism[11]. A large fraction its economic activity is tied to the marine environment[12].

Marine Ecosystems

The remote location of the Azores, underwater topography and bathymetry, and positioning at the confluence of both warm- and cold-water currents support a diverse and unique assemblage of biodiversity in the marine environment[14]. The marine environment of the Azores can be characterized by four distinct ecosystem types: the nearshore coastal areas, open-water pelagic systems, seamounts, and deep-sea benthos. There is very little continental shelf extending around the islands, less than 6% of the island's EEZ is shallower than 600 m[15,16]. The average depth of the Azorean EEZ is 3,000 m and contains unique features including hydrothermal vents, cold-water coral habitat, submarine mountain ranges, and seamounts[6].

The nearshore coastal areas of the Azores are characterized by short, shallow stretches along the shore that quickly drop off. The high energy nearshore environment has a rocky bottom and thin mats of crusting algae; the large canopy-forming brown algae species that are present in much of the rest of Europe are noticeably absent[11,17]. There is a concentration of fishing activity in the narrow band of nearshore waters that are shallow enough to be accessible (<600 m), threatening coastal ecosystems. The blackspot seabream and thornback ray are among several species that are at risk of being overexploited[11]. Due to their close proximity to ports and marinas, nearshore coastal ecosystems are also threatened by the introduction of non-native organisms via foreign vessel traffic. In recent years, scientists have documented the arrival of several non-natives including a few highly invasive species of green algae from the genus *Caulerpa* [18,19].

The open-ocean pelagic system in the Azores covers the vast majority of the EEZ. Many iconic species migrate through and reside in the offshore waters of the Azores. Sperm whales, blue whales, blue sharks, mako sharks, rays, tuna, and several dolphin species have been documented in the surrounding waters[20–23]. These ecologically and culturally important marine species supplement the regional economy through the fisheries, research and education, and tourism sectors and provide indirect benefits through non-use values (e.g., existence and bequest values). While many of these species have fairly healthy populations in the region, pelagic longlining threatens the abundance of some species. The fishing fleet is dominated by industrialized vessels from mainland Portugal and Spain and both blue and shortfin mako sharks are frequently caught as bycatch[24].

The Azores archipelago lies along a portion of the Mid-Atlantic Ridge at the intersection of the American, African, and Eurasian plates, resulting in high levels of volcanic activity[11]. This activity has created a highly variable seafloor terrain with an estimated 400-500 seamount-like structures[6]. Seamounts are known aggregators of biodiversity and biomass and, as a result, have become popular targets of many of the Azorean fisheries (longline, pole-and-line, recreational, etc.)[25]. Like the shallow coastal environment, seamount-aggregating species have begun to show patterns of over-exploitation due to fishing pressure concentrating around them[11]. In addition, seamounts are popular tourism destinations for shark diving and whale watching tours, resulting in possible congestion of the areas and possible stakeholder use conflicts.

The deep-sea benthic ecosystem is home to a collection of unique underwater features including hydrothermal vents, submarine mountain ranges, and fields of cold-water corals[6,22]. Scientists have only recently begun to study hydrothermal vents but the chemosynthetic organisms that they support are of great interest to the medicinal and biotechnology communities (see the *Medicinal/Biotechnology Option Value* section). Like hydrothermal vents, seamounts and cold-water corals often support high levels of biodiversity and act as underwater oases for many slow growing organisms with low reproduction rates (e.g., tubeworms, sponges)[26]. These high conservation priority, slow-to-recover habitats show signs of damage from demersal longlining despite fishing gear restrictions in place to protect them[11,22]. While no deep-sea mining currently exists in Azorean waters, there is emerging interest in developing this sector, which could threaten the future of the benthic communities of the Azores[8].

Ocean Governance

The Azores gained status as an autonomous region within the Portuguese Republic in 1976. This status empowered the Regional Government of the Azores to design its own economic and social development plans, participate in the negotiation of international treaties, and regulate the regional agricultural, fisheries, tourism, trade, and energy sectors[27]. The Azores is included in the European Union as one of the nine Outermost regions and is subject to EU laws, such as the Common Fisheries Policy. Under this arrangement, any EU flagged vessel has access to fish in the Azores' EEZ between 100 and 200 nm from shore (see map in Appendix 1)[28]. Thus, the marine resources in the Azorean EEZ are managed through a combination of regional, national, and international policies.

The Azores have a network of 52 marine protected areas (MPAs) within its EEZ. Nine Island Natural Parks in the Azores (one per island) comprise both terrestrial and marine protected areas, and contain 35 nearshore MPAs (0-12 nm from shore)[29]. The remaining

17 MPAs are located within the boundaries of the Marine Park of the Azores, which are unique in that they extend past the EEZ and onto the extended continental shelf (Figure 3)[30], a region outside of the EEZ which was included as part of Portugal's larger submission to the United Nations' Commission on the Limits of the Continental Shelf[29]. These groundbreaking high seas MPAs were established under the authority of the Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention")[29].

Based on the MPA categorization system from a recent study by Horta e Costa et al.[32], the majority of Azorean MPAs are weakly to moderately protected. This study indicates that they lack management plans, the capacity to enforce current regulations on extractive activities, or do not explicitly prohibit a variety of fishing gears and/or activities that have potential negative ecosystem impacts such as mining and aquaculture[33]. Thirty-one of the MPAs in the region lack fishing regulations, and only eight MPAs are fully protected MPAs, covering 0.002% of the EEZ[33]. Trawling and mineral extraction are restricted throughout much of the Azores' territorial waters to protect the seafloor (see Appendix 1 for a map of the trawl ban)[34], but none of the extended shelf MPAs limit seabed mineral exploitation[33]. Looking ahead, the Regional Government is working to draft and implement management plans for each of the existing MPAs in addition to creating more fully protected MPAs.

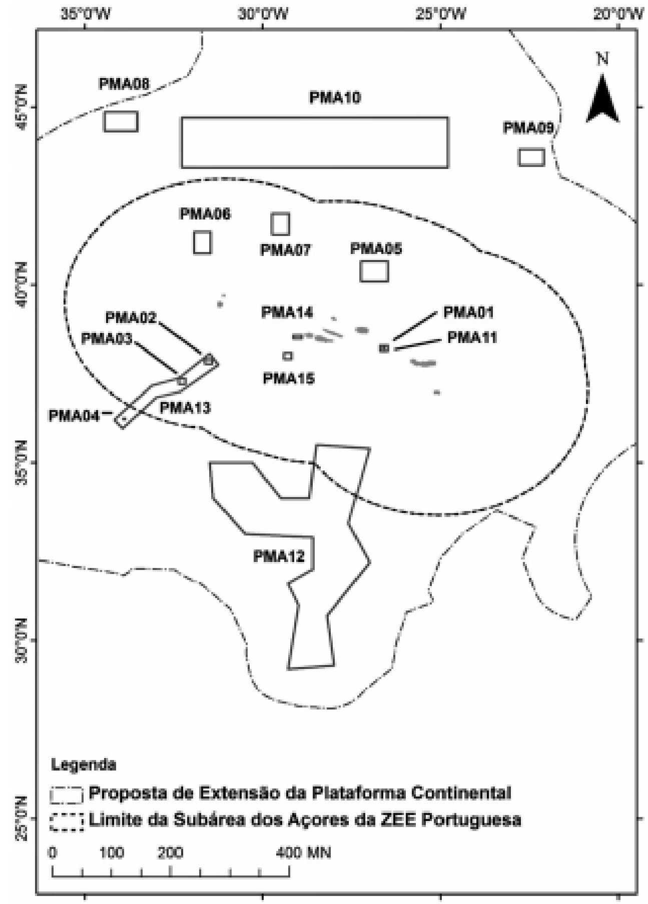

Figure 3. Pictured are the 17 MPAs (in Portuguese: "AMPs") that make up the Marine Park of the Azores, with the EEZ boundary (inner dashed line) and the limits of the continental shelf (outer dashed line). *Note:* The two MPAs that straddle the EEZ boundary are tabulated as two MPAs each (one inside and one outside) by the Regional Government[31].

Methods Overview

Overview of Ecosystem Service Valuation Methods

The goal of this study is to classify and value the most important marine ecosystem services in the Azores. People gain value from interacting with ecosystems through a variety of direct use, indirect use, and non-use activities. The goal of ecosystem service valuation is to express these diverse benefits using a common unit, such as money, energy, or time[4]. The benefit of distilling diverse values into a common unit is that it allows for explicit evaluations of tradeoffs and direct comparisons across ecosystem services. Valuation frameworks can vary widely depending on the ecosystem services included, the way economic value is defined, and the time horizon considered; and they should be designed based on the context of the policy action being considered[35].

We distinguish between services that directly generate revenue to the Azorean economy, or 'revenue-generating services', and the services that do not directly generate revenue but provide an indirect or non-use benefit, or 'non-revenue-generating services'. In a conventional market, like the one shown in Figure 4a (left panel), supply and demand are in equilibrium when the quantity (*q*) of a good or service is sold at price (*p*), which generates revenue (*R*):

$$R = p * q$$

R is represented in Figure 4a as the area of rectangle *B*+*C*. The area (*C*) under the producer's supply curve (*S*) represents the costs that the producer accrues in producing the equilibrium quantity, *q* units of the good or service. The difference between revenue (*B*+*C*) and costs (*C*) is the net benefit to producers of the good, called 'producer surplus' (*B*). The demand curve *D* depicts the consumers' marginal willingness-to-pay (WTP), the maximum amount that they would pay for an additional unit of the service. The area between the demand curve and *B*+*C* is called 'consumer surplus' (*A*), which represents the difference between the total amount a consumer would be willing to pay for a certain quantity of a good/service and what they actually paid.

From the perspective of consumers (such as tourists), the ecosystem provides value *A*+*B*+*C*, but because the consumer has to pay *B*+*C*, their net value is the consumer surplus, *A*. From the perspective of producers (likely Azorean proprietors), the revenue they generate is *B*+*C*, but because it costs them *C* to produce, their net value is the producer surplus, *B*.

On the other hand, governments and the finance sector often report values as revenue, or market capitalization, given here by the area, *B*+*C*. This approach, of defining economic value as the revenue generated by the sector (*B*+*C*), has several advantages. First, price and quantity are often directly observable, which facilitates valuation across a range of services. Second, because the shape of the demand and supply curves are often highly uncertain, this summary statistic helps to remove uncertainty. Third, the consumer surplus may be important to consumers, but is likely of much less relevance to local Azorean decision-makers. And finally, the area *B*+*C* can be estimated for both revenue-generating and non-revenue-generating services, facilitating comparisons across a range of services.

Thus, for revenue-generating services in the Azores, we calculate the economic value (hereafter, value) as the revenue, area *B*+*C*. This value comprises both the producer surplus to local producers (*B*) and the costs of

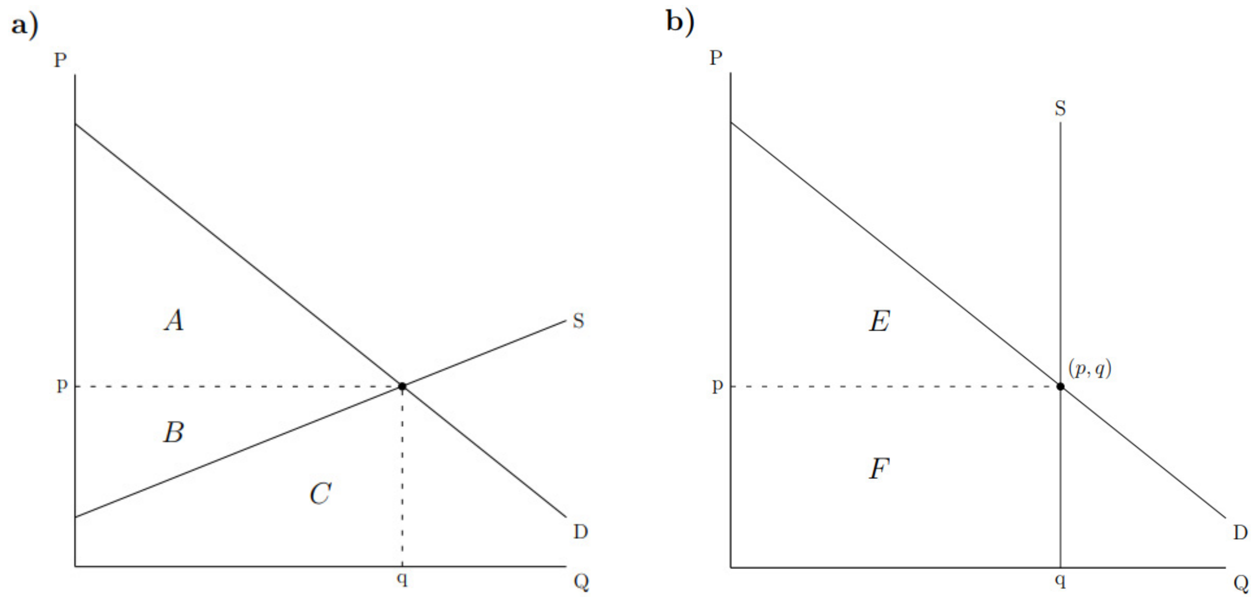

Figure 4a-b. Theoretical diagrams of supply (*S*) and demand (*D*) for a revenue-generating ecosystem service (Figure 4a, left) and non-revenue-generating ecosystem service (Figure 4b, right).

production (*C*) (Figure 4a)[36]. Production costs may include payroll expenditures (supporting the regional workforce) and expenses on materials, which are likely to be sourced from the Azoreans due to the archipelago's somewhat insulated economy[37].

Non-revenue-generating services, such as existence value and education benefits from ecosystems, are somewhat different because they are not exchanged in markets, so we cannot observe their price. Because humans consume these services without explicit payment, consumer surplus is equal to the consumers' total WTP (*E*+*F*) (Figure 4b, right panel). To quantify the value of non-revenue-generating services using an approach that is consistent to that used for the revenue-generating services, we identify and define a proxy price (*p*) and ambient quantity provided (*q*) to estimate each service's value (*EV*):

$$EV = p * q$$

The value of non-revenue-generating services is illustrated by rectangle *F* in Figure 4b. This portion of consumer surplus can be thought of as the 'shadow revenue' or revenue that would be generated if consumers were actually required to pay our defined proxy price for the current level of provision of that (ecosystem) service. This approach provides a consistent analytical framework for estimating the value of both revenue- and non-revenue-generating services. As our measures of value do not include the upper consumer surplus triangle (*A*/*E*), our estimates are inherently conservative and may not capture the full "value" of marine ecosystem services in the Azores. However, it can be difficult to precisely estimate the elasticity of demand (slope of line *D*) for ecosystem services, especially those which do not generate direct revenue. While the areas of triangles *A* and *E* are very sensitive to this slope, the areas of rectangles *B*+*C* and *F* are not. This helps avoid introducing an additional source of error into our valuation process.

The Azores Marine Ecosystem Services

We identified the most important revenue-generating and non-revenue-generating ecosystem services provided by the marine environment in the Azores (Figure 5; see detailed service descriptions in the *Results*).

Our revenue-generating ecosystem services include fisheries and tourism. Fisheries is disaggregated into five different 'subsectors': demersal, pelagic, coastal, small net, and recreational fisheries, and tourism is disaggregated into six subsectors: hospitality, whale watching, scuba diving, sport fishing, sailing/yachting, and cruise ship tourism. Our non-revenue-generating services include: marine research and education, existence/bequest values, and the option value of marine resources for future medicinal and biotechnology applications.

To limit the possible double counting of value across services, we do not explicitly value "biodiversity" or any supporting or regulating ecosystem services such as nutrient cycling, primary productivity, or waste remediation. These services help translate the living and non-living components of ecosystems into the final ecosystem services that provide goods and benefits to humans. Therefore, we posit that the value of some of these services is already embedded in the value of the final ecosystem services captured in our analysis. We also do not include marine-related sectors that do not rely on the health of marine ecosystems to provide benefits, such a maritime transport. Other sectors such as aquaculture, markets for carbon sequestration, and seafloor mineral extraction are yet to be fully developed in the Azores and sufficient information does not yet exist to analyze them. Please refer to the *Emerging Services* section at the end of this report to read more about the regional context of these sectors.

For each of the five services (and subsectors where applicable) that we include in our analysis, we provide an overview of its broader significance and report our quantitative estimate of its value. All estimates are reported as an annual value in 2017 Euro (€). Monetary estimates transferred from other countries are adjusted using purchasing power parity to address differences in income. Please refer to *Appendix 2* for an outline of how we define and quantify price and quantity for each service, our full calculations, and all parameter values.

While many sources of uncertainty are present in our calculations, three stand out and are worthy of further discussion. The first comes from variation in the data that are used as inputs into our valuation, such as different prices listed for the same activity (e.g., scuba diving trip prices) in the marine tourism valuation. Second, there is uncertainty inherent to some of the methods. For example, our estimation of the existence/bequest value and medicinal/biotechnology option value services are reliant on the assumption that people are perfectly aware of their economic preferences, an assumption that has been challenged by several empirical studies[38]. The final type of uncertainty stems from assumptions made due to lack of data to calculate quantities, prices, or revenues. For example, we make assumptions concerning the relative proportion of marine tourists to inform our hospitality sector estimate as more detailed data are not publicly available.

While uncertainty is inherent in the valuation of ecosystem services, we attempt to account for these different types of uncertainty in the estimates by calculating a value range, when appropriate, based on different data inputs or assumptions. Furthermore, we define an "uncertainty" score for each service (or subsector) based on data quality and availability. A service is only given a "low" uncertainty score if primary data are available from the Azores to directly define both price and quantity (or already aggregated at the price *x* quantity level) and no major assumptions are needed to calculate the economic value with those data. A "medium" score signals that these conditions are not met for either price <u>or</u> quantity, and a "high" score indicates that reliable primary data are not readily available for both price <u>and</u> quantity. Discussion is provided for each

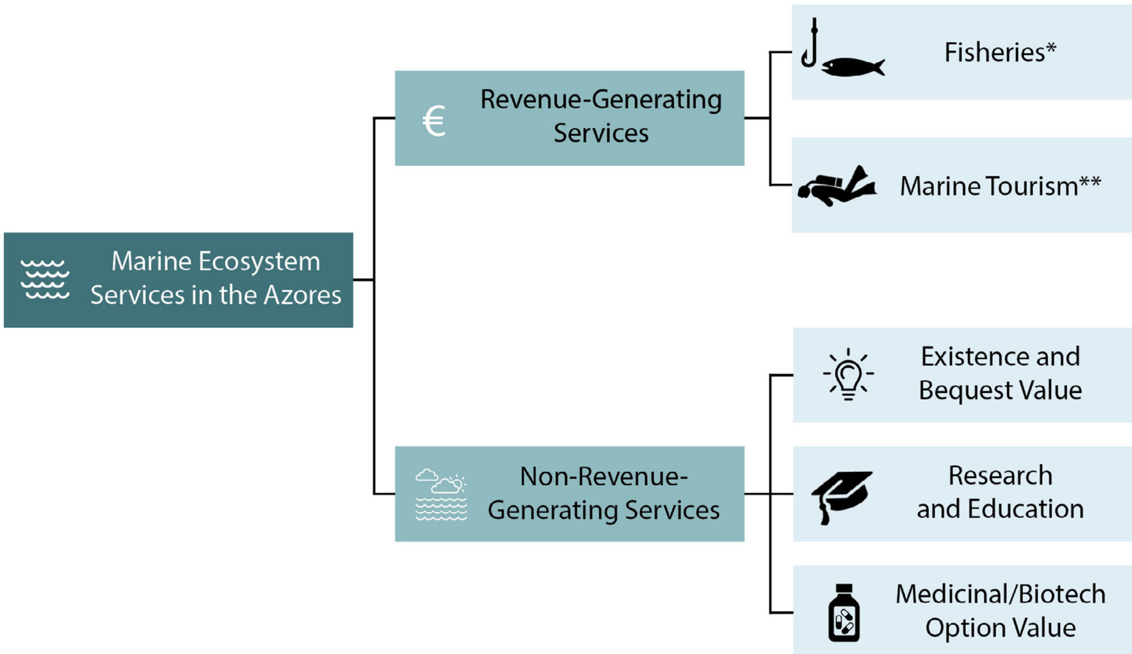

Figure 5. The marine ecosystems services of the Azores included in our economic valuation. *Fisheries: Demersal, Pelagic, Coastal, Recreational; **Marine Tourism: Hospitality, Whale Watching, Diving, Sport Fishing, Sailing/Yachting, Cruise Ship.

service to clearly delineate where improved availability of data could enhance the accuracy of our economic valuation.

Economic Value and MPAs

The framework above is designed to provide service-by-service estimates of the economic value of the marine ecosystem in the Azores. But because our overarching goal is to inform conservation policy in the Azores, it is critical to also understand how these values could be threatened or improved by the health and conservation of marine resources in the Azores. To accomplish this task, we synthesize primary literature and expert opinion to qualitatively address how the economic value of these services would most likely be affected by MPAs. While other management and conservation options may be possible, we focus on fully protected MPA implementation (hereafter any mention of MPAs should be interpreted as "fully protected") because that is a policy under current consideration in the Azores. We assign each service a score to characterize the expected effect of MPA implementation on the value of that service given the current threats to its value and how MPAs might serve to abate or exacerbate those threats: "strong benefit", "moderate benefit", or "variable/ minimal effect". This framework can help policy makers and other stakeholders understand the values that ecosystem services provide to the Azores and then place these values within the regional context of threats, ecosystem health, and the role of protected areas in mitigating threats and improving ecosystem health.

Results

Overview

We estimate the total annual 2017 value of revenue-generating marine ecosystem services to be between €55 - 99 million (Table 1). The two revenue-generating services, fisheries (€31.7 million) and marine tourism (€23.5 - 67.0 million), are important drivers of the Azorean economy and each contributed roughly 2% of the region's Gross Value Added (GVA) in 2014, which is consistent with the parity in our value estimates for these

Table 2. Estimates for the value of marine ecosystem services to the Azores in 2017 (at the subsector level where applicable) and the predicted effect of each service's value with the implementation of fully protected MPAs.

Services	2017 Value (millions of Euros)	Uncertainty Score	Effect of MPAs
Demersal Fishery	18.3	Low	Strong benefit
Pelagic Fishery	6.0	Low	Moderate benefit
Coastal Fishery	5.2	Low	Strong benefit
Recreational Fishery	2.2	High	Strong benefit
Total Fisheries Value = €31.7 million			
Hospitality	12.9 - 36.0	High	Moderate benefit
Whale Watching	5.5 - 7.3	Low	Strong benefit
Diving	2.2 - 18.3	Medium	Strong benefit
Sport Fishing	2.1 - 4.7	Medium	Strong benefit
Cruise Ship	0.4	Low	Variable/minimal
Sailing/Yachting	0.5 - 0.7	Low	Variable/minimal
Total Marine Tourism Value = €23.5 - 67.0 million			
Research/Education	3.0	Medium	Strong benefit
Existence/Bequest	0.2 - 2.1	Medium	Moderate benefit
Medicinal/ Biotechnology Value	7.9 - 8.4	Medium	Strong benefit
Total Non-revenue Value = €11.1 - 13.5			

two services[8,37]. The non-revenue-generating services (research and education, existence/ bequest value, and medicinal/biotech. option value) had a total estimated economic value of €11 - 14 million. Due to the fundamental differences in the ability to observe the economic value of revenue- and non-revenue-generating services, these values may not be directly comparable.

The three services given high uncertainty scores due to incomplete or missing data were recreational fishing, hospitality, and research/ education. In general, the non-revenue-generating-services received higher uncertainty scores as the data required by our chosen valuation methodologies were less likely to be available in the literature. This suggests that primary studies in these areas specific to the Azores could help improve our estimate. A detailed outline of major sources of uncertainty is included in the discussion of each service.

The services provided by marine ecosystems in the Azores vary in how MPAs may affect the future provisioning of their value (Figure 1). Fully protected MPAs can reduce fisheries value by limiting the areas available for fishing. However, many of the fisheries subsectors are significantly threatened by the fishing activity itself, either due to the removal of fish biomass at unsustainable levels or the destruction of essential habitat. Thus, because MPAs can be designed to both correct for over-exploitation and/or protect critical spawning or other habitat, we determined that fishery subsectors that are currently overexploited would receive a "strong benefit" from a well-designed network of MPAs with proper enforcement. A handful of ecosystem services including hospitality and existence/ bequest values depend on both residents' and visitors' knowledge and perceptions of the marine environment in the Azores. The value of these services is not as tightly connected to ecosystem health or threats, and therefore may only receive a "moderate benefit" from MPA implementation. Finally, the drivers behind the sailing/yachting and cruise ship tourism subsectors are likely largely attributed to the Azores' location in the Mid-Atlantic, and less dependent on the health of marine ecosystems. Therefore, the effect of MPAs on these services are scored as "variable/minimal".

Revenue-Generating Services

Fisheries

Ecosystem Service Description

Fishing is a key contributor to the Azorean economy[39]. Fisheries provided direct employment to over 1,500 fishermen in 2018, and additional jobs are provided through the processing industry, fish market circuit, and maritime and air transport sectors[40]. The Azores' fishing fleet comprises 654 vessels. The majority (~80%) of vessels are small (<12 m) and operate within 0-25 nm from the coast[41]. All catch landed in the Azores must go through one of the 11 Lotaçor auction houses distributed throughout the islands, where officials maintain a database that includes information about species composition, weight, and first sale price of all catch landed in the Azores[21]. Most fish landed in the Azores are sold fresh, with the exception of tuna, which is canned for export.

Fishers in the Azores target multiple species and switch between different gear types seasonally[42]. There are three main commercial fisheries in the Azores: a demersal fishery, coastal fishery, and pelagic fishery. The demersal fishery is the most important local fishery in terms of landed value, number of boats, and employment[39]. Handlines and deep-sea longlines are the primary gear type used to target multiple demersal species up to a depth of 700 m on the island slope and slopes of seamounts, which is a limited spatial area representing less than 1% of the Azores EEZ [15,25]. Although formal assessments on most demersal stocks are lacking, fishers have reported declining catch rates and many species targeted in the demersal fishery are believed to be fully or over-exploited[16,43].

There are a variety of fishing methods used in the commercial coastal fishery (< 3 nm from shore), which lands invertebrate species and some coastal fish species. Small boats use jig handlines to target squid. Crab and lobster are targeted by free divers and using traps. Limpets, urchins, and sea cucumbers are collected by hand in the intertidal zone. Algae is also collected and sold commercially for non-consumptive purposes. Coastal gill nets and hook-and-line gear are used from shore and boat to catch coastal fish species such as wrasse, parrotfish, and white sea bream.

The Azorean pelagic commercial fishery comprises three main components: 1) a small net fishery that targets small, schooling pelagic species, 2) a pole-and-line fishery that targets tuna, and 3) a pelagic surface longline fishery that primarily targets swordfish[39]. A small component of pelagic fishery catch is also from small boats trolling for pelagic species with handlines. The pole-and-line fleet is composed of approximately 75 vessels[41] that follow tuna migratory paths between April and October[15,34]. The 'one hook, one line, one fish' method employed by the pole-and-line fishery is highly selective, considered a sustainable fishery, and earned a "dolphin safe" label in 1998, meaning that there is no capture or handling of dolphins during any stage of the fishing process[44]. Migratory routes of tuna vary annually. In some years, the pole-and-line fleet operates within the Azores' EEZ and in others, tuna are found south of the Azores' EEZ so the Azores' pole and line fleet must travel further to fish near the island of Madeira[45]. For example, in 2017, most fishing effort from the pole-and-line fishery occurred outside of the Azores's EEZ and 27 Azorean vessels landed catch in Madeira[45].

The relatively small (~5 vessels; pers comm DRAM) Azorean surface longline fleet targets primarily swordfish, but also lands blue shark and shortfin mako shark[39]. The vessels often switch between targeting pelagic species with surface longlines and black scabbardfish with a modified version of a pelagic drifting longline[39]. Catch is landed in the Azores, or in mainland Europe where prices are often higher (primarily Portugal and Vigo, Spain). In addition to the Azorean surface longline fleet, EU fishing fleets have access to fish in Azores' waters between 100 and 200 nm. This outer band of the EEZ is fished by Spanish- (~120 vessels) and Portuguese- (~30 vessels) flagged longline vessels targeting swordfish, blue shark, and shortfin mako shark[39]. Catch from Spanish flagged vessels is rarely landed in the Azores[21]. Portuguese flagged vessels land catch in the Azores and in mainland Portugal or Vigo, Spain (pers comm Frédéric Vandeperre 2/26/19). Regional authorities have contested the EU's decision to allow these industrial fleets to fish in their waters, arguing that they are causing irreparable harm to the marine environment and economy[28,29,34].

In addition to the commercial fisheries, the Azores has a substantial recreational fishery that has grown in recent years[29]. Recreational fisheries generate revenue and economic benefits through expenditures on items like gear, bait, fuel, licenses, and boat maintenance[46]. Recreational fishing also provides value through food provision and social and cultural benefits. The main recreational fishing methods are spearfishing, rod fishing from shore, boat fishing, and hand collecting[21]. Recreational fishers are not mandated to report their landings, so the magnitude of recreational harvest can only be roughly estimated by survey data. There are currently approximately

3,000 licensed spearfishers in the Azores and 1,400 boats licensed for recreational fishing[47]. Shore-based fishing, which does not require a license, accounts for the largest portion of recreational catch and effort according to recent surveys[48]. Species landed by shore anglers are often the same juvenile demersal species that are targeted as adults by the commercial demersal fishery in deeper waters, which has raised concern regarding the status of these stocks[43].

Economic Valuation Results, Interpretation, and Uncertainty

Value: €31.7 million

We estimated the 2017 value of the fishery sector in the Azores to be €31.7 million. Our estimated value includes the revenue generated from landings by Azorean vessels in the Azores and the revenue generated from EU- (Spanish and Portuguese) flagged vessels fishing in the Azores' EEZ and landing catch in the Azores. We do not include the value of catch from EU-flagged vessels that fish in the Azores' EEZ and land catch in mainland Europe because this value is not captured the Azores' economy (see the *Pelagic Fishery* section for an estimate of a portion of this value).

The demersal fishery generated the most revenue and represented 58% of the total estimated value of the fishery service (Figure 6). The pelagic fishery, which included the value of catch from surface longline fleets landing in the Azores, the Azorean small net fishery, and the Azorean pole-and-line fishery, generated the second highest revenue and composed 19% of the total estimated value of the fishery sector. Catch from the coastal and recreational fisheries accounted for 16% and 7% of the total fishery service value, respectively.

We were able to accurately estimate the total value of commercial fishery landings in the Azores using Lotaçor auction house data that contained information of the weight and value of landings by species[41]. Illegal and unreported catch in the Azores commercial fishery is thought to be very rare, or nonexistent[21]. For this reason, we gave "low" uncertainty scores to our estimated values of the demersal, pelagic, and coastal subsectors. A small source of potential uncertainty may be associated with the way in which the total value of commercial landings was apportioned to each of commercial subsectors. This was done using an algorithm developed by the Department of Oceanography and Fisheries at the University of the Azores (DOP/UAç)[49]. However, a small portion of landings could not be categorized by the algorithm, in which case, a species-based classification was implemented (explained in greater detail in *Appendix 2*). The value of landings that could not be classified by the algorithm alone are

Table 3. A summary of results for fisheries ecosystem service and all subsectors.

Services	2017 Value (millions of Euros)	Uncertainty Score	Effect of MPAs
Demersal Fishery	18.3	Low	Strong benefit
Pelagic Fishery	6.0	Low	Moderate benefit
Coastal Fishery	5.2	Low	Strong benefit
Recreational Fishery	2.2	High	Strong benefit
Total Fisheries Value = €31.7 million			

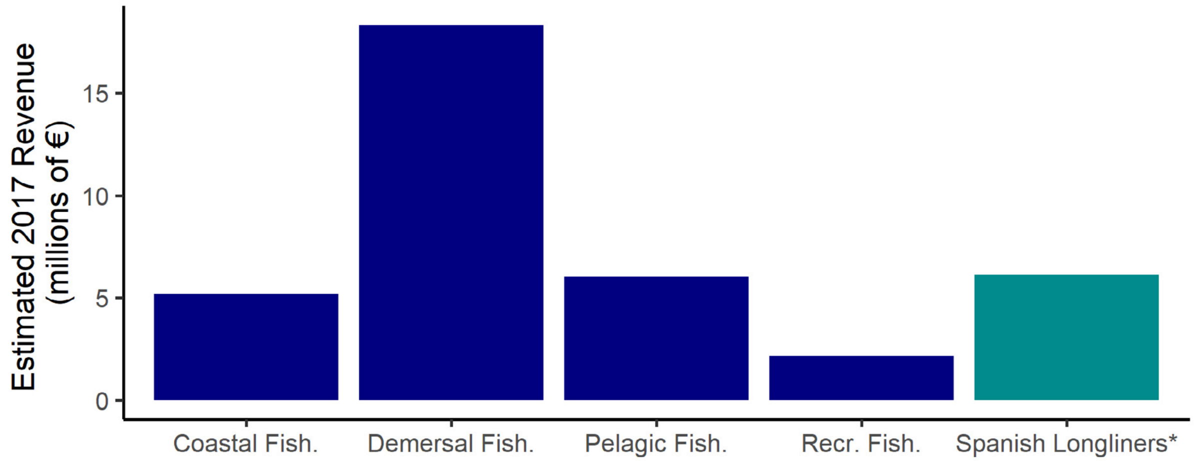

Figure 6. Total estimated value of Azores fishery sector by subsector. Data on value of commercial catch were obtained from Lotaçor data and landings were categorized into a fishery using an algorithm produced by DOP/UAç (see *Appendix 2*)[41,49]. *Our estimate of the value of the catch by Spanish-flagged longlining vessels within the Azorean EEZ but landed elsewhere is included for comparison (see *Pelagic Fishery* section).

given the label "unassigned" throughout the figures presented in this section. Detailed landings data were not available for the recreational fishery, so it was assigned an uncertainty score of "high" (see the *Recreational Fishery* section for further detail).

Demersal Fishery

Landings made using handlines accounted for the majority of the estimated value of the demersal fishery in 2017 (Figure 7).

Overfishing is the biggest threat to the demersal fishery because target species are highly vulnerable due to the long-lived, slow growing, and relatively sedentary nature of the species and small, patchy distribution of their habitat[6]. Demersal species are targeted by both the commercial fishery, which includes both industrial and artisanal vessels and has increased in fishing power over time, and the recreational fishery. The current status of species targeted in the demersal fishery is unknown, but trends in catch rates suggest many are likely overexploited[43].

Habitat damage from destructive fishing gear,

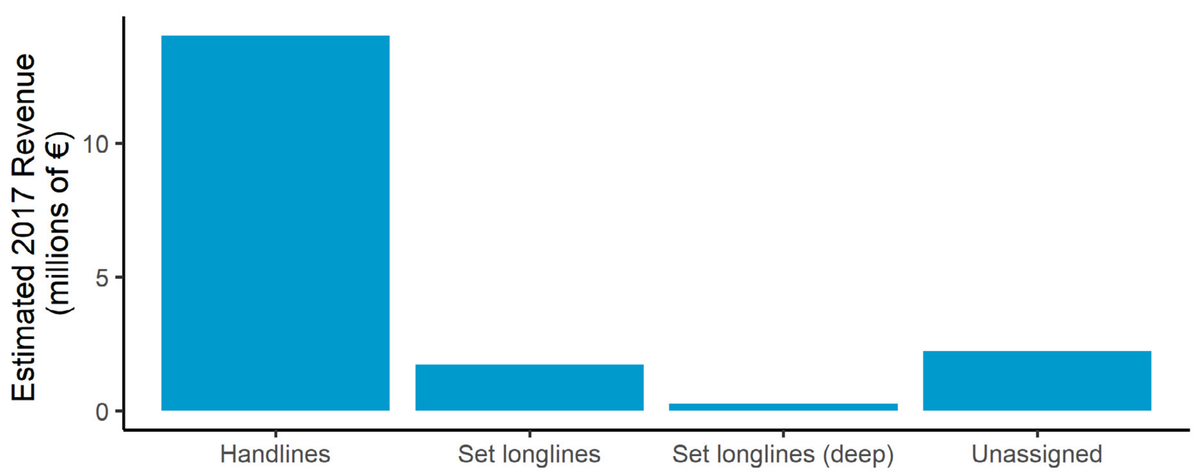

Figure 7. Estimated value of Azorean demersal fishery by métier (i.e. gear archetype) in 2017 (see *Appendix 2*)[41,49]. The value of landings that could not be classified by the DOP/UAç algorithm alone are labeled as "unassigned".

seafloor mineral extraction, or other extractive activities associated with the benthic environment is also a threat to the demersal fishery. Damage to the sensitive habitat on which demersal fish species rely can have detrimental effects to stock productivity. Reports of habitat destruction through fishing gear are currently limited in the Azores, but the overall threat may increase if other extractive activities like deep-sea mining are developed in the Azores' EEZ[50]. In particular, deep-sea mining in close proximity to seamounts can affect demersal species through the release of sediment plumes, which can cause oxygen depletion, reduced rates of hunting success for visual predators, and mortality of juveniles and larvae[51]. Finally, the effects of climate change have the potential to decrease the health or resiliency of any fish stocks, including demersal species.

We assigned a "strong benefit" MPA effect score to the demersal fishery subsector because well-designed MPAs have been an effective management tool for abating threats to demersal fisheries in other regions with fisheries experiencing overexploitation[52–54]. When designed appropriately, fully protected MPAs have successfully increased biomass and species richness in demersal fisheries in other regions[55]. The implementation of MPAs often result in a short-term economic loss to fishers due to loss of fishing grounds. However, over time, the increased fish biomass that occurs within an effective MPA can spillover outside of MPA boundaries, providing economic benefits to fishers in adjacent areas. The timescale for longer term economic benefits due to spillover will depend largely on the life history of the species and its exploitation status. In the Azores, the limited demersal fishing area means that any MPA network must be designed with careful consideration of the demersal fishery. While the demersal fishery has a high potential to receive long-term economic benefits from well-designed MPAs, an MPA network designed without consideration of impacts to the demersal fishery may result in a redistribution of fishing effort that negatively impacts the fish stocks. To optimize economic benefits of new fully protected MPAs in the Azores, the dynamics of both fishers and fish in the demersal fishery should be carefully considered and accounted for in the MPA design. MPAs are unlikely to mitigate threats to the demersal fishery from climate change.

Pelagic Fishery

Over half of the estimated value from the pelagic fishery subsector was generated by catch landed in the Azorean pole-and-line fishery (Figure 8). The value of landings from the pole-and-line fleet has large interannual fluctuations due to changes in migratory patterns of tuna associated with oceanographic conditions[56] . In 2017, the value of landings from the pole-and-line fishery in the Azores was relatively low because the majority of pole-and-line fishing activity occurred in Madeira's EEZ, with the majority of catch from Azorean pole-and-line vessels being landed in Madeira, which is not included in our estimated value.

From 2001 to 2007, an estimated 10% of catch from all surface longliners operating in the Azores was landed in the Azores[50] .The other 90% of catch was landed in Vigo, Spain or mainland Portugal, where blue shark and swordfish can be sold for higher prices. Although revenue from catch landed outside the Azores by EU-flagged vessels does not contribute directly to the Azores' economy, quantifying the value of this portion of the fishery sector is essential for understanding the total economic value of ecosystem services provided by the Azores' marine environment.

We estimated a portion of this value, catch from the Azores' EEZ by Spanish longline vessels that is landed in mainland Europe, using a combination of satellite vessel-tracking

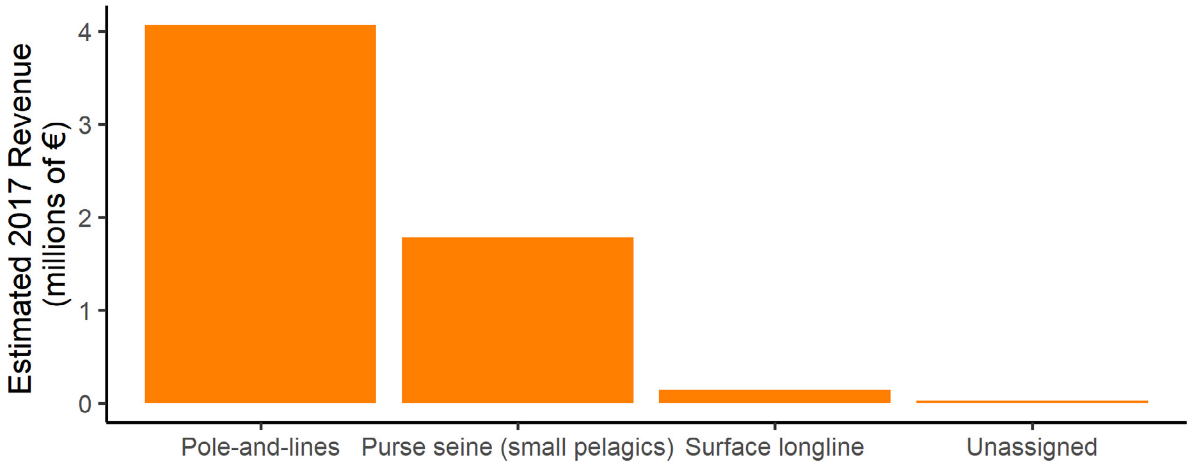

Figure 8. Estimated value of Azorean pelagic fishery by métier in 2017 (see *Appendix 2*)[41,49]. The value of landings that could not be classified by the DOP/UAç algorithm alone are labeled as "unassigned".

data and fishing logbook data. Logbook data are obtained by the Regional Government when Spanish longline vessel make port of calls in the Azores[57]. We estimated the value generated by Spanish longlining vessels from fish that are caught within the EEZ of the Azores but landed elsewhere to be €6.1 million, roughly equal to that of our estimated value generated by the pelagic fishery subsector in the Azores (see *Appendix 2* for more details). We were unable to include mainland Portuguese vessels that fish in the EEZ of the Azores but land catch elsewhere because the vessel-tracking data used to estimate fishing effort does not differentiate between mainland Portuguese vessels and vessels based in the Azores. We do not include the estimated value of these Spanish landings in our estimate of the total value of the commercial fisheries sector because it is not currently retained by the Azorean economy.

Most species targeted in the Azores' pelagic fishery are assessed at a regional level by ICCAT because they are highly migratory and may move in and out of multiple national jurisdictions. Blue sharks are targeted by Spanish longliners in the Azores' EEZ and the results of the latest assessment on North Atlantic blue sharks suggest overfishing of the stock may be occurring, but were highly uncertain[58]. The current status of short fin mako shark, which is also caught by surface longliners operating in the Azores' EEZ, is overfished and experiencing overfishing[59]. Bigeye tuna and blue marlin are additional pelagic species that are landed in the Azores that are currently experiencing overfishing[60,61]. Atlantic bluefin tuna is landed by the pole-and-line fleet in small numbers and the most recent assessment indicated that overfishing is not currently occurring[62].

Range shifts of highly migratory species as a result of climate change is an additional threat to the Azores' pelagic fishery. Landings in the Azores from the pole-and-line fishery display high interannual variability, which have been attributed to large-scale fluctuations in oceanographic conditions that affect tuna migration routes[63]. Relative to previous years, tuna from 2015-17 were not found in large abundances in the Azorean EEZ, which may be attributed to changes in sea surface temperature[45]. As a result, the Azorean pole-and-line fleet fished and landed catch primarily in the EEZ of Madeira, which likely increased fishing costs and reduced revenue generated by tuna landings in the Azores (pers comm DRAM).

Reducing the threat of overfishing to the highly migratory species targeted in the pelagic fishery is challenging through spatial management alone. High movement rates mean they are likely to move in and out of an MPA frequently and through regions with different management jurisdictions, which makes it unlikely overall fishing mortality will be reduced. Economic impacts to pelagic fishers are unlikely unless the MPA results in higher fuel prices associated with change in fishing location as a result of the MPA. MPAs are unlikely to mitigate threats to the pelagic fishery from climate change. Very large scale MPAs that cover a significant portion of a species' movement range would be needed to effectively reduce fishing mortality. Therefore, we characterized the effect between this service and MPAs as a "moderate benefit" dependent on the design of the MPA network. MPAs may be effective in protecting pelagic species if they are placed in areas that are used during vulnerable stages of their life cycles, such as breeding and feeding grounds, or key areas of the migratory route[64]. MPAs may also indirectly benefit pelagic species by increasing biomass of species lower in the food chain that they rely on for food[64].

Coastal Fishery

Invertebrate landings (from squid jigging, crustacean traps, and hand collecting) accounted for over 50% of revenue generated from coastal fisheries (Figure 9).

Although the status of coastal stocks in the region is unknown, overexploitation from increased fishing activity is believed to be a threat[29]. Climate change can result in habitat loss and change in species' distributions. We gave this service a "strong benefit" MPA effect score as well-designed and enforced MPAs are likely to improve the health of coastal fish stocks in the Azores[65].

Recreational Fishery

Recreational catch in the Azores is consumed at home or sold illegally[66]. To estimate the value of the recreational fishery, we used a replacement cost method, which assumes the value of recreational catch is equal to the market value of that catch because the fish would have to be purchased for consumption if recreational fishing was not available[67]. We used data from the literature and unpublished governmental data to extrapolate total recreational catch and estimate the total value of that catch using price data from auction markets. The number of residents participating in shore-based recreational fishing and recreational hand collection throughout the Azores is not known because licenses for these activities are not required. Estimates of total annual catch and effort were not available for recreational collection by hand[48,68] so we were unable to calculate the contribution of recreational collection by hand to the overall value of the recreational fishery. For shore-based recreational fishing, estimates

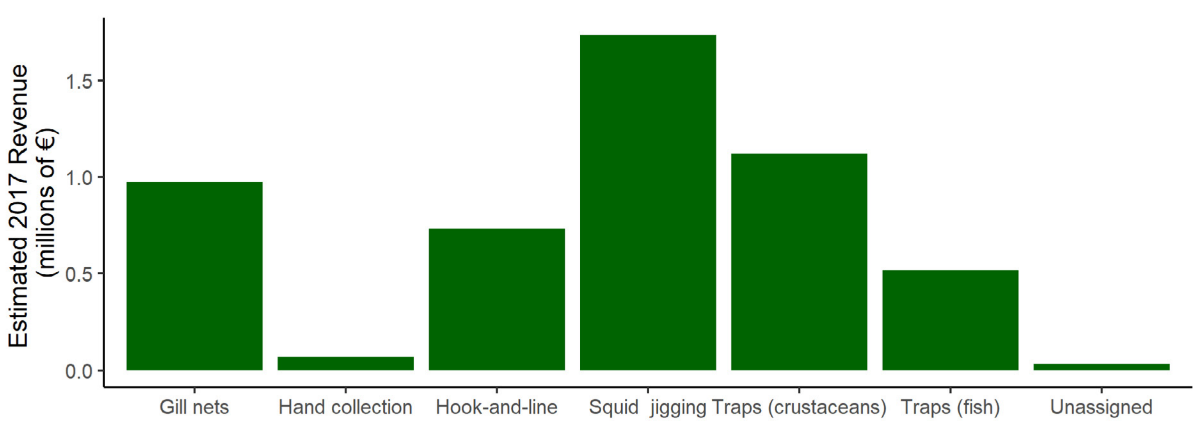

Figure 9. Estimated value of Azorean coastal fishery by métier (i.e. gear archetype) in 2017 (see *Appendix 2*)[41,49]. The value of landings that could not be classified by the DOP/UAç algorithm alone are labeled as "unassigned".

were only available for the islands of Faial and Pico and we extrapolated these data to the other islands (see *Appendix 2* for details). Thus, we assigned our estimate a "high" uncertainty score because 1) recreational landings are not reported and forced our estimate to rely heavily on the extrapolation of survey data and 2) this does not account for the social and cultural benefits derived from recreational fishing[46]. A landings reporting system or systematic surveys of the recreational fishery could provide data that would improve knowledge on the value and impact of this fishery.

Species that are targeted in the juvenile stage by the recreational fishery and the adult stage by the commercial demersal fishery are believed to be fully or overexploited. Climate change may also affect habitat and/or species distribution of species targeted in the recreational fishery. Like the demersal and coastal fisheries, the recreational fishery would receive a "strong benefit" from well-designed and enforced MPAs given the overexploited status of many stocks. Recreational fishers would likely experience a short-term decline in catch due to reduced fishing grounds, but as stocks recover long-term increases in yields can occur.

Marine Tourism

Ecosystem Service Description

The number of tourists visiting the Azores has increased steadily over the past three decades (Figure 10), accelerating over the past 6 years. The recent uptick in tourism is likely due to incentives and policies that were adopted to encourage growth in the sector[29], and the relatively recent introduction of budget airlines in the Azores and an increase in flight options. Between 2011 and 2013, the Azores experienced an average of 1.14 million tourist-nights annually[69]. In the Regional Government's 2020 operational plan[70], published in 2013, the government established a target to increase the number of annual tourist-nights from 1.14 million to 1.3-1.4 million by 2023 (objective 6.3.1). This target was met just two years later in 2015 and surpassed in the following years, with over 1.9 million annual tourist-nights spent in 2016 and 2017[69].

Tourists visiting the Azores are primarily European[71] and stay for an average length of 3-4 days[72]. The remoteness of the islands attracts visitors seeking unique experiences in nature "off the beaten path". At least 41% of visitors come to the Azores for the islands'" natural values", where the marine environment is a major attraction[73], and tourists with this motivation stay longer than other tourists[72]. The Azores is emerging as a destination for marine-related activities such as sailing, surfing, whale watching, and diving[23]. The sustainable development of the budding tourism industry will require effective conservation and management to maintain the healthy marine ecosystems that attract visitors[74].

The most common marine-related tourist activity in the Azores is whale watching, with 14.7% of all tourists in 2017 participating in a whale watching trip (unpublished govt. data). There are currently 25 licensed whale watching ventures on the archipelago operating 72 vessels[75]. Peak season for whale watching tourists occurs in the spring when fin, blue, humpback, minke, and sei whales frequent the area. Sperm whales and dolphins are found in the Azores year-round. The whale-watching industry is regulated by several laws within the archipelago[76]. A special permit is required to operate a whale watching vessel, and there are caps on the number of permits that can be issued to vessels operating in the territorial seas (0-12 nm offshore) around the islands[20]. Furthermore, there are regulations concerning the number of boats allowed around a group of whales,

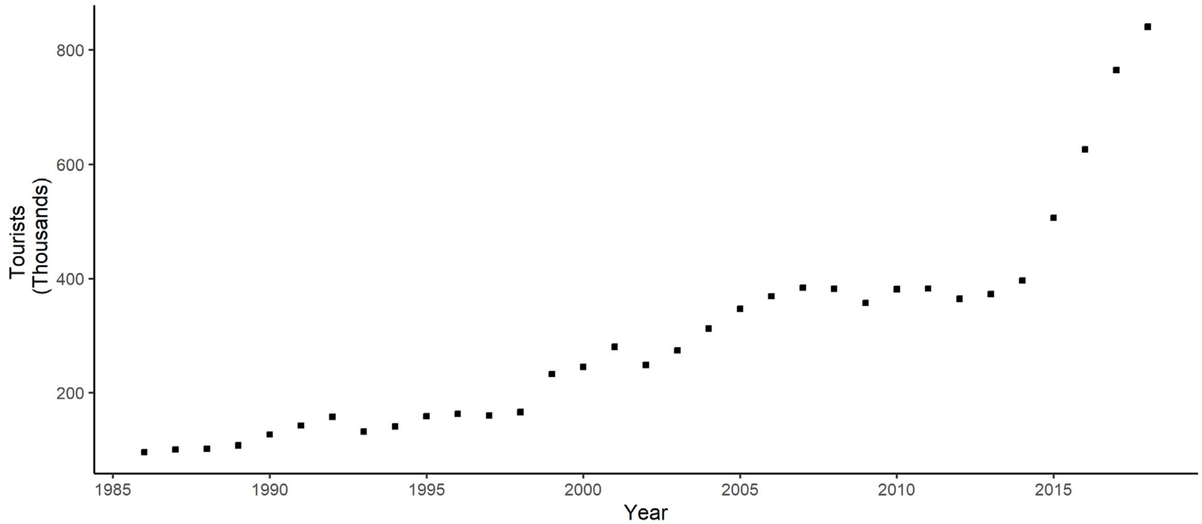

Figure 10. Annual tourist visitation (number of visitors) in the Azores since 1986[69].

minimum separation distances, and the maximum time a vessel spends near a whale[77].

Scuba diving has become a more popular tourist activity over the last decade because of the megafauna that are known to inhabit Azorean waters. According to a 2009 survey, an estimated 7% of all tourists participate in diving[73]. In 2017, Scuba Dive Magazine ranked the Azores as the third best dive destination in the world. There are currently 51 licensed dive businesses in the Azores with 91 vessels in operation[75]. The development of a shark diving industry in recent years has also been attributed to attracting more tourists[78]. In 2014, the shark diving industry generated an estimated €2.0 million to the Azorean economy[23]. The sustained growth of this unique tourism opportunity will depend on successful co-management with other tourism activities and addressing the growing concern over unsustainable shark landings by foreign fishing vessels. For more information on shark diving in the Azores, see the insert at the conclusion of the *Existence/Bequest Values* section.

The expansive pelagic environment in the Azores make it a premier big-game fishing destination for targeting trophy species such as marlin, tuna, and swordfish. Visitors also participate in other types of sport fishing such as coastal trolling, "zagaia" fishing (jigging), and spear fishing (Table 4). An estimated 3.6% of all tourists participated in sport fishing in the early 2000s, but data were not available for current participation levels. An informal survey of sport fishing operators' websites revealed that while many encourage sustainable catch and release practices, participants are offered the opportunity to retain their catch in most cases.

Table 4. Survey estimates of the breakdown of sport fishing tourism in the Azores by activity in 2014[79].

Sport fishing activity	% of total sport fishers
Demersal Fishery	18.3
Pelagic Fishery	6.0
Coastal Fishery	5.2
Recreational Fishery	2.2
Coastal Fishery	5.2

The cruise ship industry likely emerged due to the Azores' strategic geographic position for vessels crossing the Atlantic. Each year in the fall, the islands receive visits from cruise ships on annual repositioning journeys between the Mediterranean and Caribbean seas[8], and the industry appears to be growing. In 2017, the Azores received more than 150 cruise ship visits[80]. The port of Ponta Delgada on São Miguel Island is the main arrival point for cruise ships in the Azores, where the recently-constructed cruise terminal and marina feature restaurants, shops, and other amenities. The ports at Horta in Faial and Praia da Vitória in Terceira are also popular destinations for smaller cruise ships. If the Azores continues gaining popularity as a tourism destination, cruise ship infrastructure and visitation rates will most likely continue to grow into the future[8].

The Azores' location in the middle of the Atlantic Ocean has also made it an important and popular destination for yachting and sailing. In 2017, the government reported that 18,144 visitors traveled to the Azores on 4,371 yachts/sailboats[81]. The Azores is home to eight marinas for such vessels, with a total capacity of 1,855[8]. The marina on Horta in Faial is the fourth most visited in the world[82].

Economic Valuation Results, Uncertainty, and Effect with MPAs

Value: €23.5 – 67.0 million

The total value of marine tourism as an ecosystem service is calculated by aggregating the annual estimated revenues for each subsector (Table 5, Figure 11).

Hospitality

Hospitality is one of the largest contributors to the economic value of marine-based tourism (Figure 11), making up 29 - 77 % of the total. The large range in our estimation stems from the difficulties in categorizing the portion of the total hospitality sector that can be attributed to marine tourism. We parameterize the higher bound as proportional to the percentage of tourists who indicated that "natural values" were their primary motivation for traveling to the Azores in a 2014 survey[73], as we expect that many of such tourists are motivated by marine nature. The lower bound is scaled relative to the number of tourists who whale watch, the most popular marine-focused activity in the Azores by volume. We expect that the true value is between the lower and upper estimates. Furthermore, this methodology assumes that all hospitality expenditures by

Table 5. A summary of results for marine tourism ecosystem services for all subsectors.

Services	2017 Value (millions of Euros)	Uncertainty Score	Effect of MPAs
Hospitality	12.9 - 36.0	High	Moderate benefit
Whale Watching	5.5 - 7.3	Low	Strong benefit
Diving	2.2 - 18.3	Medium	Strong benefit
Sport Fishing	2.1 - 4.7	Medium	Strong benefit
Cruise Ship	0.4	Low	Variable/minimal
Sailing/Yachting	0.5 - 0.7	Low	Variable/minimal
Total Marine Tourism Value = €23.5 – 67.0 million			

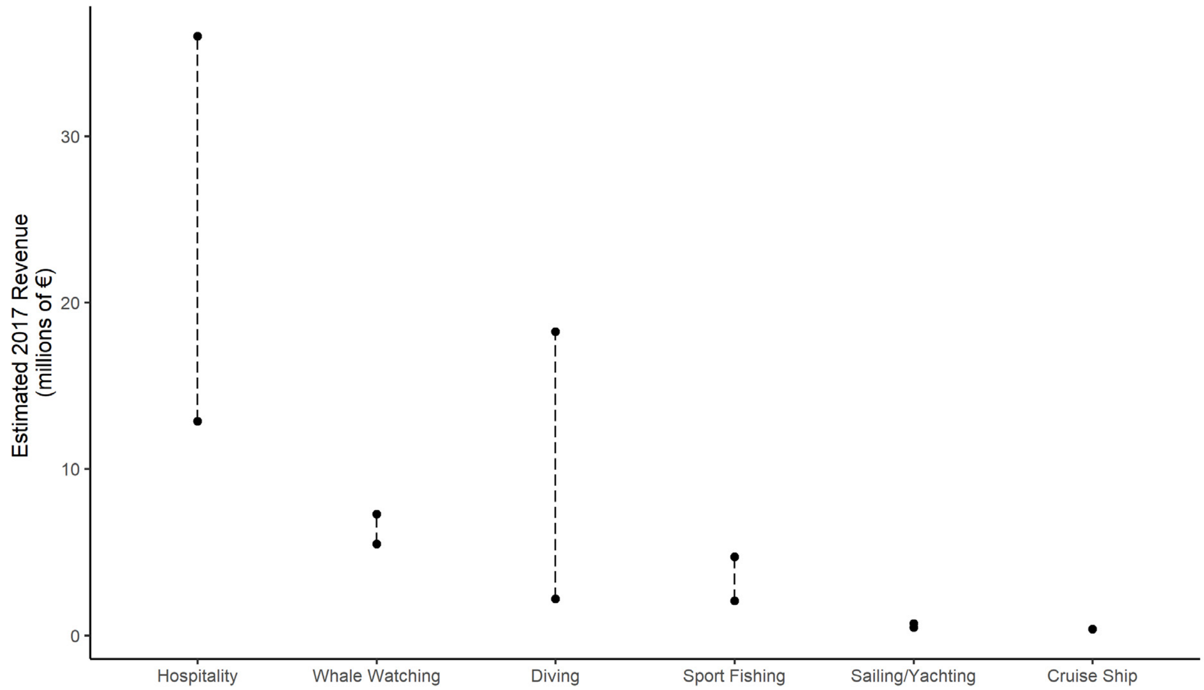

Figure 11. Our estimates of revenue for the six tourism subsectors. For activities for which we calculate both a low and a high value, two points with a connecting dashed line are used to bound the range of estimates.

these tourists can be fully attributed to the marine environment, which is likely an overestimate, as many tourists are motivated by numerous attributes of the visited location, adding more uncertainty to our estimates. Finally, our estimate is derived from traditional hotel industry statistics and does not include other hospitality sectors such as restaurants and non-traditional accommodations (e.g., Airbnb). Due to the incomplete picture of hospitality provided by available data, this service was given a "high" uncertainty score.

The ecosystem service value provided by the hospitality sector is indirectly threatened by a diverse set of stressors as it depends on the perception of the Azores as a healthy and vibrant eco-tourism destination. Many of the threats facing marine ecosystems in the Azores can be mitigated by MPAs (e.g., overfishing), but some of them cannot be addressed through protected areas alone (e.g., land-based pollution and climate change). Additionally, there may not be a strong correlation between tourists' perceptions and MPA implementation because of their imperfect knowledge of threats facing marine ecosystems in the Azores. Therefore, we assign a "moderate benefit" score to the effects of MPAs and the hospitality sector.

<u>Whale Watching</u>

The whale watching subsector accounts for 8 - 29% of the total marine tourism value. The uncertainty of this value comes from variability in the estimated price of whale watching, which we parameterized with ranges in cost of a half-day whale watching tour. We believe that our estimated value is conservative, as half-day trips are less costly than other types of whale watching excursions like full-day or overnight trips to more remote sites. The estimation of whale watching's value was attributed with "low" uncertainty as the number of whale watchers in 2017 was recorded by the Regional Government and prices were based on an observed range.

The primary threat to the whale watching subsector in the Azores is potential ship strikes due to commercial shipping activity. However, the number of reported strikes is relatively low in the Azorean EEZ[83]. Similarly, effects between cetaceans and the fishing industry are generally minimal in the Azores[15]. Studies have suggested that whale watching could have negative impacts on whales by interrupting feeding and rest time, so continued regulation of the industry may play an important role in maintaining the value of this service[84]. The main threat of ship strikes can be largely minimalized by strategic placement of MPAs in areas with high potential for whale and commercial shipping vessel interactions, prompting a "strong benefit" MPA effect score.

Scuba Diving

Scuba diving represents 4 - 46% of the total economic value of marine tourism. The range of this value comes from two different assumptions regarding the price of diving. The low estimate assumes divers spend ~€41 on diving while in the Azores (single dive), and the high estimate assumes divers spend €342 on diving (10 dive package). We believe our estimate to be conservative for two reasons. First, the calculated number of divers was based on a survey conducted in 2009, which does not account for recent growth in popularity of this subsector due to the emergence of shark diving offerings in the Azores[78]. Second, price is parameterized by the cost of a single dive/dive package which does not account for any expenditures on gears rentals, courses, or extra fees for visiting remote shark diving sites. We score this sector as having "medium" uncertainty due to the lack of more recent data on the number of divers.

The diving industry relies on the marine environment to attract dive tourists to the Azores. Degraded marine ecosystems may be less likely to continue generating revenue through dive tourism. Overexploitation of nearshore fish stocks and damage to sensitive habitats can degrade the pristine ecosystems for which divers are willing to travel further and pay more[85]. The targeting of sharks by the foreign longline fleet and disturbance of cetaceans by commercial shipping threaten iconic marine species that are featured in premium dive packages throughout the islands. Finally, marine plastics and the manifestations of climate change threaten the health and resilience of marine ecosystems in a variety of ways. MPAs can help preserve fish stocks and sensitive habitats, granting a "strong benefit" to the value of the diving sector.

Sport Fishing

Sport fishing composes 3 - 18% of marine tourism's economic value in the Azores. The uncertainty in our estimate stems from variation in the listed prices for sport fishing experiences and temporal and spatial variability in the number of sport fishing tourists who participate in each activity. We relied on a 2014 survey of sport fishing operators on São Miguel island to parameterize our estimate. Like scuba diving, sport fishing was scored with "medium" uncertainty, as more recent data with higher spatial coverage would improve the accuracy of our estimate. We assume each sport fishing tourist goes on a single tour, which is likely a conservative estimate[79].

The main threat to sport fishing in the Azores is the cumulative over-exploitation of regional fish stocks by all forms of fishing activity. The larger, trophy species sought by big-game fishers are managed at a regional level, and both blue marlin and bigeye tuna are believed to be depleted and currently experiencing overfishing[86]. Large-scale MPAs may help abate the threat of overfishing for highly migratory species (see *Pelagic Fishery* section). For sport fishers targeting coastal and demersal species, well-designed MPAs can help alleviate threats to those fish stocks to ensure they can continue to be enjoyed by sport fishers. Therefore, we assign a "strong benefit" MPA effect score to sport fishing and MPAs.

Cruise Ship Tourism

Cruise ship tourism is still developing in the Azores and currently contributes 1 - 2% of our estimated value of marine tourism ecosystem services. We defined the value of this subsector as the amount direct revenue generated to the Regional Government through port usage fees on visiting cruise ships. Cruise ship tourism also contributes indirectly to the Azorean economy through the spending of passengers on arrival, but we do not include this indirect revenue in our estimate. The port usage fee scales with the size (gross tonnage, GT) of the cruise and varies by port[87]. We calculated the revenue generated by port usage tariffs using a logbook of cruise ship arrivals and departures in the Azores during 2017 made available by the Port Authority of the Azores[80]. This subsector was assigned a "low" uncertainty score because the value calculation could be parameterized at the level of each cruise ship visit to the Azores in 2017 using the data collected by the Port Authority.

While the health and reputation of marine ecosystems could help attract more cruise ship passengers, a large percentage of cruise activity in the Azores can be attributed to its strategic geographic location for vessels crossing the Atlantic. It may be possible that many cruise ship passengers are motivated by the marine environment of the Azores or participate in marine tourism activities when in port. If so, it is possible for the implementation of MPAs to benefit the value of this service by limiting the degradation of marine ecosystems. However, the cruise ship industry is still developing in the Azores and these detailed statistics are not currently available. Therefore, this score received a "variable/minimal" MPA effect score.

Sailing and Yachting

The sailing and yachting subsector adds 1 - 3% to the total marine tourism value. Our estimate is most likely conservative in that we defined price as money spent on docking fees alone and did not include additional expenditures (e.g., fuel, boat maintenance). The uncertainty in this value is derived from the calculation of an average duration of stay based upon data aggregated at the island level and then applied across all vessels in the Azores. Additionally, data were not available regarding the distribution of resident and non-resident vessels. The lower bound assumes that all vessels shorter than 35 meters are owned by an Azorean resident and pay a cheaper docking rate, as this was the largest size class for which resident fees are available. For the upper bound, we assume all vessels are visitors and pay the higher non-resident rate. As data are available to parameterize both price and quantity fairly robustly, we gave this subsector a "low" uncertainty score. Similar to the cruise ship subsector value, it is difficult to determine how much of this revenue should be classified as an ecosystem service generated by the marine environment and how much should be attributed to the location of the Azores. In our valuation, we classify all revenue from the docking of vessels as contributing to the value of the marine tourism ecosystem service.

We scored the effect between MPAs and this sector as "variable/minimal" for similar reasons to the cruise ship sector above. It is possible that MPAs could indirectly improve the value of sailing and yachting, but the strength of that connection is unknown and may be secondary to the geographic location of the islands. Primary data concerning the motivations and spending habits of those who bring their vessels to the Azores are necessary to better understand this relationship.

Non-Revenue-Generating Services

Research and Education

Ecosystem Service Description

Small and relatively undisturbed island ecosystems are valuable for research, offering an optimal control area for studies of impacts to ocean ecosystems[88]. As of 2015, there were 256 peer-reviewed scientific articles focused on the Azores' marine environment[29]. The University of the Azores is a hub for cutting edge marine-related research that has impacted marine conservation at an international level, especially in the field of deep-sea research[8].

The Azores' ecosystem dynamics and steep coastal drop-offs offer a unique opportunity for deep-sea research. The islands sit over the Azores Triple Junction (AJT) at the intersection of three tectonic plates, which provides a favorable setting for studying seafloor and sub-seafloor geological, chemical, and biological processes[88]. Studies on complex deep-sea animal communities and hydrothermal vents have shed light on novel organisms and bioactive compounds, some of which have spurred innovations in the fields of medicine and biotechnology[89] (see the *Medicinal/Biotechnology Option Values* section). The Azores International Research Center (AIR Center), another emerging research institute, hopes to take advantage of this natural capital by expanding the presence of deep-sea research stations and technology on the islands. Their integrated research approach utilizes interdisciplinary skills to monitor ocean currents and climate regulation processes, conduct surveillance of biological ocean communities, and analyze interactions among the oceans, climate, and space[88]. Establishment of a permanent deep-sea observation presence in the Azores would be of great scientific value and would enable extensive mapping of the Atlantic seafloor[70,88].

One of the Regional Government's objectives for 2023 is to become a major hub for marine research in the Atlantic[12,70]. Private businesses, the state government, non-profits, and institutions of higher education invested €2.74 million in 2016 for projects that broadly related to the economy of the sea according to a national census of research and development expenditures[90]. This represented 23% of total research and development expenditures on the islands, the largest percentage for any of the 15 thematic categories included in the report (others include "Health", "Communication Technologies", etc.). Potential barriers to growth of marine research include biodiversity loss and environmental degradation, high technological costs, and lack of investment funds to develop new research laboratories and collaborations.

Marine education at all levels is also currently a priority in the Azores. A vocational 'Sea School' was recently established to educate and train younger residents in commercial shipping logistics, fisheries, marine tourism, and environmental monitoring activities to meet the growing demand for marine-related employment opportunities[8]. Additionally, the Azorean Sea Observatory (OMA) in Horta is an NGO that operates the museum at the whaling station and is engaged in education and outreach in primary schools throughout the archipelago.

Economic Valuation Results, Uncertainty, and Effect of MPAs

Value: €3.0 million
Uncertainty: Medium
Effect with MPAs: Strong benefit

A common method used to estimate the cultural value provided by research and education projects is to sum their budgetary expenditures[91,92]. This method assumes that the cultural benefit must be at least equal, if not greater, than the costs for these projects for them to be funded and carried out. Our estimated value of the marine research and education service is based on the budget information of projects identified by the Regional Government that are marine in nature[93]. The majority of the funding for these programs is derived from one of the European Union's research and innovation framework programs and is typically managed at either the regional level through the Regional Fund for Science and Technology (FRCT) or the national level through the Foundation for Science and Technology (FCT). Despite the availability of budget information to inform our estimation, we assigned this service a "medium" uncertainty score because our methodology assumes that a project's costs represent a lower bound of the cultural value it generates. Therefore, our analysis likely underestimates the true value of marine research and education in the Azores.

Research systems and sites are threatened by a diverse set of extractive activities that remove biomass and degrade natural habitats. In particular, seamounts and deep-sea benthic ecosystems are frequently studied in the Azores and could be jeopardized by seabed mineral extraction and destructive demersal fishing. MPAs exclude these harmful activities, indicating a "strong benefit" to the value of research and education. Furthermore, MPAs offer high utility to researchers as control sites in empirical studies focused on understanding the impacts of human activities in unprotected locations.

Existence/Bequest Values

Ecosystem Service Description

Marine ecosystems contain some of the most biologically diverse places on earth[2,94,95]. For example, many deep-sea organisms have developed unique adaptations that enable survival for long periods of time in dark, cold, and highly-pressurized environments[94,96]. The Azores has high deep-sea biodiversity including cold-water corals, sponges, crabs, lobster, worms, and several other benthic species that have evolved to thrive in these conditions[11]. In particular, cold-water corals and hydrothermal vents have recently been identified as oases of species richness and biodiversity in the nutrient abundant, deep waters of the northeast Atlantic[25,97]. However, these critical habitats are fragile and slow to recover, making them susceptible to harm from extractive human activities[3,11,98]. The region's shallow coastal shelves and seamounts are also important habitats for many of the well-known charismatic megafauna that often play the mascot role for marine conservation efforts (e.g., blue whales, sperm whales, sharks, dolphins, and manta rays)[99].

Many people intrinsically value the existence and persistence of these charismatic species and biodiversity even if they may never directly see or interact with the marine environment. However, this inherent value of marine biodiversity is difficult to estimate as it is not captured by conventional markets. Due to the difficulty in characterizing the value of biodiversity and other non-use values, they are often omitted from environmental policy analyses, resulting in sub-optimal allocations of resources[2,3]. In valuation contexts, a portion of the intrinsic value of biodiversity is commonly translated into an existence and/or bequest value (e.g., Pascual and Muradian 2010). An existence value is the personal benefit one derives from the knowledge of a resource existing without ever interacting with it. A bequest value is similar but refers to the value gained from the knowledge that a future generation will be able to derive benefits from a resource. In our report, we assess both of these values as a combined ecosystem service. For more information on the "value" of biodiversity, including alternative frameworks and valuation strategies, please refer to the biodiversity inset.

Economic Valuation Results, Uncertainty, and Effect of MPAs

Value: €0.2-2.1 million
Uncertainty: Medium
Effect of MPAs: Moderate benefit

Our valuation was informed by a survey performed in the Azores, which asked respondents how much they would be willing to donate in a one-time payment to prevent a certain percentage of species loss across all marine organisms[11]. Due to the non-market nature of existence values, there are inherent limitations and biases in valuing respondents' stated preferences (e.g., sample selection, question structure, and respondent knowledge levels). There are a few factors that suggest our estimate may not capture the full value of this service.

Respondents were asked to identify their reasons for supporting marine conservation from a list of options that included direct and indirect uses, existence values, bequest values, etc. and were allowed to indicate more than one answer. This makes it difficult to parse out exactly how much of an individual's total willingness to pay (WTP) should be attributed to existence or bequest values. However, we were able to define a lower and upper bound based upon the percentage of respondents who included existence and/or bequest values as part of their motivation (see *Appendix 2* for further detail).

Multiple studies have demonstrated that WTP increases with increased familiarity and knowledge of the subject in question[100]. Thus, preference surveys in environmental contexts are often thought to be lower bound estimates because respondents may have imperfect knowledge about the threats to or status of the species, resource, or ecosystem in question[101].

Due to the difficulty in defining an appropriate price for this service, it received a "medium" uncertainty score. Despite these potential biases, the survey results clearly demonstrate a high value for the existence and persistence of marine biodiversity and the importance of considering its intrinsic value.

As existence and bequest values are tied generally to the perception of marine ecosystem health (in this case by Azorean residents), we scored them similarly to the hospitality subsector of the marine tourism ecosystem service. The creation of MPAs can lead to heightened awareness of conservation issues and a sense of pride and happiness in helping protect the marine environment[29,102]. This would not only increase existence value, but also the bequest value of knowing these marine resources will be preserved for future generations[103]. However, the link between this service and MPA implementation is indirect and requires residents to have knowledge of marine conservation efforts in the Azores and for that knowledge to shift their beliefs about the intrinsic value of nature. Therefore, we assigned a "moderate benefit" MPA effect score to the existence/bequest service.

The "Value" of Components of Biodiversity: Sharks in the Mid-Atlantic

Marine biodiversity and the physical environment serve as the basic building blocks of marine ecosystems and underlie the provision of all ecosystem services[104]. Some argue that any attempt to value biodiversity results in a gross underestimate because its true value is infinite[105]. From this perspective, biodiversity is seen as the "glue" that holds all natural and manmade systems together, and no human capital could exist or persist without it[1]. Consistent with these ideas, we do not provide an explicit valuation of biodiversity as a standalone service. Instead, we view biodiversity as the foundational support to each of the ecosystem service economic values calculated in our report.

However, methods have been developed to estimate and communicate the value of different facets of biodiversity. In this report, we assess the intrinsic non-use value derived by Azoreans from the knowledge that biodiversity exists in the ocean – both now and into the future – via our existence/bequest service. Another framework common in the literature calculates the standalone value of a species' population, or even of a single individual. This is usually accomplished through the derivation of that entity's contribution to a non-consumptive activity like marine tourism. For example, the contribution of whales to the global whale watching tourism sector was estimated to be worth over $2 billion in 2008[106]. Similarly, an individual whale was estimated to be worth an average of $32,000 – $1,259,000 over its lifetime across three whale watching destinations on the Great Barrier Reef[107]. These types of estimated values fluctuate largely depending on the size of the population as well as the tourism sector they support. When the organism in question is also the target of an extractive activity like fishing, it is common for these values to be juxtaposed against the value generated through its trade as a market commodity, as can be done for sharks in the region.

The average value of an individual shark to the diving industry has been calculated for several regions around the world (Table 6), with estimates ranging between $9,000 - $360,000 annually and $211,000 - $5,400,000 over a shark's lifetime. It should be noted

Table 6. Estimates of the economic value of individual sharks to marine tourism over the course of a year and the average lifespan of the species.

Location	Species	Annual value per individual	Lifetime value per individual	Reference
Australia	Whale shark	$9,000	$211,000	Norman and Catlin 2007[111]
Maldives	Grey Reef	$33,500	N/A	Anderson and Ahmed 1993[112]
Galapagos Islands	Various species	$34,000	$493,000	Peñaherrera et al. 2013[113]
Belize	Whale shark	$35,000	$2,100,000	Graham 2004[114]
Costa Rica	Hammerhead	$82,000	$1,600,000	Friedlander et al. 2012[110]
French Polynesia	Lemon	$139,000 - $317,000	$2,600,000	Clua et al. 2011[115]
Palau	Various species	$179,000	$1,900,000	Vianna et al. 2010[116]
Galapagos Islands	Various species	$360,000	$5,400,000	Lynhan et al. 2017[108]

that these values are highly specific to the location and industry context from which they were derived. For comparison, these values are several orders of magnitude larger than the reported market value of a landed shark in the same studies: $91-$158 in the Galapagos[108], $108 in Palau[109], and $195 in Costa Rica[110].

A common criticism of calculating value at the individual level is that it is a calculation of average value and not marginal value. For example, a shark might be worth tens of dollars to a fisherman, but removing that same shark from the population is very unlikely to cause an economic loss to the tourism industry equivalent to the average value presented in Table 6, if any change at all[117]. However, in the context of marine conservation, if policy makers are concerned with large declines in the local population[108], the estimated average value of an individual organism can be used for a first order approximation of the marginal value of losing all (or most) of a population of animals that supports local tourism.

Both the blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*) are the subject of commercial fishing and tourism interest in the Azores. We were unable to calculate the value of individual sharks to marine tourism in the Azores due to a lack of data on the size, average lifespan, and home ranges of the populations that underpin shark diving throughout the archipelago. However, shark diving was estimated to generate nearly €2 million to the Azorean economy in 2014[23]. Comparatively, blue shark and shortfin mako landings in the Azores in that same year were reported to be less than €20,000[118]. These species are also caught in the Azorean EEZ and landed elsewhere by the European longline fleet, whose total indirect economic contribution to the region has been estimated to be on the order of €3 million[23]. However, the blue shark is classified as Near Threatened and the shortfin mako is Endangered on the IUCN's Red List, prompting concerns over their continued extraction by the pelagic longline fishery in the Mid-Atlantic. Furthermore, it is possible that the rise in popularity of shark diving and marine tourism more generally could lead to the shark diving sector becoming more prosperous in the future. These types of comparisons can be useful to shed light on the value of components of biodiversity to non-consumptive industries, motivating long-term protection of marine species.

Medicinal/Biotechnology Option Values

Ecosystem Service Description

Marine organisms' novel biological compounds offer a potential source for developing new innovations in the fields of pharmacology, cosmetics, and biotechnology[70]. For example, compounds derived from sponges have demonstrated light-conducting properties[119] and have been used to develop chemotherapeutic agents to fight cancer[120]. Additionally, the genomes of deep-sea bacteria are of particular interest in the development of novel enzymes and proteins[70]. The benefits of future ecosystem services can be quantified with an "option value," defined as the monetary value assigned for preserving the opportunity to capture future benefits from an environmental resource[121].

Economic Valuation Results, Uncertainty, and Effect of MPAs

Value: €7.9 - 8.4 million
Uncertainty: Medium
Effect of MPAs: Strong benefit

The literature on non-market valuation for marine natural products is limited and there are no Azores-specific data to our knowledge for this subsector. Our estimates of price were informed by a willingness to pay (WTP) study conducted in the United Kingdom, which we extrapolated to the Azores. However, there are inherent uncertainties associated with WTP surveys and transplanting WTP values from one setting to another. Furthermore, these WTP estimates only applied to deep-sea resources, and therefore we may have underestimated the total option value of marine natural products in the Azores. We assigned an uncertainty score of "medium" for this service as primary data were not available to inform our estimation of price.

Degradation of the marine environment is the primary threat to future marine medicinal and biotechnology discoveries. There is concern that some of these potentially useful compounds could vanish due to species extinctions from destructive marine activities before the compounds are discovered[94]. The sensitive deep-sea benthic habitats are presently threatened by fishing activities that disturb the benthos and the possible development of offshore mining facilities[74]. These threats are abatable by fully protected MPAs that prohibit these extractive activities, justifying a "strong benefit" score for this service.

Emerging Sectors

We do not include the emerging sectors of aquaculture, seabed mining, blue carbon sequestration, and deep-sea submersible tourism in our primary analysis due to the absence of an established sector in the Azores and/or a lack of data availability, but we acknowledge their importance for future valuation studies. For each emerging sector, we provide a brief introduction to their status and relevance to the Azores, as well as potential barriers to their development.

Aquaculture

Aquaculture production has become a significant economic activity for many nations over the past decade. Marine farming can help to diversify seafood production and reduce pressure on wild populations[122]. There is currently no marine aquaculture production in the Azores, however there is increasing interest in developing this industry, and the first permits for offshore aquaculture were recently granted (pers comm Regional Department for the Sea, Science, and Technology,[12]). High demand for seafood coupled with declining wild fish stocks has rendered aquaculture an attractive alternative to fishing[8].

Based on data from a recent analysis conducted by Gentry et al. (2017[123]), an estimated 934 km^2 of offshore area in the Azores is suitable for finfish aquaculture (Figure 12). The University of the Azores also recently completed a suitability assessment mapping potential aquaculture sites in the region[124]. Suitable offshore areas were identified for each of the nine islands, and three locations have since been authorized for development. The islands of Terceira, Faial, and Sao Miguel will host the first offshore aquaculture farms in the Azores, and will produce macroalgae, invertebrates, and finfish (pers comm Regional Directorate for the Sea, Science, and Technology).

The consumption of marine seafood products is a long-standing tradition in the Azores, and development of aquaculture in the area would help increase food security and economic development. Favorable sea temperatures (13-24 degrees C) and relatively low pollution levels provide ideal conditions to farm seafood[122]. Access to fish scraps from the fisheries sector provides further efficiency advantages for creating fishmeal and fish oil for feed used for fed aquaculture species. If environmental and social outcomes are considered in the planning process, aquaculture can increase self-sufficiency in the Azores and help to create a more circular economy[125].

The geographic isolation of the Azores that creates ideal water conditions also presents potential barriers to development. High transport and input costs, rough weather conditions, and steep coastal cliffs and drop-offs have hampered the development of aquaculture[122]. Furthermore, there is a lack of qualified labor to support aquaculture's expansion resulting from low interest levels among younger generations[8]. There has also been a lack of interest from investors, which the Regional Government can address by providing tax benefits and incentives until the sector is more profitable[125].

Seabed Mining

The Azores has been identified as an area where ocean mining could potentially be developed because of the polymetallic nodules, crusts, and massive sulphides containing copper, cobalt, gold, silver, and platinum located within the seabed[8,70]. However, the global exploitation of deep-sea

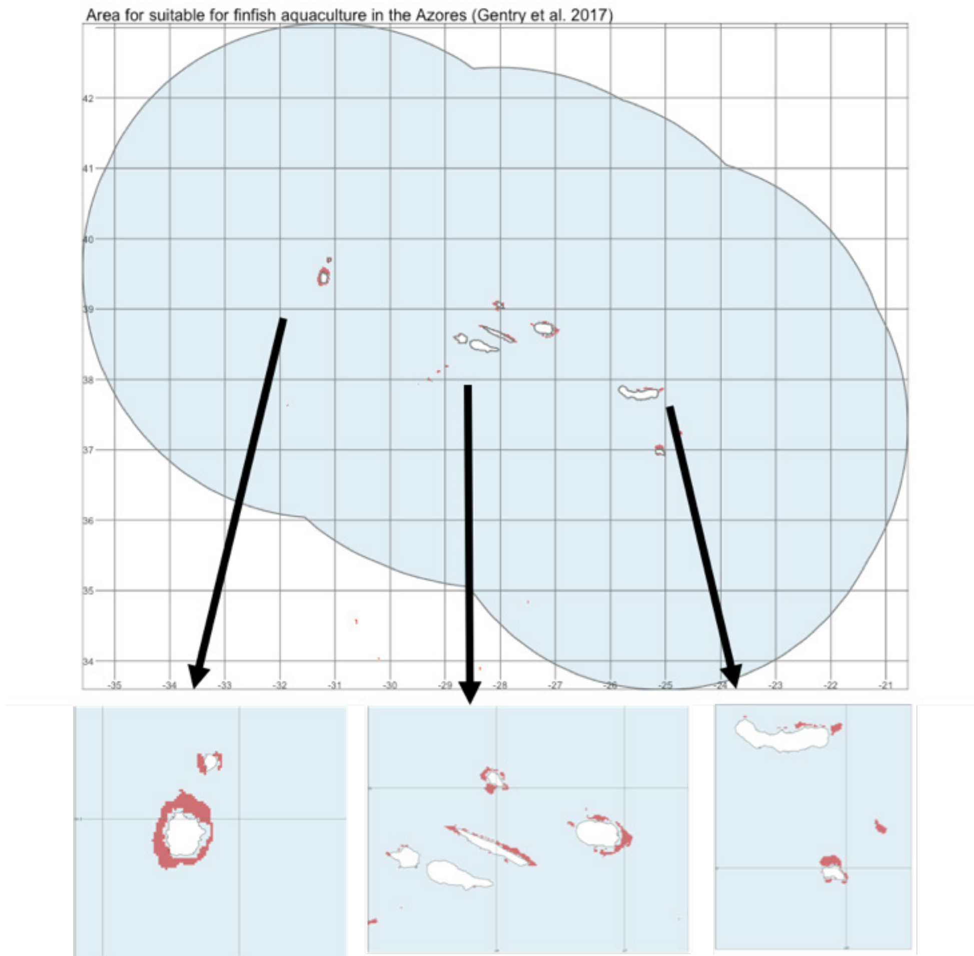

Figure 12. Areas potentially suitable for finfish aquaculture in the Azores from a global suitability analysis by Gentry et al. 2017.

mineral resources is still in initial phases and, to date, there are no seabed mining activities taking place in the Azores[8].

In 2008 and 2012, a Canadian company submitted applications for prospecting and mineral research at six locations in the Azores' EEZ[126]. To the best of our knowledge, the applications are still pending, and there is an ongoing effort by the Regional Government to delay mining activities until the environmental consequences are better understood[126].

As the world population continues to grow and terrestrial supply of metals and rare elements diminishes, the extractive focus will likely shift to the oceans[127,128]. Prospecting and the exploration of resources in the Azores' deep-sea represents an opportunity for the regional economy[70]. Nevertheless, barriers to the marine mining sector include high input costs, advanced technological requirements, and marine conservation concerns. Drilling and infrastructure development can cause permanent damage to the seafloor and may threaten ecosystem services such as those provided by fragile cold-water corals on the deep-sea benthos or the unique hydrothermal vent ecosystems found in the Azores[127,128].

Blue Carbon Sequestration

Blue carbon sequestration occurs through a combination of physical and biological processes that take carbon dioxide from the atmosphere and the shallow surface layer of the ocean and transport it to the more stable waters near the seafloor. Once there, mineralized carbon can be locked into the benthic sediment, furthering isolating it from the atmospheric carbon stock for tens of thousands to millions of years[129]. In this way, benthic sediments can be thought of as "banked" climate mitigation credits. Humans indirectly benefit from this process through the regulation of the climate. As anthropogenic CO_2 emissions continue to increase, marine climate regulation services may become increasingly important to recognize and preserve[51].

"Climate change mitigation" is an ecosystem service that is underpinned by oceanic carbon sequestration and is sometimes included in economic valuations of marine ecosystems. Mitigation can serve as a revenue-generating service where carbon offset markets exist. It can also be thought of as a non-revenue-generating service that generates a global benefit in buffering the symptoms of a changing climate. Extractive activities that disturb the sediment like trawl fishing and seabed mineral extraction are the greatest threat to benthic stocks of carbon. However, these threats are relatively limited in the Azores at present.

We do not include climate regulation by blue carbon sequestration as an ecosystem service in our principal valuation for three reasons: 1) the carbon markets in Europe are still being developed and do not currently include a mechanism to generate revenue from natural carbon sinks like the ocean, 2) the existing non-market benefit generated by climate regulation is globally diffuse, and 3) the threats to benthic carbon stocks are few in comparison to their distribution across the EEZ (Figure 13). However, we provide an example of one potential valuation methodology for

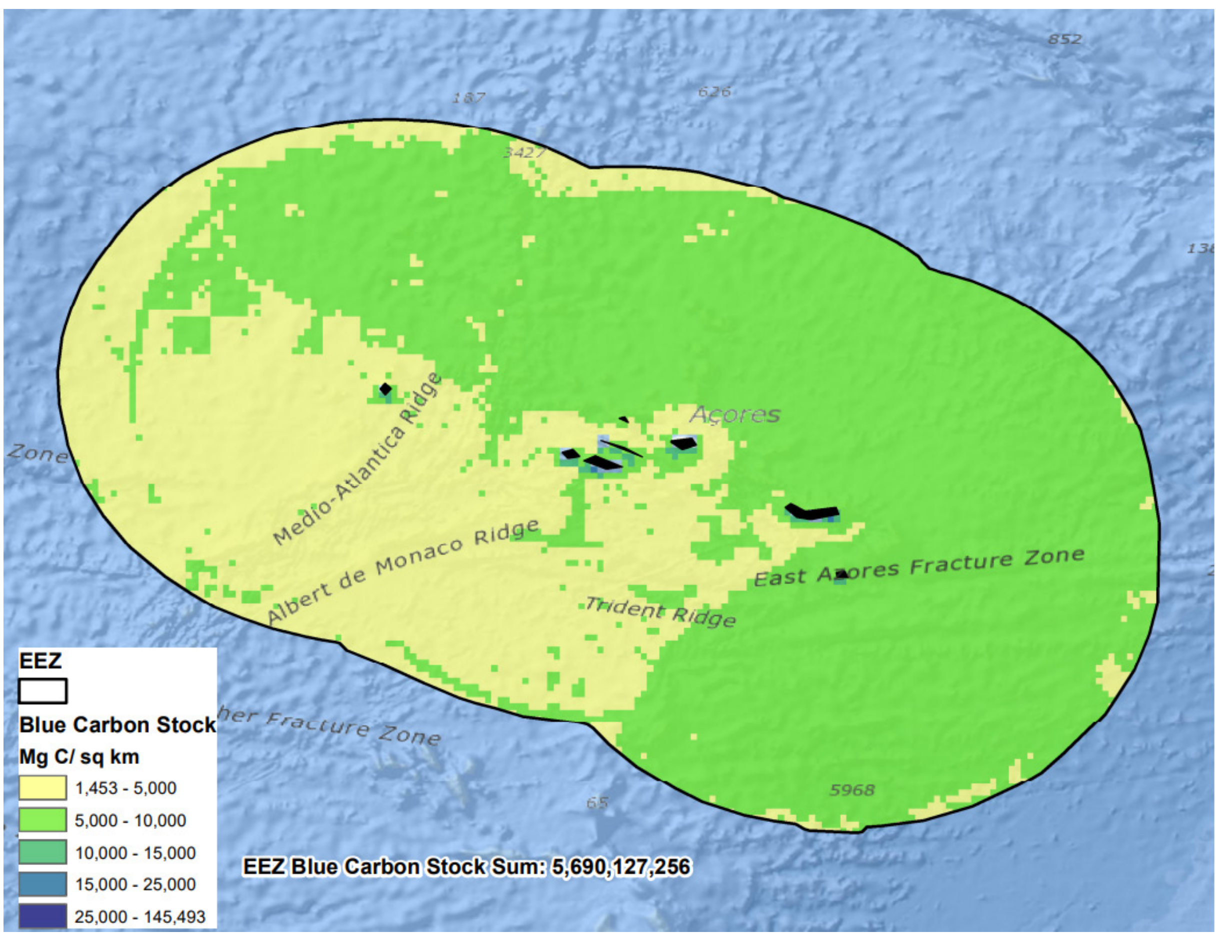

Figure 13. Predicted distribution of ocean soil carbon stocks in the EEZ of the Azores. One megagram (Mg) is equal to a metric ton. Model and graphic produced by Atwood and Witt[130].

context in case blue carbon sequestration becomes more central to the discussion of Azorean marine resource use policy.

This valuation uses a model of blue carbon ocean stocks (Figure 12)[130] and the social cost of carbon (SCC). The SCC is a marginal measure of monetary value that estimates the damages caused by an additional ton of carbon dioxide being put into the atmosphere. Multiplying these values together yields the modelled "standing stock" value of all the carbon stored in marine sediment of the Azorean EEZ. To calculate an annual value for this service, we conceptualized this lump-sum "banked" value as a series of annual payments. Our estimate of the economic value of the global benefit of blue carbon sequestration in the Azores is equivalent to the value of one of these annual payments: roughly €12.7 billion.

This estimated value of carbon sequestration is several orders of magnitude higher than the other ecosystem services included in this report. However, this figure appears to be consistent with previous valuations of carbon sequestration performed in the UK (£800–£2320 billion in a one-time payment)[3] and Spain (€3.8 billion per year)[131]. Additionally, this estimation is highly sensitive to the selected SCC, the value of which is highly debated. Derived estimates of the SCC vary across two order of magnitude, from roughly ~US$10-$1000 per ton of CO_2[132]. We selected a value of US$31.20 in 2010 (~€20.36 in 2017) based upon the best available literature[133]. Regardless of the exact value, fully-protected MPAs have the capacity to completely remove the threat of extractive activities that could diminish this service.

Deep-sea Tourism

Nearly all visits to the deep-sea in the Azores are for scientific expeditions[134]. One company operating in the region advertises trips in a submersible vehicle up to 1,000 meters deep for a price of €5,000, although these trips are largely intended for researchers, and actual prices and expenditure vary greatly based on trip specifics (pers comms FundOceano 2018). In spite of this, technological advances and lower input costs could catalyze a deep-sea submersible tourism industry in the future.

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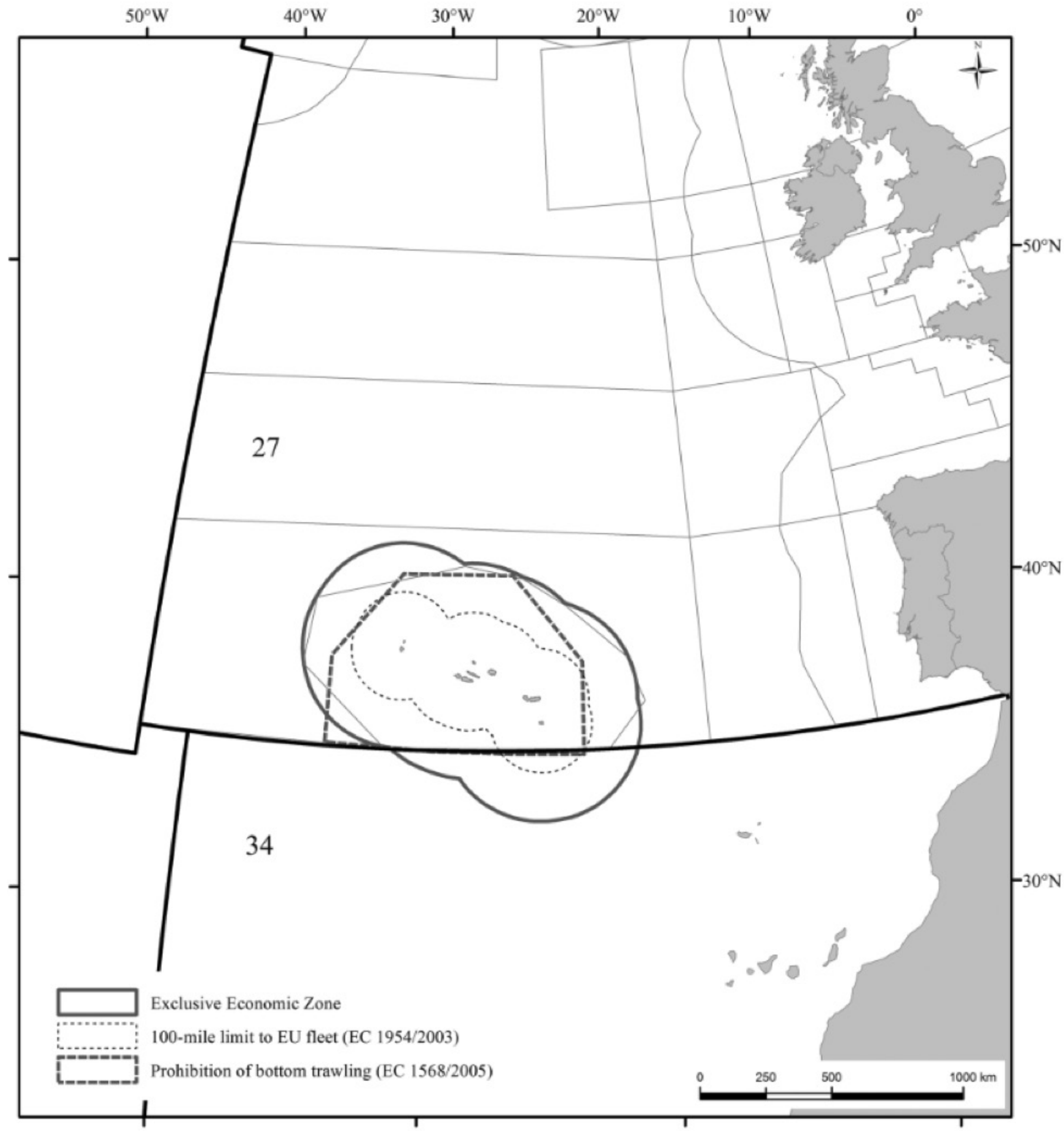
Appendices

Appendix 1. Map of EEZ, Trawling Ban, and Foreign Fishing Zone



Source: Pham et al. 2013[21].

Appendix 2. Economic Valuation Methods and Parameter Values

See *Table A1* for a full list of parameter values utilized in this economic valuation.

Fisheries

We quantified the economic value of the fisheries ecosystem service by summing the total revenue generated in 2017 by the first sale of commercial catch landed in the Azores with our estimate of the value of recreational catch landed in the Azores during 2017. We also present an estimate of the value of fish caught within the Azorean EEZ during 2017 by Spanish-flagged longlining vessels but landed outside the Azores. This value is not included in our estimated total value of the fishery sector because it is not currently captured by the Azorean economy. However, estimating the magnitude of that value can be useful to policy makers as a portion of it is derived directly from the marine resources of the Azores and then transferred elsewhere (see the *Pelagic Fishery* section for more context).

Value of Commercial Catch Landed in the Azores

Based on Lotaçor auction house data provided by the Regional Government, the total value of commercial catch landed in the Azores was roughly €29.5 million in 2017[41]. This dataset contains information on the vessel, date, species, weight, and value associated with all commercial fishery landings in the Azores. Our goal was to disaggregate the total commercial fishery sector value into separate estimates of the value of the demersal, pelagic, and coastal subsectors. We accomplished this through implementing an algorithm developed by the Department of Oceanography and Fisheries at the University of the Azores (DOP/UAç)[49]. The algorithm is a decision tree that operates on a combination of vessel characteristics and the species composition of a landing, where an individual landing is defined as all of the fish landed by a single vessel on a single day. The algorithm uses this information to assign each landing a "métier", or gear archetype. The value of a landing was calculated as the sum of the products of the weight (kg) and first sale price (€/kg) for each species included in a landing[41]. We then mapped each métier onto one of the commercial subsectors (*Table A2*).

Using the decision-tree algorithm, we were able to categorize approximately 92.2 % of the total value of commercial fishery landings in 2017 to one of the three commercial subsectors. We apportioned the remaining ~7.8% using a species-level classification (*Table A3*). We assigned species to subsectors by identifying the most common fishing method associated with each species using consumer guides developed by the University of Azores and Lotaçor[135,136]. We calculated the per-species value to the subsector it was assigned by multiplying the total catch (kg) of that species in landings that could not be categorized by the algorithm by the average first sale price (€/kg) of that species-specific catch[41].

Thus, the value of each commercial fishery subsector, $EV_{subsector}$, can be calculated as:

$$EV_{subsector} = EV\ Algorithm_{subsector} + EV\ Unassigned_{subsector}$$

Where, *EV Algorithm* is the sum of all landings assigned to a subsector that could be categorized using the DOP/UAç algorithm and *EV Unassigned* is the sum of the per-species values of the species included in landings that could not be categorized but were assigned to a subsector using the aforementioned species-based classification (*Table A3*). Finally, the total value of commercial catch landed in the Azores, $EV_{commercial}$, can be represented as the sum of the *EV*'s for each of the three subsectors, listed out below:

$$EV_{commercial} = EV_{demersal} + EV_{pelagic} + EV_{coastal}$$

Value of Recreational Catch Landed in the Azores

To estimate the value of recreational fisheries, we applied the replacement cost method which estimates the market value of recreational landings assuming that if recreational fishing were not available, the fish would have to be purchased for consumption. For each of the licensed recreational fisheries, boat-based recreational fishing and recreational spearfishing, the Regional Government produced estimates of total catch and species composition for each island using data obtained during a survey of licensed recreational fishermen in 2019[47]. These data were utilized to estimate the economic value of both licensed recreational fisheries in 2017. Shore-based recreational fishing is not licensed in the Azores and estimates of catch and effort in this fishery are only available in the literature for the islands of Pico and Faial[48]. We extrapolated these data using best available methods in the literature to estimate the economic value of shore-based recreational fishing for the entirety of the Azores[21]. Estimated total effort or catch data for recreational intertidal hand collecting were not available in the literature, so we were unable to estimate the economic value of recreational hand collecting[48,68].

The Regional Government performed a survey of licensed recreational fishermen to estimate catch per unit effort, total effort, and species composition of landings for each island in 2018 for both boat-based recreational fishing and recreational fishing[47]. Using these data, the Regional Government estimated the total landings of each licensed recreational fishery on the island-species level by scaling the estimated annual catch per fishing license specific to each island by the number of licenses for that recreational fishing activity issued on that island in 2018. We assumed that the annual catch per fishing license to be the same in 2017 for each island and activity as it was in 2018 and scaled the estimated catch from 2018 to 2017 proportionally to the number of licenses such that:

$$\frac{q_{i,activity,island,2017}}{nl_{activity,island,2017}} = \frac{q_{i,activity,island,2018}}{nl_{activity,island,2018}}$$

Where, q is the estimated catch in kilograms of species i and nl is the number of licenses issued, each specific to a given licensed recreational fishing activity, island, and year. We then calculated the estimated economic value for each licensed recreational fishing activity as:

$$EV_{activity} = \sum q_{i,activity,island,2017} * p_{i,2017}$$

Where, p is the average first sale price (€/kg) of species i for 2017 based on auction sales data from the Azores[41]. In instances where i mapped on to multiple species in the auction data (e.g. listed at the genus level in the recreational catch data), the mean price of all matching species was taken. When i could not be matched to any species in the auction data, p was imputed using the median price of all species landed by that of recreational fishing activity (*Table A4*).

For shore-based recreational fishing, estimates of average catch per unit effort and total effort were available in the literature collectively for the islands of Pico and Faial. We extrapolated this effort data point to the other islands using a similar method to Pham et al. 2013[21] in calculating a recreational index (*RI*) for each island. A recreational index is designed to account for differences in the intensity with which the population of a given island uses its coastal habitat. We calculated

RI_{island} as:

$$RI_{island} = \frac{nl_{spearfishing,island}}{population_{island}} * k_{RI}$$

Where, $nl_{spearfishing,island}$ is the number of spearfishing licenses issued on that island in 2017[137], $population_{island}$ is the population of that island in 2017[9], and k_{RI} is a scalar chosen so that the baseline $RI_{Pico\ and\ Faial}$ is equal to 1 (see *Table A5*). Pico and Faial were grouped together in the calculation of the economic value of shore-based recreational fishing because the estimate of total effort for these two islands was only available for them combined[48]. The calculated recreational indexes suggest that islands with smaller populations often experience higher intensity of coastal habitat use than those with larger populations, such as São Miguel and Terceira. The estimated shore-based recreational fishing effort in hours for each island in 2017, $E_{island,}$ was then calculated as:

$$E_{island} = population_{island} * RI_{island} * k_E$$

Where, k_E is a scalar chosen so that the above equation holds true for the baseline value of Pico and Faial provided in the literature[48]. The total estimated effort of shore-based recreational fishing in 2017, E_{shore}, was calculated as:

$$E_{shore} = \sum E_{island}$$

The magnitude of shore-based recreational landings, q_{shore}, was estimated as:

$$q_{shore} = cpue_{shore} * E_{shore}$$

Where, $cpue_{shore}$ is the average catch (kg) per hour of shore-based recreational fishing based on available data from the survey of Pico and Faial. Due to the lack of data available for the other islands, we assumed that value to be constant for recreational shore-based fishing throughout the Azores. The shore-based recreational landings (q_{shore}) of each species *i* was estimated such that:

$$\frac{q_{i,shore}}{q_{shore}} = \frac{q_{i,shore,survey}}{q_{shore,survey}}$$

Where, $q_{shore,survey}$ is the total weight of shore-based landings reported in the survey data and $q_{i,shore,survey}$ is the reported landings of species *i* in kilograms. Similar to our treatment of $cpue_{shore}$ above, we assumed the species composition of the catch captured by the survey (represented by the right side of the above equation) to be representative of shore-based recreational fishing throughout the Azores. Estimated landings for each species were matched to auction price data[41] by scientific name and the median price of all species that could be matched (2.96 €/kg) was used as a proxy for species that could not (7.8 % of estimated recreational shore-based landings by mass). This allowed the overall economic value of recreational shore-based fishing to be estimated as:

$$EV_{shore} = \sum q_{i,shore} * p_{i,2017}$$

Where, $p_{i,2017}$ is either the average first sale price (€/kg) of species i for 2017 based on auction sales data from the Azores or the imputed median price as described above. The total *EV* of recreational fishing in the Azores was calculated by summing up the values of each type of fishing activity for which data were available:

$$EV_{recreational} = EV_{boat\text{-}based} + EV_{spearfishing} + EV_{shore\text{-}based}$$

Value of Catch Landed outside the Azores (Spanish Longliners)

EU-flagged fishing vessels from outside the Azores are permitted to fish within the outer 100nm of the EEZ of the Azores but commonly land their catch in mainland Europe, where prices are higher. The majority of these vessels are Spanish-flagged longlining vessels (hereafter, Spanish longliners) catching pelagic species such as swordfish, blue shark, and shortfin mako shark. Logbook information from foreign fishing vessels is obtained on an ad-hoc basis by the Regional Government when they make a port of call in the Azores. These logbooks contain data on the gear, effort, species composition, weight, and location associated with the vessel's catch. Our analysis leveraged available logbook data for Spanish longliners which used one of two longline gear types: drifting longlines and set longlines. We estimated the revenue, *R*, generated from the first sale of fish caught within the Azorean EEZ Spanish longliners and landed outside of the Azores as:

$$R = \sum cpue_{gear,i} * E_{gear} * p_{Vigo,i}$$

Where, *cpue* is the average catch of species *i* in kg per hour for one of the two analyzed longline *gear* types, *E* is the total number of hours Spanish longliners spent fishing with that gear within the Azorean EEZ during 2017, and p_{Vigo} is the average first-sale price in €/kg for landings of species *i* made at the port of Vigo, Spain during 2017.

cpue was calculated at the species-gear level for the catch and fishing effort that could be confirmed to have occurred within the EEZ of the Azores, per available logbook data (see *Table A6*). AIS-satellite data was used to infer *E*, the total number of fishing hours by Spanish longliners using either drifting longlines or set longlines[138]. The port of Vigo, Spain is the European Union's largest commercial fishing port and many Spanish longline vessels are known to land their catch there. We used reported first-sale data of landings made in Vigo during 2017 to inform our estimates of p_i[139]. When no price data were available for species *i* during 2017, the mean annual first-sale price in Vigo during 2018 was used as a proxy.

Marine Tourism

Hospitality

Total revenue generated from the hospitality sector is collected annually by the regional government (the Azores Regional Statistical Service). We estimate the economic value of hospitality attributed to marine ecosystem services as:

$$EV_{hospitatility} = R_H * k_{H\,(low,high)}$$

Where, R_H is the total revenue generated from the traditional hospitality sector for all tourists in 2017[69], and k_H is the proportion of total tourists that are "marine tourists", which we define as the percentage of tourists who participate in whale watching (the most popular marine tourism activity)[140] at the lower bound and the percentage of tourists who indicated that "natural values" were their primary motivation for visiting the Azores[141] at the upper bound.

Whale Watching

We estimate the range of economic value (*EV*) generated from the whale watching subsector as:

$$EV_{whale\ watching} = p_{W\,(low,high)} * q_W$$

Where, $p_{W(low,high)}$ are the lowest and highest prices identified for a half-day whale watching tour through an informal online survey of 20 whale operators in 2018, and q_W is the total number of visitors that participated in whale watching in 2017[140].

Scuba Diving

The economic value (*EV*) generated by the scuba diving subsector was calculated as:

$$EV_{diving} = p_{D\,(low,high)} * q_A * k_D$$

Where, $p_{D(low,high)}$ represents the average price of a single dive (low) and a ten-dive package (high) based on an online survey of 13 dive shops. We selected these number of dives to be our assumed low and high bounds for the subsector based on phone calls with four dive operators in the Azores. q_A is the total number of tourists who visited the Azores in 2017[69] and k_D is the proportion of all tourists who scuba dive[73].

Sport Fishing

The economic value (*EV*) of sport fishing in the Azores was informed by: 1) prices obtained from an informal online survey of sport fishing operators in the islands, 2) the total number of tourists who visited the Azores in 2017[69], and 3) both the percentage of tourists who sport fish and the percentage of sport fishing tourists who participate in each one of the four main sport fishing activities (see Table 4 in the *Marine Tourism* section)[79]. We calculated the *EV* as:

$$EV_{sport\ fishing} = \sum (p_{i\ (low,high)} * q_t * k_{SF} * k_i)$$

Where, $p_{i(low,high)}$ are the low and high prices identified from an online survey of operators for each activity *i*, q_t is the total number of tourists, k_{SF} is the percentage of tourists who participate in sport fishing, and k_i is the percentage of sport fishing tourists who participate in activity *i*. Our estimate uses the conservative assumption that every individual went on a single trip for each activity. Finally, we sum the value of each activity to calculate the overall economic value of sport fishing to the Azores.

Cruise Ship Tourism

We calculated the economic value of cruise ship tourism ($EV_{cruise\ ship}$) as revenue generated through port usage tariffs paid by cruise ships. Unpublished cruise ship log data was provided by the Port Authority of the Azores and included cruise ship name, size (gross tonnage), and arrival/departure date and time for each cruise ship visit to the Azores during 2017 (149 total visits to 12 different ports, see *Table A7*)[80]. EVcruise ship was calculated as:

$$EV_{cruise\ ship} = \sum[(p_{first\ day,port} * (1 - k_{port}) * GT_i) + (p_{subsequent\ days,port} * (n_{days,i} - 1) * (1 - k_{port}) * GT_i)]$$

Which can be rewritten as:

$$EV_{cruise\ ship} = \sum [(p_{first\ day,port} + p_{subsequent\ days,port} * (n_{days,i} - 1)) * (1 - k_{port}) * GT_i]$$

Where, $p_{first\ day,port}$ and $p_{subsequent\ days,port}$ are the daily use fees specific to each port for the first day (24-hour period) and all subsequent days respectively, n_{days} is the duration of stay in indivisible 24-hour days (rounded up), k_{port} is the proportional discount on port use fee granted to cruise ships at each port, and GT_i is the gross tonnage of each cruise ship *i* arriving during 2017.

Sailing and Yachting

Data concerning sailing and yachting in the archipelago were available from the Regional Government in the following aggregate forms: 1) the total number of vessels per island, 2) the average duration of stay by a vessel for each island, and 3) the total number of vessels grouped by size class (i.e. "12 – 15 meters")[81]. We estimated a range for economic value (*EV*) of the sailing and yachting of the subsector as:

$$EV_{sailing\ and\ yachting} = k_{days} * \sum q_{size} * p_{SY\ (low,high)}$$

Where, k_{days} is the average duration of stay for a vessel in the Azores. This was calculated as the weighted arithmetic mean of the average stay per island based upon the number of vessels that docked at each island. q_{size} is the number of vessels in a particular size class and p_{SY} (low, high) are the daily docking fees for that class of vessels[82]. No residential docking fees were listed for any lengths greater than 35 meters, so we assumed this was the largest class of vessel native to the islands. For the low estimate, we assumed all vessels shorter than this threshold were owned by residents and paid the cheaper docking rate. All vessels were assumed to be owned by non-residents for the high estimate.

Research and Education

The most commonly used method to quantify the non-market value of research and education entails summing research expenditures[91,92]. This method assumes that the benefits of carrying out research must be greater than or equal to the costs in order for it to occur[95].

Through communication with the Regional Government, we were able to obtain a list of research and education projects in the Azores that were marine in nature[93]. This list included information on the overall budget, starting year, and ending year for each project. We calculated the economic value of marine research and education in the Azores as:

$$EV_{research\ and\ edcation} = \sum p_i$$

Where, p represents the average annual budget of each project i. Only projects that were in progress during 2017 were included in our analysis.

Existence/Bequest Values

We estimated the magnitude of existence and bequest values in the Azores using: 1) a contingent valuation survey conducted in the Azores to elicit resident willingness-to-pay (WTP) values for protecting marine taxa[11], and 2) population data tabulated by the Regional Government[9]. Contingent valuation surveys are one of the most accepted methods for quantifying the non-use existence value of species and ecosystems[11,142]. Unlike most market-based methods, they are capable of estimating the value of a current or future environmental state by asking respondents to assign a value to a specific scenario[143]. We calculated the value as:

$$EV_{existence\ and\ bequest} = \left(p_{E(low,high)} * \frac{CPI_{USA\ 2017}}{CPI_{USA\ 2008}} * \frac{PPP_{USA\ 2017}}{PPP_{PRT\ 2017}}\right) * d * k_{E(low,high)} * q_A$$

Where, $p_{E(low,\ high)}$ are the median (lower bound) or mean (higher bound) WTP reported in the survey converted for inflation (*CPI* ratio) and differences in currency and income (*PPP* ratio)[144,145]. The survey was framed as a one-time payment, so we used a discount rate d to convert these values into a series of infinite annual payments with the same present value. We then multiplied the annual value by $k_{E(low,\ high)}$, a scalar used to estimate how much of a respondent's total WTP was due to existence or bequest values (as opposed to use values, etc.). To do this, we calculated the fraction of respondents that indicated that existence value was at least one of their reasons for supporting marine conservation (96/246) and likewise for bequest value (152/246). We multiplied our low estimate of annual WTP by the smaller existence value ratio and the high estimate by the bequest fraction. q_A is the total population of the Azores in 2017.

The original survey experiment used partial avoided loss scenarios (i.e. a loss of 50% of all marine species). We based our estimation on the values provided in the context of this 50% loss scenario (the most extreme scenario included) which may underestimate the true total existence value of all marine taxa (100%). However, extrapolating a 100% loss scenario is not straightforward. For example, it is possible that marginal WTP for each additional species saved will decrease as the total percentage increases ("diminishing returns"). It can also be argued that the true value of biodiversity is limitless- it is the underlying glue that allows for the provision of all other ecosystem services[105]. We decided to conservatively use the data provided (50%) to avoid introducing additional error in the extrapolation process.

Medicinal/Biotechnology Option Values

The literature on marine medicinal and biotechnology non-market valuation is extremely limited and there are no Azores-specific data to our knowledge in this subsector. Therefore, we utilized a 2012 experiment from the United Kingdom to extract annual WTP option values for protecting potential deep-sea medicinal discoveries[85]. We calculated the option value as:

$$EV_{option} = \left(p_{O(low,high)} * \frac{CPI_{GBR\ 2017}}{CPI_{GBR\ 2012}} * \frac{PPP_{USA\ 2017}}{PPP_{GBR\ 2017}}\right) * q_A$$

Where, p_O are the low and high estimates of annual WTP reported from the experiment[85], the ratios of *CPI* and *PPP* adjust for inflation and relative purchasing power[144,145], and q_A is the population of the Azores in 2017[9].

Table A1. The parameter values employed in our analysis. A dash ("-") in the Symbol column indicates an intermediary result that does not appear explicitly in a valuation formula above.

Service / Subsector	Symbol	Description	Value	Unit	Reference
Fisheries	$q_{i,activity,island,year}$	Estimated landings of species *i* for a given recreational fishing *activity, island,* and *year*	varies (see *Figure A1* below)	kg	Unpublished recreational catch survey data from the Regional Government of the Azores[47]
	$nl_{activity,island,year}$	Number of fishers participating in a given recreational fishing *activity, island,* and *year*	varies	# of licenses	Unpublished data from the Regional Government of the Azores, Directorate of Marine Affairs[137]
	$p_{i,2017}$	Average first-sale price of species *i* in 2017	varies	€/kg	Lotaçor data from the Regional Government[41]
	$nl_{spearfishing,island}$	Number of licenses issued for recreational spearfishing for a given *island* in 2017	varies	# of licenses	Unpublished data from the Regional Government of the Azores, Directorate of Marine Affairs[137]
	$population_{island}$	Total population for a given *island* in 2017	varies (see *Table A5*)	individuals	SREA: "Estimativas da Populacao Media"[9]
	k_{RI}	Scalar chosen such that baseline value of $RI_{Pico\ and\ Faial}$ is equal to 1	~31.15	-	
	k_E	Scalar chosen such that baseline value of $E_{Pico\ and\ Faial}$ is equal to the 61225.6, as estimated by Diogo and Pereira 2014[48]	~2.16	-	
	$cpue_{shore}$	Average catch per unit effort (cpue) of shore-based recreational fishery	0.837	kg/hour	Diogo and Pereira 2014[48]
	$q_{shore,survey}$	Total landings of shore-based recreational fishery recorded during survey of Faial and Pico	51245.83	kg	$cpue_{shore} * ef_{shore}$
	$q_{i,shore,survey}$	Total landings of species *i* observed during survey of shore-based recreational fishing on Faial and Pico	varies (see *Figure A1* below)	kg	Diogo and Pereira 2014[48]
	$cpue_{gear,i}$	Average cpue of species *i* using a given gear from available Spanish logbook data	varies (see *Table A6*)	kg/hour	Unpublished Spanish longlining vessel logbook data[57]

Table A1 cont'd.

Service / Subsector	Symbol	Description	Value	Unit	Reference
Fisheries cont'd	$E_{drifting\ longlines}$	Total amount of fishing effort by Spanish-flagged vessels within the EEZ of the Azores in 2017 using drifting longlines	13575.6	hours	Global Fishing Watch[138]
	$E_{set\ longlines}$	Total amount of fishing effort by Spanish-flagged vessels within the EEZ of the Azores in 2017 using set longlines	139.9	hours	Global Fishing Watch[138]
	$p_{Vigo,\ i}$	Mean annual first-sale price of species *i* in 2017 at the port of Vigo, Spain. Mean price data from Vigo in 2018 were used as a proxy when 2017 data were not available	varies (see *Table A6*)	€/kg	EUMOFA first-sale database[139]
Hospitality	R_H	Total hospitality revenue (traditional accommodations)	87622095	€	SREA: "Hóspedes, Dormidas e Proveitos na Hotelaria Tradicional"[69]
	q_W	Whale watchers	112263	individuals	Regional Government of the Azores, Directorate of Tourism[140]
	q_t	Total tourists	840523	individuals	SREA: "Turismo"[69]
	$k_{H,low}$	Proportion of tourists that participate in whale watching	0.147	-	q_W / q_t
	k_{Hhigh}	Proportion tourists who indicated that " natural values" were their primary motivation for visiting the Azores	0.411	-	Queiroz et al. 2014[73]
Whale Watching	q_W	Whale watchers	112263	individuals	Regional Govt. of the Azores, Directorate of Tourism[140]
	$p_{W\ (low)}$	Half-day tour cost (low)	49	€	Online survey of 20 operators
	$p_{W\ (high)}$	Half-day tour cost (high)	65	€	Online survey of 20 operators

Table A1 cont'd.

Service / Subsector	Symbol	Description	Value	Unit	Reference
Diving	q_t	Total tourists	840523	individuals	SREA: "Turismo"[69]
	k_D	Proportion of tourists who dive	0.07	-	Queiroz et al. 2014[73]
	$p_{D\ (low)}$	Average price of single dive	40.84	€	Online survey of 13 dive shops
	$p_{D\ (high)}$	Average price of 10 dives	341	€	Online survey of 13 dive shops
Sport Fishing	q_t	Total tourists	840523	individuals	SREA: "Turismo"[69]
	k_{SF}	Proportion of tourists who sport fish	0.036	-	Vieira and Antunes 2017[79]
	-	Sport-fishing tourists	27532	individuals	$q_t * k_{SF}$
	k_{BG}	Proportion of sport fishing tourists who participate in big-game fishing	0.248	-	Queiroz et al. 2014[73]
	$p_{BG\ (low)}$	Half-day tour cost (low)	150	€	Online survey of 2 operators
	$p_{BG\ (high)}$	Half-day tour cost (high)	455	€	Online survey of 2 operators
	-	Big-game value (low)	1024201	€	$q_t * k_{SF} * k_{BG} * p_{BG(low)}$
	-	Big-game value (high)	3106744	€	$q_t * k_{SF} * k_{BG} * p_{BG(high)}$
	k_C	Proportion of sport fishing tourists who participate in coastal trolling	0.238	-	Queiroz et al. 2014[73]
	$p_{C\ (low)}$	Half-day tour cost (low)	75	€	Online survey of 4 operators
	$p_{C\ (high)}$	Half-day tour cost (high)	125	€	Online survey of 4 operators
	-	Coastal value (low)	491451	€	$q_t * k_{SF} * k_C * p_{C(low)}$
	-	Coastal value (high)	819086	€	$q_t * k_{SF} * k_C * p_{C(high)}$
	k_Z	Proportion of sport fishing tourists who participate in zagaia	0.092	-	Queiroz et al. 2014[73]

Table A1 cont'd.

Service / Subsector	Symbol	Description	Value	Unit	Reference
Sport Fishing cont'd	$p_{Z\,(low)}$	Half-day tour cost (low)	80	€	Online survey of 2 operators
	$p_{Z\,(high)}$	Half-day tour cost (high)	175	€	Online survey of 2 operators
	-	Zagaia value (low)	202638	€	$q_t * k_{SF} * k_Z * p_{Z(low)}$
	-	Zagaia value (high)	443270	€	$q_t * k_{SF} * k_Z * p_{Z(high)}$
	k_S	Proportion of tourists who participate in spearfishing	0.271	-	Queiroz et al. 2014[73]
	p_S	Half-day tour cost	48	€	Online survey of 1 operator
	-	Spearfishing value	358140	€	$q_t * k_{SF} * k_s * p_s$
Cruise Ship Tourism	$p_{first\ day,port}$	Port usage fee for the first 24-hour period for that specific *port*	varies (see *Table A7*)	€/gross ton (GT)	Secretaria Regional dos Transportes e Obras Públicas[87]
	$p_{subsequent\ days,port}$	Port usage fee for each additional 24-hour period for that specific *port*	varies (see *Table A7*)	€/GT	Secretaria Regional dos Transportes e Obras Públicas[87]
	$n_{day,i}$	The length of stay for ship *i* rounded up to the nearest day	varies	indivisible 24-hour periods	Portos dos Açores, S.A.[80]
	k_{port}	Proportional reduction in port usage fee granted to cruise ships, variable by *port*	varies (see *Table A7*)	-	Secretaria Regional dos Transportes e Obras Públicas[87]
	G_{Ti}	Gross tonnage of an individual cruise ship	varies	GT	Portos dos Açores, S.A.[80]
Sailing and Yachting	q_{size}	Number of vessels in a particular size class	varies	vessels	Regional Government, Directorate of Sea Affairs[81]
	$p_{SY\,(low,\ high)}$	Docking fee (resident, non-resident) for a size class	varies	€	Secretaria Regional dos Transportes e Obras Públicas
	k_{days}	Average length of stay of a vessel in the Azores - calculated as a weighted average (see text in *Sailing and Yachting* section above)	10.11	-	Regional Government, Directorate of Sea Affairs[81]

Table A1 cont'd.

Service / Subsector	Symbol	Description	Value	Unit	Reference
Research and Education	p_i	Annual funding for an individual project	varies	€	Unpublished budget data from the Regional Government[145]
Existence and Bequest Values	$p_{E\ (low)}$	Median willingness-to-pay (WTP) from surveyed Azorean residents as a one-time payment to prevent loss of 50% of all marine species	115	$ (2008)	Ressurreição et al. 2012
	$p_{E\ (high)}$	Mean WTP from same survey	704	$ (2008)	Ressurreição et al. 2012
	d	Discount Rate	0.03	-	
	-	Annual WTP (low) (calculated as the annual payment of a perpetuity)	3.45	$ (2008)	$p_{E\ (low)} * d$
	-	Annual WTP (high) (calculated as the annual payment of a perpetuity)	21.12	$ (2008)	$p_{E\ (high)} * d$
	$CPI_{USA\ 2008}$	CPI - USA 2008	98.73748	-	World Bank[144]
	$CPI_{USA\ 2017}$	CPI - USA 2017	112.4116	-	World Bank[144]
	$PPP_{USA\ 2017}$	Purchasing power parity* - USA 2017 (*USA is the base country for World Bank's PPP)	1	-	World Bank[145]
	$PPP_{PRT\ 2017}$	Purchasing power parity - Portugal 2017	0.58	-	World Bank[145]
	-	Annual WTP (low)	2.28	€	$p_{E\ (low)} * d * (CPI_{USA\ 2017} / CPI_{USA\ 2008}) * (PPP_{PRT\ 2017} / PPP_{USA\ 2017})$
	-	Annual WTP (high)	13.96	€	$p_{E\ (high)} * d * (CPI_{USA\ 2017} / CPI_{USA\ 2008}) * (PPP_{PRT\ 2017} / PPP_{USA\ 2017})$

Table A1 cont'd.

Service / Subsector	Symbol	Description	Value	Unit	Reference
Existence and Bequest Values cont'd	$k_{E\ (low)}$	The proportion of respondents who indicated that existence value was one of their motivations behind their WTP value	0.390	-	Ressurreição et al. 2012[11]
	$k_{E\ (high)}$	The proportion of respondents who indicated that bequest value was one of their motivations behind their WTP value	0.618	-	Ressurreição et al. 2012[11]
	q_A	Population of Azores	243862		SREA: ""Estimativas da Populacao Media""[9]
Medicinal/Biotechnology Option Values	$p_{O\ (low)}$	Annual WTP (low) from a survey in Great Britain (GBR)	35.43	£ (2012)	Jobstvogt et al. 2014[85]
	$p_{O\ (high)}$	Annual WTP (high) from a survey in GBR	37.85	£ (2012)	Jobstvogt et al. 2014[85]
	$CPI_{GBR\ 2012}$	CPI - GBR 2012	106.5286	-	World Bank[144]
	$CPI_{GBR\ 2017}$	CPI - GBR 2017	114.6436	-	World Bank[144]
	$PPP_{GBR\ 2017}$	Purchasing power parity - GBR 2017	0.69	-	World Bank[145]
	$PPP_{PRT\ 2017}$	Purchasing power parity - Portugal 2017	0.58	-	World Bank[145]
	-	WTP (low)	32.10	€	$p_{E\ (low)} * d * (CPI_{GBR\ 2017} / CPI_{GBR\ 2012}) * (PPP_{PRT\ 2017} / PPP_{GBR\ 2017})$
	-	WTP (high)	34.30	€	$p_{E\ (high)} * d * (CPI_{GBR\ 2017} / CPI_{GBR\ 2012}) * (PPP_{PRT\ 2017} / PPP_{GBR\ 2017})$

Table A2. Total value (€) and weight (kg) of the landings assigned to each métier using the algorithm provided by DOP/UAç[49] and the corresponding commercial fleets presented in this analysis. *HAND was a métier added to the algorithm that was assigned to landings in the Lotaçor data that indicated the species were collected by hand.
**Landings that could not be assigned a métier were categorized using the species-based classification presented in *Table A3*.

Fleet	Weight (kg)	Value (€)	Metier	Description	Weight (kg)	Value (€)
Coastal	1358607	5179849	FPO-CRU	fish trap gear	519227.8	1120582
			FPO-PB	crustacean trap gear	101698	515297
			GNS	gill net gear	312618.9	973215.3
			HAND*	collecting by hand	78717.95	68856.19
			LHM-CEF	squid jigging gear	214158.7	1735528
			LHP-PB	hook-and-line gear	127716.4	734336.7
			-	unassigned**	4469.7	32033.27
Demersal	2570759	18254336	LHM-PB	handlines gear	1992613	14023531
			LLS-DEEP	set longline gear	50346.29	266683
			LLS-PD	set longline gear	282099.7	1731060
			-	unassigned**	245699.8	2233061
Pelagic	2924351	6021931	LHP-TUN	pole-and-line gear	1998253	4070235
			LLD-GPP	drifting longline gear	42897.35	146413.5
			PS-PPP	purse seine gear for small pelagics	877405.1	1782137
			-	unassigned**	5795.85	23145.52
TOTAL	**6853717**	**29456115**				

Figure A1. Composition of estimated recreational landings for boat-based fishing, spearfishing, and shore-based fishing. To aid in visualization, the graphics below only display species/groups that make up at least 1% of the landings (by mass) for that type of recreational fishing activity. Species/group labels reflect those used in the data source: common names for boat-based fishing and spearfishing[47]; scientific names for shore-based fishing[48].

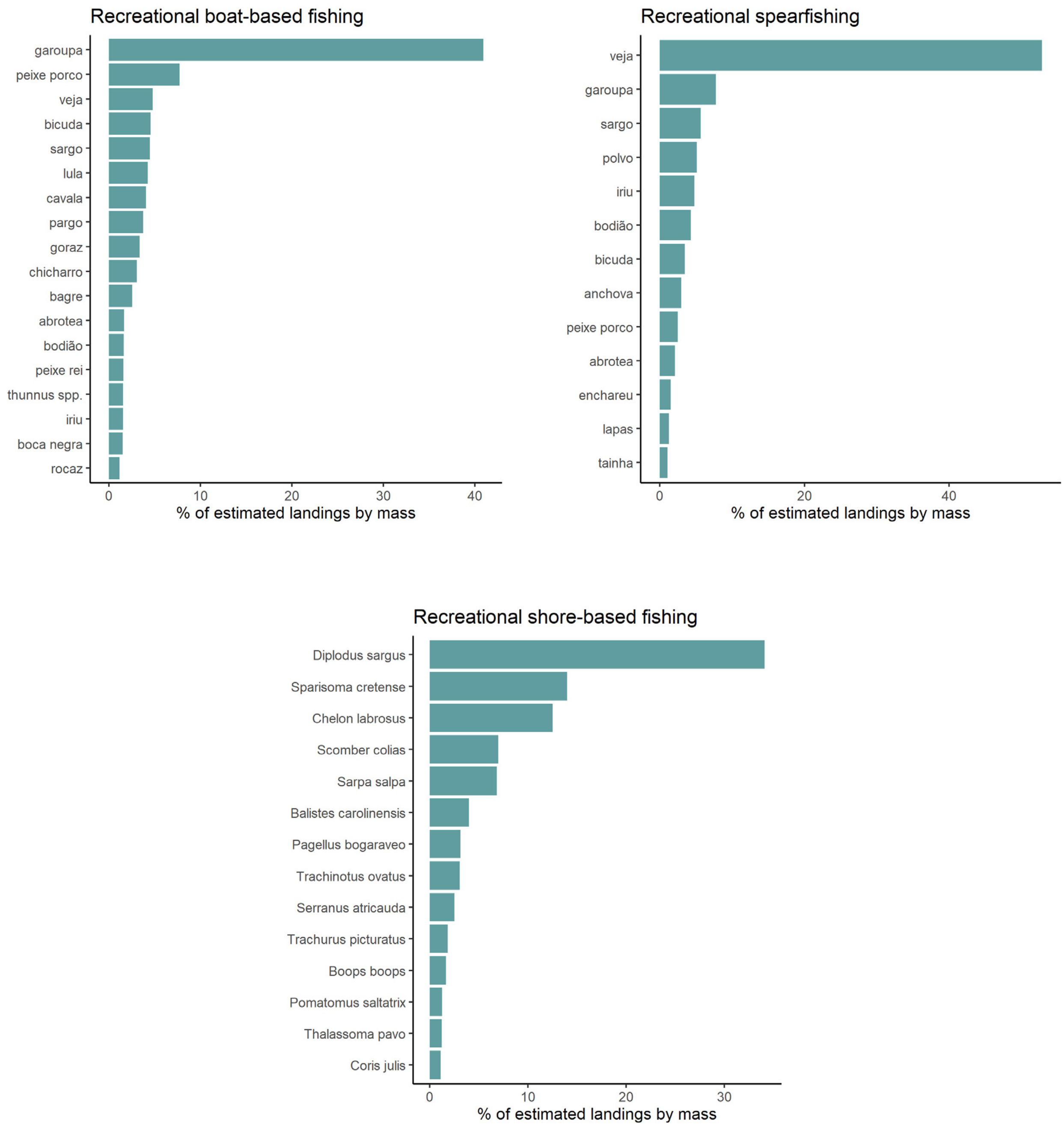


Table A3. List of species included in the Lotaçor data from 2017[41], most common fishing method[135,136], and fishery subsector it was assigned. This species-based classification was used to apportion the value of landings to one of the three commercial fishery subsectors when the landing could not be assigned to a subsector using the algorithm from the DOP/UAç[49] (methodology described in more detail in the *Fisheries section* of *Appendix 2*).

Fishery	Primary Fishing Method	Species
Coastal	by hand	agar
		algae
		barnacle
		common octopus
		grooved carpet shell
		grooved carpet shell (bivalve)
		lightfoot crab
		marbled rock crab
		marine crabs nei
		marine crustaceans nei
		nori nei
		purple laver
		rough limpet
		sargassum
		sea cucumber
		sea cucumbers nei
		seaweeds nei
		spanish agar
		urchin
		violet sea urchin
	coastal gill net	grunt
		parrotfish
		red mullet
		salema
		thicklip grey mullet

Table A3 cont'd

Fishery	Primary Fishing Method	Species
Coastal cont'd	coastal gill net cont'd	wrasses, hogfishes, etc. nei
		yellow sea chub
	hook-and-line	atlantic lizardfish
		ballan wrasse
		barred hogfish
		black moray
		blue runner
		bluefish
		brown moray
		canary damsel
		common two-banded seabream
		cuckoo wrasse
		dusky grouper
		emerald wrasse
		fangtooth moray
		gar
		garfish
		greater amberjack
		grey triggerfish
		guelly jack
		moray
		morays nei
		ornate wrasse
		rainbow wrasse
		ribbon wrasse
		sargo breams nei
		scale-rayed wrasse

Fishery	Primary Fishing Method	Species
Coastal cont'd	hook-and-line cont'd	swallowtail seaperch
		veined squid
		white seambream
		white trevally
		yellowmouth barracuda
	pots or traps	azores chromis
		common spiny lobster
		deep-sea red crab
		hermit crab
		gastropods nei
		mediterranean slipper lobster
		murex
		narval shrimp
		slipper lobster
		spider crab
		spinous spider crab
		spiny lobster
		striped soldier shrimp
		surmullet
		toothed rock crab
Demersal	handline and bottom longline	alfonsino
		angler(=monk)
		angler/monk
		atlantic pomfret
		axillary seabream
		black cardinal fish
		black scabbardfish

Table A3 cont'd

Fishery	Primary Fishing Method	Species
Demersal cont'd	handline and bottom longline cont'd	black spotted bream
		blackspot(=red) seabream
		blacktail comber
		bluntnose 6 gilled shark
		bulls-eye
		comber
		escolar
		european conger
		forkbeard
		greater forkbeard
		imperial blackfish
		island grouper
		john dory
		large-scaled scorpionfish
		Ling
		lings nei
		mediterranean moray
		megrim
		offshore rockfish
		oilfish
		pomfret
		red gunyard
		red porgy
		red scorpionfish
		risso's smooth-head
		roudi escolar
		roughskin dogfish

Table A3 cont'd

Fishery	Primary Fishing Method	Species
Demersal cont'd	handline and bottom longline cont'd	roundnose grenadier
		seabream
		shortnose velvet dogfish
		silver scabbardfish
		silvery john dory
		splendid alfonsino
		stout beardfish
		thornback ray
		tope shark
		wide-eyed flounder
		wreckfish
	handline and deepwater longline	blackbelly rosefish
		bluemouth rockfish
		common mora
Pelagic	hook-and-line	atlantic bonito
		longfin yellowtail
		pelagic stingray
		smooth hammerhead
		wahoo
	lift or surrounding net	atlantic herring
		blue jack mackerel
		bogue
		chub mackerel
		european pilchard(=sardine)
		mackerel
		pacific chub mackerel
		pompano

Table A3 cont'd

Fishery	Primary Fishing Method	Species
Pelagic	lift or surrounding net cont'd	sardines
	pole-and-line	albacore
		bigeye tuna
		bullet tuna
		common dolphinfish
		dolphinfish
		skipjack tuna
		yellowfin tuna
	surface longline	blue marlin
		blue shark
		mako shark
		shortfin mako
		swordfish

Table A4. Prices matched from 2017 auction house first-sale data[41] to the species/groups indicated as being caught by a survey of participants in one of the licensed recreational fisheries in the Azores (boat-based fishing and spearfishing)[47]. See the *Fisheries* section of *Appendix 2* for more detailed matching criteria. The price for bodião verde (0% of boat-based landings and <0.1% of spearfishing landings, by mass) was imputed using the median price of all species/groups landed by recreational spearfishers (€4.64/kg).

Species/group	Price (€/kg)
abrotea	5.88
albacora	4.10
anchova	4.76
badejo	5.88
bagre	6.11
besugo	4.53
Beryx spp.	13.13
bicuda	3.54
boca negra	5.88
bodião	2.32
bodião verde	4.64*
bodião vermelho	3.70
cavaco	27.41
cavala	1.58
cherne	15.4
chicharro	2.25
congro	2.36
cracas	2.80
enchareu	6.72
garoupa	5.42
goraz	14.09
imperador	22.11
iriu	9.66
lapas	7.20

Species/group	Price (€/kg)
lula	8.17
mero	9.74
moreia	1.70
pargo	11.52
patruça	1.27
peixe cão	3.66
peixe galo	12.1
peixe porco	1.50
peixe rei	7.37
polvo	8.13
Raia	1.58
rocaz	16.65
safia	2.51
salema	0.88
salmonete	11.79
sargo	3.66
serra	5.38
tainha	2.47
tamboril	1.96
Thunnus spp.	3.17
veja	2.96
verdugo	1.39
wahoo	2.38

Table A5. We calculated a Recreational Index (RI) for each island in order to extrapolate existing estimates of shore-based recreational fishing effort for the islands of Pico and Faial[48] to the remaining islands. Methods adapted from those used in Pham et al. 2013[21]. *RI is calculated as relative to the baseline value of Pico and Faial. **Pico and Faial are grouped because available data is presented for both islands together and could not be disaggregated.

Island	Population (2017)[9]	Recreational Index (RI)*	Estimated shore-based recreational fishing effort (hours)
Corvo	462	0.88	873.7
Flores	3662	1.51	11895.6
São Jorge	8407	1.07	19422.8
Graciosa	4267	0.55	5107.7
Terceira	55519	0.31	36695
São Miguel	137519	0.14	40794.7
Santa Maria	5649	1.75	21371.8
Pico and Faial**	28377	1*	61225.6

Table A6. Species-specific parameter values used to estimate the revenue generated by Spanish longlining vessels from fish caught within the EEZ of the Azores in 2017 but landed elsewhere. A "-" indicates a species was not landed with that gear type, per available data[57]. A "*" denotes 2018 price data from Vigo used as a proxy when 2017 data were not available for that species.

Species	Price (€/kg)[139]	$CPUE_{Drifting\ Longlines}$ (kg/hour)	$CPUE_{Set\ Longlines}$ (kg/hour)
Prionace glauca	1.45	119.89	72.38
Xiphias gladius	6.57	35.57	25.41
Isurus oxyrinchus	5.43	3.82	3.23
Thunnus obesus	5.27	2.98	0.21
Lepidocybium flavobrunneum	2.8	1.38	0.87
Thunnus alalunga	4.41	0.1	0.01
Coryphaena hippurus	5.96	-	0.05
Ruvettus pretiosus	3.12	-	0.06
Istiophorus albicans	2.33*	-	0.11
Tetrapturus pfluegerirus	2.49*	-	0.1

Table A7. The applicable port use fees (p) [87] and total number of cruise ship visits[80] for each Azorean port in 2017.

Port	$p_{\text{first day (€/GT)}}$	$p_{\text{subsequent days (€/GT)}}$	Fee reduction (k)	Cruise ship visits
Ponta Delgada	0.0787	0.0525	0.3	74
Horta	0.1571	0.0262	0.5	25
Praia da Vitória	0.1102	0.0734	0.5	19
Angra do Heroísmo	0.1571	0.0262	0.5	6
Vila do Porto	0.0787	0.0525	0.3	6
Praia da Graciosa	0.1102	0.0734	0.5	5
Lajes das Flores	0.1571	0.0262	0.5	5
Casa	0.1571	0.0262	0.5	3
São Roque do Pico	0.1571	0.0262	0.5	2
Velas de São Jorge	0.1571	0.0262	0.5	2
Lajes do Pico	0.1571	0.0262	0.5	1
Madalena	0.1571	0.0262	0.5	1

SUSTAINABLE FISHERIES GROUP
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