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Integrated climate, ecological and socioeconomic scenarios for the whale watching sector

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Science of the Total Environment

Dear Associate Editor Martin Drews,

Please find enclosed our manuscript entitled "Integrated climate, ecological and socioeconomic scenarios for the whale watching sector" which we consider suitable for publication as an original research paper to the Science of the Total Environment.

Our study focuses on the development of shared socio-economic pathways (SSPs) for the whale watching sector under a changing climate. To our best knowledge, this is the first study to downscale SSPs to the whale watching sector. Furthermore, we applied this approach to a case study in the Macaronesia region where we integrated the socioeconomic (SSPs), the climate (RCPs) and ecological (species thermal suitability responses) dimensions into four scenarios for the sector. These integrated scenarios were then used to assess the sectors' level of preparedness in a stakeholder workshop. This workshop gathered, for the first time, a diversity of decision-makers (researchers, whale watching company owners, members of each regional government) from the three different archipelagos of Macaronesia (Azores, Madeira and the Canary Islands).

We developed an integrated approach to the assessment of climate change impacts in the whale watching sector and applied it in a practical decision-making context. In addition, we discuss methodological challenges that can contribute to the future improvement and use of this approach in other areas of the world.

We believe our paper is in line with the journal's aims and scope since it provides insights into integrated climate change assessments which are useful to guide policy and research and to support management and adaptation practices.

Thank you for considering our manuscript for publication in the Science of the Total Environment.

Yours sincerely,

Andreia Sousa

Title: Integrated climate, ecological and socioeconomic scenarios for the whale watching sector

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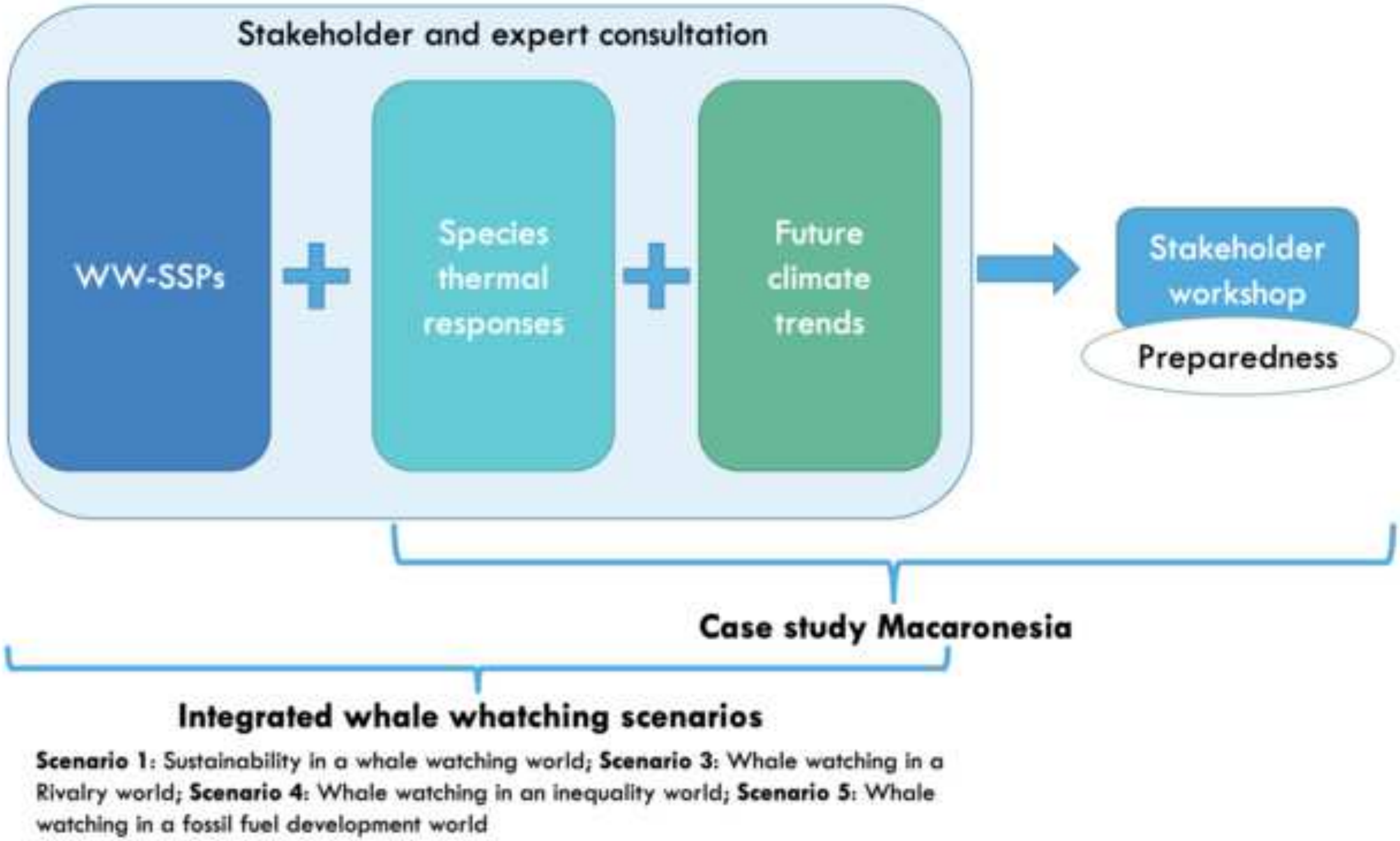
Graphical Abstract



Highlights:

- **An integrated climate change assessment is described for the whale watching sector**
- **Shared Socio-economic Pathways were developed for the sector (WW-SSPs)**
- **Integrated scenarios combined WW-SSPs with the climate and ecological dimensions**
- **Scenarios were discussed with key stakeholders in a case study for Macaronesia**
- **Results proved useful to assess the level of preparedness of the sector**

Integrated climate, ecological and socioeconomic scenarios for the whale watching sector

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Abstract

Unprecedented human induced changes to the climate system have already contributed to a variety of observed impacts to both ecosystems and populations. Decision-makers demand impact assessments at the regional-to-local scale to be able to plan and define effective climate action measures. Integrated socio-ecological assessments that properly consider system uncertainties require the use of prospective scenarios that project potential climate impacts, while accounting for sectoral exposure and adaptive capacity. Here we provide an integrated assessment of climate change to the whale watching sector by: 1) extending the European Shared Socio-economic Pathways (Eur-SSPs) and developing four whale watching SSP narratives (WW-SSPs) and 2) estimating future trends for each specific element present in the different WW-SSPs. We applied this approach in a case study for the Macaronesia region where we developed scenarios which integrate the socio-economic (WW-SSPs), climate (RCPs) and ecological (species' thermal suitability responses) dimensions of whale watching. These scenarios were used by local stakeholders to identify the level of preparedness of the whale watching sector. When confronted with scenarios that combine this ecological dimension with projected climate changes and the four different socioeconomic narratives, stakeholders assessed the whale watching sector in Macaronesia as being somewhat prepared for a Sustainable World and a Fossil Fuel Development World, but somewhat unprepared for a Rivalry World. No consensus was reached regarding the sector's preparedness level under an Inequality World scenario. Our study demonstrates the importance of considering multiple dimensions when assessing the potential challenges posed by climate change and provides a needed resource to help the whale watching sector in Macaronesia, and elsewhere, in its effort to devise efficient climate action policies and strategies.

Keywords: Integrated assessment; shared socio-economic pathways; climate change; cetaceans; whale watching

Introduction

According to the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), anthropogenic climate change is widespread, rapid, and intensifying (IPCC, 2022). Unless immediate, urgent, and large-scale reductions in greenhouse gas emissions occur, global warming of 1.5 – 2°C will be exceeded during the 21st century. Many observed and projected changes in the climate system due to past and future greenhouse gas emissions show severe and irreversible impacts which can lead to great socioeconomic and ecological effects (IPCC, 2022).

The Blue Economy concept is defined as the set of economic activities related to ocean, seas, and coasts, including those in the EU's outermost regions, such as Macaronesia (Azores, Madeira, and the Canary Islands) (European Commission, 2017). These economic activities include marine tourism and marine-related activities (e.g., boating, yachting, nautical sports) which use ecosystem services from the ocean.

Tourism has a prominent role as one of the main economic income sources in Macaronesian islands (BEST, 2016). However, the intensive development of coastal tourism, which brings additional human pressures and impacts to marine and coastal natural habitats, has decreased the destinations' attractiveness (Wolf et al., 2021). In this context, some regions tend to centre their development in sustainable tourism, which is also central in mainstreaming ocean-based economic growth (EPRS, 2019). In the Macaronesia region, the whale watching activity is a significant part of such tourism sector and an important component of a growing Blue Economy (Ressurreição et al., 2022; Suárez-Rojas et al., 2019).

Whale-watching tourism refers to commercial tours where tourists can observe cetaceans (whale, dolphin, or porpoise species) in their natural habitat (Hoyt, 2001). In Macaronesia, which comprises the volcanic archipelagos of Azores and Madeira (Portugal) and the Canary Islands (Spain) in the North Atlantic Ocean, the whale watching activity has been growing over the last decades (Bentz et al., 2016; Krasovskaya, 2017; Sequeira et al., 2009). Although the activity has different characteristics in the different archipelagos, and among islands within the same archipelago, recent estimates indicate more than 35 million euros in direct income to the region (IWC, 2022; Krasovskaya, 2017; Suárez-Rojas et al., 2021). In the Azores and Madeira, the activity has a smaller dimension, with an estimated number of 112, 263 tourists in 2017 in the Azores (DRT, 2018) and 129,158 in 2015 in Madeira (Krasovskaya, 2017), against an estimated number of 724,000 tourists in 2017 in Tenerife, where most of the activity takes place, in the Canary Islands (IWC, 2022).

Climate change is expected to impact whale watching, although the extent to which such effects will be felt is largely unknown (Moreno, 2010). To understand the potential effects of climate change in whale watching, a recent framework was developed using a participatory approach to explore the direct and indirect influence of climate-related impacts on this activity (Meynecke et al., 2017). This framework identified four key modules: 1) the biological module, consisting of species ecological related factors; 2) the climate module, related to relevant climate variables; and the 3) socioeconomic and 4) management module, related to factors such as the number of tourists and enforcement or regulations, respectively.

Scenarios have been widely used to assess climate impacts and better understand the complex interactions and associated uncertainties between the climate system, ecosystems, and human activities (e.g., Borggaard et al., 2020; Haward et al., 2013; O'Neill et al., 2017). A scenario framework has been developed by the climate community encompassing two main components: 1) a set of shared socioeconomic pathways (SSPs); and 2) representative concentration pathways (RCPs) (Ebi et al., 2014; Moss et al., 2010; van Vuuren et al., 2014). SSPs are scenarios that describe plausible and alternative visions of how society may evolve in the coming decades from a range of demographic, economic, technological, social, and environmental factors (O'Neill et al., 2017, 2014). SSPs do not consider climate change impacts and policy responses targeted to climate change action, namely for mitigation purposes. Concurrently, RCPs result from emissions trajectories that represent different levels of radiative forcing, ranging from 2.6 to 8.5 W/m^2 in the year 2100, and generate climate projections that do not correspond to specific societal pathways. Therefore, the combination of SSPs and RCPs constitutes a framework that can be used in studies where climate risk and adaptation options are assessed simultaneously (O'Neill et al., 2020; van Vuuren et al., 2014).

In addition to the qualitative descriptions of societal factors described in SSPs narratives, a subset of factors such as population, urbanization, and Gross Domestic Product (GDP) have been quantified and used in integrated assessment models (IAM), together with other factors related to the physical climate system (Riahi et al., 2017). The combination of socio-economic factors, climate projections, and policy assumptions allow for the development of integrated scenarios, facilitating research, data analysis, and informing policymaking (O'Neill et al., 2020). Global SSPs have been constructed in a conceptual space based on challenges for mitigation and adaptation (O'Neill et al., 2014) and have been extended at different scales and for different sectors (e.g., Maury et al., 2017; Merkens et al., 2016; Reimann et al., 2018). For Europe, four qualitative storylines (Eur-SSPs) were developed (Kok et al., 2018): Eur-SSP1, describes a more sustainable future, characterized by global cooperation and less intensive lifestyles; Eur-SSP3 is characterized by regional conflict where countries struggle to maintain living standards and high environmental degradation; Eur-SSP4, a future controlled by a small political and business elite with economic disparities, but where Europe becomes an important player, with a strong stance on green-energy; and Eur-SSP5, which describes a fossil-fuel driven world with a lack of environmental concerns that will be counteracted by technological development. Eur-SSP2 was not developed due to the moderate change in all elements in this scenario and to minimize the risk of being chosen by stakeholders as the best estimate (Kok et al., 2018).

To address the need for, and improvement of, integrated studies we developed in the present work, whale watching scenarios that can serve as an impact and vulnerability assessment approach to support decision-making. The specific objectives of this study were to 1) extend the Eur-SSPs to the whale watching sector (WW-SSPs) and to 2) attribute future trends to each key element comprised in the WW-SSPs. We then applied the whale watching scenarios that combine WW-SSPs with future climate scenarios (RCPs) and cetaceans' thermal response curves to a case study in the biogeographic region of Macaronesia.

2. Methodology

2.1 Developing WW-SSPs narratives

The first step in developing SSP narratives for the whale watching sector was to identify the key elements relevant for the activity. Key elements were identified from two previously published frameworks on whale watching and climate change (Lambert et al., 2010; Meynecke et al., 2017) and were validated in a stakeholder workshop and in dedicated bilateral meetings with whale watching companies working in the region of Macaronesia (Table 1). The workshop took place on 27th September 2018 with 15 local stakeholders (whale watching company owners, biologists, researchers, and members of the regional government) in the island of São Miguel in the Azores archipelago. In this first workshop whale watching elements were identified and validated. Additionally, 4 online meetings were carried out with individual whale watching companies in the remaining archipelagos of Macaronesia (Canary Islands and Madeira) to ensure all the key and specific elements were listed (Table 1).

The second step was to select the key elements of the Eur-SSPs that would frame the WW-SSPs. We followed the approach of Merkens et al. (2016), where elements from the global SSPs (O'Neill et al., 2014) were used as explanatory variables for a set of coastal SSP elements. We identified the Eur-SSP elements from Kok et al. (2018) and the coastal tourism SSPs from Merkens et al. (2016). These served as explanatory elements for the assumptions adopted in the whale watching narratives (Table 1).

Table 1 – Key socio-economic elements for whale watching and corresponding explanatory European shared socioeconomic pathways (Eur-SSP) elements from Kok et al. (2018) and Costal tourism SSPs from Merkens et al. (2016).

Whale watching [Reference]		**Selected Eur-SSPs Elements**
Key elements	**Specific elements**	
Tourists	Number (Meynecke et al., 2017)	*Coastal Tourism SSPs**
	Preferences (Bentz et al., 2016; Cornejo-Ortega et al., 2018; Mohamed, 2013; Suárez-Rojas et al., 2019;	Education investments Environmental respect

	Torres-Matovelle and Molina-Molina, 2019; Warren, 2012)	
	Type (Lambert et al., 2010)	Education investments Environmental respect Economic development
Costs (Meynecke et al., 2017)	Fuel	Economic development Technology development Quality of Governance
	Wages	Economic development Education investments Quality of Governance
	Assets	Economic development Technology development
	Insurance	Economic development Social cohesion
Income (Meynecke et al., 2017)	Ticket price	Economic development
Regulations (Meynecke et al., 2017)	Licenses Protected areas Enforcement	Quality of Governance Economic development Environmental respect
Knowledge (Meynecke et al., 2017)	Monitoring Research Education	Quality of Governance Economic development
Anthropogenic activities and main associated pressures (MISTIC SEAS II, 2018; MSFD - Annex III, 2015)	**Fisheries** (by-catch; prey availability; marine litter) **Maritime transport** (anthropogenic sound; death or injury by collision; input of contaminants) **Nautical tourism** (anthropogenic sound; input litter; disturb species) **Military exercises** (anthropogenic sound; death or injury) **Aquaculture** (input of contaminants and organic matter) **Renewable energy** (anthropogenic sound) **Seabed mining** (anthropogenic sound; destruction of seabed habitats)	Environmental respect Quality of governance Technology development
Dimension of activity (Meynecke et al., 2017)	Number of operators Number of vessels	Economic development

* In this particular element, coastal SSPs were used directly from Merkens et al., 2016.

Specifically, we assumed that environmental respect is related to ecosystem health and environmental pressures (McKinley and Fletcher, 2012). Tourist trends were derived from the coastal tourism SSPs. These trends were complemented with additional assumptions on tourists' preferences for whale watching in Europe (Table 1). We considered that education, income, and environmental values influence tourists decisions to undertake an activity (Cohen et al., 2014; Cornejo-Ortega et al., 2018; Li and Cai, 2011; Tkaczynski and Rundle-Thiele, 2018), while recognizing the complexity of factors involved in decision-making such as participants personality, attitude, preferences, or satisfaction (Bentz et al., 2016; Shahrivar, 2012; Vieira et al., 2018). In general, whale watchers consider important that tours are environmental-friendly and educational. Studies show that satisfaction factors vary according to different regions, nationalities or gender (Bentz et al., 2016; Musa, 2002). Most studies show that seeing whales, cost of trip, boat type, low crowding and closeness to the animals are important factors for tourist satisfaction (Bentz et al., 2016; Cornejo-Ortega et al., 2018; Mohamed, 2013; Suárez-Rojas et al., 2021; Torres-Matovelle and Molina-Molina, 2019; Warren, 2012). In our study, we considered two whale watchers typologies – the "generalist" and the "specialist" – which vary according to their different level of interest in observing a cetacean species (Lambert et al., 2010).

We established several links in regard to the key and specific elements of the WW-SSPs (see Table 1). In regard to energy, there are several factors that can influence its cost such as supply and demand, weather forecasts, global markets, imports and exports, and government regulations (Bilgen, 2014; Costantini et al., 2007; Umbach, 2010). While recognizing the contribution of all these factors, we assumed the cost of fuel to be related to a supply and demand behaviour and linked to economic and technological development. We also considered that governmental regulations are linked to the quality of governance which in turn can promote the evolution of the energy sector by replacing conventional energy with alternative sources of renewable energy (Abolhosseini et al., 2014; Bilgen, 2014; Kumar and Managi, 2009). Costs for maintenance of assets and infrastructure are related to technologic and economic development which are driven by energy needs and material resource intensity (Allwood et al., 2013). We assumed costs of insurance to be linked to market concentration as well as to challenges for adaptation. Market concentration is driven by economic development and social cohesion which are in turn associated to the distribution of wealth within society. We assumed that a higher level of education is linked to higher wages (Albert and Davia, 2005). The price of tour and company's income will be affected by the economic power of tourists (Tkaczynski and Rundle-Thiele, 2018). We assumed that regulations, namely number of licenses and the extension of protected areas, as well as enforcement of procedures (e.g., code of conduct), are associated with the quality of governance and economic development which ensure that financial and human resources are available to invest in the implementation and enforcement of such regulations (Bennett and Dearden, 2014; Lockwood et al., 2012).

2.2 Case study: Whale watching scenarios for Macaronesia

The Macaronesian archipelagos of the Azores, Madeira, and Canary Islands (Figure 1) were selected as a case study since they are considered a biodiversity hotspot, renowned for its diversity of species, ecosystems, and landscapes (BEST, 2016; Myers et al., 2000). A large number of cetacean species (over twenty) have been recorded in Macaronesia (Alves et al., 2018; Carrillo and Ritter, 2010; Silva et al., 2014). This largely contributed to the development of the whale watching industry in this region over the past decades making Macaronesia one of the main international destinations for this activity (Suárez-Rojas et al., 2019).

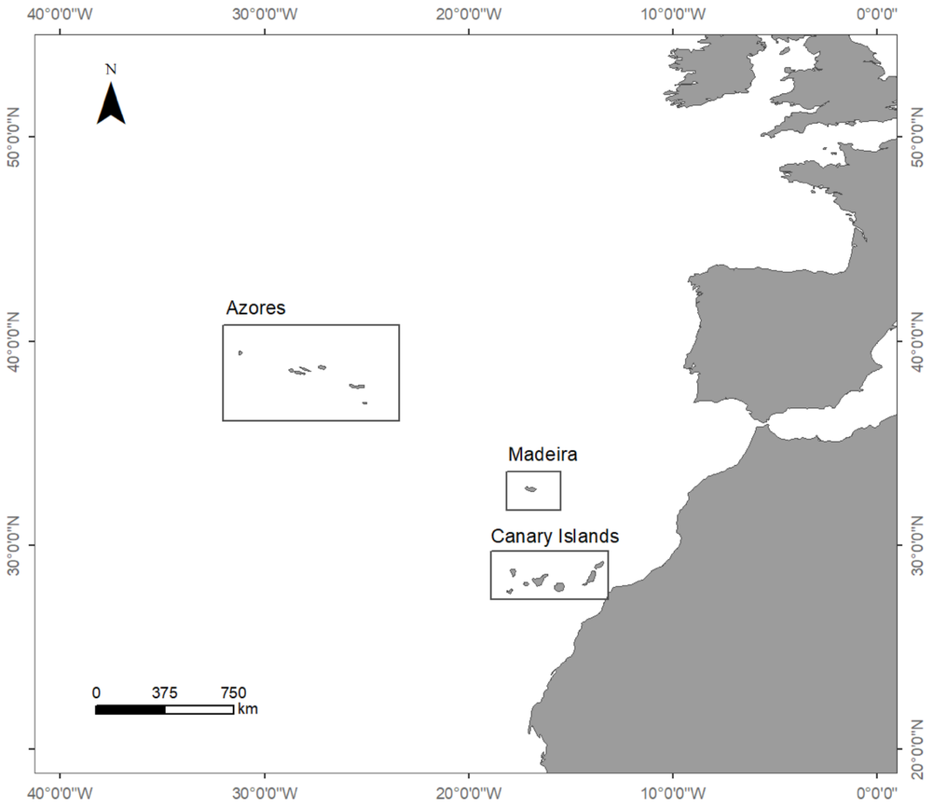

Figure 1 – Macaronesia bioregion, depicting the archipelagos of the Azores, Canary Islands and Madeira.

We developed four whale watching scenarios for the biogeographic region of Macaronesia by integrating WW-SSPs (socio-economic module) with future climate trends (climate module) and cetaceans' thermal suitability responses (biological module) (Figure 2). For simplicity, scenarios took the name of the WW-SSPs, i.e., Scenario 1: Sustainability in a whale watching world; Scenario 3: Whale watching in a Rivalry world; Scenario 4: Whale watching in an inequality world; Scenario 5: Whale watching in a fossil fuel development world.

WW-SSPs were developed as detailed in section 2.1. Future climate trends were obtained through literature review to feed the climate module. Similarly, cetaceans' thermal habitat suitability curves under RCP 4.5 were developed through expert judgement and responses to changes in sea surface temperature were projected (Sousa et al., in preparation) and further used to feed the biological module (Figure 2). We selected RCP 4.5 because, from the three most commonly applied RCPs (2.6; 4.5; 8.5), is the one for which integrated assessment models found feasible outcomes across all SSPs (O'Neill et al., 2020). The short to mid-century timeframe (2006-2055) was selected to assist decision-making processes and support adaptation measures that target species' conservation.

Finally, the developed scenarios were presented and validated through collaboration with 13 stakeholders from Macaronesia in a workshop on 28-29th June 2021. Local stakeholders included whale watching company owners, biologists, researchers, and members of the regional government from each archipelago of Macaronesia. Additionally, stakeholders were asked to identify the level of preparedness (from very prepared, somewhat prepared, somewhat unprepared, and very unprepared) of the whale watching sector in their archipelago, under different scenarios.

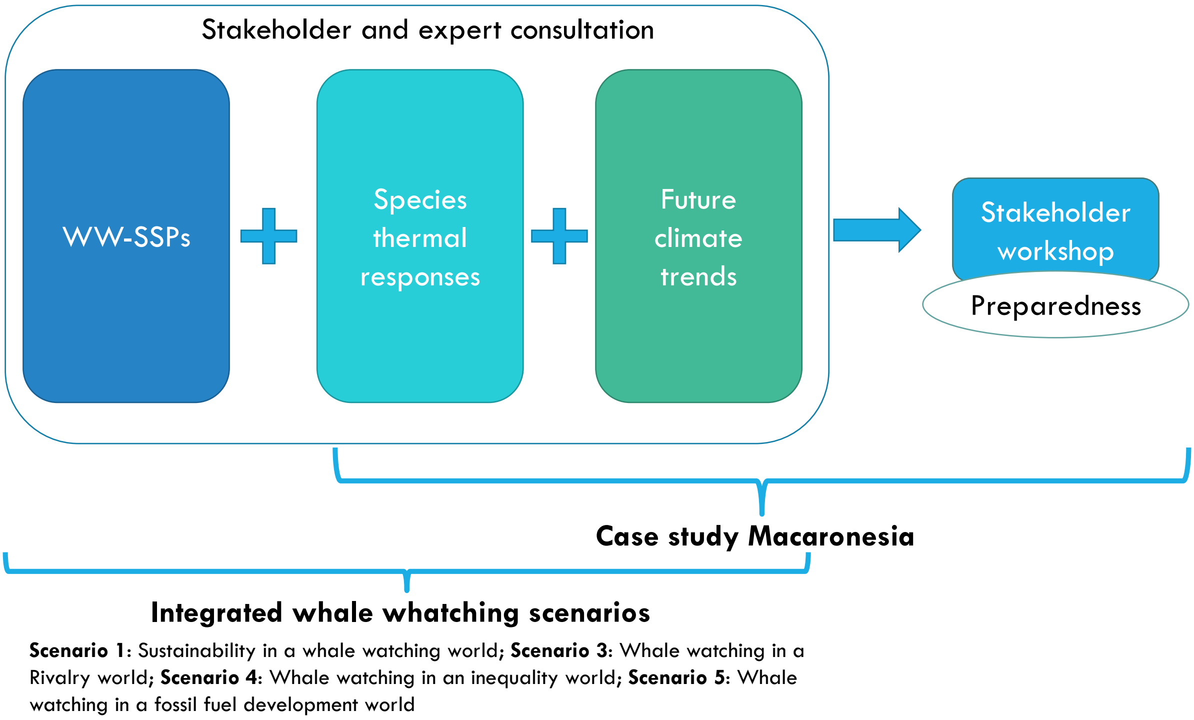

Figure 2 – Conceptual model of the development of whale watching scenarios that combine the biological, climate and socio-economic modules (adapted from Meynecke et al., 2017) which was integrated in a stakeholder workshop where the preparedness of the sector was assessed under the different scenarios.

3.Results

3.1. WW-SSPs narratives

The four WW-SSPs narratives that were developed (based on the four considered Eur-SSPs), together with future trends for each specific element in the different SSPs are presented in Table 2 and detailed in the following sub-sections.

WW–SSP1: Whale watching in a sustainable world

In Europe and worldwide, there is a shift towards a sustainable development pathway with a high commitment towards less resource intensive lifestyles. There is a greater focus on well-being over economic growth, which is supported by high levels of political and societal awareness on the importance of environmental quality. As a result, there are high cetaceans encounter rates for the whale watching activity. Environmental pressures are reduced, and a good environmental status is effectively maintained, with low impact on species. Sustainable tourism practices with low impact together with the reduction in long-range travel and the absence of mass tourism reduce the number of tourists and whale watchers. Under this pathway, the low number of tourists leads to a reduced number of operators and vessels. Whale watchers are mainly specialists who are highly interested in observing cetacean species. Ticket prices are maintained due to an initially slower economic growth, increasing in the long term by accompanying the movement towards a continued steady economic development.

Environmental-friendly conditions including commitment to existing regulations by tour operators and the educational components of the activity are valued in this pathway.

Costs are high for fossil fuels due to lower supply and strong environmental policies. There is a high incentive for the use of alternative clean energy sources (e.g., electric energy) which translates into higher costs that are recovered in overall revenues. Steady economic growth and investment in education lead to higher wages. Costs are high for maintenance of assets and infrastructure due to low material growth, low material resource and low energy intensity. Costs of insurance are low in a context of fair trade and low challenges for adaptation.

In this pathway, sustainable whale watching practices are conducted with a reduced number of operators and tourists, both with high environmental concerns, promoting sustainable practices with low impact on cetacean species and a focus on sustainability.

WW–SSP3: Whale watching in a regional rivalry world

This pathway focuses on the increase of national and regional blocks, which result in a widespread fragmentation and division at the decision-making level. There is low social cohesion, education, health, and technological investments. The environment degrades with severe ecosystem failures due to an intensive material consumption and low priority for environmental protection. Environmental degradation and increasing environmental pressures lead to lower cetaceans sighting rates. Tourism is restricted, with no international tourism, which leads to a low number of whale watchers. Short range tourism is mostly confined to national borders/regional blocks with a reduction in the number of tourists. Ticket prices and profit margins are low due to low economic development. The whale watching activity is characterized by a strong reduction in number of operators and vessels because of low economic and technological development.

Due to low investments in education and low environmental respect, tourists' satisfaction is low. The activity is less focused on education, research or monitoring with little to no respect for regulations.

The costs of whale watching activity are high for fossil fuels due to high demand, and low incentive for the use of alternative clean energy (e.g., electric energy) because technology is scarce and only available at high costs. Costs for maintenance of assets and infrastructure are low due to lack of economic resources and increasing resource intensity and fossil fuel use. Strong inequalities and low economic and education investments lead to lower labour force wages. Costs of insurance are high due to high challenges for adaptation and unregulated prices due to market concentration.

In this pathway, whale watching is characterized by a low number of operators and tourists, with a reduced number of tours and lower sighting rates due to a degraded environment with high impacts on cetacean species.

WW–SSP4: Whale watching in an inequality world

This pathway is characterized by a high social inequity that results in unequal investments in human capital, leading to large social disparities across and within countries. There is a powerful political and business elite and a lower income working class. Europe becomes a leader in green technologies with energy supply controlled by the elite. A powerful European government enforces environmental policies and commits to reduce the depletion of natural resources that are focused locally on important areas of middle and high income classes, thus creating pocket areas of environmental protection. Environmental pressures are locally mitigated resulting in the reduction of local pressures. Cetaceans sighting rates will vary depending on the area.
Tourism is high for the elites and low for most of the population leading to a decrease in number of tourists and, consequently, to a reduction in the number of operators and vessels. However, the high economic power of the elites allows for high ticket prices.
The elite is characterized by high educational and environmental values, supports environmental-friendly conditions for whale watching and the fulfilment of regulations.
Cost of fuel is high for fossil fuels and for the use of alternative clean energy due to a controlled energy supply (ran by an oligarchy of green business developers). Wages are low due to lower income for the working class in a labour-intensive work environment. Costs for assets and infrastructures are high due to market concentration of suppliers, namely for low-carbon energy technologies. Insurance costs are high due to high challenges for adaptation together with market concentration.

In this pathway, whale watching is characterized by a reduced number of elite tourists and a reduced number of operators and tours. The environment is locally protected with low impacts for cetacean species.

WW–SSP5: Whale watching in a fossil fuel development world

In a market driven, fossil fuel dependent world, populations adopt energy intensive lifestyles. Economic and social development are strongly dependent on the exploitation of fossil fuels particularly shale gas in Europe. The environment degrades but there is faith in technological solutions to manage ecological and social systems including geo-engineering. The environment is locally degraded; however, successful technological innovations address these changes allowing for an efficient search for species with guaranteed sightings. Environmental pressures are also mitigated with technology and regulations that effectively create locally protected areas to ensure that the activity takes place. Tourism is very high, characterized by mass tourism where an increasing number of whale watchers – mainly generalists – that are able to pay high ticket prices due to high economic development. The whale watching activity is characterized by a high number of operators and vessels due to strong economic development and high number of tourists where preferences related to environmental-friendly and educational tours may not be fully met. Considering the high number of tourists crowding takes place with high impact on cetacean species that are mitigated by technological developments. In addition, the likelihood of observing a cetacean species is lower but also counteracted by technology.

Costs of fossil fuels are low but tend to rise over time. The use of alternative clean energy sources increases as prices of fossil fuels rise towards the end of the century. Costs for maintenance of assets and infrastructure are low due to a strong focus on technological solutions fuelled by the exploitation of fossil fuel resources. High education investments and economic growth lead to higher wages of the working staff. Insurance costs are low due to low challenges for adaptation, despite losses due to extreme weather events. Business competition and high income ensure competitive and accessible prices of insurances.

In this pathway, whale watching is characterized by an increasing number of operators and tourists in a degraded environment with high impacts for cetacean species that are mitigated by technology.

Table 2 - Future trends for each whale watching specific element in the different whale watching shared socioeconomic pathways (WW-SSPs).

Elements	Specific elements	WW-SSP1 Sustainability	WW-SSP3 Regional Rivalry	WW-SSP4 Inequality	WW-SSP5 Fossil fuel development
Tourists	Tourist numbers	↓	↓	↑ elites ↓ lower class	↑
	Tourist satisfaction	↑	↓	↑	↓
	Tourist type	↗ specialist ↘ generalist	↘ specialist ↘ generalist	↗ specialist ↘ generalist	↘ specialist ↗ generalist
Costs	Fuel	↑	↑	↑	↓
	Wages	↑	↓	↓	↑
	Assets	↑	↓	↑	↓
	Insurance	↓	↑	↑	↓
Income	Ticket price	↗	↓	↑	↑
Regulations	Licenses	↓	↓	↓	↑
	Protected areas	↑	↓	↑	↑
	Enforcement	↑	↓	↑	↑
Knowledge	Monitoring	↑	↓	↑	↑
	Research	↑	↓	↑	↑
	Education	↑	↓	↑	↑
Anthropogenic activities (main associated pressures in table 1)	Fisheries Maritime transport Nautical tourism Military exercises Aquaculture Renewable energy	↘	↗	↘	↘
Dimension of activity	Number of operators Number of vessels	↓	↓	↓	↑

↑ high, ↓ low, ↗ increase, ↘ decrease

3.2. Case study: Whale watching scenarios for Macaronesia

3.2.1 Future climate trends

The most relevant climate variables for the whale watching activity identified by local stakeholders in Macaronesia were wind speed, wave height, frequency and intensity of extreme events that influence the number of days with suitable sea conditions, and atmospheric conditions that influence tourists' comfort levels. Comfort levels influence destination choices, which in turn impact the number of tourists traveling to each archipelago.

Tourists' thermal discomfort level for the Canary Islands indicates, through the application of the humidity index, projected an increase of 11.5 (RCP2.6) and 27.2 (RCP 8.5) number of days per year with a discomfort level greater than 35°C, for the period 2046-2065 (SOCLIMPACT, 2020). For the Azores archipelago an increase of 27.1 (SRES B1) and 35.5 (SRES A1B1) days with discomfort levels great than 35°C, for the period 2031-2050, were projected. For Madeira an increase of 0.6 (RCP 2.6) and 5.2 (RCP 8.5) days with discomfort levels were projected for the period 2046-2065 (SOCLIMPACT, 2020).

Integrated climate assessments that respond to the potential impacts of changes in coastal-to-open-ocean environments are strongly dependent on wave-climate projections (height, length, and directions) and associated levels of confidence (Morim et al., 2018). Like in other oceanic areas, future wind and wave climate trends in the Macaronesia region are constrained by large uncertainties surrounding future North Atlantic storminess (Bricheno and Wolf, 2018), including extratropical cyclone development (cyclogenesis) and storm tracks in the region (Harvey et al., 2012; Aarnes et al 2017, Lobeto et al 2021). These uncertainties in current projections are dominated by climate model-driven uncertainty (Morim et al., 2019). Additionally, the scientific community's efforts have focused more on sampling inter-model and/or inter-scenario uncertainty than on the intra-model variance originated in the chaotic nature of the climate system, making up for an influence of uncertainty that is currently greater than the actual projected changes (Morim et al., 2018).
In the North Atlantic Ocean, the scientific consensus points to a projected decrease in annual and seasonal mean significant wave height ($\overline{H}s$) and in extreme wave heights (Hs), that is more pronounced under RCP8.5 and generally consistent with projected wind changes (Aarnes et al., 2017; Lemos et al., 2021; Lobeto et al., 2021; Morim et al., 2018). Expected changes in surface wave climates are a response to changes in the frequency, intensity and position of forcing winds and storms and to changes in sea-ice and associated impact on fetch conditions (Fox-Kemper and et al., 2021).
Several explanations have been put forward for the projected decreases in the North Extratropical Atlantic region. These include the expected enhanced warming of the Artic and extratropical regions that may reduce the North-South temperature gradient, thus decreasing baroclinic instability and cyclogenesis (Aarnes et al., 2017). Additionally, projected increases in the occurrence of weather types that are dominated by high-latitude storm tracks (above 50° N) and atmospheric blocking patterns, along with decreases in the occurrence of lower-latitude storm tracks and negative North Atlantic Oscillation (NAO) patterns, are consistent with scenarios of a generalized decrease in $\overline{H}s$ and extreme Hs (Lemos et al., 2021). This can be partly explained by the spatial patterns and the north Atlantic's relatively narrow coastal

geometry, since a projected displacement of storm tracks to higher latitudes, where the presence of land masses with sheltering effect is larger, will make available open ocean areas for wave generation – fetches – limited, and in turn reduce wave heights (Semedo et al., 2015; Lemos et al., 2021).

Climate extreme events are projected to be affected by changes in ocean conditions. Future climate trends in frequency and magnitude of extreme events, such as tropical cyclones (TC), still demonstrate low confidence and high uncertainty (van Oldenborgh et al., 2017; Weinkle et al., 2012). TC are likely to decrease in frequency or remain unchanged (Christensen et al., 2013). Also, a decrease in the number of extratropical cyclones in the North Atlantic basin is expected (Michaelis et al., 2017; Zappa et al., 2013). Moreover, the number of tropical storms in the North Atlantic may decrease driven by its sensitivity to Atlantic Meridional Overturning Circulation (AMOC) and Subpolar Gyre (SPG) variations (IPCC, 2019).

3.2.2 Cetaceans' thermal responses

In Macaronesia, species' thermal suitability responses under RCP 4.5, showed that 3 out of 10 cetacean species are likely to decrease their thermal suitability, while the remaining 7 are likely to increase (Figure 3).
A higher increase in thermal suitability was found for Bryde's whale (*Balaenoptera brydei*), short-finned pilot whale (*Globicephala macrorhynchus*) and spotted dolphin (*Stenella frontalis*), while a lower increase in suitability was found for Blainville's beaked whale (*Mesoplodon densirostris*), sperm whale (Physeter macrocephalus), Cuvier's beaked whale (*Ziphius cavirostris*) and common bottlenose dolphin (*Tursiops truncatus*) (Sousa et al., in preparation) (Figure 3).

Species thermal suitability responses consider exclusively sea surface temperature. However, species occurrence patterns relate to a combination of physical and biological features, which show that different environmental variables besides temperature can influence species movements and distribution. In addition, species can occur in waters within core temperatures of their thermal niche and select, in that range, preferred habitat characteristics regardless of temperature (Correia et al., 2021; Lambert et al., 2011). Despite these limitations, future thermal suitability responses are a simple and easy to apply method, targeted for decision-makers, which provides a rapid assessment of a large number of species (Sousa et al., in preparation).

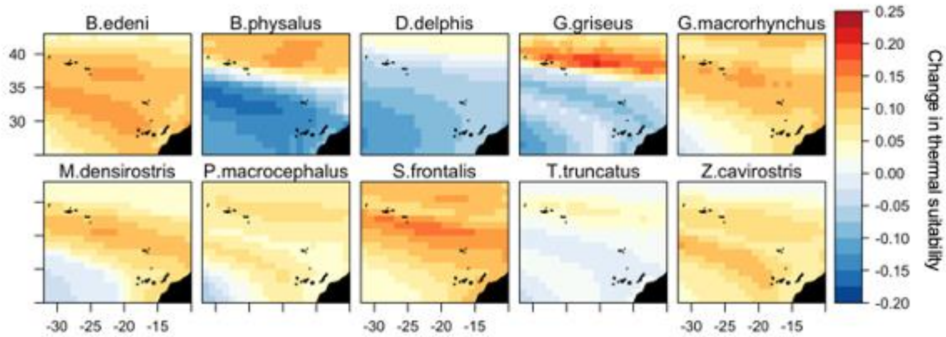

Figure 3 - Changes in thermal suitability for cetaceans in Macaronesia (adapted from Sousa et al., in preparation). The scale indicates the changes in thermal suitability between the

historical (1956-2005) and the projected (2006-2055) sea surface temperature according to species' thermal curves. Species are identified by their scientific name as follows: *Stenella frontalis* (Atlantic spotted dolphin); *Balaenoptera edeni* (Bryde's whale); *Balaenoptera physalus* (Fin whale); *Globicephala macrorhynchus* (Short-finned pilot whale); *Delphinus delphis* (short-beaked common dolphin); *Physeter macrocephalus* (Sperm whale), *Grampus griseus* (Risso's dolphin); *Tursiops truncatus* (Common bottlenose dolphin); *Mesoplodon densirostris* (Blainville's beaked whale); *Ziphius cavirostris* (Cuvier's beaked whale). Numbers in the upper left and in the bottom indicate latitude and longitude, respectively.

3.2.3 Stakeholder workshop

Overall, stakeholders in Macaronesia considered whale watching to be *somewhat prepared* for a Sustainable world (69%; n=13) and for a Fossil fuel development world (46%; n=13) and *somewhat unprepared* for a Rivalry world (62%, n=13). Stakeholders were divided between whale watching being *somewhat prepared* (31%, n=13) and *somewhat unprepared* (39%, n=13) for an inequality world. A *very unprepared* whale watching was identified in scenario 4 (15%, n=13) and especially in scenarios 3 (31%, n=13) and 5 (31%, n=13).

4.Discussion

The WW-SSPs developed in this study consider consistent and plausible scenario pathways for the whale watching sector. These scenarios were useful in raising awareness, communicating and debating the effects of climate change on the whale watching activity with decision makers and stakeholders of Macaronesia.

When extending Eur-SSPs narratives at smaller scales and to specific sectors, the assumptions defined for some key elements are often simplified. For example, there are several factors that can influence the cost of energy or tourist's satisfaction that are challenging to fully capture in the development of narratives. Tourists' satisfaction is characterized by multiple drivers that vary according to different regions, nationalities or gender (Bentz et al., 2016; Musa, 2002). In addition, several assumptions considered in each narrative scenario can be open to different interpretations (Zandersen et al., 2019). For example, in SSP4 we assumed that there was an interest in the protection of the environment by a highly educated elite. However, a balance between a protected environment and socio-economic interests by the elite may also take place. In addition, a marine environment protected by the elite only "in pockets" or an environment protected only in ones' "own backyard", such as the one described for SSP5, can be challenging to contemplate, and the spatial implications of such "pockets" or "backyard areas" difficult to assess.

Further research on the application and comparability of whale watching scenarios in other geographical areas can offer additional insights into the uncertainty and multiple interpretations considered in the narratives. While we consider that the key elements and assumptions used in our study have a generic nature and can be applied to the whale watching activities in most regions, there may be small scale specificities which can be revised and incorporated in the scenarios. In addition, we used mainly a top-down approach in the development of scenarios but these were discussed and validated through stakeholder and expert consultation. Other approaches to extend SSPs using both top-down and bottom-up approaches have been carried out with different levels of participatory involvement, where local and regional actors co-produce the narratives (Nilsson et al., 2017; Zandersen et al., 2019). Currently, there is not a commonly agreed best practice to downscale SSPs; however, work on reproducible and consistent methods to apply the SSP-RCP framework at regional and local scales is recommended (O'Neill et al., 2020).

Other recommendations to improve the SSP-RCP framework have been identified by O'Neill et al. (2020) such as the need to capture widely different yet plausible societal futures. For example, futures with low or limited growth that can maintain economic stability, societal cohesion, and an investment in innovation without additional growth (Hickel et al., 2021) or futures that are driven by disruptive technological, social, political or environmental events (e.g., Foster, 2020; Kuhnhenn, 2018; O'Neill et al., 2020; Otero et al., 2020).

Additionally, it has been acknowledged that SSPs do not explicitly address the relationship between human development and nature and fail to incorporate social-ecological feedbacks that underestimate, for example, the effects of tipping points (e.g., fisheries collapse) (Rosa et al., 2017).

To overcome this limitation, we have included in our scenarios cetaceans' thermal response curves which aim to provide information on the potential effects of climate change on species that are an integral element of the whale watching activity.

When developing WW-SSPs for Macaronesia the current characteristics of the whale watching activity in each archipelago and in islands within each archipelago determine the understanding of future narratives and the range of adaptation options to be considered. For example, Azores and Madeira would likely be better able to adapt to an environmentally driven SSP1 world as opposed to the Canary Islands. In the Canary Islands, particularly in Tenerife, the continuation of the current mass tourism model will limit the sector's sustainability in this scenario.

The environmental and socioeconomic elements in Scenario 3 will generate very challenging conditions for the sector, making it very difficult to sustain a profitable business in any of the archipelagos. The Macaronesia whale watching sector's natural dependence on international tourism in a scenario of low ticket prices, high costs of fossil fuels and low environmental status will create a problematic setting for the activity, from both a natural and human point of view.

In Scenario 4, a scenario dominated by inequality and elite driven tourism the whale watching sector will require greater adaptation efforts in all archipelagos. This is a scenario where potentially small companies would disappear and an investment in a high-end whale watching product will need to occur, driving even larger disparities in human and social capital.

Scenario 5 implies a whale watching activity where pressures on cetaceans and the environment would be substantial because of a mass tourism driven world where dilapidation of natural and social capital will be counteracted by technological developments.

Although recognizing that this is a social-ecological and environmentally challenging pathway, the participating stakeholders recognized that it is difficult to assess the future evolution of the sector in this scenario. The main reason being that economic growth and technological innovation are expected to counteract environmental degradation, creating the conditions for a continuous expansion of a sector which prides itself in being sustainable.

In this study, we used the best available climate projections for the North Atlantic, which include the Macaronesia bioregion, while acknowledging that existing information is limited and uncertain. Climate impact assessment studies require high temporal and spatial resolution climate projections, which can be obtained by downscaling data from global climate models using different techniques. These techniques have several limitations, particularly in islands, due to the limited available climate and meteorological data, the difficulties in capturing the effect of islands' topographic complexity that influence small scale atmospheric phenomena (e.g., precipitation regime), and the large computation capacities required to compute the number of simulated scenarios (Christensen et al., 2007; Tomé, 2013). Future research in areas such as Macaronesia would benefit from increasing the efforts to downscale climate projections for island regions.

5. Conclusions

To the best of our knowledge, this is the first study to extend the Eur-SSPs to the whale watching sector. Additionally, a case study to integrate the socioeconomic pathways, climate trends and species impact assessment and test the use of scenarios for adaptation planning was developed for Macaronesia. From our perspective, despite the listed limitations, obtained results were extremely useful to initiate a debate on the potential changes to the whale watching activity driven by climate change and to support and inform adaptation planning for the first time in the Macaronesia region.

Further work to quantify each whale watching key element should be carried out to support the creation of integrated impact models. To achieve a coherent quantification of WW-SPPs specific elements, standardized information on key whale watching elements should be collected by the Regional Government in each archipelago of Macaronesia.

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Figure 1

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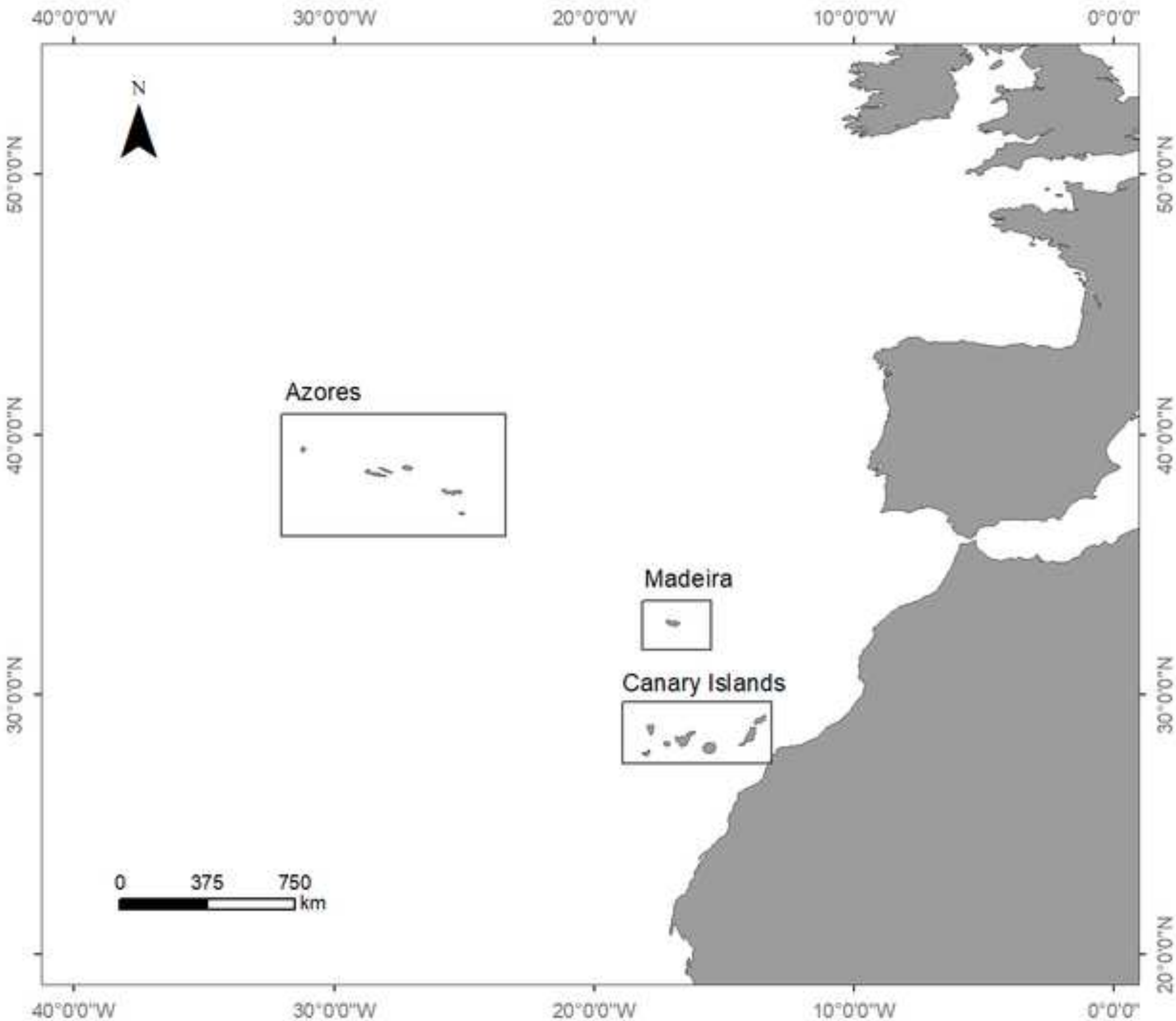

Figure 2

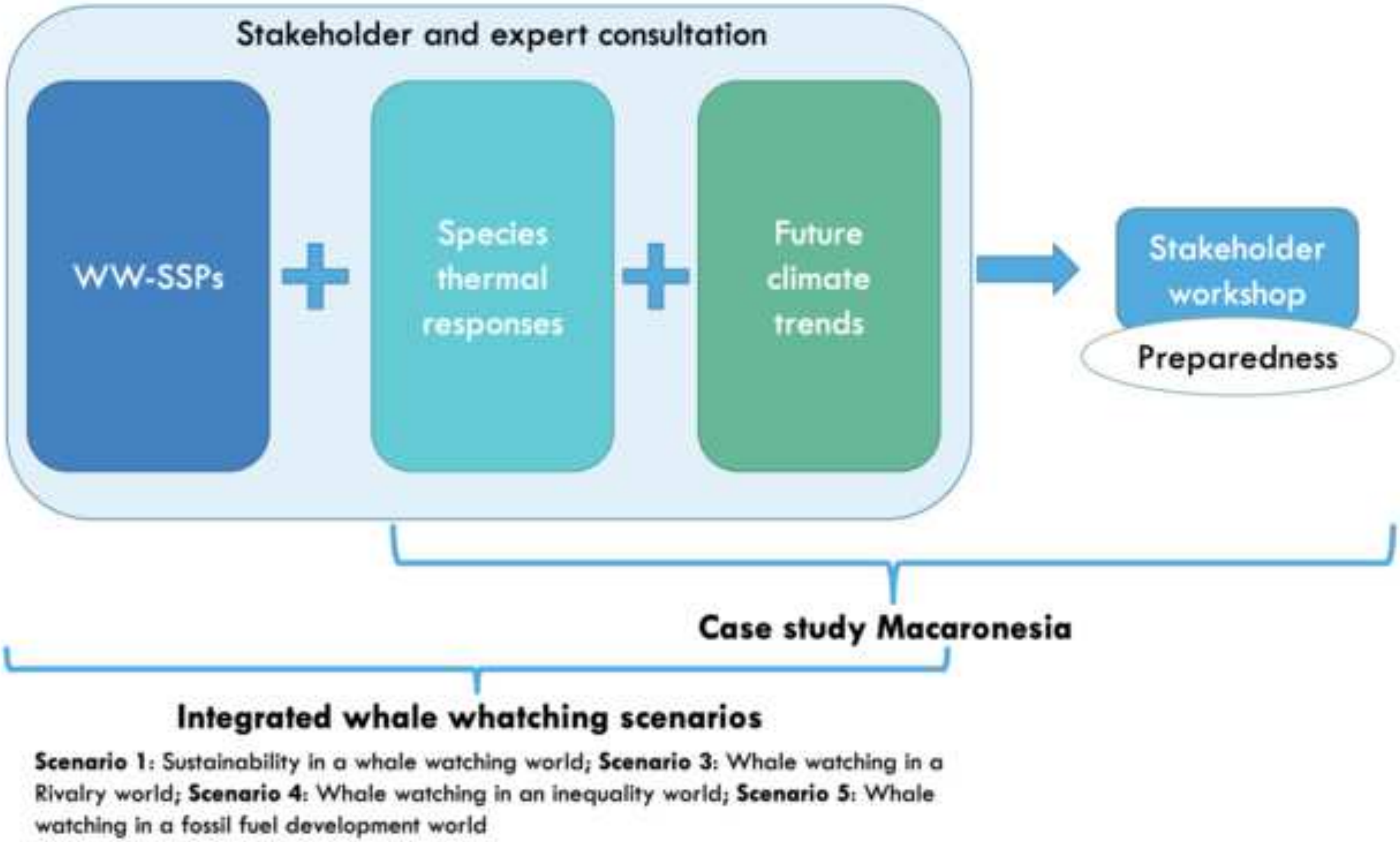
Stakeholder and expert consultation
WW-SSPs
Species thermal responses
Future climate trends
Stakeholder workshop
Preparedness
Case study Macaronesia
Integrated whale whatching scenarios
Scenario 1: Sustainability in a whale watching world; **Scenario 3**: Whale watching in a Rivalry world; **Scenario 4**: Whale watching in an inequality world; **Scenario 5**: Whale watching in a fossil fuel development world

Figure 3

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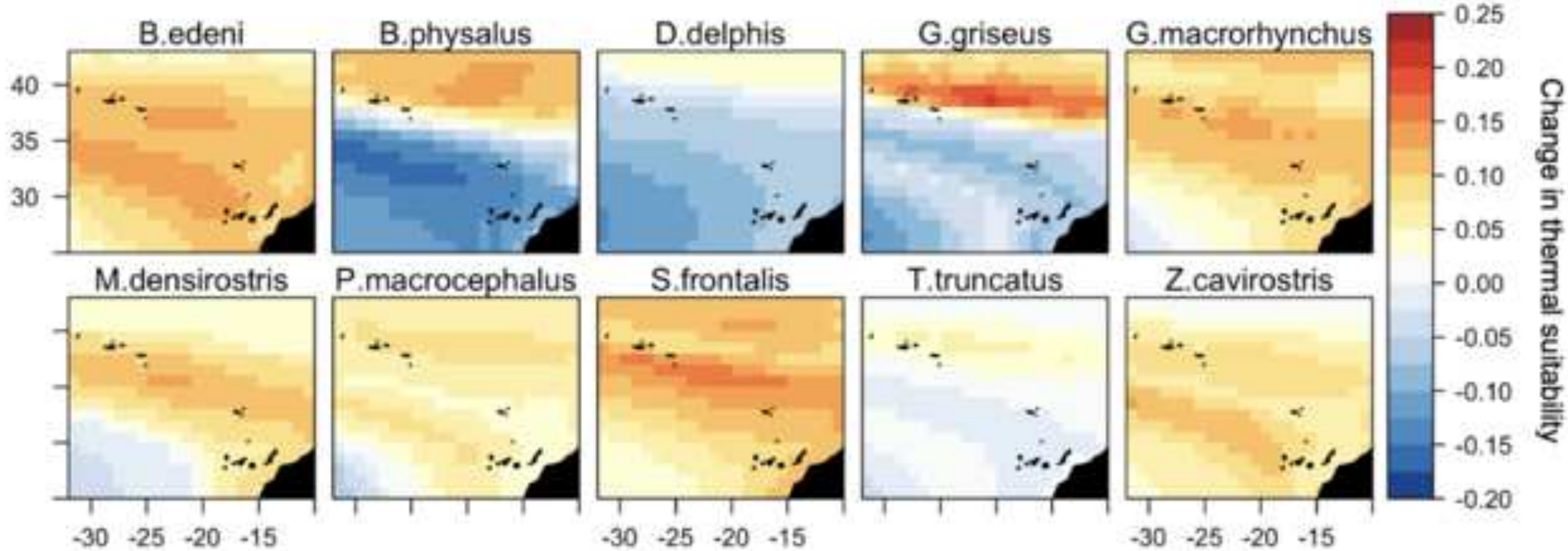

Declaration of interests

☒The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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