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Assessing the climate-related risk of marine biodiversity degradation for coastal and marine tourism

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ABSTRACT

Coastal and marine tourism faces multiple climate risks. The degradation of marine ecosystems may have profound implications for destinations, especially if marine activities are the main attraction. This study aims to assess the climate-related risk of marine habitat degradation to coastal and marine tourism. Risk analysis is undertaken through a blended methods approach by adapting the IPCC AR6 concept of climate risk, the Impact Chain framework and hierarchical multi-criteria analysis with stakeholders' participation. The study is based on representative European islands, allowing comparison of risk as a composite of hazard, vulnerability (sensitivity and adaptive capacity), and the exposure of the tourism system to the hazard. The analysis is undertaken across diverse tourism areas that share the challenge of developing tourism-based economies that are more resilient to climate change. Results indicate that the most relevant factor explaining the level of risk is adaptive capacity. The study captures islands' heterogeneities from the local perspective that might inspire collaborative policy-design. Different scenarios regarding the islands under study highlight specific adaptation policy areas that might be prioritised in each case to more effectively respond to the threat. The study demonstrates the validity of the blended methods approach for adaptation planning in coastal tourism areas.

1. Introduction

Ocean and coastal areas host key ecosystem services that sustain a wide range of blue economy activities and human settlements worldwide (Uribe et al., 2021). However, marine ecosystems are extremely vulnerable to the impacts of climate change. Ocean warming, sea level rise and the intensification of extreme weather events impact marine biodiversity dynamics at multiple temporal and spatial scales, from genes to ecosystems (Gissi et al., 2021; Hillebrand et al., 2018; IPCC, 2022). Despite the quality of marine ecosystems being paramount, downscaled data and tools that support and guide efficient governance and monitoring are still scarce (Gössling et al., 2018).

Coastal and marine tourism represents one of the most significant blue economy activities in Europe (Leposa, 2020) that is expected to be reshaped by climate change. As tourists' interaction with the sea takes the form of activities, e.g., sunbathing, snorkelling, diving, glass-bottom boating (Arabadzhyan et al., 2021; Scott et al., 2012), a satisfactory tourist experience is partly dependent on the quality of marine ecosystems (Belgrano and Villasante, 2021). Loss of biomass and biodiversity, the reduction in cleanliness and water transparency due to sea water heating, acidification and human pressure may have profound implications for the viability and value of sea activities and sports (Belgrano and Villasante, 2021). This can harm the image of coastal destinations, thereby reducing the profitability of tourism (Arabadzhyan et al., 2021). In this context, research contributions on the link between physical and socio-economic impacts is seldom accomplished when analysing climate-related damages to marine ecosystems as foundational for coastal tourism (Arabadzhyan et al., 2021; Cuttler et al., 2018; Gissi et al., 2021).

The climate impact chain methodology is useful for identifying, systemising and prioritising the climatic, environmental and socio-economic aspects that drive climate-related threats to several sectors - e.g., agriculture, energy, etc. (Zebisch et al., 2021). It is also a recommended step in preparing adaptation planning. Only a few studies provide an impact chain analysis in the coastal and marine tourism context (Menk et al., 2022). Hence, the aim of this research is to assess climate-related risk to the coastal tourism system due to marine biodiversity degradation by adapting and applying the impact chain framework.

The study revises the latest scientific advancements in climate risk

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assessment and proposes a blended methods approach, which merges the impact chain framework (Zebisch et al., 2021) with multi-criteria hierarchical analysis and stakeholder participation. The risk is analysed for a reference time period (1986–2005) and projected for two time slices (2046–2065 and 2081–2100) under a high emissions scenario, compatible with the Representative Concentration Pathway - RCP 8.5 (IPCC, 2022; Menk et al., 2022).

Risk is assessed according to the latest IPCC AR6 concept, as a compound of *hazard*, *vulnerability* and *exposure* dimensions (IPCC, 2022). The study is underpinned by a participatory process to bridge the gap between academic research and practical policy design. This allows us to obtain a shared perspective on sectoral vulnerabilities at local level, which involve tailor-made adaptation responses that would not be identified by traditional approaches.

This study focuses on a sample of five European islands (Balearics, Canary Islands, Cyprus, Malta and Sicily). These islands are known to be biodiversity hotspots and major repositories of endemism (IUCN, 2019). From an economic point of view, these islands rely heavily on coastal and marine tourism (Croes et al., 2018), and rate among the leading destinations for non-European Union (EU) member states' residents (Eurostat, 2020).

Climate change contributes to the progressive decline of these islands' extraordinarily rich marine biodiversity (Rilov et al., 2019). Since they are islands, they are more exposed to marine risks than mainland locations (Carmen et al., 2019; Gumusay et al., 2019). They share common vulnerabilities to climate change, derived from low economic diversification and capacity for sewage treatment, among other aspects. They are also characterised by having less climate-related data to inform decision-making, compared to the mainland (Jorda et al., 2020). In sum, these five islands were selected as, together, they reflect the array of risks to ocean and coastal management that European islands currently face.

The paper is structured as follows. The following section presents a literature review on climate risk assessment, with a special focus on the marine environment, as well the origin and applications of the impact chain framework. Section three introduces the methods utilised. Section four presents the results and analyses their robustness and validity to support policy design and management interventions. The fifth section discusses the findings and their potential application beyond island territories. The final section is dedicated to conclusions and recommendations.

2. Literature review

2.1. Climate change, marine ecosystems and risks for tourism

With climate change being a multidisciplinary topic, the study of the consequences of marine biodiversity degradation for tourism is increasingly attracting researchers from different fields (Arabadzhyan et al., 2021; Gissi et al., 2021). There are, for example, studies devoted to analysing the relationships between global warming and the physiological, ecological and genetic transformation of marine species that are valued by tourists and wider society (Cuttler et al., 2018; Zunino et al., 2021). In this group, researchers have evaluated the combined effects of climate hazards (e.g., seawater heating) and anthropogenic impacts - also known as human stressors - (e.g., sewage discharges), and provided valuable recommendations for ocean and coastal management (Gissi et al., 2021; Rilov et al., 2019).

Researchers have also shown that tourists' decision-making about coastal destinations can change if the quality of marine and coastal habitats is adversely affected (Cuttler et al., 2018; Schumann et al., 2019). In this context, climate-induced impacts (e.g., coral bleaching, dead seagrass, water turbidity, etc.) have serious implications for the economy, employment and other 'quality of life' components at coastal tourism destinations (Cuttler et al., 2018; Tseng et al., 2015).

Finally, it is worth noting that the literature has predominantly focused on studying coral reefs (Dimopoulos et al., 2019). This is because corals are *foundation species* that prop up very delicate ecosystems that are extremely vulnerable to seawater temperatures, acidification and extreme events (Scott et al., 2012). They also act as a shield that protects beaches from erosion (Cuttler et al., 2018), as well as being an important tourist attraction (Spalding et al., 2017). However, other foundation species in the EU Mediterranean and Atlantic sea-basins, such as the phanerogam meadows from the genus *Posidonia, Zostera* and *Cymodosea Nodosa* (Pergent-Martini et al., 2021), have been less intensively studied (Arabadzhyan et al., 2021).

2.2. Conceptual models for climate risk assessment and the impact chain framework

Climate risk assessment is intrinsically linked to predicting future hazards (i.e., physical events) and the physical, social, environmental and economic vulnerabilities of the exposed elements, together with the capacity of communities to cope with, endure and recover from adverse impacts (Rilov et al., 2019; IPCC, 2022). There is no standard way to conduct climate risk analysis. It has often been analysed using information on climate extremes, in which factors related to exposure, vulnerability and preparedness are considered exacerbating/mitigating variables determined by human actions (Scott et al., 2012). Hence, increased risk is considered a consequence of communities' inability to cope with a climate hazard by means of effective pressure reduction, mitigation or adaptation (Lane et al., 2018; Smith et al., 2016). In parallel with this traditional framing of risk, there is a well-established, more critical perspective that focuses on the drivers of vulnerabilities (Thomas et al., 2019) -e.g., the underlying conditions and political perspectives that create unjust and inequitable conditions in the economy.

Responding to the need for integrated approaches, Eurac Research created the climate impact chain framework. The concept was introduced by Isoard et al. (2008) and Schneiderbauer et al. (2013), then 'catalysed' by the German cooperation (GIZ) in the Vulnerability Sourcebook (Fritzsche et al., 2014). Since then, the impact chain framework has been increasingly applied to climate risk analysis in many fields: finance, civil protection, aviation, fishing, agriculture, urban development, food production and consumption, among others (Menk et al., 2022). Currently, an ISO Norm (ISO/DIS 14091) is being prepared to promote the use of the impact chain (Menk et al., 2022), as it is considered an appropriate tool for analysing climate change impacts (Tangney, 2019) in a way that facilitates practical policy design by decision-makers (Menk et al., 2022).

The IPCC introduced the impact chain approach for the first time in its AR5 Report in 2015. It was further developed for the 2019 IPCC SROCC report (Abram et al., 2019) and the 2022 IPCC AR6 report (IPCC, 2022). According to the latest IPCC AR6 concept, 'risk' is a potential adverse consequence of climate change for human and socio-economic systems (Abram et al., 2019). It pivots around the notion of risk as a result of *impacts of* and *responses to* climate change. From this perspective, risk is a composite of *hazards,* combined with *vulnerability* and the *exposure* of natural and socio-economic systems (Fig. 1).

Under this approach, a 'hazard' is the occurrence of a climate-related physical event or trend that leads to intermediate impacts (e.g., on livelihoods, etc.). 'Exposure' relates to the presence and imperilment of populations, as well as natural and socio-economic systems. 'Vulnerability' is the propensity to be adversely affected by hazards. The latter encompasses two main elements (i) sensitivity - or susceptibility - (e.g., the building material of houses): and (ii) the ability of the society to cope with the danger (adaptive capacity) (IPCC, 2022).

One limitation of the impact chain is that it does not cover all the complex relationships between multi-hazard origin and root causes of vulnerability that determine risks. It simply focuses on the most prominent factors in the policy area under study. As an advantage, the method allows one to pinpoint causal relationships between hazard,

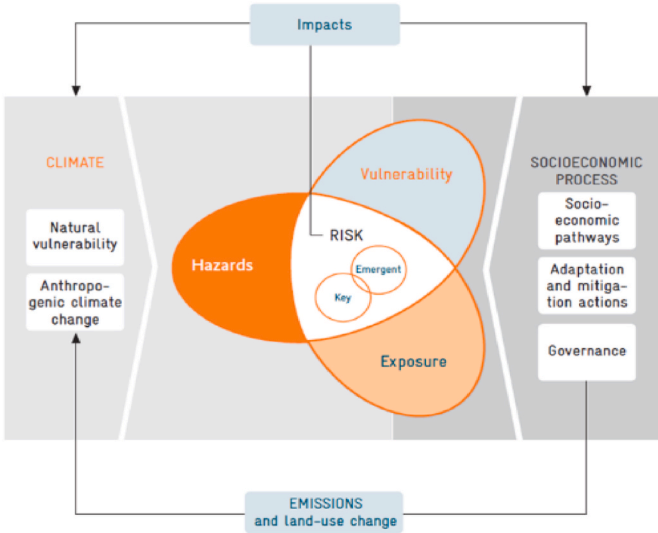

Fig. 1. Illustration of the impact chain's core concepts.
Source: IPCC (2022)

exposure and vulnerability drivers. For example, the level of risk of drought damage to agriculture can vary between regions with similar climatic conditions because of differences in the extent of cultivated land (exposure), and the existence/absence of efficient irrigation systems (vulnerability-adaptive capacity). In response, adaptation may be more effective when the local factors that exacerbate/reduce the risk are identified and analysed in advance.

Modelling such complex relationships requires a hybrid approach, which includes quantitative and qualitative techniques. While data on climate hazards are usually available, information about exposure or vulnerability seldom is (Zebisch et al., 2021). For this reason, the impact chain approach always requires an expert-assisted process. This, however, is intrinsically linked to biases in the selection of experts and the subjectivity of individuals. In turn, a validity test is needed for every impact chain application. The potential to refine participatory methods can increase the robustness of the impact chain method (Zebisch et al., 2021), which is an aim and a contribution of this study.

3. Materials and methods

3.1. Study site

European marine ecosystems are mainly structured on phanerogam meadows, which play a foundational role for biodiversity, productivity and service provisioning (Gumusay et al., 2019). The *Posidonia Oceanica* prevails in the Mediterranean while *Cymodocea Nodosa* dominates in the Atlantic Ocean. They are an indicator of marine water health (Boudouresque and Verlaque, 2012) and protect the coast from erosion. By fixing nutrients from sewage discharges (Mangos et al., 2010), they reduce turbidity and facilitate carbon sequestration/storage (Pergent-Martini et al., 2021) and water oxygenation (Boudouresque and Verlaque, 2012). They also contribute to maintaining the attractiveness of landscapes, which has implications for the psychological, cultural and spiritual wellbeing of marine-dependent communities (Gumusay et al., 2019). These species are abundant around European islands; localities that are in fact recognised as hotspots of marine biodiversity worldwide (Dattolo et al., 2017; Russell and Kueffer 2019).

As said, this study focuses on five European islands to analyse the climate-related risk to tourism due to degradation in marine biodiversity (Fig. 2). These islands were selected, first, because tourism represents a large part of their total value added. Thus, any negative impact on tourism will contribute greatly to regional GDP losses (Vrontisi et al., 2022). According to Vrontisi et al. (2022), the Canary Islands, Balearics and Crete are among the EU islands with the highest GDP share of tourism in Europe. Further, they are mainly developed around '3S tourism' (sun, sea and sand). For decades, this has been the most important tourism segment globally, and one that is extremely sensitive to, and heavily dependent on, the quality of coastal and marine environmental services (Croes et al., 2018; Jorda et al., 2020; Rosselló and Waqas, 2016).

These islands face common climate change impacts and risks derived from sea level rise, higher temperatures and lower precipitation rates, which affect the living conditions of the islanders and tourists (Veron et al., 2019). Their geographic remoteness and low economic diversification jeopardise their community's capacity to adapt, compared to the mainland (Klöck and Fink, 2019; Leon et al., 2021). Besides, top-down governance systems still prevail on many islands. This leads to decisions being made with a lack of information, which reduces the effectiveness of local adaptation efforts (Kebede et al., 2018).

The consequences of a changing climate will differ from one island to another, as they are geomorphologically, ecologically, economically, culturally and socio-politically diverse (Veron et al., 2019; Vrontisi et al., 2022). For example, the Canary Islands and Balearics are expected to suffer larger economic losses because of their greater share of tourism in the total value added (Vrontisi et al., 2022). Recent estimates show that *Posidonia Oceanica* will be more gravely affected by seawater heating in the European Western Mediterranean (Balearics, Sardinia, Malta and Sicily), with a reduction of between 14 and 35% in area coverage. This is because in the Eastern Mediterranean the *Posidonia* has adapted better to warmer conditions. Although the expected reduction of up to 35% may seem moderate, it must be remembered that the losses will be localised in nearshore areas, with a huge impact on water transparency around beaches (Jorda et al., 2020; Oliver et al., 2018).

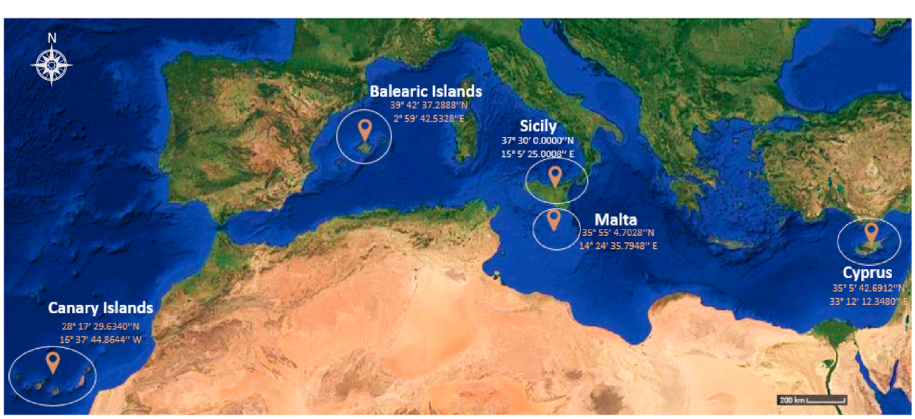

Fig. 2. Study site.

The five islands selected are considered a good representation of potential impacts that the EU's marine ecosystem services may experience this century due to climate change. As recognised in the *New EU Strategy on Adaptation to Climate Change of 2021*, although there are differences, isolation gives islands the opportunity to be excellent 'living labs' to analyse the complex relationships between the degradation of environmental services and the evolution of Blue Economy sectors, such as coastal and marine tourism. This underscores the importance of joint efforts to implement tailored adaptation responses to more effectively address climate-compounded risks (Klöck and Fink, 2019; Leon et al., 2021).

3.2. Definition of the impact chain model for coastal and marine tourism

This study was carried out in eight steps, strictly oriented towards their suitability for adaptation planning. The steps are adapted from Zebisch et al. (2021) and are briefly commented on below. The 'supplementary material' further explains the work-flow and details the type of data utilised.

Step 1- Defining the marine risks with local stakeholders from the islands.
Step 2- Developing the managerial impact chain.
Step 3- The Analytic Hierarchy Process.
Step 4- Pairwise comparisons.
Step 5- Aggregation of risk components to obtain final relative risk scores.
Step 6 and 7- Presenting and discussing the outcomes with local stakeholders.
Step 8- Conducting a sensitivity analysis.

Risk and managerial impact chain definitions (Step 1 and 2), as well as pairwise comparisons (Step 4), were produced in a participatory manner with stakeholders and experts on each island. The meetings and work sessions were held simultaneously on all the islands. In total, 21 people were engaged in the different phases. There were eleven high-level representatives and policy makers from the islands' travel, tourism and hospitality sectors, plus ten 'experts'. The experts were not necessarily based at the islands under study, but were selected because of their expertise in the climates, marine habitats and tourism systems surrounding European waters.

The starting point was the definition of risk for this study, based on the IPCC AR6 concept. The risk was defined as *the loss of attractiveness of coastal and marine areas for tourism due to climate change impacts on marine biodiversity*. In this context, 'risk' represents the level of damage to tourism on the islands - supply and demand sides - originating from climate-related marine biodiversity degradation.

In this study, the tourism system has been limited to tourists and the tourism offer. Although very important, the voices and perspectives of residents have not been considered, in order to make the analysis more manageable. This is a limitation that could be addressed in future research. Nevertheless, it is assumed that any impact on tourist activity will have implications for islander communities, employment and welfare indicators, given the significant role of tourism in the socio-economic system of the islands analysed.

Step 2 was devoted to deconstructing the theoretical impact chain (Fig. 1) into subcomponents of marine risk. These elements formed the managerial impact chain (Fig. 3). This step allows us to openly debate and promote relationships between stakeholders and experts on each island. Stakeholders' main concerns related to the complex relationships amongst the multi-hazard origin of the impacts, systemic relationships with other sectors, and the functioning of the socioecological system. At this point, the role of the experts and moderators was crucial in driving the discussions towards a consensus about the framing of the *hazard*, *vulnerability* and *exposure* dimensions within the IPCC AR6 scheme. This helped make the risk analysis both achievable and useful, to respond to local decision-makers' needs.

Hazard: The climate hazard chosen was *the increase in sea water temperature* (top of Fig. 3). According to evidence, the frequency and intensity of high sea temperature episodes is the key determinant for the long-term degradation of the *Posidonia* and *Cymodocea* meadows (Jorda et al., 2020). The reference indicator agreed to analyse the evolution of the hazard for the islands was *the number of days per year in which sea water temperature is over 26°C.* Considering that an increase in phanerogam meadow 'dying-off' episodes may affect other components of the ecosystem simultaneously, such as flagship species and water transparency, they were also incorporated in the impact chain ('ecosystem services'). However, the risk analysis did not include specific indicators on this subject.

Exposure: Four exposure indicators were included, at the level of natural (surface area covered by meadows) and social subsystems of tourism (number of tourists, divers, tourist expenditure and nights spent).

Vulnerability: Vulnerability was split into two main sub-components:

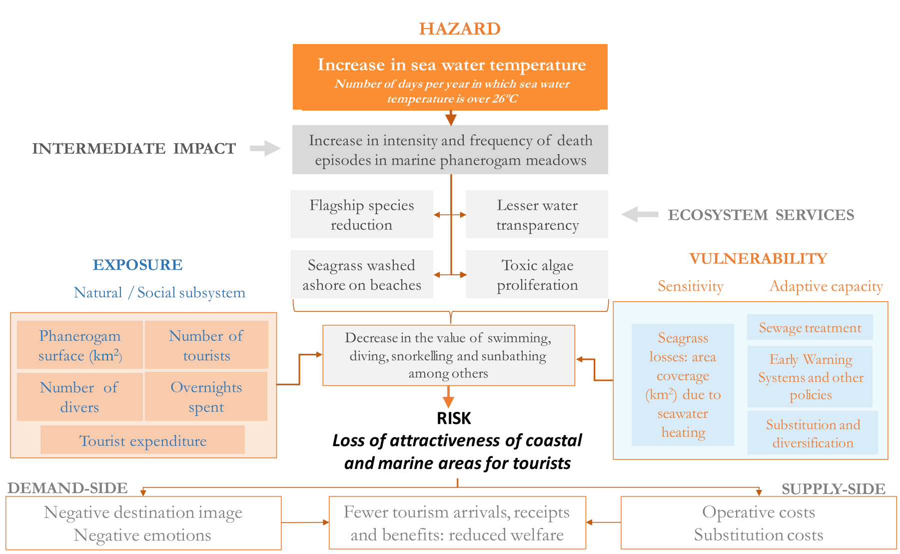

Fig. 3. Managerial impact chain components.
Source: Own elaboration with experts from the islands under study

i) *sensitivity*, defined as potential losses to the surface coverage of seagrass meadows (*Posidonia, Zostera* and/or *Cymodocea)* because of dying off episodes caused by extreme temperatures, and ii) *adaptive capacity*, which depends on the specific capacities –e.g., available technologies, institutions, and financial resources, etc.,- of each island. Three indicators of adaptive capacity were considered relevant on all islands: sewage treatment, the existence of Early Warning Systems, and the level of tourism diversification - i.e., the capacity of the island to reduce its dependence on the marine habitat for tourism development, through product and experience diversification.

Notably, each island produced very similar impact chains - a measure of their similarities regarding stakeholders' perceptions of risk determinants and the availability of information at local level. With these indicators being identified, a background material was prepared to enrich subsequent deliberations (see the supplementary material).

The principal limitation of the study arises from its focus on just one specific hazard and on the isolated analysis of the coastal and marine tourism segment. Further, the study does not consider other socio-cultural and welfare indicators that are also relevant to explaining the impact of marine habitat degradation for the EU islands, leaving room for further investigation.

Finally, this research only analyses one scenario of climatic projections without considering Greenhouse Gas (GHG) emissions, namely RCP 8.5. The RCP 2.6 scenario - that postulates the lowest temperature change by 2100 (IPCC, 2022) - was initially evaluated. However, the latter implies that emissions would have begun to decrease from 2020, which is far from the reality. A similar situation arises with the related Shared Socio-economic Pathway (SSP) scenario, the SSP1-2.6. This describes a more gradual shift towards sustainability than RCP 2.6, but also considers that fossil CO2 emissions are negative at 2100 (Meinshausen et al., 2011). In sum, given that current emission trends align more closely with higher than lower concentration pathways, the use of RCP 8.5 seems wiser, as it offers a closing window of opportunity to avert dangerous climate change, and calls for urgent and transformative actions (IPCC, 2022; Schwalm et al., 2020; Manzanedo and Manning, 2020).

3.3. The Analytic Hierarchy Process (AHP) and subsequent steps

Step 3 seeks to implement the AHP multi-criteria analysis. As mentioned above, impact chain modelling requires participatory evaluation since *vulnerability* and *exposure* indicators always rely on incomplete information (GIZ and EURAC, 2017), limiting the traditional indicator-based value scheme. The AHP method was chosen given its successful application in many fields of decision-making (Ishizaka and Labib, 2011). Hence, by integrating the AHP methodology with the participatory assessment of the impact chain, this study contributes to a more multidisciplinary and transparent evaluation of non-climate drivers of the risk, which may be relevant when calling for action.

The sound application of AHP requires a clear definition of criteria and sub-criteria (Darko et al., 2019; Ishizaka and Labib, 2011). To achieve this, a hierarchical tree was designed, underpinning the impact chain elements of Fig. 3 (see the supplementary material). The top of the tree represents the risk analysed, with the main determinants being sensitivity, adaptive capacity and exposure. The sub-criteria correspond to the measurable indicators previously defined in Step 2. The tree also includes the five islands, for comparison.

Pairwise comparisons (Step 4) were carried out in two stages: (i) sub-criteria against criteria, and (ii) sub-criteria against islands. These were performed anonymously and at individual level by the ten experts, because the ranking required a wider perspective of the five islands. Local stakeholders had access to a 'conversation' platform that was enabled during experts' deliberations. Stakeholders used a forum for questions and comments to the panel of experts. This initiative was key to collecting stakeholders' local experiences, which produced a comparative picture of the islands. Experts utilised a numerical scale of 9 points adapted from Lamaakchaoui et al. (2015). Cross-checking of information was periodically conducted with experts' responses, with a high concordance level - around 97% of total items. This process ended in April 2020 with an experts' meeting to discuss the results. When the relative values for each criterion were available, the different risk components were weighted (Step 5), delivering risk scores for each island until 2100. Thus, islands can be compared by aggregated risk scores, and across the set of sub-criteria and criteria.

Results were discussed at local level and in a joint session for representatives from all islands (Step 6 and 7), between May and July 2020. In order to reconcile views and opinions, a questionnaire was carried out during local meetings, in which stakeholders evaluated each indicator of the impact chain using a semantic scale: *very important/important/medium/limited/very limited* influence on the risk. The results per island were coherent with the experts' pairwise comparison of sub-criteria against criteria for all islands. These findings were exchanged in the joint session and served to reduce conflict due to full agreement with both the methodology and outcomes.

Some perspectives reflected stakeholders' concerns about the training of decision-makers and financial limitations that could constrain the implementation of adaptation responses. As a preparatory phase, this study was concerned with strengthening alternative policy design frameworks through the integration of local and scientific knowledge, which ultimately prepares, incentivises and engages local decision-makers to respond to climate change in more efficient ways (Becken and Hay, 2012; Kebede et al., 2018).

4. Results

This section presents the results of the risk assessment at two different scales, first comparing the different components (criteria) of risk for all islands, and then comparing islands against sub-criteria. A final ranking of islands is provided together with a sensitivity analysis, as a form of validating the robustness of the AHP method.

4.1. Criteria and sub-criteria against the risk

Experts and stakeholders agreed that adaptive capacity is, on average, the most relevant criterion for explaining the risk for all islands (Fig. 4 only shows the results of pairwise comparisons). In this vein, the vulnerability of the tourism system is subject to its ability and technical capacity to prevent seawater pollution, remove dead seagrass from beaches, and reduce the dependence of tourism on marine habitat

Fig. 4. Relative importance of each criterion in explaining the risk (average scores by island).

services. These aspects were considered to have greater importance than the sensitivity of seagrass meadow species to heat stress, which was moderately weighted (average score = 4). The lower weight attached to the sensitivity criterion was also based on evidence about the high value tourists attach to conservation and restoration (adaptation) of marine habitats on these islands (Leon et al., 2021). Regarding exposure, from the set of (5) indicators analysed, the surface coverage of seagrass species is considered the most relevant sub-criterion for all islands, as it determines the abundance and density of marine habitats. This, in turn, makes the marine environment more attractive for tourist activities.

4.1.1. According to the experts

> ˙ …. *developing capacities to address product diversification and sea pollution treatment as adaptation areas make the risk manageable and have even greater importance as the hazard or the sensitivity level of the species, which is further from being able to be modified* … ˙

According to the local stakeholders' final evaluation, the conclusion is similar:

> ˙…. *the importance of human actions is limited when the climate cannot be changed; however, this is the part upon which society can act on improving* … ˙

Stakeholders sought to prioritise initiatives to more rapidly increase adaptive capacity. According to experts and scientific evidence, no 'perfect set of measures' will completely reverse the impact of seawater heating on marine biodiversity. For instance, dead seagrass can be removed, and this will reduce, but not eliminate, its negative impact on water transparency and beaches, due to its smell and unsightliness from it lying on the sand. Conversely, the complete removal of dead seagrass may affect long-term conservation of the ecological system due to lack of nutrients. Hence, adaptation responses should consider the trade-offs of actions. In this case, experts' evaluation of islands' adaptive capacity focused on the frequency with which local authorities remove dead seagrasses from populated beaches, and the ability to combine this with other measures such as early warning systems to prevent highly toxic algal blooms.

4.2. Islands'comparison

Fig. 5 shows the relative importance of each sub-criteria/indicator in determining the level of risk. These results are presented with average scores by island according to pairwise comparisons. Regarding the 'sea heating' hazard indicator, the Canary Islands and Balearics are considered the least threatened, even though sea water temperature is expected to increase faster around these Spanish archipelagos. Meanwhile the lowest estimations are for Cyprus, followed by Malta and Sicily. According to the experts, the Balearics and Sicily have the most exposed natural systems (seagrass meadows), while the former also presents the greatest exposure because of its social subsystem.

Concerning sensitivity, experts considered the phanerogam meadows around Cyprus to be more resilient to thermal stress than those surrounding Malta and Sicily. This conclusion aligns with previous quantitative models that have shown decreasing resistance to seawater heating for seagrass from east to west in the Mediterranean basin.

Regarding adaptive capacities, island representatives provided key inputs from their local knowledge that complemented experts' comparative analysis. As far as product substitution/diversification is concerned, Sicily was the best positioned and Cyprus the worst, according to experts' weighting. The Canary Islands and Malta were shown to have similar levels of diversification capacity, although they underpin different elements. This was probably the most challenging task, as the comparison between islands should not only be based on leisure activities provided to tourists, but also on the socio-cultural offer to tourists and residents that is supported by the marine environment.

Regarding the capacity to keep beaches free of dead seagrass and maintain water transparency, the Balearics were judged the worst, while the Canary Islands received the most positive evaluation. Differences are due to both technical capacities and frequency and intensity of the episodes that affect the Balearics the most.

In the realm of seawater pollution, experts distinguished between the technical capacities of sewage treatment and the self-depurative potential of the seawater surrounding the islands. For example, even if the technical capacities are similar in the Balearics and Canary Islands, seawater pollution is generally higher around the Spanish Mediterranean islands due to higher water column stratification. Meanwhile, the

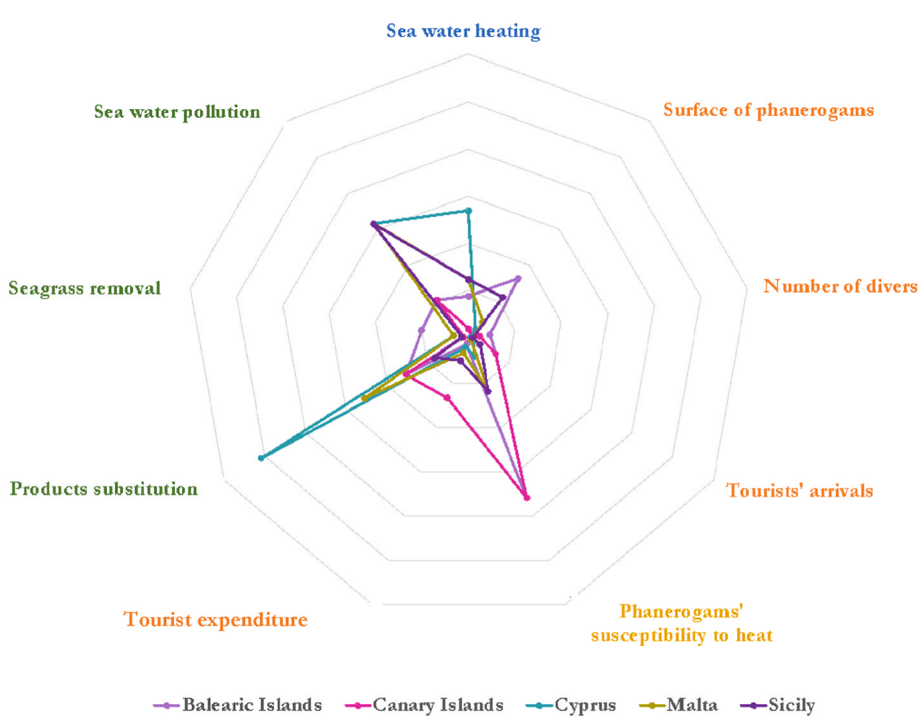

Fig. 5. Sub-criteria's relative importance to explain the risk (average scores by island).

Canary Islands are favoured by the turbulent waters of the Atlantic. Keeping these aspects in mind, and the local experiences of stakeholders regarding sewage treatment, experts concurred that the three other islands (Malta, Sicily and Cyprus) have a lower capacity to avoid sea pollution in seawater heating contexts.

4.3. Results aggregation

Table 1 shows the final weights of each island, allowing comparison for the overall risk and each impact chain component. Scores are relative values that can be analysed from the comparability of islands. According to the results, Cyprus is considered the island with the highest level of risk, followed by the Balearics, and the three less-at-risk islands: Malta, the Canary Islands and Sicily.

Cyprus leads the rankings because, in addition to the greater seawater heating estimates, it also exhibits a relatively reduced adaptive capacity to address the ecologically disruptive processes related to its closeness to the Red Sea. This Sea is the source of an increasing flow of exotic species that often destabilise Cyprus' marine ecosystems (Bédry et al., 2021; Kleitou et al., 2019). Sicily ranks top due to a balance between relatively low exposure and notable levers to cope with threats, mainly through diversification. This island boasts a wide range of cultural, social, landscape-based, gastronomic and historic resources, which underpin a tourism industry that is less dependent on the marine environment.

The Canary Islands show a relatively low level of seawater heating (Jorda et al., 2020). However, the Islands' weakness is in the size of the tourism system that is exposed, and the high aversion their tourists have towards disruptive impacts on marine habitats (tourist expenditure). This vulnerability is partially compensated for by the fact that the majority of their marine-based activities depend on ecological processes that are distinct from those supported by seagrass meadows, like cetacean watching.

The Balearics are the most exposed of the islands. This is mitigated, however, by apparent greater tourist indifference towards marine habitat degradation (tourist expenditure), which is contingent and could shift relatively quickly (Leon et al., 2021). The eradication of other pressures on *Posidonia* meadows, such as sewage and coastal infrastructure, is crucial for this archipelago to keep this risk under control, as has been outlined by recent research.

Malta has favourable starting conditions regarding the threat of seawater heating: the Maltese tourism industry is rooted more in cultural activities than in beaches and pristine marine habitats (Croes et al., 2018), and coastal leisure traditionally relies on activities that are less affected by the quality of the marine environment (e.g., charter tours, boating).

4.4. Results of the sensitivity analysis

The sensitivity analysis - Step 8 - was conducted as a validation measure of the stability of the AHP method within the impact chain approach. The results of this dynamic analysis are presented in Table 2. Cells coloured in grey show the original average weights for the sub-criterion *product substitution and diversification* for the Balearics and Cyprus (0.13 and 0.44 respectively). The remaining columns show the changes in the final risk score for each island when the weights of this sub-criteria are modified, simulating values between 0.0 and 0.60, and maintaining the relative comparisons across the other islands constant.

Increasing the weight of *product substitution and diversification* for the Balearics from 0.13 to 0.30 (more than 100%) leads to an increase in the risk faced by this archipelago by 18% (from 0.219 to 0.259); while Cyprus shows a reduction in the risk. In other words, when the vulnerability of the Balearics becomes worse, their overall level of risk increases. Meanwhile, the level of risk for Cyprus decreases, thanks to the relative lesser importance of the criterion *product substitution and diversification* when compared to the baseline scenario. Similar results were obtained when the original weights of 0.0909 and 0.2727 for Balearics and Cyprus regarding the sub-criterion *seawater pollution* were modified.

With these results, it can be concluded that the method utilised for weighting risk components is robust, as the risk scores are not highly sensitive to changes in the criteria weights, and the final ranking does not change if the weights of each sub-criterion increase or decrease within the range of 5%–20% (Sahabuddin and Khan, 2021).

From a managerial perspective, the results indicate that the lesser capacity of an island to diversify its tourism sector beyond the marine environment makes it more vulnerable to a changing climate, and therefore shortens the distance with other islands in the same situation. This emphasises the need to collectively learn from the experiences of other islands and makes room for islands' cooperation in the context of planning adaptation and risk mitigation, which poses a challenge for ocean and coastal governance.

Figs. 6 and 7 crystallise the performance of the sensitivity analysis, summarised in Table 2, allowing for identification of the intersectional values. The horizontal axis represents the parameter values (weight) of the corresponding sub-criterion with respect to the risk, while the vertical axis represents the final score of each island.

Given that the sensitivity analysis is performed for two different islands, we focus on the red line (final score for the Balearics) and on the black line (final score for Cyprus). With respect to the sub-criterion *products substitution and diversification*, the final risk score for the Balearics becomes the highest when the parameter value of the sub-criterion reaches more than 0.205 (56% or higher), as represented in the left-hand side of Fig. 6. On the other hand, Cyprus would not lead the ranking with the highest level of risk if the sub-criterion weight took on

Table 1
Final scores and islands' ranking (under RCP 8.5 distant future 2081–2100).

Criteria	Sub-criterion	Balearics	Canary I.	Cyprus	Malta	Sicily
Hazards	Seawater heating	0.018 *(8.0%)*	0.004 *(2.3%)*	0.054 *(22.0%)*	0.025 *(13.2%)*	0.025 *(14.4%)*
Exposure	Surface of marine phanerogams	0.033	0.002	0.005	0.009	0.023
	Number of divers	0.009	0.005	0.001	0.002	0.002
	Tourist expenditure	0.003	0.026	0.004	0.006	0.008
	Tourist arrivals	0.013	0.013	0.002	0.002	0.006
	Total	0.058 *(26.5%)*	0.046 *(25.9%)*	0.012 *(4.8%)*	0.019 *(10.0%)*	0.039 *(22.8%)*
Sensitivity	Phanerogam sensitivity	0.072	0.072	0.008	0.024	0.024
	Total	0.072 *(32.8%)*	0.072 *(40.6%)*	0.008 *(3.2%)*	0.024 *(12.8%)*	0.024 *(14.0%)*
Adaptive capacity	Products substitution and diversification	0.031	0.031	0.102	0.051	0.017
	Seagrass removal	0.020	0.002	0.007	0.007	0.003
	Sea water pollution	0.021	0.021	0.063	0.063	0.063
	Total	0.072 *(32.8%)*	0.054 *(30.4%)*	0.171 *(69.9%)*	0.120 *(64.2%)*	0.083 *(48.3%)*
Total Risk score		**0.219**	**0.177**	**0.245**	**0.187**	**0.171**
Rank		2	4	1	3	5
Comparison across islands		**128**	**104**	**143**	**109**	**100**

Note: Total contribution of the criterion to the final score of the island in parenthesis.

Table 2
Results of the sensitivity analysis.

Product substitution and diversification					Seawater pollution				
Param. Value	Changing param. for Balearics		Changing param. for Cyprus		Param. Value	Changing param. for Balearics		Changing param. for Cyprus	
	Balearics	Cyprus	Balearics	Cyprus		Balearics	Cyprus	Balearics	Cyprus
0.00	0.189	0.261	0.244	0.143	**0.00**	0.199	0.252	0.228	0.183
0.10	0.213	0.248	0.239	0.166	**0.09**	0.219[a]	0.245[a]	0.225	0.203
0.13	0.219[a]	0.245[a]	0.237	0.173	**0.10**	0.222	0.245	0.225	0.206
0.20	0.236	0.237	0.233	0.189	**0.20**	0.245	0.238	0.222	0.229
0.30	0.259	0.226	0.228	0.212	**0.27**	0.262	0.233	0.219[a]	0.245[a]
0.40	0.282	0.214	0.222	0.235	**0.30**	0.268	0.231	0.219	0.252
0.44	0.291	0.209	0.219[a]	0.245[a]	**0.40**	0.291	0.224	0.216	0.275
0.50	0.305	0.202	0.217	0.258	**0.50**	0.314	0.217	0.213	0.298
0.60	0.328	0.190	0.211	0.281	**0.60**	0.337	0.210	0.210	0.321

[a] Original total risk score of the island.

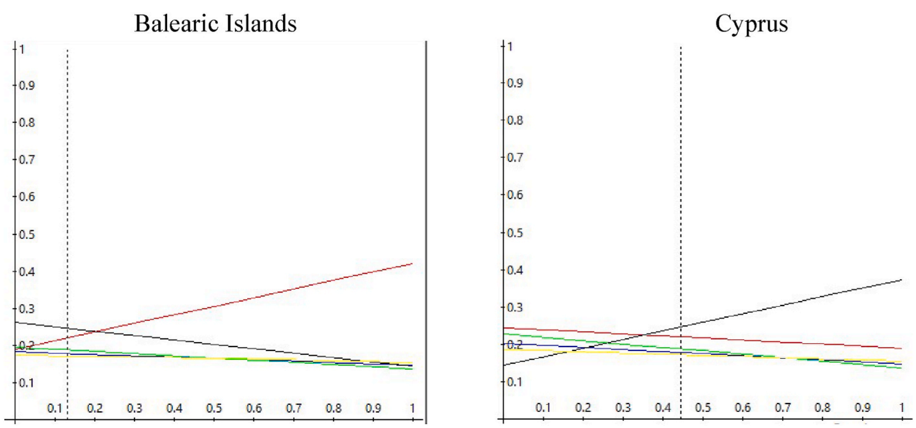

Fig. 6. Performance sensitivity: *product substitution and diversification.*

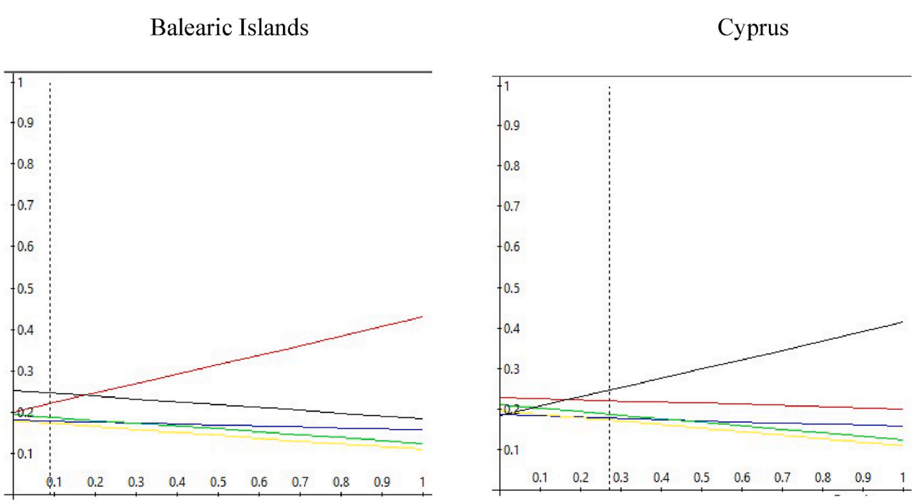

Fig. 7. Performance sensitivity: *seawater pollution.*
Note. Left: The red line depicts the sensitivity analysis for the Balearics.
Right: The black line depicts the sensitivity analysis for Cyprus.

values lower than 0.35 (21% or lower), as represented in the right-hand side of Fig. 6. Similarly, with respect to the sub-criterion *seawater pollution* (represented in Fig. 7), the final risk score of the Balearics becomes the highest when the parameter value of the sub-criterion is over 0.176, while Cyprus leads the ranking when the weight of the sub-criteria is higher than 0.174. As noted above, the final ranking of islands' risk scores is robust to changes in weights ranging from 5% to 20%, supporting even higher changes in some cases.

5. Conclusion and policy recommendations

Ocean and coastal management strategies need to create opportunities for climate-risk reduction and multi-sectoral coordination around shared socioeconomic and ecological goals. The degradation of marine biodiversity is a structural problem that conditions the leisure and cultural activities of residents and tourists in coastal areas. This study analyses the risk that marine-life deterioration, due to seawater heating, poses to the tourism attractiveness of five EU islands (the Canary Islands, Balearic islands, Malta, Sicily and Cyprus).

The multi case-studies approach allows comparison of coastal and marine tourist areas in terms of *risk*, *vulnerability* and *exposure* to the climate hazard of seawater heating. The main contribution of this research is the deconstruction of the risk into sub-components that help to better characterise and evaluate the vulnerability and exposure of each island's tourism market, through the lens of experts and stakeholders.

Results indicate that the 'smoothness' of the expected rise in sea water temperature over the Atlantic region surrounding the Canary Islands were determinant in it being located at the low end of the risk scale, despite the high level of exposure of their tourism system. The Balearics show comparatively higher risk from marine habitat degradation, as a combination of the greater exposure of their tourism system and lower capacity to contain other pressures on *Posidonia* meadows, such as sewage, when compared with the other islands. Meanwhile the lower dependence on '3S tourism' puts Malta at a relatively low level of risk from marine habitat degradation. For the Sicilian tourism system, the main strength in coping with sea heating is its potential to offer viable substitutes to marine-based tourist activities.

From a theoretical perspective, this paper has advanced on the conceptualization and analysis of the risk that climate-induced seawater heating and damage to marine ecosystems pose to the attractiveness of coastal and marine tourism. Further, the study has developed the basis for improved climate risk evaluations, by adapting and validating a blended methods approach: the integration of the AHP multi-criteria analysis within the IPCC AR6 impact chain framework. This has improved transparency of research and 'dose-response' relationships. Under this approach, the views, concerns and local experiences of stakeholders complemented experts' comparative assessment and the ranking of islands. On the other hand, experts' evaluation was fed back into local stakeholders' analysis of their own islands.

Although bottom-up approaches are widely used in diverse settings for vulnerability and risk analysis, and adaptation planning, the application of the AHP method has been an under-exploited field of research (Gissi et al., 2021). The AHP has offered an opportunity to integrate and weight qualitative information, thereby providing consistency in comparisons at all levels of the problem (Ishizaka and Labib, 2011). As an example, the Red Sea is a major threat to Cypriot marine habitats, and the AHP facilitated its consideration in the risk analysis - although there is limited information about the so-called 'blurred-border' problems of the region (Thibaut et al., 2022). Sensitivity analysis of the ranking demonstrated that the AHP method and the proposed algorithm have transferability potential, which can assist future research on climate change.

It is important to mention that the progress made in this study will only count if it is translated into effective climate action, which is ultimately a political commitment (Becken and Hay, 2012). From the policy perspective, this study has attempted to maximise its policy orientation, through robust participatory techniques. The qualitative information and experiences of local stakeholders, along with the experts' scientific knowledge, has contributed towards raising awareness at local level, and the better characterisation of some of the non-climate factors influencing the *risk*. In other words, the study has attempted to involve key players to ensure a higher level of commitment with local adaptation planning (Zebisch et al., 2021).

Although top-down governance still prevails on the islands under study, it is well–established that adaptation should fundamentally be a local issue, and local involvement and ownership are a central precondition for speeding up climate action. This is recognised by the European Commission in its latest *EU Strategy on Adaptation to Climate Change of 2021*. Nevertheless, this study may be seen as a first step. Wider applicability of this method should consider other communities' perspectives, particularly those whose livelihoods may be impacted, and decision-makers beyond the tourism domain, and at national level.

This research has also been able to capture heterogeneities, as well as shared perspectives on adaptation policies among islands of different EU member states. This might inspire local authorities to get involved in collaborative work at EU level when designing adaptation and risk management strategies. For example, the low capacity to diversify tourism was considered a dominant factor in explaining the higher risk for all the islands under study. In this sense, results indicate that tourism governance in Cyprus may pay greater attention to this aspect and learn from the other islands. Thus, exchanging information about lessons learned, risks and obstacles, may help islands to be more effective when designing adaptation plans.

Findings provide insights at different levels of adaptation policy design. At the EU level, with the coastal and marine tourism being a priority for climate action (Riccardi, 2019; Ribalaygua et al., 2019), the critical vulnerabilities identified by this research may be useful in delimiting funding priorities. Additionally, these islands' local governments are now better placed to adapt their tourism sector to changes in marine habitats under climate variability. These actions may include, for instance, incentive schemes for local tourism agencies to recognise the potential in services and products that are less dependent on marine habitats.

Author contributions

Conceptualization, M.M.G.H.; methodology, M.M.G.H. and C.G.; data curation, C.G.G.; writing—original draft preparation, Y.E.L.-G.; writing—review and editing, M.M.G.H. and C.G.; visualization, Y.E.L.-G.; supervision, C.J.L.; funding acquisition, all. All authors have read and agree to the published version of the manuscript.

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Declaration of competing interest

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.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ocecoaman.2022.106436.

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