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UNITING OCEANOGRAPHY, FISHERIES STAKEHOLDERS AND CITIZEN SCIENCE TO FIND SOLUTIONS FOR ENVIRONMENTAL MANAGEMENT IN FACE OF CLIMATE CHANGE

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Extended abstract

The issue of climate change is no longer a matter of doubt among the scientific community and society. With an unprecedented increase in global temperature rates, extreme weather events, sea level rise and loss of biodiversity are among the consequences human activities have caused, with a plethora of ramifications for ecosystems all over the world. Among the most impacted ecosystems, there is the Mar Menor, a hypersaline coastal lagoon in the southeast of Spain, which has been suffering strenuous anthropic damage, from mining, agriculture and urbanization, resulting in eutrophication episodes, species mortality, decrease in water quality and invasion of alien species.

Stopping climate change and the environmental impacts caused by human activities is not feasible, so the discussion is now to mitigate and adapt to climate change and anthropic impacts. Nature-based solutions seek to promote collaboration of people with nature to tackle societal challenges, offering advantages for both human well-being and biodiversity. In this context, environmental management planning serves as a tool for adaptation, aiming at developing strategies to curate ecosystem services as well as social aspects of various socioecological systems. Comprehensive environmental management plans must assess environmental and socioeconomic conditions, identify potential issues, and create strategies to promote sustainable practices. Therefore, they include not only scientific data but also engage public participation. Different groups of stakeholders within a socioecological system can contribute with personal knowledge and experience, which can enhance the effectiveness of management plans, foster collaboration among diverse interest groups towards a shared goal, boost public trust in scientific research, and bridge the gap between research and society, thereby informing and educating the community. Stakeholders can also contribute with monitoring efforts once environmental management plans are in action, utilizing tools such as citizen science to gather data that can be utilized by researchers in scientific studies. Furthermore, environmental education, promoted through citizen science activities or on its own as free-choice informal activities can help shape stakeholder awareness and behavior to reduce the impact cause not only by a single individual, but also by the entire population.

The aim of this thesis was to evaluate the social, economic, and environmental dimensions of the Mar Menor lagoon in Spain, with a focus on stakeholder groups such as tourists and fishermen. It

sought to understand the impacts of extreme weather events on the lagoon's oceanographic properties, explore how stakeholders perceive climate change, analyze data collected through citizen science activities for ecosystem monitoring, and examine how environmental education initiatives can raise awareness and support effective management practices.

Results showed that extreme weather events, caused or exacerbated by climate change, have significant and lasting impacts on affected ecosystems. In fact, an unexpected increase in rainfall can lead to severe consequences, not only for urban areas facing flooding and landslides but also for fragile natural ecosystems that rely on a delicate balance. This can trigger a cascade effect, permanently disrupting their functioning and threatening the survival of numerous species, including humans. To address these challenges, mitigation strategies are essential to cope with the accelerating rates of climate change in affected areas. Additionally, comprehensive management plans must consider all factors contributing to the decline of natural ecosystems, particularly pollution from agricultural and urban runoff.

Stakeholder knowledge can enhance scientific data in management plans by identifying subtle, short-term changes that scientific research might not report. Involving stakeholders in planning increases their willingness to support management efforts, boosting the resilience of affected ecosystems. Governments and policymakers must actively engage local stakeholders, who have valuable practical insights and can provide extensive data through continuous monitoring. By understanding the demographics of impacted areas and encouraging stakeholders to share their knowledge, authorities can improve the acceptance and success of management plans across all ecosystems.

Citizen science activities resulted a highly efficient way to engage numerous volunteers and gather reliable data. The citizen science approach can be adapted for use in various scenarios, serving as a valuable resource for local governments and marine managers to enhance and broaden traditional monitoring methods. Environmental education activities have positive short-term outcomes, like increased knowledge and awareness, but long-term effects revealed a decline in knowledge and attitude, though awareness remained stable. Furthermore, satisfaction with the experience was linked to higher awareness and positive attitudes.

In summary, this thesis integrates scientific research with public engagement, in an effort to analyze measures that can bring the scientific community, decision makers and the general population closer towards the same goal, a balance between human activities and natural ecosystems.

Introduction

The impact human activities have on climate change rates is un-neglectable. The current unwavering increase in global temperatures is leading to unprecedented changes, which can result in long-lasting, irreversible implications for ecosystems all over the world (IPCC, 2021). These concerning values can promote substantial changes in natural parameters and lead to extreme weather events which in turn affect economic sectors all around the globe (UNCCS, 2019; Fawzy et al., 2020).

Of all the ecosystems impacted by climate change, coastal lagoons take special focus due to their transitional status (in between land and coastal waters). They are usually shallow and subject to extreme physical-chemical gradients, which in turn contribute to high levels of productivity, and consequently of major interest from an economic point of view (Tagliapietra et al., 2009; Pérez-Ruzafa et al., 2011). The exploitation of coastal lagoons for various human activities put further stress into an already strained environment, subject to hydrodynamic, nutrient and physical-chemical alterations that contribute to a decrease in environmental quality and natural resources (Pérez-Ruzafa et al., 2011, 2019).

One such example within the Mediterranean Sea is the Mar Menor, a hypersaline coastal lagoon (Pérez-Ruzafa et al., 2005), with high ecological importance and extensive impact. Due to its environmental and socioeconomical importance, new approaches are needed for monitoring, modelling and forecasting socio-environmental dynamics in the Mar Menor, in order to create comprehensive management plans to guarantee natural resources in the future (Cecilia et al., 2021).

Although conservation measures are usually reserved to specialists and government policy makers, effective conservation strategies must also integrate public input and engagement in designing solutions (McKinley et al., 2017).

One example of citizen engagement is through informal educational activities (Meschini et al., 2021; Machado Toffolo et al., 2022). Education shapes not only knowledge and understanding, but also emotions, awareness, and personal development, which in turn can influence behavior (Gössling, 2018). Several studies indicate that when individuals have higher levels of environmental knowledge, they are more concerned about the environment (Hines et al., 1987; Lyons and Breakwell, 1994; Sh, 2009). In promoting knowledge and sensitivity, combined with a sense of power and responsibility, people are more concerned about the environment (Hines et al., 1987; Lyons and Breakwell, 1994; Sh, 2009) and can choose to contribute to a mass effort in the conservation and protection of the environment (Hungerford and Volk, 1990).

Education and conservation can also be fostered through citizen science activities. Involving volunteers in data collection for monitoring activities can be a cost-effective strategy to complement or replace the information collected by professionals (Starr et al., 2014). Citizen science projects can improve environmental education of volunteers, increase scientific knowledge and allow the collection of robust datasets (Foster-Smith and Evans, 2003; Bonney et al., 2009; Sullivan et al., 2009; Jordan et al., 2011; Branchini et al., 2015; Callaghan et al., 2019). Data collected through citizen science are a non-traditional data source that is giving a contribution to measure the United Nations (UN) Sustainable Development Goals (Fritz et al., 2019). The role of citizens is becoming central also in European Union (EU) policies, such as the Horizon 2020 funding program.

With this purpose, the SMARTLAGOON project, a H2020 funded project under the call "Environmental Intelligence", was created. With the goal of designing a digital twin, a virtual replica of the Mar Menor natural environment that can potentially to replicate the expected behavior of the lagoon, SMARTLAGOON aims to understand the socio-environmental processes that influence the already distressed Mar Menor ecosystem (agriculture, tourism, fisheries, urbanization, pollution, climate change) to shed light in future management options (Cecilia et al., 2021).

In this scenario, stakeholders play a fundamental role in SMARTLAGOON, as the so-called “participatory environmental monitoring” is a useful methodology for collecting socio-environmental data (Prandi et al., 2022). They were involved at several stages, with interviews, workshops, participatory model and scenarios development, data collection, interpretation of results, etc., in order to offer a valuable point of view about socio-environmental dynamics (Gray et al., 2017)

Motivations and aims of the thesis

The goal of this thesis was to analyze changes in the Mar Menor physical properties following events that might be caused or exacerbated by climate change, using data already existent as well as new data from the SMARTLAGOON project smartbuoy; then, in trying to assess the value and importance of including different stakeholder groups to create more inclusive management plans, gather the impressions of two stakeholder groups, fishermen and tourists in the Mar Menor region, to better understand their knowledge and willingness to collaborate in management planning. Furthermore, analyze previously obtained data to ascertain the value of engagement activities, here considered as citizen science and environmental education, to aid in the design, management and monitoring of natural ecosystems, as well as awareness raising activities to promote environmentally friendly behavior.

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Chapter I

Extreme flooding events in coastal lagoons: oceanographic parameters and rainfall over a 6-year period in the Mar Menor (SE Spain)

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Abstract

Climate change is one of the main problems that currently are strongly conditioning ecosystems all over the world. Coastal lagoons are amongst the most vulnerable habitats, being very complex, undergoing extensive human impact for their high production rates and the proximity of urban and agricultural centers. The Mar Menor, the largest saltwater lagoon in Europe, is an example of a highly impacted ecosystem. In December 2016 and September 2019, climate change-induced DANA (upper-level isolated atmospheric depression) flooding events took place in the Mar Menor, temporarily altering the lagoon oceanographic properties. Data gathered throughout the lagoon (11 stations inside and 1 outside the lagoon) from 2016 to 2021 were analyzed in order to assess the variability of oceanographic parameters: salinity, density, chlorophyll-a, turbidity and dissolved oxygen, due to DANA events. Results showed a change in oceanographic parameters, that were reestablished at different rates, 4 and 10 month in 2016 and 2019 respectively, following a description of the environmental conditions and effects that have been reported after extreme rainfall in the lagoon.

Keywords: DANA; Temporal evolution; Anthropization; Torrential rain; Mediterranean Sea; Coastal development.

Introduction

The impact of human activities for climate change is un-neglectable. The current unwavering increase in global temperatures is leading to unprecedented changes, which can result in long-lasting, irreversible implications for ecosystems all over the world (IPCC, 2021). 2019 saw the second warmest year on record, with temperatures 1.15°C higher than preindustrial values and more than double the average increase per decade (0.18°C compared to 0.07°C expected) (Ahmed, 2020). These concerning values can promote substantial changes in natural parameters such as rainfall and sea level rise, leading to hurricanes, droughts, storms, wildfires, floods, and heatwaves, which in turn affect economic sectors all around the globe (Fawzy et al., 2020; UNCCS, 2019), especially for the population and the ecosystems in regions subject to water stress (Bates et al., 2008).

The Mediterranean Sea is particularly vulnerable to these changes, as it is considered a climate change hotspot (IPCC, 2021), subject not only to great rainfall variability throughout the region (Longobardi & Villani, 2010), with ever decreasing rainfall rates and increase in evaporation with higher temperatures (Benabdelouahab et al., 2020), but also at risk of suffering extreme weather events (droughts, floods) (Achite et al., 2022), which contribute to the runoff and sedimentation of organic pollutants (León et al., 2017).

Of all the ecosystems impacted by climate change, coastal lagoons take special focus due to their rather fragile nature. Due to their transitional status (in between land and coastal waters), they are usually shallow and subject to extreme physical-chemical gradients, which in turn contribute to high levels of productivity, and consequently of major interest from an economic point of view (Pérez-Ruzafa et al., 2011; Tagliapietra et al., 2009). The exploitation of coastal lagoons for various human activities, such as fishing and aquaculture, tourism and sports, drainage basin use and agriculture put further stress into an already strained environment, subject to hydrodynamic, nutrient and physical-chemical alterations that contribute to a decrease in environmental quality and natural resources (Pérez-Ruzafa et al., 2011; Pérez-Ruzafa, Pérez-Ruzafa, et al., 2019).

One of the examples within the Mediterranean Sea is the Mar Menor, a hypersaline coastal lagoon (38.1-51) (Pérez-Ruzafa et al., 2005), one of the largest in the Mediterranean, with 135 km2 in extension and a mean depth of 3.6 m (Á. Pérez-Ruzafa et al., 2005). The lagoon is situated in the Murcia region, in southeast Spain, at the end of a watershed bordered by a wide agricultural plain of about 1440 km2 (Erena et al., 2019). The lagoon communicates with the Mediterranean Sea through three shallow channels (Encañizadas del Ventorillo y La Torre, El Estacio, and Marchamalo) (Bayo et al., 2019; Erena et al., 2019). The mean temperature ranges from 30 °C during the summer to 11.2 °C in winter (Pérez-Ruzafa et al., 2005). Annual rainfall is less than 300 mm $year^{-1}$, with evapotranspiration rates close to 900 mm $year^{-1}$ (hydrodynamic deficit of 600 mm $year^{-1}$) (Erena et al., 2019; Pérez-Ruzafa, Campillo, et al., 2019; Pérez-Ruzafa et al., 2005), and total water exchange every 318 days (Ghezzo et al., 2015).

The high ecological importance and extensive impact contributed to the official recognition as a susceptible area and the outset of several studies to mitigate the impacts and conserve the lagoon environment (Peñalver et al., 2022). This key ecosystem has suffered further impact from a natural phenomenon that has been increasingly more severe over the last years, called DANA (Depresión Aislada en Niveles Altos, or Isolated Depression in High Levels). This phenomenon is characterized by masses of cold air that encounter the warmer Mediterranean air and produce heavy storms and intense rainfall (Garcia-Ayllon & Radke, 2021), and has been influenced by climate change (Pastor et al., 2018), with changes in seasonality and water volume.

The present study focused on the Mar Menor, a coastal lagoon in Murcia, southeast Spain, a highly interesting and peculiar ecosystem. The goal was to assess the evolution of the effects of extreme flooding events induced by climate change.

Method

From August 2016 to October 2021, the IMIDA (Murcian Institute of Agricultural Research & Development) field team surveyed 12 different points covering all areas of the Mar Menor (Figure 1). Values were obtained with the SBE 19plus CTD (Sea-Bird Electronics, WA, USA). Furthermore, rainfall data was obtained from the Sistema de Información Agrario de Murcia (SIAM) database (available at: http://siam.imida.es/apex/f?p=101:46:7220879812294039).

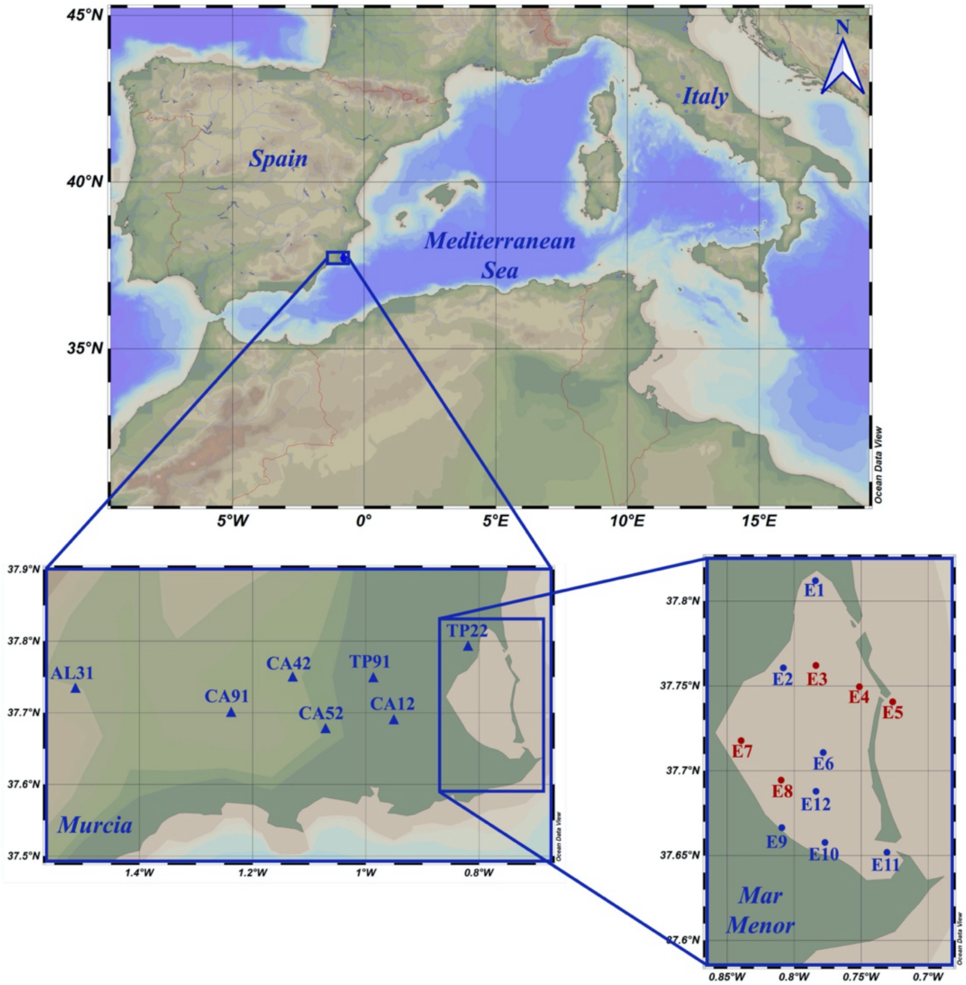


Figure 1. Location of the Mar Menor, rainfall data stations (AL31: Lebor, Totana; CA12: La Palma, Cartagena; CA42: Balsapintada, Fuente Alamo; CA52: La Aljorra, Cartagena; CA91: Campillo Abajo, Fuente Alamo; TP22: Santiago de la Ribera, San Javier; TP91: Torre Pacheco, Torre Pacheco) and sampling stations within the lagoon territory. Sampling stations colored in red are the ones used for parameter analysis, based on their location (E3, E4, E5, E7, E8).

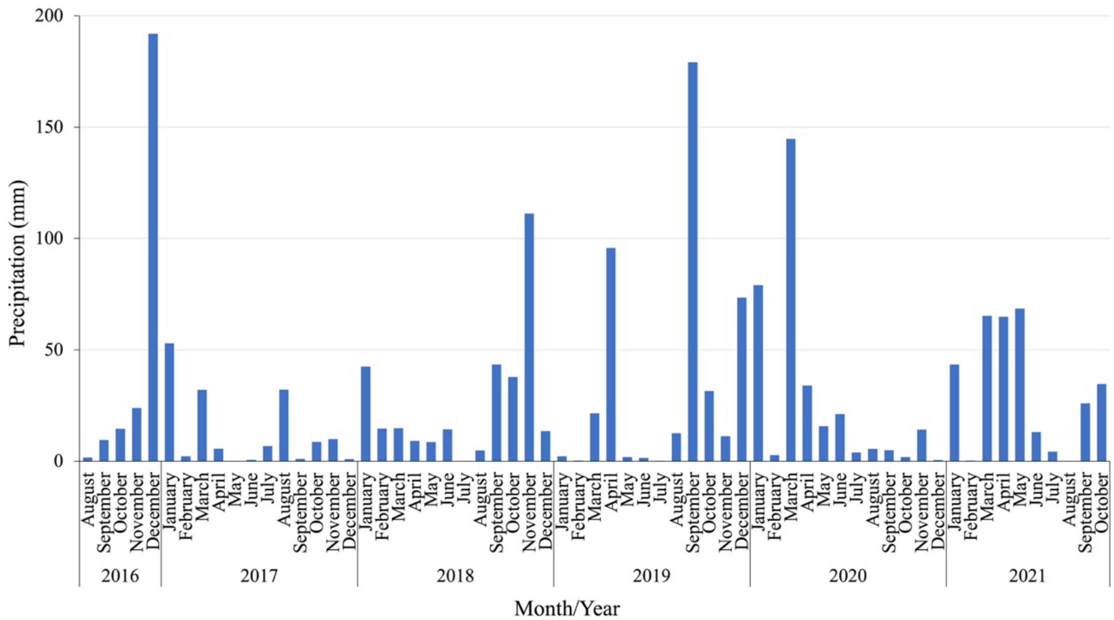
Of all 12 sampling stations, 5 were selected based on their characteristics: E3, deeper situated in the "middle of the lagoon", E4, which was closer to the ocean and far from the river flow, while being inside the lagoon, E5, which was outside the lagoon, in the open sea adjacent to the lagoon, and finally E7 and E8, which were closer to the drainage basin.

Regarding rainfall data, 7 stations were taken into consideration due to their location around rivers that flow into the lagoon, (Figure 1). They are: AL31: Lebor, Totana; CA12: La Palma, Cartagena; CA42: Balsapintada, Fuente Alamo; CA52: La Aljorra, Cartagena; CA91: Campillo Abajo, Fuente Alamo; TP22: Santiago de la Ribera, San Javier; TP91: Torre Pacheco, Torre Pacheco. Monthly precipitation values for each of the stations, reported in the SIAM database, were used to calculate mean monthly rainfall, as reported in Figure 2.

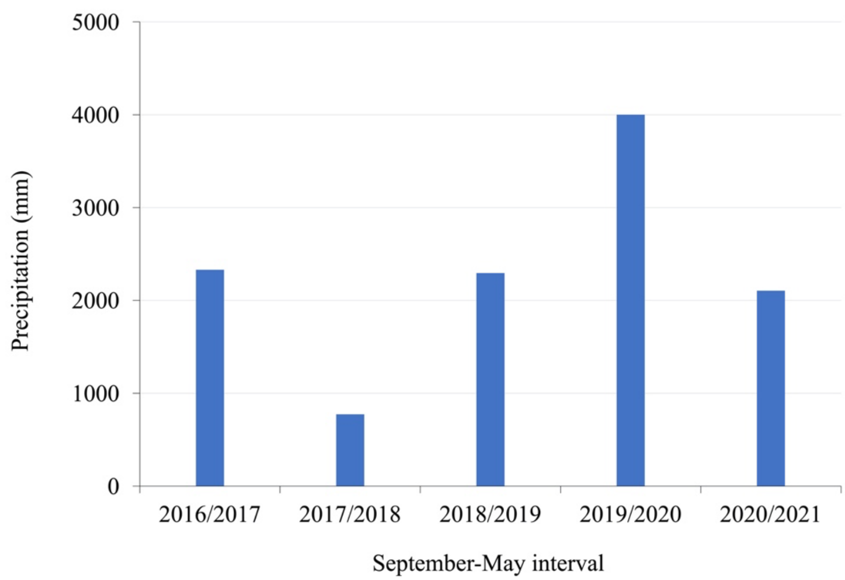
Oceanographic parameter analysis was carried out using the Ocean Data View (ODV) (Schlitzer, 2022) software to create a timeline of the hydrological properties of the Mar Menor, comparing the parameters collected from the lagoon to rainfall values to identify the consequences of the two DANA events in December 2016 and September 2019. Dissolved oxygen (initially in ml L^{-1}, later transformed in % saturation) and potential density (obtained from temperature, depth, and salinity) parameters were calculated using the ODV software, which didn't compute salinity values over 45. Higher salinity values were hence discarded to allow for parameter extrapolation.

Results

The rates of monthly average rainfall in all 7 data stations from August 2016 to October 2021 are shown in Figure 2a. Rainfall varies according to season, with four major peaks (where precipitation exceeded 100 mm $month^{-1}$) during the six-year period. These peaks in precipitation are correspondent of reported DANA events that took place in 17-18/12/2016 and 12-13/09/2019, which reported 191 and 179 mm of rainfall, respectively. Further heavy rainfall events were observed, as seen in November 2018 (111mm) and March 2020 (145mm). After March 2020, there were no heavy rainfall events observed. The sum of rainfall from September to May between 2016 and 2021, showing that 2019 saw the highest and extended value of precipitation (1366.82 mm) in comparison to the other years, can be observed in Figure 2b.



(a)



(b)

Figure 2. a) Mean monthly rainfall for the 7 stations around the Mar Menor area from 2016 to 2021; **b)** Precipitation values from September to May between 2016 and 2021.

The description of the temporal changes in salinity, density, dissolved oxygen saturation, chlorophyll-*a* and turbidity, focused on five stations inside the lagoon (stations E3, E4, E7 and E8) and one on the open sea (station E5). Inside the lagoon, salinity values (Figure 3), ranging from 38.5 to 47.2, are high compared to those in the open sea (37.0 to 43.5). There is an equal distribution in salinity, with high values (46.0 to 47.0) observed in 2016, followed by a swift decrease in 2017, related to the DANA in December 2016. There was a gradual increase in 2018, reaching higher salinity values during Summer, followed by an even greater decrease in 2019, corresponding to the DANA event occurred in September 2019. These lower values were maintained until 2021, reinforced by another high precipitation event in March 2020 and further in March-May 2021. In the open sea, a peculiar stratification was observed: the surface layer was characterized by low salinity values (around 37.5 at 0-2.5 m), while a deeper layer with higher salinity values (>40 at 2.5-6 m), with mean salinity values (34.5-39.0) as reported on other studies in the Mediterranean Sea (Brasseur et al., 1996; Grilli et al., 2020).

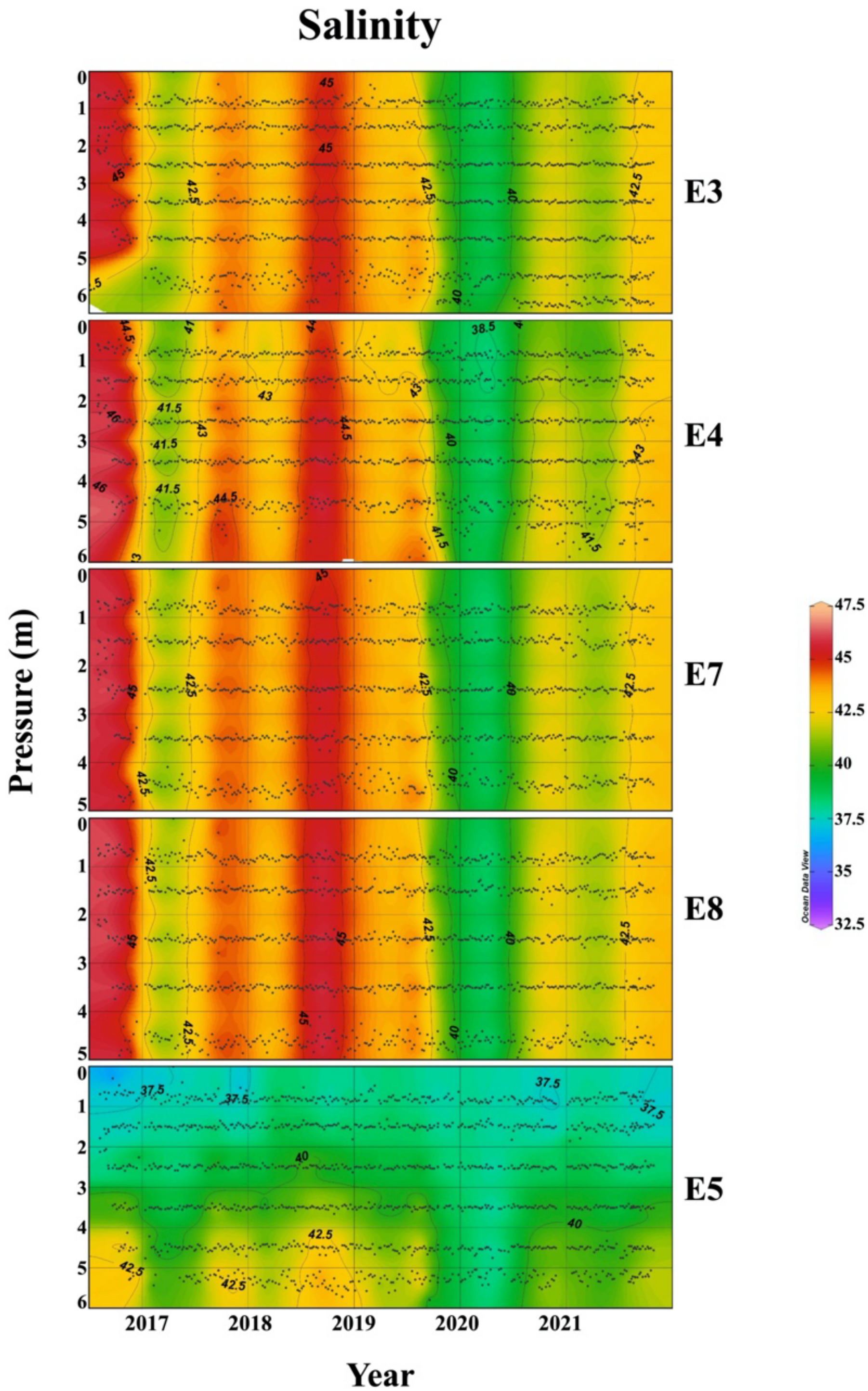


Figure 3. Temporal evolution of salinity at stations E3, E4, E7, E8 and E5 from August 2016 to October 2021.

The temporal evolution of potential density (Figure 4) for the stations inside the lagoon presented the same seasonal trend: higher density values (31-32 kg m^{-3}) in 2016, with a decrease in early/mid-

2017 (29-30 kg m^{-3}), an increase in late-2017/early-2018 (31.5-32.5 kg m^{-3}), a decrease in mid-2018 (30-31 kg m^{-3}), an increase in late-2018/early 2019 (31.5-32.5 kg m^{-3}), followed by a longer decrease in mid-2019 to mid-2020 (27-30.5 kg m^{-3}), another increase in late-2020/early-2021(28.5-31 kg m-3) and finally decreasing in mid/late-2021 (28-20 kg m^{-3}). The temporal evolution of potential density in the open sea presented a different pattern in respect to the stations inside the lagoon. In fact, potential density increased with increase in water depth (as for salinity) showing a surface layer (2.5 m depth) with values ranging from 25.5 kg m^{-3} to 28 kg m^{-3}, and a deeper layer (2.5-6m) with higher values even reaching 30-31 kg m^{-3}.

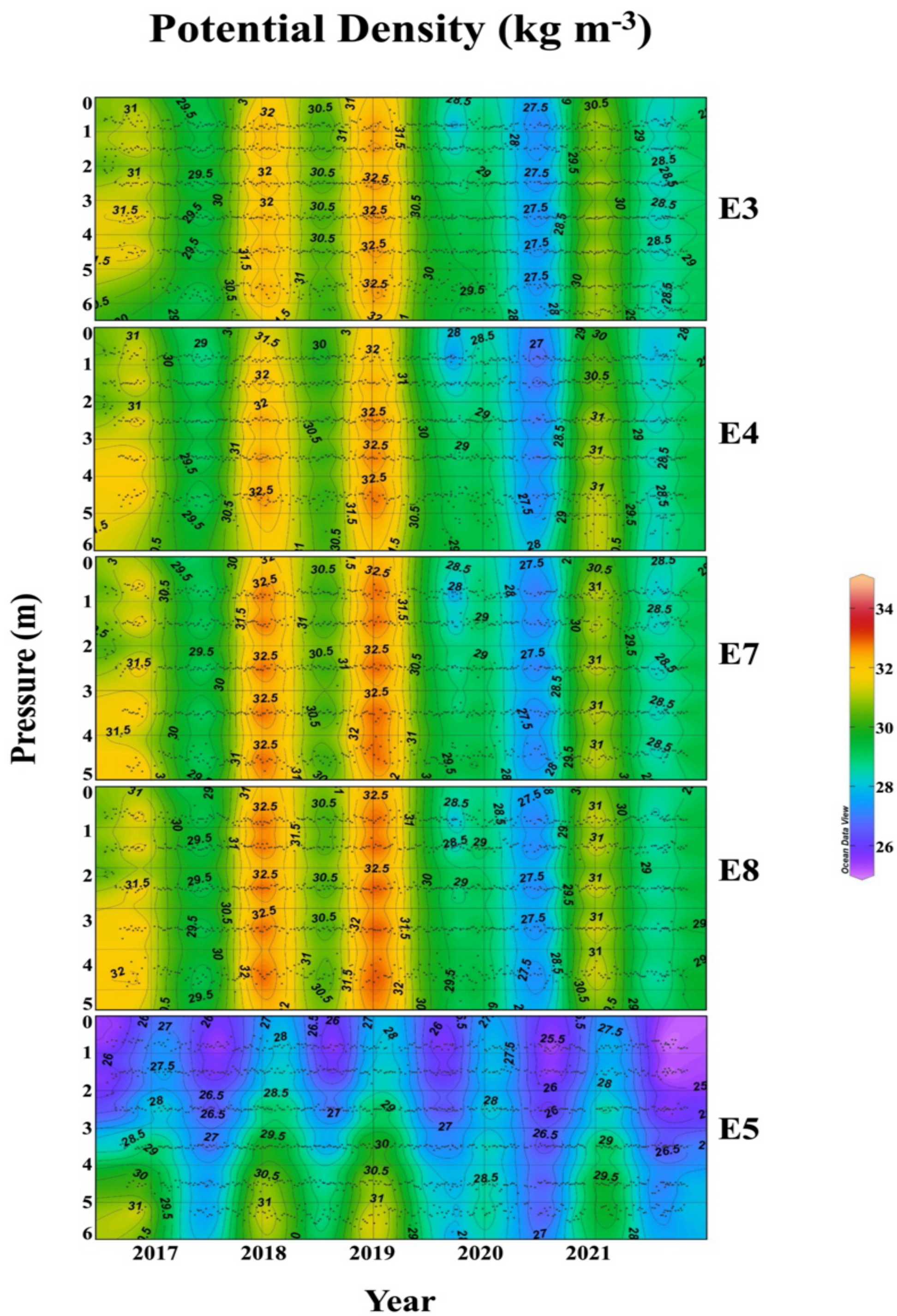


Figure 4. Temporal evolution of density at stations E3, E4, E7, E8 and E5 from August 2016 to October 2021.

Oxygen saturation (Figure 5) showed a rather homogeneous distribution throughout the sampling stations, with an overall supersaturated state (110-140%). In station E3, consistent fluctuation in saturation values were observed. During late-2019 and late-2021, there were lower saturation values at a depth of 5 m. Station E4 followed the same trend, with lower values present at a depth of 3 m in late-2017 and late-2021. E7 presented the highest saturation values (140-160%) particularly during mid-2018/mid-2019 and mid-2020/mid-2021. E8 saturation values were between 120% and 130% during 2016, while showing higher saturation values in shallow depth (0-1 m) in 2017, 2019 and 2021, and at lower depths (3-4.5 m) in early-2019, 2020 and early-2021. Finally, in station E5, results showed fluctuation between seasons of the year from 2017 to 2019, while 2020 and 2021 presented higher saturation values throughout the year.

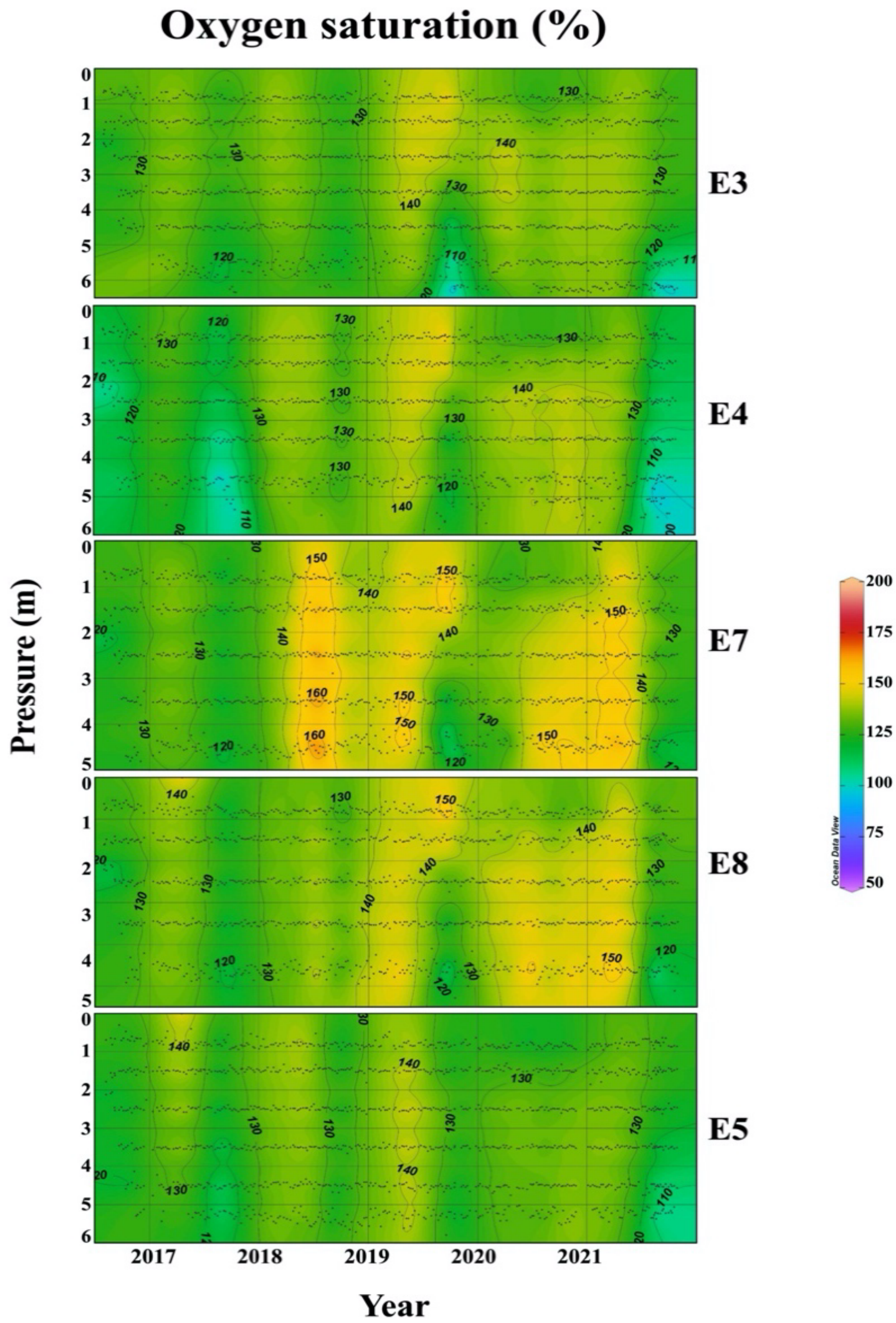


Figure 5. Temporal evolution of oxygen saturation at stations E3, E4, E7, E8 and E5 from August 2016 to October 2021.

A peak in chlorophyll-*a* (16-24 mg L^{-1}) was observed in all the stations inside the lagoon (Figure 6) during late 2016 and early 2017, followed by a decrease that remained constant ($\leqq$ 10 mg L^{-1})

throughout the following years. Station E5 showed constant lower values ($\leqq$ 10 mg L^{-1}) from 2016 to 2021, with higher values (10-14 mg L^{-1}) observed only during 2016, at 4-6 m depth.

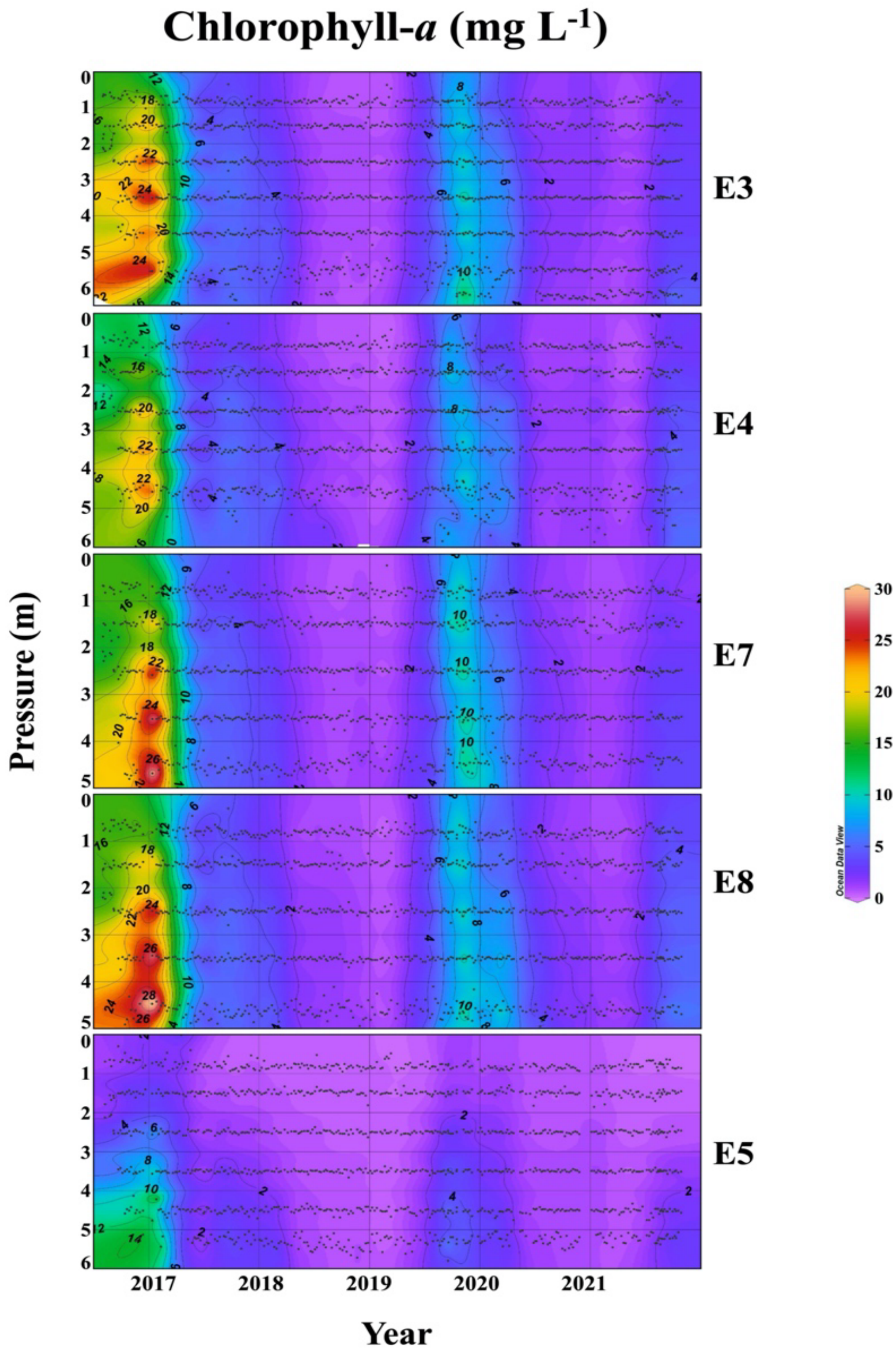


Figure 6. Temporal evolution of chlorophyll-*a* at stations E3, E4, E7, E8 and E5 from August 2016 to October 2021.

In stations E3 and E4 (Figure 7), higher (4-5) turbidity values were observed in 2016 and 2019/2020, in contrast with lower values during the other years (1-3). Station E7 showed higher turbidity values (4-10) during 2016, 2017, 2019/2020 and late 2021, with lower values (1-3) in 2018 and 2020/2021. Station E8 showed higher turbidity values (4-9) in 2016, late 2018, and 2019/2020, with lower values (1-3) in mid-2017, 2018, early 2019 and late-2020/2021. In the open sea, the higher turbidity values (4-6) were recorded in 2016 (down to 4 m depth) and in late 2019/early-2020. The lower turbidity values (1-3) were recorded from 2016 to early-2019, and late-2020/2021.

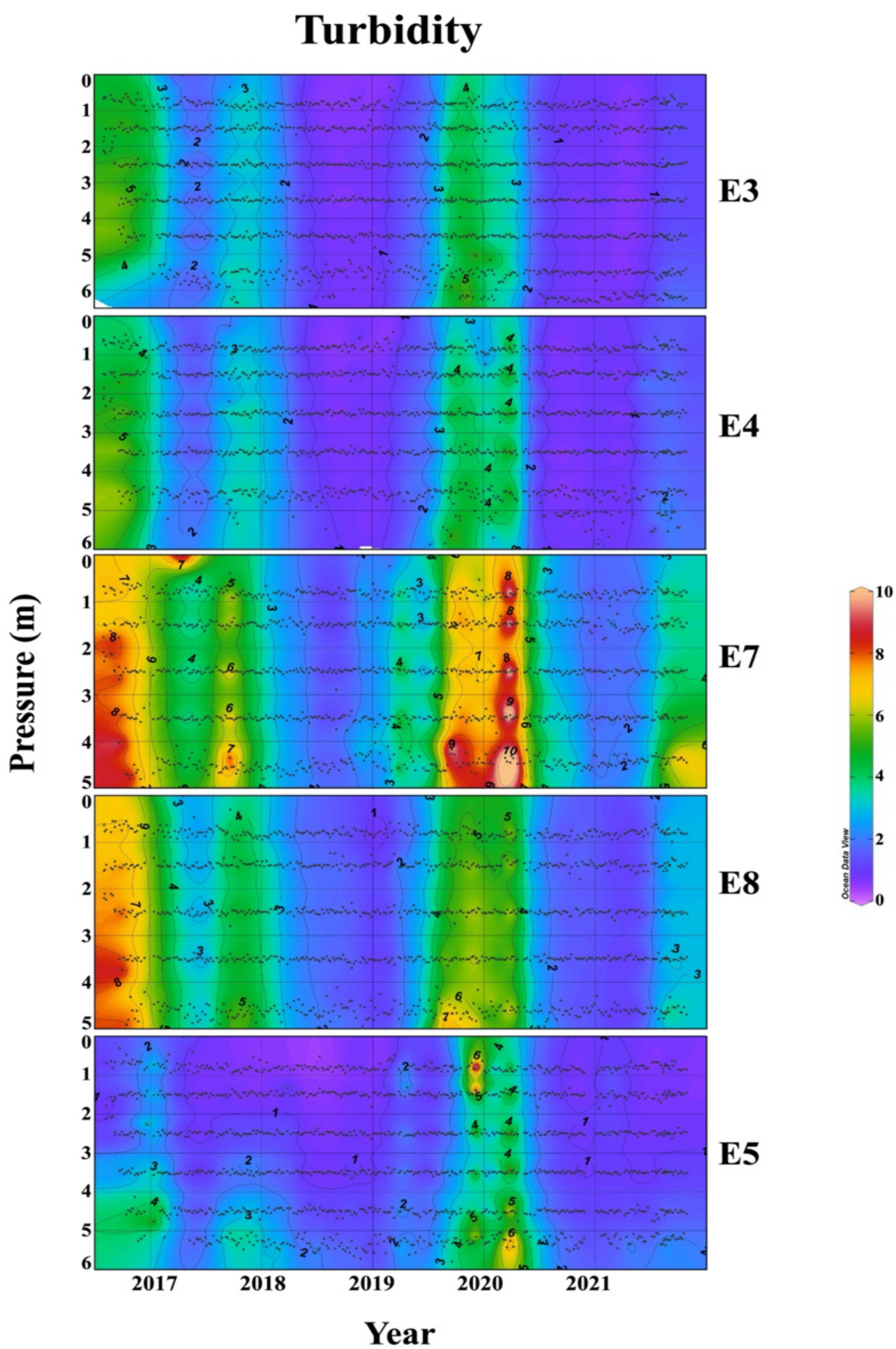
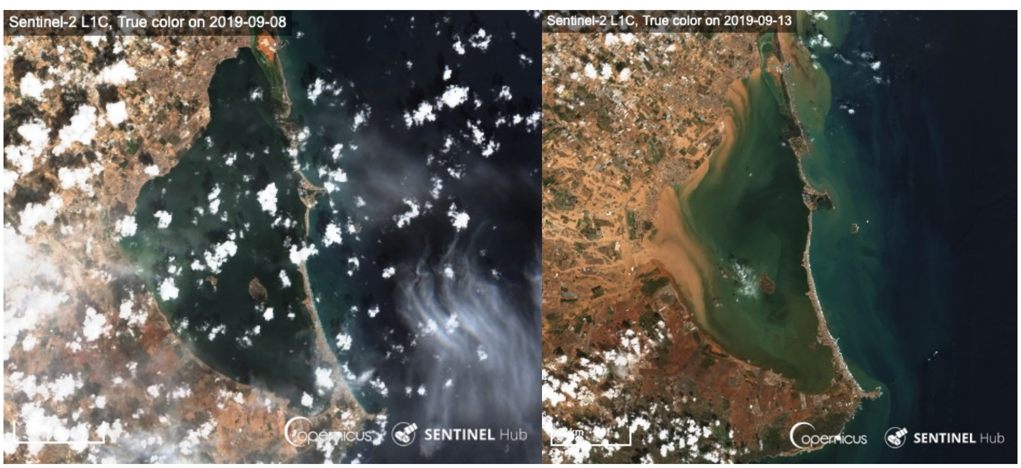


Figure 7. Temporal evolution of turbidity at stations E3, E4, E7, E8 and E5 from August 2016 to October 2021.

Discussion

The DANA events of 2016 and 2019 have had a significant impact in the environmental quality of the Mar Menor. All the analyzed parameters reported changes due to the extreme weather in all 4 analyzed sampling stations located inside the lagoon, with lesser consequences observed in the sampling station located outside the lagoon, in the open sea. Rainfall data reported the extreme inflow of water coming from land, exponentially increasing water exchange rates and carrying all sorts of substances (organic pollutants, waste, sediments), causing the observed changes in the analyzed parameters throughout the lagoon (Figure 8). The input of nutrients carried from urban and agricultural areas into the lagoon is one of the main contributors to aquatic ecosystem contamination (León et al., 2017), promoting algal proliferation, causing shifts not only to the water column but also to regions of the lagoon. These shifts (especially in deeper depths) could in turn promote an oxygen crisis and subsequent eutrophication episode, severely compromising the equilibrium of the lagoon ecosystem (Pérez-Ruzafa, Campillo, et al., 2019).



(a) **(b)**

Figure 8. Satellite images of the Mar Menor before (a) and after (b) the DANA event of September 2019.

Density values are directly dependent on salinity, which is influenced by the physical properties of the water body. Results showed that in the open sea, there is a clear stratification in the water column, influenced by exchanges with the lagoon, where the water coming from the lagoon, with higher salinity (and consequently higher density) settles deeper in the column, while the water from the open sea, with lower salinity (and less dense) moves to shallower depths. The same was not observed within the lagoon, where instead the water column is more evenly distributed due to constant mixing.

Over the 6-year period, salinity values observed inside the lagoon were higher than the open sea, corroborated the precipitation regimen of the area, with a deficit of 600 mm year^{-1} between rainfall and evaporation (Erena et al., 2019; Pérez-Ruzafa, Campillo, et al., 2019; Pérez-Ruzafa et al., 2005), resulting in higher salinity values. These values were lowered during the reported DANA events in 2016 and 2019, with an extreme inflow of freshwater that lowered salinity values for a period of 4 months in 2016/2017, and for a longer period of 10 months in 2019/2020. This could be explained by the higher volume of precipitation in 2019, followed by smaller but still intense rainfall events occurred in the following year that contributed to a decrease in salinity for a longer period of time. Consequently, density values followed the same trend, with lowest density values being observed following the DANA event in 2019.

Results showed a higher increase in chlorophyll-*a* values after the DANA event of December 2016, followed by a slightly subtler increase after the DANA in September 2019. The increase after 2019 is to be expected due to the inflow of runoff into the lagoon that can promote growth within the algal community. However, the anomalous chlorophyll-*a* values observed in 2016/2017 could be explained by two factors: i) the season is more favorable for the proliferation of algal biomass; ii) a sudden change in water quality led to an eutrophication episode reported in January 2017 (Pérez-Ruzafa, Campillo, et al., 2019), where algal bloom reached its peak. Furthermore, there was an increase in turbidity values following the DANA events, but in particular, stations E7 and E8, which were closest to the rivers that flow into the lagoon (Figure 9), presented higher turbidity values during that period in comparison with E3 and E4. Higher turbidity indicates sediments that can settle on the lagoon carrying contaminants. The effect of this process is reflected in the contamination events that occur due to the rivers carrying pollutants through agricultural fields and urban areas (León et al., 2017).

Studies show that pollutants can be found in the water column, lagoon organisms or sediments according to their physicochemical properties (Marini & Frapiccini, 2014), and water bodies with higher salinity values have shown higher sorption and lower degradation rates of pollutants over time (Frapiccini & Marini, 2015). Moreover, higher pollution rates can be directly linked to anthropogenic causes, with stronger impacts during periods where human presence is most intense (Marini & Annibaldi, 2022). Inappropriate tourist behavior is reported to negatively impact ecosystems, and therefore, informing and bringing awareness to people can contribute to the preservation of ecosystem integrity in the long term (Machado Toffolo et al., 2022).

Regarding chlorophyll-*a* values, studies show that nitrogen is directly correlated with chlorophyll-*a* (Fernández-alías et al., 2022). High nitrogen concentrations favor algal bloom, reflected in a high chlorophyll-*a* concentration. Hence, the observed peaks during 2017 and 2020 could be due to two factors: i) the DANA events of 2016 and 2019, where the heavy rainfall carried nutrients (including nitrogen) from the agricultural fields in the surrounding Murcia region to the lagoon, favoring the proliferation of photosynthetic algae species resulting in the increase of chlorophyll-*a* values (Burkholder et al., 2007; Fernández-alías et al., 2022); ii) during the winter/early-spring season, chlorophyll-*a* values tend to rise to a peak (Ricci et al., 2022), contributing to the high values observed on Figure 5. These results are in line with reported seasonal biomass peaks in transitional and coastal ecosystems (Morabito et al., 2018), as well as eutrophication episodes in the Mar Menor (Pérez-Ruzafa, Campillo, et al., 2019).

Dissolved organic matter and algal biomass (measured through chlorophyll-*a* values), can contribute to the turbidity of the water column, making these 2 parameters correlated (Chaffin et al., 2018).

Furthermore, chlorophyll-a and turbidity are also correlated with oxygen saturation values. A decrease in oxygen means that the water is more stagnant, with less exchange of water between the surface and the bottom. Therefore, the higher the movement of the water body, the higher the values of turbidity due to resuspension of organic matter in particulate sediment, algal biomass (chlorophyll-a), and oxygen saturation due to oxygenation of the water column (Hull et al., 2008). Boyer et al. (Boyer et al., 1999) also reported that temperature plays an influence on the values of dissolved oxygen, with lower saturation percentage with higher temperatures, and higher saturation percentage with lower temperatures.

According to the circulation patterns observed in the lagoon (Pérez-Ruzafa et al., 2005) (Figure 7), stations E3 and E4 have less water exchanges because they are only affected by winds and the circulation of the lagoon, while E7 and E8 are also conditioned to the rainfall and runoff inflow into the lagoon (Figure 8).

While it has been established that currents in the lagoon are motioned mainly by the wind (Figure 9) (Pérez-Ruzafa et al., 2005), the increase in turbidity could be caused by the DANA events, which brought about an extreme inflow of sediments and nutrients, with repercussions on algal bloom, that reached the whole extension of the lagoon and also the boating canal that communicates with the ocean, as shown in the station E5.

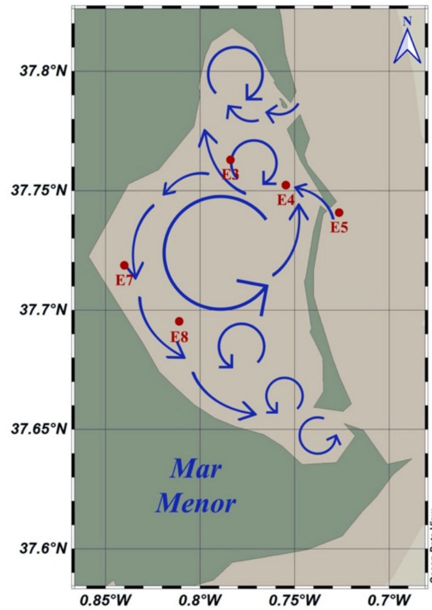


Figure 9. Current patterns, inflow watercourses and communication canals with the Mediterranean Sea of the Mar Menor (Fernández-Alías et al., 2020; García-Oliva et al., 2018; Pérez-Ruzafa et al., 2005). Adapted from "Spatial and Temporal Variations of Hydrological Conditions, Nutrients and Chlorophyll-*a* in a Mediterranean Coastal Lagoon (Mar Menor, Spain)" by Pérez-Ruzafa et al., 2005, Hydrobiologia, 550, 11–27; "Assessing the Hydrodynamic Response of the Mar Menor Lagoon to Dredging Inlets Interventions through Numerical Modelling", by García-Oliva et al., 2018, Water, 10; and "Population Dynamics and Growth in Three Scyphozoan Jellyfishes, and Their Relationship with Environmental Conditions in a Coastal Lagoon", by Fernández-alías et al., 2020, Estuarine, Coastal and Shelf Science, 243.

Conclusion

Extreme weather events have long-lasting rippling impacts on the affected ecosystems. An unexpected increase in rainfall can have devastating effects not only for urban areas with flooding and landslides but especially for natural ecosystems which require a level of homeostasis that takes time and is very fragile to maintain. Climate change rates contribute to such events and don't allow for ecosystem recovery, since they are close in time and ever more frequent. Since the physicochemical properties of a natural ecosystem are all interconnected, these circumstances create a cascade effect that can permanently compromise their functioning and be detrimental not only for the ecosystem survival but also for the plethora of organisms that directly or indirectly depend on it, of which the human race is part of. Mitigation actions are needed to cope with climate change rates within damaged territories, as well as comprehensive management plans that take into consideration all aspects that might contribute to the decline of natural ecosystems due to pollution from agricultural and urban area runoff.

Acknowledgments

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Chapter II

Effect of extreme rainfall events in the Mar Menor lagoon (SE, Spain)

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Abstract

Extreme climate events, now more frequent, are defined by the IPCC as occurrences outside typical weather ranges. Extreme rainfall, for instance, can lead to excessive freshwater inflow into saltwater environments, disrupting vulnerable ecosystems like coastal lagoons. The Mar Menor lagoon in Spain exemplifies this vulnerability, facing issues like eutrophication and habitat loss due to changing water conditions.

Continuous monitoring of water quality is essential to manage these environmental risks. While traditional sampling methods are valid, real-time data collection through buoys enables rapid response to changing conditions. This study focuses on data collected from sampling stations and a Smartbuoy in the Mar Menor lagoon, following the rainfall events on October 6th and 10th 2022, to assess the time required for the ecosystem to regain balance. Results showed that the southern part of the Mar Menor lagoon had a delayed recovery of hydrological conditions compared to the northern region. Data indicated that these rainfall events significantly affected salinity, turbidity, and oxygen saturation levels.

In the southern region, lower surface salinity was observed immediately after the rainfall due to increased freshwater inflow, while the northern part remained relatively stable. Freshwater influx also impacted bottom salinity along the western shore, demonstrating how the lagoon's current patterns facilitated this distribution.

By October 19th, while salinity in the lagoon's center had risen, it had not returned to pre-rainfall levels, and lower salinity persisted in the southern region, indicating lingering freshwater presence. Turbidity also increased along the western and southern shores due to runoff, which carried nutrients and sediments, potentially harming local ecosystems by disrupting photosynthesis and affecting benthic macrophytes. The continuous data collected by the Smartbuoy provided detailed insights into the lagoon's hydrological changes over time, allowing a better understanding of salinity fluctuations, turbidity spikes following rainfall, and variations in oxygen saturation related to day-night cycles. This real-time data is crucial for effective environmental management and decision-making, highlighting the need for more comprehensive monitoring to inform conservation efforts and interventions in the lagoon ecosystem.

Keywords: Rainfall; Live monitoring; Smartbuoy; Mar Menor

Introduction

It is no longer matter of doubt that human activities have taken temperature rates to a new high, causing climate change consequences all over the world. Increased greenhouse gas emissions from human activities lead to changes in temperature (Ermolina et al., 2021), wind (Martinez & Iglesias, 2024) and ocean currents (Doney et al., 2012; Harley et al., 2006). These changes cause impacts in the entire planet's geochemical cycle, creating more imbalances that influence the whole ecosystem (Abbass et al., 2022; Akpuokwe et al., 2024; Jacobs et al., 2021; Lee et al., 2024; Vlasceanu et al., 2024), favoring the spread of disease outbreaks (de Souza & Weaver, 2024), decreasing availability of food crops (Lee et al., 2024), and creating more extreme climatic events (Kreibich et al., 2022).

Extreme climatic events are, according to the IPCC (2012): "The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'" (IPCC 2012). Although extreme climatic events are (or used to be) considered rare in frequency, and there isn't enough historical data to allow for proper assessment of some kinds of events (e.g., droughts), observations from 1950 until now indicate a significant increase in extreme rainfall events in some global regions (IPCC, 2012). An increase in global temperature of 2ºC could double the damage done by floods worldwide (Kreibich et al., 2022).

That, paired with the increase in urbanization rates in territories all around the world (Lin et al., 2020), leads to even higher intensification of rainfall due to microclimate changes in the urban areas (IPCC 2023), creating a perfect storm for substantial damages in social, economic, and sanitary aspects (Guan et al., 2022).

In the case of extreme rainfall and floods, depending on the region, they might promote exacerbated freshwater inflow into saltwater environments. This higher freshwater discharge can influence physical aspects within the saltwater system, causing impacts on fauna and flora, potentially affecting the survival of the whole ecosystem (Gillanders & Kingsford, 2002).

Of all ecosystems subject to freshwater inflow, coastal lagoons are among the most susceptible to changes in the water column (Machado Toffolo et al., 2022). While being highly productive, they survive on a fragile equilibrium that is deeply influenced by climate change and urbanization (Meredith et al., 2022). That is the case of the Mar Menor, a highly productive shallow saltwater lagoon in the southeast of Spain, connected on one side to the Mediterranean Sea and presenting high mean temperatures (30ºC), high salinity (43) and low precipitation (300 mm year^{-1}) (Erena et al., 2019; Ghezzo et al., 2015; Perez-Ruzafa et al., 2005; Pérez-Ruzafa et al., 2005, 2019). Due to their fragile nature, impacts such as eutrophication episodes, habitat damage and species depletion are not uncommon (Erostate et al., 2020, 2022; Jones et al., 2018; Machado Toffolo et al., 2022; Newton et al., 2014). These impacts can be prompted by high freshwater inflow from the water catchment area, which can be exacerbated by floods, diluting saltwater and thus creating variations in physical parameters throughout the water column (Honfo et al., 2024; Pérez-Ruzafa et al., 2007; Sassi & Hoitink, 2013).

Water analysis is important to detect changes and act accordingly, but periodic sample monitoring is not sufficient anymore to respond to rapid changes when considering risk and environmental management. Hence, continuous monitoring is necessary (Shukla et al., 2023; Trevathan & Johnstone, 2018). For that purpose, buoys present a valuable alternative, using multiple sensors to collect physicochemical as well as biological data in real-time for swift and reliable collection (Mills et al., 2003).

The present study analyzed the data collected by 11 sampling stations and a Smartbuoy in the Mar Menor lagoon, following an extreme rainfall event in October 2022 (about 300mm) to evaluate the time required for the ecosystem to reach homeostasis again.

Method

We utilized data from 2 databases. The first set of data came from the SMARTLAGOON project's smartbuoy (Figure 1, available at: https://asap-forecast.com/public?lat=37.706415372144384&lon=-0.7771660036807169&zoom=10&projects=a1c02d60-7d35-11ed-a545-0242ac1c0003), which captures live data at 5 minute-increments and sends it directly to the project's website server and can be accessed online. Measures of wind, depth, temperature, salinity, O_2 concentration and turbidity are obtained from the EE181temperature and humidity probe, 03101 wind Sentry anemometer, SeaBird ECO Dual Channel Flurometer and Aanderaa Oxygen Sensors.

The second set of data was obtained from the IMIDA (Murcian Institute of Agricultural Research & Development) field team, which since 2016 surveyed 11 different points covering all areas of the Mar Menor (Figure 1). Values were obtained with the SBE 19plus CTD (Sea-Bird Electronics, WA, USA), equipped with additional sensors for oxygen and turbidity.
Furthermore, we utilized rainfall data from the Sistema de Información Agrario de Murcia (SIAM) database (Figure 2, available at: http://siam.imida.es/apex/f?p=101:46:7220879812294039).

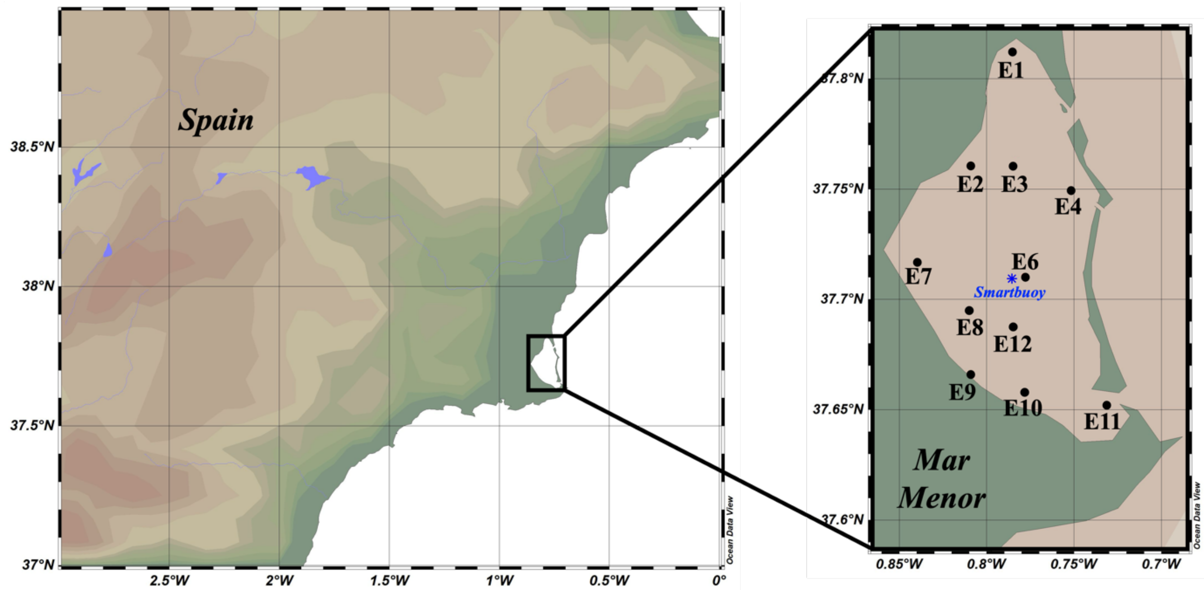

Figure 1. Location of sampling stations within the lagoon territory and smartbuoy (adapted from (Machado Toffolo et al., 2022).

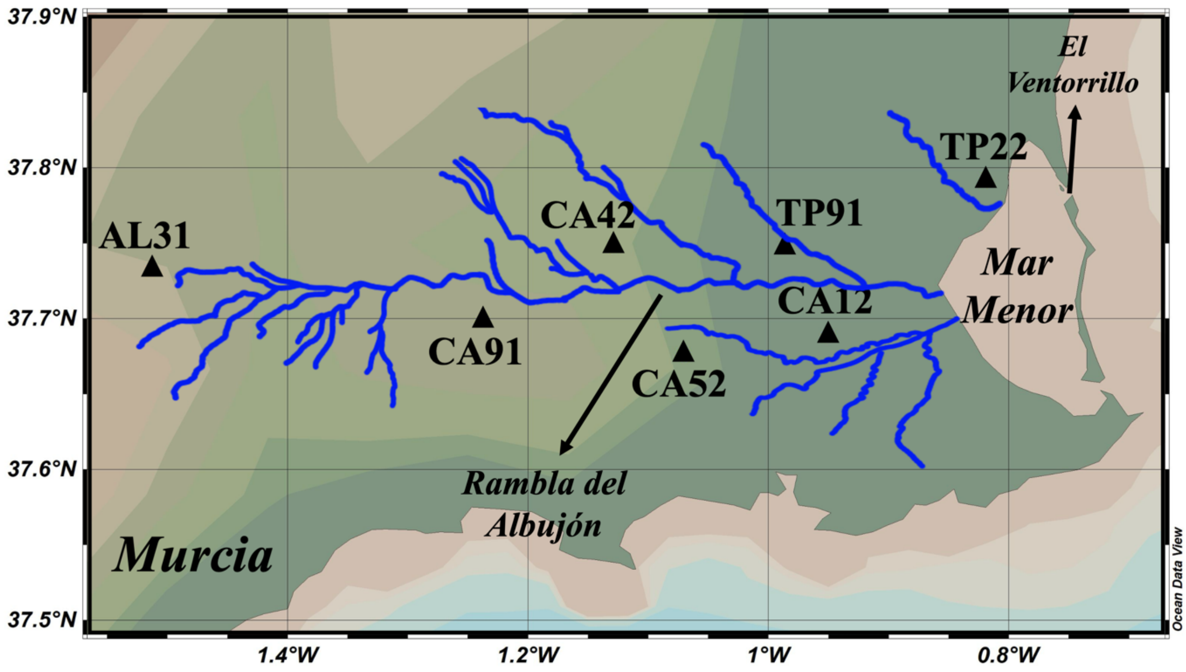

Figure 2. Location of the Mar Menor rainfall data stations along the Rambla del Albujón basin (adapted from (Alcolea et al., 2019; Machado Toffolo et al., 2022). Stations: AL31: Lebor, Totana; CA12: La Palma, Cartagena; CA42: Balsapintada, Fuente Alamo; CA52: La Aljorra, Cartagena; CA91: Campillo Abajo, Fuente Alamo; TP22: Santiago de la Ribera, San Javier; TP91: Torre Pacheco, Torre Pacheco.

All 12 sampling stations were utilized for surface and bottom maps for the parameters temperature, salinity, turbidity and O_2 saturation.

Rainfall data was obtained from 7 covering the lagoon's catchment area (Figure 2). Hourly precipitation values for each of the stations, reported in the SIAM database, were used to calculate the amount of rainfall during October 6th and October 10th 2022.

The parameters were elaborated using the Ocean Data View (ODV) [22] software. We analyzed the distribution of parameters rates on the bottom and on the surface of the lagoon on 3 dates: October 4th, before any of the 2 events, October 10th, after the first event and right before the second one, and October 19th, after both events, as well as hourly measurements from October 4th to October 19th, to identify the changes in the lagoon following rainfall events.

Results

On October 6th, there was a rainfall rate of 237.8 mm, from 01:00 to 16:00, concentrated mostly between the hours of 07:00 and 11:00 (Figure 3). October 10th saw a lower amount of rainfall, with 77.6 mm spread between 14:00 and 19:00, with the highest amount of rainfall at 17:00 (Figure 3).

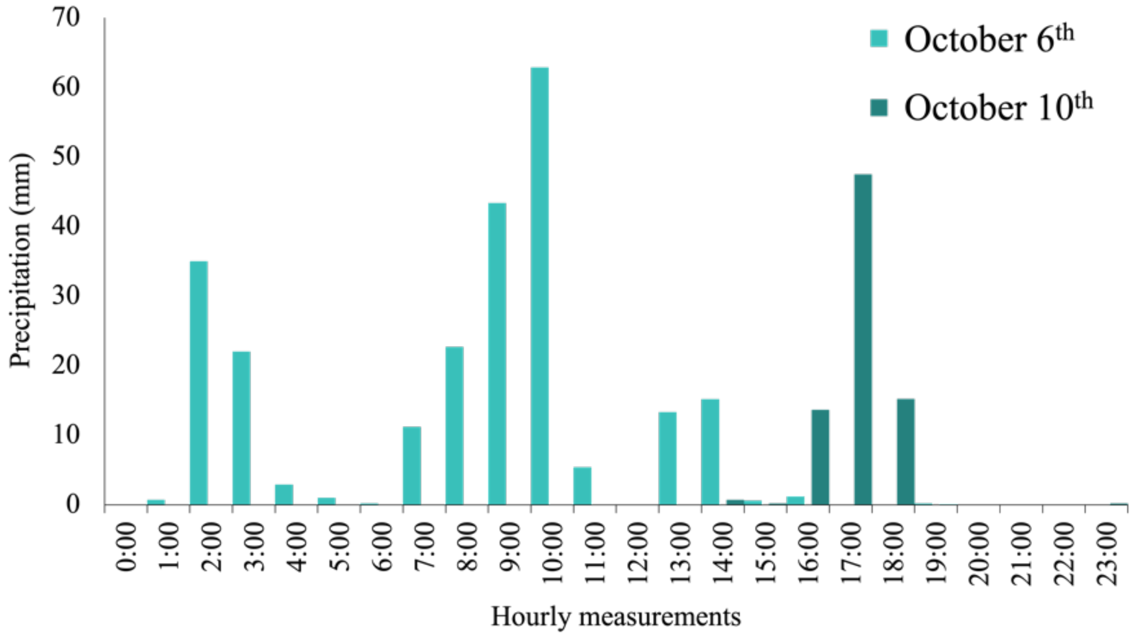

Figure 3. Precipitation values observed throughout the 7 stations during October 6th (237.8mm) and October 10th (77.6mm), 2022 (315.4 mm in total).

On October 4th, the surface of the lagoon registered temperatures from 23.2 to 23.6ºC (Fig. 4a). Salinity ranged from 42.6 to 43.4, with higher rates around the center and north of the lagoon, and lower around the southern and eastern shores (Fig. 4b). Turbidity showed low rates (0-3.5) throughout the lagoon, with higher rates (3.5) around the connection of the Mar Menor to the Rambla del Albujón watershed (Figure 4c). O_2 saturation ranged from 95 to 135%, with higher saturation rates coming from the center of the lagoon and peaking around the El Ventorillo canal.

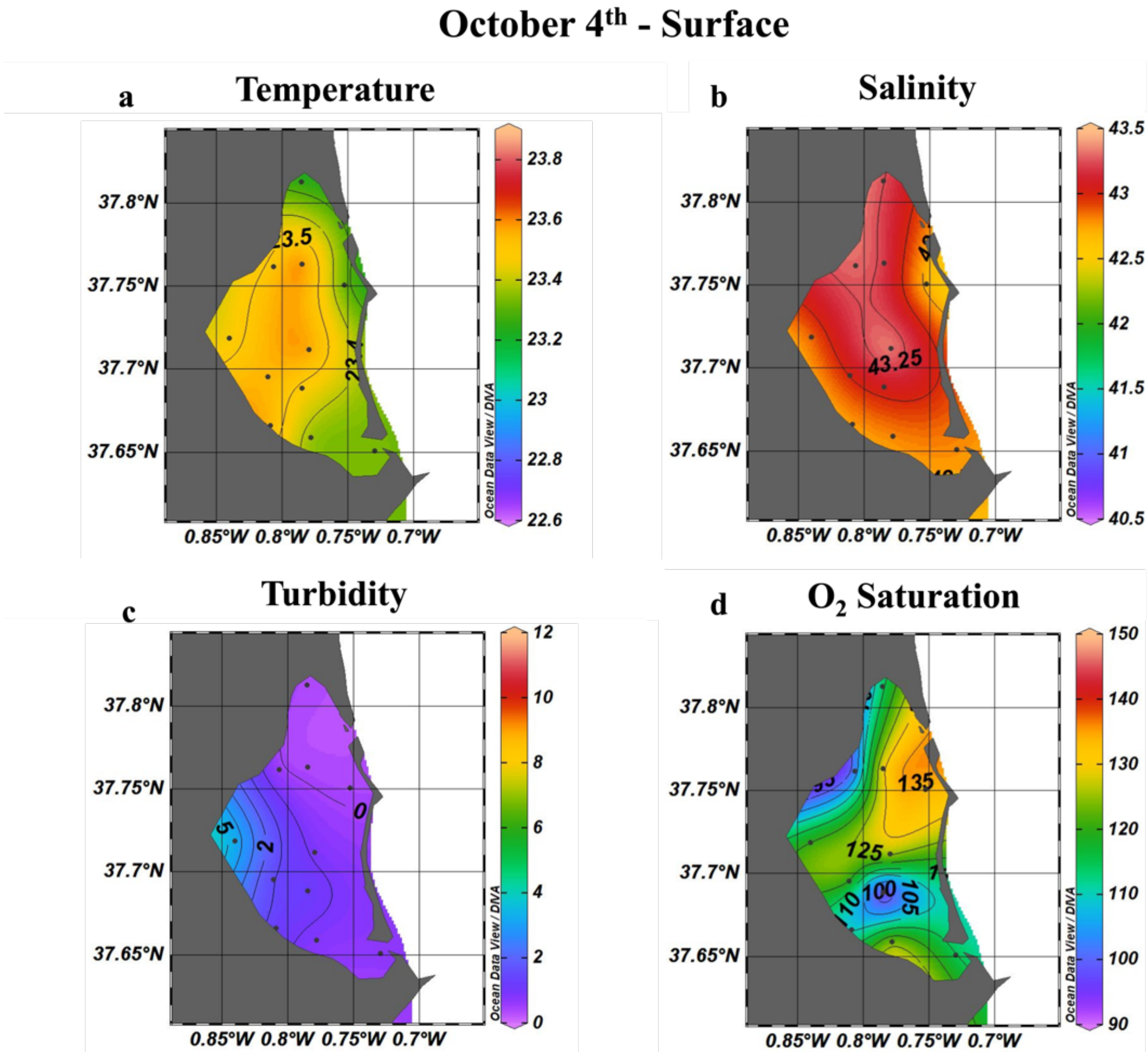

Figure 4. Horizontal distribution of surface temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) of the Mar Menor lagoon on October 4th, 2022.

The bottom of the lagoon registered temperatures from 23.2 to 23.9°C (Fig. 5a). Salinity showed a peak of 43.5, with lower values (42.7) observed around the southern shore of the lagoon (Figure 5b). Turbidity showed low rates (0-3) throughout the lagoon, with higher rates (4-7) around the Rambla del Albujón (Figure 5c). O_2 saturation showed higher values (135-140%) in the center of the lagoon, with lower values (115-120%) being observed in both southern and northern regions (Fig. 5d).

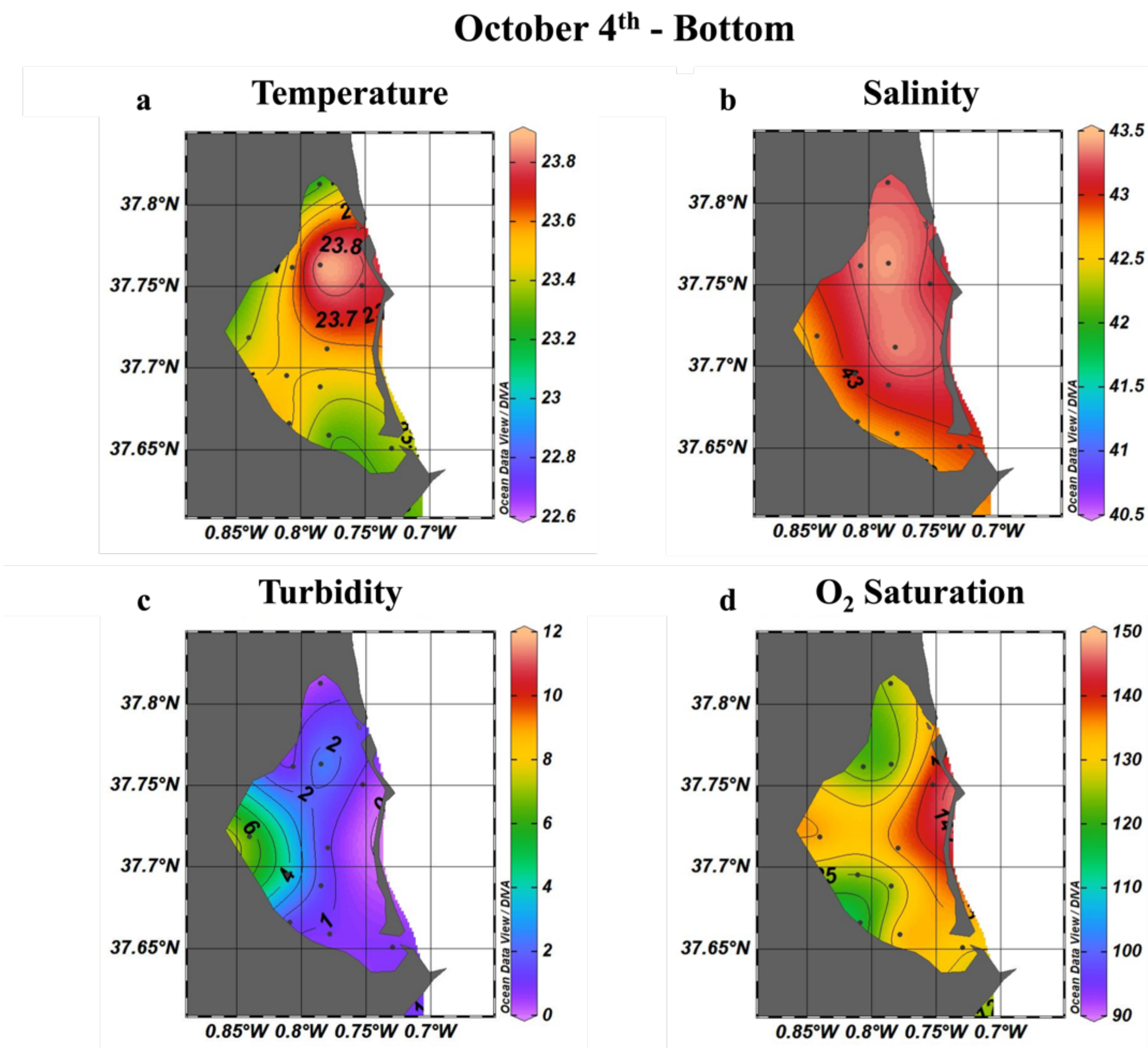

Figure 5. Horizontal distribution of bottom temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) of the Mar Menor lagoon on October 4th, 2022.

On October 10th, 3 days after the first rainfall event, the surface of the lagoon registered temperatures from 22.6 to 23.6ºC (Fig. 6a). Salinity ranged from 40.5 to 43.2, with higher rates around the center and north of the lagoon (42-43), and lower around the wetern and southern shores (42-41, Fig. 6b). Turbidity showed low rates (0-1.5) throughout the eastern part of lagoon, with higher rates (2-5) on the southern and western part of the lagoon, peaking at the Rambla del Albujón entrance (Figure 6c). O_2 saturation ranged from 110 to 145%, peaking at the south of the lagoon, with higher rates around the northern part (Fig. 6d).

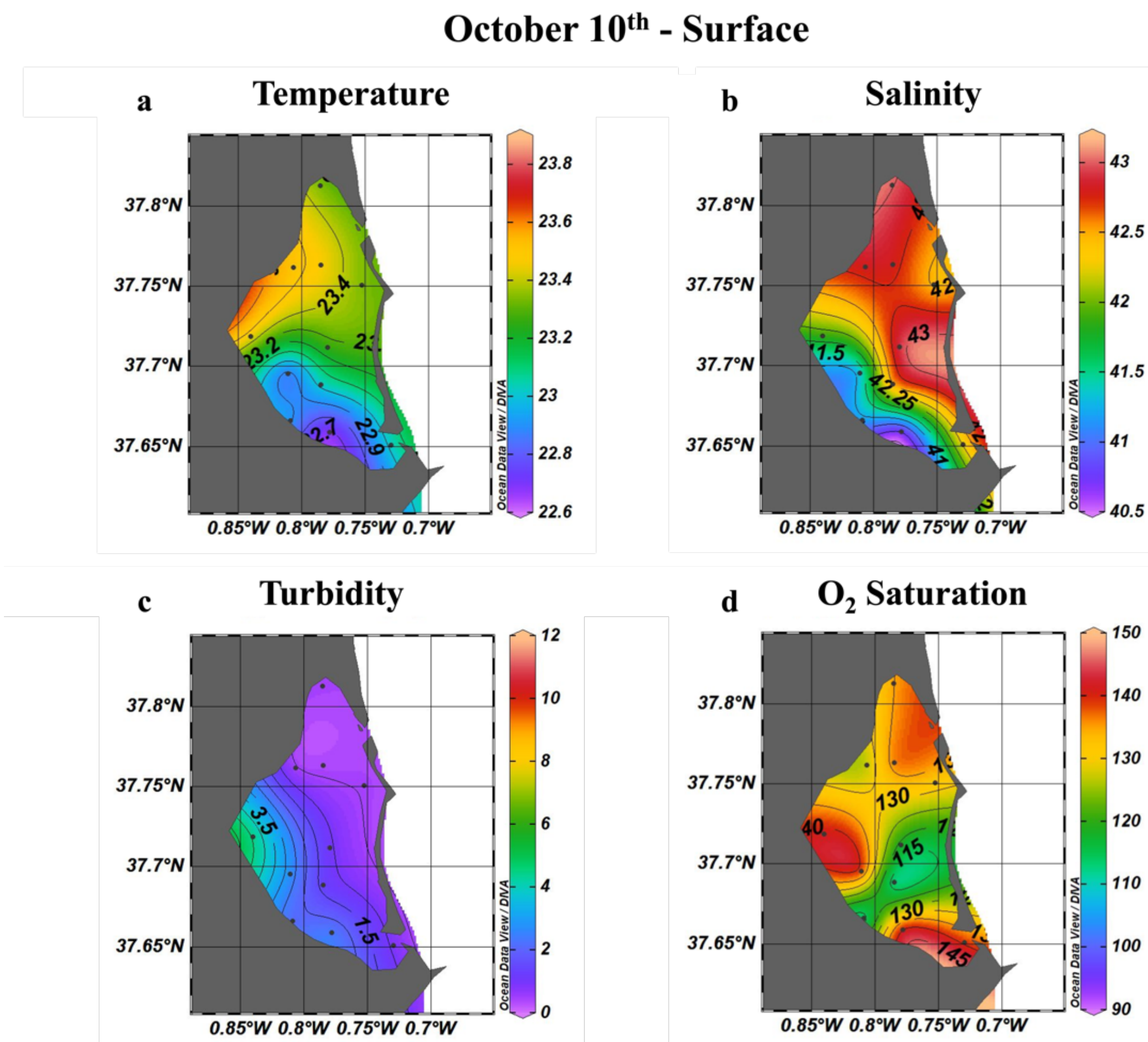

Figure 6. Horizontal distribution of surface temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) of the Mar Menor lagoon on October 10th, 2022.

The bottom of the lagoon registered temperatures from 23 to 23.5ºC (Fig. 7a). Salinity showed a peak of 43, with lower values (41.5-42) observed around the western and southern shores (Figure 7b). Turbidity showed low rates (1-2) throughout the eastern part of the lagoon, with higher rates (3.5-12) around the Rambla del Albujón (Figure 7c). O_2 saturation peaked (140%) in the north of the lagoon, with lower values (130-110%) in the western and southern parts (Fig. 7d).

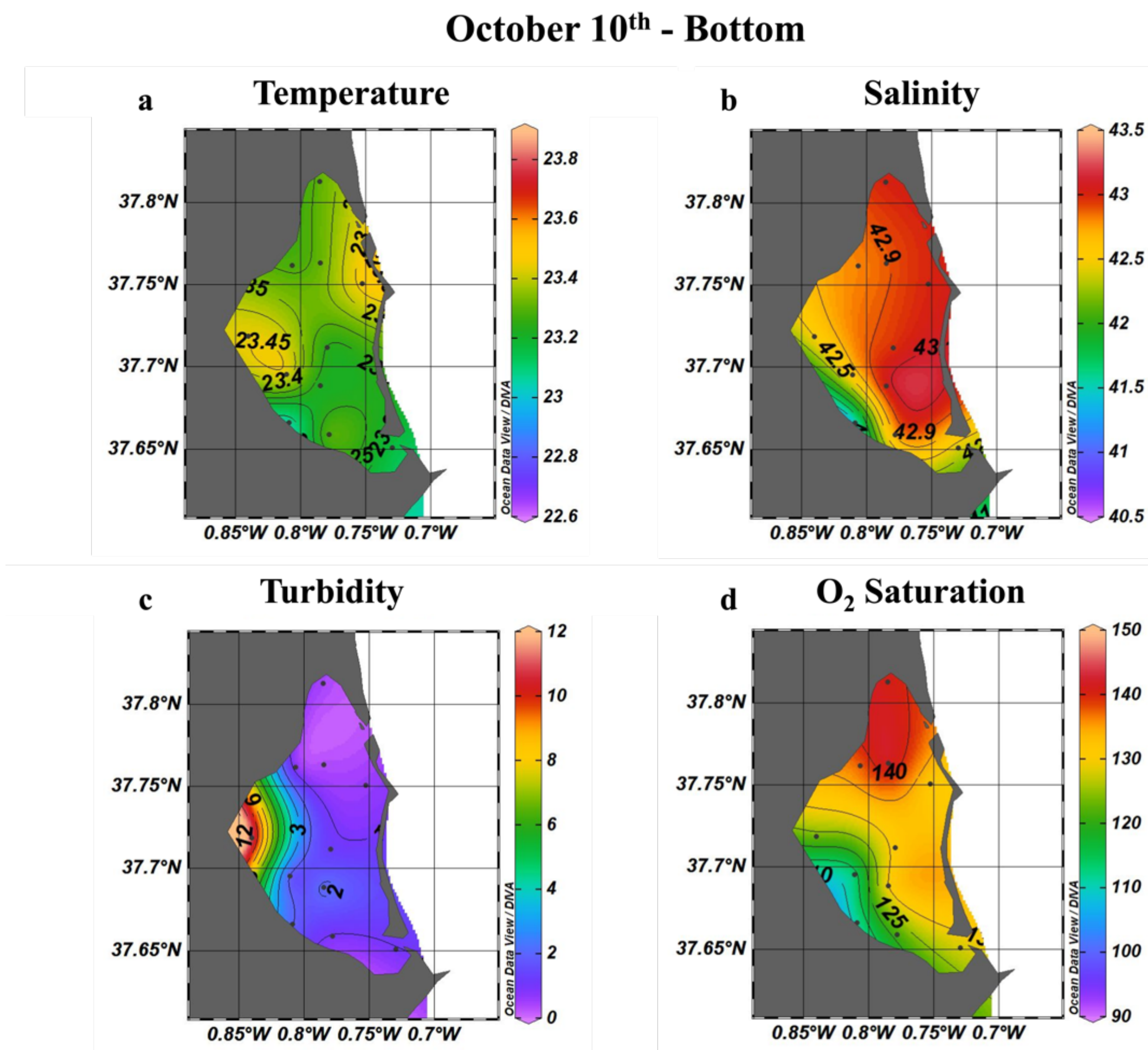

Figure 7. Horizontal distribution of bottom temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) of the Mar Menor lagoon on October 10th, 2022.

On October 19th, several days after both rainfall events, the surface of the lagoon registered the same temperatures of 23.2 to 23.6ºC (Fig. 8a). Salinity rates peaked at 42.6, with higher rates in the center and northern parts of the lagoon, and lower rates in the southern parts of the lagoon and at the eastern shore (Fig. 8b). Turbidity showed low rates (0-0.5) throughout the eastern part of lagoon, with higher rates (1.5-4) on the western part of the lagoon (Fig. 8c). O_2 saturation ranged from 100-135%, peaking in the south of the lagoon, with lower rates on the shores and higher in the center (Fig. 8d).

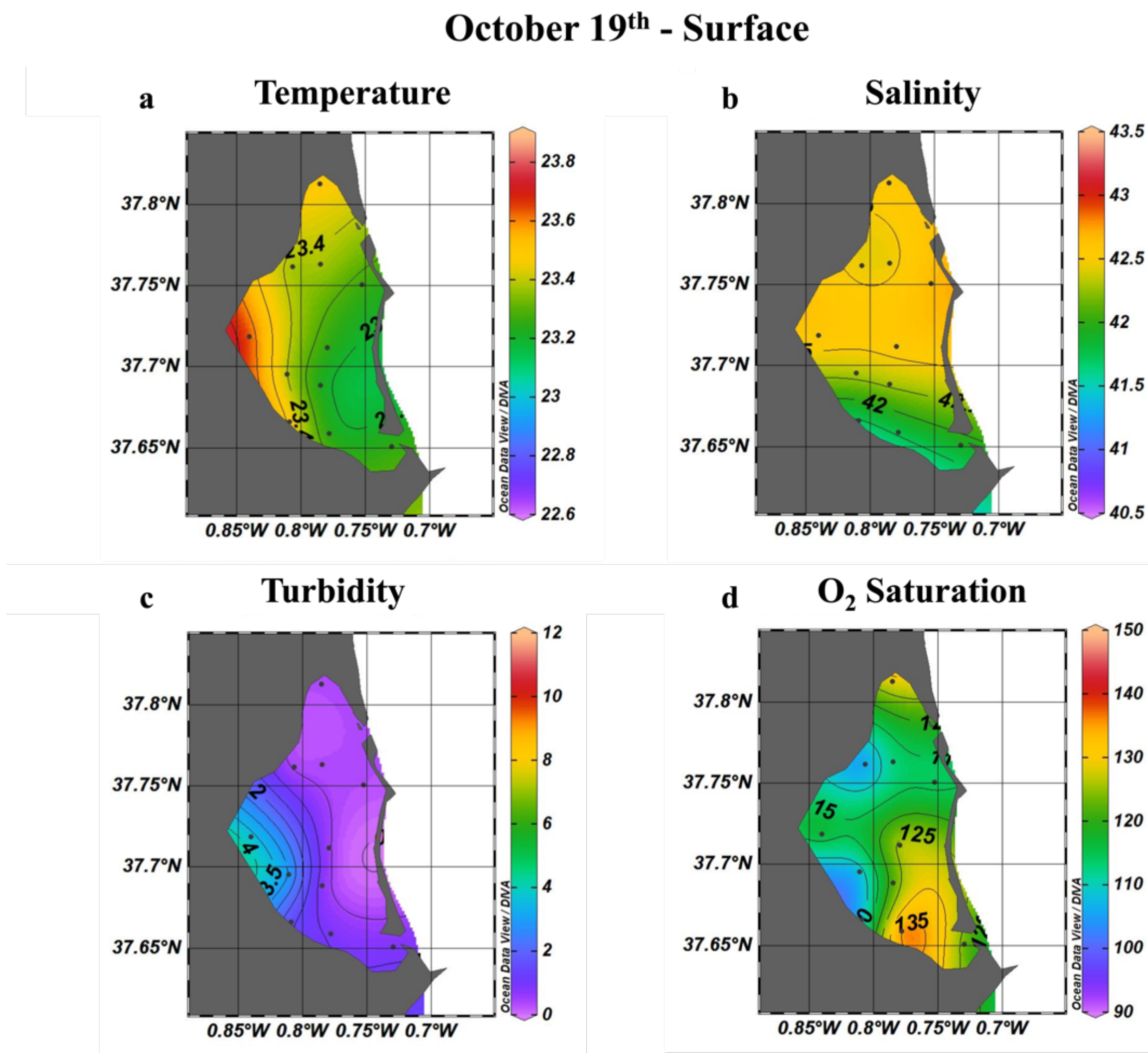

Figure 8. Horizontal distribution of surface temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) of the Mar Menor lagoon on October 19th, 2022.

The bottom of the lagoon registered temperatures from 23.3 to 23.6ºC (Fig. 9a). Salinity ranged from 42.6 to 42.7 in the northern part of the lagoon, and from 41.9 to 42.3 in the southern part of the lagoon (Fig. 9b). Turbidity remained low throughout the lagoon (0-2), with a 5 peak at the Rambla del Albujón entrance (Fig. 9c). O_2 saturation peaked at 145% in the center of the lagoon, with rates gtom 105 to 135 around the lagoon area (Fig. 9d).

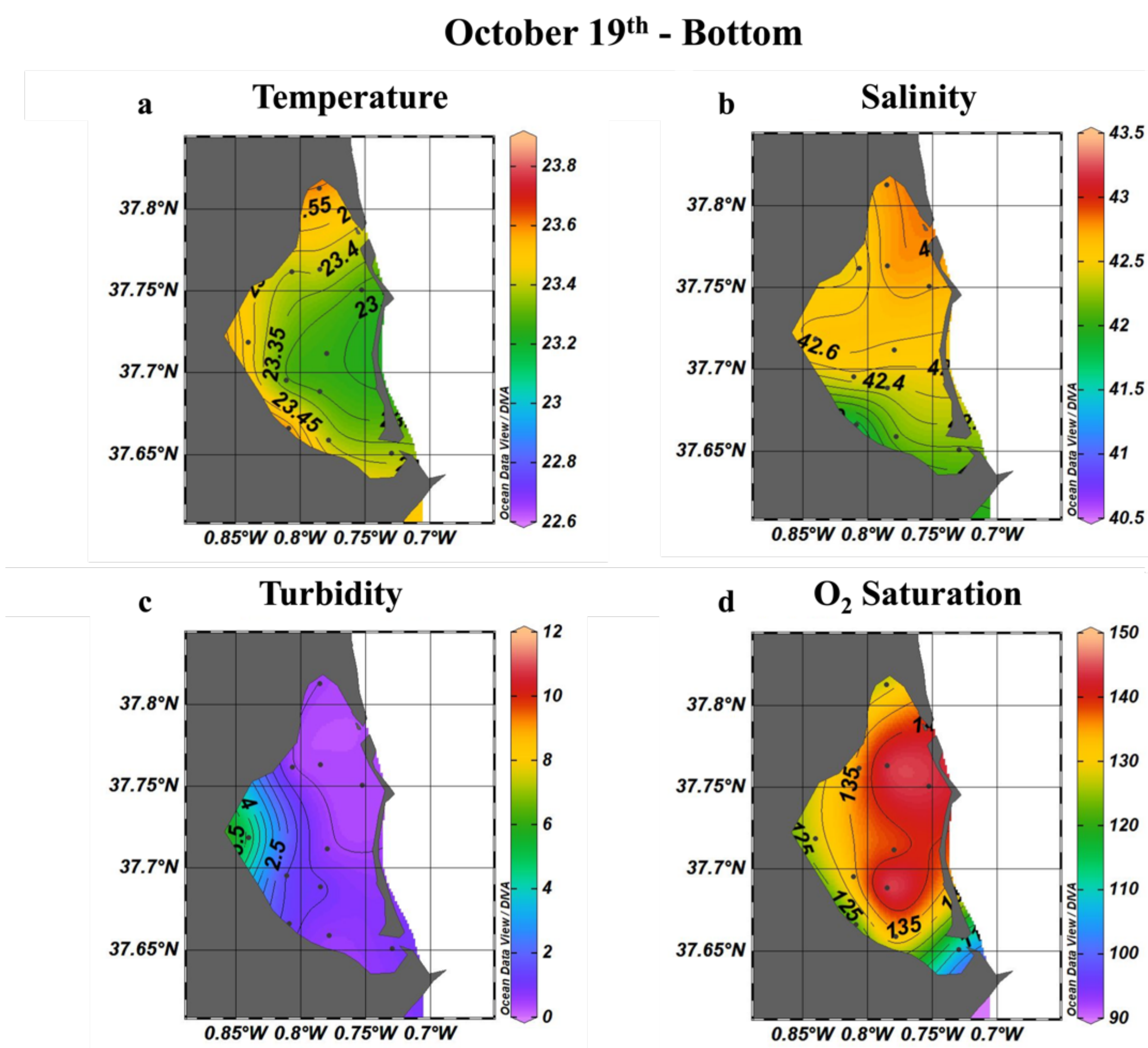

Figure 9. Horizontal distribution of bottom temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) of the Mar Menor lagoon on October 19th, 2022.

Results from the Smartbuoy data show temperature ranged from 22 to 24.5°C between the 4th and the 19th of October (Fig. 10a). Salinity rates decreased following the October 6th rainfall, increasing again in the following days, but not decreasing after the October 11th rainfall. Higher salinity rates were observed at the 3m range and lower rates in the surface and bottom (Fig. 10b). Turbidity rates peaked following the 6th October rainfall, decreasing rapidly in the following days, and no increase in turbidity during the October 11th rainfall was observed (Fig. 10c). O_2 saturation rates decreased following the October 6th rainfall, peaking during the October 11th rainfall, and decreasing on the following days, with variations correspondent to day and night periods (Fig. 10d).

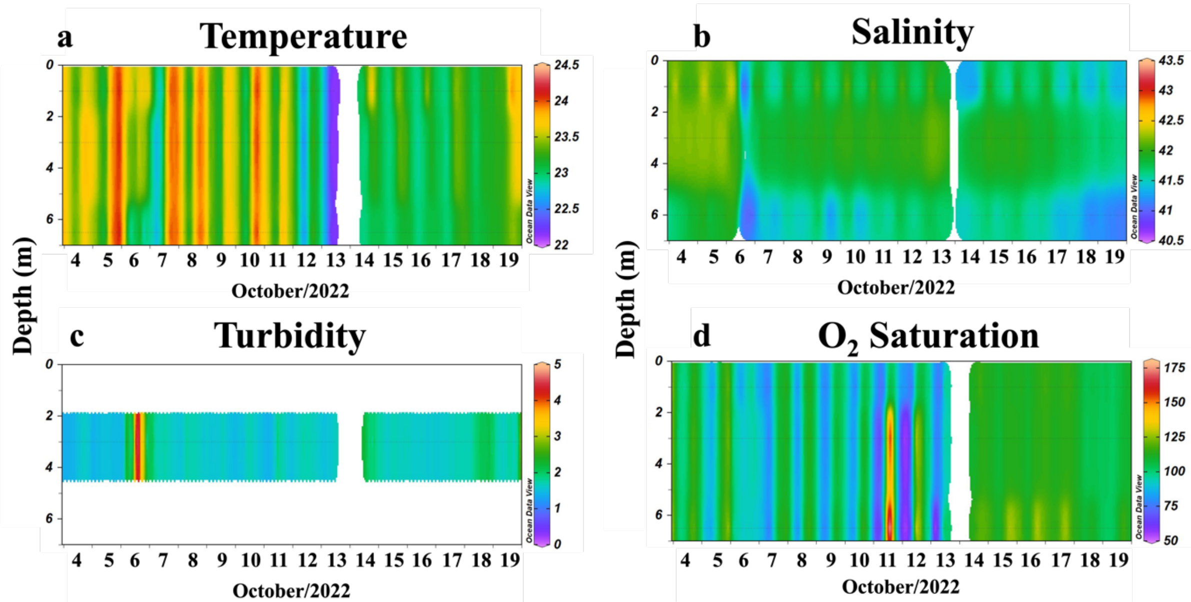

Figure 10. Temporal distribution of temperature (°C), salinity, turbidity (NTU) and O_2 saturation (%) recorded by the Smartbuoy. Turbidity values were obtained for the 3m range. Blank spaces are from defective data and therefore not considered.

Discussion

The October 19th figures show the southern part of the lagoon had not yet reprised hydrological conditions from before the rainfall events of 6th and 10th of October, while the northern part was less influenced. The results indicate that the rainfall entering the lagoon had an impact on salinity, turbidity and O_2 saturation.

Lower salinity rates were observed in the lagoon's surface, in the southern region, right after October 6th, which is to be expected as there was a higher inflow of freshwater into the lagoon. Meanwhile, the northern part remained fairly unchanged, following the lagoon's current distribution patterns (Fig. 11). The freshwater inflow changed the salinity also at the bottom along the western shore of the lagoon, while the rest of the bottom remained unaffected. This can be explained by the speed of freshwater inflow (Pérez-Martín, 2023), that together with the lagoon's current patterns, distributed freshwater within the water column, decreasing salinity rates from surface to bottom.

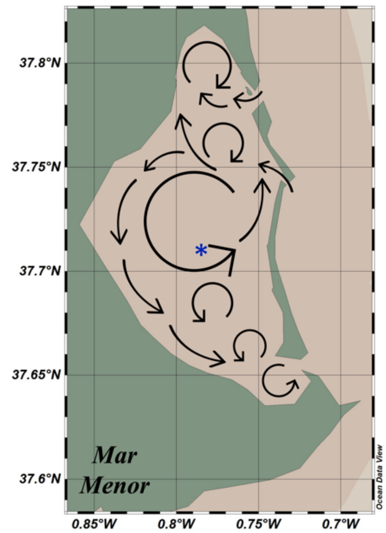

Figure 11. Current patterns around the lagoon and from the Mediterranean Sea and Smartbuoy position. Adapted from Machado Toffolo et al. (2022).

Looking at the surface salinity distribution on October 19th (Fig. XX), we observed an increase in salinity at the center of the lagoon, although it had not yet returned to pre-rainfall rates, while the southern part of the lagoon remained still low in salinity. A similar pattern was observed at the bottom of the lagoon, with higher salinity rates in the center and northern parts of the lagoon, and lower rates in the southern parts, indicating that the freshwater from the rainfall events was still present.

Following rainfall (Fig. 7), higher turbidity rates were observed along the western and southern shores of the lagoon, as runoff from the Rambla de Albujón carried nutrients, sediment, and possibly waste from the whole catchment (Ángel Pérez-Martín 2023). Bottom turbidity results indicate that sediments remained in the water column close to the Rambla del Albujón but were not widely distributed by the currents in the whole lagoon, instead settling along the western shore of the lagoon. This might cause damage to the local organism communities; seen as high turbidity rates disrupt photosynthetic potential and create impacts on benthic macrophytes (Ruiz-Fernández et al., 2022). After 10 days from rainfall events, turbidity rates remained still high close to the Rambla, although decreased in the bottom (Fig. 9), indicating no significant redistribution of sediments which could further impact the local organism community.

Nutrient inflow could also explain the increase in O_2 saturation rates following the October 6th rainfall event, particularly near the Rambla and in the northern and southern parts of the lagoon.

The ingress of nutrient-rich water allowed for the algal population to photosynthesize at extreme levels, disrupting natural balance and putting organisms under supersaturation stress (Álvarez-Rogel et al., 2020). Although there was a decrease in surface saturation rates on October 19th, high saturation rates continued to be observed both at the surface and the bottom of the lagoon, meaning the lagoon was still at an unbalanced status especially in the center area where there was less water mixing. High saturation rates from the inflow of freshwater could be enhanced by the macrophyte population at the bottom of the lagoon, which could help maintain the supersaturation status for longer, creating impacts such as difficulty in swimming for fish communities or even gas bubble disease (Ross et al., 2001).

The discharge of nutrient-rich freshwater into the Mar Menor lagoon can also have consequences beyond those immediate changes in its physical properties. The water collected from the surrounding basin can also contain pollutants such as pesticides, heavy metals and polycyclic aromatic hydrocarbons (PAHs). They enter the lagoon and deposit into the sediment or over benthic organisms (Marín-Guirao et al., 2005; Marini & Frapiccini, 2014; Moreno-González & León, 2017), creating damage at cellular and tissue levels (Tchounwou et al., 2012), impacting physiological processes such as photosynthesis (Fulke et al., 2024), being accumulated up trophic networks with further consequences for human health from biomagnification (Han et al., 2022; Pérez-Ruzafa et al., 2000).

While the surface and bottom maps provided valuable snapshots of specific moments before, during, and after the October rainfall events, the continuous data collected by the Smartbuoy offered a more nuanced view of the lagoon ecosystem throughout that period, allowing for the observation of subtle changes in various hydrologic parameters, contributing to a more comprehensive understanding of how the lagoon's properties behave over time. we could observe how salinity distributes and fluctuates through the water column, indicative of the flow exchange between the Mar Menor and the Mediterranean Sea, with constant salinity found over the 3m range due to the gyre circulation in this central area of the lagoon (Fig. 11). We could also pinpoint the time of the rainfall event of October 6th due to the extreme increase in turbidity, with subsequent recovery and stabilization of turbidity rates. Finally, we observed the changes in O_2 saturation, correspondent to the periods of day and night; higher rates correspond to the day period, where there is light and consequently photosynthesis, whereas during the night there is no O_2 production but consumption, resulting in the decrease of O_2 saturation rates. This type of data is extremely useful when planning for or adapting to environmental changes, enabling researchers and decision makers to make informed decisions that align with the dynamic nature of the ecosystem. More data points could help better represent the conditions and behavior of the lagoon, thus improving the evaluations of lagoon processes and promoting improvement interventions for the management of the territory.

Conclusion

Extreme rainfall events can have profound impacts on coastal lagoons, leading to immediate disruptive effects that require extended periods for the ecosystem to reach homeostasis again. Decreases in salinity can dramatically alter the habitat conditions, creating stress for many aquatic species. Increases in turbidity, caused by sediment runoff, along with elevated oxygen saturation levels, can further destabilize the ecosystem, creating imbalances that affect the entire biological community. When these changes persist for too long, they can lead to catastrophic consequences, such as the loss of biodiversity and the collapse of essential ecological processes.

Moreover, the influx of pollutants during these extreme events poses a significant threat to the survival of native organisms. Contaminants, whether organic, such as PAHs and pesticides, or inorganic, such as fertilizers and heavy metals, can accumulate within the lagoon environment. This bioaccumulation can disturb intrinsic ecological processes, impairing the health of the biological community. As toxins move up the food chain, they can wreak havoc on higher trophic levels, leading to declines in predator populations and further imbalance the ecosystem.

The increasing severity and decreasing intervals of extreme weather events due to climate change place the stability of entire ecosystems at risk. With each successive event compounding the effects of previous ones, the capacity for these ecosystems to recover diminishes, threatening not only the survival of native species but also overall functionality.

The observations conducted in the lagoon through periodic monitoring at designated stations, alongside the deployment of a smart buoy that collects real-time data from throughout the water column (https://asap-forecast.com/public?lat=37.706415372144384&lon=-0.7771660036807169&zoom=10&projects=a1c02d60-7d35-11ed-a545-0242ac1c0003), can significantly enhance the knowledge of the local population residing within the hydrographic basin and its surrounding areas. This knowledge can foster greater awareness regarding the protection of the lagoon and encourage active participation in its conservation through the adoption of better practices within the territory.

To enhance the resilience of the Mar Menor and mitigate the impacts of extreme rainfall events, it is essential to adopt sustainable management strategies, conduct long-term monitoring of the ecosystem, and promote interdisciplinary collaboration. Additionally, more effective climate adaptation policies will be crucial for protecting the ecological functions and biodiversity of the lagoon system.

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Chapter III

Stakeholder engagement in environmental modeling: a systematic literature review

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Abstract

The present literature review aims to explore the role of stakeholders in designing management plans through participatory modeling in marine, coastal, river, or lake environments. The research questions aim to understand how stakeholders contribute to the development of inclusive environmental management plans. The research query involved searching for relevant articles on Scopus using specific keywords related to participatory modeling and environmental contexts. The screening process initially yielded 176 articles, which were narrowed down through title, abstract, and keyword screening, resulting in 15 chosen articles based on participation type, engagement phase, and methodology, further separating them by modeling techniques used in stakeholder participation.

The studies show the significant contribution of stakeholder knowledge and experience in the creation of comprehensive and successful ecosystem management plans. Involving stakeholders in all phases of management planning not only leads to more effective strategies but also enhances acceptance and responsibility among stakeholders. Stakeholder engagement, community participation, and public consultations are highlighted as crucial for achieving sustainable management plans that address environmental resilience and local community needs. Challenges exist, particularly regarding the inclusion of local stakeholders in climate change adaptation scenarios. Local stakeholders are often overlooked in favor of decisions made at higher levels, creating issues of feasibility and acceptability at the local and regional scale. Recognizing the value of local stakeholders in monitoring ecosystem change due to climatic variability is highlighted. Maintaining contact after the consultation period ensures that stakeholders stay informed about the progress of conservation actions, allowing them to contribute to the success of the plans and provide valuable knowledge input to address potential challenges.

Keywords: ecosystem management; marine environment; climate change; sustainable adaptation; participatory process; literature synthesis.

Introduction

It has been established that human activities pose a significant threat to the survival and functioning of natural ecosystems. We are living in the so-called 'Anthropocene,' a term coined to refer to the period starting after World War II and still ongoing, during which human activities have intensified environmental impacts faster than ecosystems can recover (Crutzen, 2006). Until the late 1960s, most countries treated natural resources as infinite, without any concern for the waste and degradation that the exploitation of such resources would leave in its wake (Colby, 1991). The goods and benefits produced by nature, so-called Ecosystem Services, were exploited by society for infrastructural, economic, and social development (Daily, 1997). In 1968, the *"Tragedy of the commons"* (Hardin, 1968) drew attention, even if from an economic perspective, to the use and depletion of natural resources to generate revenue and human well-being. By 1972, after a dramatic environmental disaster with an oil tanker in Canada (Marley-Clarke, 1976), the United Nations (UN) had recognized and stressed the importance of preventing such events in order to avoid further losses in natural ecosystems, with consequences for the human race (United Nations, 1972). Such environmental impacts can put ecosystems out of balance, creating worrying consequences not only for wildlife, but having major effects on society, which depends on ecosystem services to survive and thrive (Ehrlich & Mooney, 1983).

In particular, marine ecosystems are strongly affected by anthropic activities and infrastructural development, with faster decline than any other terrestrial ecosystem (Brown et al., 2006). Land and port pollution, human sewage and agricultural runoff, and greenhouse gases are among many direct impacts that threaten marine ecosystems, such as mangroves, estuaries and coral reefs (Patterson & Glavovic, 2013)

While previously people interacted with the environment at a local level, with the expansion of globalization, countries' economies became increasingly interdependent, and there came a need of collaboration in order to tackle different society issues – social, economic and also environmental (Bălteanu & Dogaru, 2011; Cocheci et al., 2015; Colby, 1991; Selin, 1995).

They are called socioecological systems, where social, economic and cultural aspects interact with the environment, shaping and being shaped by it, evolving together (Martín-López et al., 2007; Ostrom, 2009; Reyers et al., 2018).

Socioecological systems are very complex and operate in many levels (e.g. resources, stakeholders, governance, policy) and with infinite feedback loops, which means that a seemingly small and redundant component, when altered, can trigger big effects to the system network as a whole (Kenny & Castilla-Rho, 2022; Ostrom, 2009). Hence, simplistic predictions and theories for environmental management that focus on limited aspects instead of considering the socioecological system in a holistic approach tend to fail or risk worsening its overall functioning, which is why policy and governance are required to be in constant change and adaptation in order to fully support social and economic progress while guaranteeing environmental conservation (Bauer, 1988; Folke, 2006; Jorgensen, 1990; Ostrom, 2009; Pun et al., 2002). It is essential that society take part in conservation efforts for these systems, as not only do humans depend completely on them, but also are the major impact drivers, promoting enough damage to compromise the system's own capacity for resilience (Haines-Young & Potschin, 2010; Wang et al., 2024)

The science behind conservation efforts is inter- and multidisciplinary; decision making for conservation policy must derive from knowledge and experience of all those involved and affected by it (Robertson & Hull, 2001; Syme et al., 1989). Thus, environmental conservation must go further than imposing unilateral policies expecting they will be accepted and carried out as intended; expanding the activity of drafting management strategies beyond science and technology allows for gathering unconventional forms of expertise, engaging public participation, and rendering accountable the society altogether (Castro, 2022; Daniell et al., 2006; Krueger et al., 2012).

This was reiterated in the United Nations Conference on Environment and Development, in Rio de Janeiro, 1992. The Rio Declaration called for the participation of society in environmental management. Governments were urged not only to provide the general population with access to information, but also to allow public participation in decision-making processes. (Handl, 2012). Additionally, in 1998, the UN declared 'The International Year of the Ocean' (Patterson & Glavovic, 2013). In the early 2000s, the UN launched the Millennium Ecosystem Assessment (2005), a 4-year program with the objective of providing environmental scientific data to help decision-makers in addressing ecosystem impact. The goal was to promote sustainable management of ecosystems, which directly affects the population well-being (Corvalán & Reid, 2001).

However, this call for action was far from new. Public engagement, more specifically stakeholders, i.e., citizens or groups who live within the socioecological system, and therefore possess first-hand knowledge and "hold a stake" in whatever happens (Stringer et al., 2006), has been carried out since the 1960s. Using stakeholder knowledge in environmental management can improve the efficacy of management plans; encourage groups with different interests to work together towards a common goal; improve reliance of the general public in scientific research, and bridge the gap between research and society, helping inform and educate the population (Alberts, 2007). However, there are still some challenges to be addressed when engaging stakeholders: coordinating time and availability when dealing with different stakeholder groups (Guise et al., 2013); when using participatory modelling, there are still complex systems and concepts that are difficult to understand by the general population (Voinov & Bousquet, 2010); there is still distrust among stakeholder groups in how effective the consultation process really is (Edelenbos et al., 2011); and also, if stakeholders might be putting themselves in jeopardy by speaking up about their interests and concerns (Belal, 2002; Few et al., 2007).

Over the years, stakeholder participation has increased, plummeted, and reemerged thanks to the analysis and readjustment of limitations and potentials of its use (Reed, 2008). Many studies have covered the nuances of stakeholder participation in environmental modeling, where different groups collaborate in developing scientific models that represent a certain ecosystem, together with scientists. Although there is still a gap in guidelines and best practices for approaching this challenge, due to the wide variety of stakeholder groups, which in turn hold even more varied interests and beliefs (Michaud, 2013; Reed, 2008; Voinov et al., 2016), one way to approach the process is that stakeholders must be willing to interact among them, teaching and learning from one another, collaborating in all the stages of environmental management (Frame et al., 2004; Reed, 2008). Recently, stakeholder participation in environmental modeling has gained notoriety, due to the need of different points of view to promote better insight on socioecological systems (Castilla-Rho et al., 2015; Gray et al., 2018).

The present literature review aimed to understand the role stakeholders play in the design of management plans through participatory modeling; here gather case studies in which environmental management plans using different methodologies of participatory modeling were designed, improved or assessed using the knowledge and opinions of stakeholder groups in marine, coastal, river or lake environments.

Method

Research question

The goal of our literature review was to identify the use of participatory modeling in the context of environmental management.

In order to investigate how stakeholders being called to contribute for the creation of more inclusive environmental management plans, we searched for case studies that relied on stakeholder participation as part of creating management plans.

Our research questions were:

What activities are proposed for stakeholders to participate?
At what part of the process are stakeholders engaged?
What methodologies are used?
What data are collected?

We focused our search on case studies regarding marine and freshwater environments where stakeholder participation was included as a tool in environmental modeling.

Research query

We performed our initial literature search using the search string “participatory” AND “modelling” AND “ocean” OR “sea” OR “water” OR “coastal” on the Scopus platform, due to its comprehensive database and length of reach within scientific research, limiting results to journal articles published in English between the years of 2013 and 2022, as follows:

KEY (participatory AND modeling) AND KEY (ocean OR sea OR water OR coastal) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SUBJAREA , "envi") OR LIMIT-TO (SUBJAREA , "soci") OR

LIMIT-TO (SUBJAREA , "eart") OR LIMIT-TO (SUBJAREA , "mult")) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (LANGUAGE , "english"))

Screening process

We followed PRISMA guidelines to analyze and categorize results (Page et al., 2021).
Our initial query resulted in 183 articles, of which seven were not accessible nor available (entry contained title, but no other information). Screening was made by 2 authors independently, then the outcome was checked to resolve eventual conflicts. With 176 articles, initial screening took place in the kind of result, with seven entries excluded for being conference papers and not research articles. Screening then took place at title, abstract and key word level, excluding any articles that didn't contain any of the 4 words "participatory", "stakeholder", "engagement" or "modeling", nor contained any information regarding the topic of interest, further excluding eight articles.

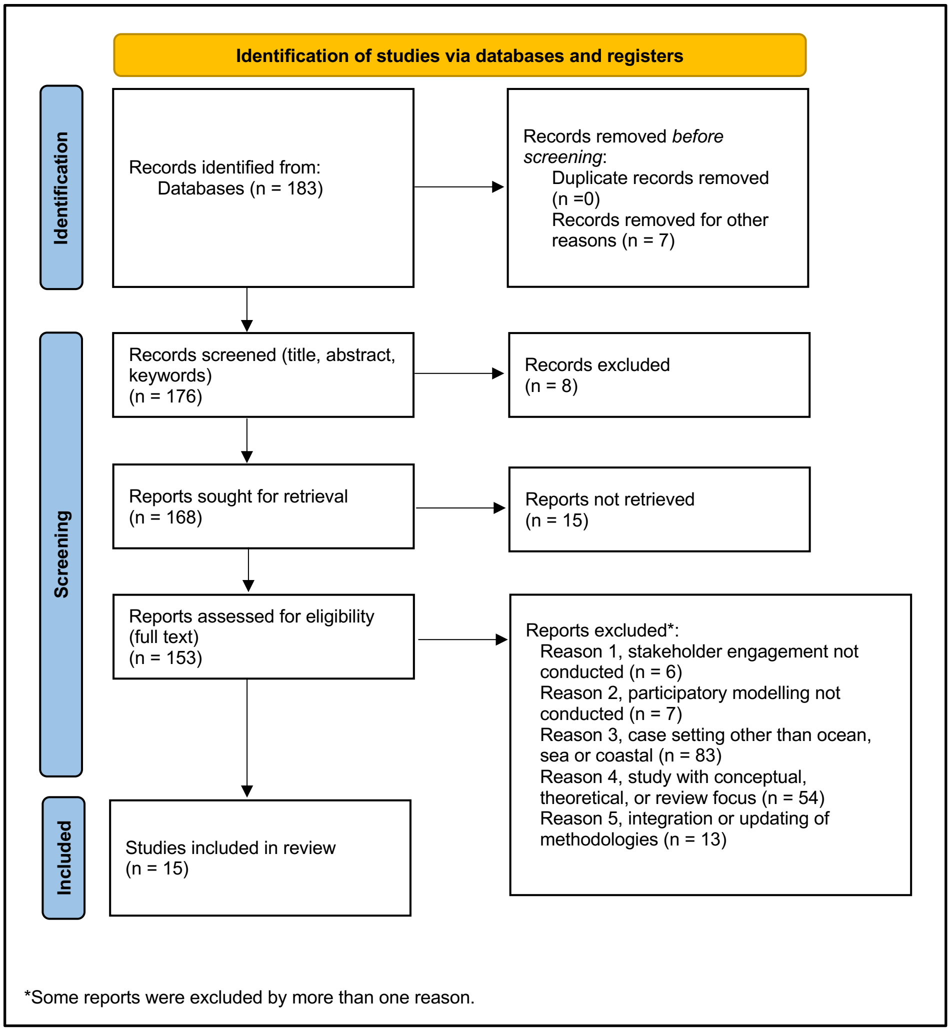

Figure 1. PRISMA chart used for screening process.

The resulting 153 articles were then screened at full-text level. Articles were read at full length and again analyzed based on inclusion/exclusion criteria (Fig. 1, Table 1)

Table 1. Inclusion and exclusion criteria utilized at the full text screening level.

Inclusion criteria	Exclusion criteria
Stakeholder engagement conducted	Stakeholder engagement not conducted
Participatory modelling conducted	Participatory modelling not conducted
Case setting regarding ocean, sea or coastal environments	Case setting other than ocean, sea or coastal environments
Study with experimental focus	Study with conceptual, theoretical, or review focus
Study focuses on stakeholder participatory modeling	Study focuses on integration or updating of methodologies

Final screening resulted in 15 articles regarding 19 case studies. For each article, we then extracted data regarding the following dimensions, i.e., the information that would help answer our research questions, from the selected articles: participation type (e.g., discussion workshops, individual and group interviews), engagement phase (e.g., at model development, after model development), methodology (e.g. Fuzzy Cognitive Mapping, Bayesian Belief Network), and type of collected data (e.g., local knowledge mapping, influence diagrams, management recommendations).

Results

Environment, region and publication year

The year with most publications was 2013, while 2015 and 2023 showed no publications (Fig. 2).

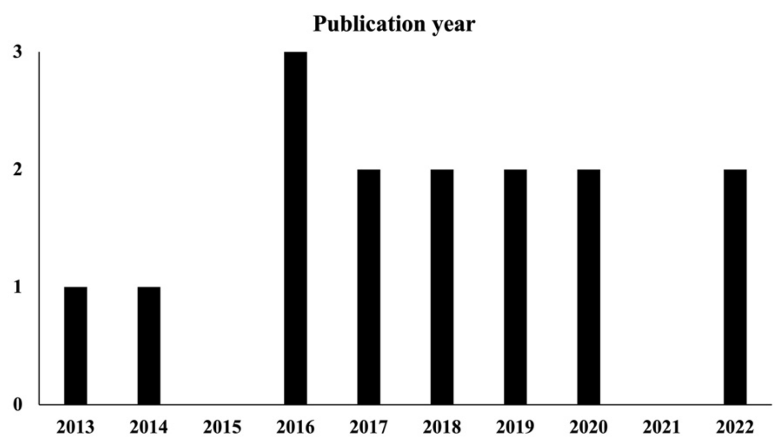

Figure 2. Selected articles by publication year. 2013: Haapasaari et al.; 2014: Gray et al.; 2016: Koenigstein et al.; Meynecke et al.; Tiller et al.; 2017: Lillebø et al.; Sampedro et al.; 2018:Armada et al.; Maravelias et al.; 2019: Crosman et al.; Gray et al.; 2020: LaMere et al.; Provot et al.; 2022: Hemmerling et al.; Salberg et al.

73% of studies were carried out in Europe (11 out of 15 articles), with 13% of studies in North America, 7% in Asia, and 7% in Oceania (Fig. 3).

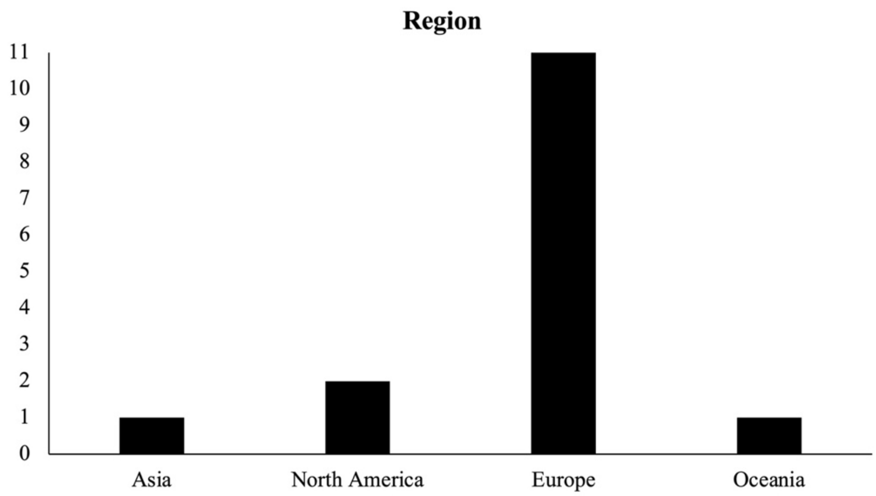

Figure 3. Selected articles by region. Numbers inside the columns refer to the number of the article within the full article list, before both screenings. Asia: Armada et al., 2018; North America: Crosman et al., 2019; Hemmerling et al., 2022; Europe: Gray et al., 2014, 2019; Haapasaari et al., 2013; Koenigstein et al., 2016; LaMere et al., 2020; Lillebø et al., 2017; Maravelias et al., 2018; Provot et al., 2020; Salberg et al., 2022; Sampedro et al., 2017; Tiller et al., 2016; Oceania: Meynecke et al., 2016.

Stakeholder participation type

Stakeholder participation was conducted through workshops (Armada et al., 2018; Gray et al., 2014; Haapasaari et al., 2013; Koenigstein et al., 2016; LaMere et al., 2020; Lillebø et al., 2017; Meynecke et al., 2016; Provot et al., 2020; Sampedro et al., 2017; Tiller et al., 2016), meetings (Maravelias et al., 2018; Sampedro et al., 2017; Tiller et al., 2016) or group and individual interviews (Crosman et al., 2019; Gray et al., 2019; Koenigstein et al., 2016; Salberg et al., 2022), collecting data on their practical knowledge through questionnaires (Gray et al., 2014, 2019; Koenigstein et al., 2016; LaMere et al., 2020; Sampedro et al., 2017), audio recordings (LaMere et al., 2020; Maravelias et al., 2018) and written text (Crosman et al., 2019; Gray et al., 2019; Haapasaari et al., 2013; Maravelias et al., 2018). Activities were also informative, with capacity-building sessions and learning activities, aiming to bring lay stakeholders into the context of the participatory modeling, the requirements, and aspects to take into consideration when making demands, and how they can contribute, by suggesting, evaluating, creating or finetuning proposed mathematical or computer-based models.

While questionnaires were useful to target specific areas of knowledge required for the development of the model, audio recordings, although longer and more complex to translate into data, allow for freedom in stakeholder speech, which can in turn shed light into aspects or problematics that weren't initially considered and hence not computed into the model.

Engagement phase

Stakeholders can participate in any or all of the four phases of the creation of a model (Robles-Morua et al., 2014). 65% of studies showed stakeholders participating in two or more of the following phases:

First, "Model Development": 80% of studies report requesting stakeholder collaboration at early stages (12 out of 15), engaging stakeholders in the initial development of the environmental model.

Second, "Model Setup, Parameterization and Calibration": In 27% of cases (4 out of 15), stakeholders were called to evaluate the already established model, at a later stage;

Third, "Model Output Analysis": 27% of studies (4 out of 15) counted on stakeholders through all phases of development, from proposal to later adjustments and evaluation;

Fourth, "Scenario Building": 87% of studies employed the use of environmental scenarios (13 out of 15) either built directly with input from stakeholders or evaluated by them after being design by researchers.

Furthermore, 40% of studies had stakeholders participate in all four phases of model creation (6 out of 15).

Gray et al. (2014) denominated "coastal management stakeholders" those with influence and experience in coastal sectors for planning and development. These were key stakeholders that could be crucial on developing climate adaptation actions. They were interviewed at the beginning of the study, before model design, and were asked questions regarding the main issues of climate adaptation, when should these actions take place and which information to use when analyzing and discussing climate change risks (Gray et al., 2014).

Subsequently, Gray et al. (2019) assessed how local concerns, expert models and broader coastal stakeholder perspectives were aligned through Fuzzy Cognitive Mapping in southwest Ireland. Stakeholders were invited to form "coastal resilience groups", where each member created a cognitive map of their local coastal socioecological system (Tralee Bay or Outer Hebrides).

Additionally, an expert-derived cognitive map was established as a reference point. The outputs from stakeholders when compared with reference points allowed for an in-depth analysis of the detection and framing of coastal climate adaptation issues (Gray et al., 2019).

In Louisiana, USA, researchers identified stakeholders to gather local perspectives as to which locations had the greatest potential to succeed in reducing vulnerability and increasing resilience through restoration efforts (Hemmerling et al., 2022). Stakeholders were involved in knowledge mapping workshops to select areas of high value, describe the problems faced directly by the stakeholders in that area, suggest and locate a nature-based solution for the Coastal Master Pan, list potential expected outcomes and identify pros and cons related to the implementation of their suggested solution. These contributions allowed for the identification of main concerns by the local residents and the prioritization of aspects considered within ecological restoration plans (Hemmerling et al., 2022).

Tiller et al. (2016) employed two methods to analyze the adaptive capacities of commercial fishers in Northern Norway in response to changing marine environments. The goal was to understand the system and explore the adaptive capacities of the selected stakeholder groups, particularly commercial fishers. An initial workshop involved independent experts from various stakeholder categories, including fisheries, aquaculture, tourism, management, and the scientific community in the region. The workshop served as a methodological test to refine the approach for later workshops. The main focus of the workshops was to assess the perceived adaptive capacity of commercial fishers in Northern Norway to cope with or maintain their current quality of life in the face of changing marine environments, gathering location and topic-specific background information, particularly regarding the main issues related to climate change and marine scenarios in the region, such as changes in marine climate and increased marine production due to warming (Tiller et al., 2016).

In the study by Koenigstein et al. (2016), interviews were conducted with regional scientific expert stakeholders from Norway and Russia. Stakeholders included representatives from fishing associations, aquaculture companies, small-scale fishers, tourism operators, non-governmental organizations, and governmental agencies. The interviews aimed to gather information on the socio-economic situation, perceptions, concerns, communication between science and stakeholders, societal impacts, adaptation options, and management strategies related to climate change impacts. The most frequently mentioned ocean uses, climate-related concerns, and ecosystem interactions from stakeholder interviews formed the basis for a model. A model-building workshop with stakeholders was held to refine the model structure based on their input and requests for inclusion of additional elements and services (Koenigstein et al., 2016).

Salberg et al. (2022) identified relevant sectors and stakeholders regarding textile washing and microfiber pollution. Stakeholders selected were researchers, sustainability and R&D managers from textile companies, engineers, representatives from wastewater treatment plants, and individuals with knowledge about laundry processes. Data collection involved individual interviews, where a five stakeholder groups collaborated. Questions covered sources of microfiber pollution, mitigation measures, environmental effects, and relevant laws or policies. After establishing the variables, participants reviewed the list and added any additional variables they deemed important. They were then asked to draw links between variables, indicating whether the relationships were positive or negative and specifying the strength using plus or minus signs. The process aimed to capture the participants' mental models of the system around microfiber pollution.

Haapasaari et al. (2013) sought stakeholders to incorporate diverse perspectives for better understanding the fishery system in the Baltic Sea. Six stakeholders were selected, representing commercial fishermen, government officials, environmental NGOs, and scientists in the region. They were asked to participate in modeling workshops, building their own models without knowledge of others' views. The aim was to capture individual perspectives and address interpersonal variation in knowledge. After the activity, feedback was collected through questionnaires. A final meeting brought all stakeholders together to explore graphical representations of biological models, discuss differences and similarities in views, and highlight areas of uncertainty. Feedback was again collected from all stakeholders during the final workshop (Haapasaari et al., 2013).

Provot et al. (2020) requested stakeholders from fisheries, the offshore wind farm industry, local authorities and scientists from different areas of expertise that could be related to the fisheries sector. They participated initially a workshop to rise issues and the main drivers related with fishing decline in the Bay of Biscay, northeast Atlantic Ocean. Subsequently, they were asked to organize this information in drafting different scenarios for fisheries in the region in the future. Once scenarios were built, one was selected and fed to the ISIS-Fish model, and results were presented to stakeholders, to answer any questions that might arise, gather impressions and possible fine-tuning suggestions (Provot et al., 2020).

Lillebø et al. (2017) also engaged stakeholders in three stages during four lagoon case studies: the Vistula Lagoon (Baltic Sea), Ria de Aveiro (Atlantic Ocean), Tyligulskyi Liman (Black Sea), and Mar Menor (Mediterranean Sea). Firstly, stakeholders provided insights, concerns, and suggestions during focus groups. Secondly, the results were used to formulate socio-economic scenarios for each lagoon around 2030; Thirdly, these scenarios were assessed by stakeholders at final workshops, leading to recommendations on achieving desirable outcomes and avoiding undesirable aspects for each lagoon. The integrated recommendations aimed to consider both social and natural science perspectives into ecosystem management planning strategies (Lillebø et al., 2017).

Armada et al. (2018) sought the evaluation of stakeholders to determine sustainable fishing effort in marine key biodiversity areas in the Philippines. Eight of these areas were presented to stakeholders through consultation workshops, aimed at finding a consensus on fishing effort that would allow the stock to maintain itself. Among the stakeholders selected were local decision makers, fishermen associations, indigenous groups, government agencies, non-governmental organizations and academia. The discussion and decision-making processes were made in collaboration with all stakeholders and facilitated by the Ecosim model, who used the suggestions and hypotheses on "right size" to simulate future scenarios. After a long evaluation process, the final proposals were then voted by the stakeholders as the best for the fisheries system according to the regions (Armada et al., 2018).

In the study by Crosman et al. (2019), stakeholders from the Quinault Indian Nation community were selected based on their history of razor clam use, a population in decline due to harmful algal blooms in the west coast of the United States. The researcher conducted interviews with seven stakeholder groups (commercial and subsistence clammers; razor clam processors; razor clam buyers; commercial fishers; young adults and elders). Stakeholders were recruited and participated in group events before model drafting in order to establish the rapport between researchers and stakeholders; they were then recontacted in three subsequent moments: the second and third were group interviews where stakeholders were asked to share knowledge and information on seasonal availability of razor clam, profits and expenses regarding razor clam fisheries, the importance of razor clam for means of survival, and potential impacts to problems with razor clam availability in the region. Finally, after all the data gathered was combined into the model, researchers reported initial results in a community meeting and asked for feedback from stakeholders (Crosman et al., 2019).

LaMere et al. (2020) used mental models of 11 expert stakeholders from Finland and Sweden to understand their perspectives on the effects of environmental change on the Baltic salmon system. Mental models were elicited through influence diagrams, representing visualized causal relationships between variables related to climate change impacts on the salmon system. Stakeholders were asked about variables, causal relationships, goals, and management strategies to protect salmon fisheries. All collected data was then used to develop influence diagrams to improve understanding and problem-solving competences, and facilitate problem framing (LaMere et al., 2020).

Maravelias et al. (Maravelias et al., 2018) categorized stakeholders into groups for discussions for the management of the narwal shrimp fishery in Greece. Initially, local knowledge data was collected from fishermen's associations, individual fishermen, and policy officers, leading to the identification of the need for a fishery management plan. Open workshops were conducted at different stages of the project, allowing stakeholders to provide feedback and insights. The final workshop presented management scenarios, leading to a consensus on specific measures for the narwal shrimp fishery by high-level stakeholders such as members of the National Greek Parliament, representatives from the Greek Ministry of Agriculture, municipal representatives, deputy mayors, and various officials responsible for fisheries-related matters (Maravelias et al., 2018).

With the goal of assessing potential climate change impacts on the whale watching industry in south-east Queensland, researchers initially developed a general systems diagram for the industry, incorporating elements and interconnections based on literature and expert knowledge. This diagram, divided into thematic sectors, was presented to stakeholders at a workshop for feedback and refinement aimed at consolidating stakeholders' understanding and perceptions of climate change impacts on the industry, resulting in a final systems diagram (Meynecke et al., 2016).

Methodology and collected data

In the case study conducted in the Philippines (Armada et al., 2018), researchers firstly developed eight trophic models using Ecopath with Ecosim (EwE), later fine-tuning it with the help of local knowledge. During proposed workshops, stakeholders detailed the changes they observed in fishery activities from 2008 to 2018, as well as potential management actions to mitigate these impacts.

Crosman et al. (2019) reports a general characterization of the decline in the razor clam population on the coast of Washington state, USA. Using Ostrom's framework (Ostrom, 2009), they conducted interviews to identify links between the razor clam population and the Quinault Indian Nation livelihood, in order to develop a social-ecological system model. Combining data from stakeholder experience with scientific information, they were able to identify complex and novel interactions within a social and cultural sphere, allowing for a more complete overview of environmental change, and how affected populations might adjust and respond.

In the case of fuzzy cognitive mapping, (Gray et al., 2014, 2019) identified expert and local stakeholders for coastal adaptation using top-down scientists and bottom-up resilience groups.

Bayesian models were used in four studies (Carmona et al., 2013; Haapasaari et al., 2013; LaMere et al., 2020; Meynecke et al., 2016) to broaden the reliability of fishery system models by aggregating scientific and social knowledge from different points-of-view.

Hemmerling et al. (2022) employed local knowledge mapping (LKM) and public-participation geographic information systems (PPGIS) to collaborate with regional stakeholders to develop a model proposed as part of the Louisiana's Coastal Master Plan.

Lillebø et al. (2017) coupled the Soil and Water Integrated Model (SWIM) with stakeolder workshops, divided in three phases, in order to gather information on how to achieve the best outcome regarding climate change impacts in four possible scenarios: Business as Usual, Managed Horizons, Set Aside, and Crisis.

Maravelias et al. (Maravelias et al., 2018) counted with stakeholder participation in all stages of developing a management plan for the narwal shrimp, in Greece. Stakeholders were involved in the preliminary stages, before project proposal, and collaborated in choosing the target species. During project development, they participated giving feedback on the proposed activities, and after, during the final presentation of the selected management scenario.

Provot et al. (2020) utilized scientists' and stakeholders' combined knowledge to evaluate and give feedback on the importance of the ISIS-Fish model to predict future fishery scenarios on the northeast Atlantic Ocean, while Sampedro et al. (2017) used the same approach with the Bio-Economic Impact Assessment of Management strategies model in the coast of Spain .

Ballarini et al. (2021) applied data collection and stakeholder knowledge to be of support for developing management strategies in the lagoon of Lesina, Italy.

Van der Vat et al. (2019) used Group Model Building to construct and validate stakeholder perceptions with various environmental models. Results showed that stakeholders found the possibility to interact and discuss opportunities among them very positive, as it allowed for the exchange of important information. It is important that all stakeholder groups understand the points of interest and concern in order to be willing to adapt and collaborate in the creation of realistic water management plans.

Shammout et al. (2013) counted on stakeholders to evaluate and contribute with the optimization scenario of the water resources model, part of the WaterWare System, in Jordan. Stakeholders gave input on water consumption, geographical, economic and management and quality data to baseline scenarios.

Sahin & Mohamed (2013) employed Analytical Hierarchy Process in order to categorize stakeholders' preferences regarding different scenarios calculated by a Spatial Temporal Decision model, regarding government actions to mitigate sea-level rise in the Gold Coast, Australia.

Stakeholders were aggregated into working groups in Alberta, Canada (Marcotte et al., 2020) and were asked to develop different water management policy scenarios for the Athabasca river basin. They were initially taught about the basin and water management scenarios and issues. After designing the policy scenarios, they were asked to evaluate and point strengths and weaknesses, explaining each group perspective and collaborating to find feasible alternatives. All these activities contributed to and were supported by the Integrated water resource management, a framework that allows different perspectives to be addressed in a balanced manner, maintaining the viability of natural ecosystems (Allan & Rieu-Clarke, 2010).

Kumar et al. (2021) interviewed stakeholders to identify the issues that impacted water quality in the Brahmani River, Eastern India. After stakeholders put issues in order of significance, they were able to apply these drivers into the Water Evaluation and Planning model, allowing to assess potential future changes in climate change scenarios and their effect on the local population.

Sampedro et al. (2017) involved stakeholders at various stages through the MYFISH project, defining stakeholder objectives and modeling management scenarios. In an initial workshop, participants from different organizations, including NGOs, fishing industry associations, management organizations, and scientists, were invited to identify objectives for the project and rank options by case studies. Stakeholder preferences were elicited through an open group survey and were asked to consider uncertainties related to the availability of necessary information, the informativeness of the available information, and the likelihood of management measures achieving the objective. The participatory approach adopted in the MYFISH project aimed to integrate stakeholder perspectives in the context of fisheries management and the Maximum Sustainable Yield objective (Sampedro et al., 2017).

Discussion

The majority of analyzed studies highlights the importance of engaging stakeholders in the beginning of the participatory process (Crosman et al., 2019; Gray et al., 2014, 2019; Haapasaari et al., 2013; Hemmerling et al., 2022; Koenigstein et al., 2016; LaMere et al., 2020; Maravelias et al., 2018; Meynecke et al., 2016; Salberg et al., 2022; Tiller et al., 2016), since it allows researchers to have most variables accounted for since the start of the process. Although only two of the analyzed studies reported repeated stakeholder consultation (Lillebø et al., 2017; Sampedro et al., 2017) engaging stakeholders through all steps of the process can respond to changes in knowledge and experience, which can result in a more accurate and feasible planning. Nonetheless, engaging stakeholders to evaluate proposed plans is also useful to adapt them to encompass both stakeholders and decision-makers interests and needs (Armada et al., 2018; Provot et al., 2020).

The contribution of stakeholder knowledge and experience was made clear during this review. Stakeholders can account for changes demonstrated by scientific data, but also contribute with personal knowledge that can't be obtained without experience (Maravelias et al., 2018; Provot et al., 2020). Requesting stakeholder collaboration in all phases of creating management plans is not only useful in developing comprehensive strategies that account for a wider range of aspects, but also allows for a higher acceptance rate and of responsibility on the part of stakeholders, and consequently more successful management plans (Maravelias et al., 2018; Tiller et al., 2016).

Stakeholder engagement, community participation and public consultations are crucial for achieving sustainable management plans that will take into consideration not only environmental resilience but also cater to the needs of local communities directly affected by them (Armada et al., 2018). Moreover, joining indigenous people, resource managers or policymakers and scientists in co-developing knowledge and drafting management strategies allows for better data resolution, long-term monitoring efforts and constant updates to render ecosystem management more effective and all-encompassing. This collaboration also works as knowledge and experience sharing, consenting all parts involved to better elaborate conceptual models that concern the complexity of social-ecological systems (Crosman et al., 2019).

However, some aspects need to be considered when engaging stakeholders in the development of environmental management plans: while local and regional stakeholders may be willing and able to collaborate with knowledge and experiences, high-level decision makers must be open to actively listen to them and use that knowledge when creating management plans. Particularly in the case of climate change adaptation scenarios, local stakeholders are often not taken into consideration, having to rely on national and even global authorities to provide information and action plans that are not always feasible or acceptable at a local and regional scale (Gray et al., 2014). Furthermore, local stakeholders are a valuable asset in monitoring ecosystem change due to climatic variability over large areas, showing great potential to gather local knowledge outputs into higher scales, which is crucial to understand and record adaptation responses resulting from climate change impacts (Gray et al., 2019). Some studies found that, although the several stakeholder groups had varying opinions on different management aspects , when taken to a higher level or even put in direct discussion amongst them, they were able to reach a consensus based on each groups needs and interests, but that would also contribute to the general good (Hemmerling et al., 2022; LaMere et al., 2020; Maravelias et al., 2018; Tiller et al., 2016).

Among all current participatory modeling approaches useful for engaging local communities in collaborating with experts, with the goal of creating suitable ecosystem management plans, one aspect is unanimous: to properly involve stakeholders and enable them to collaborate effectively, the approach must be tailored to the target population (Sampedro et al., 2017).

Some aspects reported as essential to the success of stakeholder participation are:

Identifying the target stakeholder groups that will best contribute according to management plan scenario is imperative to determine the right approach to request their collaboration; hence preliminary studies must be made onto the socioeconomical aspect of the interested region, as well as demographic data to draft a profile of the intended stakeholders.

Activities conducted in the local language and using user-friendly language to describe project goals and modeling practices are crucial to guarantee stakeholder participation and hinder the lack of trust in experts and policymakers (Sampedro et al., 2017). When presenting stakeholders with modelling results or tools usually employed by scientists and therefore of complex and difficult interpretation, it is indispensable that these results are transparent and adapted to the “layman’s eye”; if stakeholders can’t understand the information presented to them, they are less likely to trust the process and therefore contribute to it (Provot et al., 2020). The use of ecosystem services to translate management efforts into tangible economic effects can be a valuable alternative to explain potential planning results, and put stakeholders’ efforts and compliance into a practical manner (Giakoumis & Voulvoulis, 2018; Souliotis & Voulvoulis, 2021). Measuring environmental impact by means of the resources we can still or no longer extract from ecosystems is more effective than an abstract perspective. When discussing conservation efforts, for example, it is more useful to measure fishing exploitation in price per kilo or monthly revenue, rather than by fishermen catching effort (period length for fishing or quantity of fish caught). Researchers also need to allocate time for stakeholders to process and evaluate the information; ideally, referenced material should be sent in advance to scheduled meetings or workshops (Sampedro et al., 2017).

Another factor that must be taken into consideration is the economic, social and technological constraints stakeholders might have to attend consultation activities; these might be counteracted by reaching out to stakeholder groups over different platforms (telephone, social media, stakeholder associations), and even offering to cover transportation/time costs can increase stakeholder participation to the process (Meynecke et al., 2016).

Finally, once the consultation period is concluded and stakeholders have agreed on the management proposal, and once the plans are put in action, it is imperative that experts and decision-makers keep in contact with stakeholders, sharing information about the progress of the work, and keeping a communication line open so that stakeholder can contribute in maintaining conservation actions, as well as offering knowledge input to solve potential downsides (Tiller et al., 2016). Although important, this communication with stakeholders is rarely explored (Haapasaari et al., 2013).

Conclusion

We conducted a literature review to broaden our knowledge on the methodologies of participatory modeling and stakeholder participation in designing management plans. Though stakeholder participation still presents challenges regarding the distrust or lack of interest of stakeholders in the process of modeling and management plans, it is a crucial step on increasing the success rates of conservation efforts in an ever-changing, highly impacted world. Stakeholder knowledge can complement scientific data when creating management plans, as they are able to detect subtle and short-term changes that might not be flagged by scientific research. Furthermore, including stakeholders in management planning increases the chance of success, as they are more willing to comply with management efforts that they actively contributed to designing, in turn increasing the resilience potential for impacted ecosystems.

A serious effort must be made by high-level authorities to engage with local-level stakeholders, given that they possess firsthand practical knowledge on the functioning and imbalances of impacted ecosystems, and they also hold the power to produce large quantities of data from continuous and extensive ecosystem monitoring. Understanding the population profile of impacted areas, targeting the right group of stakeholders, and being able to share conservation actions and initiatives, while also asking them to input their own knowledge and experience, increase the chances of acceptance and success of management plans in all ecosystems.

There is still a gap in knowledge regarding stakeholder participatory modeling in marine and freshwater environments. Further research should be done, recontacting stakeholders who participated in the design of management plans, to ascertain whether participatory modeling plans are more effective, and stakeholders respond better.

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Chapter IV

Assessment of local stakeholder knowledge for contributing to environmental management plans: Fishermen in the Mar Menor (SE Spain)

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Abstract

Climate change rates have created various environmental issues, flooding, droughts, biodiversity loss, among others. While halting climate change may not be feasible, developing environmental management plans to adapt and mitigate its effects is crucial.
The Mar Menor lagoon in southeast Spain exemplifies an ecosystem under stress, suffering from high nutrient inflow due to intensive agriculture. The lagoon's traditional small-scale fisheries, relying on species from the Mediterranean, are facing challenges due to declining water quality and economic pressures. Policymakers are urged to create comprehensive and accessible management plans, emphasizing stakeholder engagement for effective environmental governance. Involving local fishermen as stakeholders could enhance management strategies through their valuable insights and experiences. This study aims to assess fishermen's perceptions of climate change and environmental management, as well as their willingness to participate in citizen science initiatives to aid in monitoring and preserving the Mar Menor. Stakeholders were asked to fill out a questionnaire regarding environmental issues on the Mar Menor and possible adaptation measures in two moments, May 2022 and July 2024. 20 fishermen participated in the survey. Results showed their responses reflect ecosystem changes that happened in the Mar Menor over the year, indicating their consistent presence in the lagoon allows them to observe short- and long-term changes that might not always be perceived in scientific research. They also showed enthusiasm in participating in monitoring activities through citizen science initiatives and willingness to engage in behaviors that might help mitigate environmental impact in the Mar Menor, highlighting the importance of involving stakeholders into the management planning process and subsequent monitoring, to increase success rates and contribute to acceptance within the whole community.

Keywords: stakeholder perception; fishermen; Mar Menor; participatory environmental management.

Introduction

Climate change rates have taken a toll on all natural ecosystems. A current increase of 1.09ºC in comparison to the last 150 years, of which 1.07ºC is estimated to come from human activities (IPCC, 2023), sets the tone for many different environmental impacts: melting of glaciers (Romshoo et al., 2022), floodings (Atanga & Tankpa, 2021; S Chegwidden et al., 2020), droughts (Dube et al., 2022), loss of biodiversity (Pacifici et al., 2015), disease outbreaks (McMichael, 2015), lower food security (Mukhopadhyay et al., 2021). Although seizing climate change rates might not be possible, the current trending solution lies in creating environmental management plans in adaptation to climate change, or even to try and mitigate potential impacts (Hulme, 2005). Out of all ecosystems impacted by climate change and human activity, the Mar Menor lagoon, in southeast Spain, represents an example of a balanced ecosystem pushed past its breaking point. Due to the inflow of nutrients coming from intensive agriculture around the area, in 2015, the lagoon suffered an algal bloom with culminated into a massive eutrophication episode, culminating in the loss of 85% of its macrophyte coverage (Álvarez-Rogel et al. 2020; Boix-Fayos et al. 2023). This, paired with an extreme rainfall event in 2019, resulted in the death of a vast amount of plants and animals in the ecosystem (Álvarez-Rogel et al. 2020).

Traditionally, fishing activity in the Mar Menor comes from small-scale fisheries (Maynou et al., 2014), with species of commercial interest entering the lagoon from the Mediterranean Sea for feeding (Marcos et al., 2015; Pérez-Ruzafa et al., 2004). With an estimated population of 100-150 fishermen, the activity sees many struggles as environmental lagoon quality decreases and the price of fishes is stagnant while production costs increase (Marcos et al., 2015).

The decline suffered by ecosystems might be addressed by policymakers through environmental management plans (Petak, 1980). Environmental issues are generally complex, uncertain, and operate on multiple levels, affecting a wide range of groups (Reed, 2008). However, the need for more comprehensive and accessible management plans is emergent. Tackling these problems calls for transparent decision-making, flexible to changing situations and contemplating various perspectives and values (Reed, 2008). One such aspect of environmental planning that aims at addressing different perspectives is stakeholder engagement. Developing more sustainable management strategies requires stakeholders to establish new relationships that facilitate two-way information exchange, promote mutual learning, and collaboratively raise interesting aspects to management planning of ecosystems (Stringer et al., 2006). Furthermore, stakeholders can be assets for environmental monitoring, aiding governments in collecting data for ecosystem surveillance and forecasting potential problems. This can be done through citizen science, participatory research where individuals can help scientific research in different contexts by collecting natural data in large-scale and long-term efforts (Goffredo et al., 2010), increasing the amount of available data and decreasing potential costs, all while promoting environmentally friendly behavior (Branchini, Meschini, et al., 2015).

In the case of the Mar Menor, fishermen and fisheries stakeholders may present a group of interest to participate in environmental management planning, due to their personal knowledge and experience over the fishing activities and the lagoon's environmental decline over the years.

Therefore, the present study aimed at assessing the perceptions of a group of stakeholders, fishermen, within the Mar Menor region, regarding climate change and environmental management. The final goal was to collect their points of view and beliefs regarding the ecological crisis of the Mar Menor, and also to evaluate if they were willing to engage in participatory initiatives, in particular, citizen science activities.

Method

In order to ascertain stakeholder impressions, we developed a questionnaire adapted from a study conducted by the University of Leeds, in collaboration with the University of Exeter, as part of a broader initiative to understand public perceptions of climate change and environmental policies (Whitmarsh, 2006) containing 31 items including respondents' information and opinion regarding environmental issues that are present in the Mar Menor, as well as potential strategies to aid in environmental management planning (Supplementary material, Fig. S1). The questions were framed using the Likert scale, multiple choice and open-ended questions. The data collected was processed following the European regulation on Privacy GDPR of 25/05/2018.

Data was collected in person. Stakeholders were approached randomly in two moments: during a stakeholder workshop held by the SMARTLAGOON project in May 2022 (Fig. 1), and during their working activities at the fish market in July 2024. They were asked to fill the questionnaire voluntarily, and given instructions if they had any doubts.

Figure 1. Fishermen workshop in the Mar Menor, Murcia.

Results

The questionnaire was answered by 20 people. 85% of respondents were born and raised in the Mar Menor region, were over 35 years old and worked directly with fishing in the past or present time (some recently retired).

All 20 respondents agree with the item "The environment in the Mar Menor is changing due to human activities" (Fig. 1, a). 19 respondents agreed with the items "The climate is changing" (Fig. 1, b), "Temperatures are rising" (Fig. 1, c), and "Rainfall is decreasing", while 1 remained neutral (Fig. 1, d).

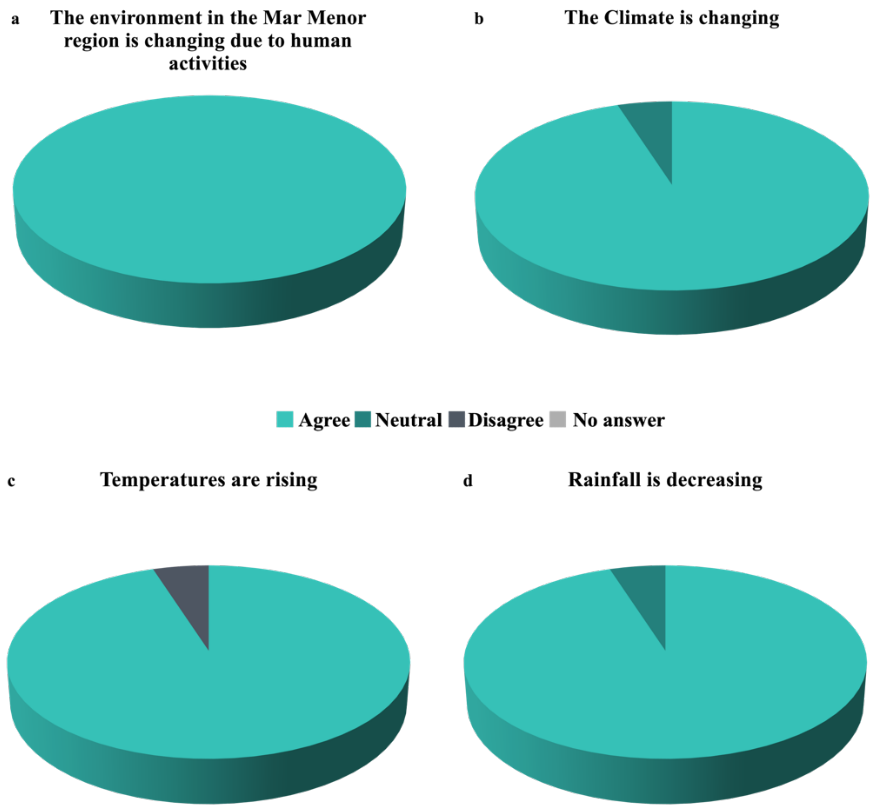

Figure 1. Respondents' answers for questions 1 (a), 2 (b), 3 (c) and 4 (d).

14 respondents agreed with the item "The weather is becoming drier", while 6 disagreed (Fig. 2, a). 16 respondents agreed with the item "There have been increase incidences of floods during the raining season", 2 remained neutral, 1 disagreed and there was 1 missing answer (Fig. 2, b). 16 respondents agreed with the item "There have been increase incidences of droughts during the raining season", 3 remained neutral and 1 didn't answer (Fig. 2, c). 15 respondents agreed with the item "The incidence of climate change will affect the sustainability of our environment", 2 remained neutral and 3 disagreed (Fig.2, d). 5 respondents agreed with the item "There is serious awareness on climate change", 2 remained neutral, 12 disagreed and 1 didn't answer (Fig. 2, e).

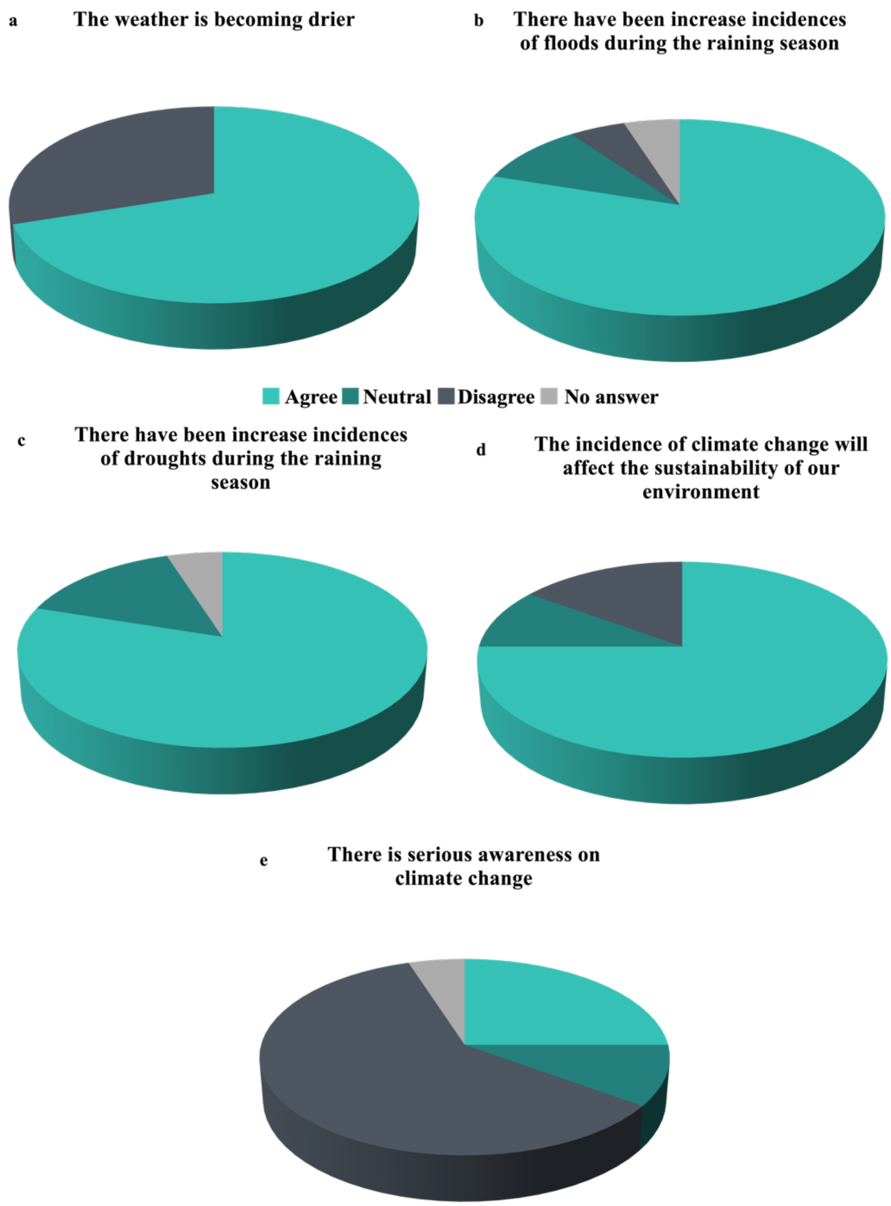

Figure 2. Respondents' answers for questions 5 (a), 6 (b), 7 (c), 8 (d) and 9 (e).

When asked about strategies to adapt to climate change, "Improve water use" received 8 answers, "Reduce fishing period" received 9 answers, "Invest in aquaculture" received 2 answers and "No need for adaptation methods" received 5 answers (it was possible to select more than one answer) (Figure 3).

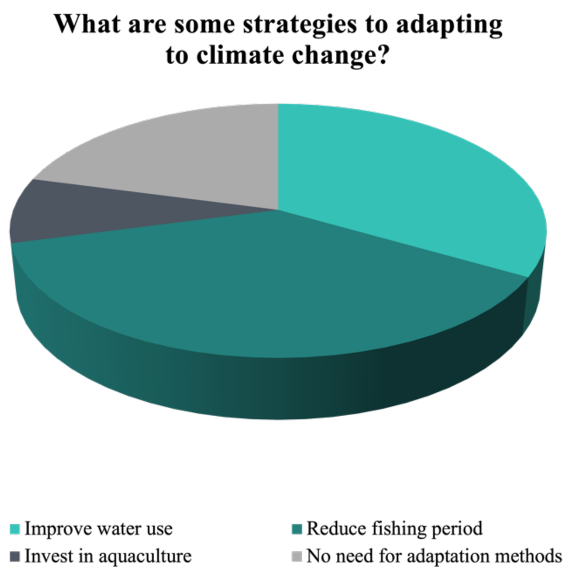

Figure 3. Respondents' answers regarding strategies to adapt to climate change.

When asked about environmental issues experienced during the past 10 years, all the following items: "Muddy sediments/ clumps of algae floating in the water", "Bad smells close to the water", "Waste in the water and on the beach", "Dead fish", and "Greenish water" were selected in some amount from 2016 to 2024 (Fig. 4).

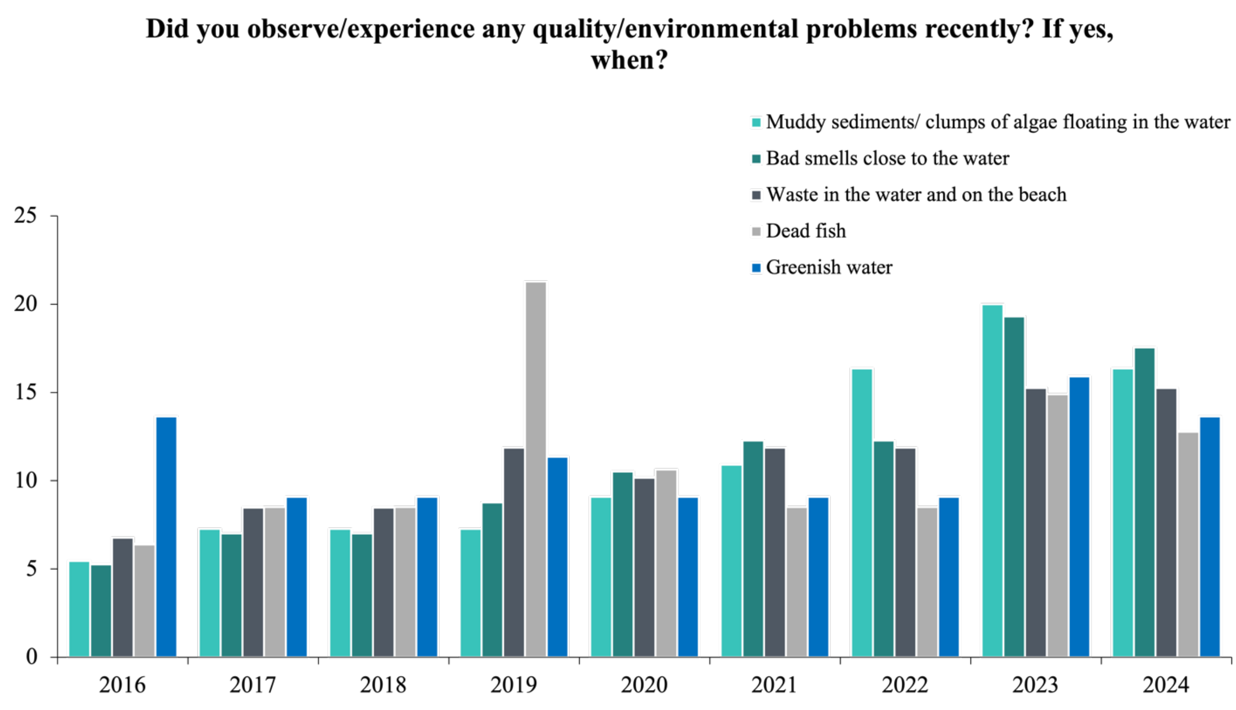

Figure 4. Respondents' answers regarding environmental problems in the Mar Menor.

Respondents also claimed to have noticed over the last 10 years a decrease in the number of fish, in fish size, and in seawater temperature, but not as much in seawater turbidity and seawater level (Figure 5, a, b, c, d, e).

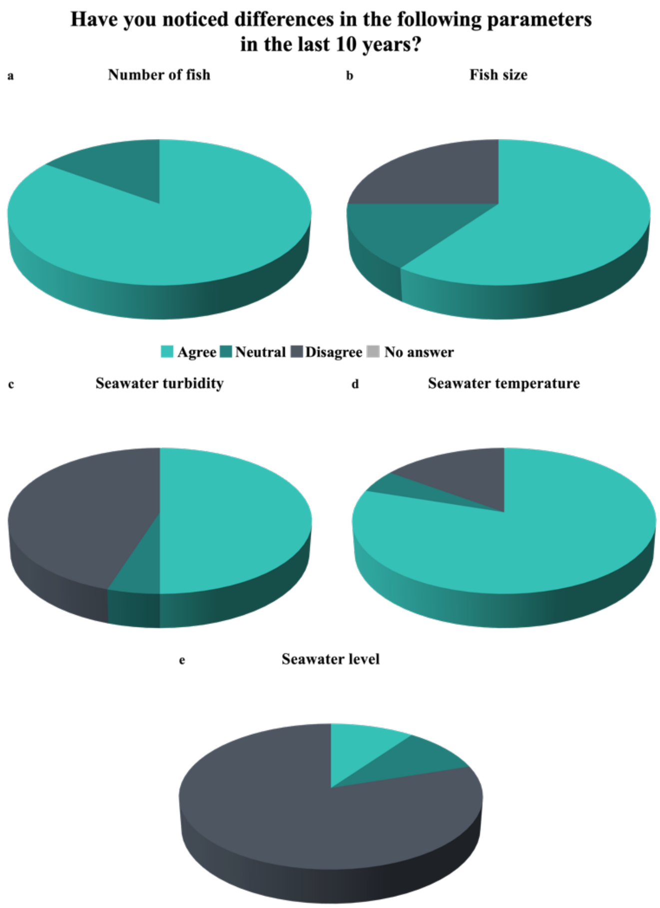

Figure 5. Respondents' answers for questions 12 (a), 13 (b),14 (c), 15 (d) and 16 (e).

12 respondents answered positively when asked if they would be interested in participating in citizen science activities to monitor the state of the Mar Menor, 4 remained neutral and 4 disagreed (Fig. 6).

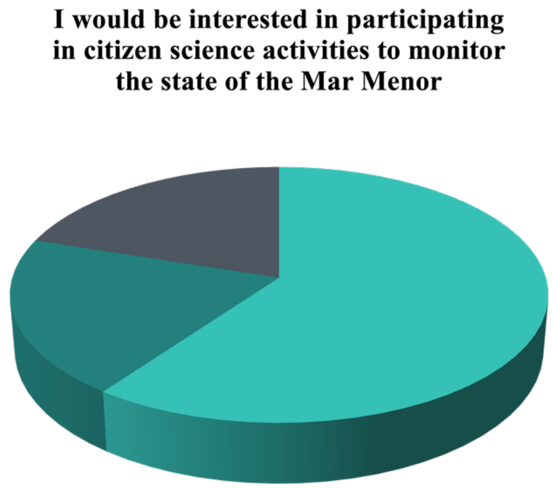

Figure 6. Respondents' answers regarding citizen science activities.

Finally, 18 respondents answered positively when asked if they would be willing to engage in different behaviors to help mitigate the impacts in the Mar Menor, 1 remained neutral and 1 disagreed (Fig. 7).

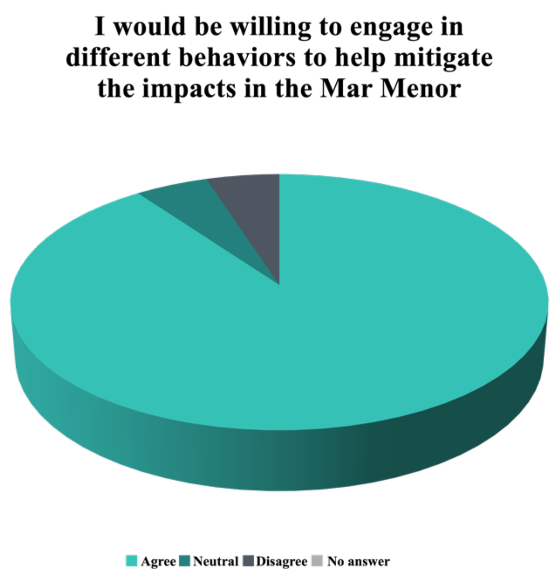

Figure 7. Respondents' answers regarding environmental-friendly behaviors.

Discussion

The respondents' impressions regarding changes in the ecosystem align with various reported incidents that have taken place in the Mar Menor region since 2016: a eutrophication episode that decimated 85% of the macrophyte coverage in the lagoon (Álvarez-Rogel et al. 2020), followed by mortality episodes of different species (Martínez-Martínez et al., 2024; Romero et al., 2020), and two events of extreme rainfall as well (Machado Toffolo et al., 2022; Romero-Díaz & Pérez-Morales, 2021). Their constant presence in the Mar Menor allow them to notice short and long-term changes that might not always be flagged by scientific research.

One aspect of note is that when asked about strategies to climate change in the region, they recognize the need to reduce the fishing effort, which might be unexpected due to the fact that they rely on fishing for their livelihood. However, they recognize that fishing less might mean fishing for longer, meaning they recognize environmental shifts from personal experience and can contribute with experienced knowledge (Rosa et al., 2014). This also signalizes that if environmental management plans call for a reduction in fishing efforts, fishermen will be able to comply. This shows fishermen possess a comprehensive understanding of the resources and environment they depend on, while also being able to offer insights into the fishing practices of the other stakeholders in their community (Wiber et al., 2012).

One further aspect is that only two of the respondents suggested to invest in aquaculture, which shows that they are not in favor of this practice, and it might mean for decisionmakers that when creating management plans, this aspect will not be welcome by the stakeholders, so further education and information programs are necessary in order to get them on board.

When asked if they would be willing to engage in citizen science activities to monitor the state of the Mar Menor, most fishermen responded positively, indicating that both governments and research institutions might be able to count on stakeholders help to collect monitoring data, creating long-term and large-scale efforts to assess the Mar Menor status and the success rates of environmental management plans when they are put to action. Previous studies show that the data gathered by citizen scientists is sufficiently reliable for scientific research purposes, and engaging in citizen science activities allows the population to be actively engaged in monitoring measures (Yochum et al., 2011), further contributing to their environmental awareness and willingness to act favorably towards the environment (Branchini, Meschini, et al., 2015; Branchini, Pensa, et al., 2015; Goffredo et al., 2010), all while bridging the gap between scientific research and the general population (Yochum et al., 2011). Furthermore, almost all fishermen claimed to be willing to engage in different behaviors to help with the mitigation of impacts within the Mar Menor, showing once again that decision makers can benefit from engaging different stakeholder groups in collaborating for the creation of environmental management plans that are more comprehensive, increasing potential success rates and having stakeholders comply willingly with them.

Conclusion

The present survey illustrates the potential contribution that different groups of stakeholders can have regarding short- and long-term changes of an ecosystem. Their willingness to participate in citizen science activities can aid researchers and institutions to install long-term and large-scale monitoring that can help forecast and adaptation to climate change rates and environmental impacts. The fishermen contribution can help governments and decision makers ascertain the potential success or failure of environmental management plans, allowing for the design of comprehensive plans that encompass all or almost all factors within an ecosystem, increasing functioning and effectiveness.

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Supplementary material

We are conducting a study to understand the perceptions of the local population regarding the current environmental quality of the Mar Menor region, as well as the impact on citizens daily lives. For this study, we would like to ask you a few questions about yourself and your experience of living in the region.
To be able to store and use your data, we need your consent.
We, therefore, ask for your consent for participation in the study. The information we collect will be stored anonymously and will be used for research purposes only. The data collected will be processed following the European regulation on Privacy GDPR of 25/05/2018, which integrates the Legislative Decree 30 June 2003 n. 196 "Code regarding the protection of personal data", guaranteeing the total anonymity of the participants. Therefore, we ask you to accept the conditions described above.

THANK YOU IN ADVANCE FOR YOUR TIME AND PRECIOUS COLLABORATION!

Are you originally from the Mar Menor region?
☐ Yes ☐ No

Were you raised in the Mar Menor region?
☐ Yes ☐ No

Please indicate your age bracket:
☐ 35-40 ☐ 41-50 ☐ 51-60 ☐ 60+

In what way is fishing a part of your life?
☐ Occupation ☐ Hobby ☐ Income supplement
☐ Tradition ☐ Family ☐ Other: ___________________

If fishing isn't your only occupation, can you please indicate your current work status?
☐ Full-time job (30+ hours/week) ☐ Part-time job (18-29 hours/week) ☐ Part-time job (-17 hours/week)
☐ Student ☐ Home maker ☐ Retired
☐ Unemployed ☐ Disability leave ☐ Other: ___________________

Please use the options below to answer the following questions according to your opinion:

The Environment in the Mar Menor region is changing due to human activities
☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

The Climate is changing
☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

Temperatures are rising
☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

Rainfall is decreasing
☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

The weather is becoming drier
☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

Climate change has led to the change of livelihood system
☐ Strongly Agree ☐ Somewhat ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

There have been increase incidences of floods during the raining season
☐ Strongly Agree ☐ Somewhat ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

Figure 1 SM. Survey questionnaire.

There have been increase incidences of droughts during the raining season

☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

The incidence of climate change will affect the sustainability of our environment

☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

There is serious awareness on climate change

☐ Strongly Agree ☐ Somewhat Agree ☐ I Don't Know ☐ Somewhat Disagree ☐ Strongly Disagree

Who are the people most seriously affected by climate change?

☐ Tourists ☐ Fishermen ☐ Farmers ☐ Politicians ☐ Researchers

What are some strategies to adapting to climate change?

☐ Reduce fishing period ☐ Improve water use ☐ Invest in aquaculture

☐ Introduce new commercial species in the Mar Menor ☐ No adaptation method needed

Did you observe/experience any quality/environmental problems recently? If yes, when?

☐ Muddy sediments/ clumps of algae floating in the water Year ______________________

☐ Bad smells close to the water Year ______________________

☐ Waste in the water and on the beach Year ______________________

☐ Dead fish Year ______________________

☐ Greenish water Year ______________________

☐ No problems Year ______________________

Have you noticed differences in the following parameters in the last 10 years?

Number of fish

☐ Yes ☐ No ☐ I don't know

Fish size

☐ Yes ☐ No ☐ I don't know

Seawater turbidity

☐ Yes ☐ No ☐ I don't know

Seawater temperature

☐ Yes ☐ No ☐ I don't know

Seawater level

☐ Yes ☐ No ☐ I don't know

Would you be interested in participating in citizen science activities to monitor the state of the Mar Menor?

☐ Yes ☐ No ☐ I don't know

Figure 1 SM. Survey questionnaire. *cont.*

It is widely known that human activities strongly contribute to climate change, impacting ecosystems all over the world. Although governments and policymakers are mainly responsible for proposing and enacting changes all over the world, there are simple daily actions that we citizens can do to contribute with mitigating this impact, helping avoid long-lasting, irreversible implications for ecosystems all over the world. Would you be willing to engage in different behaviors to help mitigate the impacts in the Mar Menor? Comment freely.

☐ Yes ☐ No ☐ I don't know

____

____

____

Who do you believe is the main culprit for the Mar Menor situation? Comment freely.

____

____

____

What do you recommend be done that will enhance the fight towards climate change? Comment freely.

____

____

____

Figure 1 SM. Survey questionnaire. *cont.*

Chapter V

Reliability analysis of data collected by volunteers during an eleven-year citizen science project in the Mediterranean Sea

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Abstract

It is becoming increasingly popular to involve the public in the collection of scientific data to support long-term environmental monitoring, known as citizen science (CS). CS projects exist in many fields and environments, and although the marine environment covers more than 70% of the planet's surface, it seems to be particularly underrepresented in the relevant scientific literature, given the challenges associated with this environment (e.g. the inaccessibility of this environment and the skills required). Since 1999, the Marine Science Group at the University of Bologna has been using a recreational CS method and has shown that it can ensure sufficient data quality while collecting a larger amount of data.

In this study, we sought to update the reliability analysis of the study conducted by Goffredo et al. (2010) in the Mediterranean Sea, using the recreational citizen science protocol. Data was analysed using 7 parameters. All parameters achieved an average score between 50 and 80%. The parameters with the lowest average score were the similarity index and consistency.

Overall, the results confirmed that the recreational citizen science approach can provide reliable data for biodiversity monitoring if it is carefully tailored to the volunteer skills required for the specific project.

While intensive training could increase the consistency of the data collected, it would drastically reduce the number of volunteers involved. This could limit the reach of citizen science projects for volunteers, as the number of volunteers involved would be lower.

Keywords: citizen science; data reliability; Mediterranean Sea; data collection.

Introduction

Lack of funding for institutions and agencies could lead to gaps in knowledge about the presence and distribution of organisms in the environment. In North America and some European countries, it has become increasingly popular to engage the public in the collection of scientific data to support long-term environmental monitoring (Donnelly et al., 2014), the so-called citizen science. One of the main purposes of citizen science monitoring projects is to collect reliable data to observe changes in the diversity of wildlife. In this way, these projects also help to increase volunteer awareness regarding environmental issues (e.g. climate change, biodiversity loss, etc.), involve the general public in the scientific process and, at the same time, gather large amounts of data that would otherwise not be achievable (Bonney et al., 2009a; Donnelly et al., 2014; Silvertown, 2009). Up to 85% of worldwide species-level data requested by governments are collected by volunteers (Kelling et al., 2019). Citizen Science projects exist in many fields and environments, but the marine environment, even if it covers more than 70% of the planet's surface, seems to be particularly underrepresented in scientific literature (Sandahl & Tøttrup, 2020). Citizen science is particularly well-suited for marine-related projects, especially given the importance of the instrumental and capacity-building benefits that citizen science can provide for the marine environment. In fact, large numbers of volunteers can increase temporal and spatial monitoring coverage, which is particularly significant for marine projects, as it is estimated that more than 80% of the oceans are unmapped and unobserved (Sandahl & Tøttrup, 2020). However, this method has led to considerable debate among academics and institutions, regarding the applicability of data collected by non-scientifically trained recorders in decision making processes (Bonney et al., 2009b; Goffredo et al., 2010; Donnelly et al., 2014; Branchini et al., 2015b; Meschini et al., 2021). While carrying out a project about coastal marine debris, Van der Velde et al., (2017) found that volunteer citizen scientists are able to collect data of a comparable quality to that of researchers when under supervision and training. These results are also supported by previous studies that involved students in citizen science projects (Delaney et al., 2008; Roy et al., 2012; Van der Velde et al., 2017). Given the nature of the citizen science method, some challenges need to be considered in the design of the study, such as volunteer lack of field experience and the type of training and direction required for the project outcomes. As has been pointed out by several authors, despite their potential for error and bias, the data collected can be of great use in examining broader patterns and long-term trends (Dickinson et al., 2010; Foster-Smith & Evans, 2003; Van der Velde et al., 2017). The underwater marine environment is even more challenging given the necessity of additional skills such as scuba diving or swimming. While some projects that employ traditional citizen science protocols, such as Reef Check and the Fish Survey Project, require volunteers to undergo long training in order to participate in data collection, a recreational protocol, which requires minimal training, could ensure sufficient data quality while collecting a large amount of data in a short period of time (Goffredo et al., 2010). In this study we sought to update the reliability analysis of the study performed by Goffredo et al. (2010) in the Mediterranean Sea using the recreational citizen science protocol. We present results of eleven years of monitoring activity through two citizen science projects developed by the Marine Science Group (MSG), at the University of Bologna, from 2002 to 2023.

Method

In the previous study we presented the reliability analysis results of the SPA-Mediterranean Underwater Project that concerned Mediterranean biodiversity data collection, involving 3825 volunteers. From 2017 to 2023, this project was replicated (Divers United for the Environment – DUE project), and here we present the updated data to give a more in-depth analysis of volunteer data reliability. During the two projects developed by the MSG in the Mediterranean Sea, a total of 7798 recreational scuba divers were involved along the Italian coast both in diving centers and coastal touristic facilities. Methods used for DUE project were the same used in Goffredo et al., (2010). Both projects' goal was to monitor the Mediterranean Sea biodiversity, using specifically-developed illustrated questionnaires. The only difference between the questionnaire used in SPA project and the DUE is that in the latter we added a "back cover" page with information about plastics and the impact cause in marine ecosystems, more specifically in the Mediterranean Sea. The two main sections of the questionnaire went unchanged: one with photographs to identify the surveyed taxa, the other with a form to record volunteer observations. Four vegetal taxa and 57 animal taxa were surveyed during these projects. The main characteristics of surveyed taxa were: i) the taxa had to be previously known by volunteer recreational divers or easily recognizable; ii) taxa were represented by benthic species (highly mobile pelagic species were not censed); iii) taxa were expected to be found throughout the entire Mediterranean Sea, based on previous literature;

iv) taxa were representative of each of the main trophic levels. These allowed non-professional volunteers to collect data through realistic and achievable tasks. The section dedicated to the form to record data was composed by three parts to respectively collect: 1) personal information (i.e., name, address, email, level of diving certification and diving agency); 2) technical information about the dive (i.e., place, date, depth, dive time, duration of the dive) and type of habitat explored (i.e., rocky bottom, sandy bottom or other habitat); 3) data about sighted taxa with an estimation of their abundance. Both projects used a recreational citizen science approach (Branchini et al., 2015b; Goffredo et al., 2004, 2010) in which normal recreational diving features and volunteer behavior are not modified for project participation. Researchers of the projects performed an annual training session for scuba instructors of the diving centers involved in the project, based on the methodology used for the study and obtained results. This allowed scuba instructors to directly involve their clients in data collection. The projects received the approval of the Bioethics Committee of the University of Bologna (prot. 2.6). Data were treated confidentially, exclusively for institutional purposes (art. 4 of Italian legislation D.R. 271/2009 – single text on privacy and the use of IT systems) and data treatment and reporting took place in aggregate form.

Data validity assessment

To assess the validity of data collected by volunteers, records of 617 volunteers were compared with those collected by a marine biologist of the MSG ("control diver") during 107 validation trials. The characteristics of the validation trials were the same used in the previous study by Goffredo et al., (2010): 1) the control diver dived with at least three volunteers; 2) the validation trial did not affect the diving center usual choice of dive site; 3) the dive was conducted between 9.00 am and 4.00 pm; 4) after the dive, the control diver filled in the questionnaire apart from volunteers, as to avoid interference with volunteer data recording. For each trial, the inventory of each taxon (with abundance ratings) sighted by the control diver was correlated with that collected by each volunteer to verify their similarity (Aceves-Bueno et al., 2017; Darwall & Dulvy, 1996; Foster-Smith & Evans, 2003; Goffredo et al., 2010; Meschini et al., 2021). To measure the quality of volunteer data, 7 reliability parameters were used: Accuracy, Consistency, Percent Identified, Correct Identification, Correctness of Abundance Ratings, Similarity, Reliability (Table 1).

Table 1. Reliability parameters used to analyze data collected by volunteers (taken from Meschini et al. 2021).

Parameter	Definition and derivation of parameter
Accuracy	Similarity of volunteer-generated data to reference values from a control diver measured as Spearman rank correlation coefficient (rho) and expressed as a percentage in the text. This measure of accuracy is assumed to encompass all component sources of error.
Consistency	Similarity of data collected by separate volunteers during the same dive. This was measured as rank correlation coefficient and expressed as percentage in the text. This measure of consistency is assumed to encompass all component source of error.
Percent Identified	The percentage of the total number of taxa present that were recorded by the volunteer diver. The total number of taxa present was derived from the control diver data (i.e., we assumed the taxa recorded by the control diver to be all the taxa present).
Correct Identification	The percentage of volunteers that correctly identified individual taxa when the taxon was present.
Correctness of Abundance Ratings (CAR)	This analysis quantified the correctness in abundance ratings made by the volunteer. It has been expressed as the percentage of the 72 surveyed taxa whose abundance has been correctly rated by the volunteer (i.e., the value of the rating indicated by the volunteer was equal to the reference value recorded by the control diver).
Similarity Index	Measure of similarity between each volunteer and the control diver ratings, using Czekanowki's proportional similarity index.
Reliability	Measure of reliability between each volunteer and the control diver ratings, using Cronbach alpha (α) correlation.

Nonparametric statistical tests were used for the analysis: 1) Spearman rank correlation coefficient to assess the accuracy of the data collected by the volunteers compared to that of the control diver; 2) Cronbach's alpha (α)-correlation to assess the reliability of the data collected between each volunteer and the control diver; and 3) Czekanowki's proportional similarity index (SI) to provide a measure of the similarity between the scores of each volunteer and the control diver (Branchini et al., 2015b; Goffredo et al., 2010; Meschini et al., 2021). Tests results were reported as mean values with 95% Confidence Interval (CI) (Darwall & Dulvy, 1996; Sale & Douglas, 1981). For the Similarity and Reliability parameters, the lower bound (calculated from the 95% CI of the means) was used (Goffredo et al., 2010). We also examined the effects of date, team size (the number of participants in each validation trial), diving certification level of each participant, depth and dive time on volunteer accuracy using the Spearman's rank correlation coefficient. All statistical analyses were calculated using SPSS 26.0 statistical software.

Results

The mean accuracy of each validation trial ranged from 38.4-94.3%, with 89.7% of trials with mean accuracy between 50-100% (Fig. 1, Table 1 Supplementary Materials (SM)).

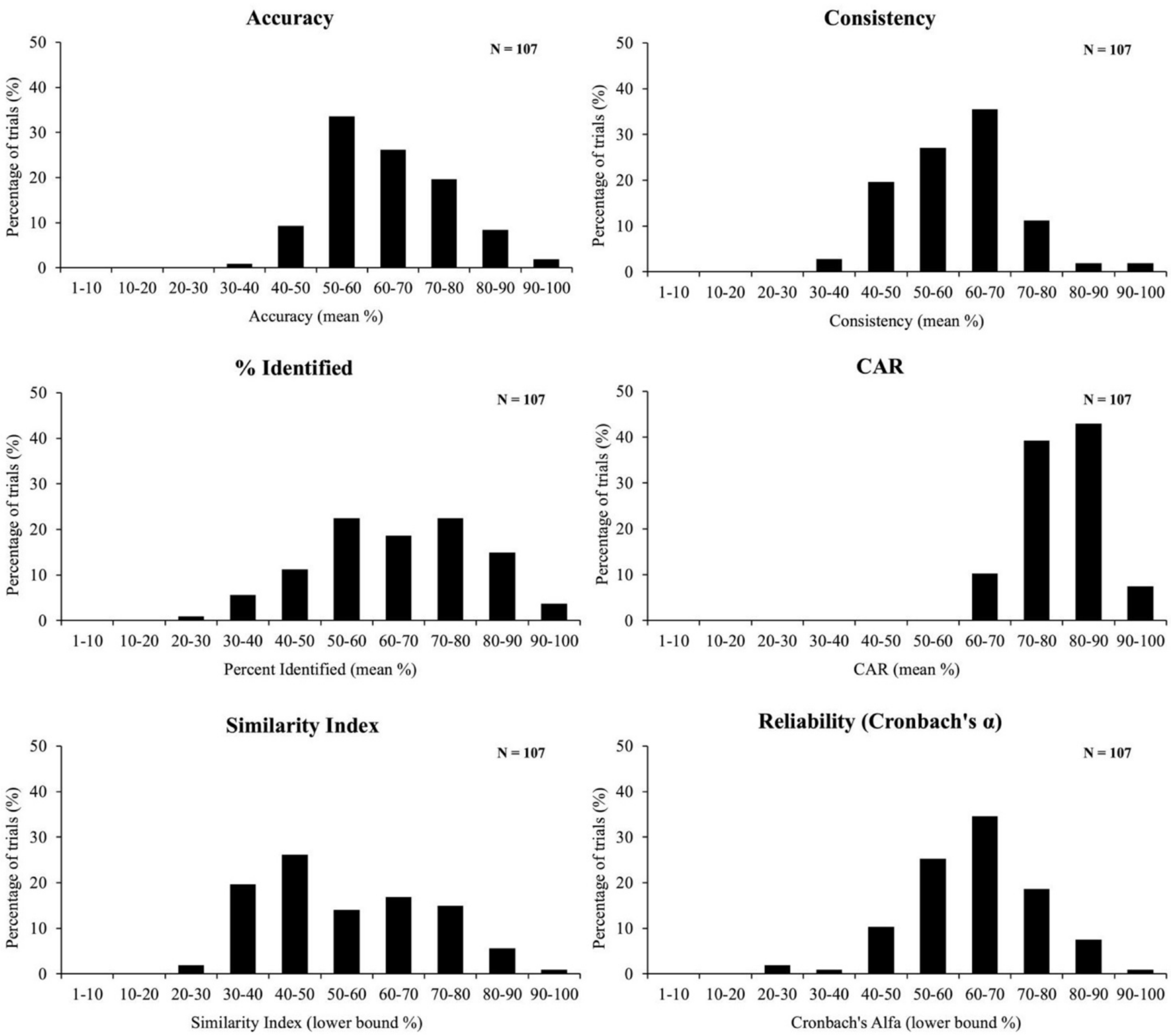

Figure 1. Quality of data collected by volunteers in the 107 validation trials performed during the two projects (2002-2023). Distribution of data is divided in classes depending on the mean score percentage that each validation trial achieved for the studied parameters. For the parameters Similarity Index and Reliability, the reference score is the lower bound calculated from 95% CI of the mean values.

Accuracy was correlated negatively with Date ($\rho s=-0.278$, N=107, $p<0.01$, Table 2).

Table 2. Correlations between reliability parameters and independent variables.

	Date	Team size	Diving certification level	Depth	Dive time
Accuracy	-0.278**	0.129	-0.002	0.030	-0.097
Consistency	-0.033	0.026	-0.106	-0.130	0.055
Percent Identified	-0.376***	0.211*	0.133	0.017	-0.025
CAR	-0.161	0.125	-0.050	-0.221*	-0.048
Similarity Index	-0.619***	0.449***	0.239*	0.127	-0.123
Reliability	0.384***	-0.244**	-0.106	-0.116	0.101

Reported number are Spearman Rho (rs) values. significance of correlation is indicated as *** = p < 0.001. ** = p < 0.01. * = p < 0.05.

The mean consistency of each validation trial ranged from 33.8-92.6%, with 77.6% of trials with mean consistency between 50%-100% (Fig. 1, Table 1 SM). Consistency was not correlated with independent variables (Table 2). The mean percent identified of each validation trial ranged from 29.5-94.4%, with 82.2% of trials with mean percentage of identified between 50-100% (Fig. 1, Table 1 SM). Percent Identified showed significant correlations with date (ρs=-0.376, N=107, p<0.001) and Team Size (ρs=0.211, N=107, p<0.05) (Table 2). The mean correctness of abundance ratings (CAR) of each validation trial ranged from 58.7%-96.6%, with 72% of trials with mean CAR between 70-100% (Fig. 1, Table 1 SM). CAR was correlated with depth (ρs=-0.221, N=107, p<0.05) (Table 2). The mean lower bound of the Czekanowki's proportional similarity index (SI) of each validation trial ranged from 28.8% to 92.3%, with 72% of trials with mean lower bound SI between 40-80% (Fig. 1, Table 1 SM). 51 trials (47.7%) performed with levels of precision below the sufficiency threshold (SI, 95% CI lower bound ≤50%); 38 trials (35.5%) scored a sufficient level of precision (SI, 95% CI lower bound >50% ≤75%), and 18 trials (16.8%) scored high levels of precision (SI, 95% CI lower bound >75% ≤100%). SI was correlated with date (ρs=-0.619 N=107, p<0.001), team size (ρs=0.449, N=107, p<0.001, Table 2) and diving certification level (ρs=0.239, N=107, p<0.05, Table 2). The mean lower bound reliability (α) of each validation trial ranged from 28.9% to 94.5%, with 78% of trials with mean reliability between 50-80% (Fig. 1, Table 1 SM). 14 trials (13.1%) performed with an insufficient level of reliability (α, 95% CI lower bound ≤50%); 27 trials (25.2%) scored acceptable (Goffredo et al., 2010) relationship with the control diver census (α, 95% CI lower bound >50% ≤60%); 37 trials (34.6%) scored an effective reliability level census (α, 95% CI lower bound >60% ≤70%); 29 trials (27.1%)

performed from definitive to very high levels of reliability census (α, 95% CI lower bound >70% ≤100%). Reliability was correlated with date (ρs=0.384, N=107, p<0.001) and team size (ρs=-0.244, N=107, p<0.01).

The mean correct identification of each taxon varied from 0-91.1%, with a positive correlation between the number of validation trials in which the taxon was present and the level of correct identification performed by volunteers (ρs=0.568, N=107, p<0.001) (Fig. 2, Table 3). Six rare taxa were not present (were not recorded by the control diver) in any of the 107 validation trials.

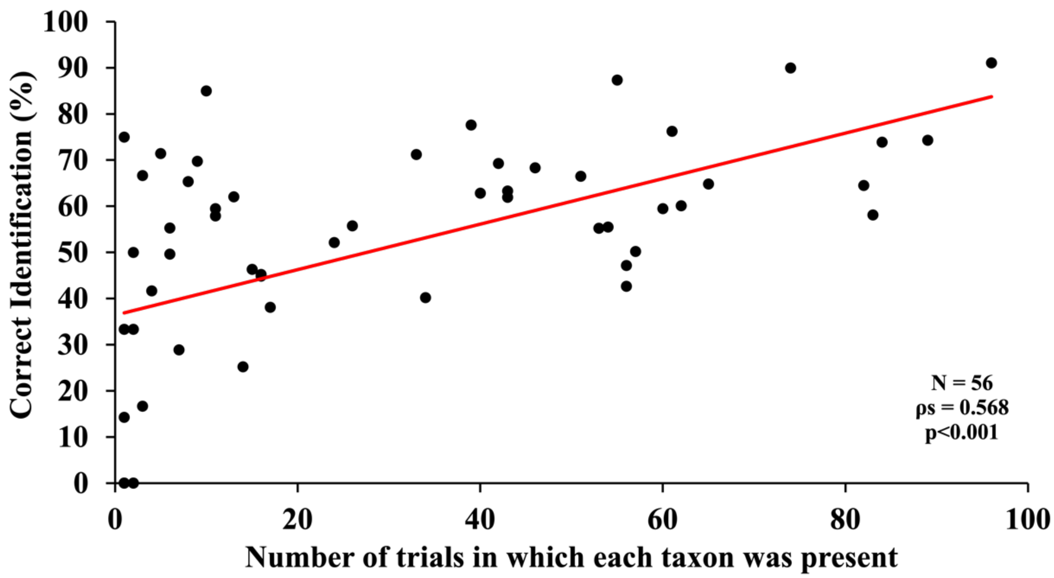

Figure 2. Significant correlation between the percentage of correct identification performed by volunteers (expressed as mean percentage for each taxon) and number of trials in which each taxon was present (based on the control diver sighted). Based on 61 studied taxa and presence of litter. Indicated in red the trendline of the correlations. N = number analyzed organisms; ρs = Spearman coefficient value.

Table 3. Correct identification of organisms by volunteers. Correct identifications were generated from a maximum sample size of 107 validation trials performed at the stations listed in Table 1 SM, from April 2002 to December 2020. N is the actual sample size for each taxon (i.e., presence frequency, the number of validation trials in which the taxon was present). Refer to Table 1 for definition of ‘‘correct identification.’’

Common name	Correct Identification			
	Mean	95% CI		N
17/M damselfish	91.1	87.7	94.4	96
1/C mediterranean tapeweed	89.9	85.2	94.7	74
1/A mermaid's wine glass	87.3	80.3	94.4	55

3/A precious red coral	85.0	61.7	108.2	10
17/C moray eel	77.6	68.8	86.5	39
17/L salema	76.2	67.8	84.7	61
6/A giant tun	75.0	-	-	1
other fishes	74.3	68.2	80.3	89
17/N rainbow wrasse	73.9	68.7	79.0	84
9/C spider crab	71.4	56.8	86.0	5
4/A snakelocks anemone	71.2	59.6	82.8	33
3/B violescent sea-whip	69.8	43.2	96.4	9
4/B yellow cluster anemone	69.3	59.5	79.0	42
2/B stony sponge	68.3	59.9	76.7	46
8/B cuttle fish	66.7	20.9	112.4	3
5/A Mediterranean fanworm	66.5	56.7	76.2	51
9/B common spiny lobster	65.4	39.1	91.6	8
other sea stars	64.8	57.5	72.1	65
other sponges	64.5	57.4	71.5	82
litter	63.3	53.3	73.4	43
other octocorals	62.8	52.6	73.0	40
6/C dotted sea slug	62.0	41.5	82.6	13
17/H dusky grouper	61.9	50.5	73.3	43
other echinoids	60.1	51.4	68.8	62
8/A common octopus	59.5	34.6	84.4	11
1/B sea rose	59.5	50.2	68.7	60
other vegetals	58.1	51.5	64.8	83
2/A chicken liver sponge	57.9	47.1	68.7	11
7/A fan shell	55.7	42.3	69.2	26
10/A false coral	55.5	44.3	66.6	54
11/A feather star	55.3	19.1	91.5	6
16/A red sea-squirt	55.2	45.9	64.6	53
10/B sea lace	52.1	44.5	59.7	24
other holothurians	50.2	40.3	60.1	57
14/A smooth brittlestar	50.0	-48.0	148.0	2
other ophiuroids	49.6	17.5	81.7	6
other sedentary worms	47.2	37.4	56.9	56
17/I sea raven	46.3	32.8	59.9	15
4/C cylinder anemone	45.2	25.0	65.4	16
other decapods	44.8	24.9	64.8	16

other hexacorals	42.7	33.1	52.2	56
6/B purple dye murex	41.7	10.4	72.9	4
other gastropods	40.2	29.6	50.8	34
other bivalves	38.1	20.7	55.4	17
other crinoids	33.3	-32.0	98.7	2
15/A red lance urchin	33.3	-	-	1
other ascidians	28.9	0.8	57.0	7
other bryozoans	25.2	17.6	32.8	14
17/O anglerfish	16.7	-16.0	49.3	3
12/A royal cucumber	14.3	-	-	1
3/C red dead men's fingers	0.0	-	-	1
7/B wing shell	0.0	-	-	1
9/A European lobster	0.0	-	-	2
13/A pentagon sea star	0.0	-	-	1
17/A common torpedo	0.0	-	-	2
17/F short-snouted seahorse	0.0	-	-	1
other cephalopods	-	-	-	0
9/D box crab	-	-	-	0
17/B thornback ray	-	-	-	0
17/D John Dory	-	-	-	0
17/E long-snouted branched seahorse	-	-	-	0
17/G flying gurnard	-	-	-	0

Discussion

Despite the large number of species studied and the recreational dive profile (i.e., divers followed the normal recreational dive path for a given dive site rather than the pre-established transects), the reliability achieved during the validation trials was encouraging. All the parameters achieved an average score between 50 and 80%, indicating that the accuracy was comparable to that obtained by volunteer divers in other projects (Darwall & Dulvy, 1996; Mumby et al., 1995) or in community-based land monitoring on accurate transects (Foster-Smith & Evans, 2003). The parameter that had the lowest mean score was consistency. This result is consistent with previous studies that used the recreational approach and is likely related to the different personal interests of volunteers that led them to focus on different species (Branchini et al., 2015b; Meschini et al., 2021). In fact, divers interested in macro-photography may have focused their attention on small benthic organisms, while others interested in large pelagic fish (e.g., sharks) directed their attention away from the reef. Greater consistency of results was found when an optional intensive training program in marine life identification and study techniques was conducted (Forrester et al., 2015; Meschini et al., 2021; Mumby et al., 1995). The negative correlation of accuracy with date might be due do a lower number in repeaters, divers that have participated multiple times filling out questionnaires throughout both projects. This indicates a different level of outreach in the DUE project with respect to the SPA project, but could also indicate that follow up activities should be encouraged to guarantee the continuous participation of volunteers. While intensive training could increase the accuracy of data collected, it would drastically reduce the number of volunteers involved. This could limit the educational role of citizen science projects for volunteers as well as data collection, as the number of volunteers involved would be smaller. Czekanowski's proportional similarity index (SI) showed that volunteer abundance scores were below the sufficiency threshold in 47.7% of validation trials, suggesting that volunteers may encounter difficulties in estimating abundance, as has been noted in other studies (Done et al., 2017; Gillett et al., 2012). The large variability in the mean scores for the Correct Identification parameter could be due to volunteers finding it difficult to identify and report less common or evident taxa, or even identify organisms that could fit in the "other" category (e.g. other hexacorals, other gastropods, etc.), while they performed better in recording the most common, familiar, and simple species, as already found in previous studies (Bernard et al., 2013; Branchini, Pensa, et al., 2015; Cox et al., 2012; Forrester et al., 2015; Goffredo et al., 2010; Kosmala et al., 2016; Meschini et al., 2021). As pointed out by several authors (Kosmala et al., 2016; Lewandowski & Specht, 2015; Specht & Lewandowski, 2018), a limitation to the recreational citizen science approach is that using professional or expert data (in the case of our study, the "control diver") as reference for assessing volunteer data would also require an assessment of the reliability of the data collected by the professionals or experts (Specht & Lewandowski, 2018). In this study, the control divers were marine biologists from the MSG, trained in the specifics of the project and present at the studied sites for a few weeks at a time, which should ensure good quality of the data collected. In Citizen Science projects, it is essential to develop appropriate tasks for volunteers to ensure high quality data collection (Kosmala et al., 2016; Magurran et al., 2010; Meschini et al., 2021; Schmeller et al., 2009; Tulloch et al., 2013). In the present study, as in previous MSG studies (Branchini, Pensa, et al., 2015; Goffredo et al., 2010; Meschini et al., 2021), data quality was ensured by (1) asking volunteers to complete the questionnaire soon after the dive to avoid possible overlooking of species; (2) training diving instructors in the data collection method annually (during public events) or on-site, when the control diver was present at dive centers.

Conclusion

This study had reiterated previous findings that recreational citizen science is an efficient and effective way to recruit many volunteers and provide reliable data when well designed (Branchini, Meschini, et al., 2015; Goffredo et al., 2004, 2010; Meschini et al., 2021, Dickinson et al., 2012). Using citizen science activities to supplement research data can contribute to more robust amounts of data that are scientifically viable, while contributing to bridging the gap between the general population and academia and research. Furthermore, these data can be used by governments and marine managers as a valuable tool to complement and expand the range of traditional monitoring methods (Dickinson et al., 2010).

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Supplementary material

Table 1 SM. Quality of volunteer-generated data; results of the 107 validation trials performed during the eleven-year research projects (2002–2005 + 2017-2023). Parameter definitions are in Table 1 and in Materials and methods. Values in parentheses are 95% Confidence Interval (CI)

Station name	Date	Team size	Certification level	Depth (m)	Diving time	Accuracy
2002						
Gorgonie	25-Apr-02	9	3 (2.1-3.9)	20.7 (19-22.4)	42.1 (40.6-43.4)	62.5 (53.3-71.7)
Punta Della Madonna	2-Jun-02	7	2.4 (1.6-3.3)	25.6 (19.6-31.6)	37.3 (32.1-42.4)	42.7 (34.6-50.8)
Scogliera Parco Marino	15-Jun-02	7	2.3 (1.3-3.3)	4.3 (3.8-4.8)	63.4 (58.4-68.5)	57.6 (50-65.2)
Tato Point	22-Jun-02	10	1.7 (1.3-2.1)	28 (25.8-30.2)	43.3 (39.5-47.1)	54.2 (48.7-59.6)
Calafuria	23-Jun-02	10	1.8 (1-2.6)	13.3 (10.8-15.7)	58.4 (54.5-62.4)	54.8 (50.6-58.9)
Ancorone	24-Aug-02	6	1.5 (0.8-2.2)	17.1 (15.4-18.8)	46.1 (43.2-48.9)	70.4 (54.2-86.5)
Gorgonie	25-Aug-02	9	1.4 (0.9-2)	16.6 (14.9-18.3)	40.3 (40-40.7)	69.8 (58.1-81.4)
Tato Point	25-Aug-02	10	1.4 (1-1.8)	17.6 (16.2-18.9)	42.9 (41.5-44.2)	66.1 (56.8-75.5)
Scoglione	4-Oct-02	4	2.7 (1.6-3.8)	15.8 (14.3-17.2)	49 (42.5-55.5)	57.6 (40.7-74.4)
Secca Del Turco	4-Oct-02	5	3 (2.4-3.6)	22.6 (19.8-25.5)	44 (40.1-47.9)	49 (39.8-58.1)
Scoglione	5-Oct-02	7	1.6 (0.8-2.3)	14.1 (12.8-15.4)	55.7 (52.3-59.1)	38.4 (26.4-50.4)
Secca Del Turco	5-Oct-02	7	2.7 (2.2-3.3)	24.5 (21.5-27.5)	37.1 (35.1-39.2)	53.8 (47-60.6)
2003						
Cartellino	11-May-03	4	2.3 (1.3-3.2)	21.5 (20.5-22.5)	48.5 (45.6-51.4)	68.5 (53-84)
Calafuria	18-May-03	6	2 (1.1-2.9)	10.3 (7.4-13.2)	45 (44-46)	80.7 (63.6-97.9)
Cala Fetente	23-May-03	6	2.3 (1.5-3.2)	7.7 (5.9-9.4)	33 (30.2-35.8)	68 (57.4-78.6)
Capo Spartivento	24-May-03	6	3 (2-4)	21.5 (16.2-26.8)	42.5 (41.1-43.9)	67 (55.2-78.8)
Grotta Azzurra	24-May-03	11	2.5 (1.6-3.3)	15.8 (12.9-18.6)	47.5 (43.3-51.6)	52.3 (44.9-59.7)
Civitata	7-Jun-03	7	1.4 (0.8-2)	11.4 (10.8-11.9)	50.4 (49.6-51.3)	90.1 (87.2-93.1)
Formiche	8-Jun-03	5	1.4 (0.6-2.2)	13.2 (11.9-14.5)	49.8 (46-53.6)	67.7 (65.2-70.2)
Forbici	4-Jul-03	15	2.1 (1.4-2.7)	16.6 (14.5-18.6)	48.6 (44-53.2)	61.5 (55.8-67.1)
Picchi Di Pablo	5-Jul-03	9	2.7 (1.9-3.4)	18.1 (14.6-21.6)	43.8 (35.3-52.3)	59 (52.3-65.6)
Scoglio Del Remaiolo	26-Jul-03	6	1 (0-0)	16.7 (15.2-18.1)	41.7 (40.4-43)	80.1 (70.1-90.1)
Secca Di Fonza	26-Jul-03	6	1 (0-0)	17.4 (15.9-18.9)	39.3 (38.9-39.6)	74.3 (54.6-94.1)
Portoazzurro	7-Nov-03	11	1.5 (0.8-2.1)	6.9 (6-7.7)	30 (29.4-30.6)	72.7 (59.3-86)
2004						
Punta Della Fica	28-May-04	6	2.3 (1.7-3)	16 (11.7-20.2)	41.7 (41.3-42.1)	68.1 (59.7-76.4)
Formiche	30-May-04	10	1.5 (0.9-2.1)	12.9 (12-13.8)	47.1 (45-49.2)	69.4 (64.8-74)
Calafuria	13-Jun-04	14	1.5 (0.9-2)	7 (6.5-7.5)	38.3 (37.9-38.7)	63.1 (55.8-70.5)
Scoglio Del Remaiolo	23-Jul-04	12	1.8 (1-2.5)	11.8 (11-12.7)	44.4 (42.2-46.7)	68.6 (62.3-74.9)
Corbelli	24-Jul-04	19	1.5 (1-2)	12.1 (11.1-13)	46.9 (45.4-48.4)	71.2 (63.3-79.1)
Scoglio Del Remaiolo	24-Jul-04	18	1.5 (1-2)	11.8 (11.5-12.2)	51.1 (49.8-52.3)	76 (70.3-81.8)
Capo Focardo	25-Jul-04	10	1.6 (0.8-2.4)	7 (6.3-7.6)	42.7 (42.3-43.1)	84.7 (78.9-90.6)

Cannelle	27-Nov-04	8	1.8 (0.8-2.7)	10.1 (6.8-13.3)	40.1 (37.1-43.2)	78.6 (62.7-94.4)
Picchi Di Pablo	28-Nov-04	13	1.5 (0.9-2.1)	10.2 (9.2-11.1)	47.3 (41.8-52.7)	73.4 (61.6-85.2)
2005						
Cala Dei Turchi	27-Oct-05	3	4.2 (2.5-5.8)	23.3 (20.1-26.6)	45.7 (43.3-48)	80.6 (63.6-97.6)
Portoazzurro	29-Oct-05	9	1.7 (0.8-2.5)	8.2 (7.2-9.3)	45 (43-47)	75.3 (66-84.6)
Punta Secca Di Caprara	27-Oct-05	3	3.5 (2-5)	26.7 (20.1-33.2)	46.3 (42.7-50)	88.5 (77.9-99.1)
Scoglio Del Remaiolo	30-Oct-05	10	1.6 (0.8-2.4)	12.7 (10.7-14.6)	45.6 (39.4-51.9)	74.4 (64-84.8)
Cala Caffè	31-Oct-05	5	3.5 (2.3-4.7)	20.6 (18.3-22.9)	45.4 (44.6-46.2)	82 (69.8-94.2)
2017						
Capo Di Stella	11-Nov-17	4	1 (0-0)	20.5 (14.3-26.7)	40.5 (39.9-41.1)	55.8 (46.6-65)
Coralline	9-Dec-17	3	2 (0-0)	20 (0-0)	36 (34.9-37.1)	62.6 (44.3-80.8)
Corbelli	12-Nov-17	4	1 (0-0)	10.3 (9.8-10.8)	48 (0-0)	58.9 (40.6-77.2)
La Crociata	9-Apr-17	5	2.6 (1.4-3.8)	26.4 (23.3-29.5)	43.6 (42.8-44.4)	78.3 (65.7-90.9)
Formiche Della Zanca 1	28-May-17	3	2 (0-0)	16.3 (12.7-20)	53.3 (52-54.6)	52.6 (44.2-61.1)
Formiche Della Zanca 2	28-May-17	3	1 (0-0)	15 (0-0)	42 (0-0)	62.4 (57.5-67.2)
Le Gorgonie	9-Apr-17	5	2.6 (1.4-3.8)	28.8 (27.8-29.8)	42.2 (40.8-43.6)	78.3 (65.7-90.9)
Punta Della Madonna	27-May-17	9	1.3 (1-1.7)	12.4 (11.7-13)	43.9 (41.5-46.2)	64.5 (55.7-73.3)
Punta Morcone	11-Nov-17	5	1 (0-0)	12.9 (10-15.9)	41.6 (35-48.2)	75 (63.5-86.4)
Punta Nasuto	28-May-17	3	1.3 (0.7-2)	9.7 (9-10.4)	47 (45-49)	64.9 (48.8-81)
Scoglietto 1	27-May-17	3	1 (0-0)	30 (0-0)	41.7 (41-42.3)	78.6 (60.9-96.2)
Scoglietto 2	27-May-17	3	2 (0-0)	13.7 (10-17.3)	47.3 (46-48.6)	70.2 (57.7-82.8)
Scoglietto 3	27-May-17	4	1 (0-0)	20 (0-0)	45.3 (35.9-54.6)	67 (51.7-82.2)
2018						
Grotta De Grongo	11-Nov-18	3	1 (0-0)	17.1 (15.4-18.8)	43.3 (41.6-45.1)	47.8 (39.1-56.4)
La Fenicia	30-Nov-18	3	1 (0-0)	3.7 (3-4.3)	54 (50.1-57.9)	57.8 (45.8-69.8)
Le Formiche	1-Dec-18	3	2 (0-4)	23.3 (16.8-29.9)	40.6 (30.6-50.5)	70.3 (43.7-96.9)
Punta Morcone	3-Jun-18	3	1 (0-0)	12 (11.9-12)	43.3 (41.6-45.1)	80.9 (55.7-100)
Punta Nasuto	2-Dec-18	3	1 (0-0)	33.7 (30-37.3)	28 (0-0)	72.5 (52.8-92.1)
Spiaggia Di Morcone	1-Jun-18	5	1.8 (0.2-3.4)	3.9 (3.1-4.7)	55.4 (51.1-59.7)	55 (44.6-65.4)
2019						
Calafuria	31-May-19	4	3 (0.7-5.3)	6.9 (5-8.8)	81.5 (74.9-88.1)	53.2 (41.6-64.7)
Capo Stella 1	15-Jun-19	3	1.3 (0.7-2)	15 (0-0)	47.2 (42.9-51.6)	78.5 (68.4-88.5)
Capo Stella 2	16-Jun-19	4	1 (0-0)	21.5 (4.8-38.2)	48.4 (46.2-50.6)	70 (52.3-87.6)
Grottoni	19-Oct-19	5	1.2 (0.8-1.6)	10 (0-0)	59 (58.1-59.9)	49.8 (46.9-52.7)
La Manza	20-Oct-19	5	1.4 (0.9-1.9)	9.2 (4.9-13.6)	47.2 (46.5-47.9)	47.7 (44-51.3)
Le Corbelle	14-Jun-19	3	1.3 (0.7-2)	14.7 (14-15.3)	48.7 (47.4-50)	75.4 (50.9-99.8)
Monterosso Alga	30-Oct-19	7	3 (0-0)	0 (0-0)	40 (0-0)	88.4 (83.9-92.8)
Paguro	11-May-19	6	4 (3.1-4.9)	13.5 (11.1-15.9)	42.7 (37.4-47.9)	51.6 (41.1-62)
Punta Della Fica	18-Oct-19	4	1 (0-0)	10 (0-0)	49.9 (48.2-51.6)	68.4 (62.3-74.6)

Secca Del Turco	19-Oct-19	4	1 (0-0)	21 (0-0)	53.3 (47.2-59.3)	60.9 (48.2-73.5)
Torre Del Porto	20-Oct-19	3	1.3 (0.7-2)	10.8 (9.2-12.4)	51.7 (49.9-53.4)	45.5 (40.3-50.8)
Spiaggia Della Fenicia	12-Jul-19	3	2.7 (1.4-4)	5 (0-0)	120 (0-0)	94.3 (88.1-100)
2020						
Formiche Della Zanca	5-Jul-20	3	2.2 (1.1-3.3)	17.3 (9.6-25)	51.3 (49.6-53.1)	45.5 (42.8-48.2)
Formiche Della Zanca	18-Oct-20	4	1.6 (0.8-2.4)	13 (11.614.4)	58.8 (57.8-59.7)	64 (55.6-72.3)
La Madonnina 1	17-Oct-20	4	1.7 (0.6-2.8)	19.3 (17.820.7)	37 (0-0)	55.5 (44.5-66.4)
La Madonnina 2	17-Oct-20	4	1.3 (0.7-2)	13.3 (11.215.3)	42.5 (40.2-44.8)	58.9 (47.4-70.3)
Punta Della Madonna	17-Oct-20	3	2 (0-4)	12.2 (4.419.9)	38.3 (33.6-43)	49.8 (45.2-54.3)
Punta Nasuto	4-Jul-20	3	1.8 (0.8-2.7)	14.3 (7.721)	42 (40-44)	75.1 (68.8-81.5)
Punta Nasuto	18-Oct-20	4	2.1 (0.9-3.4)	16.5 (13.519.5)	46 (44-48)	54.1 (41.3-66.9)
Spiaggia Della Fenicia	3-Jul-20	4	3.3 (1.6-4.9)	4.7 (2.37)	81.3 (55.2-107.3)	84.1 (68.5-99.8)
2021						
Calafuria	24-May-21	5	3.3 (1.2-5.3)	4.8 (3.2-6.4)	77.5 (72.4-82.6)	53.4 (43.7-63)
Jacques Mayol	24-Oct-21	3	1.7 (1-2.3)	11.8 (8.7-14.9)	44.7 (43.4-46)	58.2 (46.7-69.8)
Spiaggia Della Fenicia	17-Jun-21	12	1.4 (0.7-2.1)	9.2 (1.3-17)	31.4 (25.5-37.3)	55.5 (50.5-60.4)
Lo Schioppo	10-Jul-21	3	1 (1-1)	12 (9.7-14.3)	59 (56-62)	47.4 (35.9-58.8)
Morcone	22-Oct-21	3	1.4 (-0.4-3.2)	4.1 (3.3-5)	45 (35.2-54.8)	50.4 (32.6-68.2)
Punta Della Madonna	9-Jul-21	4	1.5 (0.9-2.1)	11 (9-13)	51.3 (49.4-53.1)	64.1 (54.5-73.6)
Punta Della Madonna	10-Jul-21	4	2 (2-2)	17.3 (15.4-19.1)	41.5 (38.7-44.3)	63.9 (51.8-75.9)
Punta Della Madonna	19-Jun-21	5	1.8 (0.2-3.4)	8.5 (7.4-9.6)	54.6 (48.4-60.8)	58.5 (44.3-72.8)
Punta Della Madonna	19-Jun-21	5	1.8 (0.2-3.4)	8.2 (7.1-9.4)	47.2 (41.1-53.3)	68.7 (55.5-81.9)
Punta Stella 1	22-Oct-21	4	1.5 (0.9-2.1)	13.8 (6.9-20.7)	42.8 (36.7-48.8)	56.4 (38.6-74.2)
Punta Stella 2	23-Oct-21	4	2.3 (1-3.5)	15.5 (10.7-20.3)	40.8 (36-45.5)	51.6 (45.9-57.4)
Remaiolo	24-Oct-21	4	1.8 (1.3-2.2)	18.8 (14.5-23.2)	43.3 (42.8-43.7)	53.1 (46-60.1)
Scoglio Fino	7-Nov-21	3	2.7 (0.3-5)	16 (11.8-20.1)	46.5 (31.8-61.2)	61.1 (49.7-72.5)
Secca Di Fonza	23-Oct-21	3	1.3 (0.7-2)	11.9 (9.6-14.2)	41.3 (40-42.6)	57.5 (41-74.1)
Spiaggia Della Fenicia	18-Jun-21	6	1.2 (0.8-1.5)	6.1 (5-7.1)	52 (48.8-55.2)	58.3 (49.6-67.1)
2022						
Calafuria	23-Jun-22	5	2 (0.8-3.2)	4.6 (3.4-5.8)	71.5 (65.4-77.6)	54.6 (45.2-63.9)
Scoglietto	23-Jul-22	4	2.3 (1.3-3.2)	15.8 (12.3-19.3)	40.3 (35.8-44.7)	54 (36.4-71.5)
Scoglietto	26-Jun-22	8	2 (1.4-2.6)	14.3 (13.7-14.9)	43 (39.6-46.4)	66.5 (58.1-74.9)
Nemo's Garden	10-Jul-22	3	2.3 (0.6-4.1)	7.7 (7-8.3)	59 (57-61)	64.9 (56.2-73.5)
Punta Della Madonna	25-Jun-22	9	1.7 (1.2-2.1)	15 (12.9-17.1)	46.2 (40.1-52.4)	54.2 (48.8-59.6)
Punta Nasuto	25-Jun-22	4	2.3 (1.8-2.7)	15.3 (14.8-15.7)	40.5 (39.9-41.1)	72.4 (67.4-77.4)
Secca Di Fonza	1-May-22	3	1.3 (0.7-2)	10 (10-10)	41 (39-43)	49.6 (37.3-61.9)
Spiaggia Della Fenicia	24-Jun-22	7	1 (1-1)	8 (8-8)	52.4 (49.3-55.6)	62.2 (49.4-75)
2023						
Calafuria	29-May-23	3	1 (1-1)	7 (5-9)	6.7 (4.1-9.3)	51.7 (40.7-62.7)
Enfola	9-Jul-23	4	2 (1.2-2.8)	17 (17-17)	47 (47-47)	52 (47.7-56.3)

Formiche Della Zanca	3-Jun-23	4	2.8 (1.1-4.4)	8 (8-8)	50 (50-50)	59.5 (52.1-66.8)
Punta Della Madonna 1	3-Jun-23	5	2.4 (0.9-3.9)	9 (9-9)	50 (50-50)	54.8 (45.4-64.2)
Punta Della Madonna 2	8-Jul-23	3	2 (0.9-3.1)	13.3 (6.1-20.6)	37.3 (24.3-50.4)	52.1 (44.9-59.3)
Spiaggia Della Fenicia 1	2-Jun-23	4	2.3 (0.4-4.1)	4 (4-4)	44 (44-44)	77.9 (71.2-84.6)
Spiaggia Della Fenicia 2	7-Jul-23	6	1.3 (0.9-1.7)	5 (4.1-5.9)	129 (100.4-157.6)	58.3 (50-66.6)

Table 1 SM. *cont.*

Station name	Consistency	Percent Identified	Correctedness of Abundance Ratings	Similarity Index	Reliability (α)
2002					
Gorgonie	43.4 (38.5-48.4)	67.5 (60.5-74.5)	81.7 (78.4-85)	75.7 (66.6-84.8)	59.7 (52.2-67.1)
Punta Della Madonna	44.3 (36.3-52.2)	64.8 (47.8-81.9)	72.8 (69.3-76.4)	55.1 (47.2-63)	44.1 (37.2-51)
Scogliera Parco Marino	52.3 (47.8-56.7)	63.8 (49-78.6)	80.6 (78.7-82.6)	68.8 (58.1-79.5)	55.1 (43.4-66.7)
Tato Point	61.9 (58.3-65.4)	58.5 (53.3-63.6)	79.5 (77.7-81.3)	77.3 (73.5-81.1)	57.8 (54.4-61.2)
Calafuria	49.5 (44.2-54.8)	65.3 (58.6-72)	76 (73.6-78.3)	64 (55.7-72.3)	52.4 (46.6-58.3)
Ancorone	65.4 (56.3-74.5)	79.5 (72-86.9)	84.1 (76.3-92)	78.2 (62.8-93.7)	67.4 (49.6-85.1)
Gorgonie	58.2 (51.8-64.6)	83.3 (76.3-90.4)	85.3 (78.9-91.7)	82.7 (75-90.4)	65.7 (53-78.4)
Tato Point	60.5 (56-65)	78 (68-88)	82.4 (76.4-88.5)	81.6 (76.3-87)	63 (54.8-71.1)
Scoglione	48.5 (43.7-53.3)	75 (58.7-91.3)	82.3 (70-94.5)	77.4 (62.6-92.2)	51.3 (28.9-73.8)
Secca Del Turco	49.3 (42.4-56.2)	60 (46.1-73.9)	80.6 (78.9-82.4)	69.9 (60-79.7)	50.4 (40.3-60.6)
Scoglione	39 (28.5-49.5)	57.1 (39.9-74.4)	73.3 (68.9-77.6)	52.2 (35.3-69.1)	39 (29.5-48.4)
Secca Del Turco	50.6 (43.9-57.4)	54 (45.2-62.8)	85.7 (83.2-88.2)	77.4 (67.2-87.5)	56.3 (46.7-66)
2003					
Cartellino	60.8 (50-71.5)	77.3 (58-96.5)	67.7 (59.1-76.4)	79.7 (66.7-92.8)	67.6 (54.7-80.6)
Calafuria	56.1 (45.1-67.1)	85.2 (71.8-98.6)	89 (80.3-97.7)	79.5 (64-95)	66.8 (46.3-87.2)
Cala Fetente	49.5 (41.3-57.7)	70.8 (55.8-85.9)	94.1 (92.1-96)	84.5 (73.2-95.8)	63.1 (50.7-75.5)
Capo Spartivento	61.1 (56.5-65.7)	72 (60.4-83.6)	74.7 (68.2-81.2)	82.9 (76.1-89.7)	70.5 (60.9-80.1)
Grotta Azzurra	57 (53.4-60.6)	73.9 (67.9-79.8)	68.3 (63.9-72.8)	66.9 (60.6-73.1)	54.1 (48.9-59.3)
Civitata	90.5 (88.5-92.5)	93.2 (91.3-95.1)	92.6 (88.9-96.4)	94.7 (92.3-97)	88.9 (84.3-93.4)
Formiche	74.9 (69.7-80.2)	77.9 (72.8-82.9)	73.5 (70.3-76.8)	79.5 (77.3-81.6)	66.5 (63.6-69.5)
Forbici	55 (52.7-57.4)	67.4 (60.1-74.6)	73.1 (70.4-75.8)	72.7 (67.2-78.1)	58.6 (53.9-63.3)
Picchi Di Pablo	51.5 (46.1-56.8)	71.4 (61.3-81.6)	73.8 (70-77.7)	73 (66.7-79.3)	56.7 (50.4-62.9)
Scoglio Del Remaiolo	76.4 (70-82.8)	86.1 (78.3-93.9)	84.1 (76.4-91.9)	86.7 (78.7-94.7)	76.8 (66.9-86.8)
Secca Di Fonza	57.9 (47.9-68)	76.4 (55.8-97)	84.7 (73.8-95.6)	83.3 (68.4-98.3)	74 (53.8-94.2)
Portoazzurro	54.2 (47.6-60.8)	64.8 (47.7-81.9)	90.8 (86.9-94.7)	80.6 (68.6-92.6)	65.2 (49.2-81.2)
2004					
Punta Della Fica	62.8 (56.9-68.7)	64.6 (56.4-72.7)	81.7 (77.3-86.2)	83.2 (75.9-90.4)	65.5 (57.7-73.3)
Formiche	65.8 (61.1-70.4)	75.6 (68.3-82.9)	73.9 (72.3-75.5)	81.5 (78.4-84.7)	66.5 (62.5-70.5)
Calafuria	72 (69-74.9)	62.2 (55.6-68.9)	84.2 (81.6-86.8)	82.6 (77.5-87.6)	64.9 (57.9-71.8)
Scoglio Del Remaiolo	63.3 (59.8-66.8)	80.8 (73-88.5)	77 (70.7-83.3)	81.5 (76.7-86.4)	64.7 (57.2-72.3)
Corbelli	61.3 (58.9-63.7)	74.6 (68.3-80.8)	80.6 (75.4-85.9)	83.1 (77.9-88.4)	70 (62.6-77.4)
Scoglio Del Remaiolo	65.9 (63.7-68.1)	85.8 (81.2-90.3)	80.8 (76.7-85)	85.7 (81.3-90.1)	73.7 (67.9-79.4)
Capo Focardo	81.2 (77.9-84.6)	85.2 (80.5-89.9)	87.3 (82.2-92.3)	90.9 (87.2-94.6)	81.5 (75.6-87.5)
Cannelle	64.6 (56-73.2)	84.2 (74.3-94)	86.7 (78.2-95.2)	84.4 (69.7-99.2)	77.7 (61.8-93.5)
Picchi Di Pablo	64.4 (60.2-68.7)	74.8 (60.8-88.9)	75.7 (68-83.3)	82.6 (74.7-90.5)	68.3 (56.1-80.5)

2005					
Cala Dei Turchi	67.5 (55.4-79.7)	79.6 (57.6-100)	85.5 (77.5-93.4)	92.6 (87.1-98.2)	80.8 (68.4-93.1)
Portoazzurro	71.4 (66.6-76.1)	76.3 (69.4-83.2)	87.1 (83-91.1)	85.2 (76.5-93.9)	73.2 (65.3-81.1)
Punta Secca Di Caprara	74.6 (66.2-82.9)	84.1 (67.7-100)	88.2 (82.6-93.7)	94.9 (89.6-100)	85 (73.6-96.4)
Scoglio Del Remaiolo	71.7 (67.7-75.6)	77.9 (69.6-86.1)	94.6 (90.8-98.4)	83.8 (76.3-91.3)	71.5 (61.3-81.6)
Cala Caffè	68.3 (60.3-76.4)	85.7 (73.5-97.9)	86.5 (77.7-95.2)	91.1 (83.2-99)	83.3 (71.7-94.8)
2017					
Capo Di Stella	69.1 (61.6-76.5)	74 (59.7-88.3)	84.8 (80.9-88.8)	76.4 (65-87.8)	90.1 (82.6-97.5)
Coralline	72 (64.8-79.1)	76.3 (64.5-88.1)	82.3 (77.1-87.5)	76.1 (65.6-86.7)	88.2 (81.2-95.2)
Corbelli	55.7 (50.1-61.2)	54.7 (45.2-64.1)	71.3 (67.3-75.4)	56.3 (48.4-64.3)	77.2 (71-83.4)
La Crociata	70.1 (64.1-76)	71.9 (51-92.8)	83.3 (74.7-92)	68.9 (49-88.7)	85.5 (73.7-97.3)
Formiche Della Zanca 1	69.6 (61.4-77.8)	68.5 (52.7-84.3)	78 (74.2-81.8)	66.3 (58.2-74.5)	81.6 (74.4-88.9)
Formiche Della Zanca 2	64.2 (48-80.4)	51.4 (34.5-68.2)	79.4 (73.9-85)	57.7 (40.8-74.6)	82 (70.9-93.1)
Le Gorgonie	43.1 (28.6-57.5)	63.9 (58.4-69.3)	75.3 (71.5-79.1)	55.1 (51-59.3)	73.5 (67.5-79.6)
Punta Della Madonna	53.3 (44.9-61.7)	59.3 (52-66.5)	73.7 (69.4-77.9)	57.6 (51.5-63.8)	75.5 (73-77.9)
Punta Morcone	62.5 (49.8-75.2)	51.3 (38-64.6)	85.5 (82.3-88.6)	58 (46.1-69.9)	82.8 (73.9-91.6)
Punta Nasuto	43 (36-49.9)	47.5 (32.3-62.7)	72.2 (68.2-76.1)	50.9 (36.4-65.5)	73.4 (67.3-79.5)
Scoglietto 1	63.9 (56.3-71.5)	69 (56.8-81.2)	77.7 (73.3-82.1)	66.4 (53.4-79.5)	82.2 (72.4-92)
Scoglietto 2	56.5 (46.9-66.1)	50 (27.8-72.2)	75 (70.4-79.6)	51.5 (36.9-66.2)	74.7 (65.7-83.7)
Scoglietto 3	41.4 (13.3-69.5)	58 (37.5-78.5)	72.6 (66.3-78.9)	55.4 (41.2-69.7)	73.1 (61.2-85.1)
2018					
Grotta De Grongo	61 (52.1-69.9)	59.1 (38.6-79.6)	72.6 (68.1-77.1)	53.9 (42.3-65.4)	68.9 (59.3-78.5)
La Fenicia	66.7 (40.5-92.9)	81.5 (55.3-100)	89.8 (77.4-100)	80.4 (49.3-100)	89.9 (71.8-100)
Le Formiche	40.5 (4.3-76.7)	60 (20.8-99.2)	81.2 (77.4-85)	39.3 (35.2-43.4)	65.5 (58.1-72.8)
Punta Morcone	57.4 (45.8-69.1)	81 (68.6-93.3)	75.3 (70.7-79.9)	56.2 (48-64.3)	73.4 (66.8-80)
Punta Nasuto	55.9 (40.1-71.6)	78.8 (57.4-100)	84.9 (80.4-89.5)	63.6 (42.5-84.8)	81.9 (54.4-100)
Spiaggia Di Morcone	65.2 (49-81.4)	78.1 (50.5-100)	76.9 (64.7-89)	71.9 (50.4-93.5)	81.6 (68.8-94.5)
2019					
Calafuria	46.5 (36.9-56.1)	51.5 (45.6-57.5)	83.6 (81.5-85.7)	47 (42.2-51.8)	67 (60-74.1)
Capo Stella 1	54.4 (45.9-62.9)	45.3 (39.4-51.2)	75.4 (70.2-80.6)	47 (42.4-51.5)	69.1 (58.3-79.8)
Capo Stella 2	64.9 (49.2-80.7)	80 (57.4-100)	91.9 (84.6-99.2)	67.9 (38.7-97.2)	74.1 (44.7-100)
Grottoni	65.8 (64.2-67.4)	87.2 (77.1-97.2)	88.2 (83.6-92.8)	77.7 (68.8-86.5)	88.6 (85.3-91.9)
La Manza	57.4 (51.1-63.6)	70 (52.1-87.9)	81.5 (70.3-92.6)	69.6 (54.3-84.8)	81.6 (68.8-94.3)
Le Corbelle	92.6 (89.1-96.1)	90.9 (80.6-100)	98.4 (96.6-100)	90.7 (81.1-100)	97.2 (94.5-100)
Monterosso Alga	72.9 (64.1-81.7)	58.3 (47.2-69.5)	83.5 (82.7-84.3)	52.1 (43.5-60.7)	74.9 (69.8-80)
Paguro	62.1 (54.5-69.6)	36.7 (30.1-43.2)	77.1 (75-79.2)	42.2 (34-50.3)	72.8 (66.7-79)
Punta Della Fica	63.4 (49.2-77.7)	40.9 (29.4-52.4)	85.9 (83.2-88.6)	47.8 (37.4-58.3)	80.1 (73.7-86.4)
Secca Del Turco	49.5 (42.9-56)	29.5 (24.1-35)	71.3 (70.7-71.9)	38.6 (34.9-42.3)	74.9 (72.5-77.3)
Torre Del Porto	43.6 (41.9-45.2)	38.1 (33.4-42.8)	77.4 (72.6-82.2)	44.6 (40.8-48.3)	71.4 (69.2-73.5)
Spiaggia Della Fenicia	80.8 (77.9-83.7)	88.8 (82.8-94.8)	87.8 (85.9-89.7)	76.3 (71.7-80.9)	89 (86.1-92)

2020					
Formiche Della Zanca	79.3 (70.1-88.4)	82.1 (68.7-95.5)	94.8 (90.8-98.7)	76 (59.5-92.5)	89.7 (80.6-98.9)
Formiche Della Zanca	63.9 (53.8-74)	94.4 (83.6-100)	87.1 (83.9-90.3)	57.8 (54.5-61.1)	78.7 (73-84.4)
La Madonnina 1	49.3 (29-69.6)	46.2 (37.4-54.9)	75.8 (69.2-82.4)	42.7 (37.8-47.7)	60.8 (56.5-65.1)
La Madonnina 2	50 (37.1-62.8)	54.3 (48.8-59.8)	67.7 (60.6-74.9)	55 (46.5-63.5)	71.4 (60.9-81.9)
Punta Della Madonna	42 (32.3-51.7)	61.9 (47.1-76.7)	71.4 (65.1-77.6)	57.4 (45-69.9)	73.3 (66.1-80.5)
Punta Nasuto	43.5 (14.7-72.2)	50 (33.7-66.3)	79.6 (78.5-80.6)	51.5 (50-53)	73.1 (69.5-76.7)
Punta Nasuto	45.2 (37.3-53.1)	52.8 (39.5-66.1)	67.5 (65.4-69.5)	54.7 (42.9-66.6)	76.7 (68.9-84.5)
Spiaggia Della Fenicia	43.4 (36.6-50.1)	32.9 (21.4-44.4)	67.3 (63.4-71.3)	48.6 (31.1-66)	69.7 (58.5-80.9)
2021					
Calafuria	33.8 (20.5-47.1)	53.8 (28.5-79.2)	78.2 (74-82.4)	45.2 (31.2-59.1)	67.7 (57.1-78.3)
Jacques Mayol	60.3 (44.5-76.1)	45.3 (35.9-54.8)	67.7 (62.9-72.6)	51.4 (41-61.7)	75.1 (67.8-82.4)
Spiaggia Della Fenicia	56.9 (53.7-60)	59.7 (52.2-67.2)	88.2 (86.2-90.2)	52.6 (46.7-58.4)	76.7 (72-81.3)
Lo Schioppo	63.5 (40.1-86.9)	61.1 (46.7-75.5)	76.3 (73.6-79.1)	48.9 (37.7-60.1)	60.9 (45.5-76.3)
Morcone	65.7 (54.8-76.5)	31.1 (23-39.3)	84.5 (81.4-87.6)	42.9 (32.8-53)	67.8 (54.9-80.6)
Punta Della Madonna	65.2 (61.8-68.5)	52.7 (40.4-64.9)	64.5 (62.7-66.3)	58.5 (49.2-67.7)	80.5 (73.6-87.4)
Punta Della Madonna	58.6 (51.2-65.9)	53.4 (39.2-67.7)	66.1 (61.1-71.1)	56 (43.4-68.6)	77 (68.7-85.3)
Punta Della Madonna	57.5 (47.2-67.8)	84 (76.2-91.8)	87.1 (82.1-92.1)	52.3 (35.9-68.7)	75.7 (59.5-91.8)
Punta Della Madonna	51.4 (42.2-60.7)	85 (73-97)	89.4 (87.2-91.5)	58.2 (45.8-70.6)	81.2 (69.4-93)
Punta Stella 1	52.7 (44.5-60.9)	62.5 (38-87)	83.1 (78.2-88)	53.9 (34.1-73.7)	70.7 (55.1-86.2)
Punta Stella 2	44.3 (30.5-58)	40 (25.6-54.4)	72.2 (67.5-76.9)	40.7 (30.8-50.6)	66.3 (60-72.5)
Remaiolo	59.4 (48.7-70.1)	47.5 (42.6-52.4)	73 (68.1-77.9)	54.6 (44.7-64.4)	74.1 (65-83.1)
Scoglio Fino	59.2 (49.3-69.1)	69.9 (63.6-76.1)	70.4 (68.3-72.5)	59.1 (48.1-70.2)	74.9 (64.6-85.2)
Secca Di Fonza	37.7 (29.5-45.9)	48.7 (24-73.5)	70.4 (58.7-82.2)	50.2 (28.8-71.6)	73.4 (61.4-85.4)
Spiaggia Della Fenicia	54.7 (48.4-60.9)	58.3 (38.7-78)	87.4 (86.1-88.6)	46.3 (35.4-57.1)	66.6 (57.5-75.8)
2022					
Calafuria	61 (55.3-66.7)	53.8 (36.9-70.8)	77.2 (74.2-80.1)	49.7 (40.4-59)	72.2 (63.7-80.7)
Scoglietto	53.8 (44.1-63.4)	39.6 (20.3-58.9)	68.1 (64.6-71.6)	46.8 (29.1-64.5)	75.7 (65.8-85.7)
Scoglietto	58.6 (53.9-63.4)	71.9 (60.8-83)	82.5 (78.1-86.8)	62.8 (55.3-70.3)	81.8 (75.9-87.7)
Nemo's Garden	59.2 (48.4-70)	64.8 (61.2-68.4)	75.3 (69.4-81.1)	63.1 (60.3-65.8)	79.9 (73-86.8)
Punta Della Madonna	50 (45.5-54.5)	46.3 (35.4-57.2)	68.5 (65.4-71.5)	47.3 (39.8-54.9)	72.4 (69.2-75.7)
Punta Nasuto	76.6 (69-84.2)	70 (66-74)	76.2 (72.5-79.9)	63.6 (60.7-66.4)	80.6 (77-84.2)
Secca Di Fonza	69.2 (39.3-99.1)	58.3 (42-74.7)	79.6 (78.5-80.6)	47.2 (36.2-58.1)	59.2 (40.9-77.5)
Spiaggia Della Fenicia	56.5 (48.3-64.7)	69 (51-87.1)	88.9 (87.1-90.8)	60.5 (54.4-66.6)	84.1 (80.4-87.7)
2023					
Calafuria	73.9 (61.3-86.6)	46.2 (37.4-54.9)	81.2 (76.6-85.8)	47.7 (37.6-57.8)	64.5 (52.6-76.5)
Enfola	63.1 (50.6-75.6)	48.8 (39.5-58)	69.4 (66.5-72.2)	47.6 (40-55.2)	68.9 (66.8-71)
Formiche Della Zanca	60.4 (53.6-67.1)	59.7 (50.4-69)	73 (68.8-77.1)	56.9 (51.8-61.9)	75.9 (72.7-79.1)
Punta Della Madonna 1	62.2 (55-69.4)	77.7 (75.9-79.5)	76.8 (72.7-80.8)	49.4 (37-61.9)	66.7 (58.1-75.3)
Punta Della Madonna 2	40.7 (26.2-55.2)	63.3 (46-80.6)	80.6 (70.5-90.8)	51.1 (43.4-58.7)	62.2 (54.5-69.8)

Spiaggia Della Fenicia 1	66.8 (57.1-76.5)	92.9 (84.8-100.9)	87.1 (82.6-91.6)	67.5 (61.1-73.9)	87.7 (84.7-90.7)
Spiaggia Della Fenicia 2	62.2 (57-67.5)	55.6 (44.7-66.4)	91.4 (90.1-92.7)	49.8 (41.8-57.8)	74.5 (69.1-79.8)

Chapter VI

Assessment of local stakeholder knowledge for contributing to environmental management plans: Tourists in the Mar Menor (SE Spain)

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Abstract

Tourism plays a very complex role in ecosystems all over the world. While tourism drives economic growth, it can also lead to significant environmental degradation, especially in ecologically sensitive areas like the Mar Menor, in southeast Spain. The region receives significant economic impact from tourism, but the environmental changes it entails highlight the necessity for sustainable tourism practices that balance ecological conservation with economic benefits. Understanding tourist perceptions is crucial for developing effective management strategies that promote sustainability. Engaging tourists in environmental awareness initiatives can help foster responsible behaviors and support the socio-environmental health of the region. This study aimed to assess tourists' views on the attractiveness of the Mar Menor and associated environmental issues, providing insights to guide tourism development and educational initiatives that promote sustainability. Stakeholders were asked to fill out a questionnaire during their stay in two hotels in the Mar Menor region on August, 2022. Results showed most respondents have been coming to the Mar Menor for many years, although the ongoing ecological crisis has diminished the appeal of the lagoon's beaches, with many tourists favoring Mediterranean beaches instead. They also indicated to value cultural and historical attractions, suggesting opportunities to diversify tourism beyond natural attractions. This shift could enhance sustainability efforts in the region. Despite awareness of environmental issues affecting the Mar Menor, many tourists still chose to visit, possibly due to perceptions that media coverage is exaggerated. This highlights a need for improved communication and education about the lagoon's condition. Finally, tourists reported experiencing various environmental problems during their stay, which not only threaten the ecosystem but also negatively impact local businesses and livelihoods. Addressing these issues through informal educational activities could raise awareness and foster conservation efforts, benefiting both the tourism industry and the long-term health of the Mar Menor ecosystem.

Overall, while poorly planned tourism can harm the environment, it can also enhance landscapes and generate revenue for conservation. Engaging tourism stakeholders in the planning process is essential to maximize the plans' viability and success.

Keywords: Stakeholder perception; Tourism; Mar Menor; Participatory environmental management.

Introduction

Tourism represents a significant and dynamic force that motivates individuals to engage with natural environments, pursue adventurous experiences, and immerse themselves in diverse cultural and societal contexts (Lyon & Wells, 2012). As a complex and multidimensional sector, tourism plays a vital role in the global economy while promoting cultural exchange through a broad spectrum of activities and experiences. However, while exerting positive effects on employment, wealth creation and the economy, mobilizing large numbers of tourists can have significant environmental consequences (Andlib & Salcedo-Castro, 2021; Stefãnica & Butnaru, 2015).

In the case of the Mar Menor, in southeast Spain, the largest European saltwater lagoon that has suffered extensive anthropic impact over the years, resulting in environmental issues such as eutrophication episodes, species mortality and water quality deficit, tourism can be detrimental, requiring adequate planning and stakeholder participation in order to develop more sustainably (Irawan et al., 2022). The area around the lagoon houses 60,000 people all year long, but during Summer, an estimated 700,000 people occupy the same space (Conesa & Jiménez-Cárceles, 2007). This exponential growth required unplanned urban development, affecting the area within and around the lagoon (Montealegre, 2020). Construction of artificial beaches, sewage systems and the opening of communication canals with the Mediterranean Sea have led to changes in the lagoons' ecosystem, increasing amounts of organic matter and temperature, and decreasing salinity and fish populations (Velasco et al., 2018). Although urbanization efforts have improved treatment and recycling of greywater in the Mar Menor area, decreasing the amount of nutrient runoff into the lagoon (Guaita-García et al., 2021), tourism and urbanization undeniably bring costs and impacts to the entire region they affect. Nevertheless, they can also enhance the quality of life in the area and support sustainability initiatives that may benefit the local community. The Murcia Region Tourism Institute estimated that in 2022, tourists stayed for an average of 12.28 days in the region, with average expense of 99 euros per person, the same as the Spanish average, and above the average of the Valencia and Andalucía regions. Tourists mainly from the United Kingdom, France and Nordic countries brought a revenue to the region of roughly 588 million euros that year (Instituto de Turismo Región de Murcia (ITREM), 2023).

Tourism is interconnected with different working sectors; hence, different stakeholder groups within the local community can benefit from it (Roxas et al., 2020). Furthermore, tourism and tourism stakeholders might hold the key to pivoting mass exploited systems into a more sustainable approach, not only ecologically, but also socially and economically (Roxas et al., 2020).

The need to approach tourism from a sustainable manner is adamant. Sustainable tourism can be an important instrument in the conservation of ecosystems, as well as contribute to increasing quality of life to its stakeholders (Imran et al., 2014). Achieving sustainability requires collaboration among different stakeholders to develop better and more comprehensive initiatives across social, economic and ecological aspects that support both tourism and ecosystem conservation (Björk, 2000; Heslinga et al., 2019; Roxas et al., 2020).

Analyzing tourists and other stakeholder impressions can help with management planning, understanding the interconnectedness of factors that create impact and can mitigate issues (Byrd, 2007; Waligo et al., 2013). Assessing perceptions of tourists is important to help tailor measures to achieve social, economic and environmental sustainability of regions. By creating and enhancing environmental awareness, they can act as advocates for more sustainable practices and environmentally responsible behavior (Machado Toffolo et al., 2022; Pulido-Fernández & López-Sánchez, 2016), while allowing the socioenvironmental system to progress (Imran et al., 2014; Simão & Partidário, 2012).

To this aim, the present study aimed at assessing the perceptions of a group of tourists within the Mar Menor region, regarding the attractiveness of the region and possible environmental issues. The goal was to collect socioeconomic values regarding their touristic interest that would allow for a better understanding of the development of tourism in the region, eventually favoring educational initiatives to engage tourists for environmental awareness and sustainability measures.

Method

We developed a questionnaire containing 17 items regarding tourists' impressions and holiday experience in the Mar Menor (Supplementary materials Fig. S1). The questions were framed using Liker-scale type answers, as well as multiple choice answers. The data collected was processed following the European regulation on Privacy GDPR of 25/05/2018.

The questionnaires were answered in person at two hotels in the region, the Thalasia Costa de Murcia and Entremares La Manga, in August, 2022. Tourists were approached at the reception of the hotels and proposed the questionnaires. They were asked to fill the questionnaire voluntarily, and given instructions if they had any doubts.

Results

The questionnaire was answered by 59 tourists. The average age was 45.4 years old, ranging from 18 to 75 years old. 33 males (55.9%) and 26 females (44.1%) coming from 18 different regions in Spain (55, 93.2%) and from France (1, 1.7%), Ireland (1, 1.7%), Netherlands (1, 1.7%), and Poland (1, 1.7%).

53.1% of respondents claimed to come to the Mar Menor due to tradition, they used to come to the region as children and grew up around the area, followed by the option of both the Mar Menor and the Mediterranean Sea (18.8%) and recommendation from friends and family or travel agencies (7.8%) (Fig. 1).

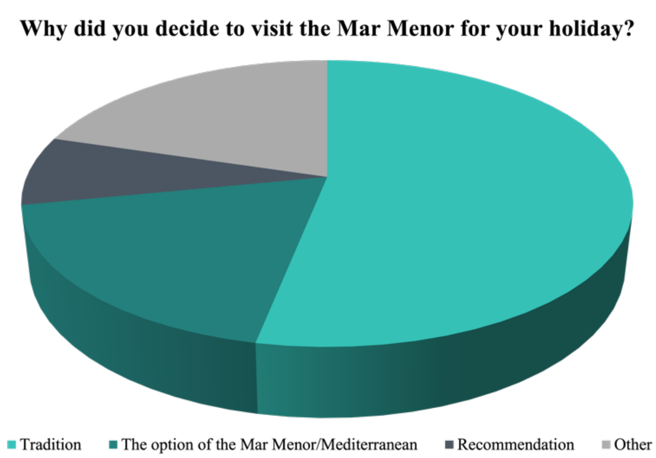

Figure 1. Respondents' answers for question 1.

Among the elements that make the Mar Menor region attractive to them, the easiness to reach the region was ranked very important to 27.1% of them, important to 49.1%, moderately important to 10.2%, slightly important to 3.4%, and not important to 10.2% (Figure 2a). The beaches at the Mar Menor region ranked very important to 1.5% of respondents, important to 11.9%, moderately important to 13.5%, slightly important to 10.2%, and not important to 50.8% of them (Figure 2b). The Mediterranean beaches were considered very important to 30.5% of respondents, important to 40.7%, moderately important to 11.9% and not important to 16.9% (Figure 2c). Cultural and historical attractions was very important to 8.5% of respondents, important to 20.3%, moderately important to 22%, slightly important to 11.9% and not important to 37.3% of them (Figure 2d). The friendliness of the local people was considered very important to 23.2% of respondents, important to 20.3%, moderately important to 8.5%, slightly important to 11.9%, and not important to 27.1% of them (Figure 2e). Finally, the presence of eco-tourism options was ranked very important to 25.4% of respondents, important to 23.7%, moderately important to 10.2%, slightly important to 11.9%, and not important to 28.8% of them (Figure 2f).

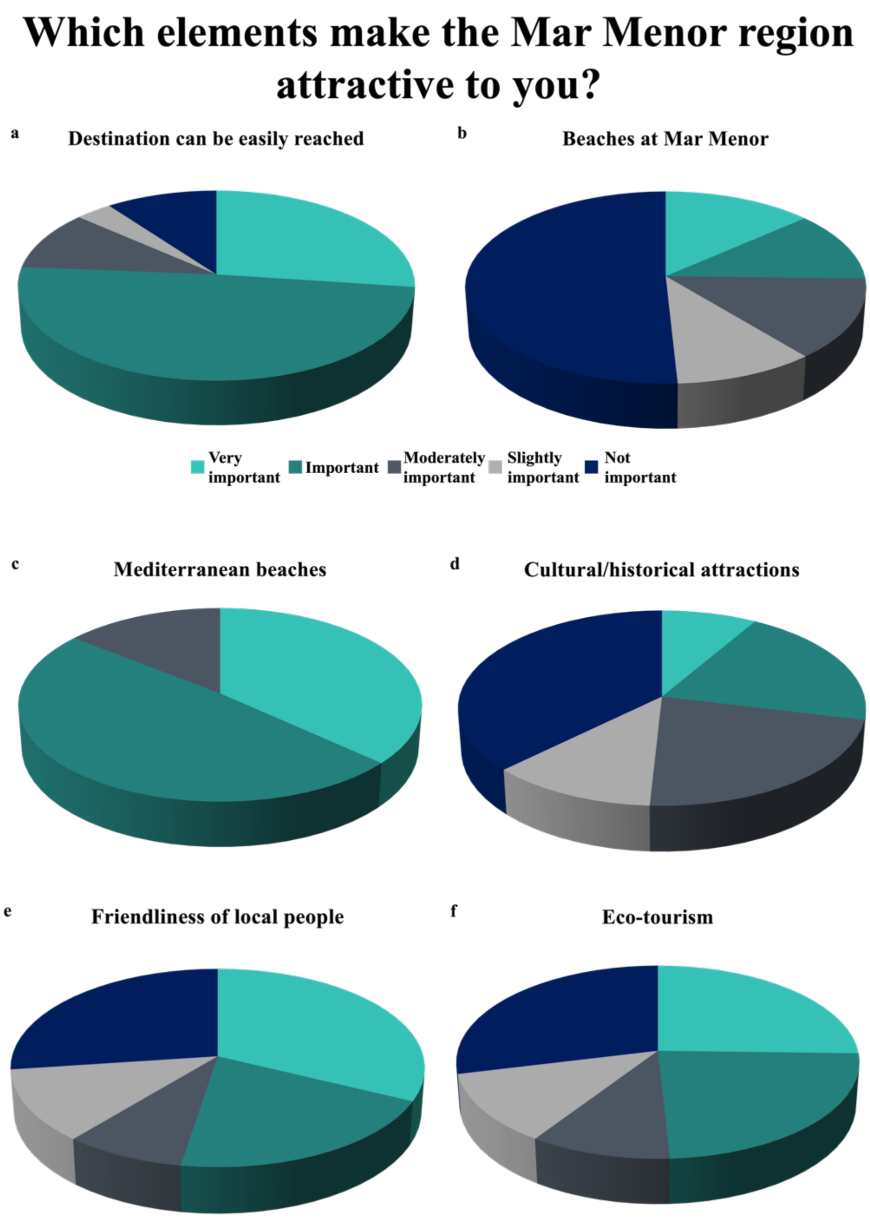

Figure 2. Respondents' answers for questions 2 (a), 3 (b), 4 (c), 5 (d), 6 (e) and 7 (f).

When asked if they had heard about any environmental issues within the Mar Menor region, 76.9% of them responded yes, they heard about environmental problems in the area (Figure 3a), and 65.4% claimed that such issues would strongly impact their holiday experience (Figure 3b). However, these issues did not influence their holiday, because they claimed to stay in the

Mediterranean side (42.3%), they believe the news regarding the Mar Menor are exaggerated (15.4%), they are used to pollution (15.4%), or they believe that tourism and the lagoon's protection must be compatible (3.8%), among other concerns (23.1%) (Figure 3c).

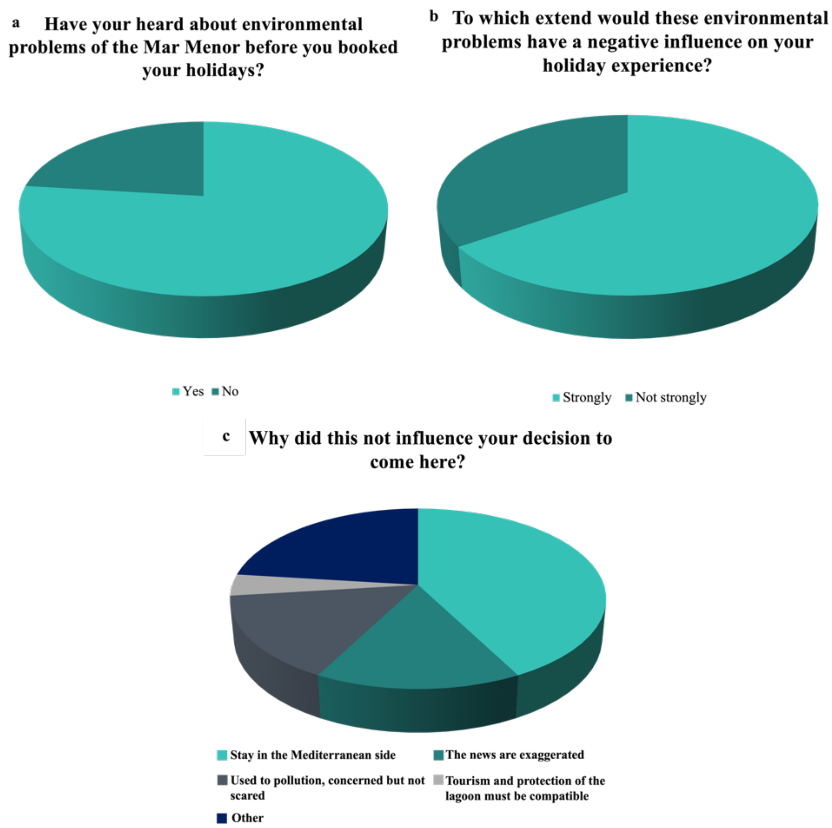

Figure 3. Respondents' answers for questions 8 (a), 9 (b) and 10 (c).

Among the environmental issues experienced, 21.2% claimed to have seen muddy/slimy sediments in the water, 7.6% saw greenish water, 12.1% bad smells, 6.1% saw waste in the water and on the beach and 9.1% claimed to not have experienced anything (Figure 4a).

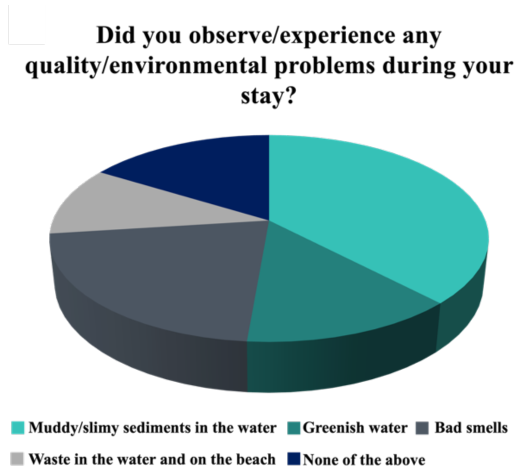

Figure 4. Respondents' answers for question 11.

Discussion

The fact that most of the interviewed tourists come to the Mar Menor due to tradition means they have seen the environment change over the years. This could be useful for data collection, seen as they see the Mar Menor during the same period every year. Research institutions could approach many different subjects with the help of tourists through citizen science, a tool that entails the engagement of the general population in data collection for scientific research, creating large-scale monitoring that might not be feasible with only researchers' work (Goffredo et al., 2010). Furthermore, they might provide helpful insight into the creation of effective management plans using participatory modeling (Alberts, 2007).

The easiness to reach the Mar Menor region could be explained by the fact that most respondents came from Spanish territory, hence used short-range transportation means to arrive in the area. The increase in urbanization led to the construction of several road pathways such as the Campo de Cartagena, covering 8km2 with 4,297 km in length (Romero et al., 2017).

Most interviewed tourists claimed that the beaches of the Mar Menor are not important for the attractiveness of the region, which can be explained by the current ecological crisis that hovers over the lagoon. Meanwhile, they responded the Mediterranean beaches were indeed important, which can indicate that they do not rely on the beaches of Mar Menor during their vacation, preferring the Mediterranean side. A heavily developed part of the Mar Menor region is the strait of La Manga, a sand strip 22 km long and 100-900m wide that separates the Mar Menor from the Mediterranean Sea with 5 canals where both water bodies encounter (García-Ayllón, 2018). That is where most of tourists spend time at the Mar Menor, which could explain the preference for Mediterranean beaches by the survey respondents.

Cultural/historical attractions and friendliness of the local people are considered important by respondent tourists. The region offers different types of tourism in addition to the lagoon, such as La Unión-Cartagena, where lays a mining landscape declared as a historical site of cultural interest by the Region (Morales Yago, 2015). There are also popular festivals that have been maintained throughout the years by the local population (Montealegre, 2020). This shows a potential to shift tourism initiatives beyond the natural environment, which could enrich the sector and create new opportunities that can help with sustainability issues (Teruel-Sanchez et al., 2021).

The importance of ecotourism offers by the respondents indicate that a shift towards sustainability could be well received by tourists in the region. Investing in ecotourism options can be a way to promote environmental awareness among tourists, while creating opportunities for local businesses and also maintaining areas of interest without mass exploitation (Ballesteros Pelegrín, 2014).

Even though respondents claimed to have heard about the environmental problems of the Mar Menor before their holidays, and stated that these problems would have a strong negative influence into their holiday experience, they still decided to visit the Mar Menor, declaring mainly that they stay in the Mediterranean side, which is in line with the previously declared importance of the Mediterranean beaches, or they believe that the news about the Mar Menor are exaggerated. Such perceptions bring to light a concerning aspect of misinformation, indicating that the information transmitted to tourists is not being received or believed as it should. This issue could be tackled by informal education activities, carried out with tourists in a free-choice manner during their stay. Environmental awareness, encouraged through educational activities for tourists, can be an asset for everyone in the tourism industry. By increasing awareness of the human impact on ecosystems, it fosters a concern for conservation. This not only helps to ensure ongoing profitability for businesses, but also contributes to the long-term preservation of the environment (Branchini et al., 2015; Machado Toffolo et al., 2022; Meschini et al., 2021).

Finally, respondents declared to have experienced environmental problems during their stay in the Mar Menor. These issues are well known and studied, such as nutrient runoff, eutrophication episodes, flooding events, loss of biodiversity, pollutants and heavy metals contamination, with overall water quality decrease (Bayo et al., 2019; Carratalá et al., 2017; Erena et al., 2019; Fernández-Alías et al., 2022; García-Oliva et al., 2018; Pérez-Ruzafa et al., 2019). Environmental problems, beyond the major threat to ecosystem survival and human subsistence, create problems for businesses and can further weaken the livelihood of people who depend it.

Conclusion

The present study gathered tourist perceptions regarding environmental issues and potential attractiveness of the Mar Menor. When developing environmental management plans, it is important to consider all the aspects that surround an ecosystem. Tourism can be harmful to the environment when poorly planned, but has the potential to shape whole landscapes and create revenue that allows for conservation and long-term maintenance of ecosystems. Therefore, it is important to engage stakeholders from the tourism sector in the design of these plans, to maximize viability and success rates of execution.

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Supplementary material

We are conducting a study to understand the preferences of tourists to the Mar Menor region and their perceptions of the environmental quality of the region. For this study, we would like to ask you a few questions about yourself and your experience of being a visitor in the region.

To be able to store and use your data, we need your consent.

We, therefore, ask for your consent for participation in the study. The information we collect will be used for research purposes only. The data collected will be processed following the European regulation on Privacy GDPR of 25/05/2018, which integrates the Legislative Decree 30 June 2003 n. 196 "Code regarding the protection of personal data", guaranteeing the total anonymity of the participants. The collected material will be stored anonymously. To continue with the questionnaire we ask you to accept the conditions described above.

Why did you decide to visit the Mar Menor for your holiday?

☐ Tradition – I have been coming here for several years ☐ I like having the option of beach recreation both in the Mar Menor and the Mediterranean ☐ Recommendation

☐ Other: ___________________

Which elements make the Mar Menor region attractive to you?

Destination can be easily reached

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Beaches at Mar Menor

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Mediterranean beaches

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Cultural/historical attractions (architecture, traditions, local cuisine)

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Friendliness of local people

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Eco-tourism (e.g. Sierra de la Muela, El Majal Blanco, Flamingos in the Las Salinas y Arenales de San Pedro Regional Park)

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Did you observe/experience any quality/environmental problems during your current stay?

☐ Muddy / slimy sediments when you enter the water ☐ Greenish water ☐ Flocks/clumps of algae floating in the water

☐ Dead fish ☐ Bad smells close to the water ☐ Waste in the water and on the beach

☐ None of the above ☐ Other: ___________________

What role does the water quality of the beaches at the Mar Menor and the Mediterranean play for your vacation?

☐ Very important ☐ Important ☐ Moderately important ☐ Slightly important ☐ Not important

Have your heard about environmental problems of the Mar Menor before you booked your holidays?

☐ Yes ☐ No

Figure 1 SM. Survey questionnaire.

To which extend would these environmental problems have a negative influence on your holiday experience?

☐ Not at all ☐ To a limited extend ☐ Neutral ☐ Strongly ☐ Very strongly

Why did this not influence your decision to come here?

☐ I am used to this kind of news ☐ I do not trust this news ☐ I am not spending time on Mar Menor (e.g., I prefer Mediterranean seaside and/or the hotel swimming pool)

☐ I am confident that, despite all, the Mar Menor water condition is not dangerous for human health ☐ Other: ___________________

Figure 1 SM. Survey questionnaire. *cont.*

Chapter VII

Long term effects of an informal education program on tourist environmental perception

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Abstract

Tourism is one of the most important economic sectors worldwide, with significant overarching impact on the environment, including negative effects caused by tourist inappropriate behavior while on vacation. By providing informal educational activities, tourism also has an educative role that leads to positive learning outcomes and beneficial environmental effects. Here we present the short- and long-term outcomes of a project for environmental education (Glocal Education) carried out in three travel destinations, aimed at promoting sustainability variables (knowledge, attitude, and awareness) in participating tourists. Since psychological components can affect learning outcomes, we also considered tourist satisfaction in participating in the project and identification with its values, as well as the intention to travel with the hosting tour operator again in the future. Tourists were asked to compile evaluation questionnaires three times: before Glocal Education activities, right after activities (i.e., while still on vacation), and after at least one year from initial project participation. Short- and long-term learning outcomes were tested, and possible relations between these variables and psychological components (satisfaction, identification, and intention) of the learning experience were verified. Overall, knowledge, attitude and awareness increased in the short term, while in the long term, knowledge and attitude decreased, and awareness remained constant. In most cases, psychological components showed positive relation with sustainability variables, which suggested their important role in structuring and carrying out environmental education activities. This study suggests that informal environmental education activities can be advantageous for tourism stakeholders in terms of customer loyalty, while promoting environmentally friendly tourist action.

Keywords: Environmental education; Knowledge; Attitude; Awareness; Tourism; Informal learning; Cognitive dissonance.

Introduction

Tourism, currently one of the largest industries in the world, is an example of human activity with an overarching impact on the environment, contributing to global pollution, infrastructure development, and land use (Gössling, 2002; World Tourism Organization (UNWTO), 2017). Although the modernization of transportation has helped promote global connectivity and affordable air travel (Cohen, 2012), the previous trend that predicted 1.8 billion international tourist arrivals by 2030 (UNWTO & ITF, 2019) has been severely impacted by the coronavirus (COVID-19) pandemic, leading to a decline of more than 50% in international tourist arrivals for the year 2020 (UNWTO, 2020). Hence, predicting long-term touristic global trends is currently problematic (Gössling et al., 2020; UNWTO, 2020).

Many popular travel destinations are often locations known for their appealing natural environments, such as tropical locations, often characterized by unique ecosystems and biodiversity (e.g., coral reefs and tropical forests). In addition to the aforementioned social impacts, tourists can significantly impact the environment through inappropriate behavior while on vacation (Davenport & Davenport, 2006; Gössling, 2002; Pickering & Hill, 2007). For example, trampling by tourists can lead to disturbance of local vegetation and damage in coastal environments (sand dunes and intertidal areas), and also underwater, damaging coral reefs. (Davenport & Davenport, 2006; Defeo et al., 2009; Pickering & Hill, 2007). Further issues are harvesting of natural components or their acquisition as souvenirs, such as local and sometimes endangered plant and animal species, seashells, coral fragments, and sand (Defeo et al., 2009; Gössling, 2002; Kowalewski et al., 2014; Pickering & Hill, 2007), and also interaction with wildlife: touching and feeding animals create disturbance for wildlife and can lead to behavioral and reproductive modifications, increased human dependency or aggression (Green & Giese, 2004; Orams, 2002).

Short-term effects derived from inappropriate and unaware tourist behavior can cumulatively develop into long-term impacts on populations and ecosystems (Green & Giese, 2004; Kowalewski et al., 2014; Pickering & Hill, 2007). Thus, it is important to address these issues, by acting on a small, local scale, to reduce overall environmental impact (Defeo et al., 2009; Green & Giese, 2004). Reducing such effects benefits the environment and the tourism stakeholders, both public and private, as natural ecosystem integrity guarantees the lasting appeal of travel destinations and continuous economic influx from tourism (Gössling, 2002).

For these reasons, The UN Conference on Sustainable Development Rio+20, in 2012, reported the need to support sustainable tourism activities and the promotion of environmental awareness, with governments, tourists, local communities, and stakeholders all having interest in promoting sustainable tourism development (United Nations, 2012, 2015). Further initiatives aim to comply with the sustainable development goals of the Agenda 2030, such as the UN Decade of Ocean Science (Ryabinin et al., 2019) and the EU Green Deal and Horizon Europe (Eckert & Kovalevska, 2021).

Environmental education can contribute to achieving more sustainable tourism (Tilbury, 1995; United Nations, 1993, 2015). Education shapes not only knowledge and understanding, but also emotions, awareness, and personal development, which in turn can influence behavior (Gössling, 2018). Knowledge (cognition, understanding topics, and issues), attitude (concern and active improvement and protection), and awareness (consciousness, sensitivity to issues) are among the objectives that environmental education should address (Cheng & Wu, 2015; Constitution, 1977; Pooley & O'Connor, 2000). Several studies indicate that when individuals have higher levels of environmental knowledge, they are more concerned about the environment (Hines et al., 1987; Huang & Shih, 2009; Lyons & Breakwell, 1994). Moreover, Cheng and Wu (Cheng and Wu, 2015) found that when tourists feel attached to the destination they are visiting, they tend to feel protective towards such a destination, showing intention to actively prevent negative impacts to that given place.

Knowledge, awareness, and attitude are not the only variables contributing to environmental perception, possible behavioral changes and increased sustainable actions (Gössling, 2018; Grob, 1995). Other important variables in the path of environmental education are the so-called "empowerment variables" (hereafter, psychological variables) (Hungerford & Volk, 1990). These variables, affective attributes that contribute to empathy towards the environment (Chawla, 1998), are the cornerstone in environmental education and include: identification with the environmental cause, intention to act in favor of the environment, and personal satisfaction in being an active participant to environment protection (Bamberg & Möser, 2007; Hungerford & Volk, 1990). In creating sensitivity, combined with a sense of power and responsibility, people can choose to contribute to a mass effort in the conservation and protection of the environment (Hungerford & Volk, 1990).

Although there is a plethora of touristic targets (gastronomic, historical, cultural, wildlife, and so on), we focused our study on mass tourism resorts located in naturalistic tropical destinations. Such resorts are popular touristic destinations, raising concerns about possible social, economic, and environmental consequences (Cowburn et al., 2018; Grilli et al., 2020; Richins, 2009). Nevertheless, these touristic destinations can be profitably employed to put environmental education into practice and, in the long-term, select the best educational model prompting novel, conservation-oriented, public attitudes toward vulnerable ecosystems.

This study aimed to assess the short-term and long-term effects of recreational activities offered to tourists while on vacation. Specifically, these activities were provided within the Glocal Education project, an environmental education project carried out as a pilot study at three different tropical resort facilities located in Madagascar and the Maldives. The study considered variables related to sustainability and environmental perception (environmental knowledge, attitude, and awareness) and psychology (satisfaction, identification, intention), and the possible relation between them.

Method

Ethics statement

Glocal Education project and its consent acquisition procedure have received the approval of the Bioethics Committee of the University of Bologna (Prot. 118055). For this study, participants (or parents/guardians in case of minors) gave their consent by signing a declaration inserted in the questionnaires., and their personal data (name and surname) were collected to guarantee the comparison between the initial environmental education assessment and that after participation in project activities. We have treated the data confidentially, exclusively for institutional purposes (art. 4 of Italian legislation D.R. 271/2009 - single text on privacy and the use of IT systems) and according to art. 12, 13, and 14 of EU Regulation 2016/679 - General Data Protection Regulation (GDPR). Data treatment and reporting took place in aggregate form.

Field activities

The activities were carried out in three travel destinations as part of the environmental education project “Glocal Education”. These locations were Nosy Be island (Madagascar), Dhiggiri island and Maayafushi island (Maldives) (see (Meschini et al., 2021a).

To test for long-term effects of the Glocal Education project (GE-LT), tourists who agreed to leave their email address were re-contacted after approximately 12-16 months from initial participation, to fill out a third evaluation questionnaire (T_2), using the Qualtrics online survey platform (Qualtrics, Provo, UT, USA. https://www.qualtrics.com).

Environmental education evaluation questionnaire

The questionnaire, previously developed to detect short-term effects (see (Meschini et al., 2021a) was repeated after one year of tourist participation in the project. The evaluation questionnaire (Supplementary Figure 1-7) was developed by the Department of Psychology of the University of Bologna and was divided into sections as follows:

- Section A: aimed to collect participants' personal and demographic information, to evaluate if these factors could affect initial levels of environmental education and their variation in time. This information was used to pair questionnaires compiled by the same participant over time, to have repeated measures for every participant. Requested information: sex, age, education, nature contact (frequency of activities carried out in nature regularly).
- Section B: aimed to measure the knowledge variable, with 10 items (number 1 to 10), regarding knowledge in basic biology and ecology topics covered during Glocal Education activities. Some items were customized accordingly to the ecosystem of each location.
- Section C: aimed to measure the attitude variable, with 8 items (number 11 to 18), regarding the intention to carry out pro-environmental and sustainable actions, therefore a positive behavior towards the environment.
- Section D: aimed to measure the awareness variable, with 9 items (number 19 to 27) regarding the emotional component of individual awareness towards environmental issues.
- Section E: aimed to measure the satisfaction variable, with 4 items (number 28 to 31), regarding the personal impression of the quality of the proposed project activities.

- Section F: aimed to measure the identification variable, with 4 items (number 32 to 35), regarding participants' sense of affinity to the project and its values.
- Section G: aimed to measure the intention variable, with 4 items (number 36 to 38), regarding the intention to travel with the same tour operator who hosted the environmental education activities, again in the future.

For sections B-G, scores were calculated according to (Meschini et al., 2021a)). We defined sustainability variables, the variables of knowledge, attitude, and awareness which represented overall environmental perception before participation in Glocal Education activities (T_0), in the short term (T_1) and long term (T_2) after project participation. We defined psychological variables, related to participating in the Glocal Education project, the variables of satisfaction, identification, and intention, measured in the short term (T_1) and long term (T_2).

Statistical analysis

For each variable measured with the Likert scale (attitude, awareness, satisfaction, identification, intention), reverse formulated items were recalculated accordingly (Paulhus, 1991), and reliability analysis using Cronbach's alpha (α) was conducted to test the internal consistency of items for each repeated measure of the variables at T_0, T_1, and T_2. When Alpha values resulted in below acceptable scores ($\alpha < 0.50$), items were removed to reach acceptable internal consistency. Reliable items for each section were used to calculate mean scores as representative of the measure of each variable, for all individuals (Supplementary Table 1). All scores for all variables were normalized for every participant on a scale from 1 to 10.

Levene's test was used to test homogeneity of variance and Kolmogorov-Smirnov's test was used to test the normality of variance, for sustainability and psychological variables; these analyses were performed using IBM SPSS Statistics v. 22.

Using PRIMER-e v.6 – Quest Research Limited and PERMANOVA+ (Anderson et al., 2008), a first permutational multivariate analysis of variance (PERMANOVA) was carried out with two factors ("location" with 3 levels: Nosy Be, Dhiggiri, Maayafushi; and "time" with 3 levels: T_0, T_1, T_2) based on Euclidean distance and 999 permutations to test the effect of the factor "location" on sustainability variables. A second PERMANOVA with five factors ("time" with 3 levels: T_0, T_1, T_2; "sex" with 2 levels: male, female; "age" with 2 levels: under 40, 40 and over;

"education" with 2 levels: high school diploma, college degree; "nature contact" with 2 levels: naturalist, non-naturalist), based on Euclidean distance and 999 permutations, was carried out to test the effect of participants demographic factors on sustainability variables. Pairwise comparisons were subsequently carried out to investigate the main effects of factor time on sustainability variables.

For interpretation of all PERMANOVA analyses and pairwise comparisons, a threshold value for the average scores of sustainability variables was set to identify statistical significance that also indicated an actual difference in overall environmental education from participation in the Glocal Education project. The threshold for the difference in average scores was set at 0.5, which indicated that at least half of total participants (n = 97) answered at least one additional question correctly, corresponding to a variation of at least +1 in a variable score, in T_1 relatively to T_0 and in T_2 to T_1.

Assumptions for parametric statistics were not met, so Wilcoxon signed-rank test was carried out (IBM SPSS Statistics v. 22) to compare repeated measures of psychological variables for participants in time (T_1, T_2). To test for relations between sustainability variables and psychological variables, Spearman's rank correlation analyses were performed using IBM SPSS Statistics v. 22. Variation for each sustainability variable in time, from T_1 to T_2, was calculated for every participant:

$$\Delta variable = \left(\frac{T_2\ average - T_1\ average}{T_1\ average}\right) \times 100$$

and tested for correlation with psychological variables as described above.

Results

From August 2016 to April 2019, 1851 tourists participated in Glocal Education – Short term study. Of these, a subset of 1192 tourists expressed availability to be re-contacted in the future and were invited to compile the long-term evaluation questionnaire between May 2018 to November 2019. 223 individual responses were received (19% response rate). Incomplete questionnaires were removed, resulting in 194 valid questionnaires for Glocal Education – Long term (GE-LT) analysis, each questionnaire having been compiled by one single participant. The present study focused on the 194 tourists who participated in GE-LT by compiling three valid sequential environmental education questionnaires (T_0, T_1, T_2). Participation was slightly higher among females (n = 111, 57%) compared to males (n = 83, 43%). The overall average age was 43 years old, with the slightly underrepresented age category of under 40 (n = 84, 43%) relatively to 40 and over (n = 110, 57%). The level of education was divided quite equally between participants having up to a high school diploma (n = 100, 52%) and those with a graduate degree or higher (n = 94, 48%). Most participants carried out activities in contact with nature up to once a month (n = 124, 64%) and the minority more than once a month (n = 70, 36%).

Effects on sustainability variables in time

PERMANOVA analyses to test for the effects of factors location and time on sustainability variables showed no interaction between factors ($p > 0.05$; Supplementary Table 2) while there was a significant effect for the factor time on all sustainability variables ($p < 0.01$; Supplementary Table 2). For the factor location, there was no effect on variables knowledge and attitude ($p > 0.05$; Supplementary Table 2), but a significant effect for variable awareness ($p < 0.01$; Supplementary Table 2).

Pairwise comparisons (Supplementary Table 3) showed that awareness scores for Maayafushi (Avg = 9.3, 95% CI = 9.2-9.4) were significantly different from Nosy Be (Avg = 8.9, 95% CI = 8.7-9.1) and Dhiggiri (Avg = 9.0, 95% CI = 8.9-9.1). However, the difference in average scores was below the threshold of 0.5, thus they were not considered meaningful in educational terms. Data from sustainability variables from all locations were aggregated for all following analyses.

Pairwise comparisons showed that all sustainability variables were significantly different ($p < 0.01$) for levels of factor time (T_0, T_1, T_2), except for the variable awareness that showed no significant difference between T_1 and T_2 (Supplementary Table 4).

Knowledge average scores increased from T_0 (Avg = 7.6; 95% CI = 7.4-7.9) to T_1 (Avg = 8.7; 95% CI = 8.6-8.8) and decreased from T_1 to T_2 (Avg = 8; 95% CI = 7.8-8.2), with T_2 scores higher than T_0 scores (Figure 1).

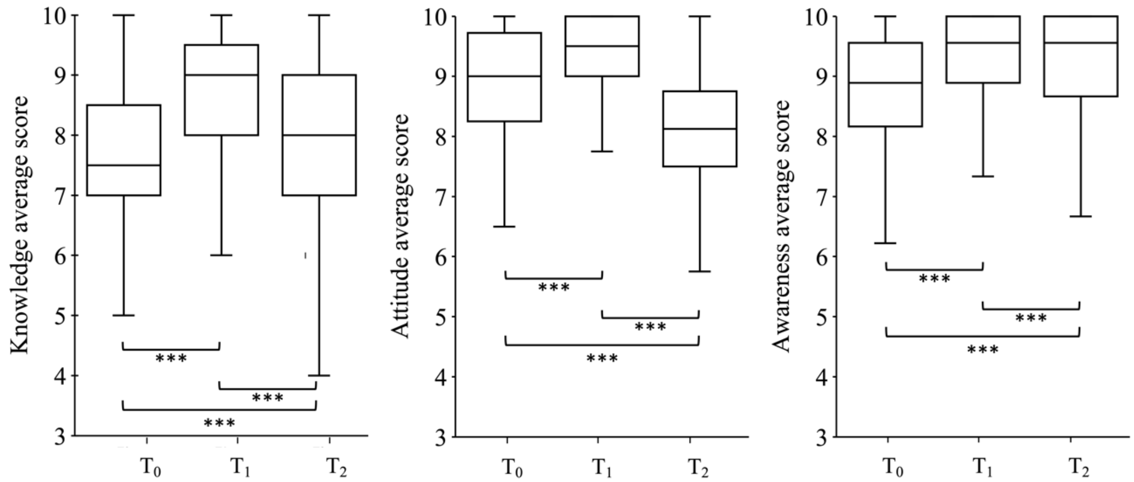

Figure 1. Average scores of sustainability variables (knowledge, attitude, awareness) in time (T_0, T_1, T_2). Brackets with asterisks indicate significant differences between two groups: *** ($p < 0.001$). The box indicates the 25th and 75th percentiles, the line within the box marks the median, and the cross is the average. Whisker length is equal to 1.5 × interquartile range. N = 194.

Attitude average scores increased from T_0 (Avg = 8.9; 95% CI = 8.8-9.0) to T_1 (Avg = 9.4; 95% CI = 9.3-9.5) and decreased from T_1 to T_2 (Avg = 8.1; 95% CI = 8-8.2), with T2 scores lower than T_0 scores (Figure 1). Awareness average scores increased from T_0 (Avg = 8.8; 95% CI = 8.7-8.9) to T_1 (Avg = 9.3; 95% CI = 9.2-9.4) and were not significantly different from T_1 to T_2 (Avg = 9.2; 95% CI = 9.1-9.3) (Figure 1).

The PERMANOVA analysis to test for the effects of demographic factors on sustainability variables showed no interaction between time and any of the demographic factors ($p > 0.05$; Table 1).

Table 1. PERMANOVA test for demographic factors and factor time. Tests were run using Euclidean distances among samples and 999 permutations in the software Primer+PERMANOVA. Significative effects ($p<0.05$) are indicated in bold.

	Knowledge		Attitude		Awareness	
Factor	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p
Time	35766	**0.001**	87837	**0.001**	16703	**0.001**
Sex	62087	**0.012**	0.29328	0.602	23068	0.121
Age	25468	0.135	96361	**0.004**	58306	**0.011**
Edu	15901	**0.001**	0.85084	0.337	0.38406	0.536
Nat	0.14363	0.675	0.13823	0.696	40326	**0.039**
Time x Sex	1369	0.251	0.32893	0.725	0.71503	0.468
Time x Age	0.30922	0.745	0.22683	0.792	15881	0.218

Time x Edu	15499	0.221	17446	0.16	0.21271	0.8
Time x Nat	0.46255	0.636	0.25739	0.792	0.28467	0.766
Sex x Age	25371	0.104	27207	0.123	11794	0.277
Sex x Edu	10148	0.313	0.50348	0.459	0.31044	0.59
Sex x Nat	16935	0.194	0.55182	0.442	0.6251	0.434
Age x Edu	0.53916	0.502	17654	0.166	0.24543	0.643
Age x Nat	7.48	**0.008**	0.30379	0.581	107.38	0.93
Edu x Nat	0.11778	0.733	0.19976	0.648	724.89	0.801
Time x Sex x Age	558.97	0.952	0.12892	0.885	0.16881	0.825
Time x Sex x Edu	0.19867	0.815	0.16121	0.86	15106	0.229
Time x Sex x Nat	0.12759	0.887	0.5919	0.537	0.40413	0.674
Time x Age x Edu	0.23891	0.777	0.77832	0.465	11687	0.265
Time x Age x Nat	0.22737	0.796	0,77011	0.455	588.55	0.944
Time x Edu x Nat	11948	0.287	14537	0.214	0.36744	0.698
Sex x Age x Edu	203.96	0.884	24399	0.12	21227	0.151
Sex x Age x Nat	942.16	0.743	27264	0.101	0.59801	0.42
Sex x Edu x Nat	63028	**0.011**	34643	0.065	45173	**0.031**
Age x Edu x Nat	0.13425	0.714	0.41963	0.519	89.05	0.77
Time x Sex x Age x Edu	0.26343	0.779	0.32579	0.724	0.91012	0.417
Time x Sex x Age x Nat	0.10286	0.904	19094	0.148	0.7476	0.505
Time x Sex x Edu x Nat	0.82229	0.444	0.22631	0.809	0.46871	0.627
Time x Age x Edu x Nat	0.10138	0.902	587.35	0.932	0.39267	0.656
Sex x Age x Edu x Nat	0.15291	0.665	386.91	0.857	40949	**0.039**
Time x Sex x Age x Edu x Nat	0.38767	0.7	0.68597	0.508	12407	0.307

The full analysis of demographic factor effects did not provide clear patterns of interpretation (see Tables S5-S11). Since the effects of factor time were independent of participants' demographics, data from all demographic groups were aggregated.

Relation between sustainability and psychological variables

Wilcoxon signed rank test showed that all psychological variables were significantly different between T_1 and T_2 (Satisfaction $p < 0.001$; Identification $p < 0.001$: Intention $p < 0.001$; Supplementary Table 12).

Spearman's correlation analyses among sustainability and psychological variables within the short term (T_1) and within the long term (T_2) were performed (Figures 2-4, Supplementary Table 13, Supplementary Figures 8 and 9).

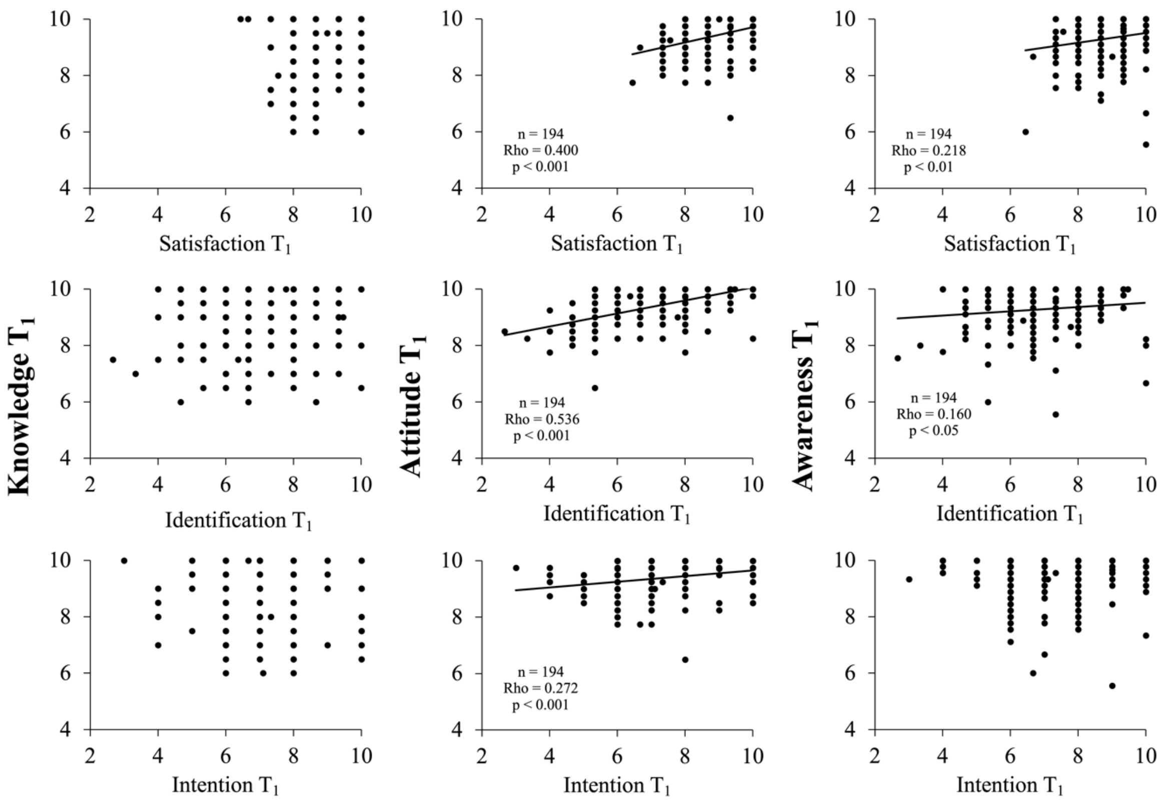

Figure 2. Correlation plots between sustainability variables (knowledge, attitude, awareness) and psychological variables (satisfaction, identification, intention) at T_1. Only significant ($p<0.05$) regressions are drawn. n: number of participants; Rho: Spearman's rank correlation coefficient; p: p-value.

Within both T_1 and T_2 knowledge showed no correlation with any psychological variables ($p > 0.05$; Figures 2 and 3).

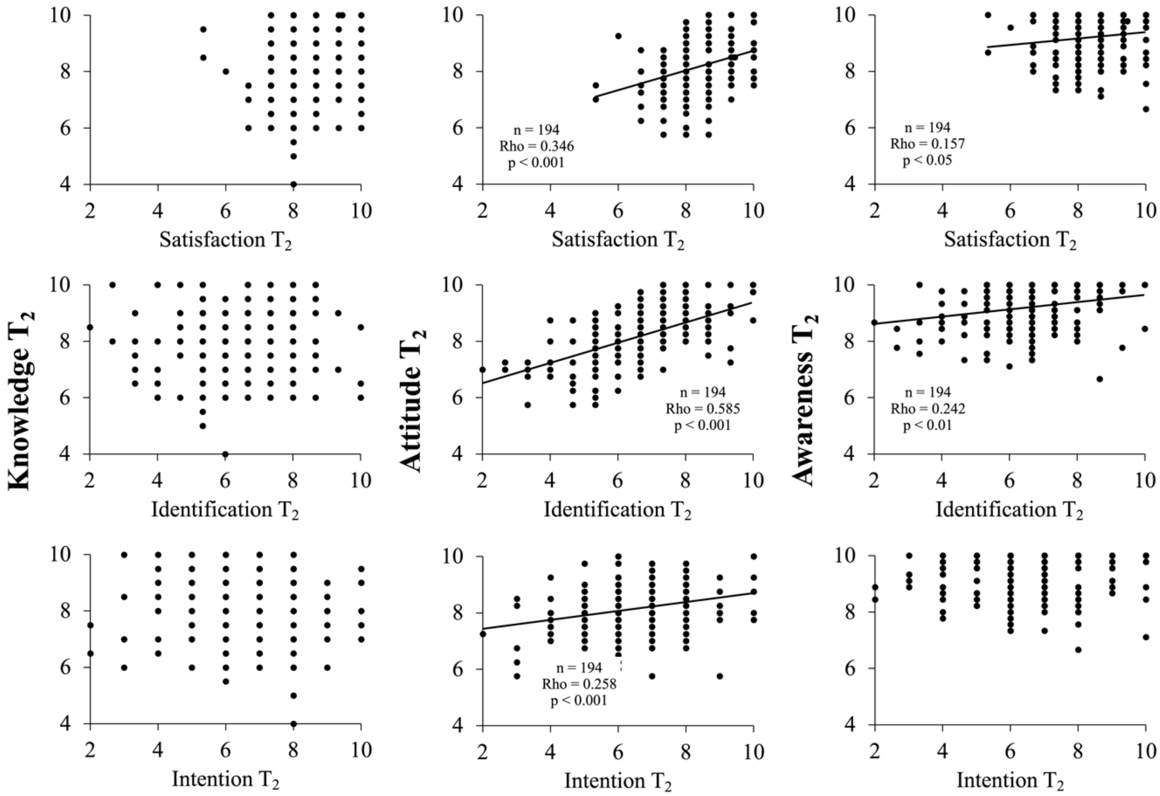

Figure 3. Correlation plots between sustainability variables (knowledge, attitude, awareness) and psychological variables (satisfaction, identification, intention) at T_2. Only significant ($p<0.05$) regressions are drawn. n: number of participants; Rho: Spearman's rank correlation coefficient; p: p-value.

Attitude showed positive correlation with all psychological variables ($p < 0.001$ for satisfaction; $p < 0.001$ for identification; $p < 0.001$ for intention; Figures 2 and 3). Awareness showed positive correlation with two out of three psychological variables ($p < 0.01$ for satisfaction; $p < 0.01$ for identification; Figures 2 and 3).

All sustainability variables at T_2 showed positive correlation with satisfaction measured at T_1 ($p < 0.05$ for knowledge; $p < 0.001$ for attitude; $p < 0.01$ for awareness; Figure 4). Attitude and awareness variables also showed positive correlation with identification at T_1 ($p < 0.001$ for attitude; $p < 0.05$ for awareness; Figure 4).

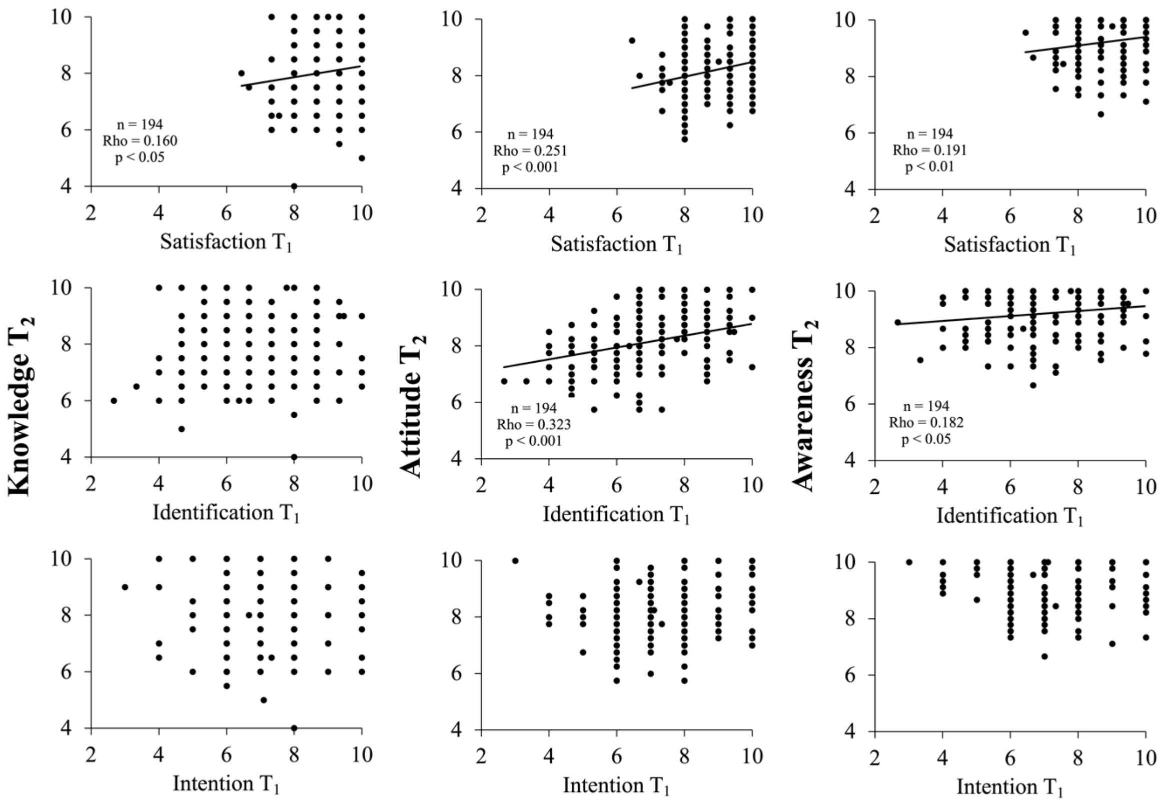

Figure 4. Correlation plots between sustainability variables (knowledge, attitude, awareness) at T_2 and psychological variables (satisfaction, identification, intention) at T_1. Only significant ($p<0.05$) regressions are drawn. n: number of participants; Rho: Spearman's rank correlation coefficient; p: p-value.

The variation of knowledge scores between T_1 and T_2 positively correlates with satisfaction at T_1 ($p < 0.05$; Supplementary Figure 8) and the variation of attitude positively correlates with all psychological variables measured at T_2 ($p < 0.01$ for satisfaction; $p < 0.001$ for identification; $p < 0.01$ for intention; Supplementary Figure 9).

Discussion

The Glocal Education project may contribute to investigating potential outcomes of environmental education activities as learning opportunities in tourism when mediated by an educator figure and inserted within the informal context of a leisure vacation. Previous studies show that positive learning outcomes can derive from participation in tourist activities such as wildlife safaris, whale watching experiences, citizen science projects and aquarium/zoo visits (Ballantyne & Packer, 2011; Branchini et al., 2015; Higginbottom et al., 2009; Hughes et al., 2011). The aim of this study was not to bring tourism impact to a zero, as that would not be possible, but rather create food for thought and sensitize tourists so that gradually, through simple day-to-day actions, the mass tourism impact on local communities may decrease, and hopefully trending towards a more sustainable tourism industry.

Sustainability variable scores (knowledge, attitude, awareness) were the same in the three travel destinations (one in Madagascar and two in the Maldives). This suggested that the same project can be carried out in different locations leading to the same result. A possible bias to this outcome could be that all localities were within tropical ecosystems, and therefore similar amongst them. To address this issue, future studies should test the Glocal Education project in a wider range of locations, such as in the Mediterranean Sea and possibly other temperate environments.

Subsequently, we verified that effects of project participation were equal amongst different demographic groups. Informal education experiences can vary significantly among them, and contrasting information exists regarding learning outcomes for different demographic groups: in some cases, demographics have a significative effect, and in some cases they do not (Rodari, 2009). In the case of Glocal Education, all participants expressed similar learning outcomes, regardless of previous education, gender, age, or nature contact. This implies that everyone can benefit equally from the learning experience provided by Glocal Education and that possible outcomes on environmental perception and sustainable behavior can be achieved equally by all participants.

When evaluating learning experiences, time passed after participation is to be considered as educational outcomes may show up at different times (Falk et al., 2012; Rodari, 2009). Short-term outcomes are the most reported as they are easier to verify, but there are also long-term outcomes that can appear much later or that can have important long-lasting effects (Rodari, 2009). Long-term outcomes are the most difficult to record as they require tracking of individuals over time. However, they are necessary to assess the influence of education over time (Rodari, 2009). In order to verify the long-lasting effects of the Glocal Education project, all sustainability and psychological variables were tested in participants after one year of taking part in Glocal Education activities.

In the short term, knowledge, attitude, and awareness increased compared to pre-participation scores. Being informed with the appropriate notions and taking part in dynamic activities within the natural setting of the location, tourists had more knowledge regarding their surrounding environment and were more aware of environmental issues. Tourists also were more careful to avoid direct harmful and damaging behavior towards the environment and showed a positive attitude in promoting such behaviors with others. From an environmental point of view, this positive result highlights the importance and effectiveness of implementing informal education projects in travel destinations. If our proposed project were to be implemented in a large number of resorts worldwide, the positive short-term outcomes seen for each individual would be multiplied by engaging a large number of participants simultaneously, leading to an overall reduction of environmental impact.

In the long term, knowledge scores decreased to intermediate values compared to pre-project participation and short-term outcomes. In this case, it is probable that acquired concepts about tropical reefs and exotic ecosystems while being of interest to tourists on vacation were forgotten in the long run, being of minor relevance in individuals' daily lives and likely not repeated often once returned home. Long term attitude scores decreased compared to both short-term outcomes and pre-project participation. On the other hand, awareness scores remain stable in time after the increase registered in the short-term indicating that positive outcomes achieved from project participation tied to the emotional components of environmental education are maintained even after one year. Long term outcomes of the Glocal Education project indicate that having knowledge and being aware of environmental issues does not always translate into a more sustainable attitude towards the environment and sustainable actions. This result is in line with social psychology studies indicating that there is a gap between environmental awareness and actual pro-environmental behavior (Hines et al., 1987; Kollmuss & Agyeman, 2002) and highlights how some educational outcomes, such as attitude, may be subject to complex social/emotional factors beyond simple knowledge of environmental facts (Bamberg & Möser, 2007). Behavioral intentions (here, attitude), which in turn shape actions, can be influenced by economic constraints, social pressures and constructs, moral norms, and the opportunity to choose different actions (Bamberg & Möser, 2007; Hines et al., 1987; Steg & Vlek, 2009). The resulting pro-environmental behavior is therefore a mixture of self-interest and pro-social motives, with attitude being one of the many components (Bamberg & Möser, 2007; Kollmuss & Agyeman, 2002; Steg & Vlek, 2009). Another explanation for higher attitude scores before participating in the educational activities and lower scores in the long term, can be found in cognitive dissonance: this social-psychological theory is based on the knowledge that people tend to act consistently with personal beliefs to avoid discomfort (Festinger, 1962; Thøgersen, 2004). The Glocal Education project participation occurred while the tourist was enthusiastic, immersed in a compelling natural environment, and in the presence of the educator figure. Such factors could have influenced individuals to answer the questionnaire according to what they think is the most appropriate answer, as opposed to what they would actually do in that particular situation (Thøgersen, 2004). Furthermore, after one year or more from the vacation, individual initial enthusiasm may have worn off. This reasoning can also be applied to the difference recorded in psychological variables, with higher scores registered in the short term also attributed to direct emotional involvement with the Glocal Education project on location. In the case study of Glocal Education, tourists were fully immersed in an exotic location, which coupled with participation in Glocal Education activities led to an overall boost in environmentally friendly behavior on vacation. Negative effects caused by individual actions were thus reduced while on vacation. However, once returned home, individuals tended to revert to behaviors and habits determined by other external factors such as routine or social constructs, which led to knowledge and attitude declining in long term even when high awareness scores were maintained. Furthermore, because of the lack of reinforcement of the positive outcomes acquired on vacation via subsequent similar learning experiences, immediate effects dissipated in the long term as has been observed in the case of free-choice education activities (Ballantyne & Packer, 2011). For this reason, if activities like those proposed by the Glocal Education project were to be consistently implemented in a greater number of touristic resorts worldwide, tourists would benefit from further reinforcement of previous learning experiences and educational achievements in future vacations.

Correlation analysis showed no relation between knowledge and psychological variables. Attitude and awareness showed a positive relationship with both satisfaction and identification in all tested cases (6 out of 6; Supplementary Table 13). The more participants were satisfied in having participated in the Glocal Education project, and the more they identified with project values, the higher was their awareness of the environment and attitude. This goes in line with previous findings (Meschini, Prati, et al., 2021), indicating that psychological components of educational activities can contribute to greater learning outcomes leading to pro-environmental behavior. In most cases (2 out of 3; Supplementary Table 13) attitude also correlated with the intention to travel with the same tour operator again. From an economic perspective, individuals with higher attitude scores expressed higher intention to travel with the same tour operator again, a strong indication of customer loyalty toward the host who provided the educational program. For these reasons, we propose the implementation of the Glocal Education project to be carried out by the main stakeholder organizations that represent commercial, touristic, and service businesses, travel agents, and tour operators, in mass tourist resorts, since we believe that it could be beneficial from an environmental, social, and economic perspective.

In the case of Glocal Education, these positive correlations found with the psychological components of participating in activities demonstrate the importance of valuing social and emotional aspects of environmental education projects in tourism. Furthermore, participants with higher psychological scores in the long term showed a higher value in attitude after one year. To reinforce positive attitudes to behave sustainably, satisfaction and identification of individuals are therefore important features to consider (Thøgersen, 2004). Since the study analyzed a reduced sample size (194 out of 1851 who initially participated in the project), the observed results could be corroborated by further studies with a larger sample size, achieved through higher engagement of participants on the follow up analysis. Higher tourist engagement can be achieved not only through the development of a user-friendly app, rendering the activities easier and more interactive, but also with the employment of "vacation coupons", discount coupons to be raffled among project participants. GE activities should be adapted to other contexts such as zoos, parks, etc. according to the target audience (children, schools, other touristic facilities), to render the project accessible and efficient in different scenarios.

The tourism industry is a complex and interconnected system, where socioeconomic and environmental interactions and impacts take place over distances (Liu et al., 2019). Hence, a useful tool to analyze the industry as a whole would be through telecoupling, an integrated framework suited to understand the interconnected world and help map possible pathways towards the United Nations' Sustainable Development Goals and other global challenges. Nonetheless, our study had a more limited scope, focusing on educational activities within touristic facilities. Such activities, applied over a larger range of touristic facilities and involving a larger number of participants to mitigate volunteer bias, could in the future present useful to the tourism industry, at which point they could be added to the telecoupling framework. As this is a pilot study, further analyses are required.

It is un-neglectable that global tourism is leaving its ecological and social footprint, and that global actions should be undertaken to promote awareness, educate people, and achieve a meaningful behavioral change towards more environmentally parsimonious ways of life. The rationale behind the Glocal Education project is to provide individuals with an enhanced perception of the environment and related issues to reduce the direct environmental impact caused by tourists while on vacation. The ultimate aim is to improve a localized action that, together with other localized initiatives, can try to contribute to mitigating the global problem of mass tourism impacts on biodiversity and natural landscapes. The present study reported the first outcomes for the Glocal Education project on a limited number of tourist resorts. Thus, the reported data do not allow to discuss or make societal impact projections on a broad spatial scale. In this context, the informal educational activities described here could be applied to different locations and could have a wide outreach, involving a significant number of participants.

Informal education activities are in line with the UN Sustainable Development Agenda and can aid the tourism sector in pursuing this goal on multiple fronts. There is social and educative importance focused on the direct involvement of tourists who gain knowledge, awareness, and positive attitudes regarding sustainable behaviors while on vacation. There is a financial interest for stakeholders, such as tour operators, who can benefit from increased competitiveness by hosting environmentally friendly programs and becoming more appealing to customers. In addition, maintaining ecosystem integrity by reducing impact guarantees continuous natural appeal in the long term for tourists, and therefore a continuous economic return for the tourism sector. Finally, by tailoring Glocal Education to the reality of touristic facilities, tourists can address environmental and biodiversity issues, thus engaging in sustainable behavior not only while on vacation, but also upon returning home.

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Supplementary material

Date__________________

ENVIRONMENTAL EDUCATION EVALUATION QUESTIONNAIRE

SECTION A - The personal data collected through the questionnaire is to be used only for scientific research purposes and will be treated anonymously.

FULL NAME: ______________________________________ GENDER: M ☐ F ☐

BIRTH YEAR: ___________________________ NATIONALITY: ____________________

ADDRESS:____

E-MAIL: ____

EDUCATION: ☐ Elementary School Diploma ☐ High School Diploma ☐ Undergraduate Degree ☐ Master's Degree ☐ PhD

HAVE YOU EVER VISITED THIS DESTINATION BEFORE? ☐ Yes ☐ No

HOW OFTEN DO YOU TAKE PART IN NATURE-RELATED ACTIVITIES?

☐ Up to 3 times a year ☐ At least once a month ☐ Up to 3 times a month ☐ At least once a week ☐ More than once a week

Figure 1 SM. Demographical data section, present in questionnaire T_0.

SECTION B - For each of the following sentences choose "true" (T), "false" (F) or "I don't know" (DK)

	T	F	DK
1. Corals are animals			
2. Whale sharks are mammals (DH, MY) / Chameleons change color according to temperature, light, and their mood (NB)			
3. Freshwater use needs to be limited in the Maldives (DH, MY) / in Madagascar (NB)			
4. Even when wild animals seem harmless and friendly, it is best to avoid touching them			
5. Sea turtles are amphibians (DH, MY) / Madagascar's flora and fauna are threatened by long periods of drought (NB)			
6. The purchase of souvenirs or direct harvesting of coral reef organisms (such as shells, sea stars, etc.) is harmful to the coral reef			
7. Coral reefs are threatened by sea tides and marine predators (DH, MY) / The flowers of the vanilla orchid wilt after one day if not pollinated (NB)			
8. Despite being an herbivore, the parrot fish is one of the biggest contributors to sand formation (DH, MY) / Lemurs are considered at risk of extinction (NB)			
9. Feeding animals can help them survive			
10. My touristic activity impacts the environment only through direct contact with the nature that surrounds the destination I am visiting			

Figure 2 SM. Knowledge section of questionnaires T_0, T_1 and T_2 for the localities of Dhiggiri (DH), Maayafushi (MY), the Maldives, and Nosy Be (NB), Madagascar.

SECTION C – For each of the following statements, please indicate to what degree you would be willing to:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
11. Attend nature-related lectures					
12. Touch wildlife during excursions					
13. Advise others to dispose of waste responsibly					
14. Advise my close ones to not waste water					
15. Participate in excursions with the Glocal Education biologists					
16. Take home souvenirs made from natural resources					
17. Advertise the Glocal Education initiative to others					
18. Get to know the ecosystems on the destinations I visit					

Figure 3 SM. Attitude section of questionnaires T_0, T_1 and T_2 for all 3 localities.

SECTION D - For each of the following sentences, please indicate the answer best corresponding to your opinion. During excursions:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
19. I feel guilty in touching the animals					
20. I feel I act responsibly by not taking sand home as a souvenir					
21. I feel comfortable feeding the animals					
22. I feel I act responsibly by not feeding the animals					
23. I feel guilty in taking sand home as a souvenir					
24. I feel comfortable touching the animals					
25. I feel guilty in feeding the animals					
26. I feel I act responsibly by not touching the animals					
27. I feel comfortable in taking sand home as a souvenir					

Figure 4 SM. Awareness section of questionnaires T_0, T_1 and T_2 for all 3 localities.

SECTION E - Please indicate in what measure you agree with the following statements:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
28. The Glocal Education activities have met my expectations					
29. I feel my ideas are respected by the Glocal Education project group					
30. I feel satisfied with having participated in the Glocal Education initiative					
31. I'm happy to be a participant in the Glocal Education project					

Figure 5 SM. Satisfaction section of questionnaires T_1 and T_2 for all 3 localities.

SECTION F - Please indicate in what measure you agree with the following statements:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
32. When I talk about the ideas of the Glocal Education project, I use "us" and not "them"					
33. I am proud to consider myself a supporter of the Glocal Education project					
34. When someone speaks ill of the Glocal Education or similar project, it is as if they did it to me					
35. I share the ideas behind the Glocal Education project					

Figure 6 SM. Identification section of questionnaires T_1 and T_2 for all 3 localities.

SECTION G - Please indicate in what measure you agree with the following statements:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
36. When choosing the tour operator for my next vacation, I will check for the presence of an environmental education project					
37. I will go on vacation with Francorosso again next year					
38. I will go on vacation with Francorosso again over the next 3 years					

Figure 7 SM. Intention section of questionnaires T_1 and T_2 for all 3 localities.

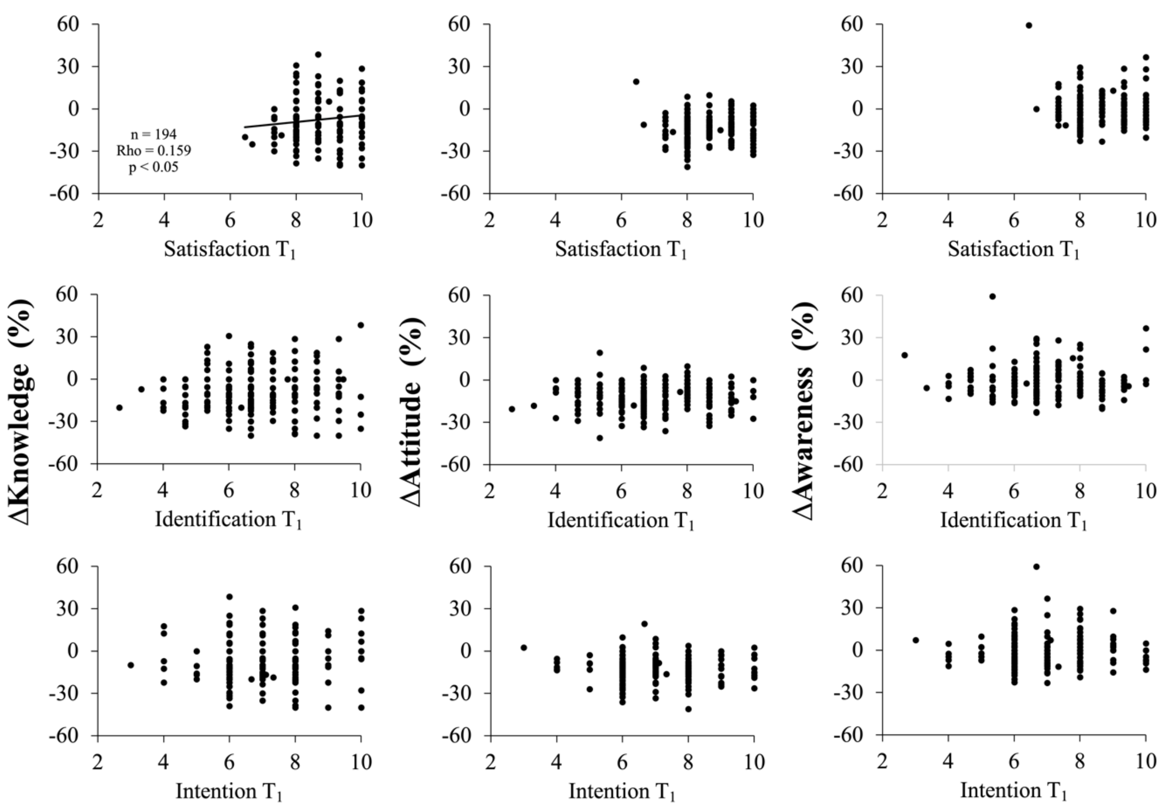

Figure 8 SM. Correlation plots between percent variation (Δvariable %) of sustainability variables (knowledge, attitude, awareness), calculated as in paragraph 2.3, and psychological variables (satisfaction, identification, intention) at T1. Only significant ($p<0.05$) regressions are drawn. n: number of participants; Rho: Spearman's rank correlation coefficient; p: p-value.

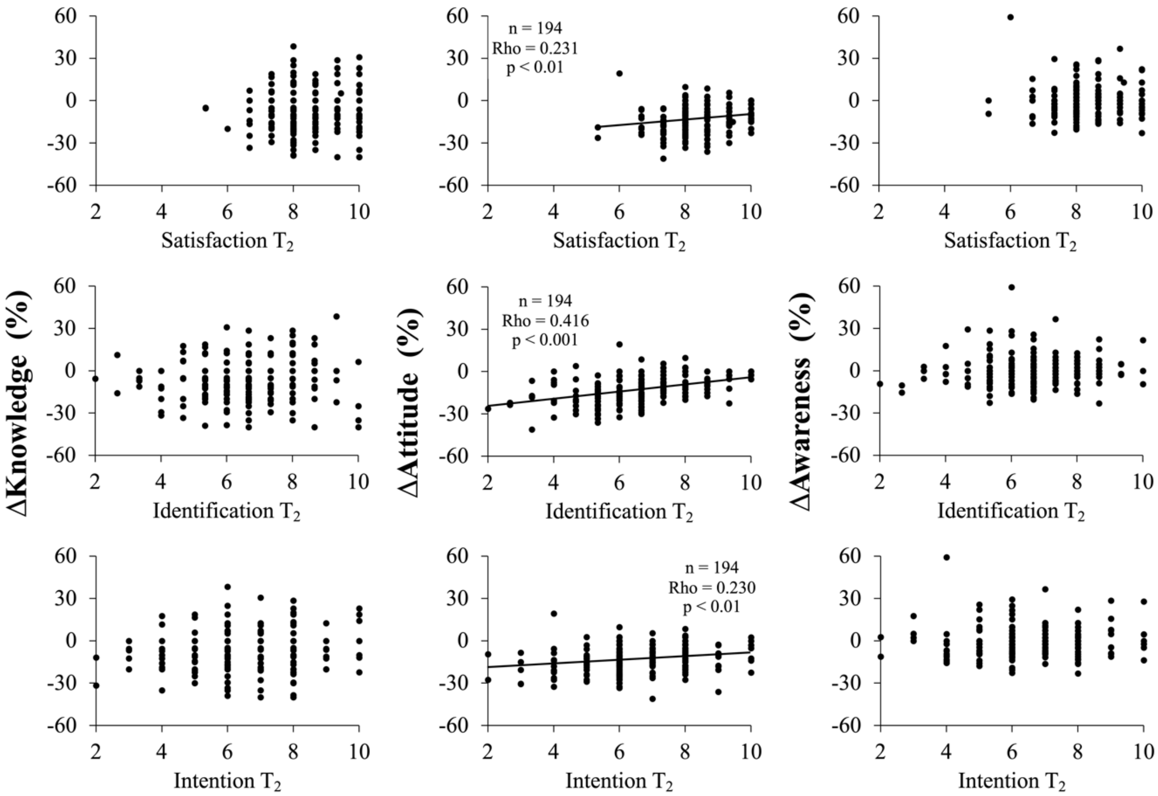

Figure 9 SM. Correlation plots between percent variation (Δvariable %) of sustainability variables (knowledge, attitude, awareness), calculated as in paragraph 2.3, and psychological variables (satisfaction, identification, intention) at T_2. Only significant ($p<0.05$) regressions are drawn. n: number of participants; Rho: Spearman's rank correlation coefficient; p: p-value.

Table 1 SM. List of items from the environmental education evaluation questionnaire with corresponding values of Cronbach's α for each measure of the variable in time.

Variable	Item number	Item	Reliable items	Cronbach's α[c] T_0	T_1	T_2
Attitude	11	Attend nature-related lectures	x[a]	0.534	0.688	0.567
	12	Touch wildlife during excursions	(r)[b]			
	13	Advise others to dispose of waste responsibly	x[a]			
	14	Advise my close ones to not waste water	x[a]			
	15	Participate in the excursions with the Glocal Education biologists	x[a]			
	16	Take home souvenirs made from natural resources	(r)[b]			
	17	Advertise the Glocal Education initiative to others	x[a]			
	18	Get to know the ecosystems on the destinations I visit	x[a]			
Awareness	19	I feel guilty in touching the animals	x[a]	0.740	0.743	0.722
	20	I feel I act responsibly by not taking sand home as a souvenir	x[a]			
	21	I feel comfortable feeding the animals	(r) [b]			
	22	I feel I act responsibly by not feeding the animals	x[a]			
	23	I feel guilty in taking sand home as a souvenir	x[a]			
	24	I feel comfortable touching the animals	(r) [b]			
	25	I feel guilty in feeding the animals	x[a]			
	26	I feel I act responsibly by not touching the animals	x[a]			
	27	I feel comfortable in taking sand home as a souvenir	(r) [b]			
Satisfaction	28	The Glocal Education activities have met my expectations	x	NA	0.701	0.706
	29	I feel my ideas are respected by the Glocal Education project group	x[a]			
	30	I do not feel satisfied with having participated in the Glocal Education initiative	(r)[b]			
	31	I'm happy to be a participant in the Glocal Education project	x[a]			
Identification	32	When I talk about the ideas of the Glocal Education project, I use "us" and not "them"	x[a]	NA	0.694	0.675
	33	I am proud to consider myself a supporter of the Glocal Education project and the like	x[a]			
	34	When someone speaks ill of the Glocal Education or similar project, it is as if they did it to me	x[a]			
	35	I do not share the ideas behind the Glocal Education project	(r)[b]			
Intention	36	When choosing the tour operator for my next vacation, I will check for the presence of an environmental education project		NA	0.658	0.679
	37	I will go on vacation with Francorosso again next year	x[a]			
	38	I will go on vacation with Francorosso again over the next 3 years	x[a]			

a. Reliable items.
b. Reverse items, formulated in negative phrasing, reversed scored for analysis.
c. Acceptable scores: Cronbach α > 0.50.

Table 2 SM. PERMANOVA[a,b] analyses testing the effect of factors location and time on sustainability variables (knowledge, attitude, awareness).

	Knowledge		Attitude		Awareness	
Factor	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p
Location	0.352	0.706	19425	0.142	82376	0.002
Time	33975	0.001	97472	0.001	14158	0.001
Location x Time	24354	0.051	14763	0.198	0.894	0.460

a. Tests were run using Euclidean distances among samples and 999 permutations.
b. Significative effects ($p < 0.05$).

Table 3 SM. Pairwise comparison[a] among locations for the variable awareness.

Variable	Pairwise-comparison	t	p
Awareness	Nosy Be vs Dhiggiri	0.67998	0.492
	Nosy Be vs Maayafushi	3243	0.001
	Dhiggiri vs Maayafushi	35976	0.001

a. Significative comparisons ($p < 0.05$) are indicated in bold.

Table 4 SM. Pairwise comparison[a] among times (T_0: before GE activities; T_1: short term after GE activities; T_2: long term after GE activities) for all sustainability variables (knowledge, attitude, awareness).

Variable	Pairwise-comparison	t	p
Knowledge	T_0 vs T_1	83218	0.001
	T_0 vs T_2	3022	0.003
	T_1 vs T_2	51729	0.001
Attitude	T_0 vs T_1	4673	0.001
	T_0 vs T_2	86764	0.001
	T_1 vs T_2	13584	0.001
Awareness	T_0 vs T_1	46358	0.001
	T_0 vs T_2	42616	0.001
	T_1 vs T_2	0.4	0.705

a. Significative comparisons ($p < 0.05$) are indicated in bold.

PERMANOVA analysis to test for the effects of demographic factors and factor time on sustainability variables showed no interaction between time and any of the demographic factors ($p > 0.05$) for all tested variables (Table 2), therefore the effect of factor time on all variables was independent from demographic categories. Significant interaction terms were found amongst demographic factors. Pairwise comparisons were conducted on significant interactions in the case of knowledge and awareness, and for the single demographic factor age in the case of attitude. Average scores were compared to interpret results.

For the variable knowledge, significant demographic effects were found for the interacting terms Sex x Education x Nature contact ($p < 0.05$, Table 2) and Age x Nature contact ($p < 0.001$, Table 2).

Pairwise comparisons (Supplementary Table 4 & 5) and respective comparisons of average scores (Supplementary Table 6 & 7) revealed that 7 out of 12 cases were non-significative ($p > 0.05$), and amongst significative cases (5 out of 12, $p < 0.05$) there were no clear patterns among demographic groups.

Table 5 SM. Pairwise comparisons[a] of knowledge scores for interacting factors Sex x Education x Nature contact.

Pairwise Comparison	t	p	Unique permutations
Male vs Female	Within College, Non naturalists		
	2989	0.001	993
	Within College, Naturalists		
	0.89828	0.361	993
	Within High school, Non naturalists		
	13664	0.171	999
	Within High school, Naturalist		
	25148	0.016	987
High school vs College	Within Males, Non naturalists		
	40692	0.001	996
	Within Males, Naturalists		
	10831	0.287	996
	Within Females, Non naturalists		
	820	0.928	996
	Within Females, Naturalists		
	29722	0.005	996
Non Naturalist vs Naturalist	Within Males, College		
	0.22924	0.814	998
	Within Males, High school		
	16724	0.102	996
	Within Females, College		
	10503	0.304	997
	Within Females, High school		
	22881	0.018	994

a. Significant comparisons ($p < 0.05$) are indicated in bold.

Table 6 SM. Pairwise comparisons[a] of knowledge scores for interacting factors Age x Nature contact.

Pairwise Comparison	t	p	Unique permutations
Under 40 vs Over 40	Within Non naturalists		
	0.98094	0.341	998
	Within Naturalists		
	26467	0.009	994
Non naturalist vs Naturalist	Within Over 40		
	24318	0.019	996
	Within Under 40		
	16368	0.107	998

a. Significant comparisons ($p < 0.05$) are indicated in bold.

Table 7 SM. Knowledge average score divided by levels of the interacting factors Sex x Education x Nature contact with the 95% Confidence Interval (CI).

Demographic group	N	Average	95% CI
Male, College, Non naturalist	78	8.5	8.3-8.7
Male, College, Naturalist	36	8.6	8.2-9.0
Male, High School, Non naturalist	81	7.7	7.4-8.1
Male, High School, Naturalist	54	8.3	8.0-8.6
Female, College, Non naturalist	111	8.0	7.8-8.3
Female, College, Naturalist	57	8.3	8.0-8.6
Female, High School, Non naturalist	102	8.1	7.8-8.3
Female, High School, Naturalist	63	7.7	7.4-8.1

Table 8 SM. Knowledge average score divided by levels of the interacting factors Age x Nature contact with the 95% Confidence Interval (CI).

Demographic group	N	Average	95% CI
40 and Over, Non naturalist	189	8.0	7.8-8.2
40 and Over, Naturalist	141	8.3	8.1-8.5
Under 40, Non naturalist	183	8.1	8.0-8.3
Under 40, Naturalist	69	7.8	7.6-8.1

For the variable attitude, the effect of factor Age ($p < 0.01$, Table 2) was analyzed by comparing average scores amongst demographic groups (Supplementary Table 8). While the factor age was statistically significant, difference in average scores was below the set threshold (0.5), therefore there was no actual educational effect.

Table 9 SM. Attitude average scores divided by levels of the factor age with the 95% Confidence Interval (CI).

Demographic group	N	Average	95% CI
Under 40	252	8.7	8.6-8.8
40 and Over	330	8.9	8.8-9.0

For the variable awareness, significant demographic effects were found in the interacting terms Sex x Age x Education x Nature contact ($p < 0.05$, Table 2) and therefore were analyzed within pairwise comparison (Supplementary Table 9) and comparison of average scores (Supplementary Table 10). 28 out of 32 cases were non-significative ($p > 0.05$) and among significant cases (4 out of 32, $p < 0.05$) there were no clear patterns for demographic effects on the variable awareness.

Table 10 SM. Pairwise-comparisons[a] of awareness scores for interacting factors Sex x Age x Education x Nature contact.

Pairwise Comparison	t	p	Unique permutations
Male vs Female	Within Over 40, College, Non naturalists		
	0.4851	0.646	986
	Within Over 40, College, Naturalists		
	0.88471	0.367	989
	Within Over 40, High school, Non naturalists		
	19.935	0.045	981
	Within Over 40, High school, Naturalists		
	1.565	0.127	977
	Within Under 40, College, Non naturalists		
	7.05E+01	0.924	976
	Within Under 40, College, Naturalists		
	12.437	0.231	960
	Within Under 40, High school, Non naturalists		
	1.469	0.151	987
	Within Under 40, High school, Non naturalists		
	18.347	0.07	968
Under 40 vs Over 40	Within Males, College, Non naturalists		
	0.58347	0.545	996
	Within Males, College, Naturalists		
	12.993	0.211	938
	Within Males, High school, Non naturalists		
	0.93964	0.36	954
	Within Males, High school, Non naturalists		
	10.354	0.275	977
	Within Females, College, Non naturalists		
	14.479	0.143	964
	Within Female, College, Naturalists		
	0.78517	0.444	971
	Within Female, High school, Non naturalists		
	0.89913	0.369	989
	Within Female, High school, Non naturalists		
	27.001	0.015	980
	0.87074	0.422	991
	Within Males, Under 40, Naturalists		
	10.826	0.302	972
	Within Females, Over 40, Non naturalists		
	0.18963	0.838	963

a. Significant comparisons ($p < 0.05$) are indicated in bold.

Table 10 SM *(cont)***.** Pairwise comparisons[a] of awareness scores for interacting factors Sex x Age x Education x Nature contact.

Pairwise Comparison	t	p	Unique permutations
High school (or lower) vs College	Within Males, Over 40, Non naturalists		
	0.63195	0.493	988
	Within Males, Over 40, Naturalists		
	10.342	0.323	990
	Within Males, Under 40, Non naturalists		
	0.87074	0.422	991
	Within Males, Under 40, Naturalists		
	10.826	0.302	972
	Within Females, Over 40, Non naturalists		
	0.18963	0.838	963
	Within Females, Over 40, Naturalists		
	0.43989	0.646	988
	Within Females, Under 40, Non naturalists		
	0.99123	0.317	986
	Within Females, Under 40, Naturalists		
	21.637	0.038	979
Non naturalist vs Naturalist	Within Males, Over 40, College		
	0.88559	0.347	982
	Within Males, Over 40, High school		
	0.76272	0.457	978
	Within Males, Under 40, College		
	0.17822	0.868	990
	Within Males, Under 40, High school		
	20.209	0.052	977
	Within Females, Over 40, College		
	10.531	0.304	988
	Within Females, Over 40, High school		
	0.77979	0.462	990
	Within Females, Under 40, College		
	21.294	0.043	959
	Within Females, Under 40, High school		
	12.393	0.229	986

a. Significant comparisons ($p < 0.05$) are indicated in bold.

Table 11 SM. Attitude average scores divided by levels of the interacting factors Sex x Age x Education x Nature contact

Demographic group	N	Average	95% CI
Male, Over 40, College, Non naturalist	45	9.1	8.7-9.4
Male, Over 40, College, Naturalist	27	9.3	9.0-9.5
Male, Over 40, High School, Non naturalist	54	8.9	8.7-9.2
Male, Over 40, High School, Naturalist	42	9.1	8.8-9.3
Male, Under 40, College, Non naturalist	33	8.9	8.6-9.2
Male, Under 40, College, Naturalist	9	8.9	8.0-9.7
Male, Under 40, High School, Non naturalist	27	8.7	8.4-9.1
Male, Under 40, High School, Naturalist	12	9.4	8.9-9.9
Female, Over 40, College, Non naturalist	24	9.2	8.8-9.6
Female, Over 40, College, Naturalist	30	9.4	9.2-9.6
Female, Over 40, High School, Non naturalist	66	9.2	9.0-9.4
Female, Over 40, High School, Naturalist	42	9.4	9.1-9.6
Female, Under 40, College, Non naturalist	87	8.9	8.7-9.1
Female, Under 40, College, Naturalist	27	9.3	9.0-9.6
Female, Under 40, High School, Non naturalist	36	9.1	8.8-9.4
Female, Under 40, High School, Naturalist	21	8.8	8.4-9.2

Table 12 SM. Average scores calculated for psychological variables (satisfaction, identification, intention) with the 95% Confidence Interval (CI) in each time (T_1, T_2), followed by Wilcoxon's test statistics[a] (Z).

Variable	Time	N	Average score	95% CI	Z	p
Satisfaction	T_1	194	8.7	8.6-8.8	-4.541	0.000
	T_2	194	8.3	8.2-8.5		
Identification	T_1	194	7.0	6.8-7.2	-3.563	0.000
	T_2	194	6.6	6.3-6.8		
Intention	T_1	194	7.0	6.8-7.2	-4.324	0.000
	T_2	194	6.5	6.3-6.7		

a. Significant comparisons ($p < 0.05$) are indicated in bold.

Table 13 SM. Spearman's rank correlation[a,b] analysis between sustainability variables (knowledge; attitude; awareness) and psychological variables (satisfaction; identification; intention).

Sustainability variables	n	Psychological variables					
		Satisfaction T_1		Identification T_1		Intention T_1	
		Rho	p value	Rho	p value	Rho	p value
Knowledge T_1	194	0.002	0.973	-0.011	0.877	-0.059	0.414
Attitude T_1	194	0.400	0.000	0.536	0.000	0.272	0.000
Awareness T_1	194	0.218	0.002	0.160	0.026	-0.006	0.933
		Satisfaction T_2		Identification T_2		Intention T_2	
		Rho	p value	Rho	p value	Rho	p value
Knowledge T_2	194	0.058	0.421	0.110	0.125	0.042	0.565
Attitude T_2	194	0.346	0.000	0.585	0.000	0.258	0.000
Awareness T_2	194	0.157	0.028	0.242	0.001	0.114	0.113
		Satisfaction T_1		Identification T_1		Intention T_1	
		Rho	p value	Rho	p value	Rho	p value
Knowledge T_2	194	0.160	0.026	0.096	0.185	0.005	0.947
Attitude T_2	194	0.251	0.000	0.323	0.000	0.097	0.180
Awareness T_2	194	0.191	0.008	0.182	0.011	0.042	0.562
		Satisfaction T_1		Identification T_1		Intention T_1	
		Rho	p value	Rho	p value	Rho	p value
ΔKnowledge (%)	194	0.159	0.027	0.098	0.174	0.081	0.261
ΔAttitude (%)	194	0.062	0.389	0.019	0.787	-0.051	0.482
ΔAwareness (%)	194	0.024	0.740	0.022	0.757	0.018	0.803
		Satisfaction T_2		Identification T_2		Intention T_2	
		Rho	p value	Rho	p value	Rho	p value
ΔKnowledge (%)	194	0.008	0.917	0.068	0.348	0.106	0.141
ΔAttitude (%)	194	0.231	0.001	0.416	0.000	0.230	0.001
ΔAwareness (%)	194	0.046	0.521	0.073	0.312	0.080	0.269

a. Variation of sustainability variables (Δvariable %) calculated as in paragraph 2.3.
b. Statistically significant correlations ($p < 0.05$) in bold.

General conclusions

Extreme weather events, particularly unexpected increases in rainfall, can have profound and lasting effects on both urban and natural ecosystems. Urban areas face immediate challenges such as flooding and landslides, which can disrupt infrastructure, displace communities, and pose risks to public safety. These challenges necessitate quick responses from local authorities to mitigate damage and ensure recovery. On the other hand, natural ecosystems struggle to maintain their delicate balance in the face of such disturbances. The accelerated rate of climate change exacerbates these extreme weather events, often preventing ecosystems from recovering adequately between occurrences. The interconnected physicochemical properties of these ecosystems can trigger a cascade effect, putting the survival of its inhabitants at risk and creating consequences that reverberate through the entire socioecological system that depends on them.

Coastal lagoons, in particular, are highly vulnerable to extreme rainfall events, which can drastically alter habitat conditions and disrupt ecological functions. For instance, decreases in salinity levels, increases in turbidity due to sediment runoff, and elevated oxygen saturation can create stressful environments for aquatic species, destabilizing established biological communities. Such prolonged changes can lead to significant biodiversity loss and the collapse of essential ecological processes that sustain both flora and fauna. Furthermore, the influx of pollutants during extreme weather events can accumulate within these ecosystems, impairing ecological health, disrupting food webs, and threatening the survival of native species. As resilience wanes, ecosystems become more susceptible to further disturbances, creating a precarious situation that necessitates urgent action. Therefore, adopting sustainable management strategies, conducting long-term ecological monitoring, and promoting interdisciplinary collaboration are essential steps toward enhancing resilience and safeguarding biodiversity in the face of changing climatic conditions.

To create effective management plans, engaging stakeholders is paramount. Participatory management enables diverse groups with different interests in a particular ecosystem to collaborate in developing management strategies that address a wide array of potential risks and opportunities. Although challenges such as stakeholder distrust may arise, their insights can significantly enhance conservation efforts by complementing scientific data with local knowledge and experiences. By leveraging the insights of all stakeholders, we can create robust management strategies that not only protect ecosystems but also foster community involvement and economic growth. It is essential for decision-makers to prioritize collaboration with local stakeholders, who often possess valuable insights into ecosystem dynamics and can contribute to extensive monitoring efforts that provide a clearer picture of environmental health.

Furthermore, continuous monitoring and availability of information is paramount for ecosystem management. Real live data monitoring that is available and free for all allows for perceiving subtle changes within an ecosystem, as well as encouraging stakeholders to learn more about the ecosystem they live in, and potentially prompt collaborative actions. To this end, stakeholders can aid in continuous monitoring of ecosystems for evaluation and adaptation of management plans through citizen science initiatives. The potential for citizen science to bolster ecosystem monitoring efforts is substantial. Engaging a variety of stakeholder groups facilitates long-term, large-scale monitoring that is crucial for anticipating and adapting to environmental changes. Contributions from local fishermen, for instance, can offer invaluable perspectives on fish populations and habitat health, providing critical insights into the viability of environmental management plans. These collaborative approaches can be adapted globally, serving as effective tools for local governments and research institutions in conjunction with traditional monitoring methods.

Finally, stakeholders' perception regarding environmental issues and the attractiveness of ecosystems like Mar Menor is crucial when developing management plans. In the case of the Mar Menor, an ecosystem heavily dependent on tourism revenue, when poorly planned, tourism can have detrimental effects on the environment, but well-managed tourism also has the potential to generate significant revenue that can fund conservation efforts. Therefore, it is vital to engage stakeholders from the tourism sector in the design of management plans to ensure that both economic viability and environmental protection are prioritized. This collaborative approach can enhance the likelihood of successful implementation and promote a sustainable balance between conservation and tourism development. Investing in environmental education activities can foster a more sustainable tourism, by creating awareness among stakeholders, emphasizing the need for action and seeking to promote long-lasting action changes that might prompt beneficial behavior.

The goal is not to eliminate tourism impacts entirely, as this is not possible, but to raise awareness and encourage sustainable practices among tourists, thereby reducing negative effects on local communities.

In summary, developing effective management plans to support both people and ecosystems is a challenging task. However, by leveraging various tools and fostering collaboration among society, academia, and governments, progress can be achieved. Continuous monitoring involving researchers and stakeholders through citizen science, along with environmental awareness campaigns that utilize informal education, can help bridge gaps. Together, these efforts can create a shared understanding that enables society to advance while ensuring ecosystems can withstand the impacts of climate change.

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