This publication is part of PTQ2020-011287, funded by MCIN/AEI/10.13039/501100011033 and by the European Union NextGenerationEU/PRTR.

ECOAZUL - MED

Report on Socioeconomic Impacts of Future Climate Conditions on Aquaculture, Fisheries, and Coastal Tourism in the Spanish Mediterranean Coast

ALBA DE LA VARA

This publication is part of PTQ2020-011287, funded by MCIN/AEI/10.13039/501100011033 and by the European Union NextGenerationEU/PRTR.

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1. Introduction

The **Mediterranean region** is considered by the scientific community as a hotspot of climate change because it provides an amplified warming signal (Giorgi, 2006). Additionally, this region is very prone to the development of extreme weather events (e.g., atmospheric and marine heatwaves, heavy precipitation). In the coming decades, climate models project an increase in the frequency and/or intensity of these events (Darmaraki et al., 2019; González-Alemán et al., 2019; IPCC, 2019). These factors make the densely populated Mediterranean coasts, such as the Spanish eastern coastline, susceptible to experience negative impacts on the blue economy, with the concomitant socioeconomic losses. It is worth noting that the blue economy is an essential source of wealth and prosperity for the Mediterranean, providing opportunities for growth, employment, and investments. Therefore, the development of a strategic vision for sustainable development, as well as ensuring policies and actions aimed at promoting the blue economy, are of vital importance in the current context of climate change.

Specifically, **aquaculture, fishing, and tourism** are relevant sectors of the blue economy due to their contribution to social and economic development along the Spanish Mediterranean coastline. Currently, the availability of solid and reliable information derived from systematic research on the economic impact of climate change on the **blue economy** is limited. In this regard, the only available tool to obtain such information is through climate models used to make projections of future climate. The ECOAZUL-MED project **aims** to generate, for the first time, a publicly accessible web tool providing climate information from high spatial resolution regional coupled climate simulations. This tool will enable the anticipation of the effects of climate change on aquaculture, fishing, and tourism, assuming different emission scenarios for the next 40 years along the Spanish Mediterranean coast. This will allow the provision of relevant climate information to companies, public administration, and other stakeholders for planning these economic activities. It will also highlight the need for innovation in these sectors for their adaptation to climate change in the coming decades along the Spanish coast, which is fundamental for ensuring their sustainable development.

It is important to emphasize the relevance of considering in this type of analysis the use of integral approaches that not only encompass scientific-technical environmental elements but also are framed within a proper study of relevant social, economic, and contextual characteristics (Colantonio, 2009) to estimate the effects that such projections may have and assist in the subsequent decision-making process (see Figure 1). **This report presents the results of the potential socio-economic effects of a series of future climatic conditions by stakeholders from the three study sectors: aquaculture, fishing, and coastal tourism. The climatic conditions are derived from the analysis of climate data conducted within the framework of the ECOAZUL-MED project, in the preparation of graphical material for its subsequent inclusion in the tool.**

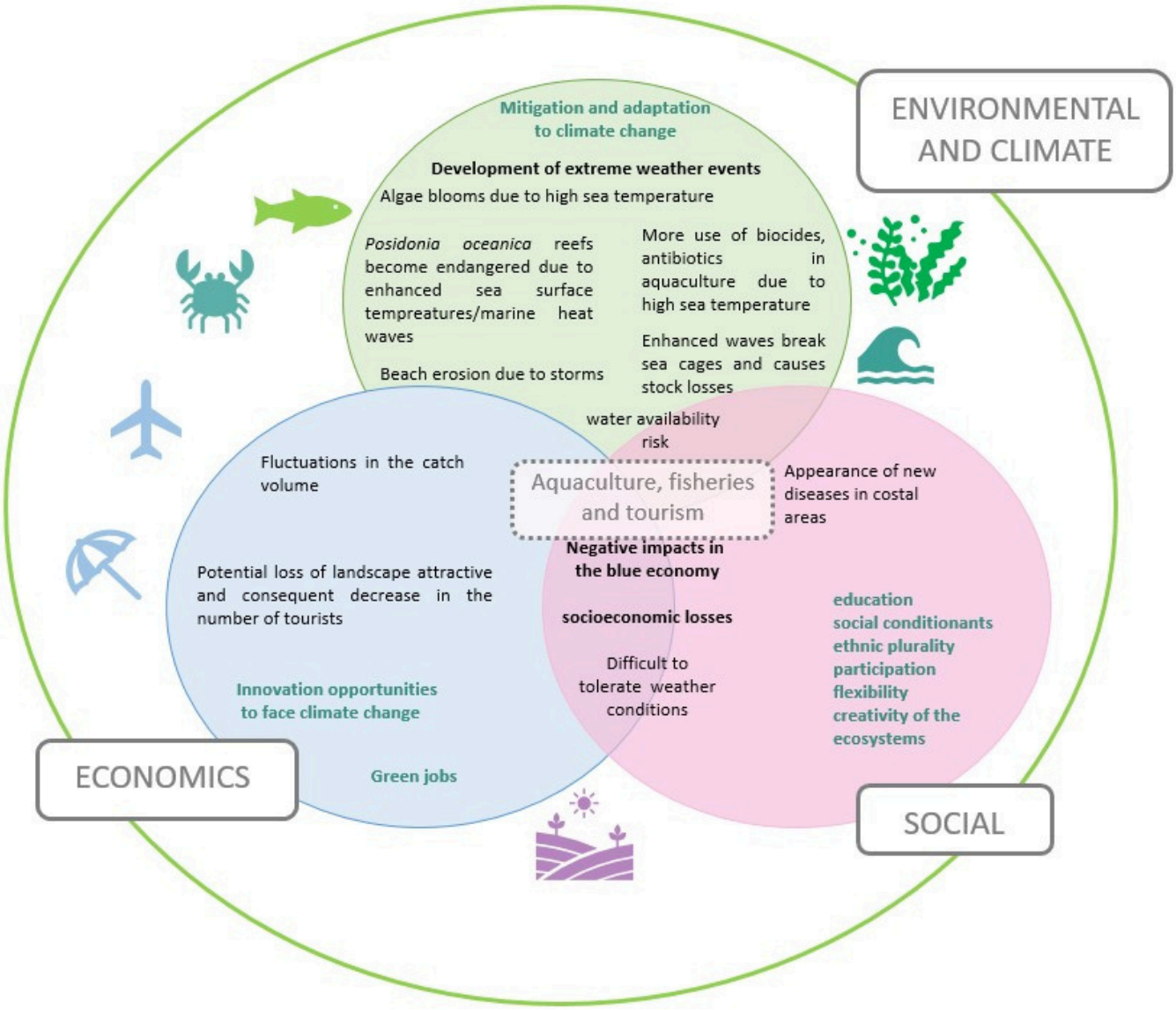

Figure 1. Integral approach of the ECOAZUL-MED Project

2. Methodology

In order to gather the opinions of relevant stakeholders from the three sectors, found in a preliminary phase of mapping and identification, a battery of online questionnaires was designed using the Jotform program. In this study, the **Delphi method** was employed, which is a projective technique involving the interrogation of stakeholders through successive questionnaires, aiming to reveal convergences of opinions and deduce potential agreements. The objective of using this technique was to understand the possible socio-economic impacts of future climate conditions derived from the preliminary results of the tool by stakeholders associated with aquaculture, fishing, and coastal tourism along the Spanish Mediterranean coast.

The first questionnaire was general and common to all sectors—although participants were asked to specify the sector to which they are linked to analyze the responses according to their profile. This questionnaire consisted of two differentiated blocks of questions. The first block was quantitative, where participants assigned scores to certain climate conditions based on their potential socio-economic impacts (1: no negative impact expected, 5: significant impact expected). A second qualitative block was included, where participants assigned scores to certain

climatic conditions based on their potential socio-economic impacts (1: no negative impact expected, 5: significant impact expected). In this second qualitative block, participants briefly explained the possible socio-economic impacts associated with a series of future climate conditions, the quantification of which was deduced from the results obtained in the project.

The questionnaires for the second round (one for each sector) aimed to establish consensus on those issues where there was disagreement in the scores assigned in the quantitative block of the first questionnaire, or to understand the reasons for such divergences. To achieve this, before drafting the questionnaires for this second round, the responses given in the previous questionnaires were analyzed in detail, considering there was a discrepancy in cases where the scores given to the impacts of a particular climatic condition showed a difference of 3 or more points. In the questionnaires for the second round, for each of the sectors, the quantitative questions where there was a discrepancy were taken into account so that participants could re-score them, explaining their reasons afterward. Besides, an additional qualitative question was added concerning the potential impact of climate conditions on aspects such as employment or gender gap.

The surveys had the participation of 13 stakeholders, of which 5 belong to the coastal tourism sector, 4 to the aquaculture sector, and 4 to the fishing sector. Of these, 10 completed the second round of surveys, which was sufficient to understand the divergences in the results obtained or to reach an agreement. The results derived from the surveys, both general and for each of the sectors, are described below.

3. General Results

In this section, we briefly analyze the scores assigned by participants from the three sectors to the different future climate conditions derived from our analyses (Figures 2-4). Starting with the case of **aquaculture**, there are two variables with a score equal to or greater than 4, indicating they are perceived as potentially harmful to the sector (details will be provided in specific results). These variables are the speed of marine currents and the increase in sea-surface temperature (Figure 2). In the following cases, there was no consensus in the first round, while in the second round, consensus was reached, or the information provided by the participants was sufficient to understand the causes of such discrepancies:

- Increase in the number of heatwave episodes over land: discrepancies, which persist in the second round, revolve around the possibility of these episodes affecting the sea-surface temperature or not (depending on their geographical location). It is mentioned that if they affect the sea surface, the warming would cause an increase in temperature, which could negatively affect farmed species that do not withstand large temperature changes. Additionally, over land, it is mentioned that it would entail higher energy expense for controlling water temperature in tanks and negatively affect product transportation by road, which is quite sensitive.

- Increase in the number of days with summer-like conditions in spring and autumn: in the second round, there is still no consensus due to a division of opinions among participants. Some consider it will have little effect, while others presume it could affect species behavior and reproduction, altering their life cycle (advancing it, delaying it, or causing unsuitable conditions for reproduction).

- Increase in the frequency of heavy precipitation: Consensus is reached after the second round. Participants indicate that this could complicate logistics, with its effect on production being minor since any resulting changes in salinity would be short-lived and, therefore not harmful to cultivated species. However, there could be a negative impact on offshore farms near rivers due to runoff. Onshore installations might experience flooding and power outages, which could potentially pose a problem.

- Decrease in relative humidity over land: Consensus is reached in the second round, with participants generally indicating it will have little effect.

- Decrease in sea-surface salinity: There is no consensus in the second round mainly because it is considered to have little effect on aquaculture operations overall, as the decrease would need to be significant for it to matter. However, it is mentioned that it would negatively impact farmed bivalves, as their stability would be compromised, and they typically thrive in high salinity conditions.

For the **fishing sector**, the change perceived as most detrimental is an increase in sea surface-temperature. In addition to this factor, other changes perceived as potentially negative (score equal to or greater than 4) include an increase in maximum air temperature, especially in summer; in sea-surface temperature; in heatwaves; in days with summer-like conditions in autumn and spring; and changes in the salinity, direction, and speed of marine currents (Figure 3). In this case, the conditions regarding which there was no consensus in the first round are:

- Increase in the frequency of heavy precipitation: Consensus is reached in the second round, with participants mentioning that, although heavy precipitation may have an indirect impact on fishing, it is not one of the main factors influencing it. However, there is some difficulty in quantifying the associated impact.

- Decrease in relative humidity over land: Consensus is reached, although participants highlight the difficulty in evaluating the impact of this factor.

- Decrease in sea-surface salinity: Consensus is reached, with participants mentioning that it could affect marine currents.

In the case of **coastal tourism**, an increase in maximum air temperature during summer and an increase in heatwave episodes, also during this season, are considered the climatic conditions that could have the greatest negative impact on the sector (Figure 4). In this case, the conditions regarding which there were some discrepancies in the first round of questions are:

- Increase in the number of days with summer-like conditions in spring and autumn: In this case, it is suggested that it could be beneficial for the sector to allow the extension of the tourist season. However, there is one participant who gave a score of 4.

- General decrease in precipitation: Consensus is reached in the second round. It is highlighted that it could even be positive for the sector by allowing tourists to enjoy the beach, as long as there is enough water available for urban-tourist supply.

- Increase in the frequency of heavy precipitation: Consensus is reached, and it is mentioned that if the tourist towns are not prepared to handle this type of rainfall (structural measures in the urban pattern: SDUS, nature-based solutions, etc.), this could be a significant problem.

- Increase in sea-surface temperature: After the second questionnaire, there are still some discrepancies. On one hand, it is mentioned that it is closely related to the increase in tropical nights, which could have some negative consequences. On the other hand, some consider it neutral. Further details regarding this aspect will be developed in specific results.

From these results, it can be concluded that the increase in temperature (of the air and/or the sea) is considered a factor that could lead to negative socio-economic impacts in all sectors.

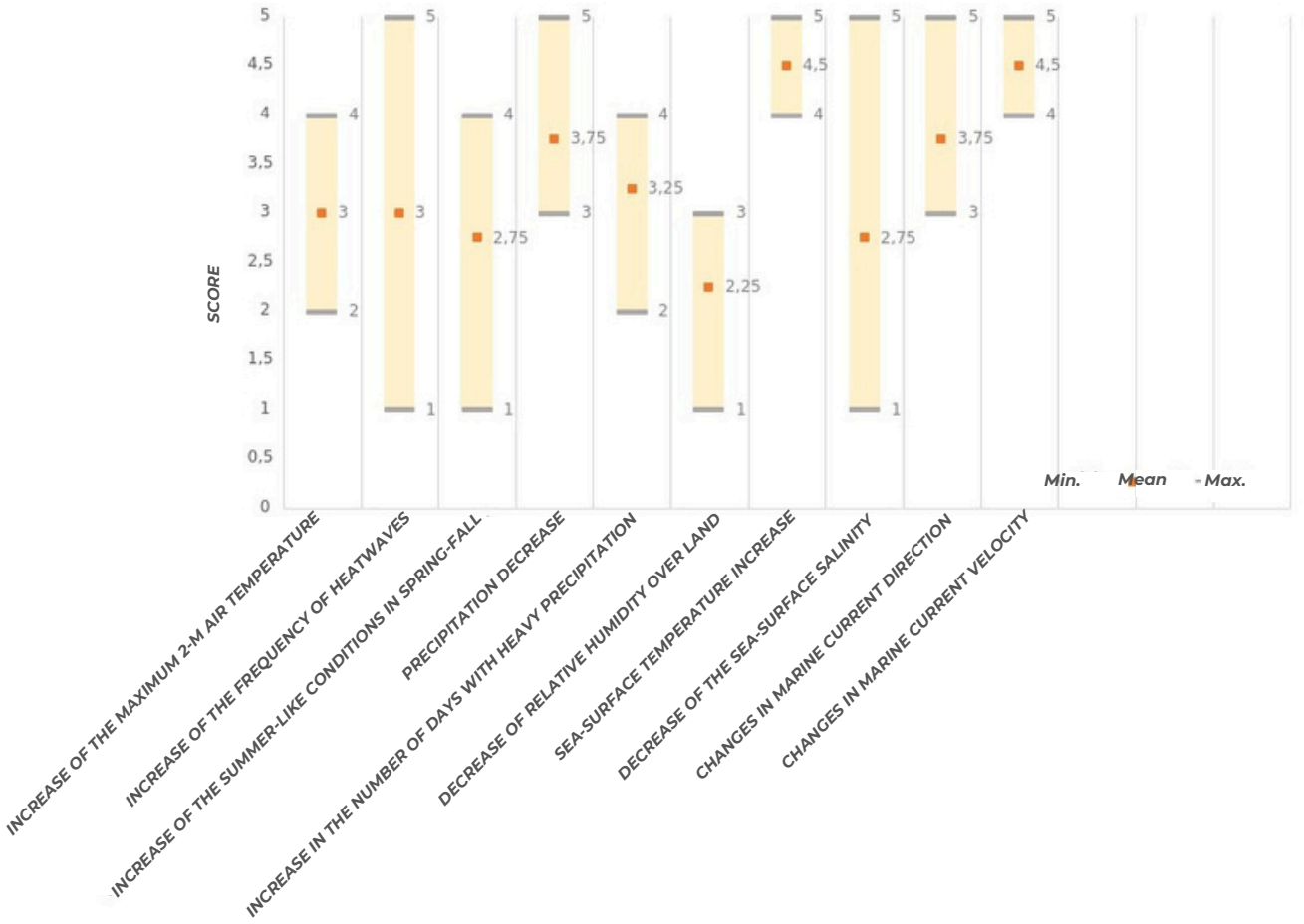

Figure 2. Scores assigned by stakeholders from the aquaculture sector to different climatic conditions based on expected socio-economic impacts (1: no negative impacts expected; 5: very negative impacts expected). The average score is shown with an orange dot, while the maximum and minimum values found are shown at the corresponding ends in gray.

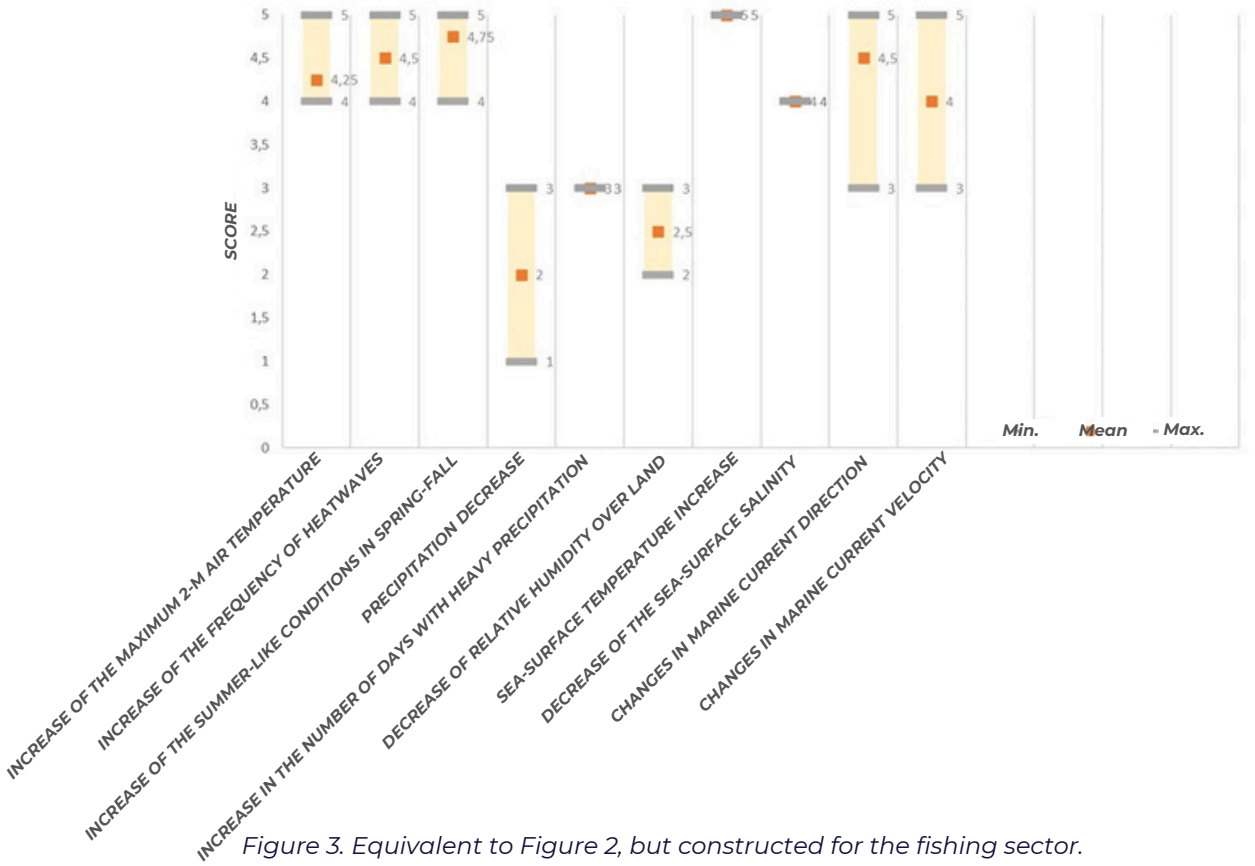

Figure 3. Equivalent to Figure 2, but constructed for the fishing sector.

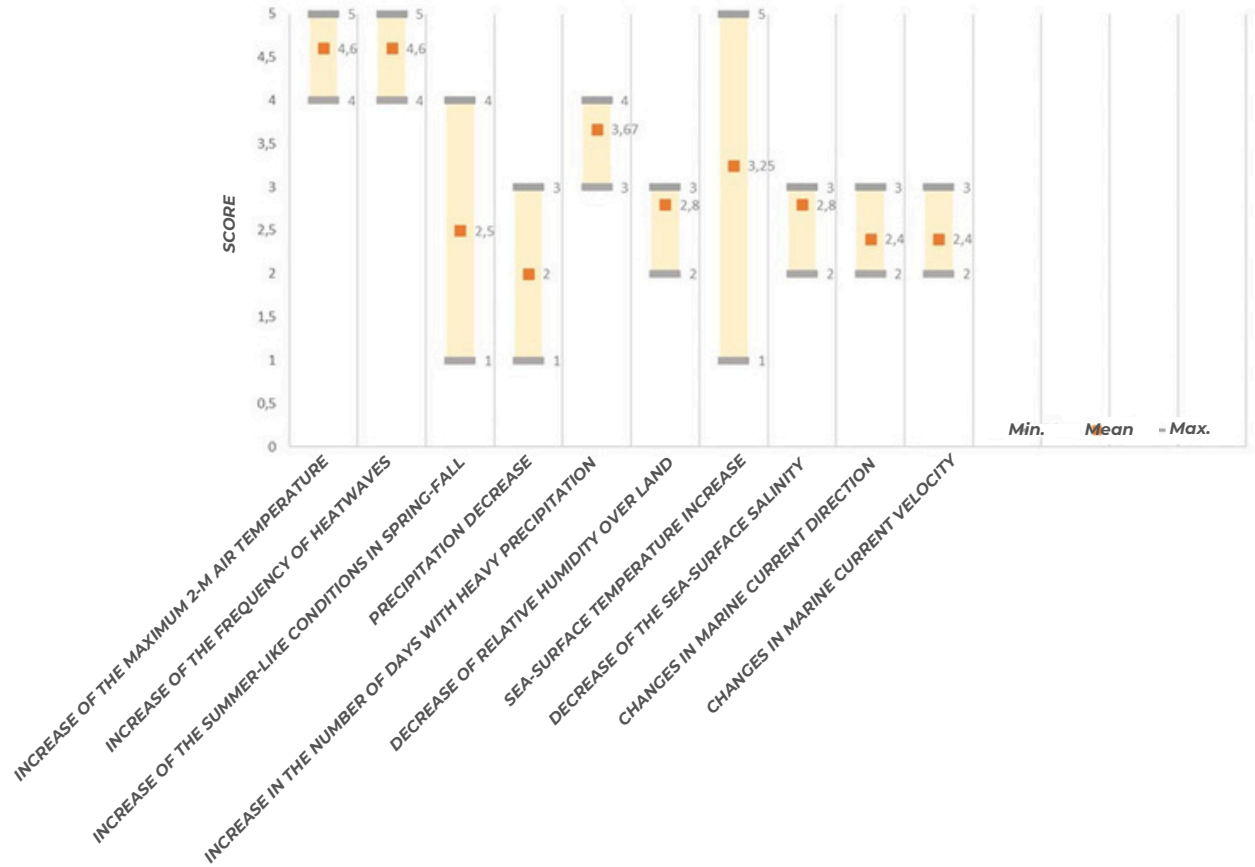

Figure 4. Equivalent to Figures 2 and 3, but constructed for the tourism sector.

4. Specific Results

In this section, we elaborate on the potential socio-economic impacts (positive or negative) that the described climatic conditions could have on each sector in the coming decades, as outlined in the questionnaires.

4.1. Aquaculture Results

- **An increase in the maximum daily air temperature of 1-3.5°C in summer.**

Although the air temperature would not have a direct effect on aquaculture, indirectly, the warming of the sea surface could affect fish reproductive physiology, increase the occurrence of pathological events, etc. Additionally, some species may not tolerate this change, rendering them unsuitable for cultivation.

- **An increase in the number of days of land heatwaves by 5 to 40 days in summer.**

Similar effects to those mentioned in the previous point would be expected. Additionally, during extreme temperature episodes, oxygen levels in the water could decrease. This could increase mortality rates in cultivated species that cannot withstand such temperature increases.

- **An increase in the number of days with summer-like conditions (daily maximum temperature exceeding 25°C) in spring or autumn by 2 to 16 days.**

Individuals may experience slower growth as they invest their energy in coping with this change rather than increasing biomass. Effects similar to heatwaves could be observed, potentially affecting water flow and oxygen levels.

- **An increase in the number of days of heavy precipitation in all seasons (2-4% per season).**

This could lead to a higher risk of flooding and problems in continental aquaculture facilities. Additionally, it could interfere work in the marine environment (feeding, maintenance, etc.) and potentially increase damage to cages and marine facilities. It could also induce changes in salinity, which could affect the physiology of cultivated species.

- **An increase in sea-surface temperature of between 0.8 to 3°C in summer.**

The rise in sea temperature has opposing effects. On one hand, it could promote fish growth. On the other hand, it could alter the physicochemical conditions of the water, for example, by reducing the concentration of dissolved oxygen, which affects the fish's ability to metabolize and assimilate food. The thermocline would be very pronounced, leading to poor nutrient exchange, resulting in inadequate food reaching the cultivated species (e.g., in bivalve cultures). Additionally, the temperature rise could lead to an increase in some pathogen populations, promoting infectious and parasitic diseases. Although it is difficult to assess the overall net effect, it is clear that it will occur.

- **An increase in the number of days of marine heatwaves by 10 to 70 days in summer.**

Similar effects to those of the previous point would be expected, but more severe, especially if the heatwave has a longer duration, as this would result in sustained temperature increases.

- **A decrease in sea surface salinity of up to 0.8 ‰.**

Variations of this magnitude in salinity would have little effect on the cultivated species currently being cultivated in marine installations.

Do you think that the future climatic conditions highlighted in the surveys could have an impact on aspects such as employment or the gender gap?
Climate change is the major challenge facing the sector. Its effects on marine aquaculture developed along our coasts would be mainly direct due to:
- Increasingly extreme weather conditions in the sea: currents, waves, winds, etc.
- The rise in sea temperature and its effects on oxygen, and pathologies.
Indirectly due to:
- The global impact on plant productions used in feed manufacturing, such as soybeans, corn, etc.
Poor animal health could lead to economic losses due to mortalities or illnesses, resulting in losses and the closure of companies. Jobs would be lost, and they would need to be adapted to the new climate situation to maintain them. Regarding the gender gap, it might be an indirect problem deriving from the aforementioned job losses.

4.2. Fishing Results

- **An increase in the maximum daily air temperature by 1-3.5°C in summer.**

This implies an increase in sea temperature, which would cause alterations in marine ecosystems and changes in the behavior of target species for fishing fleets, which would move to deeper waters. It could displace migratory species both spatially and temporally (such as tuna, swordfish, albacore, etc.), making the proper management of resources more difficult. Additionally, it would negatively affect the conservation of catches on board vessels during the journey to port, leading to increased costs.

- **An increase in the number of days of land heatwaves by 5 to 40 days in summer.**

This fact would have a quick impact on the sea, and therefore, the same consequences mentioned in the previous section.

- **An increase in the number of days with summer-like conditions (daily maximum temperature exceeding 25°C) in spring or autumn by 2 to 16 days.**

It could change the temporal distribution of commercial fish stocks. Currently, there are good fishing seasons in spring and at the end of summer or the beginning of autumn. This temperature range would be reduced, directly affecting distribution and catches.

- **An increase in the number of days of heavy precipitation in all seasons (2-4% per season).**

This would directly impact the reproduction of species dependent on freshwater inputs (rivers), such as sardines and anchovies, therefore altering their spawning and consequently, the entire cohort of these species.

- **An increase in sea surface temperature of between 0.8 to 3°C in summer.**

This could change species distribution, increasing populations of some species while decreasing others, making proper resource management more challenging. It would affect bluefish species that inhabit the surface layer of the sea; an increase in this range could directly impact their presence or absence in traditional fishing grounds for species like horse mackerel, mackerel, sardines, anchovies, and tunas.

- **An increase in the number of days of marine heatwaves by 10 to 70 days in summer.**

This would lead to a rise in sea temperature, causing alterations in marine ecosystems and changes in the behavior of target species for fishing fleets, which may move to deeper waters. It could change species distribution, again increasing populations of some while decreasing others, complicating resource management. Likely, species typically found in our fishing grounds would relocate to other areas to maintain their optimal temperature range. Additionally, it would negatively affect the conservation of catches on board vessels during the journey to port, resulting in increased costs.

- **A decrease in sea surface salinity of up to 0.8‰.**

This could potentially alter marine ecosystems and change species behavior. Salinity levels could affect marine species, both commercially valuable and those comprising the broader ecosystem. It is possible that species currently thriving in the current salinity ranges might migrate to areas with higher salinity.

Do you think that the future climate conditions highlighted in the surveys could have an impact on aspects such as employment or gender gap?

Climate conditions always have an impact. In any case, fishing is affected by multiple factors: energy costs, consumption habits, competition, lack of generational turnover, overfishing, etc. Climate change is affecting the types of species caught. Conditions change and fish alter their habits. This has benefited certain fisheries, for example, with the increase in white shrimp in certain areas of the Mediterranean, while others have been disadvantaged. There is no perceived relationship between the gender gap and climate conditions.

4.3. Tourism Results

- **An increase in the maximum daily air temperature by 1-3.5°C in summer.**

It could cause a loss of thermal comfort, leading to increased use of air conditioning and changes in the times when residents and tourists enjoy the destination. Additionally, it could lead to a shift in destination preferences among foreign tourists, reducing the flow of tourists and therefore the demand for the service sector.

- **An increase in the number of days of land heatwaves by 5 to 40 days in summer.**

Initially, it would generate a loss of thermal comfort, which could lead to potential rejection of destinations affected by frequent and intense heat waves by tourists. In this regard, some individuals, for health reasons (possible increase in mortality) or thermal comfort, may change the time when they take their vacations to the destination.

There would be an increase in the use of air conditioning in all spaces, which would imply higher expenses and a potential increase in solar energy to cope with the increased expenses for this reason.

- **An increase in the number of days with summer conditions (daily maximum temperature exceeding 25°C) in spring or autumn, ranging from 2 to 16 days.**

In this case, the impacts would be positive as it would increase thermal comfort in spring or autumn, and it would also improve it in winter. This could extend the tourist season towards the extremes (June, September-October), improving deseasonalization.

- **An increase in the number of days of intense precipitation in all seasons (2-4% per season).**

This could potentially be negative if destinations do not implement adaptation measures to prevent flooding. Destinations should therefore adjust their resilient management and have plans to adapt to extreme weather events. Communication (warnings) for tourists regarding this type of situation should be managed so that they are aware of the circumstances and the danger of these extreme events, to avoid accidents and tragedies. This could also have a negative impact on infrastructure and the quality of water and coastal sands.

- **An increase in the sea surface temperature of between 0.8 to 3°C in summer:**

Initially, in the tourism sector, the increase in sea-surface temperature would not be problematic for the comfort of tourists. However, if that temperature generates problems in local flora and fauna, or deteriorates the bathing water quality, those problems would eventually affect tourists. In particular, this could cause greater harm in the case of foreign tourists, who might prefer other destinations (e.g., Riviera Maya, Mexico). It could also lead to a loss of thermal comfort due to an increase in tropical nights.

- **An increase in the number of days of marine heatwaves between 10 and 70 days in summer.**

Similarly to the previous case, this could lead to a change in destination preference by foreign tourists and discomfort among visitors. Likewise, tourists would not perceive it as negative unless there are changes in the quality of bathing water, biodiversity in the area, etc.

- **A decrease in the salinity of the sea surface by up to 0.8 ‰.**

As in previous responses, tourists would not perceive this as negative unless it affects marine ecosystems, etc.

Do you think that the future climate conditions highlighted in the surveys could have an impact on aspects such as employment or the gender gap?

Negative effects can be mitigated if destinations and the tourism sector itself implement adaptation measures. In this sense, destinations should minimize the impact that the negative effects of climate change may have and take advantage of those that could have "positive" results to extend the tourist season and the daily stay of tourists on the beach. To minimize negative effects, urban and architectural design measures would be necessary in destinations. These measures should be implemented in the short term because the process of climate change, for now, is unstoppable.

5. Conclusions

This analysis highlights that climate conditions greatly influence the sustainable development of these economic activities, and adaptation is key to achieving it. For the three sectors (aquaculture, fishing, and tourism), the **increase in temperature**, either of the air and/or the sea, is perceived as the factor with the greatest potential to lead to negative socio-economic impacts.

In particular, in **aquaculture**, the increase in sea temperature could, on the one hand, promotes the growth of fish. However, on the other hand, it could alter the physico-chemical conditions of the water, affecting the ability of fish to metabolize and assimilate food. Additionally, the temperature rise could lead to an increase in some pathogen populations, favoring infectious and parasitic diseases. Although it is difficult to assess the overall net effect, it is clear that it will have an impact. Furthermore, changes in marine currents' velocity are perceived as a factor that could have negative socio-economic consequences. The impacts of climate on marine aquaculture are both direct (e.g., increase in sea temperature, hydrodynamics) and indirect (e.g., global impact on plant productions used in feed manufacturing, such as soybeans, corn, etc.). Therefore, there may be jobs that potentially would be lost, and efforts would be needed to adapt them to the new climatic conditions to sustain them over time.

In **fishing**, an increase in sea-surface temperature could alter the distribution of species, increasing the populations of some and decreasing others, therefore complicating the proper management of resources. This would affect species of bluefish that move in the surface layer of the sea, directly impacting their presence or absence in usual fishing grounds for species such as mackerel, sardines, anchovies, and tunas. In addition to temperature, other factors perceived as particularly negative would be changes in marine currents' direction, velocity, or salinity. Although fishing is affected by numerous factors (e.g., energy costs, consumption habits, competition, lack of generational turnover, or overfishing), climate change is affecting the types of species caught. This has favored or disadvantaged (and will continue to do so in the future) fisheries depending on specific observed changes. Therefore, climate will indeed have a potential impact on Mediterranean fisheries.

In **coastal tourism**, the increase in temperature is perceived as negative as it would lead to a loss of thermal comfort, which could result in a possible reduction in tourist influx to destinations affected by frequent and intense heatwaves. Additionally, some individuals, for health reasons (possible increase in mortality) or thermal comfort, would change the timing of their vacations at the destination. The use of air conditioning would increase, leading to higher expenses. In this context, destinations should minimize negative impacts and "take advantage" of those that could be "positive" to extend the tourist season. Adaptation measures by destinations are considered crucial to maintain the sustainability of the coastal tourism sector.

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7. Acknowledgments

AEI, MCIN, NextGenerationEU, PRTR

Equipo Kveloce

Florence Sevault (CNRM)

Laurent Li (Laboratoire de Météorologie Dynamique, IPSL)

Giovanni Zizzi (Centro Euro-Mediterraneo sui Cambiamenti Climatici, CMCC)

Dmitry Sein (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, AWI)

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