

**Name of the MPA- VULNERABILITY ASSESSMENT**



**MPA ENGAGE**

<Insert name of the author>

Version <Insert number>

<Insert date>

IDENTIFICATION

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| --- | --- | --- | --- |
| **Project Number** | 5MED18\_3.2\_M23\_007 | **Acronym** | MPA-ENGAGE |
| **Full title** | MPA Engage: Engaging Mediterranean key actors in Ecosystem Approach to manage Marine Protected Areas to face Climate change | | |
| **Axis** | 3.2: To maintain biodiversity and natural ecosystems through strengthening the management and networking of protected areas | | |
| **Partner Responsible** | <Insert name> | | |
| **Contact Person** | <Insert name> | | |

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# Summary

[ 1-page. Present a one-page summary of the main points included in your report, including the settings and the main results of the vulnerability assessment.]

# Introduction of (*name of the MPA*)

[1.5 pages. Provide a description of the Marine Protected Area including its general characteristics (area, protection status, history), its main features (species and habitats), its management regulations and the local socio-economic context. Depict also the users whose activities are performed in the MPA (all, not constrained to the vulnerability assessment)*.* Include evidence (if any) of climate change impacting the MPA or other threats.]

# Scope of the Vulnerability assessment

[3-pages approx. Describe the intention and scope of the Vulnerability Assessment presented in this report.]

The present vulnerability assessment evaluates the habitats, species, uses and management of the MPA in the face of climate change future impacts. The analysis focuses on the MPA social-ecological vulnerability, which considers the ecological sustainability under climate change as well as the vulnerability of the MPA uses. The units of analysis are the MPAs, and we also include information about species groups and habitats, as well as user groups. However the analysis is based on indicators and groups of species, habitats and users, and is not spatially explicit (although it could be transformed to be, for example based on species distribution or habitats and human uses).

## Defining the units of analysis

A co-development process was initiated within the project and guided by UVIGO to identify the units of analysis. From each MPA, we provided information about the habitats, species and user groups at the local scale, as well as on their interactions this process started with several questionnaires done to managers, and interactions during the training of vulnerability and the following exercises. The process started in January 2020, within the context of the MPA-Engage project that helped provide guidance and expert support from the rest of the consortium. A series of regular meetings and training events facilitated the development of the approach and the data collection process. The MPAs provided all the inputs for the quantification of the indicators that were then processed by UVIGO partners, who developed the tool where we can calculate our results and interpret them and improve them.

The **objective** of the vulnerability assessment is to have a useful tool to evaluate the MPA risks and performance confronting these climate change impacts and help in the design of adaptation plans. THe specific objectives are: 1) to understand ecological and socio-ecological vulnerability in the MPA; 2) to identify the species at risk and the habitats most vulnerable; 3) to identify the user groups that are most vulnerable in the MPA ;4) to identify key vulnerability factors that can be improved to decrease vulnerability in the future. At the same time, the results of the vulnerability assessment can be used for dissemination purposes and awareness raising.

The assessment focuses on the four groups of species that we have identified during the development of the vulnerability approach: endangered species, fished species, flag species and invasive species. The hazards we focus on are the increase in maximum Sea Surface Temperature (SST99) over the periods of 2050 and 2100 and the increase in Marine heat Waves (MHW) intensity over the same period, based on model projections over three scenarios of low (RCP2.6), medium (RCP4.5) and high emissions (RCP8.5) scenarios. Therefore this vulnerability assessment is respect to future expected impacts in the MPA, in years 205 and 2100, and under three climate change scenarios (2.6, 4.5 and 8.5).

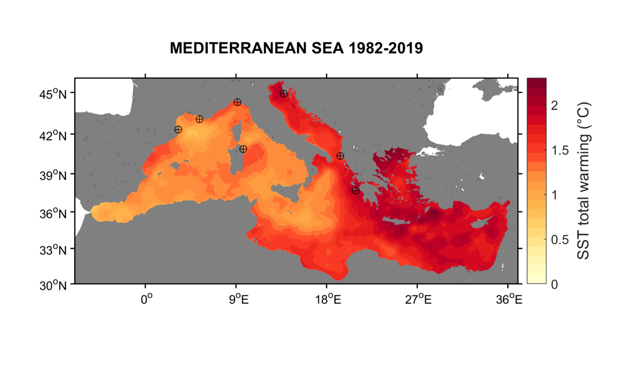
As a result, the assessment has a visualization and index calculation tool where we are able to introduce a template with all the data for the MPA. The outputs we obtain are the figures shown in this report, basically the main overall indices of vulnerability (0 low vulnerability, 1 high vulnerability) for ecological and social-ecological vulnerability. Another input is the results by species, users and habitats. Finally, we also have results in terms of the indicators contributing most to vulnerability, and information on the gaps in data and quality of the analysis.

## Climate change impacts in the MPA

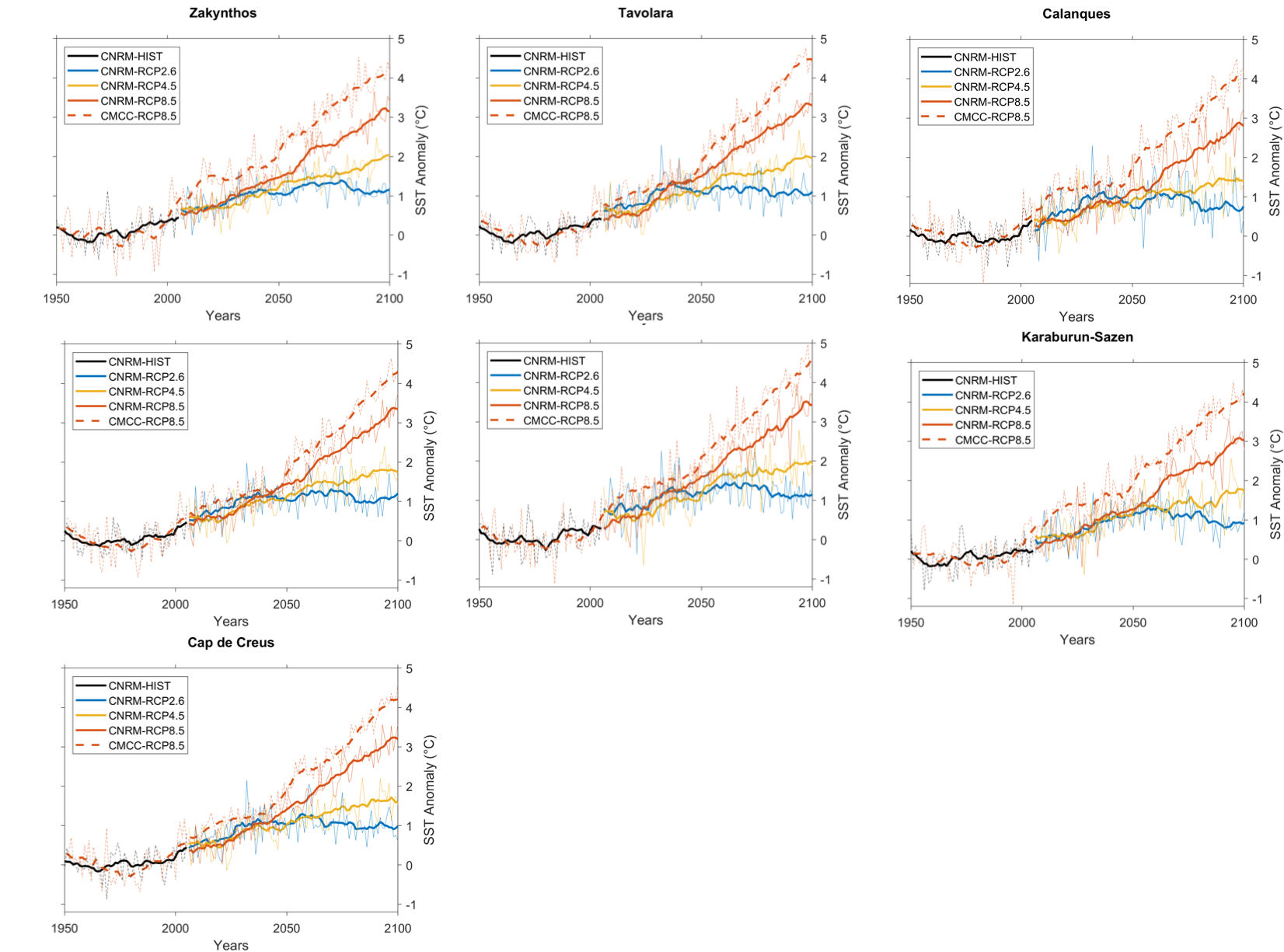
Climate change impacts are in the form of Sea Surface Temperature increase (SST99) and Marine heatwaves (MHW) increase in the periods of 2041-2050 and 2091-2100 , as defined here:

* SST99: 99th percentile of SST yearly anomaly (ºC) with respect to reference period (1950-1980)
* MHW: Cumulative intensity of MHW events (ºC \* days) with respect to the reference period (1950-1980)

This climate data is retrieved using multi-model and multi-scenarios from MedCordex, also known as Fully coupled Regional Climate System Models, from CNRM, representative of global warming scenarios with respect to the 1950-1980 average. Robust min and max (1st and 99th percentiles) were calculated over the entire Mediterranean and for each MPA. The same method was applied at Mediterranean scale (over each pixel of CNRM simulations) for the RCP8.5 scenario to define mean, as well as robust min and max anomaly (1st and 99th percentile) for normalization of warming data at two time horizons: 2041-2050 and 2091-2100.

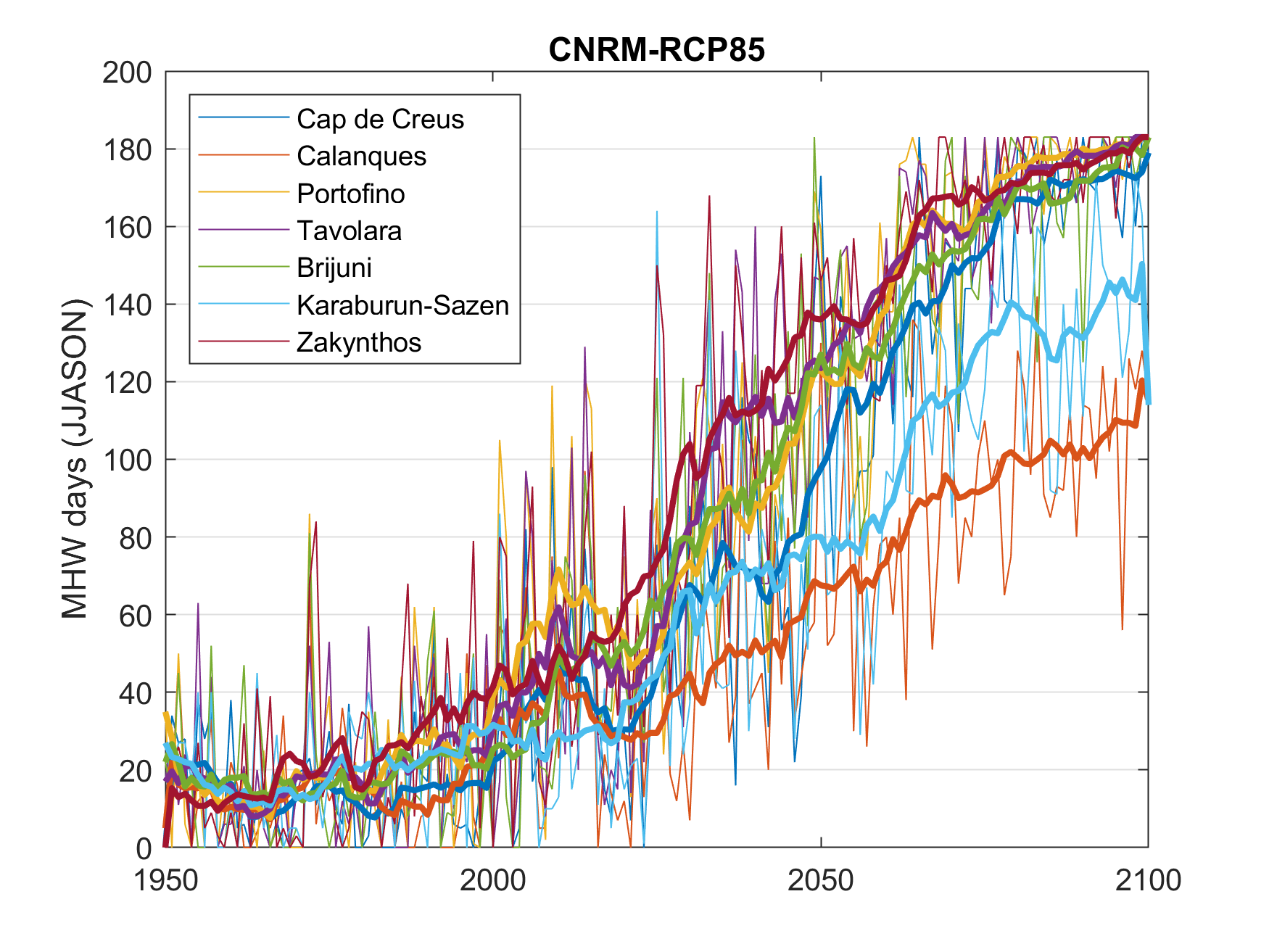
**Figure X. Current warming observed in Mediterranean MPAs, period 1982-2019 respect to 1950-1980.**

**Figure X. SST99 anomaly projected for the MPA with climate change scenarios.**



Marine Heatwave analysis following the definition of Hobday et al. (2016), as fully described in Bensoussan et al. (2019). We consider the warm period from June to November (JJASON), and quantify MHW-days and MHW maximum intensity (°C). These two metrics are aggregated into the cumulative MHW value (ºC\*days) that we use, applied to MedCordex simulations, considering historical run of 1950-2005, and scenarios 2006-2100, 30 years climatology over the 1950-1980 period.

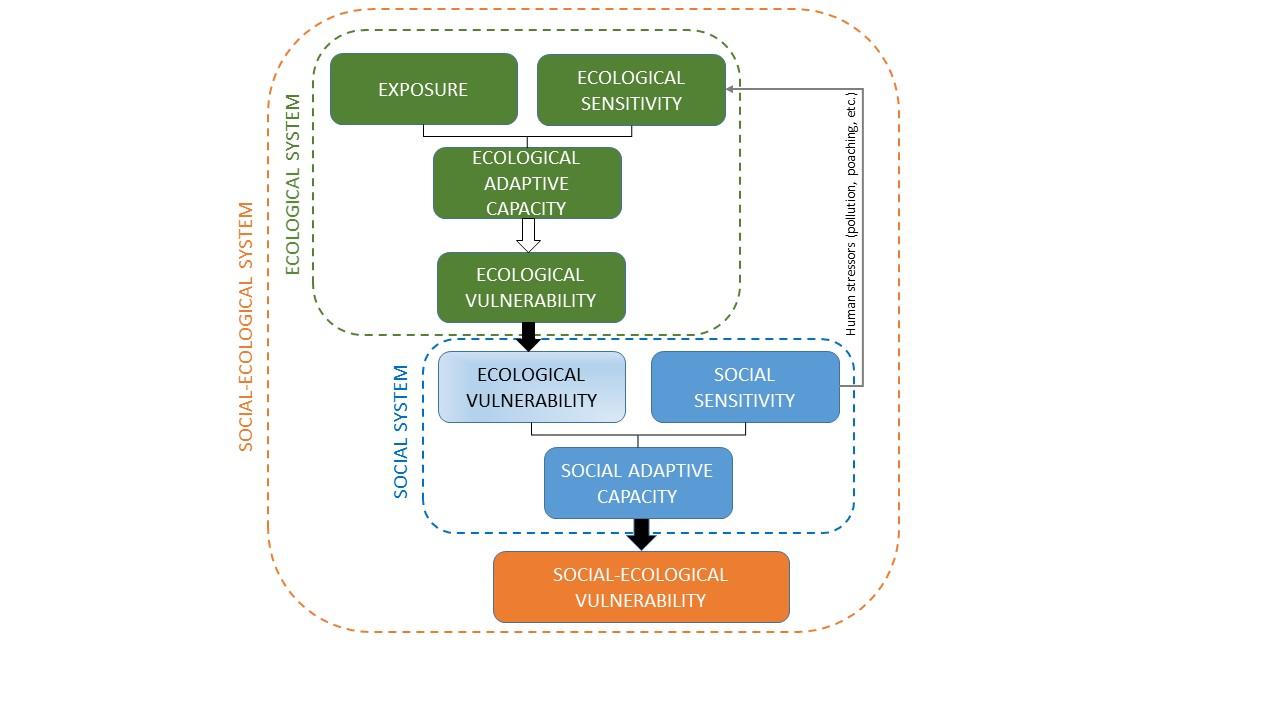
**Figure X. Projected MHW-days over the warm period (JJASON) of each year under climate change scenario 8.5.**



# Methodology

## Socio-ecological Vulnerability assessment

A standardized and replicable Socio-Ecological Vulnerability Assessment has been implemented within the MPA-Engage project. Vulnerability refers to a degree to which a system is susceptible to the impacts of climate change, defining how severe the effects of climate change can be. The elements that make up to the Vulnerability of the system are three: exposure, sensitivity and adaptive capacity (Figure X). The exposure refers to the direct impacts of the changing climate on the system, sensitivity refers to the degree to which the system could be damaged and adaptive capacity refers to its capacity to reduce its disturbance by taking actions to enhance resilience. This framework aggregates a set of qualitative and quantitative indicators along the dimensions of vulnerability, to provide a composite index on vulnerability.

**Figure X. Social-ecological climate Vulnerability framework. **

The application of the Socio-Ecological Vulnerability Assessment to the Marine Protected Areas contexts represents a useful tool to analyse and interpret the vulnerability of the MPA and its species, habitats and user groups in relation to the projected impacts of climate change. Information on both the ecological system in the MPA and the social system (users of the MPA) can be combined under this framework. As a result, this methodology is replicable and can be updated over time to track the evolution of the MPA risks and facilitate adaptation planning.

## Vulnerability assessment tool

The vulnerability assessment tool follows the framework in Figure X above and combines indicators of exposure, sensitivity and adaptive capacity. The indicators represent the basis of the index and by aggregating them, we obtain the components, which combined make up the dimensions of exposure, sensitivity and adaptive capacity, that together form the Vulnerability Index (Figure X). While sensitivity and exposure increase the vulnerability of the MPA, adaptive capacity reduces its vulnerability and therefore we correct for the relationships between indicators, factors and dimensions to aggregate the final index. The indicators have been selected considering the ecological and socio-economic context of Mediterranean Marine Protected Areas and are presented in Annex9.1 tables.

**Figure X. Levels in the composition of the vulnerability index.**

indicator

component

factor

dimension

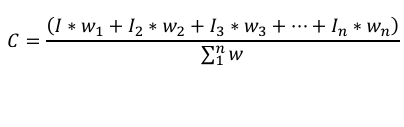
For the calculation of the Vulnerability Index, the combination of indicators, their normalization and weighting is operationalized in an online tool. The tool performs a standardized calculation of the Social-Ecological Vulnerability in a MPA based on a scaling system at the Mediterranean level. This allows for cross-MPA comparison. The tool works through an input file that includes the indicators with their values assigned, the scale of the indicator (MPA, species, habitat, user and hazard), the number of years that the values refers to, and if it is a qualitative or quantitative way of measurement.

Once the input file has been uploaded the programme normalizes the values of each indicator between 0 and 1, following the normalization ranges established in the methods (see document VA-tool indicator processing for normalization values). Normalization ranges are numerical values for quantitative indicators, based on the Mediterrannean when possible, this is establishing the maximum and minimum ranges outside of the MPA data. Normalization for qualitative indicators is done in the same way, but converting qualitative scales into numerical scales first (i.e. very low to 1; low to 2, intermediate to 3; hgh to 4 and very high to 5). Both normalization processes follow equation (1), where X can be an indicator, a component a factor or a dimension:

(1)

Indicators are tested for correlations and in the case of a Pearson correlation value between indicators or above 0.8 one of the indicators is randomly dropped. This process is to avoid double information and using indicators that are very closely related to each other.

The normalized indicators (*I*) are then aggregated at the component level (*C*), following the index structure in Tables 9.2A and 9.2B (Annex9.2) considering the weights (*w*), following equation (2) :

 (2)

The same process of aggregation is repeated for each component, factor, dimension and the final index., also using equation (2). At each step, values of the components, factors, dimensions and indicators are always normalized following equation (1), such that the Vulnerability Index score for the MPA is going to be a value that ranges between 0 and 1.

Finally, the weights we use are based on an expert consultation process where only the components were assessed. For the ecological components and the social components, four experts each evaluated the level of contribution to these components to vulnerability. The experts used a scale from 0 to 10 (*W*) for the contribution to vulnerability, and a confidence level n their response that ranged from 0-1 (ϑ). To calculate the final component weight we use equation (3):

(3)

These expert elicited weights are used in equation (2) for the aggregation of the components (see table X weights). For the aggregation of indicators and factors and dimensions, although we also use equation (2), in this case all the weights are all 1 (no weights). All the indicator processing and final index values for the templates are in the documents “VA-tool indicator processing”, “Template” and “Raw data”.

Table X. Social and ecological components weight. Colour legend: Exposure components (blue), Ecological sensitivity components (light green), Ecological adaptive capacity components (green), Social sensitivity component (orange), Social adaptive capacity components (pink)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Dimension** | **Component** | **Weight** | **Dimension** | **Component** | **Weight** |
| Exposure | SST threat | 4,69 | Social  sensitivity | Fishing dependency | 1,78 |
| MHW threat | 5,31 | Fishing effort | 0,96 |
| Ecological sensitivity | Water condition | 1,88 | Local dependence | 2,29 |
| Human pressure | 2,97 | Divers dependence | 1,69 |
| Habitat integrity | 2,68 | Nautical activities dependence | 1,06 |
| Species integrity | 2,45 | Tourism activities dependence | 1,20 |
| Ecological adaptive capacity | Habitat redundancy | 1,58 | Recreational fishers activities dependence | 1,01 |
| Habitat recovery potential | 2,98 | Social adaptive capacity | Flexibility | 2,34 |
| Species recovery potential | 2,03 | Social organization | 2,47 |
| Effectiveness | 1,58 | Learning | 2,14 |
| Conservation effort | 1,84 | Assets | 1,55 |
| Adaptive management | 1,68 | Agency and socio cultural aspects | 1,50 |

## Quality of the vulnerability results

There are three measures for the quality of the assessment that are available from the tool. The first measure is the data coverage in terms of how many indicators of the list are covered by the MPA. A percentage number is given for each dimension, indicating the proportion of indicators for which this MPA has data in the assessment. The more indicators covered, the more comprehensive is the assessment. The second indication of quality is the timeframe that quantitative indicators cover. This is an average number per dimension, and the higher the number the more comprehensive the assessment is, as it includes time series of the indicators, as opposed to being a snapshot. The third level of quality is the percentage of quantitative indicators in the assessment. The higher this number, the higher we expect the quality of the assessment to be. Additionally, the weighting exercise incorporates an assessment of uncertainty.

There are some limitations to the current data collection and quantification of indicators, most of them intrinsic to the nature of multidisciplinary approaches such as vulnerability assessments. In the ecological domain, sensitivity of habitats and species to climate change temperature increase is based on species thermal ranges from existing global databases (fishbase and sealifebase). Both sources obtain species thermal tolerance information from models based on occurrence data. Despite many publications rely on *aquamaps* (Kashner et al., 2016) for species distribution modelling and thermal ranges (Gaines et al., 2018; Oremus et al., 2020, among others), there are two important limitations. The first one is the reliability of thermal tolerance ranges for species with very scarce occurrence data. The second limitation is the lack of information for some species that can be very important in the Mediterranean context. For example, at this point we could not find thermal tolerance ranges for the species: *Paramuricea clavata*, *Lithophyllum spp.*, *Cystoseira amentacea*, *Caulerpa cylindracea*, *Physeter macrocephalus*, *Patella ferruginea*, *Aplysina spp.* and *Myriapora truncata*. Therefore the current assessment has no information on sensitivity to climate change hazards for these species, and ecological sensitivity is not dependent on the hazards (does not vary per scenario). A second limitation is the assumption we performed for habitats, where sensitivity to SST and MHW is calculated based on the habitat key species, where we averaged across key species sensitivity. While this indicator is the best we could use to have a sense of species responses to future hazards, there are important knowledge gaps in the literature about species occurrence and thermal tolerances that could affect these results.

Another line of discussion is the stakeholder approach. While key representative stakeholders are knowledgeable about s specific user group, using them as the voices for the groups has its risks. The more questionnaires to different key representative stakeholders, the better the input data for the social components of the vulnerability assessment. This is an area for future methodological improvements where all stakeholders can be addressed and results of the questionnaires compared. At the same time, further refinements can incorporate the performance of the questionnaires, as to have first-hand information on the use and activities performed in the MPA.

## Habitats, species and users selection

A series of habitats, species and users were selected to assess their Vulnerability to the impacts of climate change. For each of the three categories a list was provided in order to allow the comparability of habitats, species and users between different MPAs.

### Habitats

The habitats subject of this assessment were picked from a list which considered the habitat types used for the monitoring protocols and other activities of the project. The habitats were chosen through a survey done at the kick-off meeting in Barcelona in January 2020 and revised along the implementation of the vulnerability approach.

Table X. Habitats selected for the assessment in the XXX MPA.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Posidonia oceanica meadows** | **Other seagrass meadows** | **Coralligenous** | **Infralittoral rocky bottoms dominated by macroalgae** | **Caves** |
|  |  |  |  |  |

### Species

The species subject of this assessment were picked from a multi-category list which considered endangered species, climate impacted species, target fishing species, monitored species, keystone species and flagship species. Between 3 and 5 species per criteria were chosen through an exercise during the Webinar series, performed by the MPA managers.

Table X. Species selected for the assessment in the XXX MPA

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Monitored species** | **Endangered species** | **Climate impacted species** | **Target fishing species** | **Keystone species** | **Flagship species** |
|  |  |  |  |  |  |

### User groups

The user groups selected for this assessment were picked from a list of the most common activities that take place in all the MPAs involved in the project. The user groups were chosen through a survey done at the kick-off meeting in Barcelona 2020 and revised along the implementation of the vulnerability approach.

Table X. Users selected for the assessment in the XXX MPA

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Professional fishers** | **Recreational fishers** | **Diving sector** | **Nautical activities** | **Tourist sector** |
|  |  |  |  |  |

## Data collection process

[ 2-3 pages. Describe the general strategy adopted for the indicators selection (exercise 7 from webinar), the data collection process (data collection template), and the implementation of questionnaires. Complete existing info if necessary. With inputs from UVIGO]

The vulnerability guidelines document (D.4.2.1. Vulnerability Assessment Guidelines) presented in spring 2020 provides the full approach for the development of the present analysis. This approach established a preliminary indicator list, and the potential data collection methods. A series of webinars with MPA managers were performed during spring and summer 2020 to advance on the data collection process and approach. There are three main sources of data for the vulnerability assessment: 1) secondary data collected from the literature; 2) data collected by the MPA for the assessment, and 3) stakeholder questionnaire data. Each MPA identified during the exercises the data availability for the indicators, and proposed a way to fill in the information at the local scale. Like this, the MPA identified the data sources and UVIGO prepared a data collection process.

Secondary data: information on exposure, species sensitivity, or species dispersal, population, and others was collected by UVIGO based on the literature and contributions from experts (exposure).

Data from MPA: a series of indicators were directly collected by MPA managers with specific questionnaires designed by UVIGO and existing information (data collection template). These are for example indicators like MPA shape, monitoring activities, assets in the MPA, among others.

Stakeholder questionnaires: MPAs selected representative stakeholders to ask them a series of questionnaires to derive information for the indicators on the user group (stakeholder questionnaires). UVIGO developed the questionnaires and the MPAs translated the questionnaires and implemented them.

Add more information on the process, how many stakeholders from the user group, dates, etc.

A complete list of the data sources per indicator is available in the document “Raw data MPAname.xlsx”.

# Results

[4-5 pages. Describe and explain the findings obtained from the results of the Socio-Ecological Vulnerability Assessment of your MPA. Present the following Figures and the Vulnerability Index results obtained from your data collection at the MPA, habitats and species level.]

**Figure X. Socio-ecological vulnerability index of the MPA XX.**

Quality indices included for both 2050 and 2100 are the same

rep-image-social-ecological-vul

**Figure X. Ecological vulnerability index results.**

rep-image-ecological-vul

**Figure X. Key indicators contributing to vulnerability**

(RCP 8.5 for 2100)

rep-image-key-indicators

**Figure X. Habitat vulnerability index**

(RCP 8.5 for 2100)

rep-image-habitat-vul

**Figure X. Species Vulnerability Index\***

(RCP 8.5 for 2100)

rep-image-species-vul

**Figure X. Users Vulnerability Index\***

(RCP 8.5 for 2100)

rep-image-user-groups-vul

**Figure X. Vulnerability to hazards**

MPA vulnerability to Sea Surface Temperature Increase (SST) and Marine Heatwaves

rep-image-hazard-vul

# Discussion and Findings

[ 1-2 pages. Provide a description of your interpretation of the significance of your results and how are they informative for the MPA management and adaptation plans. Highlight any new findings that are new for the MPA.]

# Conclusion

[ 0.5-1-page. Provide a synthesis of the key points of the Socio-Ecological Vulnerability Assessment conducted in your MPA.]

# References

In the report cite the references as (author, year). Use *Harvard style* for listing the references at the end of the report.

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# Annexes

## annex 1

**Table 9.1A List of indicators of ecological exposure and ecological sensitivity.** The table below indicates the “code” used to identify each indicator and for the Vulnerability index calculation, the “indicator name” and a description of the indicator.

|  |  |  |
| --- | --- | --- |
| Code | Indicator Label | Description |
| SST | SST Increase | Quantitative change in sea surface temperature projected under climate change scenarios, relative to baseline period |
| MHW | Marine heatwaves | Quantitative change in the frequency and duration of MHW in the projected scenarios, relative to a baseline period. |
| POL | Pollution | Measures the quality elements for the classification of ecological surface water status in coastal waters based on the EU Water Framework Directive 2000/60/EC, page 49 considering the Physic-chemical quality elements of the section “1.2.4 Definition for high, good, moderate ecological status in coastal waters”. |
| SAL | Salinity | Measures the annual mean water salinity in the MPA. |
| DEOX | Deoxygenation | Measures the annual average level of oxygen of in the MPA |
| MME | Mass Mortality events | Measure the range of abrupt events that cause the sudden mortality of a great number of marine organisms due to alteration of the water conditions |
| PDEN | Coastal population density | Measures the density of people living in the adjacent areas of the MPA. Can include population density within a MPA-10Km radius OR, the population density of the city council where the MPA is located. |
| POA | Poaching professional fishers | Measures the level of poaching event and/or illegal fishing estimated inside the MPA waters done by professional fishers |
| POA | Poaching recreational fishers | Measures the level of poaching event and/or illegal fishing estimated inside the MPA waters done by recreational fishers |
| GNET | Ghost nets | Evaluates the impact of lost fishing gears that are found at the sea bottom |
| FGEAR | Fishing gear restrictions professional fishers | Evaluates the type of fishing gears that are used for professional fishing activities in MPA waters. Following a classification system for marine protected areas and gears from the literature, we will assign a value for the indicator, based on the gears used. |
| FGEAR | Fishing gear restrictions recreational fishers | Evaluates the type of fishing gears that are used for recreational fishing activities in MPA waters. Following a classification system for marine protected areas and gears from the literature, we will assign a value for the indicator, based on the gears used. |
| FPRES | Fishing pressure | measures the amount of tons of the species most caught in the MPA |
| IMP | Nautical activities impact | Measures the level of nautical activities, quantifying the annual number of boats in the area of the MPA where nautical activities are allowed. |
| HB.SEN | Habitat sensitivity to SST | Measures the level of sensitivity of the habitat to the effects of climate change (SST) in the MPA using a qualitative scale based on expert assessment. |
| HB.SEN | Habitat sensitivity to MHW | Measures the level of sensitivity of the habitat to the effects of climate change (MHW) in the MPA using a qualitative scale based on expert assessment. |
| HB.BENT | Condition of the benthic community | Measures the current condition of the benthic community in the habitat, using a qualitative scale based on expert assessment and the monitoring experience in the project. |
| END.SP | Endangered species | Number of endangered and threatened species present in the MPA based on IUCN, SPAMI and Habitat Directive Annex 4 lists. |
| HB.INV | Invasive species | Evaluates the diversity of invasive species present in the MPA at the habitats level. |
| RISK.INV | Risk of invasive species | Measure the risk of 9 new coming invasive species in the MPA area in the next 30 years due to the favorable water conditions, considering the most optimistic and most pessimistic scenario (RCP 2.6 and 8.5 by 2050). |
| WARMW | Warm water species | Measure the presence and expansion of warm-water species over temperate and cold-water species in the MPA water. |
| SP.SEN | Species sensitivity to climate hazard (SST) | Measure the level of sensitivity of the species to climate hazards (SST increase) in the MPA using a qualitative scale based on expert assessment. |
| SP.SEN | Species sensitivity to climate hazard (MHW) | Measure the level of sensitivity of the species to climate hazards (MHW) in the MPA using a qualitative scale based on expert assessment. |
| SP.DIS | Species distribution | Total area of distribution of *a species*  in the Mediterranean basin. If the studied species is restricted to a narrow area, it results more sensitive to abrupt changes compared to species that have broader distributional ranges. In fact these species have a higher chance to come back and repopulate an area if there is a perturbation in the system. |
| SP.POP | Species population | Measures abundance of individuals of a *species* in the MPA |
| END.ST | Endangered status | Measures if the *species* considered in the MPA assessment is an endangered or threatened species based on IUCN, SPAMI and Habitat Directive Annex 4 lists. |
| INV.ST | Invasive species status | Measure if the species considered in the assessment is an invasive species |

Table 9.1B List of indicators of Ecological adaptive capacity. The table below indicates the “code” used to identify each indicator and for the Vulnerability index calculation, the “indicator name” and a description of the indicator.

|  |  |  |
| --- | --- | --- |
| code | Indicator Label | Description |
| DIVHB | Habitat diversity | Number of different habitats inside de MPA, using the MPA-ENGAGE habitat list (coralligenous, Posidonia oceanica meadows, other seagrass meadows, caves, infralittoral rocky bottoms with macroalgae). |
| SHAPE | MPA shape | Shape of the MPA prioritizing simple shapes (squares or rectangles), compared to elongated or convoluted ones, to minimize edge effects. |
| SAREA | Fully protected area | Size of the area in the MPA that is fully protected. Implementing fully protected areas at least twice the size of target species' home ranges would ensure ecological beneﬁts at the local population scale. The area should be greater than twice the size of the largest individual home range assessed. A spatial area of 3.6km2 should be considered as a minimal threshold that has been seen to increase the density of local populations of the species in MPAs. |
| HB.COM | Habitat complexity | Level of complexity of each habitat present in the MPA (coralligenous, Posidonia oceanica meadows, other seagrass meadows, caves, infralittoral rocky bottoms with macroalgae) using a qualitative scale based on expert assessment. |
| HB.EXT | Habitat extension | Current area of each habitat type inside the MPA. |
| HB.CON | Habitat connectivity | Distance between a habitat type inside the MPA and the nearest patch outside the MPA. |
| HB.DEPTH | Habitat depth | Maximum and average depth of each of the MPA habitat types. (Deeper habitats are considered to have higher recovery potential as they are less disrupted). |
| SP.DISP | Larval dispersal capacity | Evaluates the larval dispersion ability of a species. |
| SP.HB | Species habitat specificity | Recovery potential of a species based on its habitat restriction. Habitat generalist species are more resilient as they are present in different habitat types. Habitat specialist species are more sensitive as they are restricted to one habitat. |
| FECUN | Fecundity potential | Measures the reproductive capacity of a stock species considering the length of first maturity. |
| SP.SIZE | Species size distribution | Measure the occurrence of large individuals which indicate a more even size-spectra and an increase in fecundity using the underwater visual census technique. |
| PGOV | Polycentric Governance | Measure whether the MPA has established a multiple governing bodies approach that interact to make and enforce rules to improve the MPA functionality (Central government, Local institutions, Local NGOs, Local users groups, etc.) |
| BUDG | Budget capacity | Status of the annual economic budget that the MPA has access to, for the management of the MPA. A higher budget capacity increases the opportunity to meet a more effective management of the MPA. |
| STAFF | Staff capacity | Measures the current status of the staff employed that is actively working in the MPA. A higher and adequate staff capacity and presence increases the opportunity to meet a more effective management of the MPA |
| M.PLAN | Presence of a management plan | Presence of a formal or informal arrangement between MPA management body and professional fishermen which details the agreed objectives for the fishery and specifies the management rules and regulations which apply to it |
| ENFOR | Capacity of enforcement | Measures the enforcement capacity and consistency that the MPA has to improve its effectiveness through legislations and regulations |
| MON.HB | Resources Monitoring Habitat | Number of habitats present in the MPA included in the following list (coralligenous, Posidonia oceanica meadows, other seagrass meadows, caves, infralittoral rocky bottoms with macroalgae) that are part of monitoring activities. |
| MON.SP | Resources Monitoring Species | Number of species present in the MPA that are part of monitoring activities. The higher the number of vulnerable species and/or habitats that are monitored the higher their recovery potential. |
| SUR | Surveillance | Level of surveillance in the MPA to control poaching and illegal activities such as boat accessing or diving in restricted areas, poaching, collecting endangered species… |
| HB.REST | Habitat restoration | Measures the existence of restoration actions in the MPA targeting at specific habitats of the following list (coralligenous, Posidonia oceanica meadows, other seagrass meadows, caves, infralittoral rocky bottoms with macroalgae). |
| SP.REST | Species restoration | Measures the existence of restoration actions in the MPA targeting specific species. |
| ZON | MPA Zoning | MPAs are divided in different levels based on access and activities restrictions where zone A represents the zone of very strict protection, no-take/no-use zone. The greater the % of area of full protection the higher the potential of recovery of the area. |
| WCM | Water column monitoring | Measures if the MPA is implementing activities to monitor physical and chemical properties of the water column (including temperature, pH, Salinity, Oxygen...) |
| SCADV | Level of climate scientific advice | Measures if the MPA is working in collaboration or is regularly receiving training by climate scientist regarding the effects of climate change in MPAs |

**Table 9.1C List of indicators of Social sensitivity.** The table below indicates the “code” used to identify each indicator and for the Vulnerability index calculation, the “indicator name” and a description of the indicator.

|  |  |  |
| --- | --- | --- |
| code | Indicator Label | Description |
| AF.AREA | Available fishing area | Measures the percentage of the MPA area where fishing is allowed. |
| SP.DEP | Species catch dependence | Level of occurrence of endemic species from which fishers have been depending historically within the last 10 years |
| FVULN | Climate vulnerable species | Measures the number of climate vulnerable species related to fishing inside the MPA. **Vulnerable species** are defined as those currently endangered, climate sensitive and targeted by local user groups according to the monitoring protocol species list, the Mediterranean red list of species and “The overview of the conservation status of the marine fishes of the Mediterranean Sea”. |
| F.RATE | Catch rate from MPA | Measures the fisherman economic dependence from the species they are allowed to catch in the MPA.  The indicator considers the average tons of catch and the average price of the resource for the last 5 years. |
| F.DAY | Fishing days | Loss in ﬁshing days due to the extreme weather conditions within the last 10 years |
| F.DEN | Fishers density | Measure the density of fishermen that can harvest in allowed fishing areas of the MPA. |
| FATTACH | Attachment to occupation | Measures the eventuality of giving up fishing for another job in the face of the increasing climate change impacts |
| F.INC | Local income dependence on fishing | Measure the percentage of income in the region that comes from artisanal fisheries activities carried out within the country EEZ . |
| LOC.F.DEP | Local job dependence on fisheries | Measure the percentage of population in the region that works in the fishery sector over the total working population. |
| DIVER | Divers | Measures the average number of divers visiting the MPA per year, in the last 5 years |
| D.AREA | Diving area | Diving sites in the MPA where diving is allowed |
| DVULN | Climate vulnerable species | Measures the number of climate vulnerable species related to the diving activities inside the MPA. |
| LOC.D.DEP | Local dependence on diving activities | Measures the number of jobs that depend on the diving and snorkeling activities in the local area within 30km |
| WILD | Wildlife watching | Average level of dependence of the last 5 years of the nautical activities on the flagship species of the MPA. A flagship species are species that act as an ambassador or symbol of the MPA such as turtles, marine mammals, sharks. |
| BVULN | Climate vulnerable species | Number of climate vulnerable species related to nautical activities inside the MPA. |
| BOAT | Recreational boats | Average number of private boats per day in high and low season that entered the accessible areas of the MPA waters for recreation purposes (not diving companies, not fishing nor recreational fishing boats). |
| LOC.B.DEP | Local dependence on nautical activities | Number of jobs that depend on the nautical activities in the local area within 30km (wildlife watching companies, rental boats, boats constructions and shops that sell related things) |
| B.AREA | Area for recreational transit | Percentage or area in the MPA area where recreational boat transit (sailing) is allowed |
| TOUR | Tourist arrivals | Measures the average of the last 5 years about the number of annual visitors coming to the MPA for beach tourism |
| T.AREA | Beach area | Percentage of beach length over the total coastal length that is protected by the MPA and that it is accessible by tourists. |
| TVULN | Climate vulnerable species | Measures the number of climate vulnerable species related to tourists’ activities inside the MPA. |
| LOC.T.DEP | Local job dependence on tourism | Percentage number of jobs that depend on tourism in the local area within 30km (restaurant, accommodation). |
| REC.F | Recreational fishers | Measure the amount of people that can practice recreational fishing in the MPA. |
| LOC.RF.DEP | Local  recreational fishing dependance | Proportion of jobs (%) that depend on recreational fishing in the local area within 30km (fishing shops). |
| RF.SPDEP | Recreational fishers Species dependence | Level of change in the last 5 years in the occurrence of species from which recreational fishers are targeting. |
| RF.VULN | Recreational fishers vulnerable species | Measures the number of climate vulnerable species related to recreational fishing activities inside the MPA. |
| RF.AREA | Available area for recreational fishing | Percentage or area in the MPA area where recreational fishing is allowed |

**Table 9.1D List of indicators of Social Adaptive capacity.** The table below indicates the “code” used to identify each indicator and for the Vulnerability index calculation, the “indicator name” and a description of the indicator.

|  |  |  |
| --- | --- | --- |
| code | Indicator Label | Description |
| U.SUBS | Substitute areas outside the MPA (all users groups) | Measures if the activities performed inside the MPA can also be performed in the surrounding areas, maintaining the quality/satisfaction level of the activity |
| U.TARG | Number of targeted species | Number of species that are considered most important to an activity inside the MPA. Most important species for fishing (i.e. represent 80% of the catch), for tourism (flagship species), for diving, etc. |
| L.DIV | livelihood diversity | Level of professional fishermen that have additional sources of income from secondary jobs or activities |
| F.GRES | Gear diversity professional fishers | Amount of gears that fishers in the area have license for to fishing within the MPA |
| F.GRES | Gear diversity recreational fishers | Amount of gears that fishers in the area have license for to fishing within the MPA |
| U.COLW | Collaboration within sectors | Measures the level of cooperation of users within a sector |
| U.COLA | Collaboration among sectors | Measures the level of cooperation of users across sectors |
| U.PART | Participation in decision making | Measures the level of users’ participation in the decision-making of the MPA management such as monitoring activities, regulation enforcement, training activities, |
| U.TRUST | Level of trust | Measures the users level of trust towards local leaders in the MPA management |
| TRANS | Transparency | Measures the level of access to the information about the MPA management decision-making process |
| U.CONFW | User conflict within sectors | Measures the perception about increasing conflicts within the users of a sector due to the impacts of climate change. |
| U.CONFA | User conflict among sectors | Measures the perception about increasing conflicts, due to the impacts of climate change, between a user group and the other user groups within the MPA |
| ACCO | Accountability | Measure how easy is for users to identify to whom they should report if any issues arises in relation to the management of the MPA |
| U.SCI | Users engagement in citizen science | Measures the level of integration of users in scientific activities to advance the MPA scientific research and increase the users’ understanding of science (e.g monitoring programs) |
| U.TRAI | Training activities for MPA users | Measures if the MPA organizes MPA training that users can access (i.e. training on MPA design and management, ecosystem services, local biodiversity and biodiversity conservation directed to different education levels) |
| U.FIN | Financial resources of users | Measure if users can have access to credit from formal institutions or other mean (i.e. Insurances, bank loans, subsidies...) |
| U.FAC | User facilities | Measures the level of available facilities |
| U.RISK | Risk attitudes in user groups | Measures the user risk perception level regarding sea surface temperature increase (SST) |
| U.INC | Fishers income | Measures the income status of fishers for the activities performed in the MPA waters compared to their cost of living. |
| U.JUST | Access to justice | Measure the effectiveness of a mechanism that addresses disagreements or conflicts that may arise between user groups and the MPA management. |
| U.AGE | Age of user groups | Average age of the users groups which performs activities inside the MPA |
| U.GEN | Gender of user groups | Percentages of gender of the users which perform activities inside the MPA |

## annex 2

**Table 9.2A Structure of the Index.** The table shows the different levels that compose the ecological vulnerability index including the vulnerability dimensions, subdimensions, factors, components and indicators. The column “scale” specifies the level of resolution of each indicator; MPA, habitats (HB), species (SP), hazards (HZ) and user groups (UG).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Dimension | Subdimension | Factor | Component | Indicator | Scale |
| ECOLOGICAL VULNERABILITY | EXPOSURE | climate stressors | SST threat | SST | MPA |
| MHW threat | MHW | MPA |
| ECOLOGICAL SENSITIVITY | non-climate stressors | water cond | POL | MPA |
| SAL | MPA |
| DEOX | MPA |
| human pressure | PDEN | MPA |
| POA | MPA, UG |
| GNET | MPA |
| FGEAR | MPA, UG |
| FPRES | MPA |
| IMP | MPA |
| ecological status | habitat integrity threats | HB.SEN | HB, HZ |
| HB.BENT | MPA, HB |
| MME | MPA, SP |
| END.SP | MPA |
| HB.INV | MPA, HB |
| RISK.INV | MPA |
| WARMW | MPA |
| species integrity threats | SP.SEN | SP, HZ |
| SP.DIS | SP |
| SP.ST | SP |
| END.ST | SP |
| INV.ST | SP |
| SP.POP | MPA, SP |
| ECOLOGICAL ADAPTIVE CAPACITY | recovery potential | hab.redundancy | DIVHB | MPA |
| SHAPE | MPA |
| SAREA | MPA |
| hab. Recovery potential | HB.COM | MPA, HB |
| HB.EXT | MPA |
| HB.CON | MPA, HB |
| HB.DEPTH | MPA, HB |
| sp. Recovery potential | SP.DISP | SP |
| SP.HB | SP |
| FECUN | SP |
| SP.SIZE | MPA, SP |
| MPA management | effectiveness | PGOV | MPA |
| BUDG | MPA |
| STAFF | MPA |
| M.PLAN | MPA,UG |
| ENFOR | MPA |
| conservation efforts | MON.SP | MPA, SP |
| MON.HB | MPA,HB |
| SUR | MPA |
| HB.REST | MPA |
| SP.REST | MPA |
| ZON | MPA |
| Adaptive management | WCM | MPA |
| SCADV | MPA |

Table 9.2B The table shows the different levels that compose the social dimension of vulnerability index including the vulnerability dimensions, subdimensions, factors, components and indicators. The column “scale” specifies the level of resolution of each indicator; MPA, habitats (HB), species (SP), hazards (HZ) and user groups (UG).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Dimension | Subdimension | Factor | Component | Indicator | Scale |
| SOCIAL SENSITIVITY | SOCIAL SENSITIVITY SUBDIMENSION | Fishers sensitivity | Fishing dependency | AF.AREA | MPA, UG |
| SP.DEP | MPA, UG |
| FVULN | MPA, UG |
| F.CATCH | MPA, UG |
| Fishing effort | F.DAY | MPA, UG |
| F.DEN | MPA, UG |
| local dependency | FATTACH | MPA, UG |
| F.INC | MPA, UG |
| LOC.F.DEP | MPA, UG |
| Diving sector | Divers sensitivity | DIVER | MPA, UG |
| D.AREA | MPA, UG |
| DVULN | MPA, UG |
| LOC.D.DEP | MPA, UG |
| Boat sector | Boat sensitivity | WILD | MPA, UG |
| BVULN | MPA, UG |
| BOAT | MPA, UG |
| LOC.B.DEP | MPA, UG |
| B.AREA | MPA, UG |
| Tourist sector | Tourism sensitivity | TOUR | MPA, UG |
| T.AREA | MPA, UG |
| TVULN | MPA, UG |
| LOC.T.DEP | MPA, UG |
| Recreational fishing sector | Rec. fishers sensitivity | REC.F | MPA, UG |
| LOC.RF.DEP | MPA, UG |
| RF.SPDEP | MPA, UG |
| RF.VULN | MPA, UG |
| RF.AREA | MPA, UG |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Dimension | Subdimension | Factor | Component | Indicator | Scale |
| SOCIAL ADAPTIVE CAPACITY | SOCIAL ADAPTIVE CAPACITY SUBDIMENSION | Users Adaptive Capacity | Flexibility | U.SUBS | MPA, UG |
| U.TARG | MPA, UG |
| L.DIV | MPA, UG |
| F.GDIV | MPA, UG |
| Social Organization | U.COLW | MPA, UG |
| U.COLA | MPA, UG |
| U.PART | MPA, UG |
| U.TRUST | MPA, UG |
| TRANS | MPA, UG |
| U.CONFW | MPA, UG |
| U.CONFA | MPA, UG |
| ACCO | MPA, UG |
| Learning | U.SCI | MPA, UG |
| U.TRAI | MPA, UG |
| Assets | U.FIN | MPA, UG |
| U.FAC | MPA, UG |
| Agency and socio-cultural | U.RISK | MPA, HZ, UG |
| U.INC | MPA, UG |
| U.JUST | MPA, UG |
| U.AGE | MPA, UG |
| U.GEN | MPA, UG |

## annex 3

**Climate MPA socio-ecological index aggregation.**

Normalized indicators are aggregated following the architecture of the index, which goes from the indicator level to the components, factors and dimensions. Indicators are first combined to compute the ecological vulnerability index. We are able to have three outputs here: the general ecological vulnerability index; the habitats vulnerability and the species vulnerability.

Next we compute the social sensitivity and social adaptive capacity, and these are combined with the ecological vulnerability to compute the social-ecological vulnerability index. The final general index has also the output of user groups’ index results.

**Calculation of ecological vulnerability**

Ecological vulnerability is composed of exposure, ecological sensitivity and ecological adaptive capacity, where adaptive capacity reduces vulnerability and exposure and sensitivity increase vulnerability. Hereafter we depict the composition of components and factors.

**1. Exposure:** is defined as the sum of *n* climate change threats in the *i* MPA (1). Each threat corresponds to one indicator (SST and MHW).

(1)

Where n=1: N, and N=2: SST, MHW.

**2. Ecological sensitivity:** is the sum of two factors: *Non-climate stressors* and *Ecological status*.

* 1. *Non-climate stressors:* this factor is MPA-specific, and is calculated combining the components: water conditions (and human pressure ), for each *i* MPA. *Water conditions* ( is composed of three indicators (POL, SAL and DEOX) (2). Human pressure ) is composed of 6 indicators (POA, FGEAR, GNET, FPRES, PDEN and IMP) (3). The final factor is the aggregation of these two components plus population density in the MPA area (4).

(2)

(3)

(4)

* 1. *Ecological status.* Is the mean of two components: habitat integrity and species integrity , and varies per MPA (*i*), per habitat type (*j*) for *J* habitats, per species type (*k*) for *K* species. Note that each MPA can have a set of habitats and species so *J* and *K* vary with *i*.
     1. *Habitat integrity*: this component integrates MPA-specific information on the habitats, and is also specific to *j* habitat types. Habitat integrity is composed by 7 indicators following equation 5,

+ + (5)

where is the habitat integrity of each habitat type in a given MPA, that can be aggregated for the MPA if necessary by:

(6)

* + 1. Species integrity: this component integrates MPA-specific species lists with indicators that are species-specific (*k*), following equation (6).

(6)

where is the individual species integrity, that can be aggregated at the MPA-level (7) using the specific MPA species lists by:

(7)

Finally, the Ecological status factor is calculated combing these two components as in (8):

(8)

And finally, the combination of the two factors (ecological status) and non-climate stressors provides the Ecological Sensitivity subdimension (9):

(9)

**3. Ecological adaptive capacity:** is the sum of the factors *Recovery potential* and *MPA management*, and contributes inversely to ecological vulnerability

* 1. *Recovery potential* is the combination of 3 components, *habitat redundancy* , *habitat recovery potential* (, and *species recovery potential* . While habitat redundancy varies at the MPA scale, habitat recovery potential varies with the habitat types (j) and species recovery potential varies with the species type (k).

(10)

* + 1. *Habitat recovery potential*: depends on the MPA *i* and is computed with 4 indicators (11):

(11)

To obtain the habitat recovery potential metric at the MPA-level, we can average across habitats (12):

(12)

* + 1. *Species recovery potential* (SRP) varies per species and not per MA, but each MPA *i* has different species to study, and is computed with 4 indicators (13). For those species common to more than one MPA, we expect the SRP indicator to be the same.

(13)

For the species recovery potential metric at the MPA-level, we average across the species we use (K) for each particular MPA) (14):

(14)

Finally, the recovery potential factor is calculated with the sum of the three components, as in (15):

(15)

* 1. *MPA management* is the combination of *management effectiveness* , *conservation efforts* and *adaptive management* . All these indicators are MPA-specific and don’t vary per habitat or species.
     1. *Management effectiveness* is computed with 5 indicators as in (16)

(16)

* + 1. *Conservation efforts*  is computed with 6 indicators as in (17)

(17)

* + 1. *Adaptive Management*  is computed with 2 indicators as in (18):

(18)

Finally, the *MPA management* factor is calculated with the sum of the three components, as in (19):

(19)

To finalize, the subdimension Ecological Adaptive Capacity is calculated with the sum of the two factors, following equation 20:

(20)

1. **Ecological vulnerability:** Ecological vulnerability varies across MPA (i) and is calculated combining the three subdimensions computed above, following equation 21:

(21)

**Calculation of socio-ecological vulnerability**

Socio-ecological vulnerability is composed of ecological vulnerability (21), social sensitivity and social adaptive capacity, where social adaptive capacity reduces vulnerability and ecological vulnerability and social sensitivity increase vulnerability. Hereafter we depict the composition of components and factors.

We already have ecological vulnerability (also known as social exposure), so for the composite index we need to compute the social sensitivity and social adaptive capacity factors.

1. **Social sensitivity:** is the sum of each MPA user group sensitivity to climate change.
2. Artisanal Fishing
   1. *Fishers sensitivity:* is the combination of three components; Fishing dependency (FDEP), fishing effort (FEF) and local dependency (LOCAL.DEP) (22). It varies across MPAs (i).

(22)

* + 1. Fishing dependency: varies across MPAs (i) and species (k) ans is calculated with 4 indicators following equation 23:

(23)

* + 1. User effort: varies across MPAs (i)

(24)

* + 1. Local dependency: varies across MPAs (i)

(25)

1. Divers:

Divers’ sensitivity is the combination of the number of divers (DIVER), diving area (D.AREA), and local dependence on diving activities (LOC.D.DEP) (26). It varies across MPAs (i).

(26)

1. Recreational boats:

Sensitivity of recreational nautical is the combination of wildlife watching (WILD), recreational boats (BOAT), local job dependence on nautical activities (LOC.B.DEP) and area for recreational transit (B.AREA), and it varies across MPAs (i) (27).

(27)

1. Tourist activities:

Combination of tourist arrivals (TOUR), beach area (T.AREA), and local dependence on tourism (LOC.T.DEP), and varies across MPAs (i).

(28)

1. Recreational fishing:

Sensitivity of recreational fishers is the number of recreational fishers, local dependence on recreational fishing (LOC.RF.DEP), species dependence (RF.SPDEP), the area for recreational fishing (RF.AREA), recreational fishing (REC.F) and climate vulnerable species(RF.VULN) and varies across MPAs (i).

(29)

Social sensitivity can be averaged across user groups (U), if we aim to have MPA aggregates:

5. Social adaptive capacity: Is the combination of 5 different factors that vary with the user groups (u) and MPAs (i).

1. Flexibility can be averaged across user groups (U), if we aim to have MPA aggregates:

Social organization can be averaged across user groups (U), if we aim to have MPA aggregates:

1. Learning can also be averaged across user groups (U), if we aim to have MPA aggregates:
2. Assets can also be averaged across user groups (U), if we aim to have MPA aggregates:
3. Socio-cultural adaptive capacity can be averaged across user groups (U), if we aim to have MPA aggregates:

Social adaptive capacity is the combination of these 5 domains, following Cinner et al., 2018:

**Final social-ecological index:** the final index combines the three dimensions of ecological vulnerability (21), social sensitivity and social adaptive capacity.