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Downscaling climate impacts and decarbonisation pathways in EU islands, and enhancing socioeconomic and non-market evaluation of Climate Change for Europe, for 2050 and beyond

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Work Package 4:

Modelling climate shocks and biophysical impacts

Deliverable 4.4e. Report on estimated seagrass density

Coordinated by UIB (Gabriel Jordà, Núria Marbà and Iris Hendriks) and reviewed by Salvador Suarez and Ghislain Dubois, according to the quality review internal process.

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1 Abstract

Seagrasses are the main habitat for coastal marine ecosystems. They provide different services like sediment retention (and thus clearer waters), coastal protection (in front of marine storms), shelter for marine organisms, etc... Therefore, the state of the seagrasses are a convenient proxy for the state of coastal environment. Here we have analysed temperature projections for different European Islands and assessed wether the upper thermal limit of the main four foundation species would be met under different climate change scenarios. Our results suggest that noticeable seagrass losses could be expected under scenario RCP8.5 by the end of the century. In particular the losses would be concentrated in the Western Mediterranean (Balearic, Sardinia, Malta and Sicily) in which the coverage of Posidonia Oceanica would be reduced between a 14 and 35%. In the eastern Mediterranean the thermal threshold is higher as far as Posidonia has adapted to the warmer conditions, and thus is more resilient to projected warming. Although the projected reduction may seem moderate, it has to be kept in mind that the losses will be localized in the nearshore areas, so it is expected a large impact on water transparency in beach areas. Ecosystem services will be probably be less affected.

2 Introduction

Seagrasses are the main habitat for coastal marine ecosystems. They provide different services like sediment retention (and thus clearer waters), coastal protection (in front of marine storms), shelter for marine organisms, etc... Therefore, the state of the seagrasses are a convenient proxy for the state of coastal environment. That is, large well preserved extensions of seagrasses lead to a better coastal marine environment which in turn is more resilient in front of hazards.

Seagrass rank among the most threatened habitats in the biosphere, with about 1/3 of the area lost since the 1940's and accelerated loss rates over time (Waycott et al. 2009). The bulk of losses are attributable to the wasting disease that devastated Zostera marina meadows in the 1930's (Tutin 1943) and eutrophication-driven losses (Orth et al. 2006). However, there are growing reports of seagrass mortality associated with marine heat waves, including mortality of Posidonia oceanica in the Western Mediterranean following the 2003 heat wave (Marbà and Duarte 2010; Diaz-Almela, Marbà, Martínez, Santiago, Duarte, 2009), mass mortality of Amphibolis antarctica in Shark Bay following an unprecedented marine heat wave in 2010/2011 (Arias-Ortiz et al. 2018), and warming has been implicated in recent mass mortality of shallow Thalassia testudinum meadows in Florida Bay (Carlson et al 2018) and Zostera marina and Ruppia maritima in Chesapeake Bay (Moore and Jarvis, 2008; Moore, Shields, Parrish , 2014).

Whereas much attention is devoted to understanding warming-induced bleaching and mortality of corals (e. g., Lough, Anderson, Hughes, 2018; Hughes et al. 2018), similar mass-mortality on seagrass has received comparatively little attention, despite evidence that these impacts are propagating across the ocean as marine heat waves become more prevalent and intense (Frölicher, Fishcher, Gruber, 2018; Oliver et al 2018). A first step, required to determine the risk of seagrass mortality under marine heat waves, is to determine the thermal thresholds for seagrass mortality. In contrast to corals, whose distribution is restricted to the subtropics and tropics and, therefore, experience relatively narrow climatic conditions and comparatively uniform thermal niches (Spalding, Ravilious, Green, 2001), seagrasses occur from polar regions (in the northern hemisphere) to the Equator, thereby experiencing broad thermal regimes (e.g. Lee, Park, Kim, 2007; Olesen, Krause-Jensen, Marbà, Christensen, 2015). For marine ectotherms, both upper and lower thermal limits generally decrease with latitude toward the poles (Sunday, Bates, Dulvy, 2011). This pattern has been observed to be consistent with respect to both fundamental thermal limits (i.e. based on laboratory experiments; Sunday et al. 2011), and realized thermal limits (i.e. based on species distributions; Stuart-Smith, Edgar, Bates, 2017), across a range of animal taxa including fishes, benthic and pelagic invertebrates (Sunday et al. 2011; Stuart-Smith et al. 2017). To date, however, large-scale geographic patterns in the thermal limits of marine plants remain untested.

Here we evaluate the present coverage of seagrasses in most European islands, test the hypothesis that seagrass thermal limits decline with increasing latitude, and assess the proximity of extant seagrass meadows to their upper thermal limits as well as the time required for these thermal limits to be met under different emission scenario of greenhouse gases emissions (RCP, Collins et al., 2013). We do so by combining a synthesis of reported empirically- or experimentally-determined thermal limits for seagrass with current and future thermal regimes derived from an ocean reanalysis and global climate models (GCMs).

3 Methods

3.1 Thermal limits

We compiled the available seagrass upper thermal thresholds published in the literature by conducting a search using Web of Knowledge with the keywords combinations seagrass AND (temperature OR warming) and seagrass AND ("thermal limit" OR "thermal threshold" OR "critical temperature" OR "thermal niche") and by screening the reference list of relevant papers found in these searches. We amended the compilation with our own experimentally-derived unpublished observations. We only included data of seagrass populations growing submersed within their native geographical range. The upper thermal thresholds were derived from mesocosm experiments where seagrasses were exposed to at least 2 temperature treatments (encompassing up to 5ºC to 18 ºC) above average in situ summer temperature which extended the experimental thermal range beyond the upper seagrass thermal limit, or empirical observations of seagrass die-off events attributed to heat waves, in combination with other simultaneous stressors (hypersalinity, Carlson et al 2018; low light availability, Moore and Jarvis 2008, Moore et al., 2014) (Table 1).

Unless reported in the compiled papers, the upper thermal limit was defined as: a) the upper temperature at which shoot survival, shoot growth or biomass above optimal temperature started to decline in experimental studies; or b) the seawater temperature during the heat wave that triggered die-off events. More details can be found in Marbà et al., (2020).

In particular, here we consider four different species, Posidionia Oceanica, Zostera Marina, Cymodocea Nodosa and Halophila. The present coverage of seagrasses has been obtained from UNEP-WCMC (2017) and from the Spanish Atlas of marine seagrasses (Ruiz et al,. 2015). The upper thermal limit established for each of the species has been 28.0ºC, 26.2 ºC, 34.0ºC and 36.2ºC, respectively.

3.2 Thermal projections

For the Atlantic islands present temperatures at different depths are characterized using the ORAS4 ocean reanalysis, while the CMIP5 ensemble of global climate models is used to project the temperature evolution under different greenhouse gases emissions (Table 1). For the Mediterranean, the MEDHYMAP product has been used to characterize present temperatures, while the MedCORDEX ensemble of ocean models (Soto-Navarro et al., 2020) has been selected for the projections. Those products have been chosen as they provide a more robust representation of the processes inside that complex basin (Table 2). Summer temperatures in the whole water column have been considered as the key diagnostic to determine whether a particular location will reach the upper thermal threshold for each species. Another important aspect is that no simulations for scenario RCP2.6 are available, so we have used a scaling approximation. Namely, the projected changes in sea level rise under RCP2.6 are considered to be about half of the projected changes under RCP4.5, while keeping the same spatial structure in each model. That is, the impact of the greenhouse gas concentration is basically a change in the intensity of a spatial pattern, which is model dependent. Therefore, in order to approximate the future evolution under the RCP2.6 scenario we have multiplied by 0.5 the changes modelled under RCP4.5.

Model acronym	Responsible institution
ACCESS1-0	CSIRO and BOM, Australia
BCC-CSM1.1	Beijing Climate Center, China Meteorological Administration
CanESM2	Canadian Centre for Climate Modelling and

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	Analysis
CNRM-CM5	CNRM and CERFACS
CSIRO-Mk3-6-0	CSIRO and QCCCE
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory
GISS-E2-R	NASA Goddard Institute for Space Studies
HadGEM2-CC	Met Office Hadley Centre
HadGEM2-ES	Met Office Hadley Centre
INM-CM4	Institute for Numerical Mathematic
IPSL-CM5A-LR	Institut Pierre-Simon Laplace
IPSL-CM5A-MR	Institut Pierre-Simon Laplace
MIROC5	AORI ,NIES and JAMSTEC
MIROC-ESM	AORI ,NIES and JAMSTEC
MIROC-ESM-CHEM	AORI ,NIES and JAMSTEC
MPI-ESM-LR	Max Planck Institute for Meteorology
MPI-ESM-MR	Max Planck Institute for Meteorology
MRI-CGCM3	Meteorological Research Institute
NorESM1-M	Norwegian Climate Centre
NorESM1-ME	Norwegian Climate Centre

Table 1: Ensemble of CMIP5 simulations used to estimate the temperature evolution in the Atlantic and Baltic islands. RCP4.5 and RCP8.5 scenarios are available for each simulation.

Model	RCP2.6	RCP4.5	RCP8.5
AWI50		X	X
AWI25			X
LMD-CNRM			X
LMD-IPSL			X
LMD-MPI			X
JRC-EC		X	X
JRC-MPI		X	X
UBEL-MPI			X
ENEA-CNRM		X	
CNRM-CNRM	X	X	X

Table 2: MedCORDEX ensemble of regional ocean models used to estimate the temperature evolution in the Mediterranean islands.

4 Results

The results are presented in terms of % of area lost by warming for each region and each species for which coverage information was available (Table 3). The only noticeable changes projected are for Posidonia seagrasses in the western Mediterranean (Balearic, Sardinia, Malta and Sicily) in which the coverage of that dominant seagrass would be reduced between a 14 and 35% at the end of the century under scenario RCP8.5. In the eastern Mediterranean the thermal threshold is higher as far as Posidonia has adapted to the warmer conditions, and thus is more resilient to projected warming.

Island	Specie	Present Area covered (km^2)	A loss (%) RCP85 (2046-2065)	A loss (%) RCP85 (2081-2100)	A loss (%) RCP45 (2046-2065)	A loss (%) RCP45 (2081-2100)	A loss (%) RCP26 (2046-2065)	A loss (%) RCP26 (2081-2100)
Balearic	**Cymodocea**	30,2	0,0	0,0	0,0	0,0	0,0	0,0
Balearic	**Zostera**	0,3	100,0	100,0	16,7	100,0	0,0	16,7
Balearic	**Posidonia**	1002,0	0,0	35,1	0,0	0,0	0,0	0,0
Canary	**Cymodocea**	83,1	0,0	0,0	0,0	0,0	0,0	0,0
Canary	**Zostera**	4,3	0,0	0,0	0,0	0,0	0,0	0,0
Canary	**Halophila**	4,3	0,0	0,0	0,0	0,0	0,0	0,0
Crete	**Posidonia**	17,4	0,0	0,0	0,0	0,0	0,0	0,0
Sardinia	**Posidonia**	1963,2	0,0	14,4	0,0	0,0	0,0	0,0
Corsica	**Posidonia**	2258,9	0,0	0,0	0,0	0,0	0,0	0,0
Cyprus	**Posidonia**	84,3	0,0	0,0	0,0	0,0	0,0	0,0
Malta	**Posidonia**	143,6	0,0	20,1	0,0	0,0	0,0	0,0
Sicily	**Posidonia**	966,3	0,0	28,3	0,0	0,6	0,0	0,0

Table 3: Present coverage (in km2) of the main seagrass species in those islands where the information was available. Projected change in relative terms (in %) of the coverage of each seagrass under different scenarios and two time horizons, the near future (2046-2065) and the far future (2080-2100).

To get a better insight in the process, we focus on the Balearic islands, where seagrass losses are expected to be the largest (maps for the other islands can be found in deliverable 4.3), and on the Posidonia Oceanica, the dominant seagrasse in the region (covering 1000 km^2). Present summer temperatures at seagrass locations range from over 25ºC in the shallower areas to 15ºC in the deeper locations where seagrass is found (30-40 m depth, see Figure 2). Therefore, as expected, seagrasses in the shallowest areas are more exposed to warming and closer to their upper thermal limit. The projected temperature change for the end of the century (2080-2100) under a business-as-usual scenario (RCP8.5) is up to 4 $\pm$ 1ºC in most of the shallowest locations (uncertainty defined by the intermodel spread). In the deeper areas the expected warming is lower, although noticeable (2-2.5 $\pm$ 1ºC). Under a moderate scenario (RCP4.5), the largest expected warming is below 2 $\pm$ 0.75 ºC at all locations.

As a consequence of the warming pattern, the upper thermal limit for Posidonia Oceanica (28ºC) will be reached in the shallowest parts of the Balearic Islands at the end of the century under scenario RCP8.5. This in turn would imply the functional loss of Posidonia Oceanica seagrasses in those parts (see red dots in Figure 3). The final result will be a loss of 35% of the area covered by this plant.

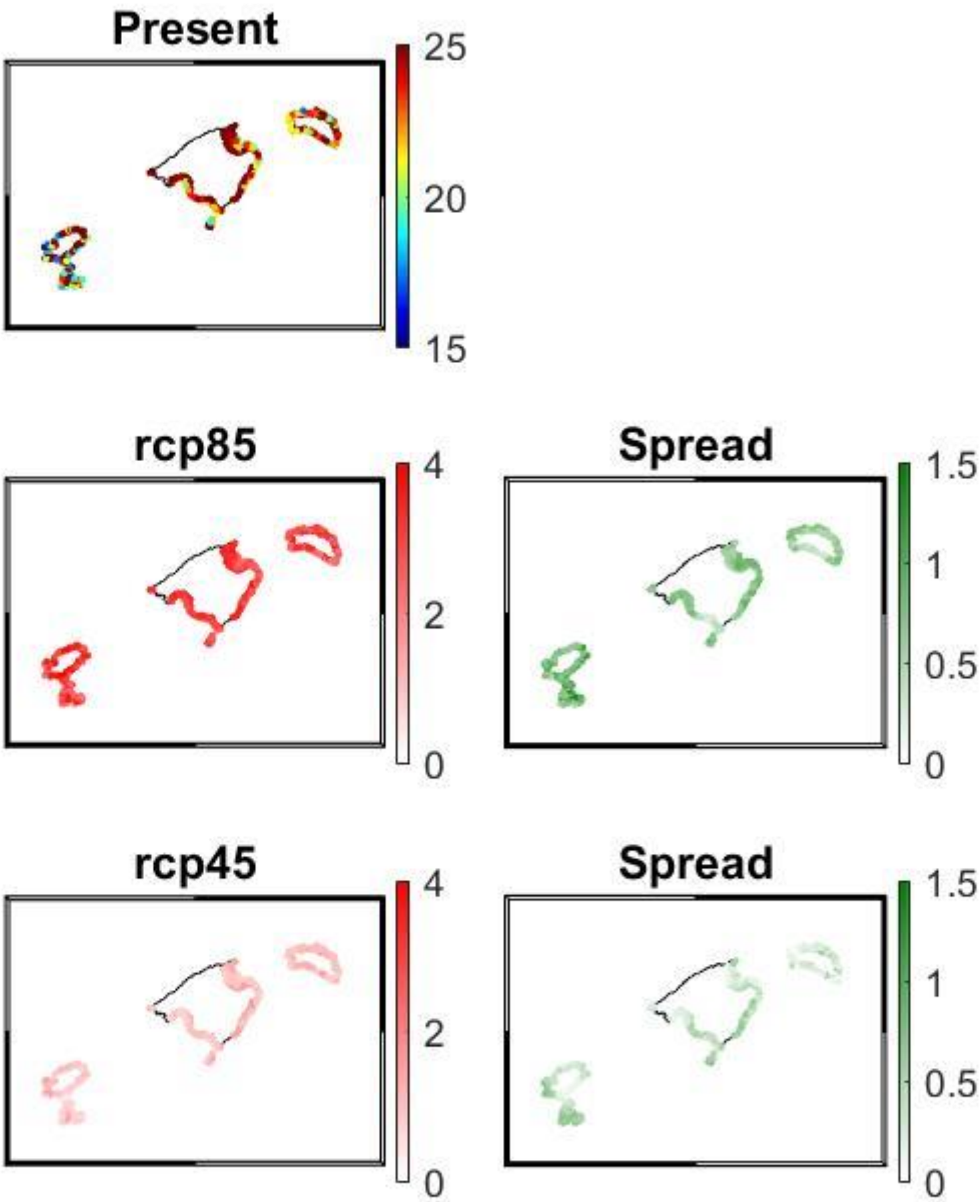

Figure 2- Summer temperature (in ºC) in the Balearic islands at the locations where Posidonia Oceanica is present. (Top) Present temperatures (Middle) Projection of summer temperature anomalies for 2080-2100 under scenario RCP8.5. (Bottom) Projection of summer temperature anomalies for 2080-2100 under scenario RCP4.5. In the right column the intermodel spread (i.e. uncertainties) are shown.

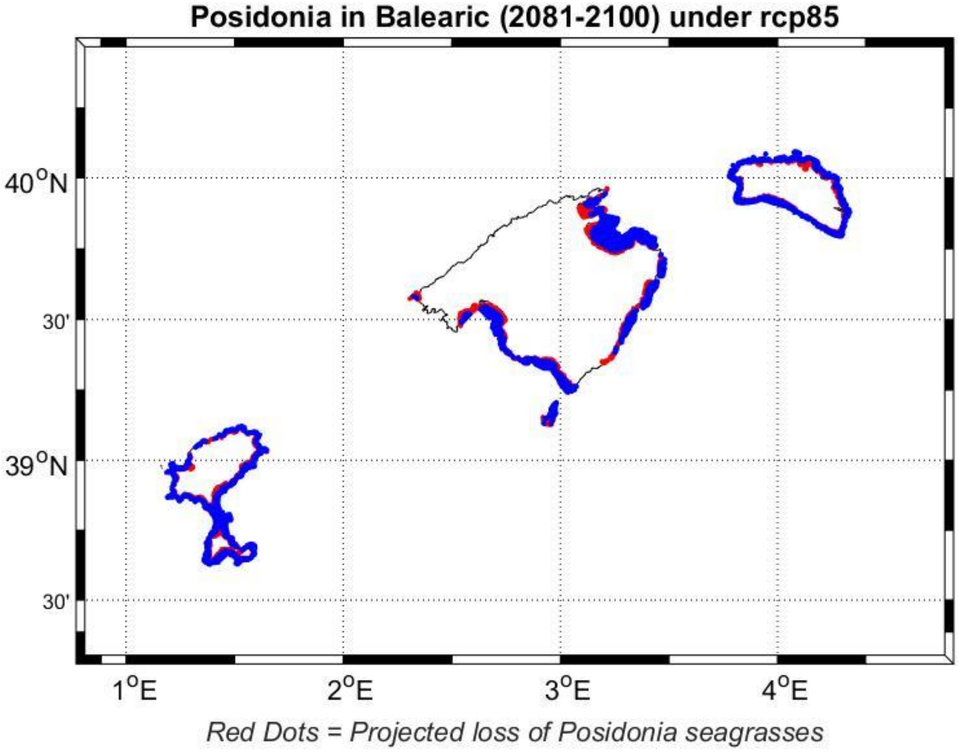

Figure 3- Spatial coverage of Posidonia Oceanica in the Balearic Islands (blue) and projected losses under scenario RCP8.5 at the end of the 21st century.

5 Conclusions

Seagrasses are the main habitat for coastal marine ecosystems. They provide different services like sediment retention (and thus clearer waters), coastal protection (in front of marine storms), shelter for marine organisms, etc... Therefore, the state of the seagrasses are a convenient proxy for the state of coastal environment. Here we have analysed temperature projections for different European Islands and assessed wether the upper thermal limit of the main four foundation species would be met under different climate change scenarios. Our results suggest that noticeable seagrass losses could be expected under scenario RCP8.5 by the end of the century. In particular the losses would be concentrated in the Western Mediterranean (Balearic, Sardinia, Malta and Sicily) in which the coverage of Posidonia Oceanica would be reduced between a 14 and 35%. In the eastern Mediterranean the thermal threshold is higher as far as Posidonia has adapted to the warmer conditions, and thus is more resilient to projected warming. Although the projected reduction may seem moderate, it has to be kept in mind that the losses will be localized in the nearshore areas, so it is expected a large impact on water transparency in beach areas. Ecosystem services will be probably be less affected.

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