ERANet-LAC - JOINT CALL 2015-2016

Climate driven Changes in the Habitat Suitability of Marine Organisms (CLIMAR)

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D5.1. A synthesis report of the results from the geographical and system case studies

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Deliverable D5.1.

Summary
This deliverable describes the predictions on the future thermal habitats of the marine species investigated, using the results obtained from the coupled physiological-oceanographic models applied at the different study cases. Numerical simulations were used to compare the thermal environment characterizing different climatic scenarios including the Present Day scenario (PD), the Future Day RCP45 and the Future Day RCP85. For each scenario and study site, the spatial and temporal variability of the daily sea water temperature were simulated considering a full decade for both present day (i.e. 1996-2005) and future (i.e. 2090-2099) scenarios. For each study case, the variation in the thermal habitat of a given species was analysed at different scales, from coastal to regional, in order to model THR (i.e. Average Thermal Risk) and THB (Average Thermal Buffer) of each species. This report presents the general principles used in the coupling, using the Mediterranean Sea and South West Atlantic regions as the first examples. The plans for the implementations on the model are outlined for the Chilean coast and the Baltic Sea.

Numerical simulations: Numerical simulations were carried out to compare the thermal environment characterizing different climatic scenarios including the Present Day scenario (PD), the Future Day RCP45 and the Future Day RCP85. For each scenario and study site the spatial and temporal variability of the daily sea water temperature were simulated considering a full decade corresponding to the 1996-2005 for the PD and to the 2090-2099 for both the future scenarios (RCP45

and RCP85). Therefore, model results (T) were used as input data for solving the THR (i.e. Average Thermal Risk, the relative distance from the middle temperature to CTMIN or CTMAX, see Deliverable 3.1.) and THB (i.e. Average Thermal Buffer, the maximum range in temperatures available at an in-situ temperature prior to exceeding one of the two extremes, see Deliverable 3.1.) functions for each study site and selected marine species. The obtained results were processed to analyse the effects of climatic changes on the habitat shifting.
A 2-levels approach was followed consisting into a low resolution application at global scale and a high resolution numerical application carried out at local scale. In the first phase, the data provided by the CMCC Earth System Mode CMCC-ESM2 accounting for interactive dynamics of atmosphere ocean, sea-ice and land-components with the inclusion of the marine biogeochemistry were used to reproduced at basin scale the time and space variability of the sea water temperature for each climatic scenario for both Mediterranean Sea and the South-West Atlantic Ocean.
The second phase consisted into applying a high resolution ocean model to specific coastal sites in order to reproduce the sea water temperature variability during a full year characterizing the Present Day and the RCP45 and RCP85 climatic scenario. Data from available ocean and meteorological large scale models were used as model forcing for the Present Day scenario, whereas both future climatic scenarios were simulated following a delta approach by computing the differences in water temperature between the PD and each future scenario from the previous large scale ocean dataset and applying the obtained delta to the present Day simulated daily temperature fields.
Finally, both the datasets at basin and coastal scale were used to reproduce the daily variation of the THR and THB 3D-fields in each selected study and for each marine species.

A) Mediterranean Sea

For the Mediterranean study case the variation in the thermal habitat of *P. lividus* were analysed both at regional, sub-regional and coastal scale. For the sake of clarity only the results obtained from the thermal buffer analysis were reported.
In Figure 1 the yearly average THB distribution obtained from the sea surface temperature data are depicted for the Present Day (panel A), RCP45 (panel B) and RCP85 (panel C) climate scenarios. THB varies, at basin scale, between 0.6 and 0.8 for scenarios PD, between 0.7 and 0.9 for scenario RCP45 and, between 0.65 and 0.8 for scenario RCP85. The comparison between PD and the future scenarios evidenced that the increasing of the sea surface temperature due to the climate change, will generally favor the metabolic activities of the sea-urchins in the Western and Central part of the basin (higher THB) whereas it will reduce the available temperatures ranges in the eastern part (lower THB).

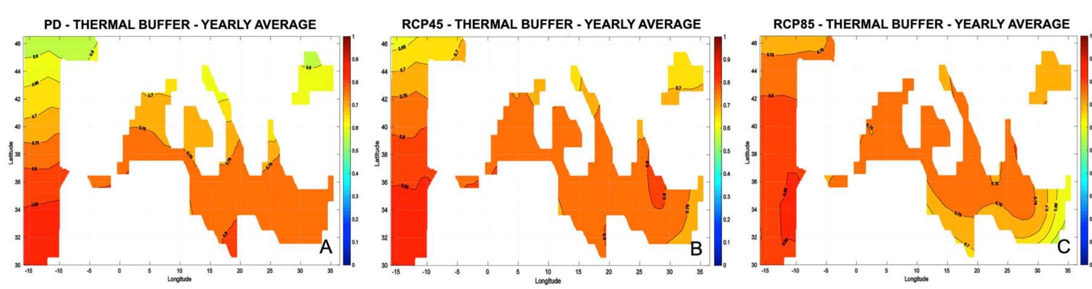

Fig. 1. 10 years averaged THB distribution obtained from sea surface temperature data for scenario PD (panel A), scenario RCP45 (panel B) and scenario RCP85 (panel C).

In figure 2, the seasonal evolution of the THB was computed for 5 sites located from West to East in the Mediterranean Sea as depicted in the map. For all the sites, the effects of the climate change results into an increasing of the THB during the cold periods (Winter and early Spring and late Fall) and a generalized reduction of the THB during hot periods especially in Summer. This trend is particularly marked for the eastern locations where during summer the THB dumps from 0.65 in PD to 0.3 in RCP85.

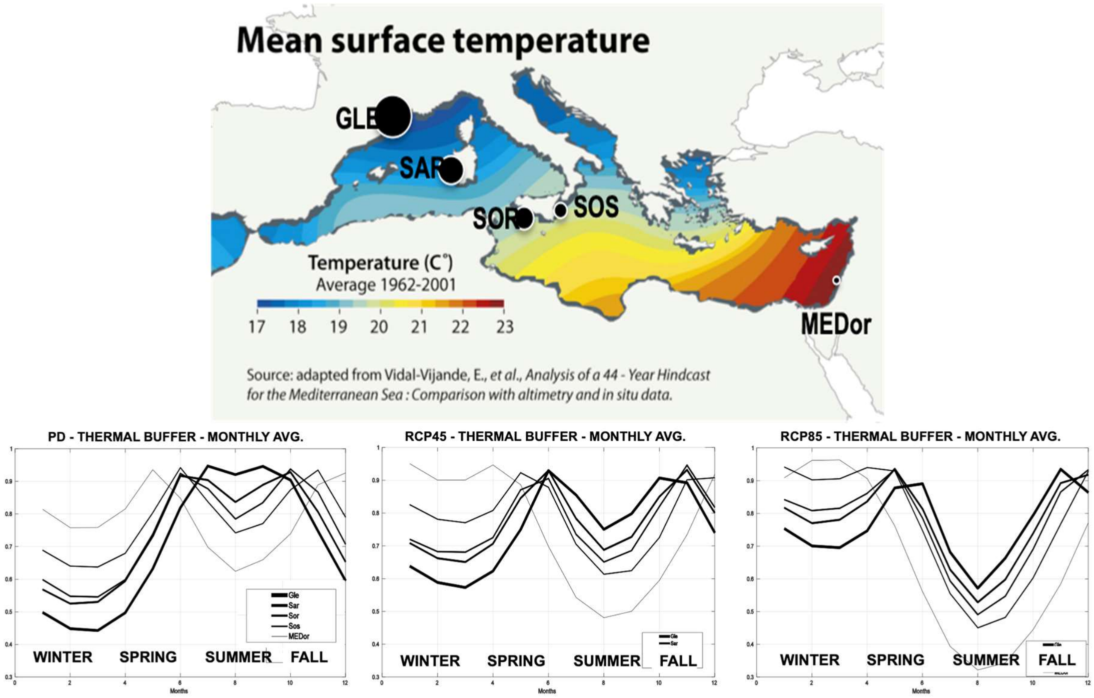

Fig. 2. 10 years daily average THB time series for the 5 sites from West to East in the Mediterranean Sea for PD, RCP45 and RCP85

At local scale the analysis focused on a specific site located on the eastern side of the Sicily Island where the Sea Urchins constitute an economic resources. In figure 3, the model domain as discretized throughout the finite element method is reported along with the geographical location of the Augusta Bay, the selected study site, and the monthly averaged sea surface temperature obtained for January and August from the downscaling procedure of the PD simulated scenario.

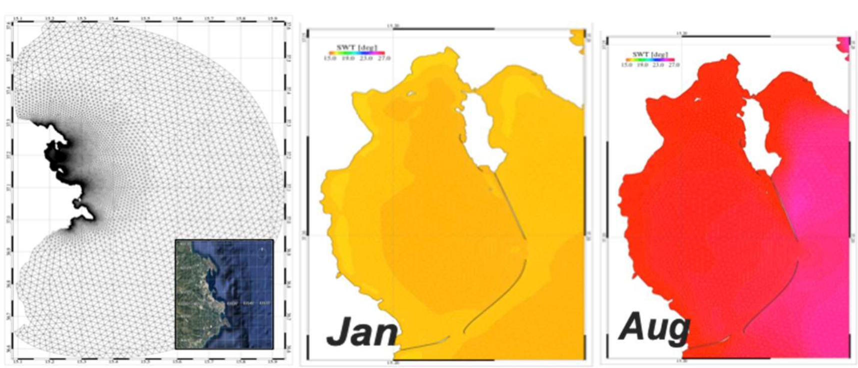

Fig. 3. high resolution model domain of the Augusta Bay (left panel) and monthly averaged sea surface temperature computed for January and August from PD scenario numerical results.

The data obtained from the numerical simulations at daily frequency were analysed at seasonal time scale evidencing that, for the PD scenario, the sea water temperature at coast generally varied between 15° in Winter up to 28 degrees in Summer season. The delta approach was then applied to obtain the time and space variation of the sea water temperature at coastal scale. The adopted temperature increments were varying in time as obtained from the comparison of a full year simulated run. For both scenario, , the highest temperature increments were in Summer with value up to 2.3° for RCP45 and up to 4° for RCP85. The obtained dataset were used as input for the THB functions and the results reported in form of time series for a site located on the bay coastal area are depicted in Figure 4.

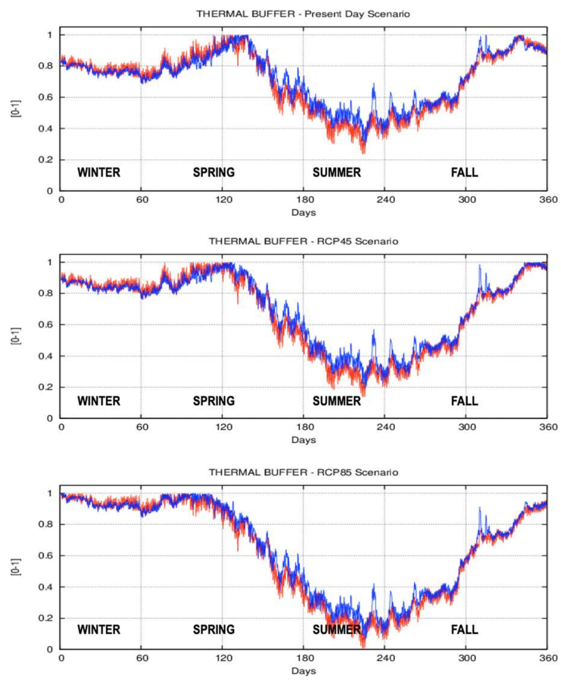

Fig. 4. THB time series obtained from each simulated scenario for the coastal areas of the Augusta Bay.

As for the large scale analysis the THB seasonal evolution, characterized by general higher values in Winter and Lower in Summer, is strongly affected by the increment of the sea water temperature due to climate change. Comparing the THB time series obtained from the PD scenarios and the RCP45 and RCP85 scenarios, the values increase during the cold periods and strongly decrease during hot season. In particular, considering the RCP85 scenario results, a critical condition, denoted by THB=0, could be experienced by the sea urchin population living in the Augusta bay coastal area in the next century.

B) Southwest Atlantic Ocean

For the Southwest Atlantic Ocean study case the variation in the thermal habitat of *E. maclovinus* were analyzed both at regional and coastal scale. For the sake of clarity only the results obtained from the thermal buffer analysis were reported.

In Figure 5, the yearly average THB distribution obtained from the sea surface temperature data are depicted for the Present Day (panel A), RCP45 (panel B) and RCP85 (panel C) climate scenarios for the whole South Atlantic and Pacific Ocean.

In the area between 32°S and 56°S, which correspond to the distributional area of *E. maclovinus*, the THB varies between 0.3 and 1 for scenarios PD, between 0.1 and 1 for scenario RCP45 and, between 0 and 1 for scenario RCP85. The gray line in panel A of figure 5 indicates the zone THB is at its

maxima which correspond to the strip around the 40°S of latitude. As a results of the climate change and of the consequent increment of the temperatures the optimal thermal zone moves southward in both RCP45 and RCP85 scenarios results. In particular, a south-shifting trend varying between 6° to 3° degrees is detected between the PD and the RCP45 scenario (yellow line in panel B of figure 5, whereas differences up to 5°-8° are found when considering the RCP85 scenario results.
The comparison between PD and the future scenarios highlighted that the increase of the sea surface temperature due to the climate change, will generally favor the metabolic activities of *E. maclovinus* in the southern part of the domain (increments in THB) whereas it will reduce the available temperatures ranges in the northern part of the domain (lowering of the THB).

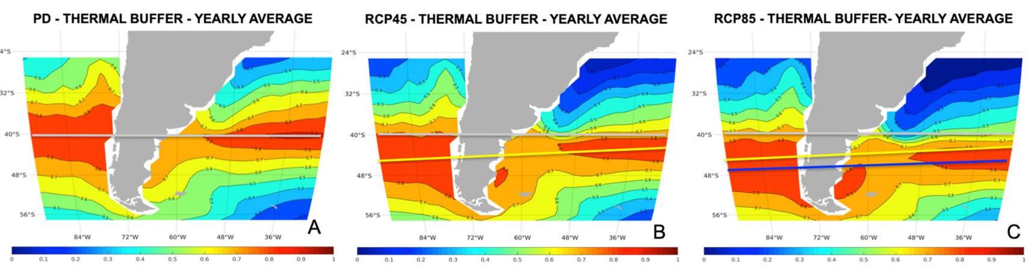

Fig. 5. 10 years averaged THB distribution obtained from sea surface temperature data for scenario PD (panel A), scenario RCP45 (panel B) and scenario RCP85 (panel C).

Similarly to the Mediterranean study case in figure 2, the seasonal evolution of the THB was computed for 4 sites located from North to South (Fig. 6). The temporal variation of THB depends on the latitude of the site, with point A (northernmost) characterized by low THB values around 0.4 and with higher values in winter and lower in summer; point B at 40°S with highest values in middle seasons, spring and fall, and lower values in both winter and summer; point C at 48°S with highest values in Summer and Spring and lower in Winter and point D at 56°S similarly with maximum in hot seasons and minimum in winter. The effect of climate change on the THB time varaibility is also strongly related to the latitude, with southernmost point D experiencing a generally increasing of the THB due to the higher water temperature and the northernmost point A with THB dumped to low values during the whole year. At the intermediate sites B and C, the THB increase during the winter periods and decrease during the summer. This trend is particularly evidenced for the RCP85 scenario results with THB values lower than 0 reached at northernmost location during most of the year and therefore indicating a very critical thermal condition for the living of *E. maclovinus*. On the other hand, the southernmost position is strongly favored by the temperature increments predicted by RCP85 scenario which push THB values up to 0.85.

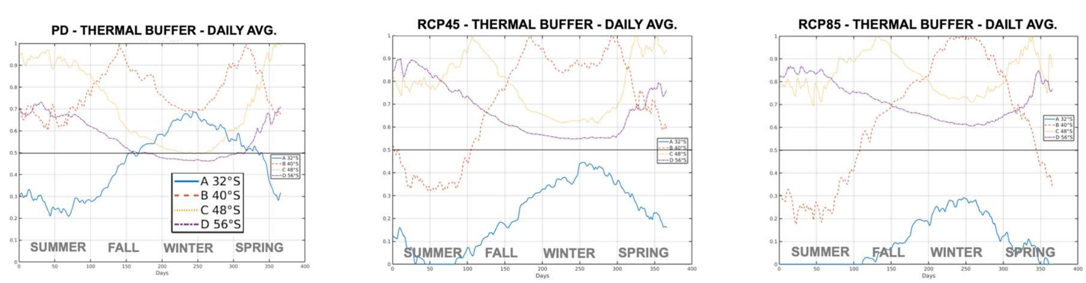

Fig. 6. 10 years daily average THB time series for the 4 sites located along the coast of the Southwest Atlantic Ocean for PD (left panel), RCP45 (central panel) and RCP85 (right panel).

At local scale the analysis was focused on the Beagle Channel coastal area located on the Southernmost tip of the South America where *E. maclovinus* is present. In figure 7, the high resolution model domain is reported depicting the yearly averaged sea water temperature and salinity distribution.

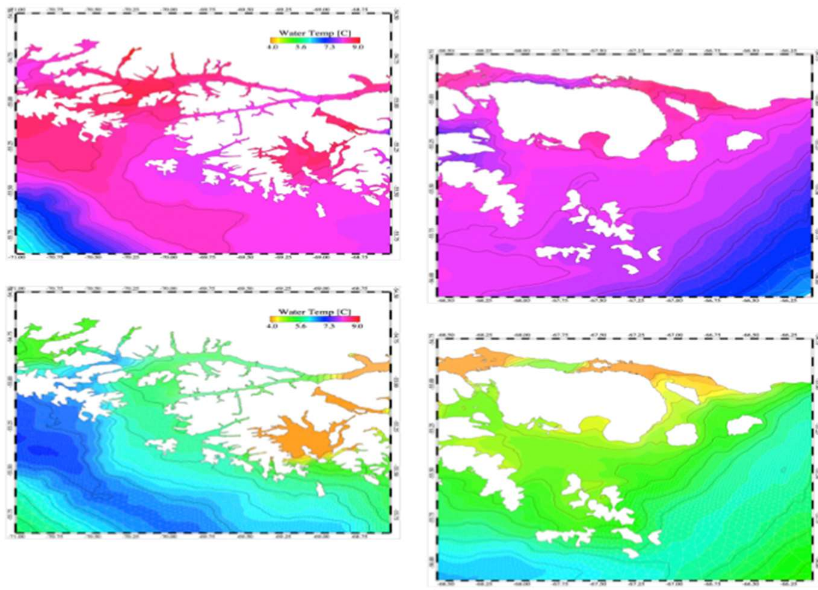

Fig. 7. High resolution model domain of the Beagle Channel. Yearly averaged sea surface temperature (left panels) and salinity (right panels) computed for the investigated area from the PD scenario numerical results.

As for the Mediterranean study case the delta approach was applied to the PD numerical results obtain the time and space variation of the sea water temperature at coastal scale and consequently the THB distribution for all the three scenarios. In figure 8 the THB time series during a whole year is reported for a coastal site inside the channel in proximity of the Ushuaia Bay for all the three scenarios.
As for point D in previous large scale analysis the THB seasonal evolution, characterized by general higher values in Summer and Lower in Winter, is affected by the increment of the sea water temperature due to climate change. In particular, at these latitudes THB values generally increase during the whole year due to the increment of the water temperature indicating that the future climatic scenarios could favor the physiological performances of *E. maclovinus.*

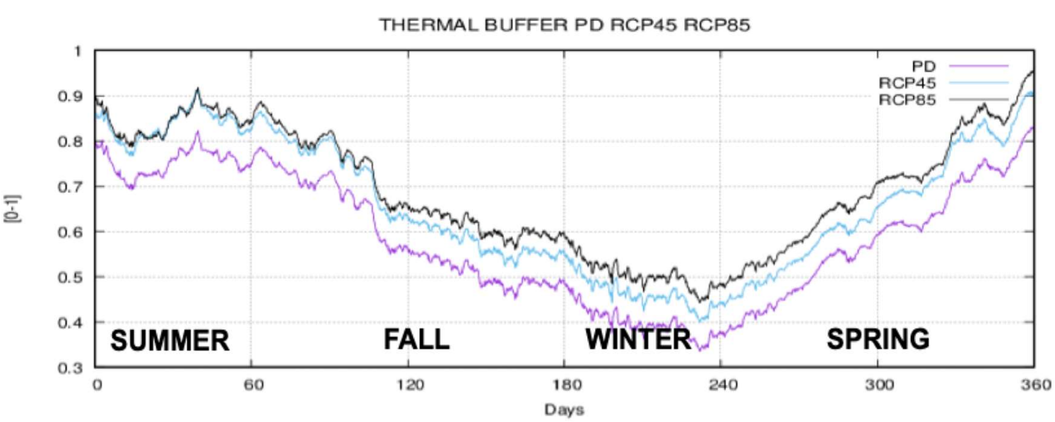

Fig. 8. THB time series obtained from each simulated scenario for coastal areas locate in Beagle Channel.

C) Chilean coast

The corresponding oceanographic model is still under development. We only started the work of developing the oceanographic model once the laboratory experiments were finished by the end of the last year (October 2019). This model is a regional numerical model to simulate the spatial and temporal variability of the sea surface temperature in the north-central coast of Chile for present and the near future conditions. The model, with high spatial resolution, will be used along with the biological responses measured in both species to predict potential effects of increments in the sea surface temperature on theme in this area of our country (northern Chile). Once the model is finished we will incorporate the behavioral data and then we will able to make predictions on the future thermal habitats of the investigated marine species in northern Chile.

D) Baltic Sea

Coupling to the downscaled physical and biogeochemical model runs is ongoing. These steps are described in Del 3.1. Ecophysiological results on embryos and young larvae of herring and garpike (along with other available information from the peer-reviewed literature) will be used to create thermal buffers and thresholds for both species linked to physical and biogeochemical projections for Baltic Sea coastal areas. The results of a literature synthesis including new laboratory measurements on Atlantic herring and European sea CTmax and CT min produced in CLIMAR (Moyano et al. 2017) were made available to climate projection modelers in the EU project CERES "Climate Change and European Aquatic Resources – ceresproject.eu). Future projections of changes in the distribution and productivity of herring were simulated using a DBEM (Dynamic Bioclimate Envelop Modeling). Those results are provided in Chapter 5 of the CERES synthesis report (Peck et al. 2020) and in "Storyline 16 – herring in the North Sea" (report with projections). The temperature limits were important for these projections. A major limitation of current projection modelling efforts, however, is the lack of confidence in projections of change in alkalinity (including pH) of marine systems. An important result of CLIMAR is to highlight the importance of creating more robust physical and biogeochemical projections of change in both temperature and pH.