Modelling coralligenous habitat distribution in the Northern Adriatic Sea in a severe climate change scenario

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INTRODUCTION

Marine ecosystems play several key roles such as supporting human and maritime activities, hosting a large portion of global biodiversity, and regulating the global climate dynamics. However, climate change is having a strong impact on oceanographic, biogeochemical, and hydrological processes that regulate the structure and functioning of marine systems. Because of the resulting effects changes in the geographic range of habitats were observed, together with the variations of species distribution adapted to new conditions or seeking new ones.

To forecast the possible variation of habitat distribution under climate change scenarios Habitat Suitability Models (HSMs) have begun to be implemented. These models explore the present and future patterns of species distribution and correlate their occurrences with the environmental variables. In particular, in this study, was analyzed the distribution of the coralligenous, a widespread habitat of the Mediterranean Sea recognized for its importance in providing many ecosystem services. Climate change effects are threatening the presence of this habitat, and since it is of priority importance for conservation, this study investigated the outcrops occurrences in the Northern Adriatic Sea in relation to the mean trends of environmental variables known as essential for the coralligenous growth. Specifically, in the first step of the modeling phase, two-decade means of temperature, salinity, velocity, and light at the sea bottom and concentration of phosphates and nitrates were correlated with the habitat distribution. Successively, temperature, salinity, and velocity at the sea bottom were modeled under an RCP 8.5 climate change scenario, allowing to characterize the future spatial suitability maps and estimate potential habitat shifts.

MATERIALS AND METHODS

The two machine learning methods of HSMs implemented in this study were Random Forest and Maxent.

The coralligenous outcrops occurences in the North Adriatic Sea were collected by georeferencing information reported in Ponti et al. (2005), Falace et al. (2015), and Martin et al. (2014). Each outcrop was classified under habitat typologies by using the classification provided by Falace et al. (2015). Information regarding the habitat typologies is in **Table 1**.

The environmental variables employed in this study were extracted from different sources: temperature, salinity, and velocity at the sea bottom were sampled by the ROMS model; light at the sea bottom was downloaded from the Bio-Oracle dataset; phosphates and nitrates concentration were sampled from the Copernicus Marine Service (CMEMS).

Each model applied run a “Historical” scenario ranging 1999 and 2018, and a climate change scenario under RCP 8.5 for the period 2070 - 2099.

Model accuracy evaluation

The goodness-of-fit and performance were evaluated using the AUC (Area Under the Curve) and the TSS (True Skill Statistic).

AUC visualizes how well the model is performing, ranging between 0 and 1, where 1 means perfect matching.

TSS considers omission and commission errors, it ranges between -1 and +1, where +1 means perfect agreement.

Environmental variables’ importance

Environmental variables' importance and contribution were analyzed using the Mean Decrease Accuracy - %IncMSE for Random Forest, and the Permutation Importance for Maxent.

Table 1: description of the habitat typologies

Habitat	Description
A	Opportunistic and tolerant macroalgal species resistant to mud and organic matter
B	Massive Porifera erect Tunicata and non-calcareous encrusting algae
C	Non-articulated calcareous macroalgae, tunicate

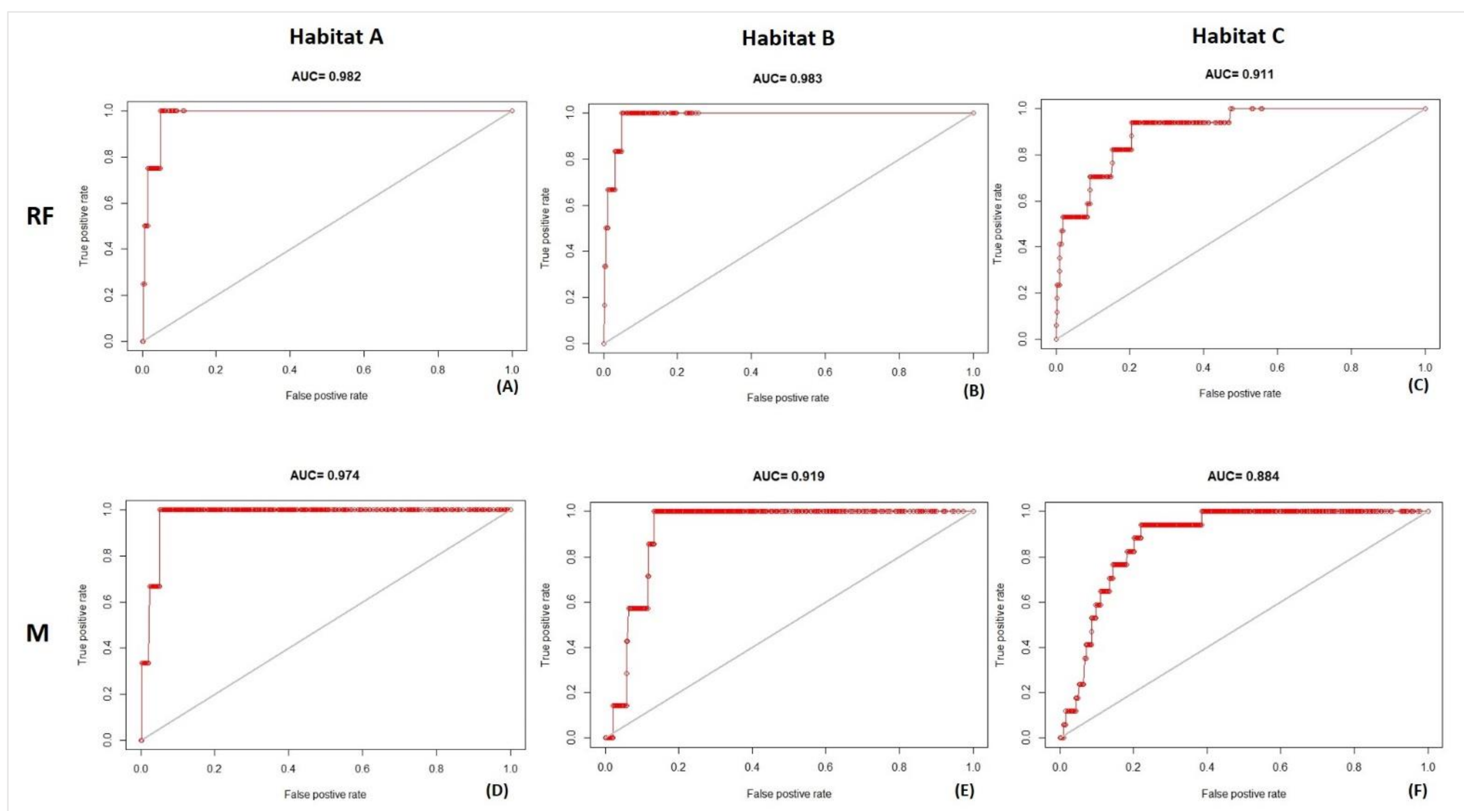

Figure 1: AUC graphics on test dataset

Table 2: Models accuracy evaluation using TSS metrics

TSS	Habitat A	Habitat B	Habitat C
Random Forest	0.95121951	0.95121951	0.73690818
Maxent	0.948328267	0.86666667	0.72099298

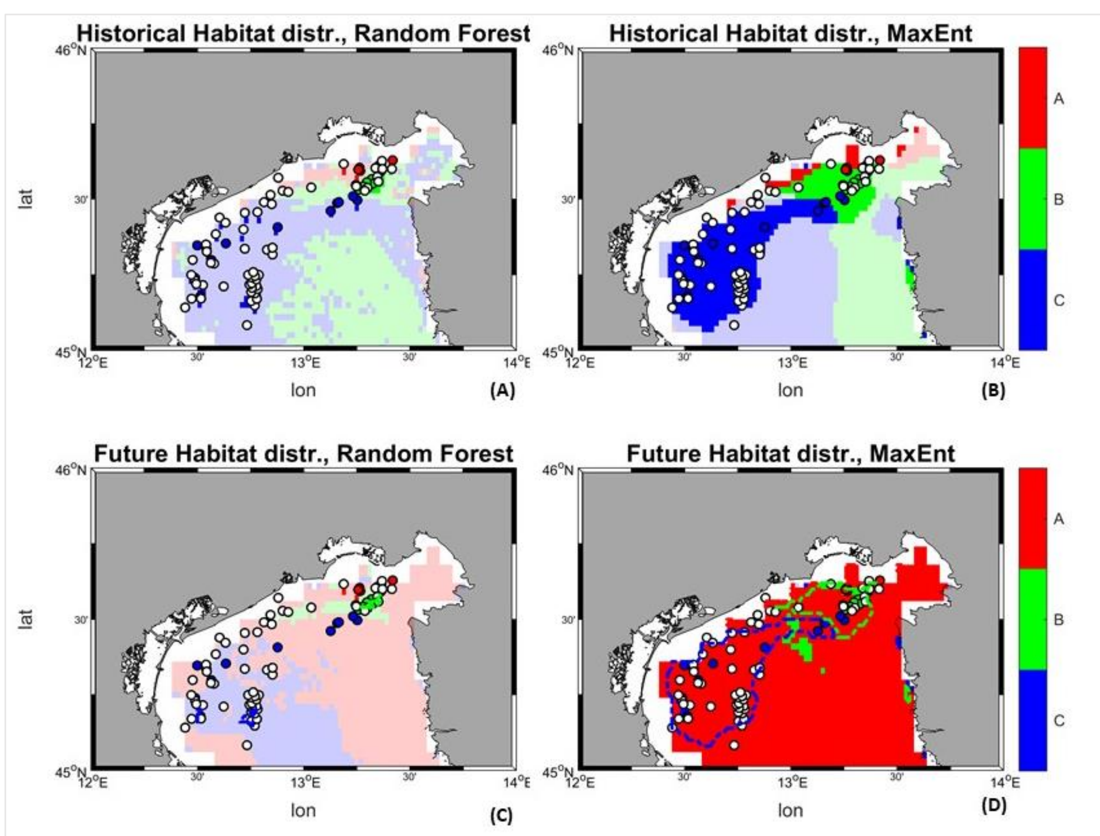

Figure 4: Map with the historical and future distribution of habitats

RESULTS

Accuracy evaluation

AUC values for both Random Forest and Maxent were high (above 0.8), meaning that the models have high prediction accuracy (Fig. 1).

High TSS values were also reported, indicating that both models were reliable (above 0.7) (Table 2). The models were confirmed to be very reliable and worked properly.

Variable importance and contribution

In Random Forest habitat A appeared to be influenced by salinity, phosphates, and nitrates. Habitat B by salinity, temperature, and light. Habitat C is influenced by nitrates, salinity, and temperature. In Maxent habitat A seemed to depend on temperature. Habitat B is influenced by temperature and phosphates and habitat C by salinity, nitrates, and light.

Habitat suitability distribution

The models' output permitted to obtain suitability maps of both the “historical” and “RCP” scenarios (Fig. 2 and Fig. 3). With Random Forest all the three habitats were found to be potentially present in a narrower area close to the occurrences' point. The prediction modeled by Maxent displayed wider areas as suitable with different ranges around the occurrences point. Marked variation between the “Historical” and “RCP” scenarios was observed compared to Random Forest predictions.

Habitat shift

Maps in Fig. 4 allowed to visualize which of the three habitat typologies were most likely to be found in the area of interest. Shaded colors indicated suitability values below 0.5 meaning for low-medium ranges (0.5 = 50% of probability). Marked colors stood for values above 0.5 and overall suitability belonging to high ranges.

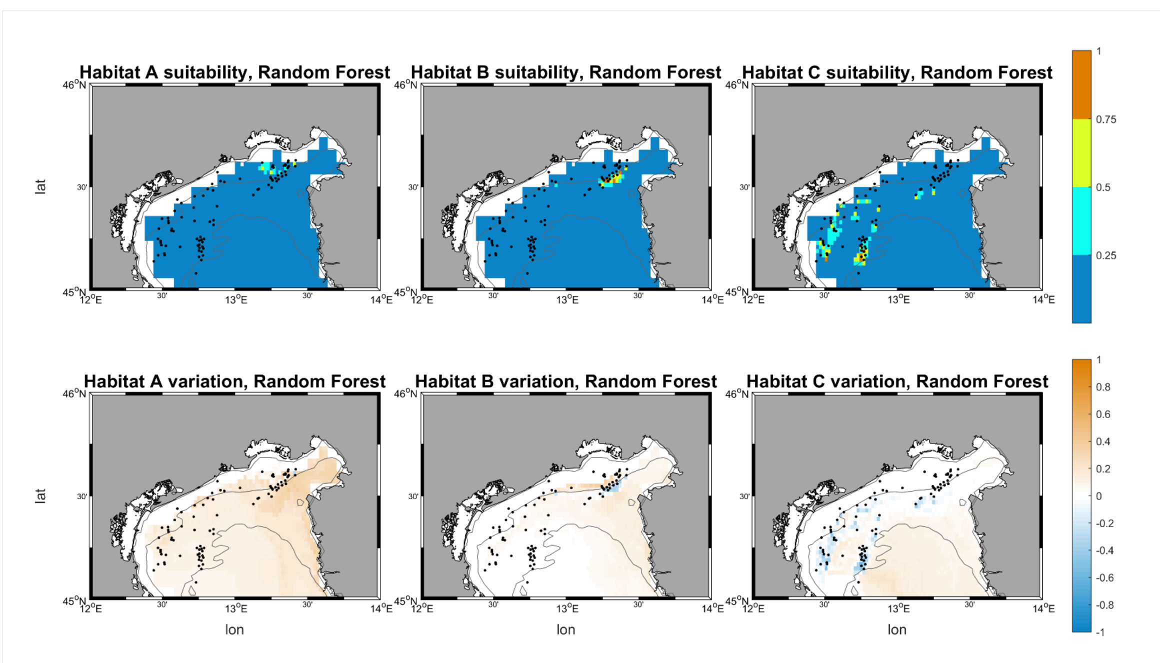

Figure 2: Random Forest suitability maps

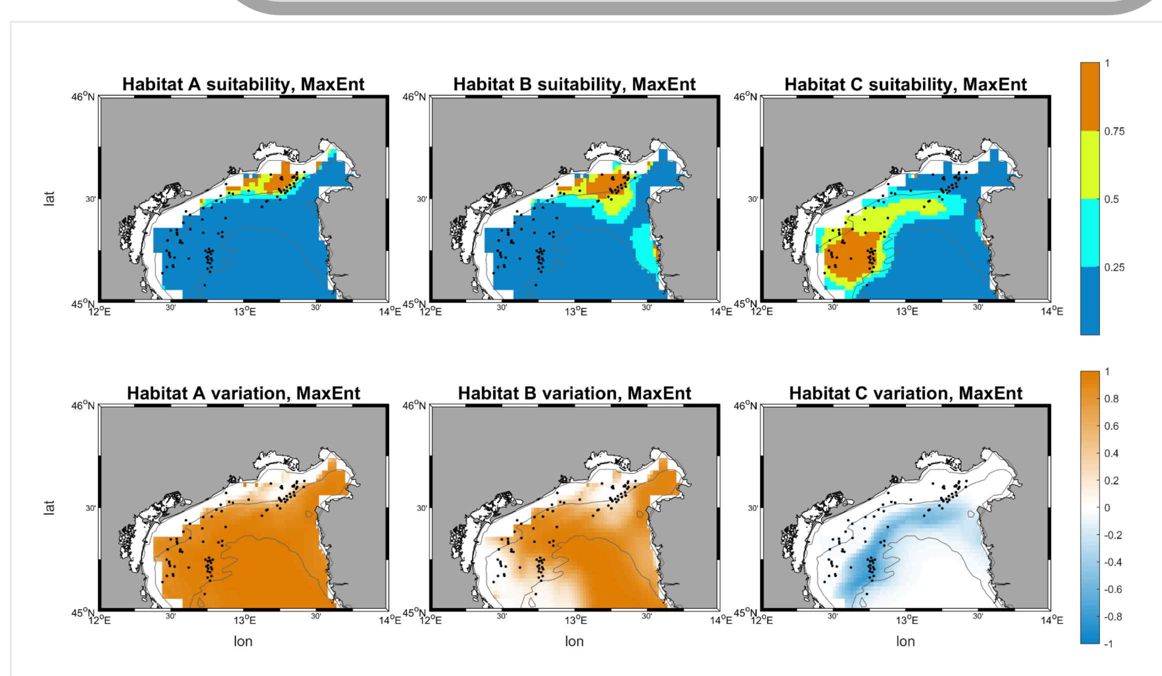

Figure 3: Maxent suitability maps

DISCUSSION

The two applied models were confirmed to be very accurate in predicting the potential spatial distribution of Northern Adriatic coralligenous concretions. Besides, the models were able to correlate environmental features with coralligenous distribution under the climate change RCP 8.5 scenario. Temperature, salinity, and nitrates were found to be the variables that mainly influence the distribution of coralligenous outcrops in the Northern Adriatic Sea.

The habitat suitability maps reported different but comparable results, indeed the two models at a finer scale showed the presence of different suitability ranges. While Maxent reported wider areas suitable for the presence of the coralligenous with a gradual decrease as moving away from the records, Random Forest showed narrower suitable areas. These results are probably due to the presence in Maxent of a built-in parameter called “regularization parameter” which prevented the overfitting of the model by relaxing the algorithm constraints (for more details please see Elith et al., 2010). An ensemble approach combining the diverse models could increase the reliability of the prediction outputs. Under the future climate change scenario, the opportunistic organisms belonging to habitat A were found to expand in stressful conditions. On the contrary, habitat C, mainly characterized by calcareous algae, resulted to be more affected by shifts in the environmental conditions due to climate change.

CONCLUSIONS

The two modeling approaches adopted provided reliable results on the potential distribution of the different habitat types characterizing the Northern Adriatic coralligenous. Partly different outputs arose mainly due to the diverse potential of model algorithms and the built-in parameters that eventually characterize them. Results of future scenarios revealed a potential shift in the distribution of coralligenous communities with the expansion of more tolerant and opportunistic species at the expense of the vulnerable ones under climate changes, with consequential loss of biodiversity in the Northern Adriatic sub-basin.

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