University of the Aegean
Department of Marine Sciences
MSc Integrated Coastal Management

Predictive modeling for the identification of spatial distributions of benthic animal species and key ecological features across the Aegean Sea

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Abstract

Detailed knowledge on the distribution of ecological features is crucial for their effective management and conservation. Existing information is sparse and fragmented and at the same time costly and time consuming to obtain. In this dissertation, predictive modeling was carried out, based on environmental variables, in order to produce the continuous maps of 21 animal species and key ecological features across the Aegean Sea. The predicted distribution maps provide critical information about where the ecological features are most likely to occur. The outputs of the study can be used for the development of marine spatial plans or to guide cost-effective future surveys and monitoring efforts towards areas that are presently poorly-sampled.

1 Introduction

Marine biodiversity is threatened by human activities, global warming, invasive species etc. The need for protection of species and habitats is constant and continuous; international and national policies such as the Barcelona Convention (1976), the Marine Strategy Framework Directive (Directive 2008/56/EC) and the Maritime Spatial Planning Directive (Directive 2014/89/EU) dictate it. When aiming at the effective management and conservation of marine resources, detailed knowledge on the distribution of species and habitats is needed. It has been estimated that only 5–10% of the seafloor is mapped at a comparable resolution to similar studies on land (Wright & Heyman, 2008). Even when geospatial data for species and habitats are available, their extent is limited to specific areas that have been surveyed. Moreover, absence records only exist at those surveyed areas. Mapping marine habitats and species is complicated, costly and time consuming (Katsanevakis et al., 2017).

In the Mediterranean Sea, there have been several attempts at assessing the distribution patterns of species and habitats across the entire basin, based on literature reviews (Bianchi & Morri, 2000; UNEP-MAP-RAC/SPA, 2009;UNEP-MAP-RAC/SPA, 2009; Coll et al., 2010; Danovaro et al., 2010; Giakoumi et al., 2013). Recently, Katsanevakis et al. (2017) produced predictive distributional maps of Potential Habitat Index (PHI) for several animal species, identifying areas that could be prioritized for conservation measures in the Aegean Sea. Sini et al. (2017) utilized a range of data sources and methodological approaches to compile and complement the available data on 68 ecological features of conservation interest in the Aegean Sea. They applied a standardized data evaluation procedure in order to assess the sufficiency of the datasets. The overall dataset was found to be sufficient in terms of reliability and spatio-temporal cohesion, but it lacked in completeness, showing that there are still large areas of the Aegean that remain understudied, while further research is needed to elucidate the distribution patterns and conservation status of several ecological features.

A number of modeling techniques can be used to fill gaps in the knowledge of the spatial distribution of species and habitats by predicting the location of areas that are likely to be suitable for a species to live. Models are usually based on physical and environmental variables (e.g. water temperature, salinity, depth, nutrient concentrations, seabed types, etc), which are typically easier to record and map in contrast to species and habitat data. Despite inherent limitations and associated uncertainties, predictive modeling is a cost-effective alternative to field surveys as it can help identifying and mapping where sensitive marine ecosystems may occur (Martin et al., 2014).

In the present study, predictive modeling was carried out to produce continuous maps of 18 animal species and 3 vulnerable ecological features in the Greek territorial waters of the Aegean Sea (NE Mediterranean) up to 150 meters depth. The datasets used were recently compiled and published by Sini et al. (2017). We anticipate that our results can be used(i) for the development of spatial planning initiatives, and (ii) to guide cost-effective future surveys and monitoring efforts towards areas that are presently poorly-sampled and under-represented in current conservation planning exercises.

2 Materials and Methods

2.1 Study area

The study area includes the Greek territorial waters of the Aegean Sea (NE Mediterranean) up to 150 meters depth (Figure 1). The Aegean archipelago consists of several thousand islands and rock islets with a combined area of 17,550 km^2 and a total coastline length of about 5,880 km (Eurosion, 2004). It has a complex geomorphology, reflecting past geological and geodynamic processes (Sakellariou & Alexandri 2007). It is connected to Black Sea through the Dardanelles straits and to Eastern Mediterranean through the Cretan Arc straits. The Aegean Sea has a high relief, including an extensive shelf (N. Aegean shelf), a tectonic trough (N. Aegean Trough), a central platform (Cyclades plateau) with a large concentration of islands and deep basins (Monioudi et al., 2017).

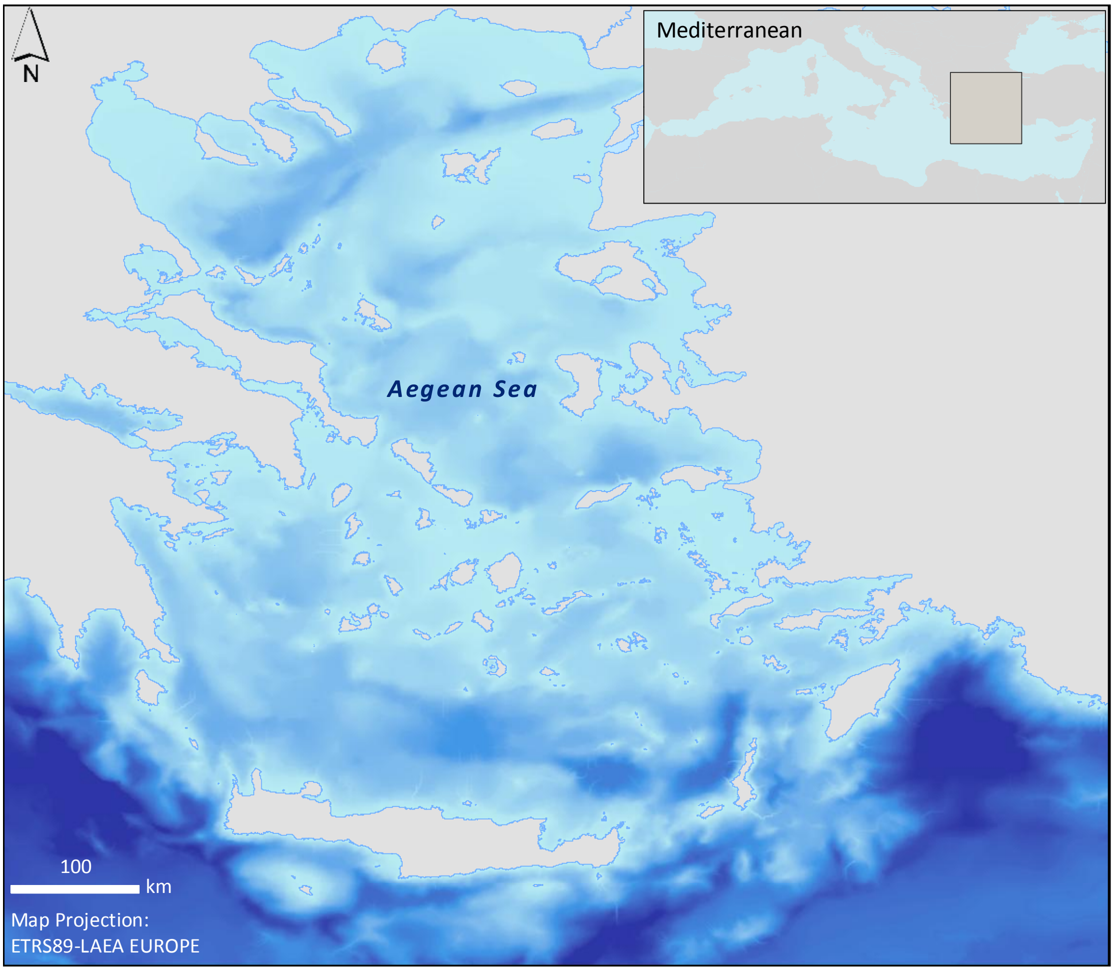

Figure 1: The study area

2.2 Animal species and key ecological features

The selection of animal species was based on their occurrence in the shallow waters (< 150 m depth) of the Aegean Sea, and their protection status. The list of animal species includes 8 Porifera, 1 Anthozoa, 7 Mollusca, 2 Echinodermata and 3 Actinopterygii (

Table 1) and was limited to those that are under strict protection status, and whose collection and deliberate capture or killing is prohibited according to the Annex II of the “Protocol for Specially Protected Areas and Biological Diversity in the Mediterranean” of the Barcelona Convention, Annex IV of the EU Habitats Directive (92/43/EEC), Annex II of the Bern Convention, and Appendix II of the Greek Presidential Decree 67/81 on the protection of native flora and wild fauna (Sini et al., 2017).

An additional group of other vulnerable ecological features (

Table 2) – which do not strictly fit the definition of a “habitat”–, were also considered, as they represent structurally important biotic components that are characterized by high vulnerability to anthropogenic stressors, slow growth rates and low resilience (Sini et al., 2017).

Table 1: List of marine species whose distribution was investigated through the present study, and their protection status according to the Annexes of international conventions and directives. Bc: Barcelona Convention for the protection of the marine environment and the coastal region of the Mediterranean; BeC: Bern Convention on the conservation of European wildlife and natural habitats; Hd: Habitats Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora; Bd: Birds Directive 2009/147/EC; PD: Greek Presidential Decree 67/81 on the protection of native flora and wild fauna, I, II, IV, V: Annex or Appendix number (Sini et al., 2017).

Taxonomic group	Species	National and International Laws, Conventions & Directives	Type of data
Porifera	*Aplysina* sp.	Bc II; BeC II	Points
	Axinella cannabina (Esper, 1794)	Bc II	Points
	Axinella polypoides (Schmidt, 1862)	Bc II; BeC II	Points
	Geodia cydonium (Linnaeus, 1767)	BC II	Points
	*Sarcotragus foetidus (*Schmidt, 1862)	Bc II	Points
	Sarcotragus pipetta (Schmidt, 1868)	Bc II	Points
	Tethya aurantium (Pallas, 1766)	Bc II	Points
	Tethya citrina (Sarà & Melone, 1965)	Bc II	Points
Anthozoa	*Cladocora caespitosa* (Linnaeus, 1767)	Bc II	Points
Mollusca	*Charonia variegata* (Lamarck, 1816)	Bc II; BeC II	Points
	Erosaria spurca (Linnaeus, 1758)	Bc II; BeC II; Pd II	Points
	Lithophaga lithophaga (Linnaeus, 1758)	Bc II; Hd IV	Points
	Luria lurida (Linnaeus, 1758)	Bc II; BeC II; Pd II	Points
	Pinna nobilis (Linnaeus, 1758)	Bc II; BeC II; Hd IV; Pd II	Points
	Tonna galea (Linnaeus, 1758)	Bc II; BeC II; Pd II	Points
	Zonaria pyrum (Gmelin, 1791)	Bc II; BeC II; Pd II	Points
Echinodermata	*Centrostephanus longispinus* (Philippi, 1845)	Bc II; BeC II; Hd IV	Points
	Ophidiaster ophidianus (Lamarck, 1816)	Bc II; BeC II	Points
Actinopterygii	*Hippocampus* sp.	Bc II; BeC II	Points

Table 2: List of vulnerable ecological features whose distribution was investigated in the present study, and their associated habitat type codes according to two habitat classification systems: the Habitats Directive 92/43/EEC and the European Nature Information System (EUNIS) (Sini et al., 2017).

Vulnerable ecological features	Habitat's Directive codes	EUNIS codes	Type of data
Rhodolith beds	Included in 1110	A5.51	Points & Polygons
Coralligenous formations	Included in 1170	A 4.32; A4.26	Points & Polygons
Corals of the sublittoral zone	Included in 1170; 1110	A4.26	Points

2.3 Predictor variables

Depth was included as a predictor variable as it is the main gradient along which faunal changes occur in shelf assemblages, mainly because of its correlation with crucial Predictor variables such as light intensity, temperature, nutrient concentration, and primary and secondary productivity (Katsanevakis et al., 2017; Katsanevakis et al., 2009). Temperature, productivity, light intensity and chlorophyll (as a proxy of nutrient supply) are also important in predicting species distributions (Tyberghein et al., 2012; Katsanevakis et al., 2017).

Daily values of sea surface temperature (for the period 01/01/2012-31/12/2016), chlorophyll concentration (for the period 14/04/2014-28/02/2017) and diffuse attenuation coefficient of light at 490 nm (kd490) (for the period 01/12/2014-31/05/2017) were obtained from the COPERNICUS Marine Environment Monitoring Service at a 1x1km resolution. At this scale we estimated average annual values of SST, chlorophyll concentration and kd490, and also average annual minimum and maximum temperature values for each cell using R software (R Development CoreTeam; www.rproject.org). Kd490 is defined as the diffuse attenuation coefficient of light at 490 nm, and is a measure of the turbidity of the water column, i.e., how visible light in the blue-green region of the spectrum penetrates the water column. It is directly related to the presence of scattering particles in the water column and is estimated through the ratio between Rrs at 490 and 555 nm.

Monthly values of primary production (for the period 01/10/1997-31/09/2008) were obtained from the Environmental Marine Information System at a 4x4km resolution. At this scale we estimated average annual values of primary production for each cell using R software (R Development CoreTeam; www.rproject.org). Initial data description, time stamps sources and resolutions are shown in Table 3. All derivative datasets were downscaled to a 0.5km x 0.5km Grid of the study area using IDW interpolation method on ArcGIS 10.2.2 software(ESRI) (Figures 2-8).

Table 3: Initial data for predictor variables

Name	Description	Time Stamp	Source	Native resolution
Bathymetry	Digital Terrain Model of the Greek Seas	15/05/2017	Hellenic Navy Hydrographic Service (HNHS) download	15" x 15"
Sea Surface Temperature	Mediterranean sea high resolution and ultra high resolution sea surface temperature analysis	01/01/2012-31/12/2016	COPERNICUS Marine Environment Monitoring Service download	0.0625deg. x 0.0625deg
Chlorophyll concentration	Daily interpolated surface chlorophyll concentration from multi satellite observations	14/04/2014-28/02/2017	COPERNICUS Marine Environment Monitoring Service download	1km x 1km
Diffuse attenuation coefficient of light at 490nm	Mediterranean sea remote sensing reflectances and attenuation coefficient at 490nm from multi satellite observations	01/12/2014-31/05/2017	COPERNICUS Marine Environment Monitoring Service download	1km x 1km
Primary Productivity	EMIS - SeaWiFS Monthly climatology primary production	01/10/1997-31/09/2008	Environmental Marine Information System download	4km x 4km

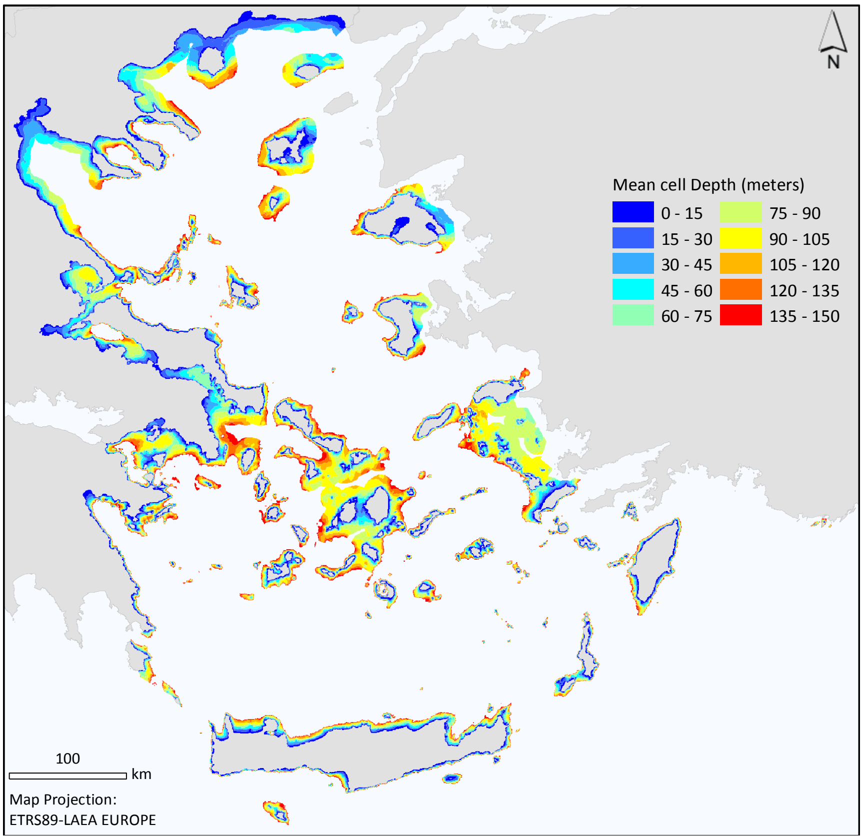

Figure 2: Predictor variables - Mean cell depth (meters)

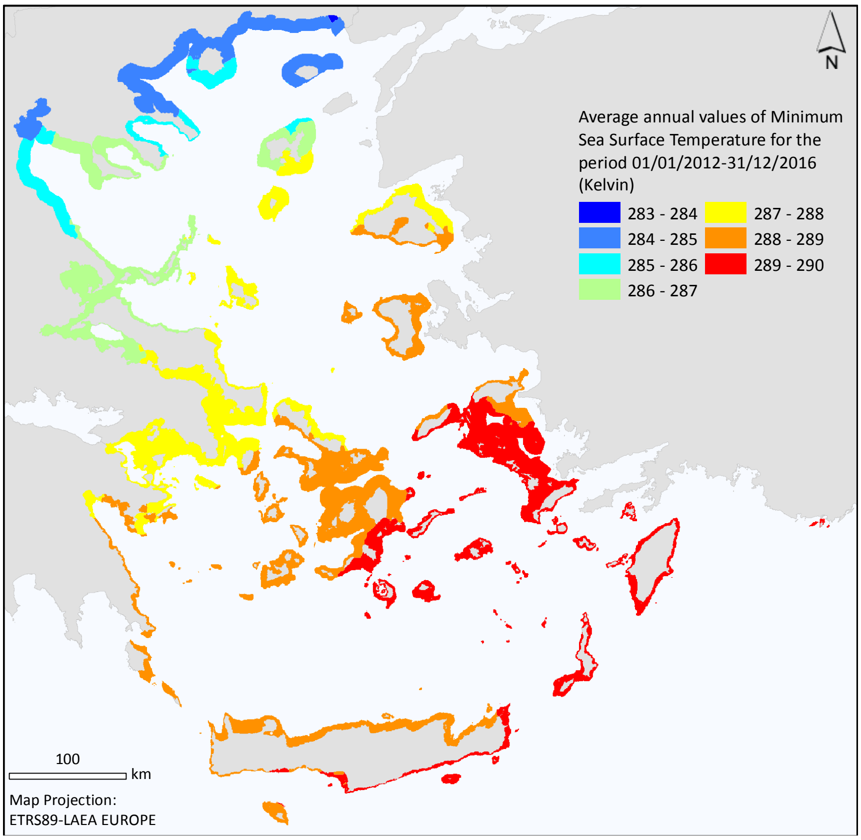

Figure 3: Predictor variables - Average annual values of Minimum Sea Surface Temperature (Kelvin) for the period 01/01/2012-31/12/2016

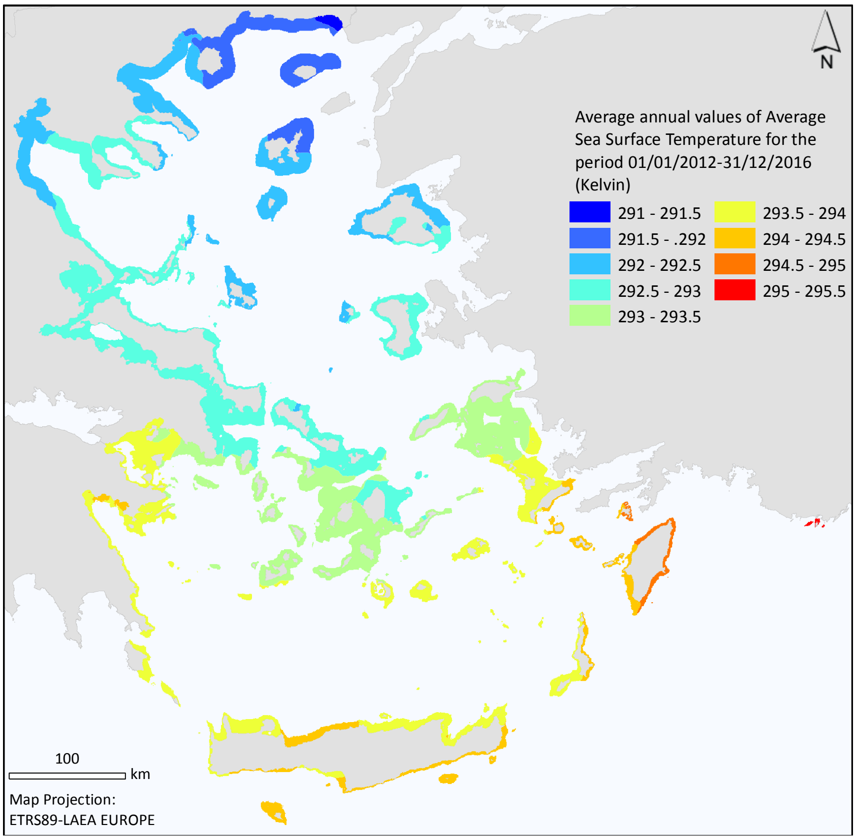

Figure 4: Predictor variables - Average annual values of Mean Sea Surface Temperature (Kelvin) for the period 01/01/2012-31/12/2016

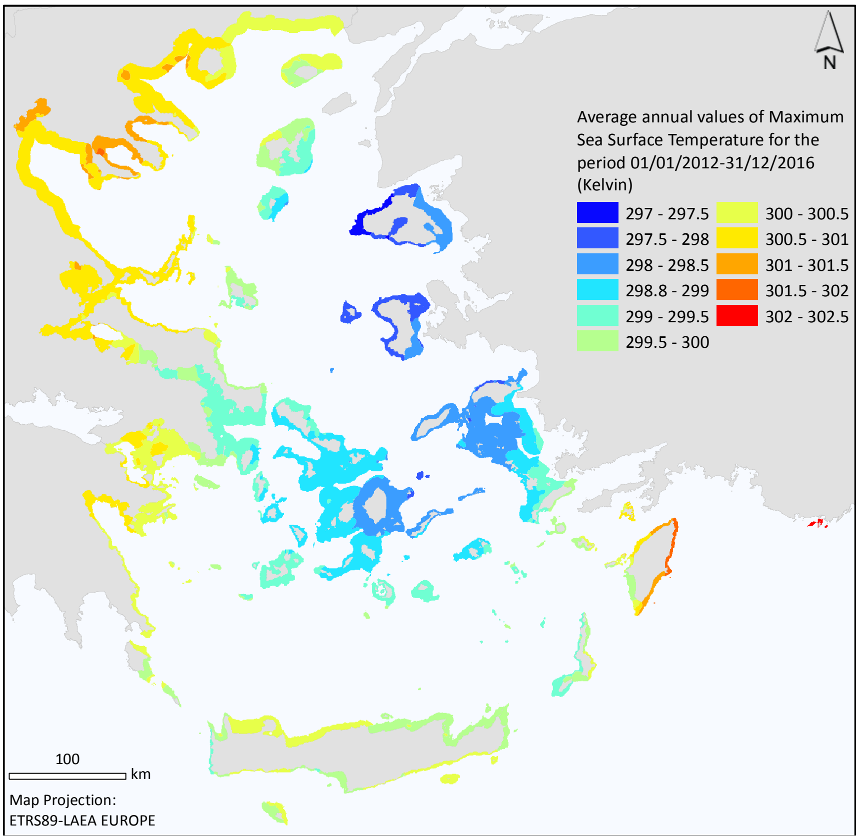

Figure 5: Predictor variables - Average annual values of Maximum Sea Surface Temperature (Kelvin) for the period 01/01/2012-31/12/2016

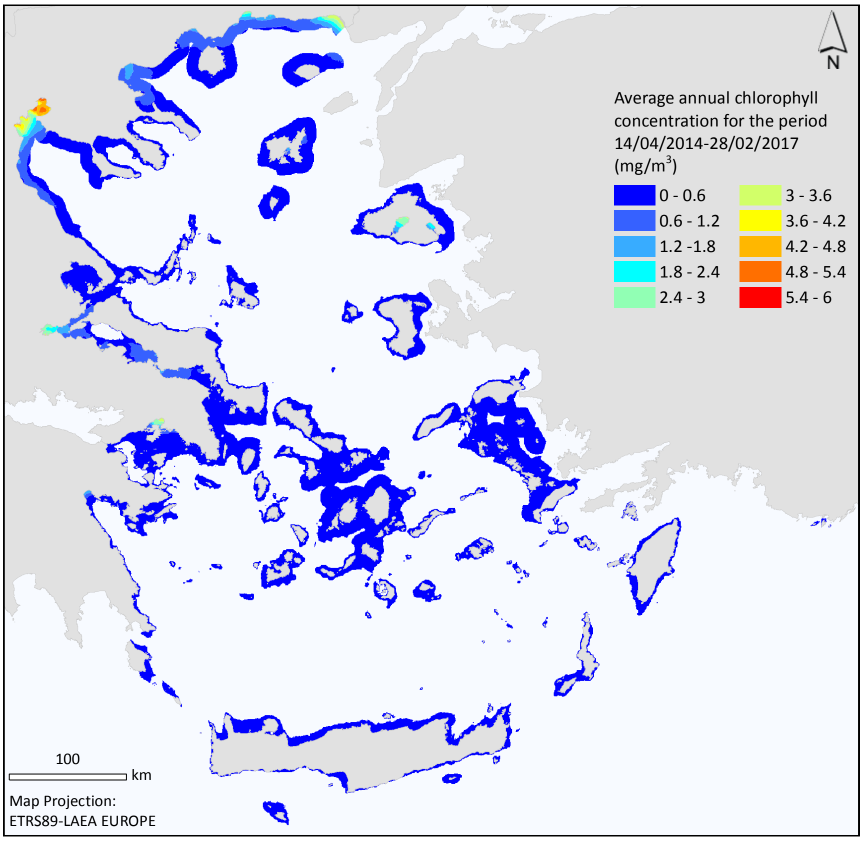

Figure 6: Predictor variables - Average annual values of Chlorophyll concentration (mg/m^3) for the period 14/04/2014-28/02/2017

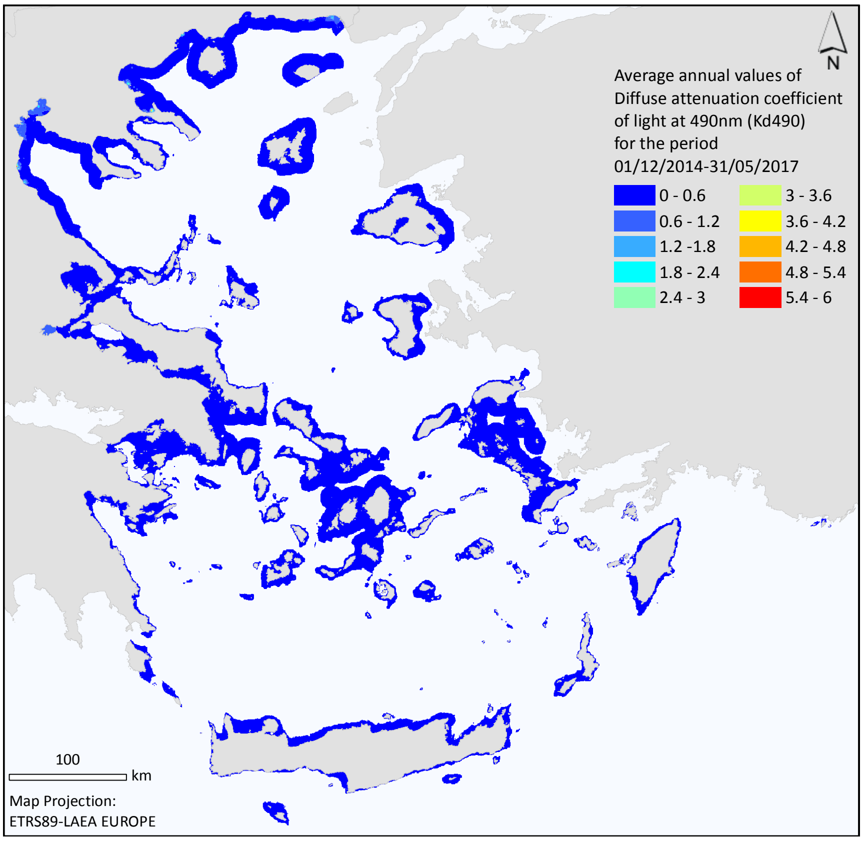

Figure 7: Predictor variables - Average annual values of Diffuse attenuation coefficient of light at 490nm (Kd490) for the period 01/12/2014-31/05/2017

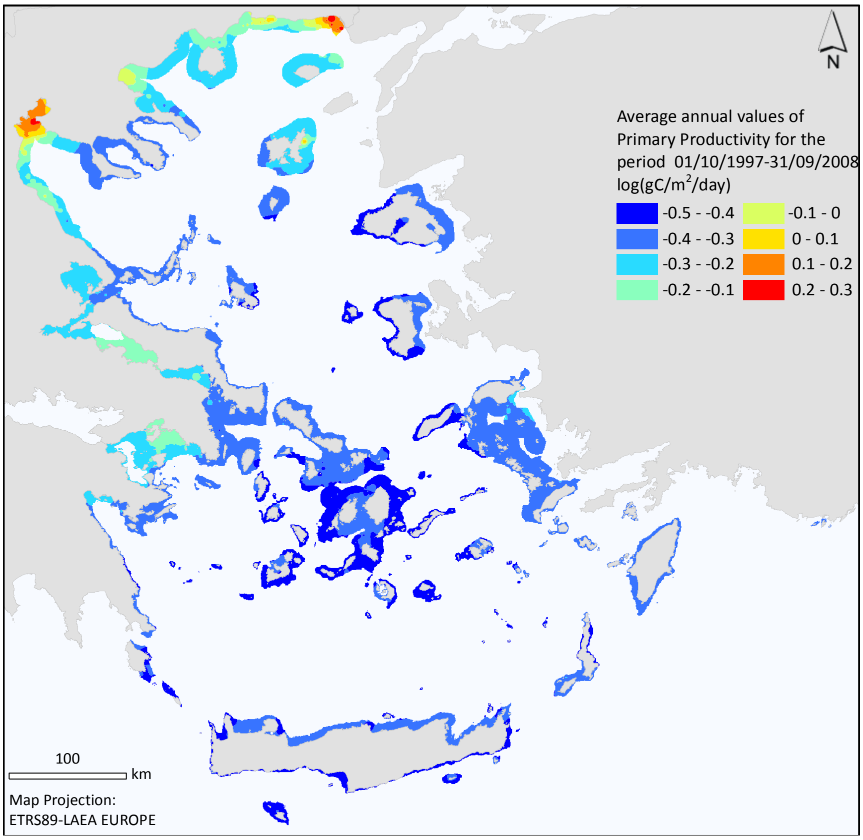

Figure 8: Predictor variables - Average annual values of Primary Productivity for the period 01/10/1997-31/09/2008 log(gC/m^2/day)

2.4 Model Development

Data exploration was carried out on the predictor variable datasets, using R software (R Development CoreTeam; www.rproject.org), so as to detect potential outliers. Modeling techniques are often sensitive to multicollinearity among the predictor variables used. Available predictor variables (7) were hence iteratively tested for multicollinearity based on a combination of variance inflation factor (VIF<2.5) and Spearman's rank correlation (rs<0.8). This resulted in a subset of 6 mostly uncorrelated predictor variables (Zuur et al., 2007) (Figure 9), which were used as initial input to the models. The software Maxent (Phillips et al. , 2006; Phillips et al., 2017) was used to build models for animal species and key ecological features, starting with the subset of 6 predictor variables. The algorithm used in Maxent aimed to find the largest spread, or maximum entropy, in the geographic dataset composed of occurrence records of animal species and key ecological features, in relation to the 6 predictor variables. For each of the 21 models being developed, Maxent started with a uniform distribution of occurrence probability values for animal species and key ecological features over the study area, and conducted an optimisation routine that iteratively improved model fit, measured as the loss of entropy (i.e. the ''gain'' of information).

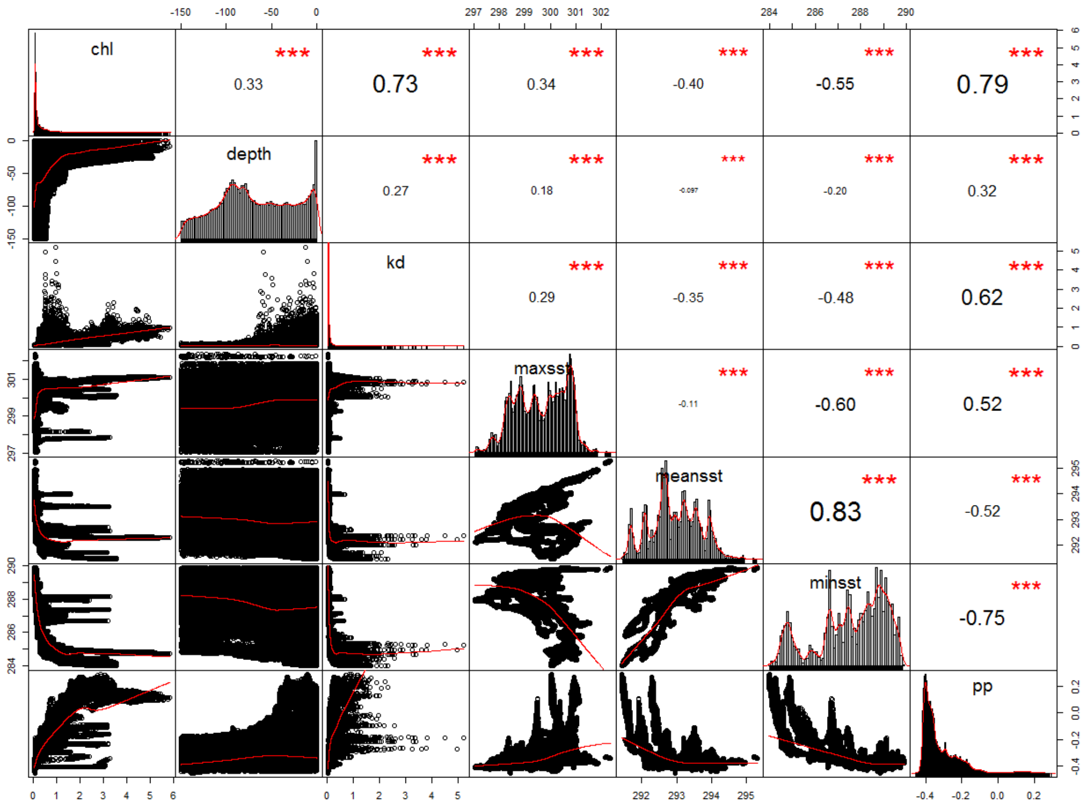

Figure 9: Correlation matrix for the predictor variables selected for model development

Available occurrence points for each ecological feature were randomly split between 'training' and 'test' sets. The importance of each retained predictor variable was then measured through a jackknife (also called 'leave-one-out') test of variable importance, by training with each predictor variable first omitted, and then used in isolation. The model output was spatialised in the form of raster showing the logistic probability (ranging from 0 to 1) of suitable conditions for ecological features considered. The Receiver Operating Characteristic (ROC) curve was used to investigate the trade-off between prediction sensitivity and specificity. The associated Area Under the Curve (AUC) is 0.5 in the case of random prediction, and higher values (to a maximum of 1) correspond to better performing models.

Each model was run in 20 replicates and the average values of the logistic probability of suitable conditions for ecological features, ROC curves and response curves were calculated and visualized. The ROC and response curves show the mean response of the 20 replicate Maxent runs (red) and the mean +/- one standard deviation (blue).

2.5 Hotspot analysis

In order to identify potential biodiversity hotspots two approaches were followed. Firstly, the output average values of the logistic probability of suitable conditions for all ecological features were summed using ArcGIS 10.2.2 software(ESRI). Since 21 ecological features were modeled, the maximum cumulative logistic probability of suitable conditions for all ecological features is 21. In order to limit the regions identified as hotspots, we followed a second approach in which after deciding a universal threshold for all ecological features the distribution probability for each species was differentiated between 1 (presence) and 0 (absence). The presence of all ecological features were summed using ArcGIS 10.2.2 software(ESRI). Again the maximum score for the biodiversity hotspot map is 21.

3 Results

3.1 Model development

Table 4 summarizes the results of this dissertation and shows that bathymetry is one of the most important contributor to most of the models. Detailed results for each species or key ecological feature are presented in the following paragraphs.

Table 4: Results summary, the main contributors for each model are marked in red fonts for combined contribution >80% and in bold for combined contribution >90%.

Species	No of points	mean AUC	standard deviation	Bathymetry	Mean SST	Maximum SST	Kd490	Primary Productivity	Chlorophyl Concentration
Rhodolith beds	590	0.947	0.016	4.3	**29.1**	-	3.4	**50.4**	**12.8**
Coralligenous formations	1047	0.834	0.029	**14.2**	**19.5**	**46.2**	1.2	**17.4**	1.5
Corals of the sublittoral zone	142	0.876	0.069	**10.2**	**38.2**	**12.8**	0.8	**20.5**	**17.6**
Aplysina spp	315	0.842	0.043	**72.7**	**14.7**	-	3.2	3.6	**5.8**
Axinella cannabina	164	0.838	0.066	**67.3**	**19.1**	-	5.4	**5.6**	2.6
Axinella polypoides	30	0.753	0.226	**46.6**	3.2	**20.7**	0.7	**20.4**	**8.3**
Geodia cydonium	67	0.717	0.159	**41.7**	**14.9**	**3.9**	3.1	3.6	**33.0**
Sarcotragus spp	274	0.869	0.031	**60.2**	**5.7**	**6.3**	5.2	**21.7**	1.0
Tethya aurantium	35	0.842	0.188	**64.5**	**15.9**	1.4	**8.8**	**5.1**	4.3
Tethya citrina	25	0.871	0.133	**41.8**	**17.2**	1.3	**20.8**	0.5	**18.3**
Cladocora caespitosa	141	0.9	0.046	**61.6**	**18.5**	0.9	**8.7**	1.6	**8.6**
Charonia variegata	108	0.889	0.053	**56.7**	1.7	6.0	0.2	**28.9**	**6.4**
Erosaria spurca	37	0.89	0.088	**69.5**	2.8	**4.4**	3.4	**12.3**	**7.6**
Lithophaga lithophaga	91	0.828	0.06	**78.0**	**8.6**	0.7	**5.5**	4.8	2.5
Luria lurida	66	0.866	0.103	**60.4**	5.8	**16.9**	**6.2**	2.3	**8.3**
Pinna nobilis	460	0.877	0.032	**75.8**	**5.5**	**9.8**	1.2	3.3	4.4
Tonna galea	95	0.882	0.052	**74.1**	**7.7**	**4.0**	3.1	3.6	**7.6**
Zonaria pyrum	19	0.909	0.174	**22.4**	**65.7**	1.3	**7.2**	0.3	3.0
Centrostephanus longispinus	85	0.84	0.084	**45.5**	3.7	**11.4**	1.2	**7.0**	**31.2**
Ophidiaster ophidianus	91	0.864	0.084	**61.7**	4.8	**10.8**	1.1	3.5	**18.1**
Hippocampus spp	133	0.801	0.074	**55.1**	**17.8**	1.6	0.9	**8.0**	**16.7**

3.1.1 Rhodolith beds

A total of 590 presence points were used to model the occurrence of Rhodolith beds across the study area. The mean AUC of all models was 0.947 (standard deviation 0.016 - Figure 10). Primary Productivity, Mean SST and Chlorophyll concentration were the three main contributors to the model (combined contribution of 92.3%; Table 5), whilst the remaining two predictors (Kd490 and Bathymetry) had a combined contribution of 7.7%.

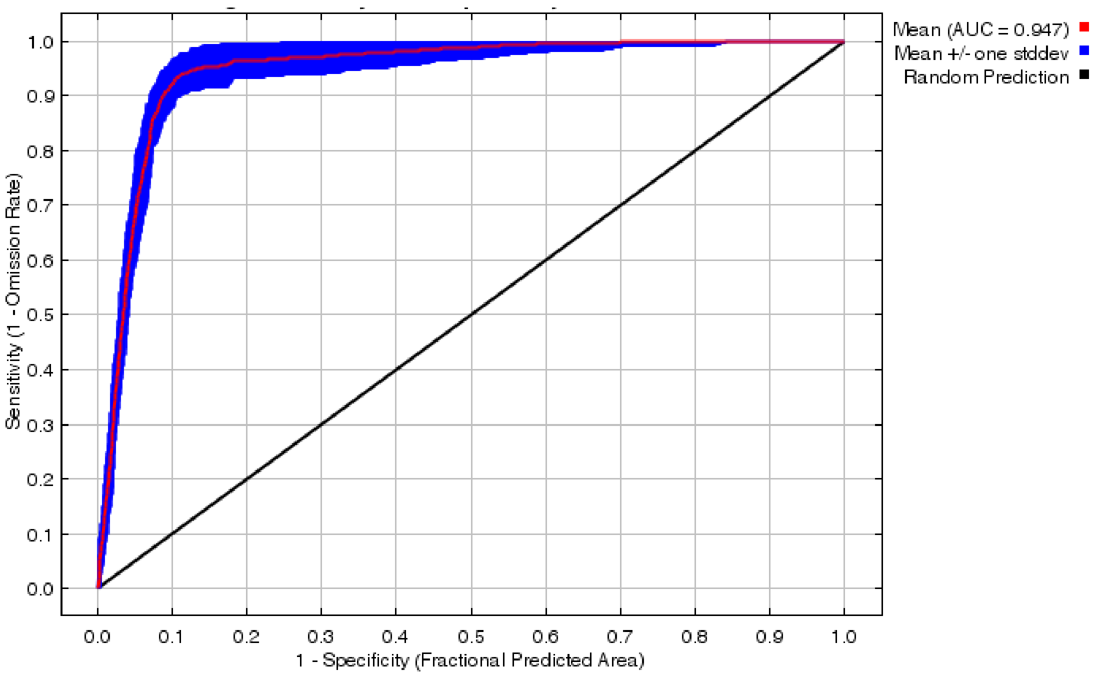

Figure 10: ROC curve for the training test of Rhodolith beds

Table 5: Relative contributions of each predictor variable to the distribution model of Rhodolith beds

Predictor variable	Contribution (%)
Primary Productivity	50.4
Mean SST	29.1
Chlorophyll concentration	12.8
Bathymetry	4.3
Kd490	3.4

Based on a jackknife test of variable importance (Figure 11a), the predictor variable with the highest gain when used in isolation was Mean SST, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 11b) confirmed that Primary Productivity, Mean SST and Chlorophyll concentration were the main contributors to the model.

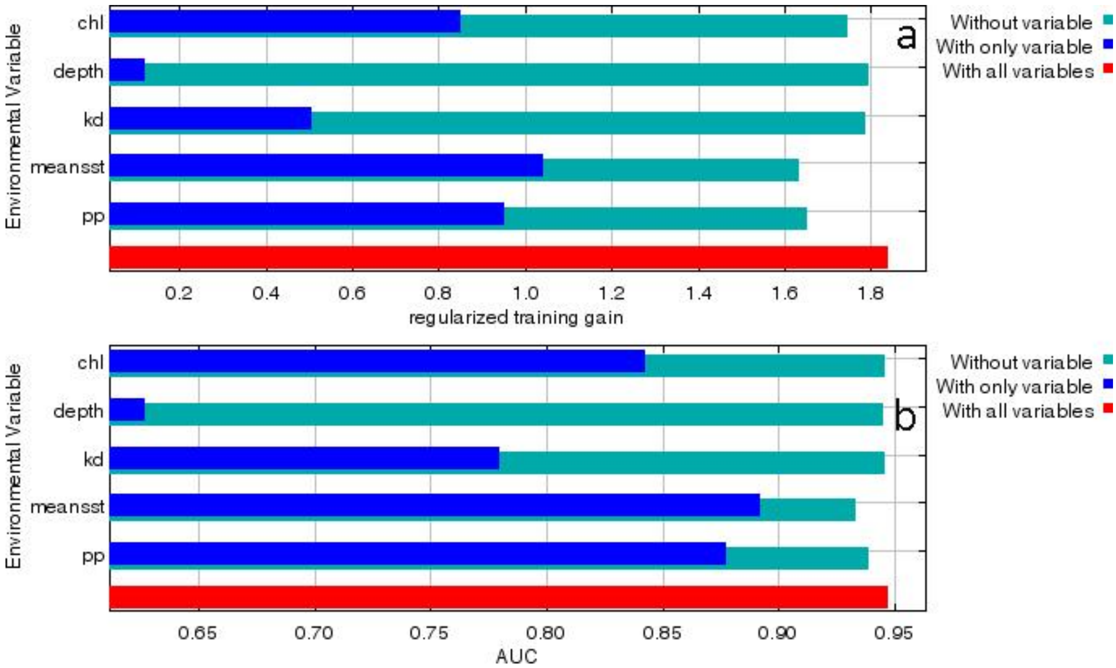

Figure 11: Jackknife of regularized training gain (a) and AUC (b) for Rhodolith beds

Western Lesvos, Skyros, Psara, western Ikaria and the Cyclades are the areas where the most suitable conditions for Rhodolith beds occur (Figure 12). Figure 13 shows the response curves of Rhodolith beds to Primary Productivity, Mean SST and Chlorophyll concentration. Rhodolith beds seem to be negatively related to primary productivity and they do not occur at values greater than approximately 0.42[1] $gC/m^2/day$. Rhodolith beds prefer mean temperatures between 292.4K and 293.1K and do not occur at Chlorophyll concentrations greater than $1.7mg/m^3$. Table 6 shows the minimum and maximum values of each environmental variable in the cells where Rhodolith beds have been recorded.

Table 6: Minimum and maximum values of predictor variables in the cells where Rhodolith beds have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,43	-0,30
Mean SST	292,21	293,49
Kd490	0,03	0,13
Chlorophyll concentration	0,07	0,56
Bathymetry	-146,47	-1,58

[1] log (0.42)=-0.376

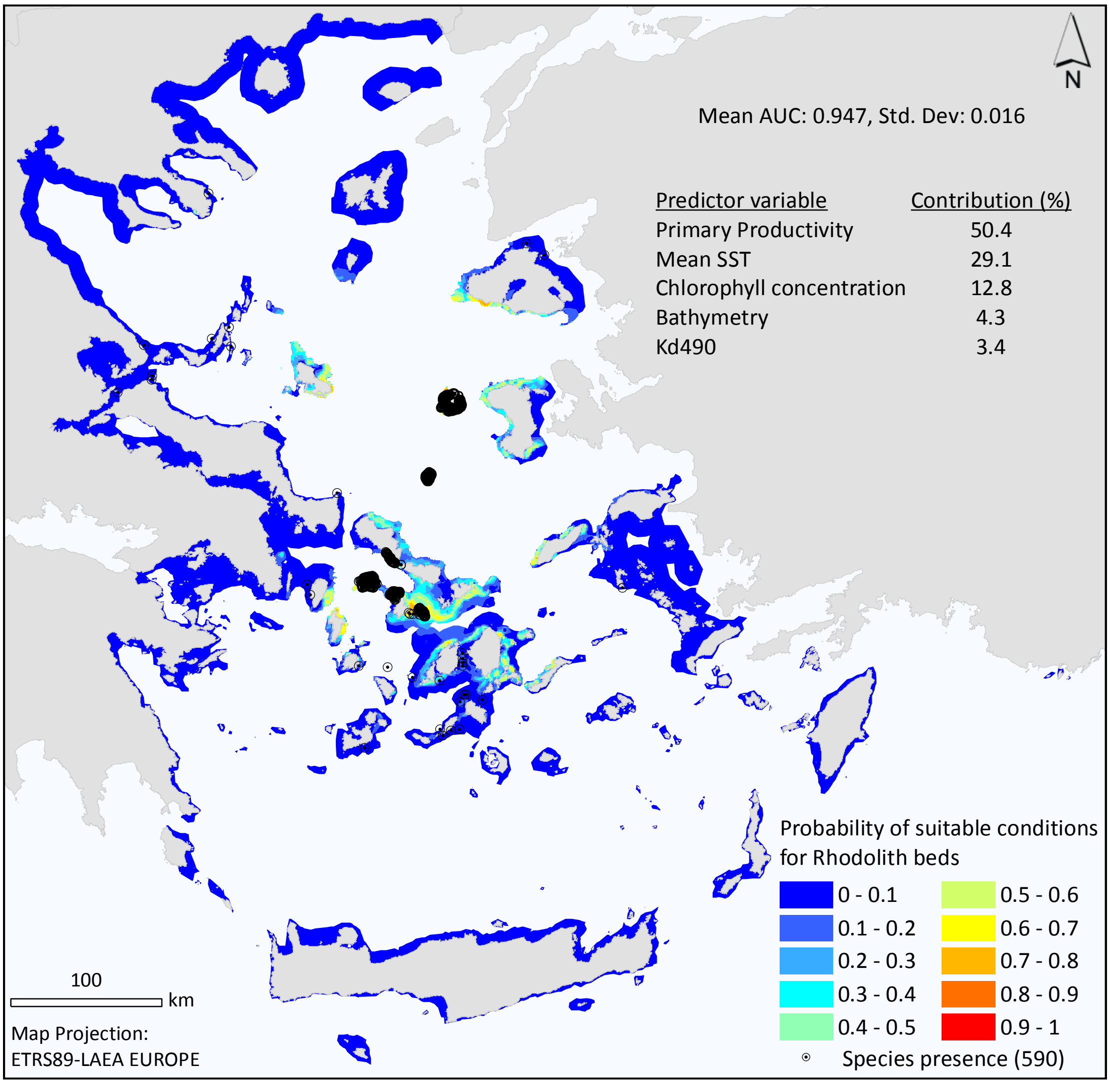

Figure 12: Probability of suitable conditions for Rhodolith beds

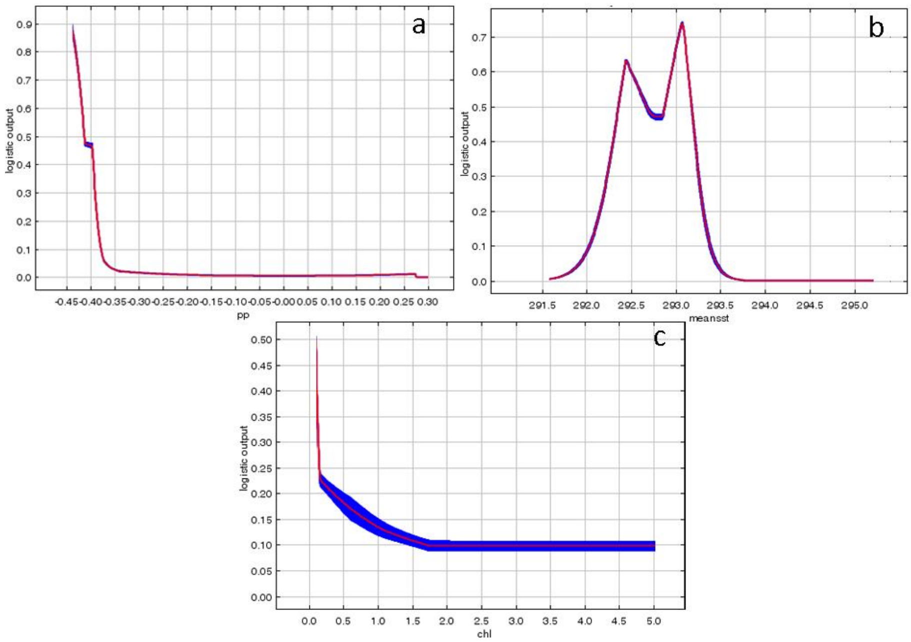

Figure 13: Response curves of Rhodolith beds to Primary Productivity (log(gC/m^2/day)) (a), Mean SST (K) (b), and Chlorophyll concentration (mg/m^3)(c).

3.1.2 Coralligenous formations

A total of 1047 presence points were used to model the occurrence of Coralligenous formations across the study area. The mean AUC of all models was 0.834 (standard deviation 0.029 - Figure 14). Maximum SST, Mean SST and Primary Productivity were the three main contributors to the model (combined contribution of 83.1%; Table 7), whilst the remaining three predictors (Bathymetry, Chlorophyll concentration and Kd490) had a combined contribution of 16.9%.

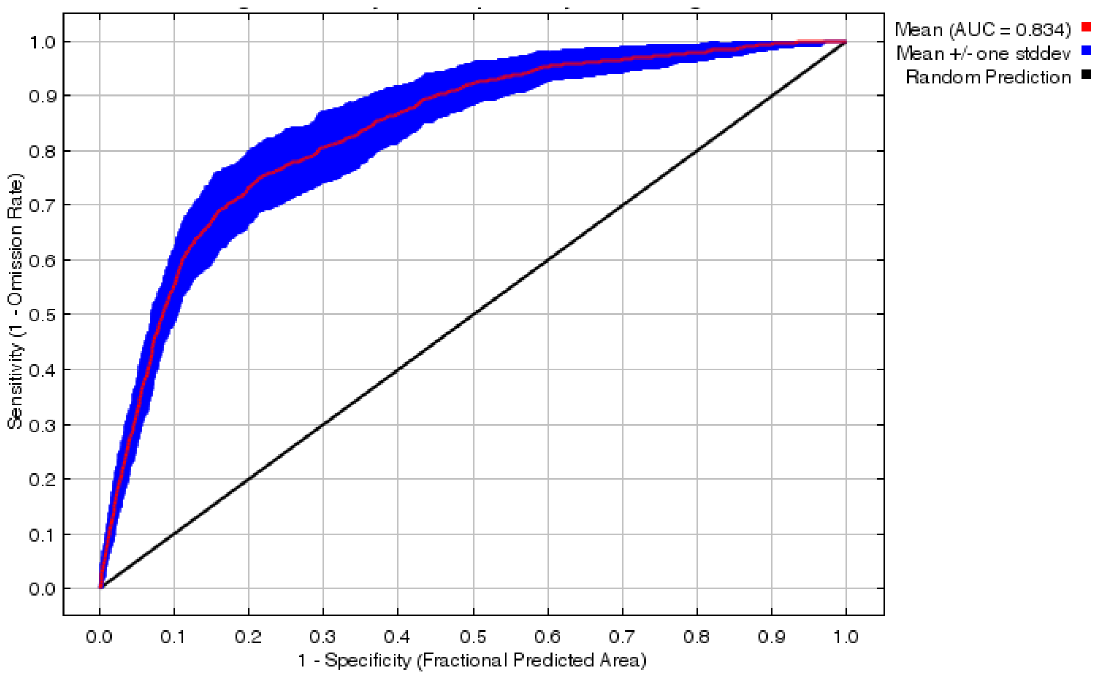

Figure 14: ROC curve for the training test of Coralligenous formations

Table 7: Relative contributions of each predictor variable to the distribution model of Coralligenous formations

Predictor variable	Contribution (%)
Maximum SST	46.2
Mean SST	19.5
Primary Productivity	17.4
Bathymetry	14.2
Chlorophyll concentration	1.5
Kd490	1.2

Based on a jackknife test of variable importance (Figure 15a), the predictor variable with the highest gain when used in isolation was Maximum SST, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 15b) confirmed that Maximum SST, Mean SST and Primary Productivity were the main contributors to the model.

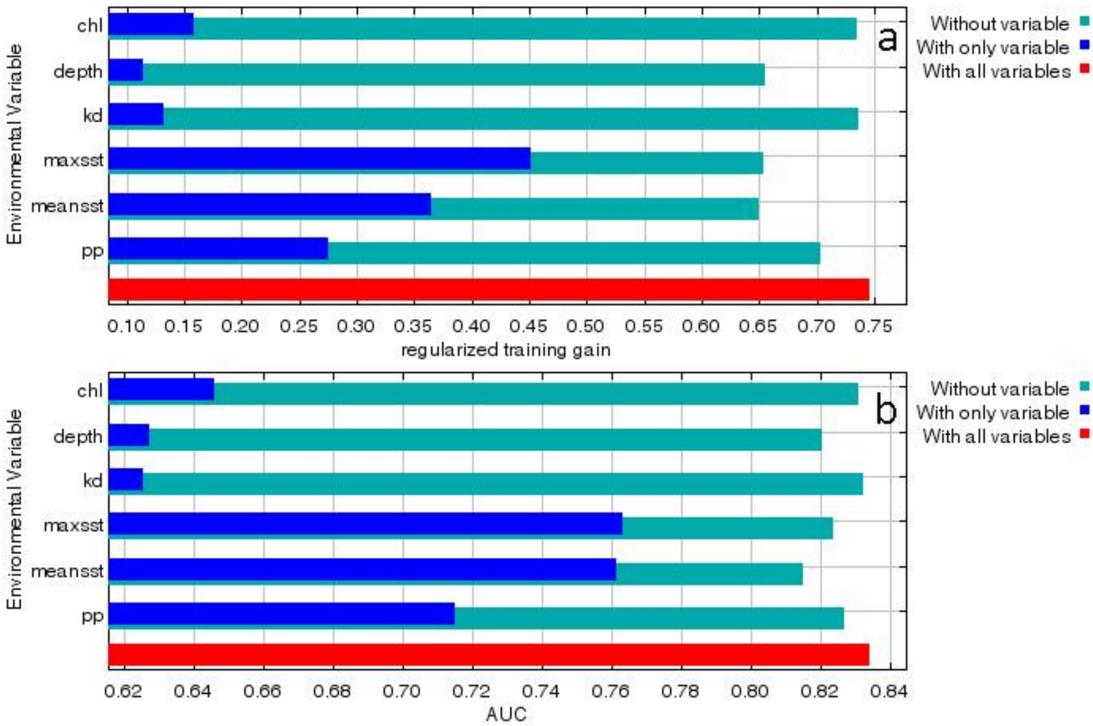

Figure 15: Jackknife of regularized training gain (a) and AUC (b) for Coralligenous formations

The Cyclades, northeast Lemnos and Samothraki are the areas where the most suitable conditions for Coralligenous formations occur (Figure 16). Figure 17 shows the response curves of Coralligenous formations to Maximum SST, Mean SST, Primary Productivity, and Bathymetry.Coralligenous formations do not prefer low or high maximum or mean SSTs and they peak at maximum SSTs between 298K and 299K and mean SSTs between 292.7K and 293.4K. They prefer low values of primary productivity. The most suitable depths for coralligenous formations are between 30m and 120m. Table 8 shows the minimum and maximum values of each environmental variable in the cells where Coralligenous formations have been recorded.

Table 8: Minimum and maximum values of predictor variables in the cells where Coralligenous formations have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	-0,15
Mean SST	291,57	294,27
Maximum SST	297,09	301,18
Kd490	0,02	0,21
Chlorophyll concentration	0,06	0,95
Bathymetry	-148,20	-0,30

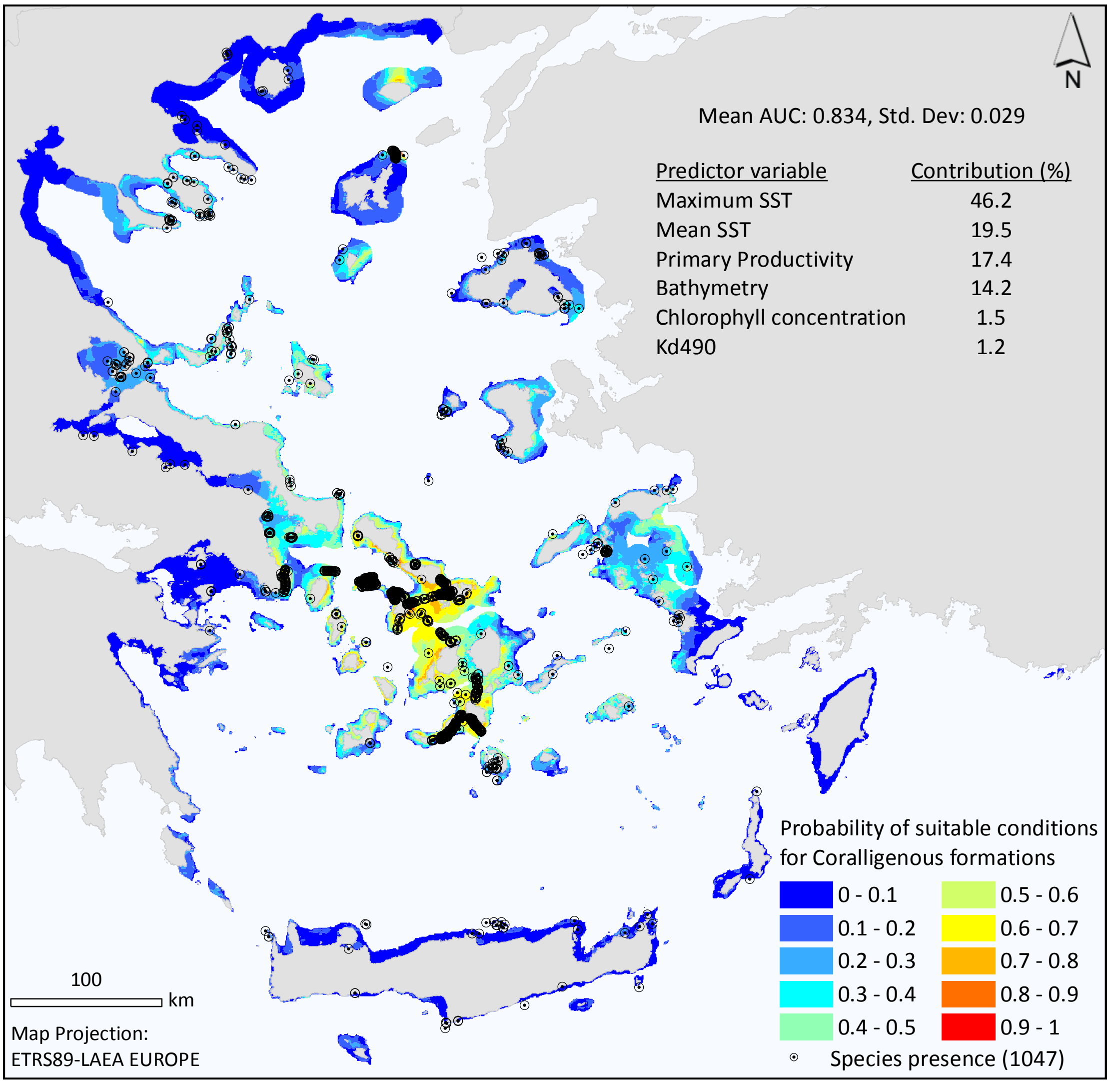

Figure 16: Probability of suitable conditions for Coralligenous formations

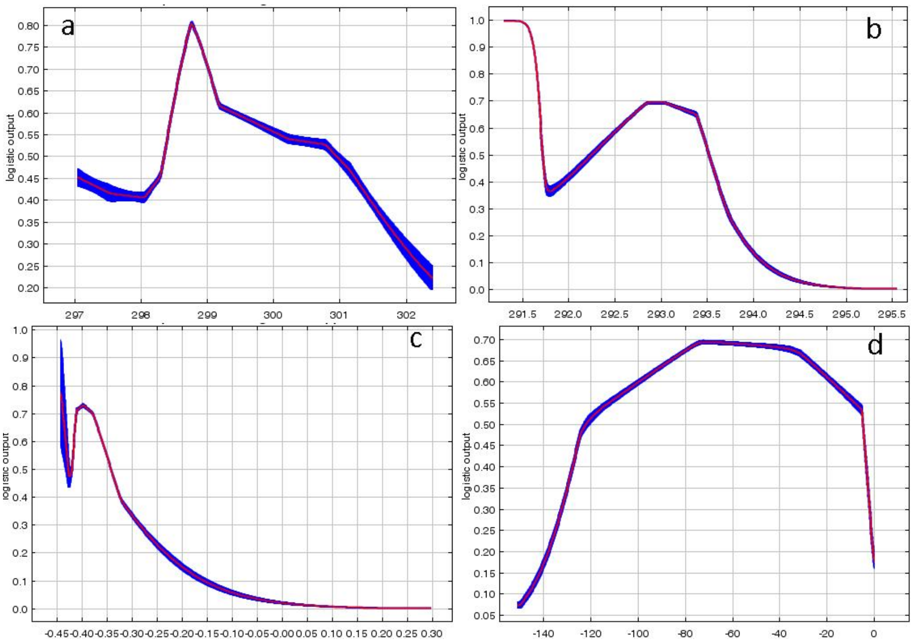

Figure 17: Response curves of Coralligenous formations to Maximum SST (K) (a), Mean SST (K) (b), Primary Productivity (log(gC/m^2/day)) (c), and Bathymetry (m) (d).

3.1.3 Corals of the sublittoral zone

A total of 142 presence points were used to model the occurrence of Corals of the sublittoral zone across the study area. The mean AUC of all models was 0.876 (standard deviation 0.069 - Figure 18). Mean SST, Primary Productivity and Chlorophyll concentration were the three main contributors to the model (combined contribution of 76.3%; Table 9), whilst the remaining three predictors (Maximum SST, Bathymetry, and Kd490) had a combined contribution of 23.7%.

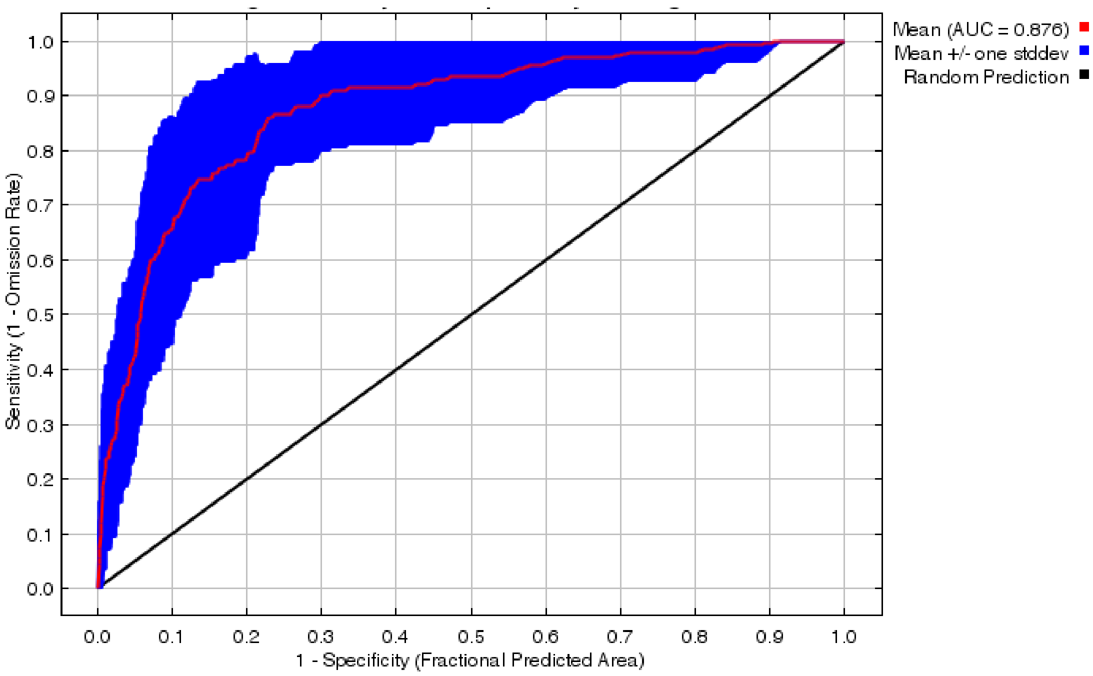

Figure 18: ROC curve for the training test of Corals of the sublittoral zone

Table 9: Relative contributions of each predictor variable to the distribution model of Corals of the sublittoral zone

Predictor variable	Contribution (%)
Mean SST	38.2
Primary Productivity	20.5
Chlorophyll concentration	17.6
Maximum SST	12.8
Bathymetry	10.2
Kd490	0.8

Based on a jackknife test of variable importance (Figure 19a), the predictor variable with the highest gain when used in isolation was Mean SST, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 19b) confirmed that Mean SST, Primary Productivity and Chlorophyll concentration were the main contributors to the model.

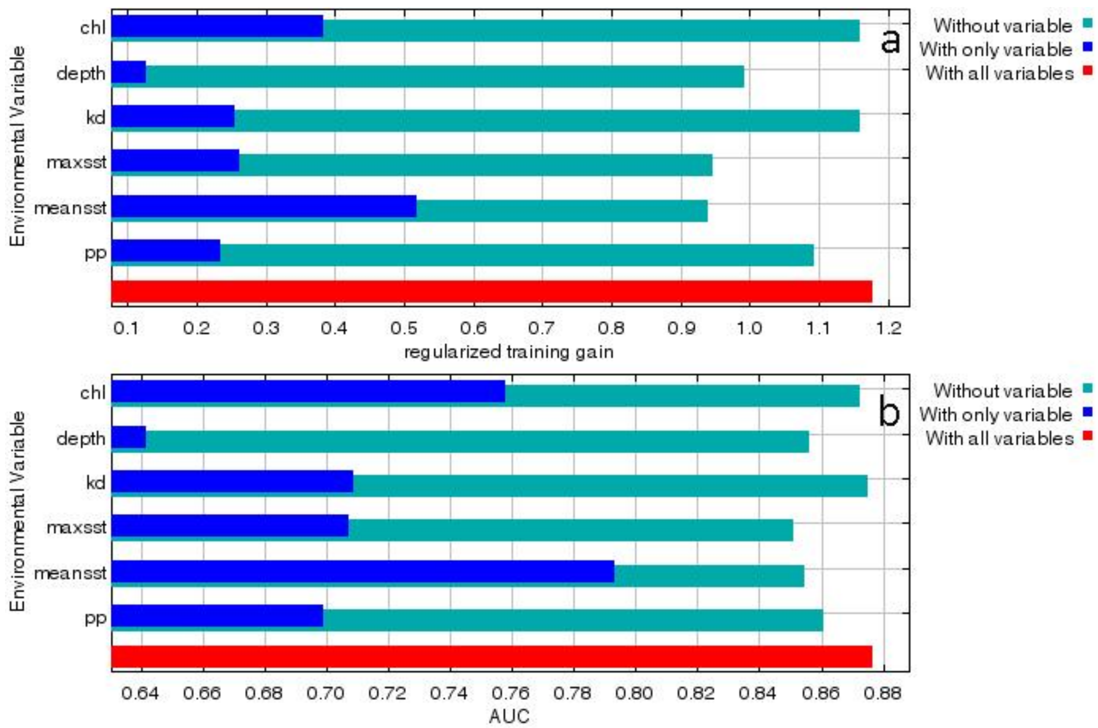

Figure 19: Jackknife of regularized training gain (a) and AUC (b) for Corals of the sublittoral zone

The areas where the most suitable conditions for Corals of the sublittoral zone occur are located in Northwest Aegean Sea, especially in Chalkidiki, the Northern Sporades and northwest Evia (Figure 20). Figure 21 shows the response curves of Corals of the sublittoral zone to Mean SST, Primary Productivity, Chlorophyll concentration, Maximum SST and Bathymetry. Corals of the sublittoral zone peak at low mean SST (approx.292K-292.5K), they prefer low values of primary productivity (approx. 0.39 $gC/m^2/day$) and decline as primary productivity increases. The most suitable conditions for them include low chlorophyll concentrations and the suitability declines with the increment of chlorophyll concentrations. Regarding maximum SSTs, the most suitable conditions are 300K - 301K. The most suitable depths for Corals of the sublittoral zone are up to 50m with declining suitability as depth increases. Table 10 shows the minimum and maximum values of each environmental variable in the cells where Corals of the sublittoral zone have been recorded.

Table 10: Minimum and maximum values of predictor variables in the cells where Corals of the sublittoral zone have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,41	-0,20
Mean SST	291,70	294,06
Maximum SST	297,17	301,23
Kd490	0,03	0,23
Chlorophyll concentration	0,08	1,19
Bathymetry	-144,70	-2,29

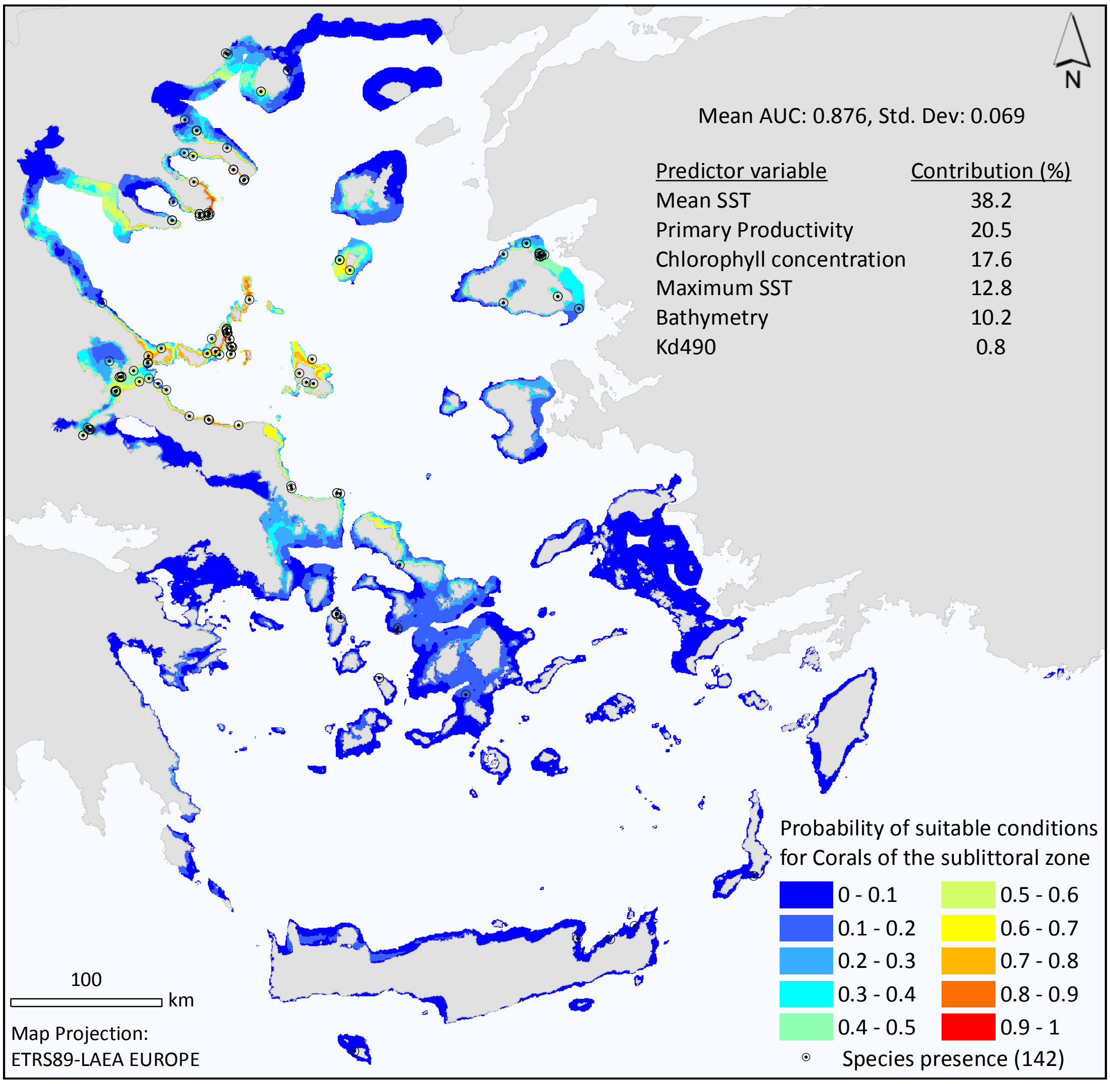

Figure 20: Probability of suitable conditions for Corals of the sublittoral zone

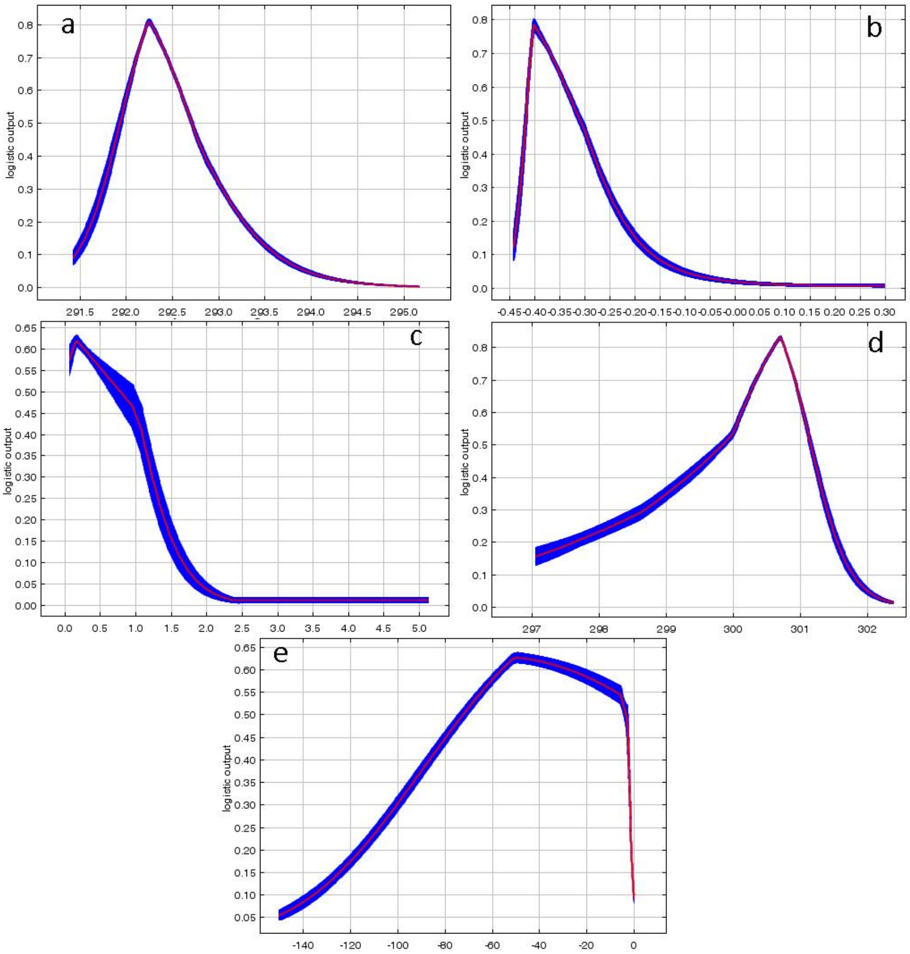

Figure 21: Response curves of Corals of the sublittoral zone to Mean SST (K) (a), Primary Productivity (log(gC/m^2/day)) (b), Chlorophyll concentration (mg/m^3) (c), Maximum SST (K) (d), and Bathymetry (m) (e).

3.1.4 *Aplysina* spp.

A total of 315 presence points were used to model the occurrence of *Aplysina* sp. across the study area. The mean AUC of all models was 0.842 (standard deviation 0.043 - Figure 22). Bathymetry and Mean SST were the two main contributors to the model (combined contribution of 87.4%; Table 11), whilst the remaining three predictors (Chlorophyll concentration, Primary Productivity and Kd490) had a combined contribution of 12.6%.

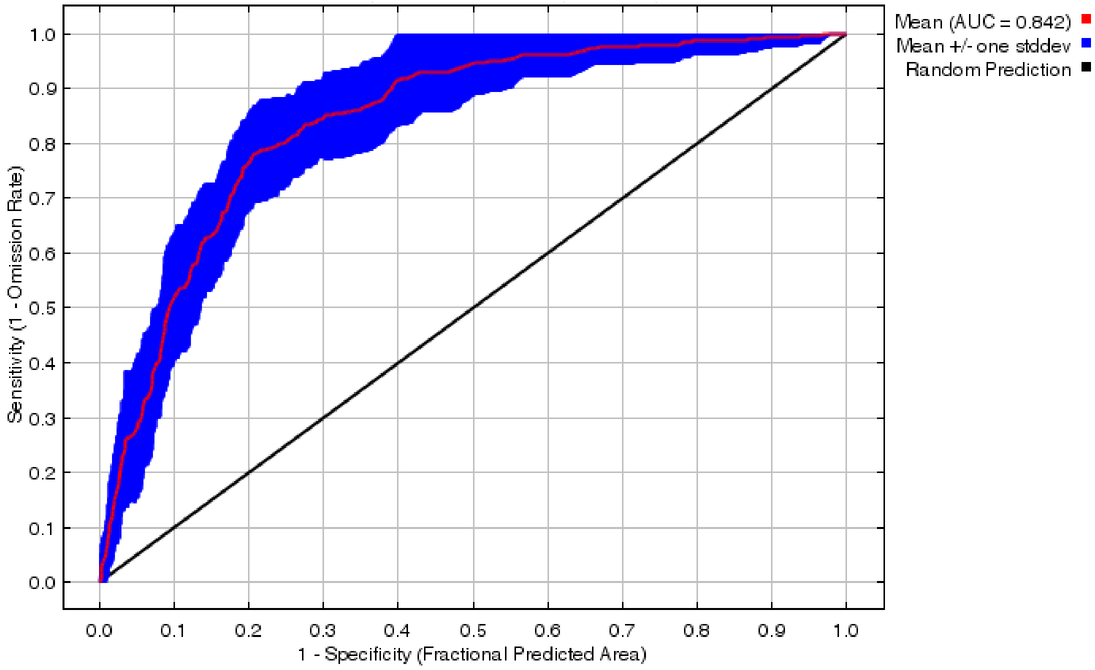

Figure 22: ROC curve for the training test of *Aplysina* sp.

Table 11: Relative contributions of each predictor variable to the distribution model of *Aplysina* sp.

Predictor variable	Contribution (%)
Bathymetry	72.7
Mean SST	14.7
Chlorophyll concentration	5.8
Primary Productivity	3.6
Kd490	3.2

Based on a jackknife test of variable importance (Figure 23a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 23b) confirmed that Bathymetry, Mean SST and Chlorophyll concentration were the main contributors to the model.

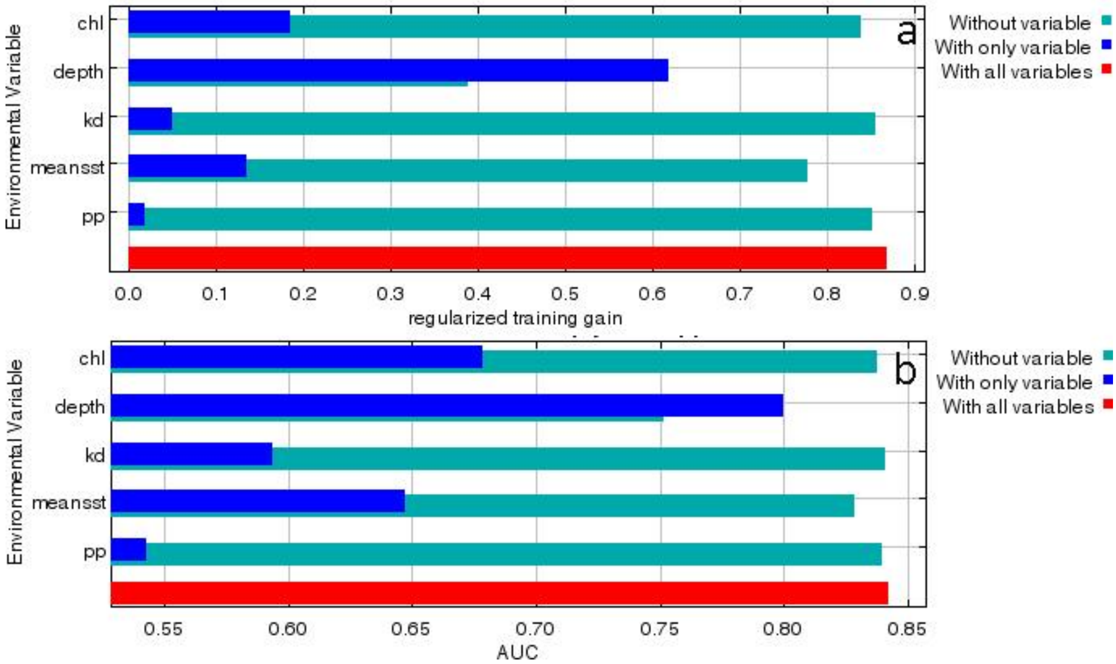

Figure 23: Jackknife of regularized training gain (a) and AUC (b) for *Aplysina* sp.

Central and Western Lesvos island, Skyros island and Tinos island are the areas where the most suitable conditions for *Aplysina* sp. occur followed by scattered areas among North and central Aegean Sea (Figure 24). Figure 25 shows the response curves of *Aplysina* sp. to Bathymetry, Mean SST and Chlorophyll concentration. *Aplysina* sp. peaks at depths around 7m and declines as depth increases, it prefers mean temperatures between 292.2K and 293.6K and low Chlorophyll concentrations. Table 12 shows the minimum and maximum values of each environmental variable in the cells where *Aplysina* sp. individuals have been recorded.

Table 12: Minimum and maximum values of predictor variables in the cells where *Aplysina* sp. individuals have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	0,22
Mean SST	291,57	294,24
Kd490	0,02	0,72
Chlorophyll concentration	0,07	3,07
Bathymetry	-137,88	0,00

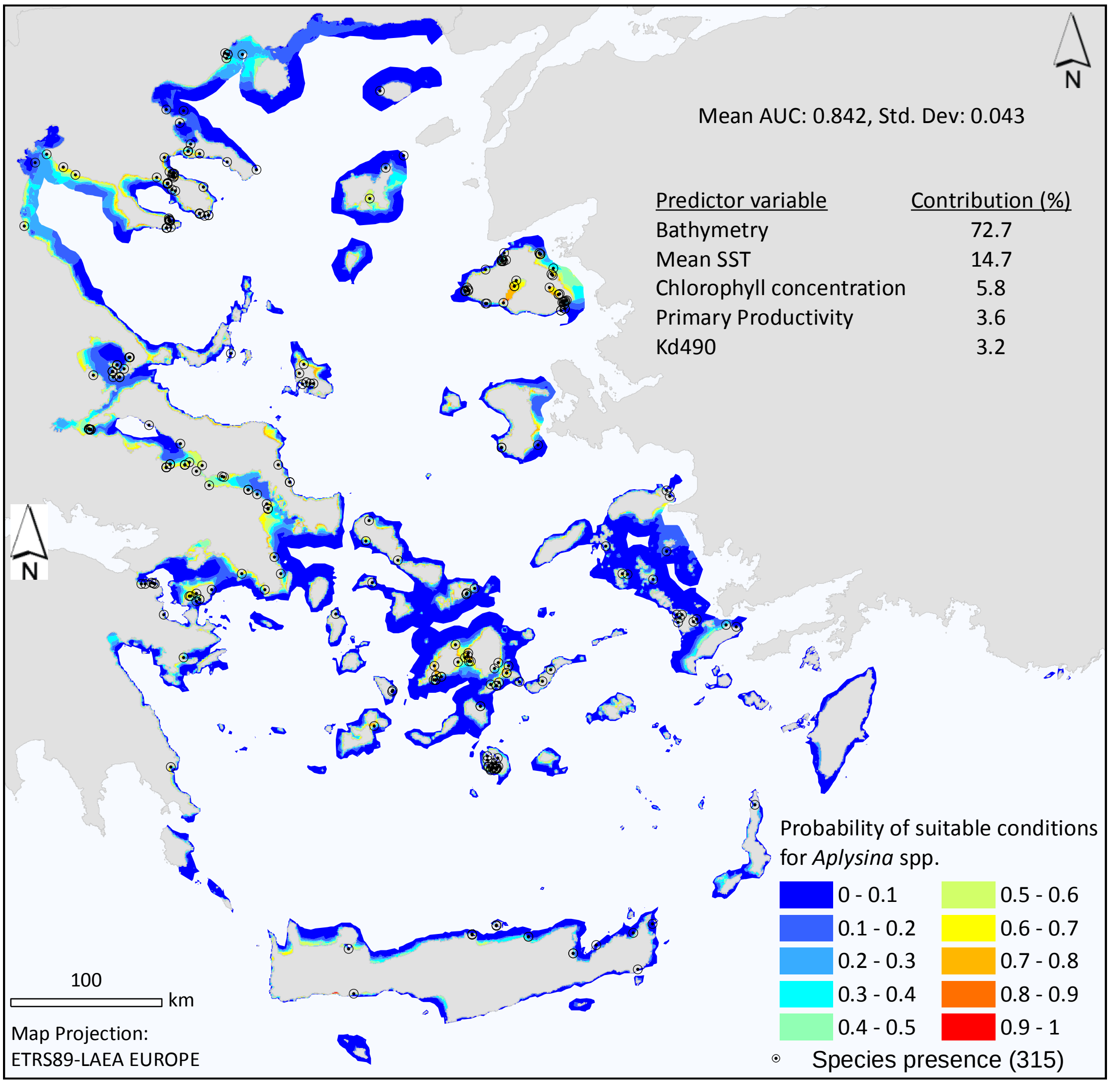

Figure 24: Probability of suitable conditions for *Aplysina* sp.

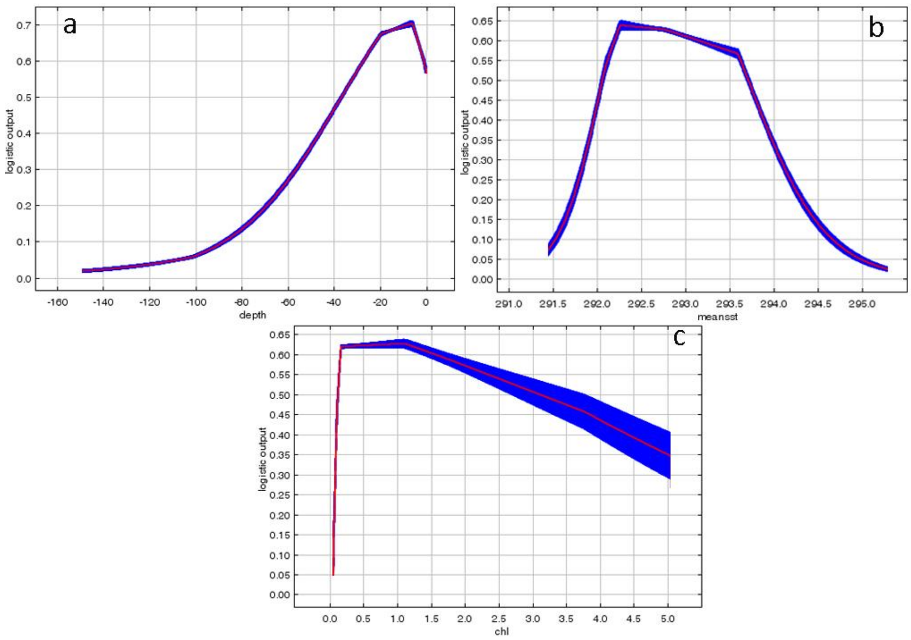

Figure 25: Response curves of *Aplysina* sp. to Bathymetry (m) (a), Mean SST (K) (b) and Chlorophyll concentration (mg/m^3) (c).

3.1.5 *Axinella cannabina*

A total of 164 presence points were used to model the occurrence of *A. cannabina* across the study area. The mean AUC of all models was 0.838 (standard deviation 0.066 - Figure 26). Bathymetry and Mean SST were the two main contributors to the model (combined contribution of 86.4%; Table 13), whilst the remaining three predictors (Primary Productivity, Kd490 and Chlorophyll concentration) had a combined contribution of 13.6%.

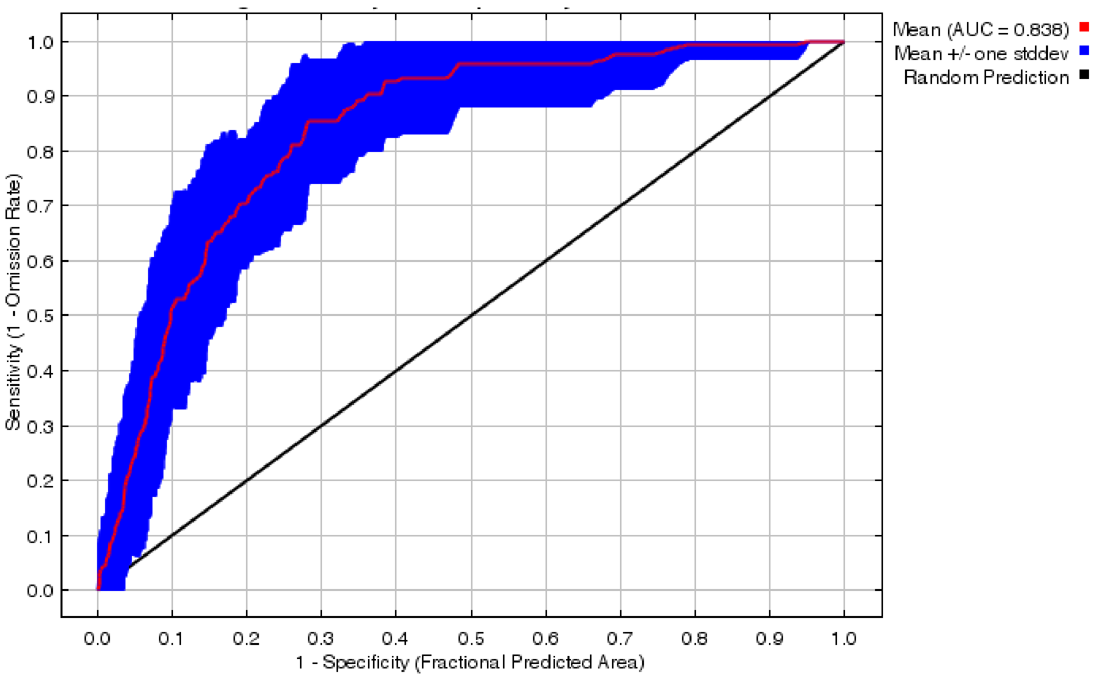

Figure 26: ROC curve for the training test of *A. cannabina*

Table 13: Relative contributions of each predictor variable to the distribution model of *A. cannabina*

Predictor variable	Contribution (%)
Bathymetry	67.3
Mean SST	19.1
Primary Productivity	5.6
Kd490	5.4
Chlorophyll concentration	2.6

Based on a jackknife test of variable importance (Figure 27a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 27b) confirmed that Bathymetry and Mean SST were the main contributors to the model.

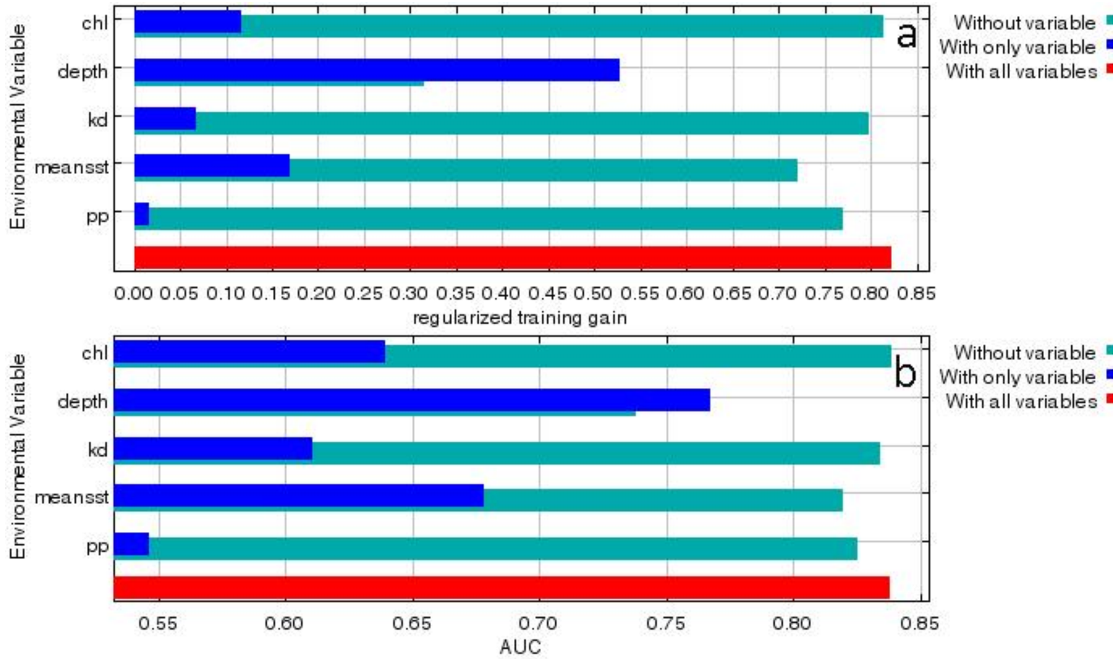

Figure 27: Jackknife of regularized training gain (a) and AUC (b) for *A. cannabina*

Northwest Crete, central Lesvos and Skyros island are the areas where the most suitable conditions for occur, followed by scattered areas among North and central Aegean Sea (Figure 28). Figure 29 shows the response curves of *A. cannabina* to Bathymetry, Mean SST and Primary Productivity. *A. cannabina* peaks at depths around 17m and declines as depth increases, it prefers mean temperatures around 292K and 292.5 and decreases as mean temperatures rise. It prefers low values of Primary productivity and declines as primary productivity increases. Table 14 shows the minimum and maximum values of each environmental variable in the cells where *A. cannabina* individuals have been recorded.

Table 14: Minimum and maximum values of predictor variables in the cells where *A. cannabina* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	0,08
Mean SST	291,55	294,56
Kd490	0,03	1,58
Chlorophyll concentration	0,07	2,53
Bathymetry	-111,94	-0,08

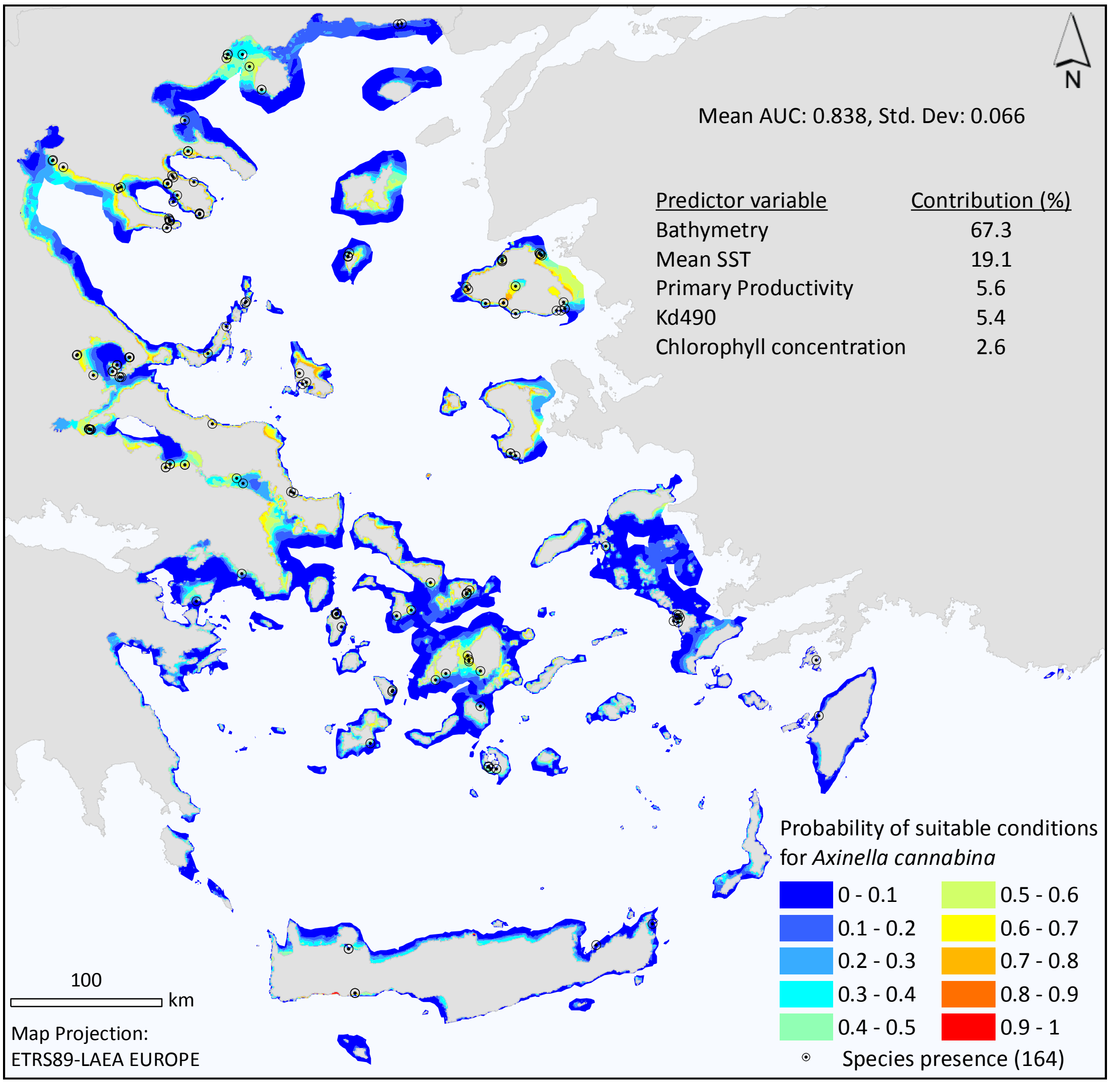

Figure 28: Probability of suitable conditions for *A. cannabina*

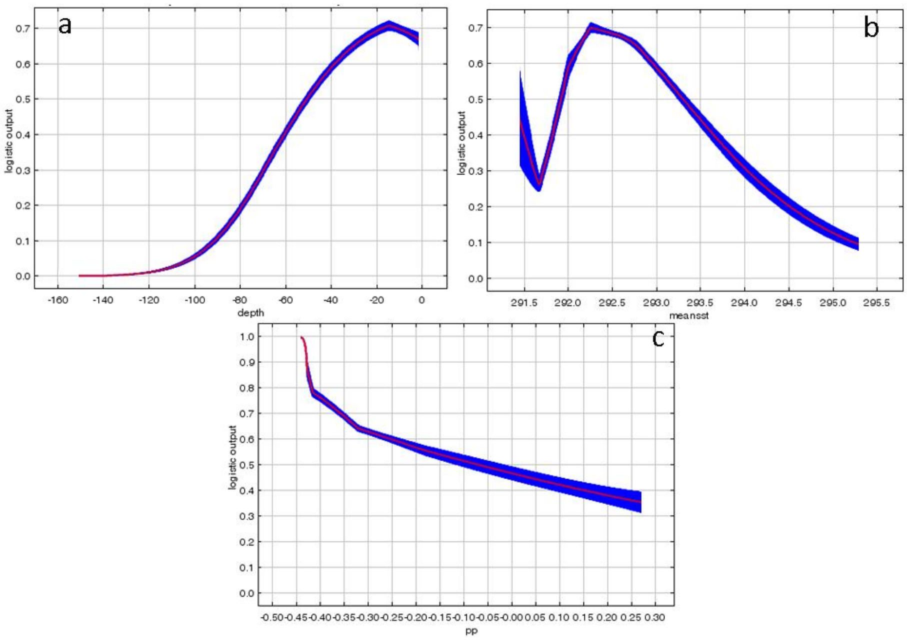

Figure 29: Response curves of *A. cannabina* to Bathymetry (m) (a), Mean SST (K) (b), and Primary Productivity (log(gC/m^2/day)) (c).

3.1.6 *Axinella polypoides*

A total of 30 presence points were used to model the occurrence of *A. polypoides* across the study area. The mean AUC of all models was 0.753 (standard deviation 0.226 - Figure 30). Bathymetry, Maximum SST and Primary Productivity were the three main contributors to the model (combined contribution of 87.7%; Table 15), whilst the remaining three predictors (Chlorophyll concentration, Mean SST and Kd490) had a combined contribution of 12.3%.

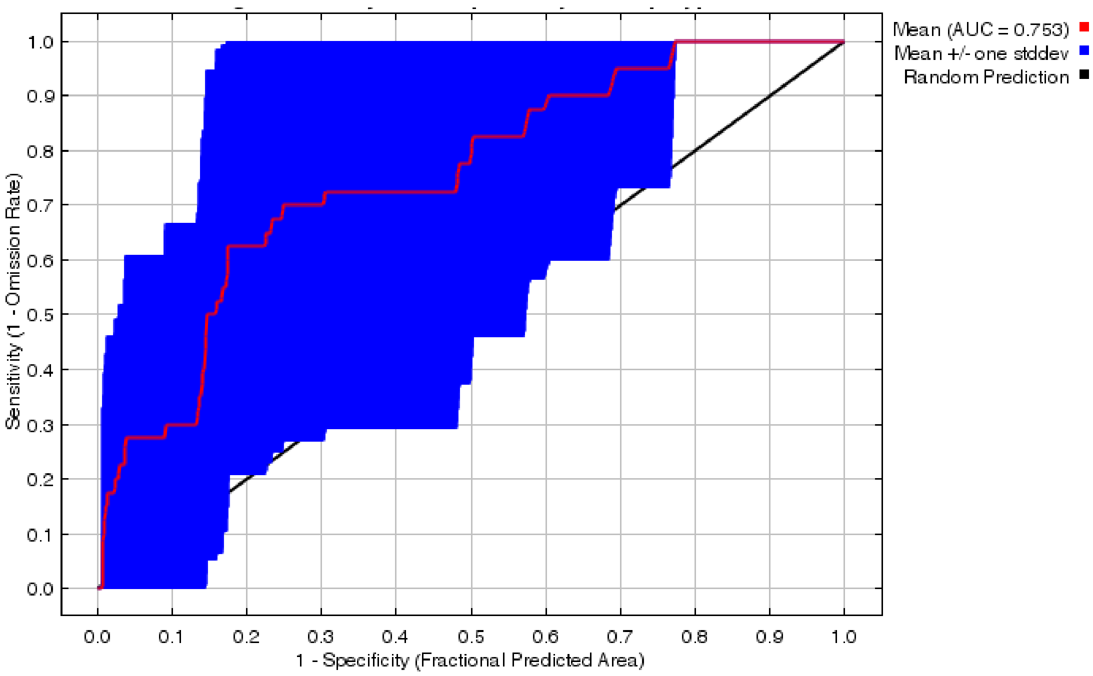

Figure 30: ROC curve for the training test of *A. polypoides*

Table 15: Relative contributions of each predictor variable to the distribution model of *A. polypoides*

Predictor variable	Contribution (%)
Bathymetry	46.6
Maximum SST	20.7
Primary Productivity	20.4
Chlorophyll concentration	8.3
Mean SST	3.2
Kd490	0.7

Based on a jackknife test of variable importance (Figure 31a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 31b) confirmed that Bathymetry, Maximum SST and Primary Productivity were the main contributors to the model.

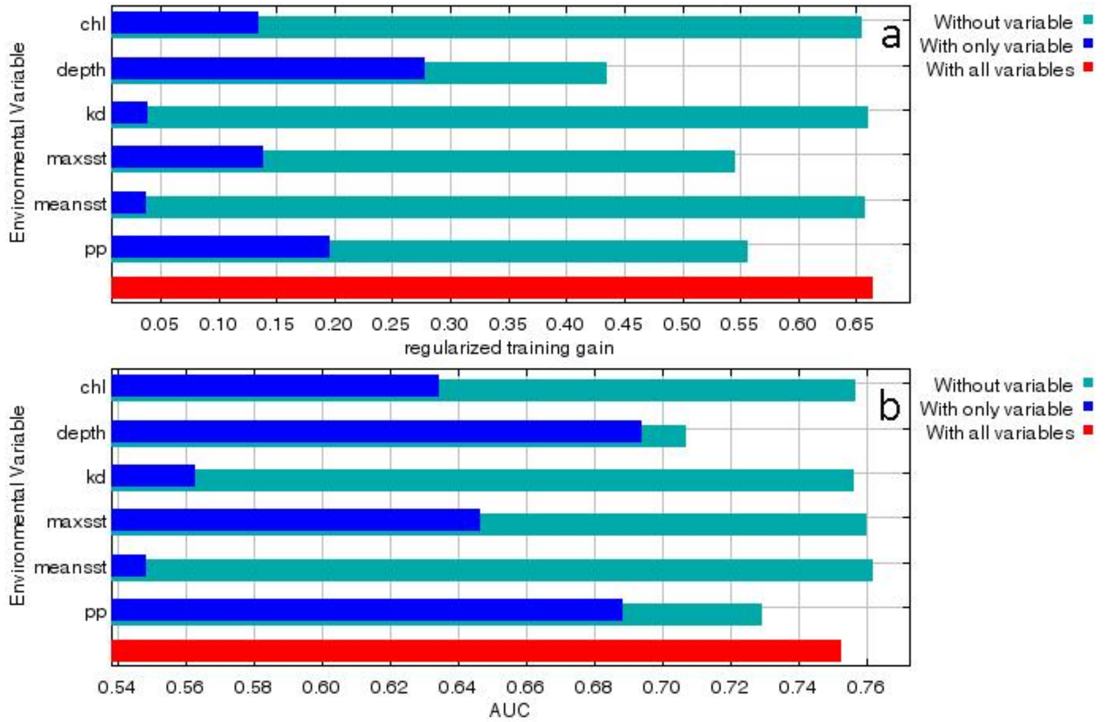

Figure 31: Jackknife of regularized training gain (a) and AUC (b) for *A. polypoides*

Modeling of *A. polypoides* is less successful than other animal species studied in this dissertation. This could be due to few recorded presences of the species (30 records) in the Aegean Sea. The areas with high probability of suitable conditions for A. *polypoides* are scattered across the Aegean Sea, with the highest probabilities being located in southeast Evia, Agios Eftratios, Santorini, Kasos, southwest Crete and Samos (Figure 32). Figure 33 shows the response curves of *A. polypoides* to Bathymetry, Maximum SST, Primary Productivity and Chlorophyll concentration. *A. polypoides* has higher probabilities to be located at depths between 5m and 50m, it peaks at maximum SSTs of approximately 299K-300K, it prefers areas with low values of primary productivity and does not occur at areas with primary productivity larger than 0.7[2]gC/m^2/day. *A. polypoides* has a declining response to areas with increasing chlorophyll concentration but with a big range of responses at each value. Table 16 shows the minimum and maximum values of each environmental variable in the cells where *A. polypoides* individuals have been recorded.

Table 16: Minimum and maximum values of predictor variables in the cells where *A. polypoides* individuals have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,41	-0,22
Mean SST	292,01	294,56
Maximum SST	298,25	301,13
Kd490	0,03	0,14
Chlorophyll concentration	0,08	0,67
Bathymetry	-124,50	-0,47

[2] log (0.79)=-0.1

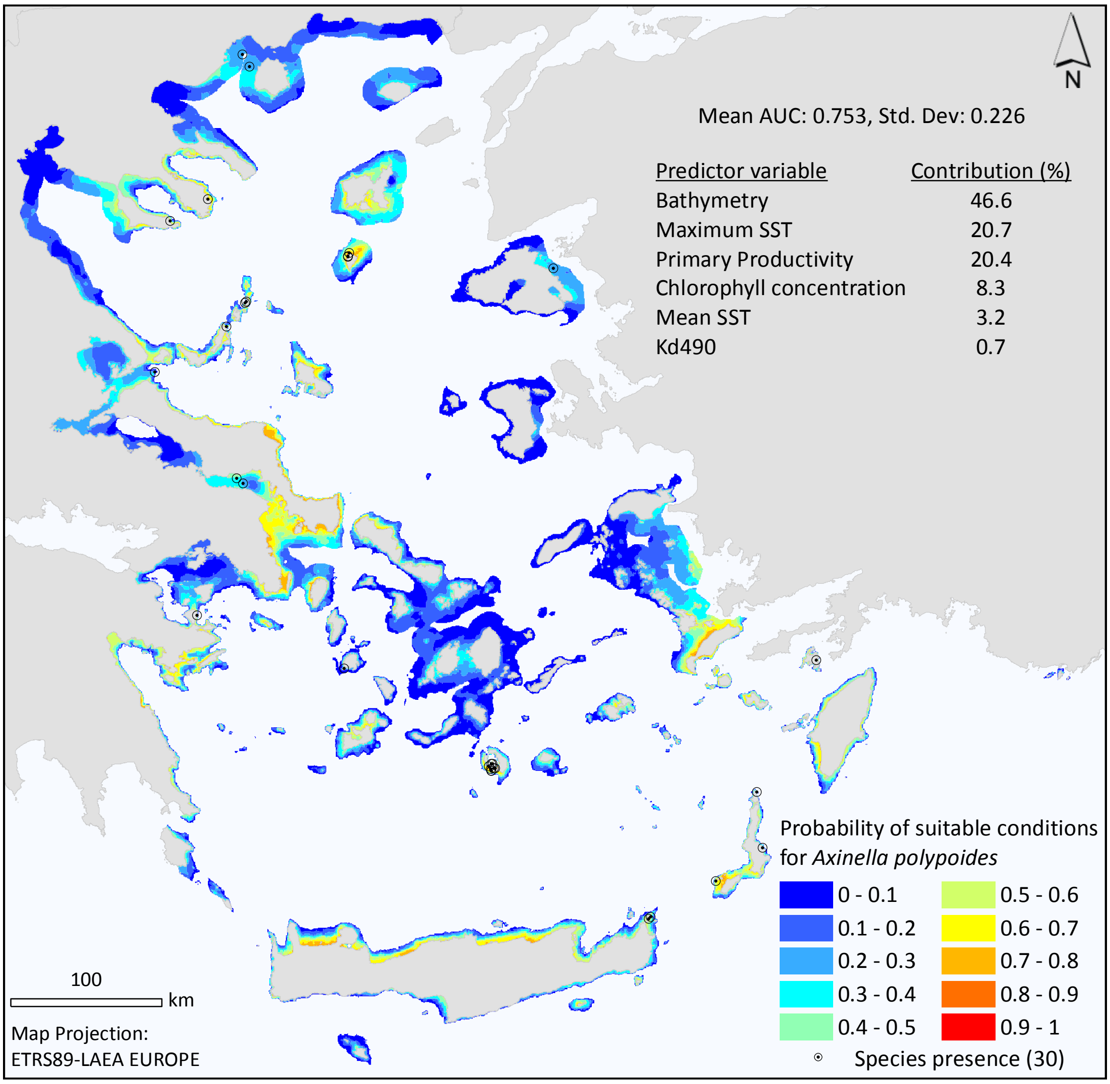

Figure 32: Probability of suitable conditions for *A. polypoides*

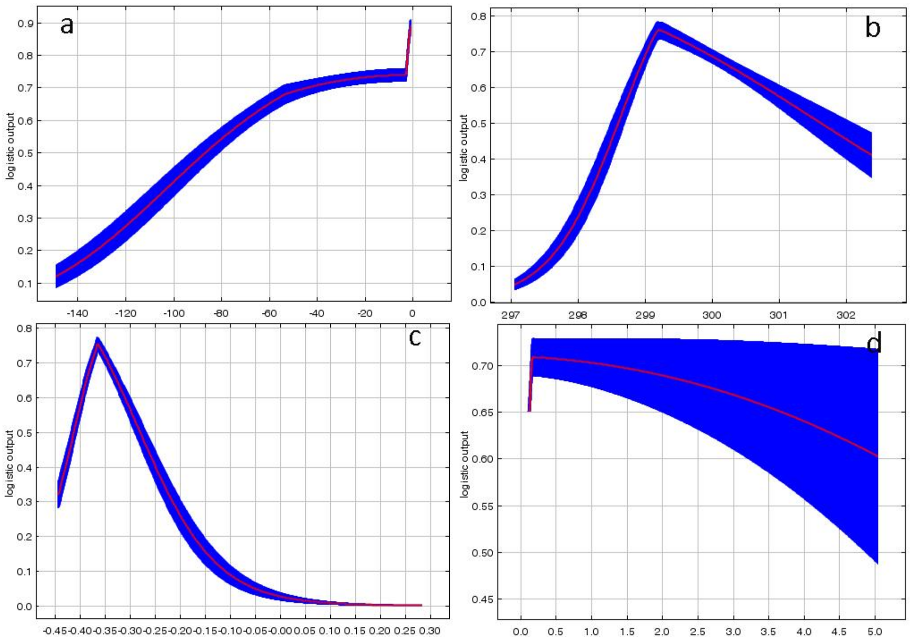

Figure 33: Response curves of *A. polypoides* to Bathymetry (m) (a), Maximum SST (K) (b), Primary Productivity (log(gC/m^2/day)) (c) and Chlorophyll concentration (mg/m^3) (d).

3.1.7 *Geodia cydonium*

A total of 67 presence points were used to model the occurrence of *G. cydonium* across the study area. The mean AUC of all models was 0.717 (standard deviation 0.159 - Figure 34). Bathymetry, Chlorophyll concentration and Mean SST were the three main contributors to the model (combined contribution of 89.6%; Table 17), whilst the remaining three predictors (Maximum SST, Primary Productivity and Kd490) had a combined contribution of 10.4%.

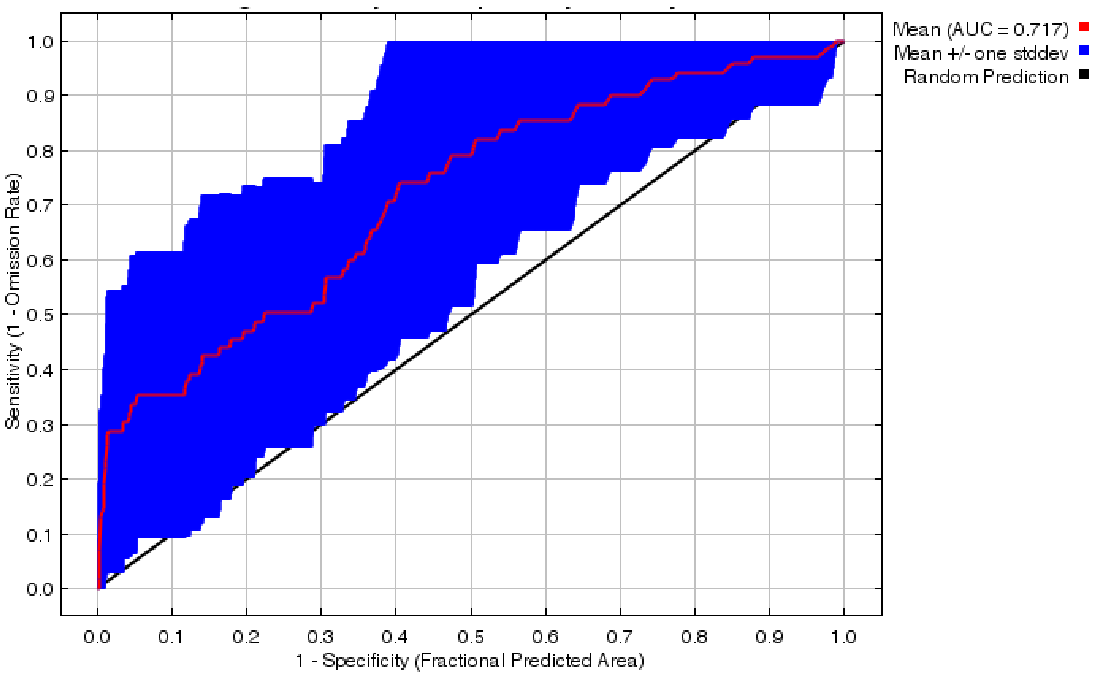

Figure 34: ROC curve for the training test of *G. cydonium*

Table 17: Relative contributions of each predictor variable to the distribution model of *G. cydonium*

Predictor variable	Contribution (%)
Bathymetry	41.7
Chlorophyll concentration	33.0
Mean SST	14.9
Maximum SST	3.9
Primary Productivity	3.6
Kd490	3.1

Based on a jackknife test of variable importance (Figure 35a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 35b) confirmed that Bathymetry, Chlorophyll concentration and Mean SST were the main contributors to the model.

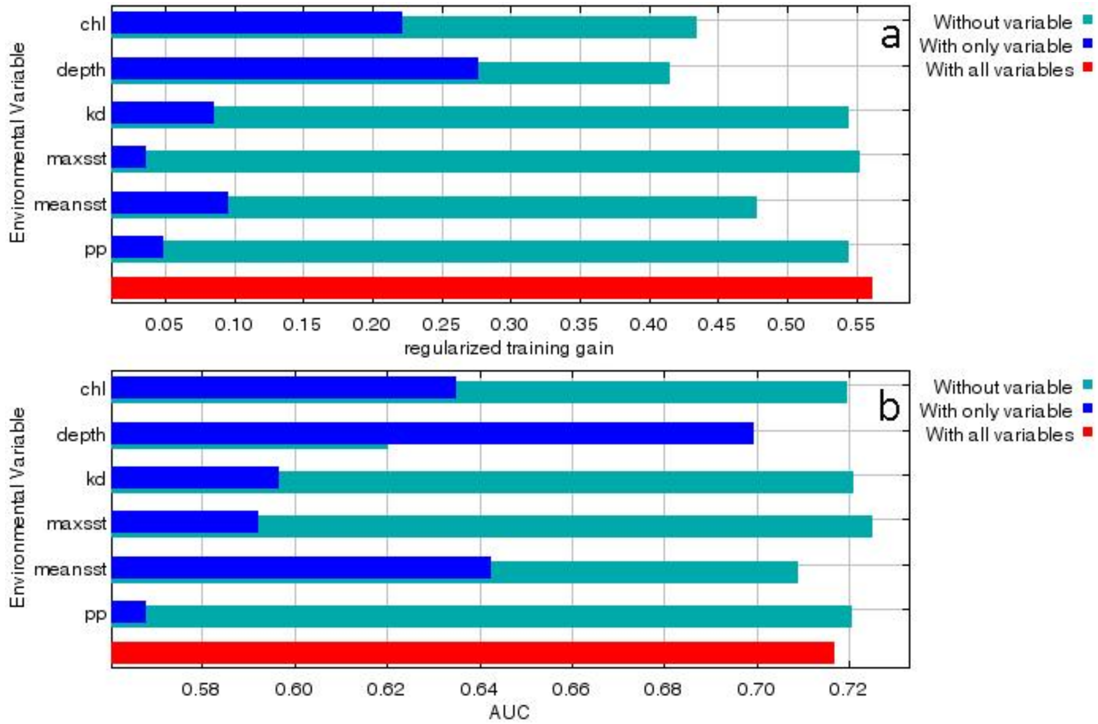

Figure 35: Jackknife of regularized training gain (a) and AUC (b) for *G. cydonium*

Modeling of *G. cydonium* is less successful than other animal species studied in this dissertation. The areas with high probability of suitable conditions for *G. cydonium* are scattered across the Aegean Sea, with the highest probabilities being located in Lesvos and specifically in the gulfs of Kalloni and Gera (Figure 36). Figure 37 shows the response curves of *G. cydonium* to Bathymetry, Chlorophyll concentration, Mean SST and Maximum SST. *G. cydonium* has a declining response to increasing depth, it prefers areas with low values of chlorophyll concentration and mean SST. It has a declining response to maximum SST which stabilizes at approximately 299K. Table 18 shows the minimum and maximum values of each environmental variable in the cells where *G. cydonium* individuals have been recorded.

Table 18: Minimum and maximum values of predictor variables in the cells where *G. cydonium* individuals have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	0,18
Mean SST	291,57	294,24
Maximum SST	297,09	301,20
Kd490	0,03	0,46
Chlorophyll concentration	0,07	2,88
Bathymetry	-138,45	-0,04

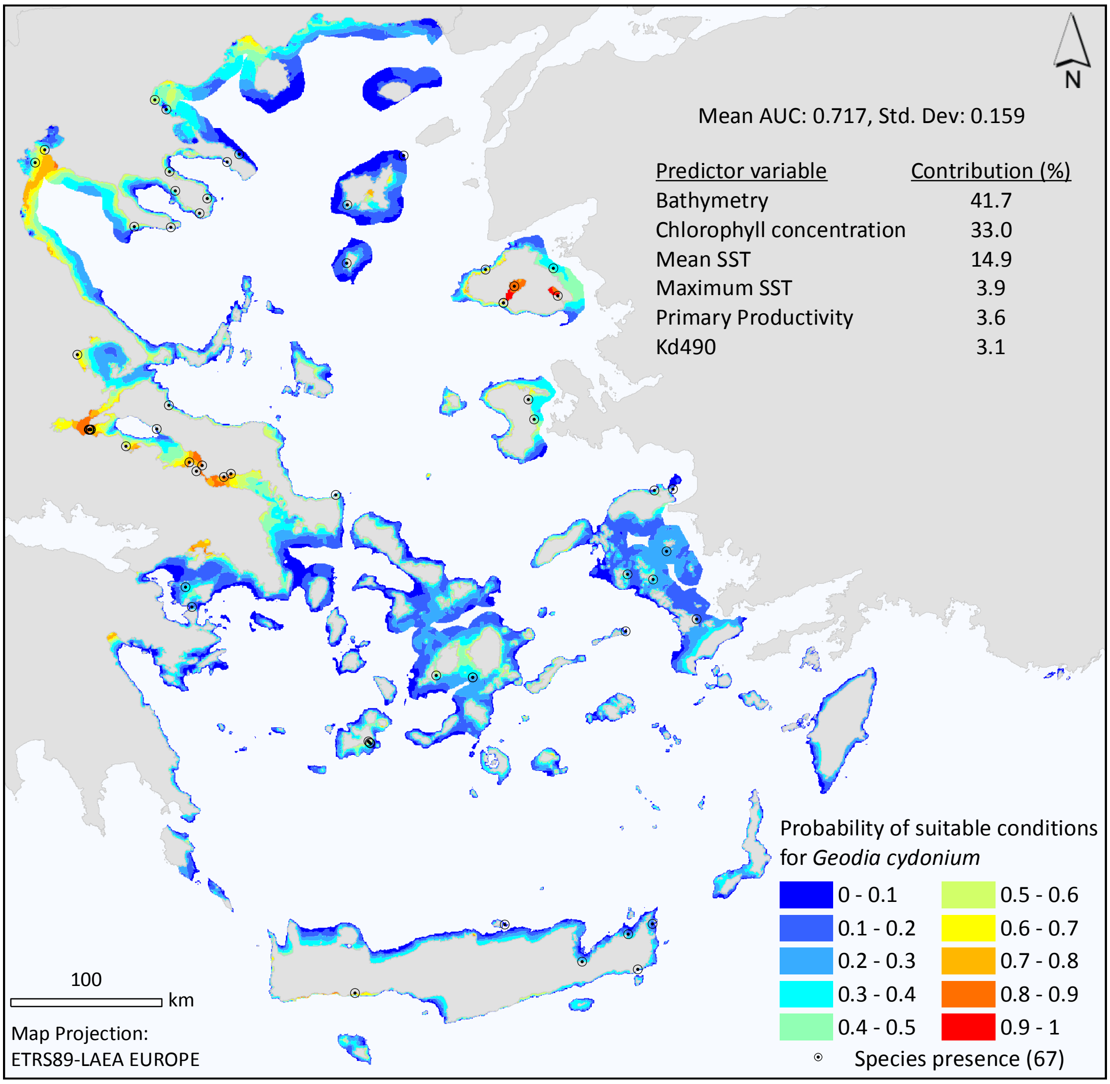

Figure 36: Probability of suitable conditions for *G. cydonium*

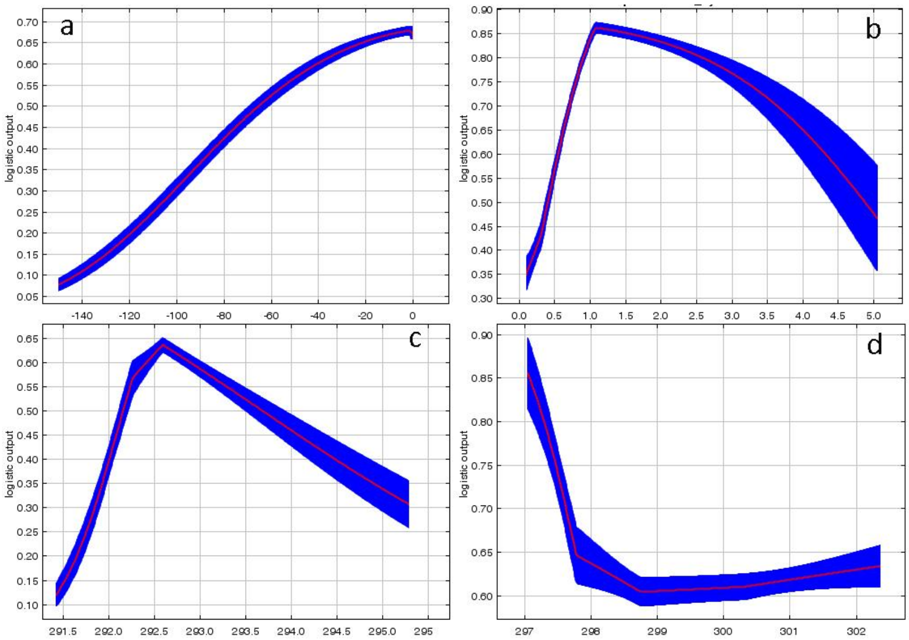

Figure 37: Response curves of *G. cydonium* to Bathymetry (m) (a), Chlorophyll concentration (mg/m^3) (b), Mean SST (K) (c) and Maximum SST (K) (d).

3.1.8 *Sarcotragus* spp.

A total of 274 presence points were used to model the occurrence of *Sarcotragus* sp. across the study area. The mean AUC of all models was 0.869 (standard deviation 0.031 - Figure 38). Bathymetry and Primary Productivity were the two main contributors to the model (combined contribution of 81.9%; Table 19), whilst the remaining four predictors (Maximum SST, Mean SST, Kd490 and Chlorophyll concentration) had a combined contribution of 18.1%.

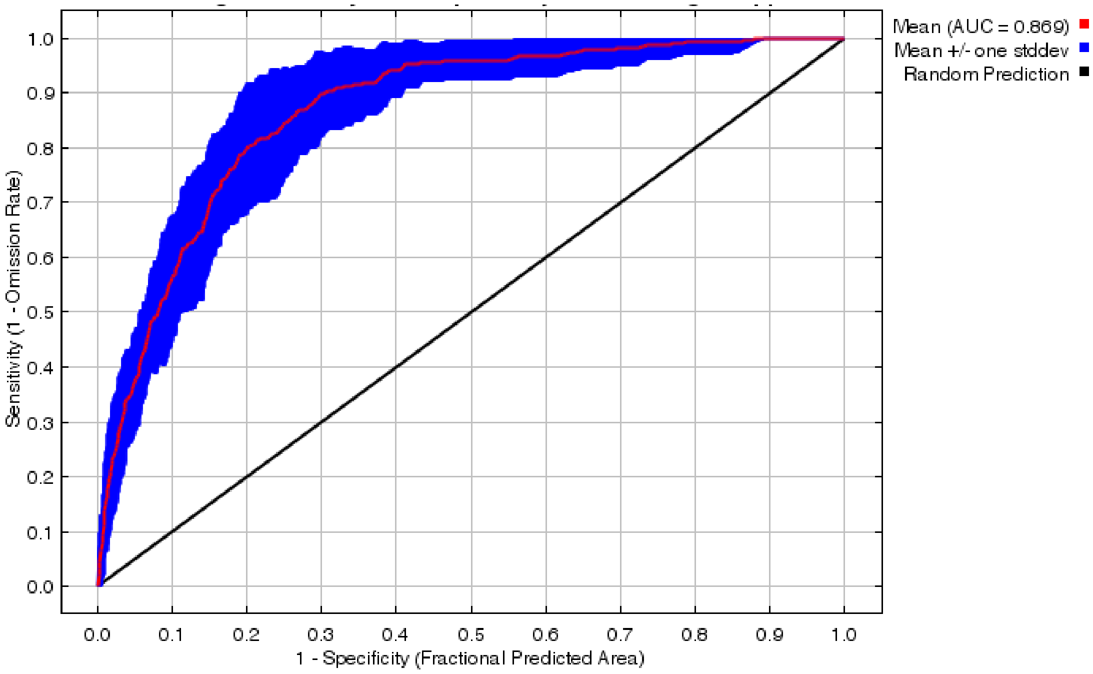

Figure 38: ROC curve for the training test of *Sarcotragus* sp.

Table 19: Relative contributions of each predictor variable to the distribution model of *Sarcotragus* sp.

Predictor variable	Contribution (%)
Bathymetry	60.2
Primary Productivity	21.7
Maximum SST	6.3
Mean SST	5.7
Kd490	5.2
Chlorophyll concentration	1.0

Based on a jackknife test of variable importance (Figure 39a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 39b) confirmed that Bathymetry and Primary Productivity were the main contributors to the model.

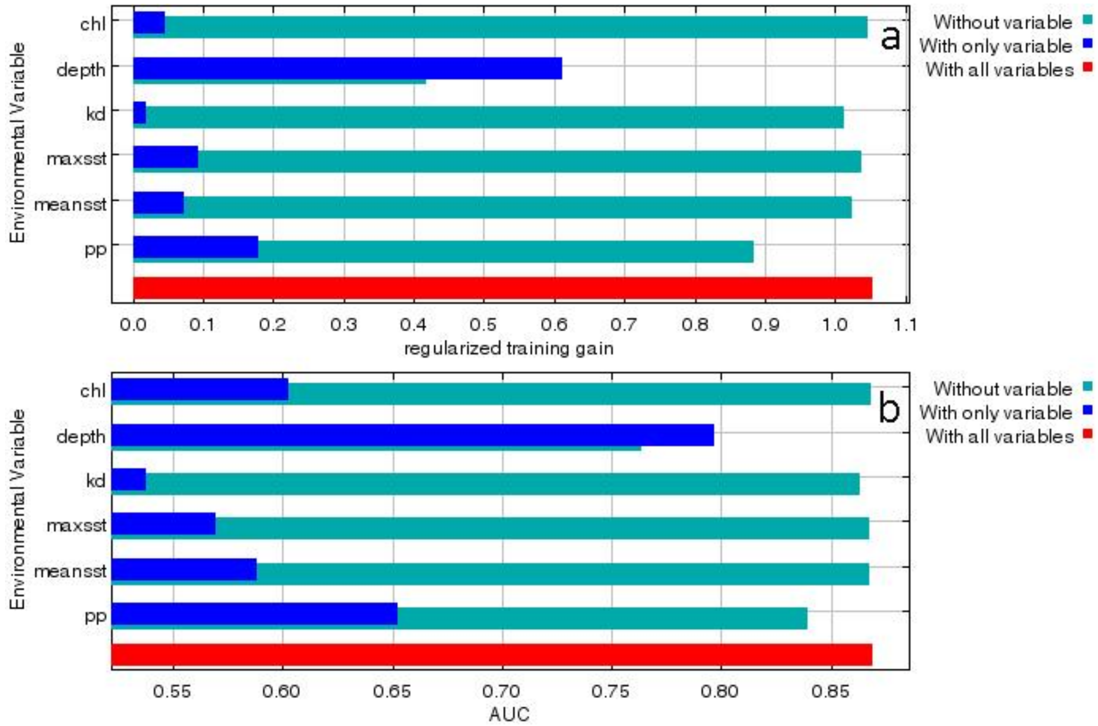

Figure 39: Jackknife of regularized training gain (a) and AUC (b) for *Sarcotragus* sp.

The areas with high probability of suitable conditions for *Sarcotragus* sp. are scattered across the Aegean Sea, with the highest probabilities being located in southwest and northern Crete and Anafi (Figure 40). Figure 41 shows the response curves of *Sarcotragus* sp. to Bathymetry, Primary Productivity, Maximum SST and Mean SST. The most suitable depths for *Sarcotragus* sp. are 3-20m with declining suitability as depth increases, up to the depth of 120 after which the species does not exist. Regarding primary productivity, *Sarcotragus* sp. prefers low values with declining suitability, at values higher 0.89[3]gC/m^2/day the species has very small probabilities of occurring. The most suitable SSTs for *Sarcotragus* sp. are maximum values of approximately 301k and mean values between 292-293K. Table 20 shows the minimum and maximum values of each environmental variable in the cells where *Sarcotragus* sp. individuals have been recorded.

Table 20: Minimum and maximum values of predictor variables in the cells where *Sarcotragus* sp. individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	-0,11
Mean SST	291,67	294,56
Maximum SST	297,07	301,47
Kd490	0,02	0,72
Chlorophyll concentration	0,07	2,49
Bathymetry	-123,26	-0,04

[3] log (0.89)=-0.05

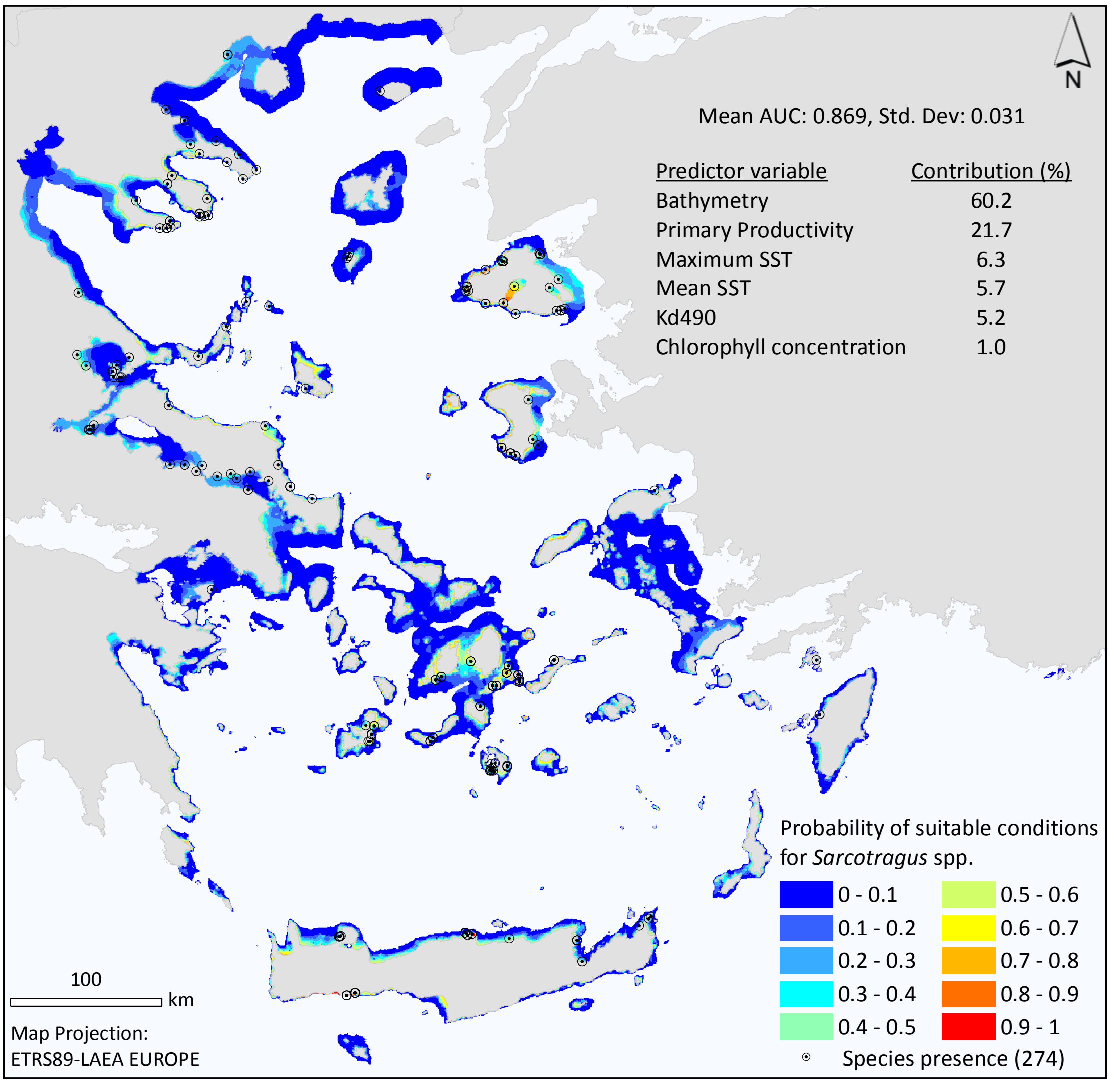

Figure 40: Probability of suitable conditions for *Sarcotragus* sp.

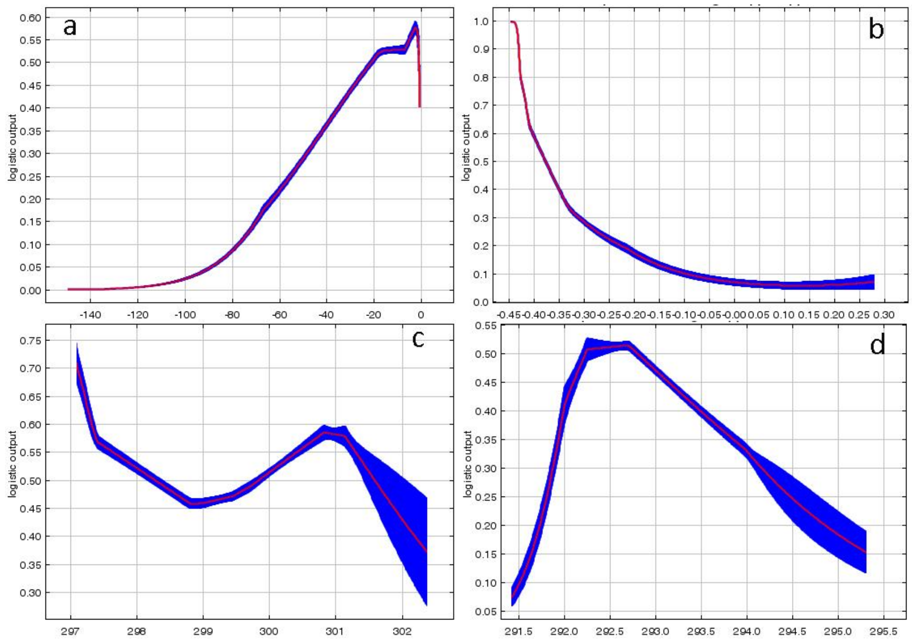

Figure 41: Response curves of *Sarcotragus* sp. to Bathymetry (m) (a), Primary Productivity (log(gC/m^2/day)) (b), Maximum SST (K) (c) and Mean SST (K) (d).

3.1.9 *Tethya aurantium*

A total of 35 presence points were used to model the occurrence of *T. aurantium* across the study area. The mean AUC of all models was 0.842 (standard deviation 0.188 - Figure 42). Bathymetry and Mean SST were the two main contributors to the model (combined contribution of 80.4 %; Table 21), whilst the remaining three predictors (Kd490, Primary Productivity, Chlorophyll concentration and Maximum SST) had a combined contribution of 19.6%.

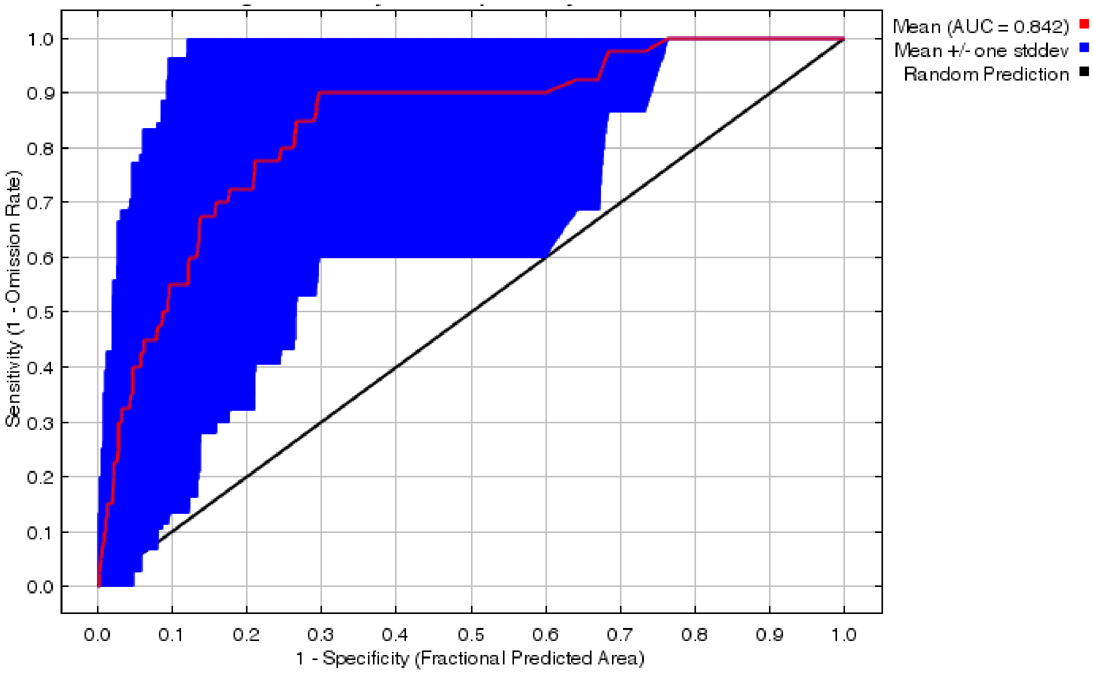

Figure 42: ROC curve for the training test of *T. aurantium*

Table 21: Relative contributions of each predictor variable to the distribution model of *T. aurantium*

Predictor variable	Contribution (%)
Bathymetry	64.5
Mean SST	15.9
Kd490	8.8
Primary Productivity	5.1
Chlorophyll concentration	4.3
Maximum SST	1.4

Based on a jackknife test of variable importance (Figure 43a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 43b) confirmed that Bathymetry and Mean SST were the main contributors to the model.

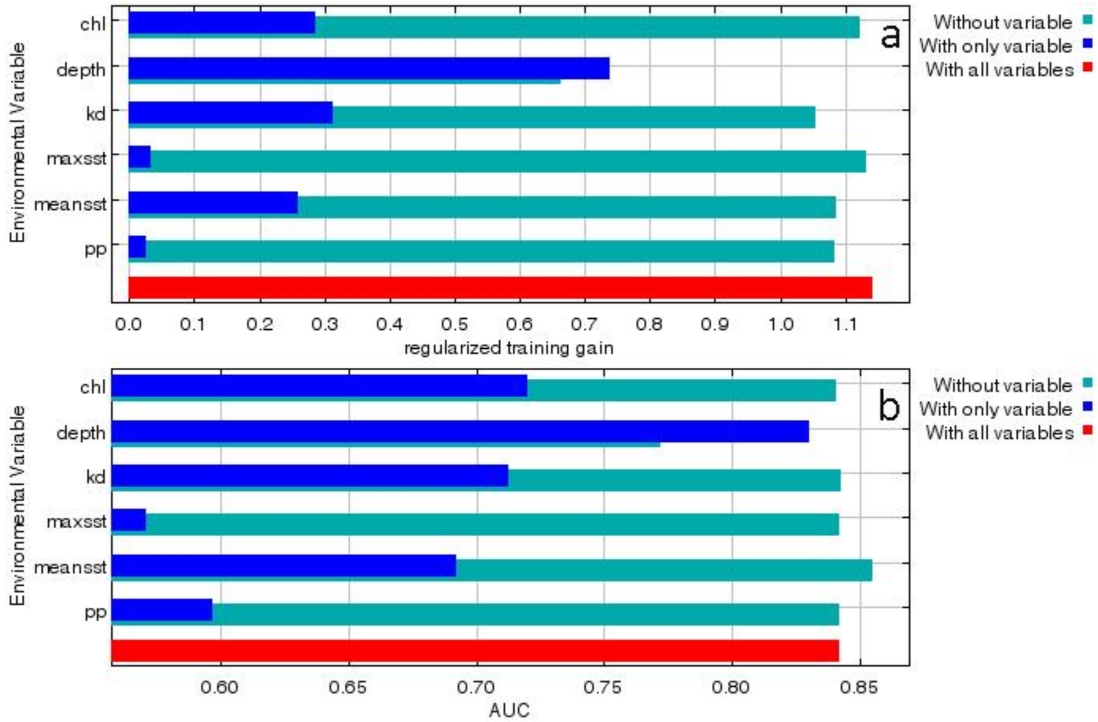

Figure 43: Jackknife of regularized training gain (a) and AUC (b) for *T. aurantium*

The areas with high probability of suitable conditions for *T. aurantium* are scattered across the Aegean Sea, with the highest probabilities being located in Kalloni gulf (Lesvos), NE Chios, Chalkidiki and SE Evoikos gulf (Figure 44). Figure 45 shows the response curves of *T. aurantium* to Bathymetry, Mean SST, Kd490 and Primary Productivity. The most suitable depths for *T. aurantium* are 3-20m with declining suitability as depth increases. The most suitable mean SSTs are up to 292.7K and the suitability declines with the increase of mean SST. *T. aurantium* has a stable high response to values of Kd490 greater than 0.2 and responds negatively to increasing values of primary productivity. Table 22 shows the minimum and maximum values of each environmental variable in the cells where *T. aurantium* individuals have been recorded.

Table 22: Minimum and maximum values of predictor variables in the cells where *T. aurantium* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,42	-0,04
Mean SST	291,57	294,36
Maximum SST	297,53	301,32
Kd490	0,03	0,95
Chlorophyll concentration	0,09	2,49
Bathymetry	-101,64	-1,81

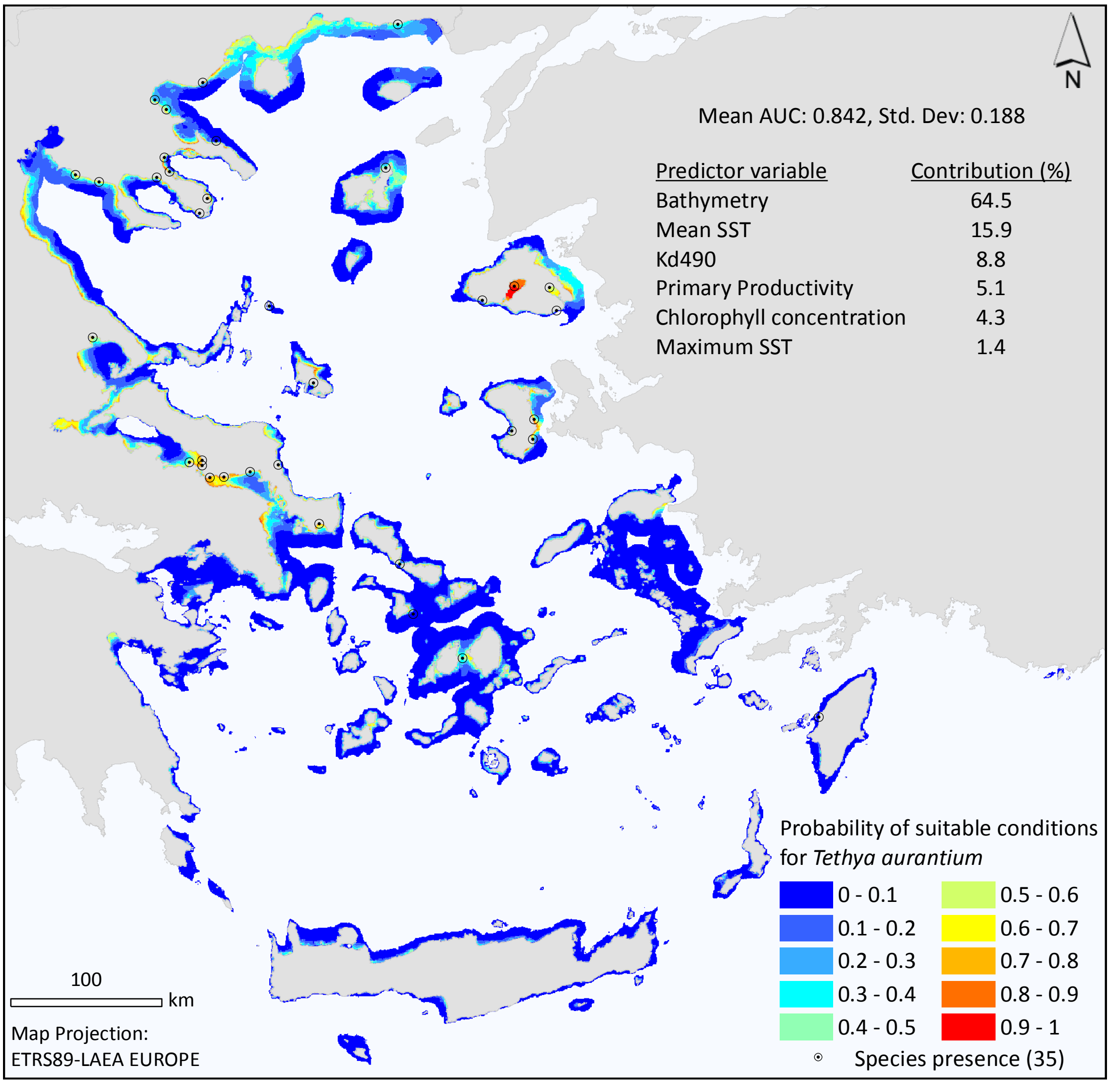

Figure 44: Probability of suitable conditions for *T. aurantium*

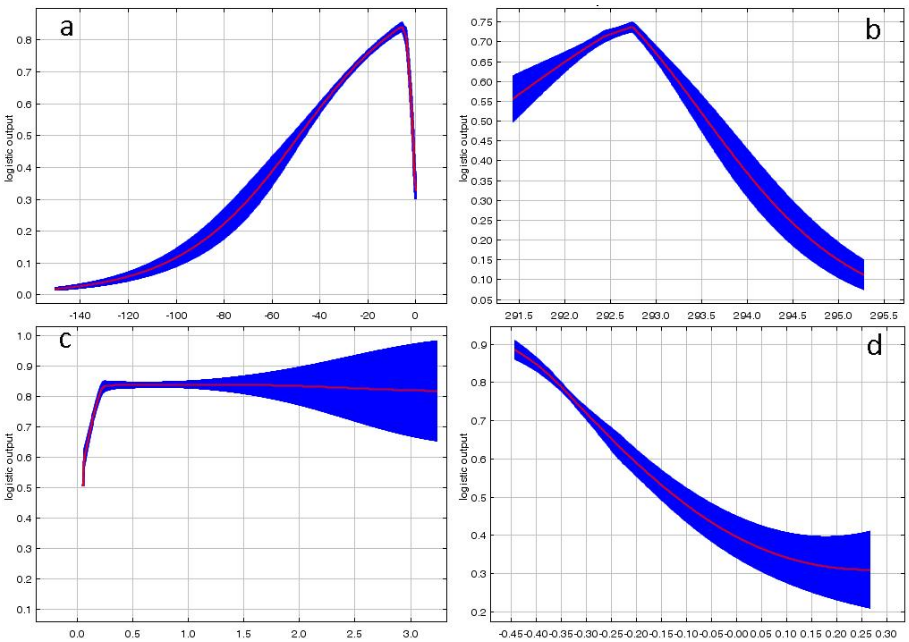

Figure 45: Response curves of *T. aurantium* to Bathymetry (m) (a), Mean SST (K) (b), Kd490 (m^{-1}) (c) and Primary Productivity ($log(gC/m^2/day)$) (d).

3.1.10 *Tethya citrina*

A total of 25 presence points were used to model the occurrence of *T. citrina* across the study area. The mean AUC of all models was 0.871 (standard deviation 0.133 - Figure 46). Bathymetry, Kd490 and Chlorophyll concentration were the three main contributors to the model (combined contribution of 80.9%; Table 23), whilst the remaining three predictors (Mean SST, Maximum SST and Primary Productivity) had a combined contribution of 19.1%.

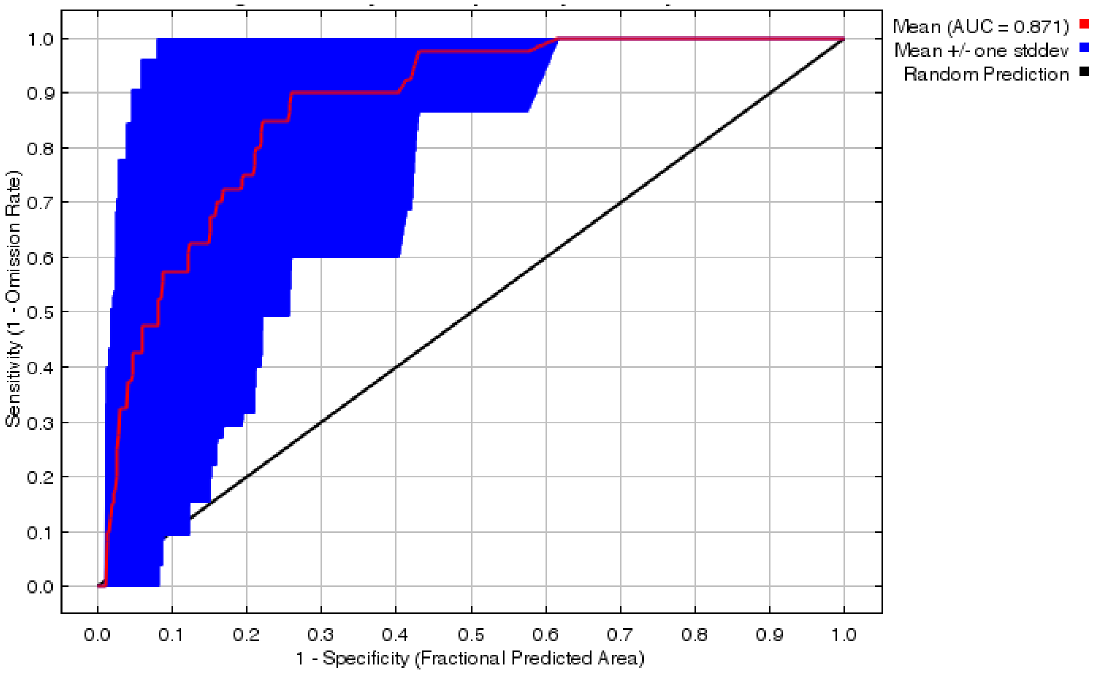

Figure 46: ROC curve for the training test of *T. citrina*

Table 23: Relative contributions of each predictor variable to the distribution model of *T. citrina*

Predictor variable	Contribution (%)
Bathymetry	41.8
Kd490	20.8
Chlorophyll concentration	18.3
Mean SST	17.2
Maximum SST	1.3
Primary Productivity	0.5

Based on a jackknife test of variable importance (Figure 47a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 47b) confirmed that Bathymetry and Kd490 were the main contributors to the model.

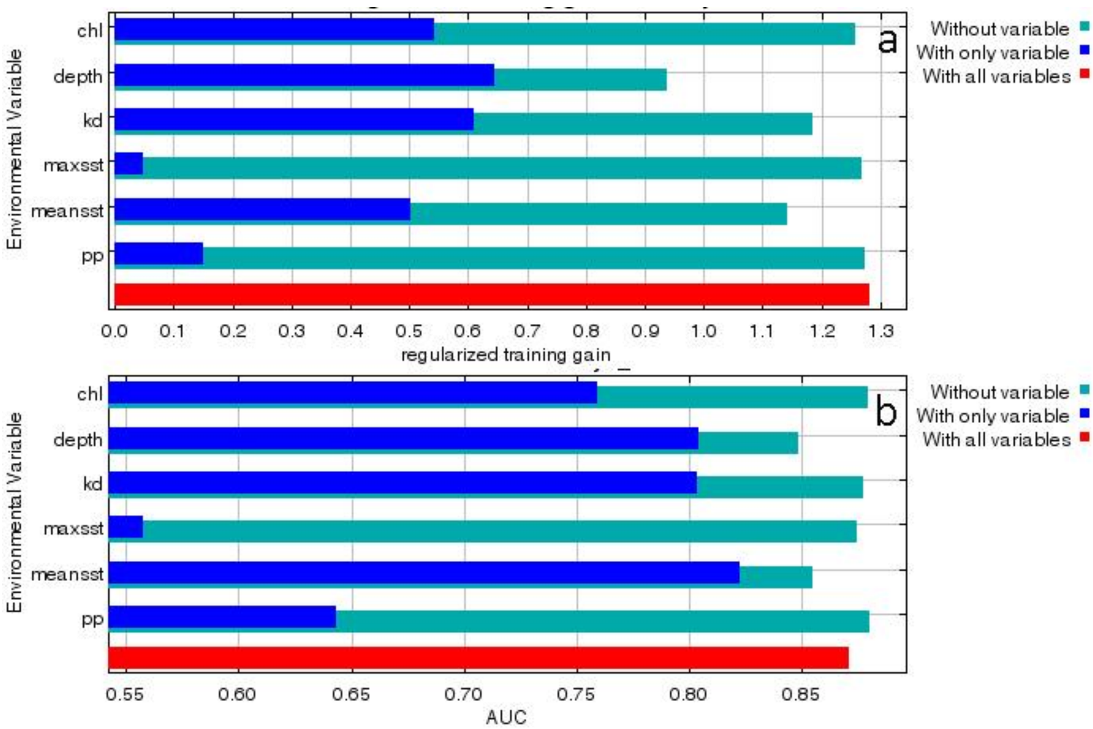

Figure 47: Jackknife of regularized training gain (a) and AUC (b) for *T. citrina*

The areas with high probability of suitable conditions for *T. citrina* are scattered across the North Aegean Sea, with the highest probabilities being located in Kalloni gulf (Lesvos) (Figure 48). Figure 49 shows the response curves of *T. citrina* to Bathymetry, Kd490, Chlorophyll concentration and Mean SST. *T. citrina* prefers small depths, low values of Kd490 and chlorophyll concentration with negative responses to all three variables. *T. citrina* has a better response to mean SSTs of 292.4K-293K. Table 24 shows the minimum and maximum values of each environmental variable in the cells where *T. citrina* individuals have been recorded.

Table 24: Minimum and maximum values of predictor variables in the cells where *T. citrina* individuals have been recorded

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,41	-0,02
Mean SST	291,67	292,78
Maximum SST	297,51	301,01
Kd490	0,04	0,41
Chlorophyll concentration	0,12	2,49
Bathymetry	-92,37	-0,02

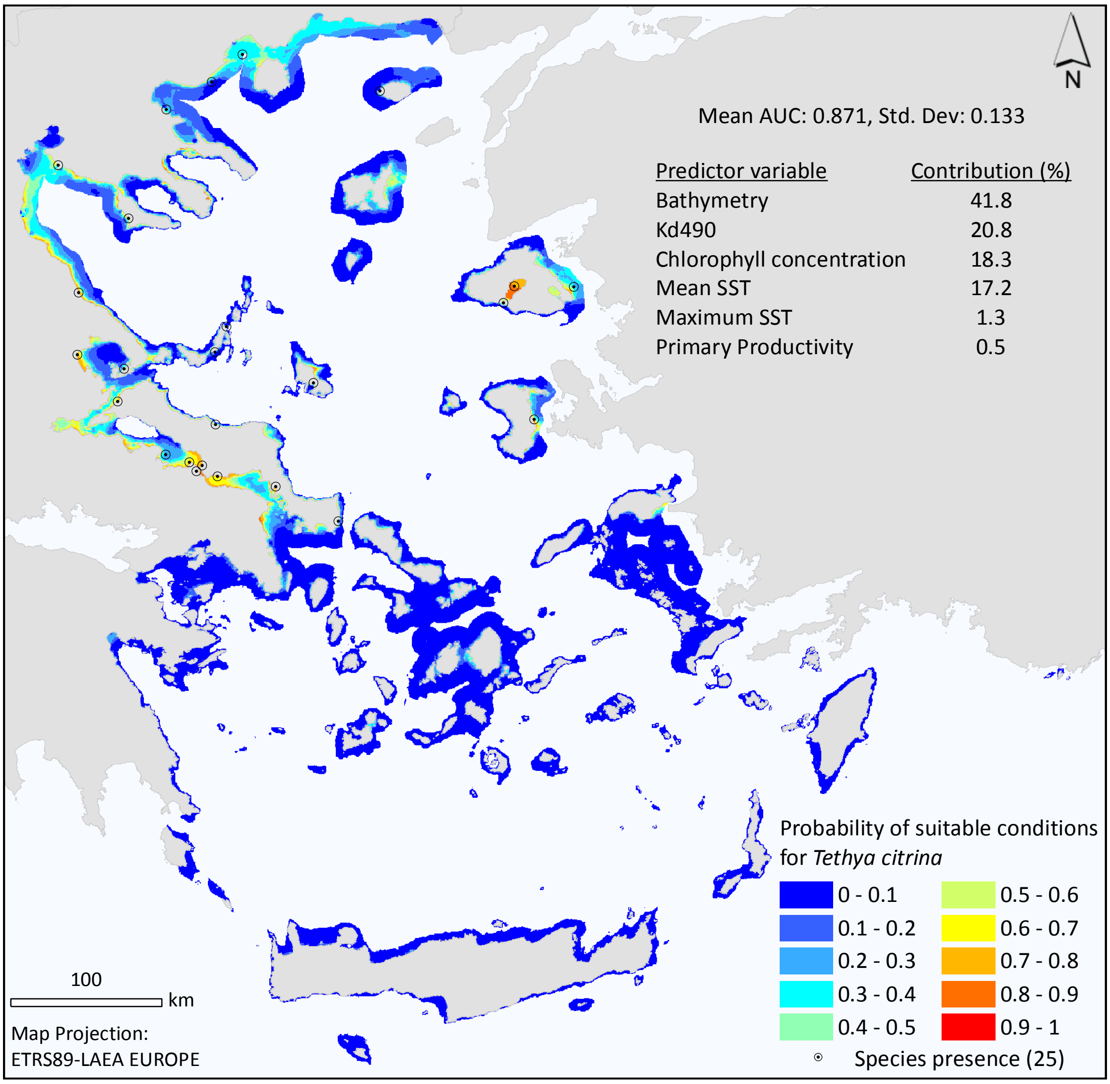

Figure 48: Probability of suitable conditions for *T. citrina*

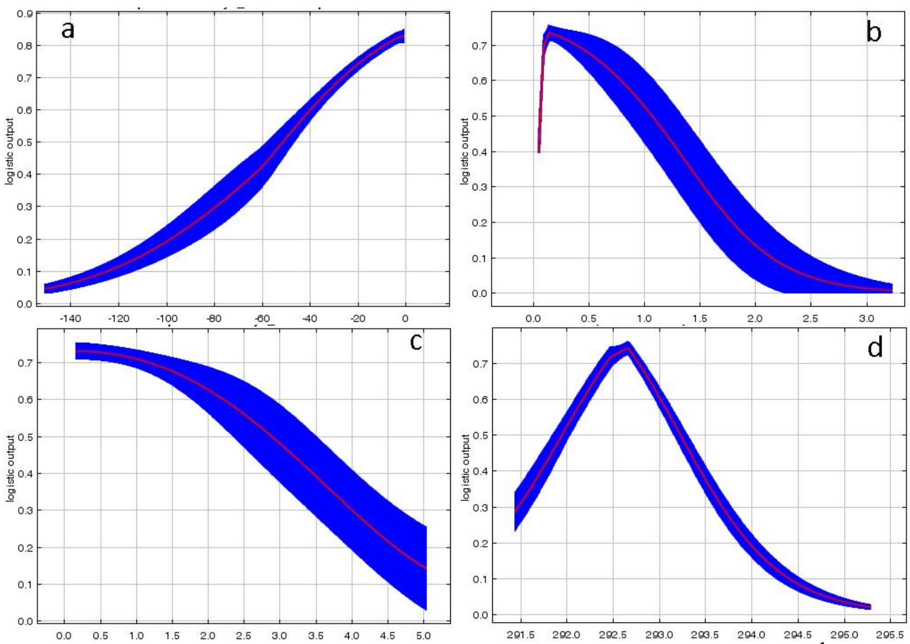

Figure 49: Response curves of *T. citrina* to Bathymetry (m) (a), Kd490 (m^{-1}) (b), Chlorophyll concentration (mg/m^3) (c), and Mean SST (K) (d).

3.1.11 *Cladocora caespitosa*

A total of 141 presence points were used to model the occurrence of *C. caespitosa* across the study area. The mean AUC of all models was 0.900 (standard deviation 0.046 - Figure 50). Bathymetry and Mean SST were the two main contributors to the model (combined contribution of 80.1%; Table 25), whilst the remaining four predictors (Kd490, Primary Productivity, Chlorophyll concentration and Maximum SST) had a combined contribution of 19.9%.

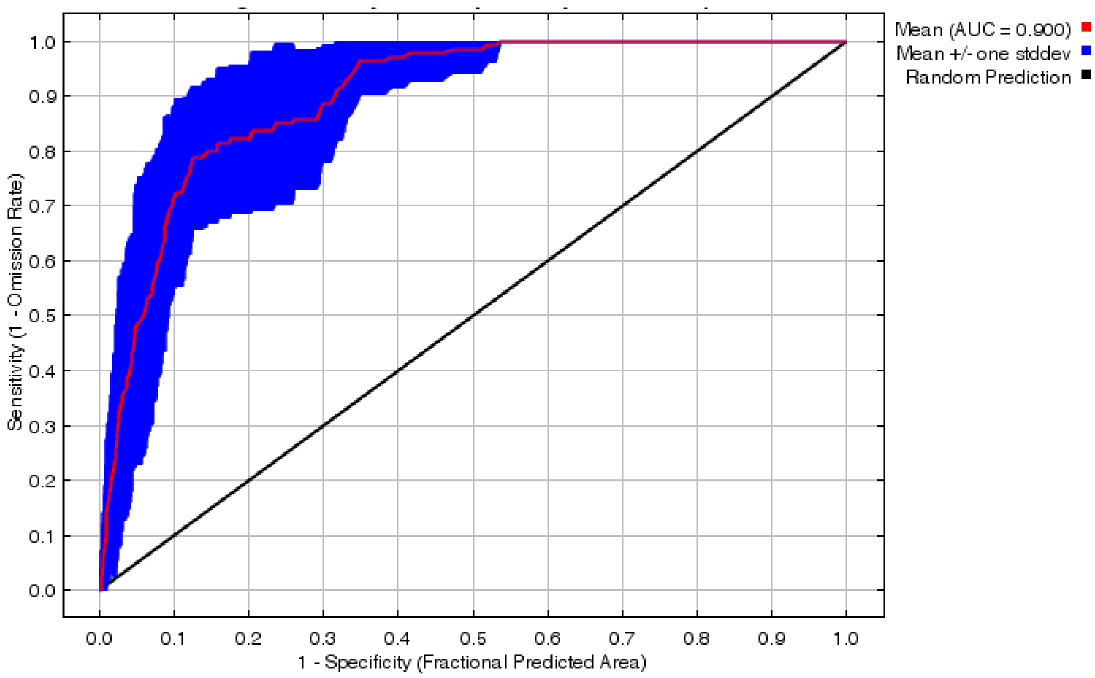

Figure 50: ROC curve for the training test of *C. caespitosa*

Table 25: Relative contributions of each predictor variable to the distribution model of *C. caespitosa*

Predictor variable	Contribution (%)
Bathymetry	61.6
Mean SST	18.5
Kd490	8.7
Chlorophyll concentration	8.6
Primary Productivity	1.6
Maximum SST	0.9

Based on a jackknife test of variable importance (Figure 51a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 51b) confirmed that Bathymetry and Mean SST were the main contributors to the model.

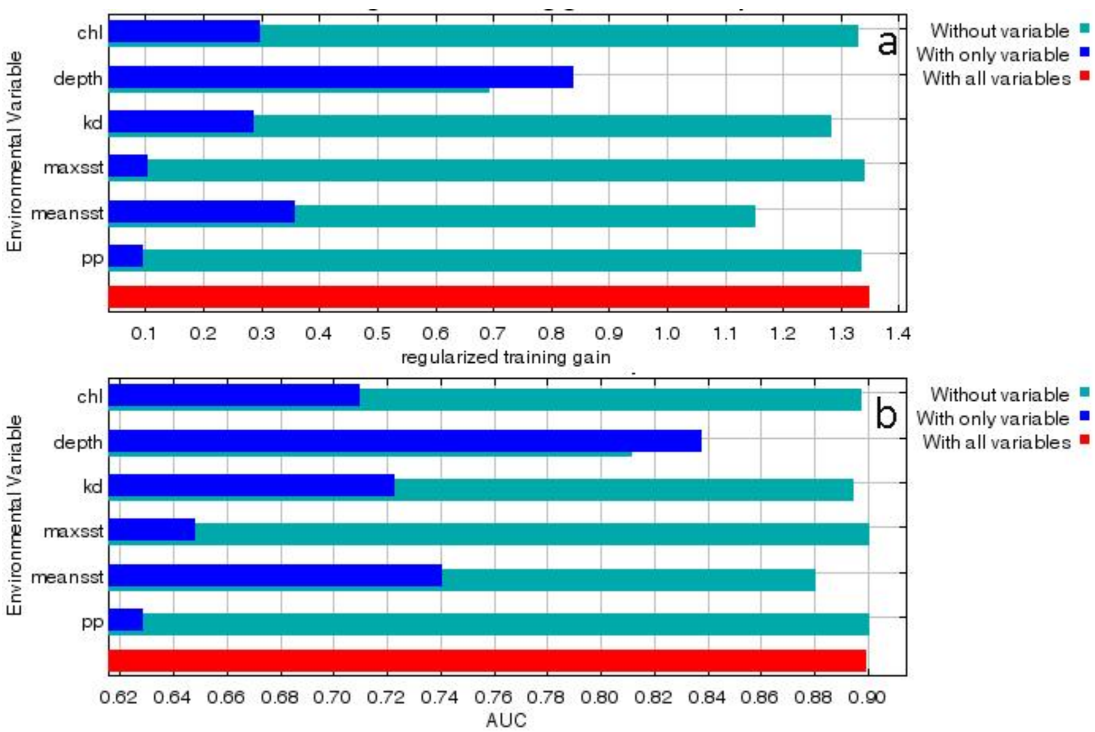

Figure 51: Jackknife of regularized training gain (a) and AUC (b) for *C. caespitosa*

The areas with high probability of suitable conditions for *C. caespitosa* are scattered across the North Aegean Sea, with the highest probabilities being located in Evoikos gulf, Pagasitikos gulf, Thermaikos gulf, Lesvos and Chios (Figure 52). Figure 53 shows the response curves of *C. caespitosa* to Bathymetry, Mean SST, Kd490, and Chlorophyll concentration. *C. caespitosa* responds negatively to increasing depth and Kd490. It prefers mean SSTs between 292.3K and 293K with intensely declining preference to lower and higher mean SSTs. Concerning chlorophyll concentration, it prefers values between 0.2mg/m^3 and 2mg/m^3. Table 26 shows the minimum and maximum values of each environmental variable in the cells where *C. caespitosa* individuals have been recorded.

Table 26: Minimum and maximum values of predictor variables in the cells where *C. caespitosa* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	0,22
Mean SST	292,01	294,13
Maximum SST	297,18	301,22
Kd490	0,03	0,64
Chlorophyll concentration	0,07	3,00
Bathymetry	-85,85	-0,04

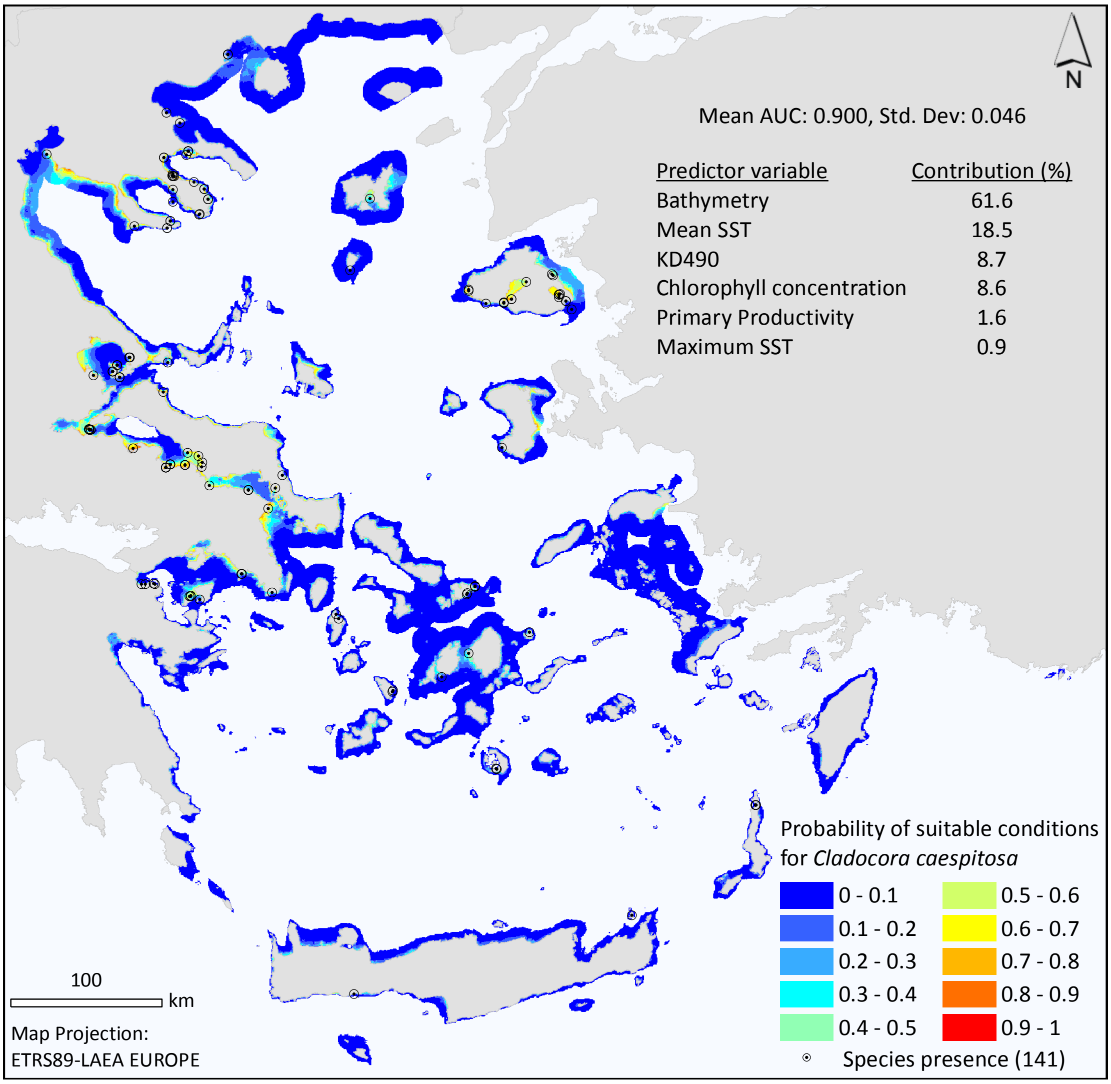

Figure 52: Probability of suitable conditions for *C. caespitosa*

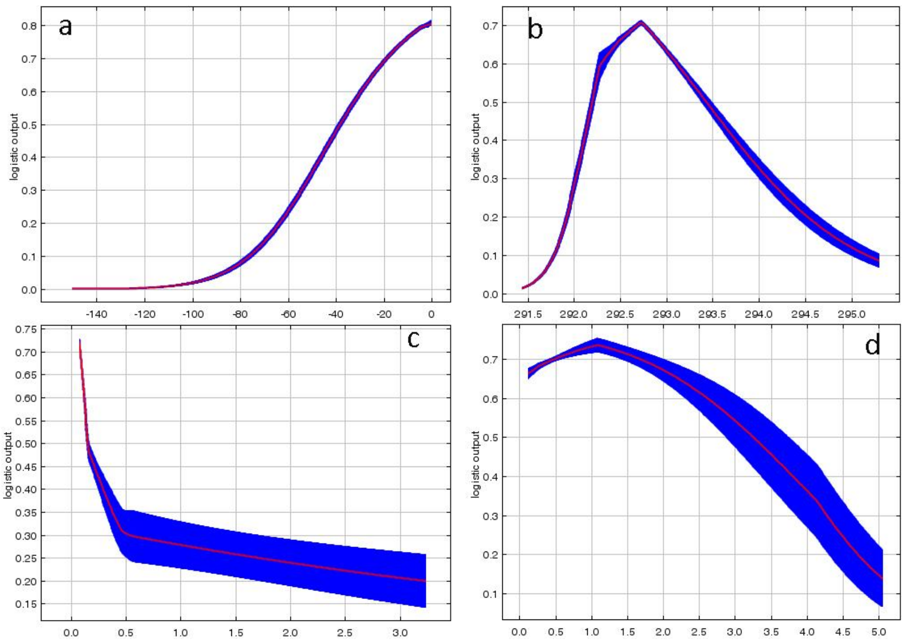

Figure 53: Response curves of *C. caespitosa* to Bathymetry (m) (a), Mean SST (K) (b), Kd490 (m^{-1}) (c), and Chlorophyll concentration (mg/m^3) (d).

3.1.12 Charonia variegata

A total of 108 presence points were used to model the occurrence of *C. variegata* across the study area. The mean AUC of all models was 0.889 (standard deviation 0.053 - Figure 54). Bathymetry and Primary Productivity were the two main contributors to the model (combined contribution of 85.6%; Table 27), whilst the remaining four predictors (Chlorophyll concentration, Maximum SST, Mean SST and Kd490) had a combined contribution of 14.4%.

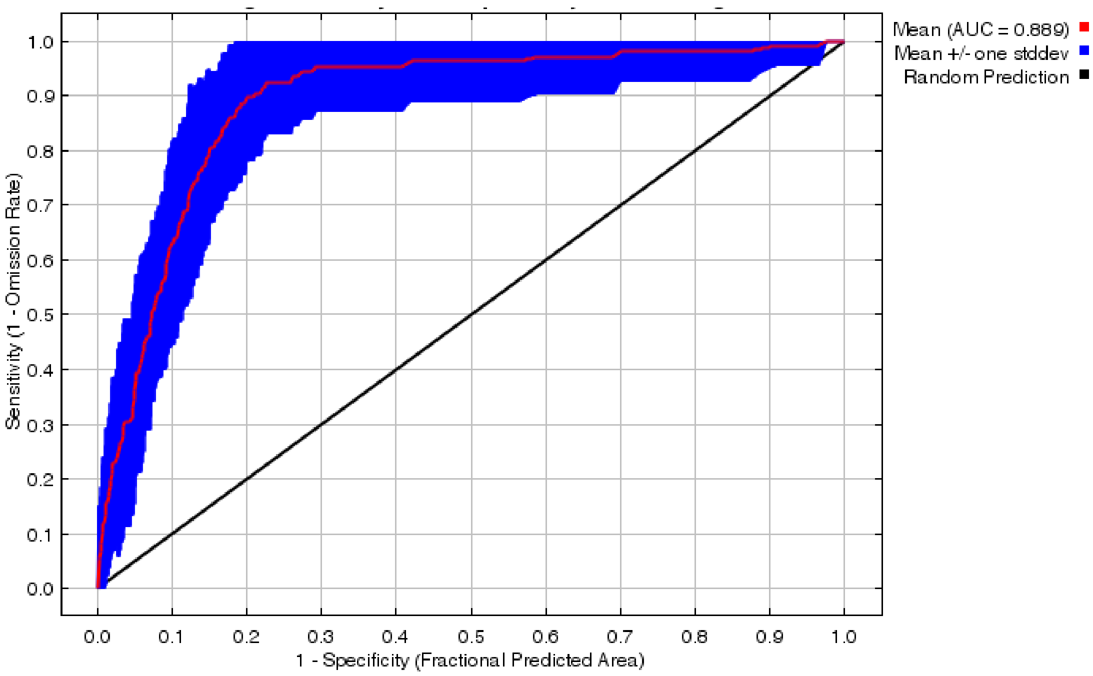

Figure 54: ROC curve for the training test of *C. variegata*

Table 27: Relative contributions of each predictor variable to the distribution model of *C. variegata*

Predictor variable	Contribution (%)
Bathymetry	56.7
Primary Productivity	28.9
Chlorophyll concentration	6.4
Maximum SST	6.0
Mean SST	1.7
Kd490	0.2

Based on a jackknife test of variable importance (Figure 55a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 55b) confirmed that Bathymetry and Primary Productivity were the main contributors to the model.

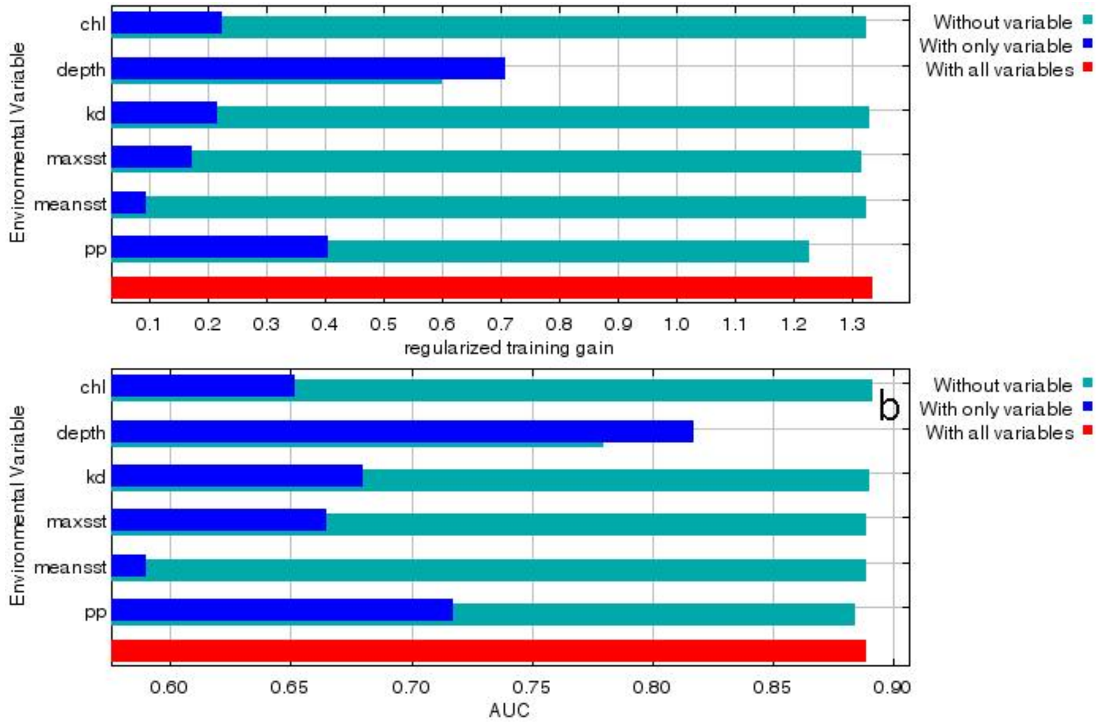

Figure 55: Jackknife of regularized training gain (a) and AUC (b) for *C. variegata*

The areas with high probability of suitable conditions for *C. variegata* are scattered across the North Aegean Sea (Lesvos, Chios, Psara, Ikaria and Samos), the Cyclades and SW Crete with the highest probabilities being located in SW Crete (Figure 56). Figure 57 shows the response curves of *C. variegata* to Bathymetry, Primary Productivity and Chlorophyll concentration. Concerning depth, the suitability increases with depth up to 12m and then declines. It is rather improbable to locate *C. variegata* at depths greater than 60m. Suitability of conditions decreases as primary productivity increases with very low probabilities at values greater than 0.63[4]gC/m^2/day. *C. variegata* has a medium response to low chlorophyll concentrations, with a declining trend to increasing concentrations up to 0.5mg/m^3. Table 28 shows the minimum and maximum values of each environmental variable in the cells where *C. variegata* individuals have been recorded.

Table 28: Minimum and maximum values of predictor variables in the cells where *C. variegata* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	-0,14
Mean SST	292,10	294,54
Maximum SST	297,09	301,18
Kd490	0,02	0,35
Chlorophyll concentration	0,07	2,53
Bathymetry	-137,88	-0,02

4 log (0.63)=-0.2

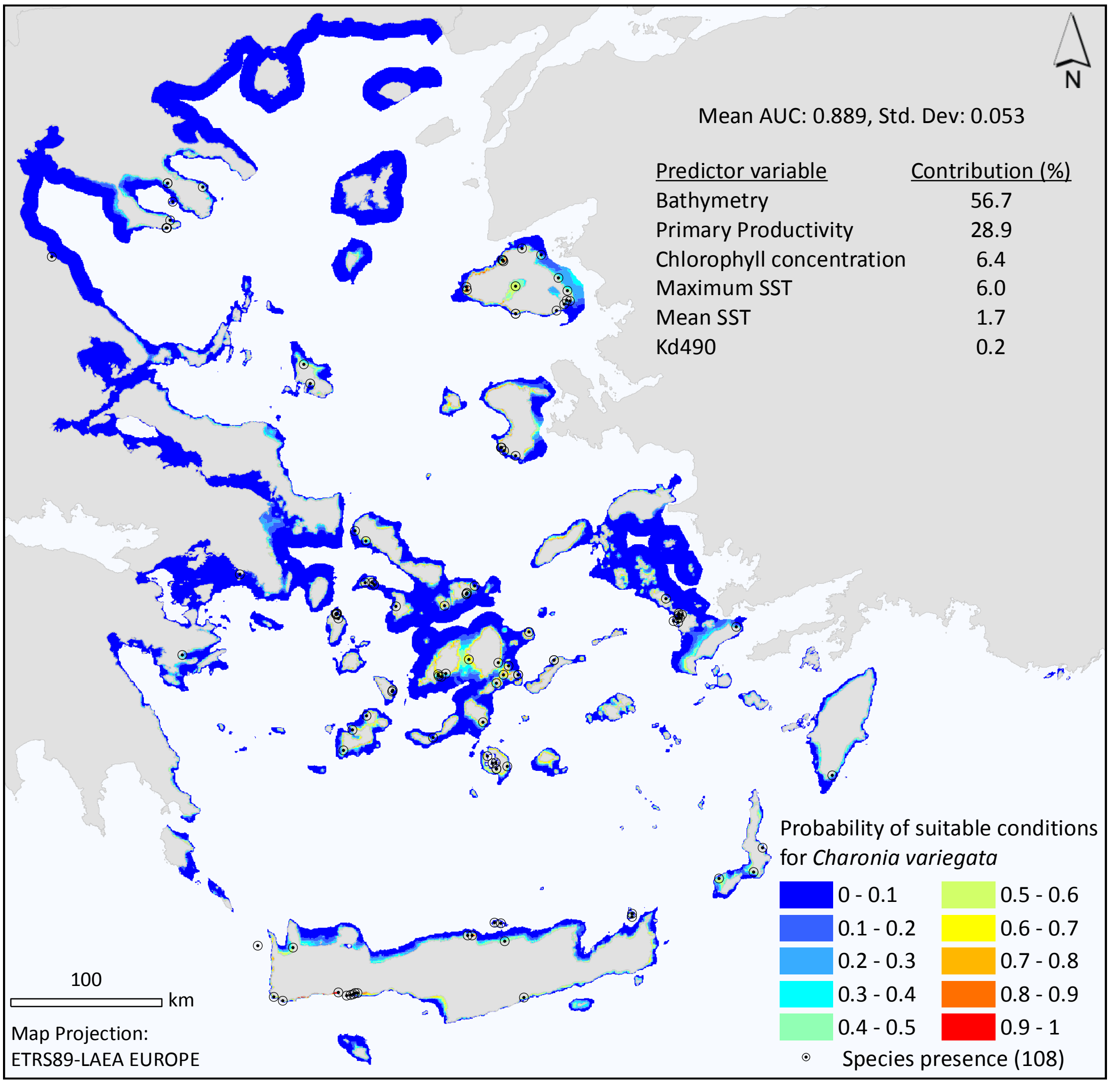

Figure 56: Probability of suitable conditions for *C. variegata*

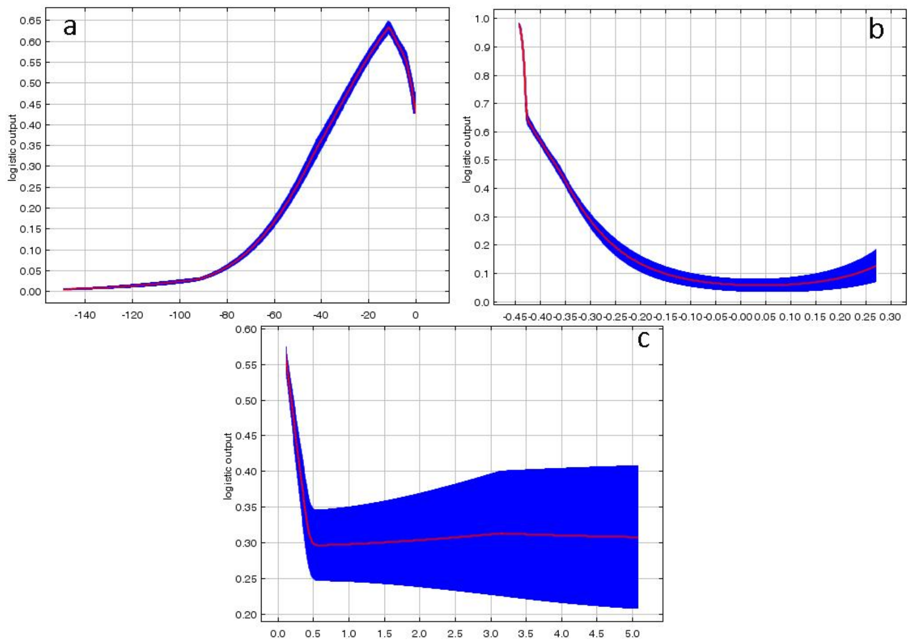

Figure 57: Response curves of *C. variegata* to Bathymetry (m) (a), Primary Productivity (log(gC/m^2/day)) (b), and Chlorophyll concentration (mg/m^3) (c).

3.1.13 *Erosaria spurca*

A total of 37 presence points were used to model the occurrence of *E. spurca* across the study area. The mean AUC of all models was 0.890 (standard deviation 0.088 - Figure 58). Bathymetry and Primary Productivity were the two main contributors to the model (combined contribution of 81.8%; Table 29), whilst the remaining four predictors (Chlorophyll concentration, Maximum SST, Kd490 and Mean SST) had a combined contribution of 18.2%.

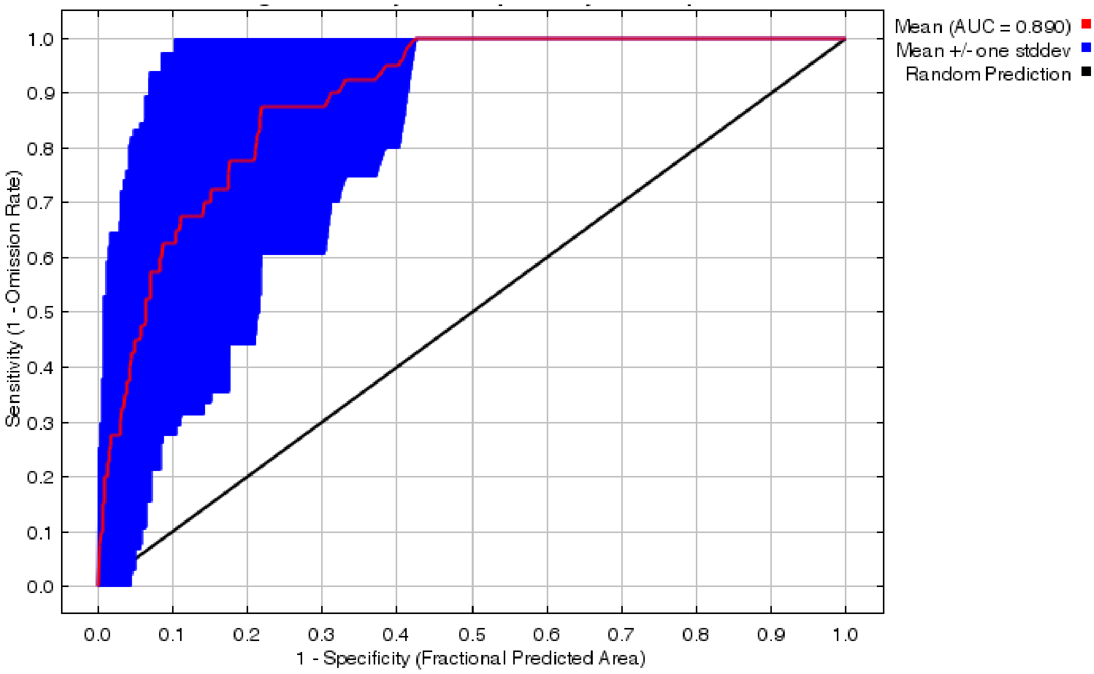

Figure 58: ROC curve for the training test of *E. spurca*

Table 29: Relative contributions of each predictor variable to the distribution model of *E. spurca*

Predictor variable	Contribution (%)
Bathymetry	69.5
Primary Productivity	12.3
Chlorophyll concentration	7.6
Maximum SST	4.4
Kd490	3.4
Mean SST	2.8

Based on a jackknife test of variable importance (Figure 59a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 59b) confirmed that Bathymetry and Primary Productivity were the main contributors to the model.

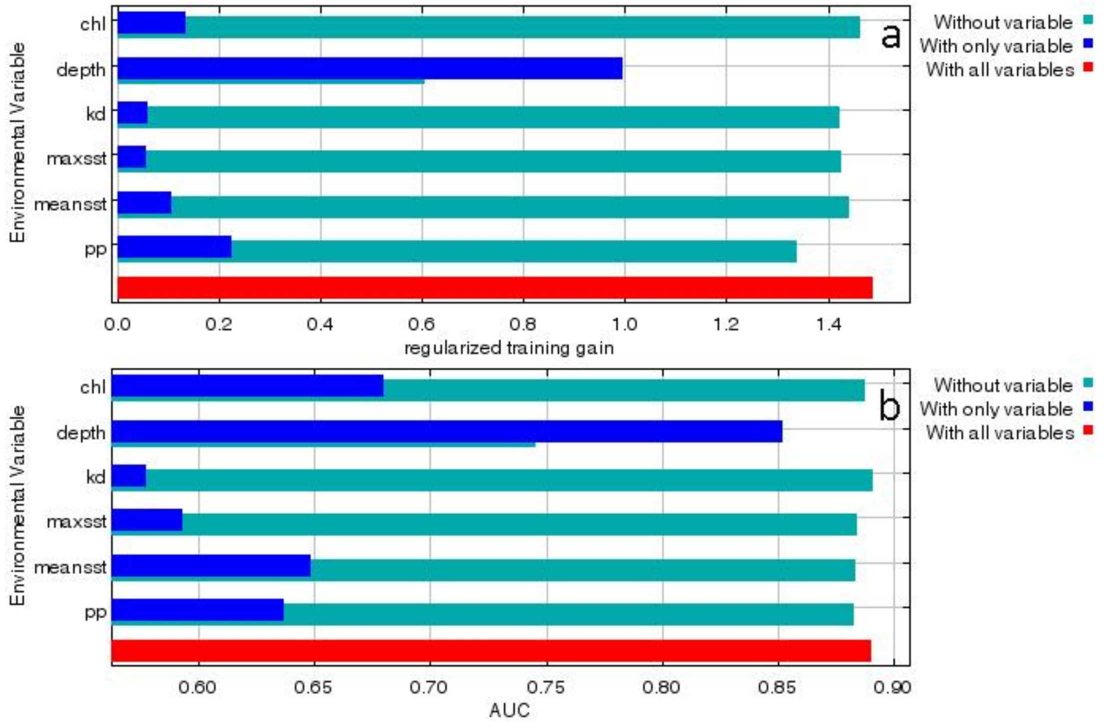

Figure 59: Jackknife of regularized training gain (a) and AUC (b) for *E. spurca*

The areas with high probability of suitable conditions for *E. spurca* are scattered across the Cyclades, the Dodecanese and SW Crete with the highest probabilities being located in SW Crete (Figure 60). Figure 61 shows the response curves of *E. spurca* to Bathymetry, Primary Productivity, Chlorophyll concentration, and Maximum SST. The most suitable conditions for *E. spurca* are at low depths and chlorophyll concentrations with declining suitability up to 70m and 3mg/m^3respectively. Regarding primary productivity, *E,spurca* is most probable to be found at areas with high values of primary productivity; the probability stabilizes at around 40-50% at values greater than 0.45[5]gC/m2/day. *E,spurca* prefers areas with low maximum SSTs (297-298.2K). Table 30 shows the minimum and maximum values of each environmental variable in the cells where *E. spurca* individuals have been recorded.

Table 30: Minimum and maximum values of predictor variables in the cells where *E. spurca* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	-0,16
Mean SST	292,10	294,93
Maximum SST	297,09	301,71
Kd490	0,03	0,29
Chlorophyll concentration	0,07	0,93
Bathymetry	-65,68	-0,01

5 log (0.45)=-0.34

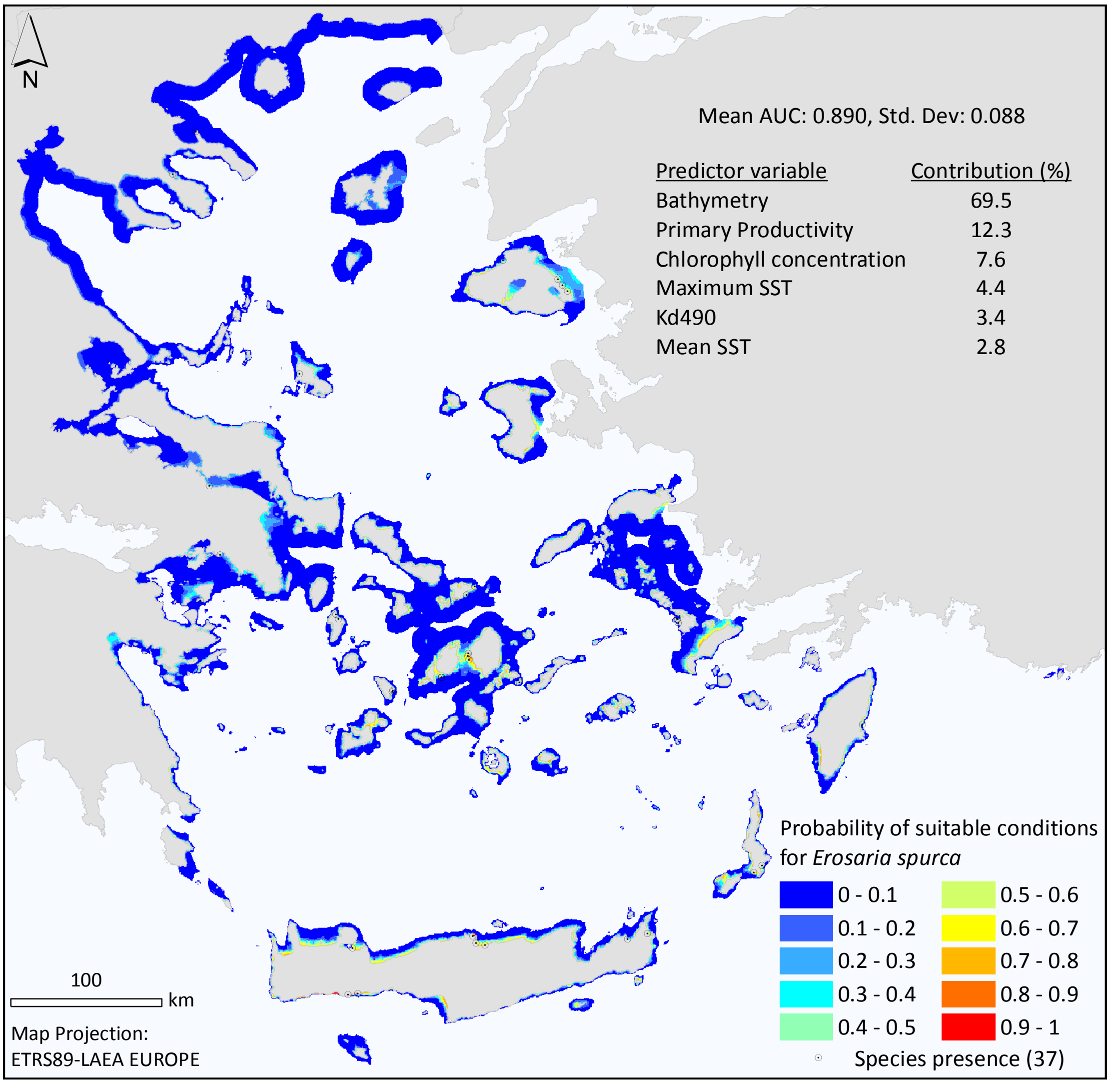

Figure 60: Probability of suitable conditions for *E. spurca*

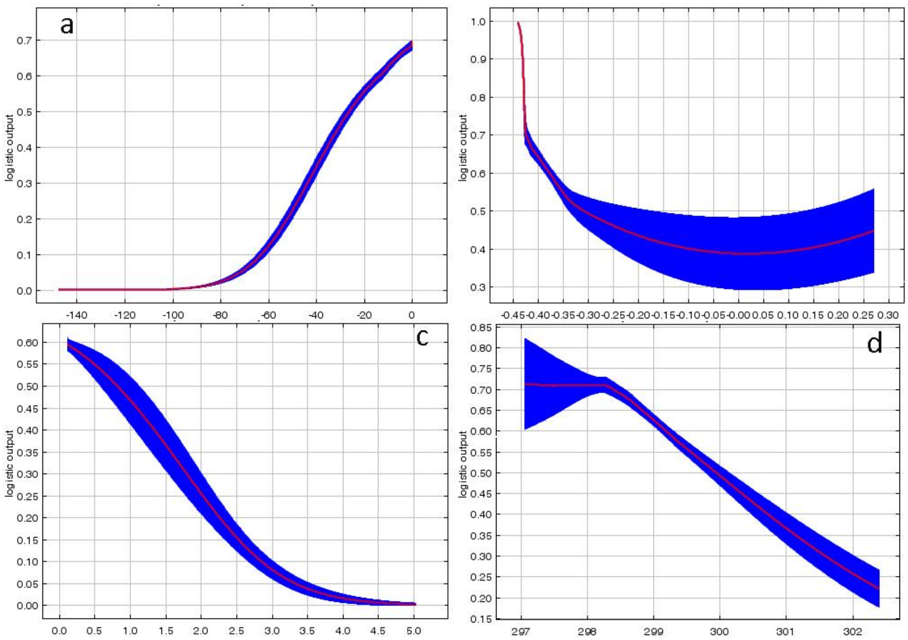

Figure 61: Response curves of *E. spurca* to Bathymetry (m) (a), Primary Productivity ($log(gC/m^2/day)$) (b), Chlorophyll concentration (mg/m^3) (c), and Maximum SST (K) (d).

3.1.14 *Lithophaga lithophaga*

A total of 91 presence points were used to model the occurrence of *L. lithophaga* across the study area. The mean AUC of all models was 0.828 (standard deviation 0.060 - Figure 62). Bathymetry and Mean SST were the two main contributors to the model (combined contribution of 86.6%; Table 31), whilst the remaining four predictors (Kd490, Primary Productivity, Chlorophyll concentration and Maximum SST) had a combined contribution of 13.4%.

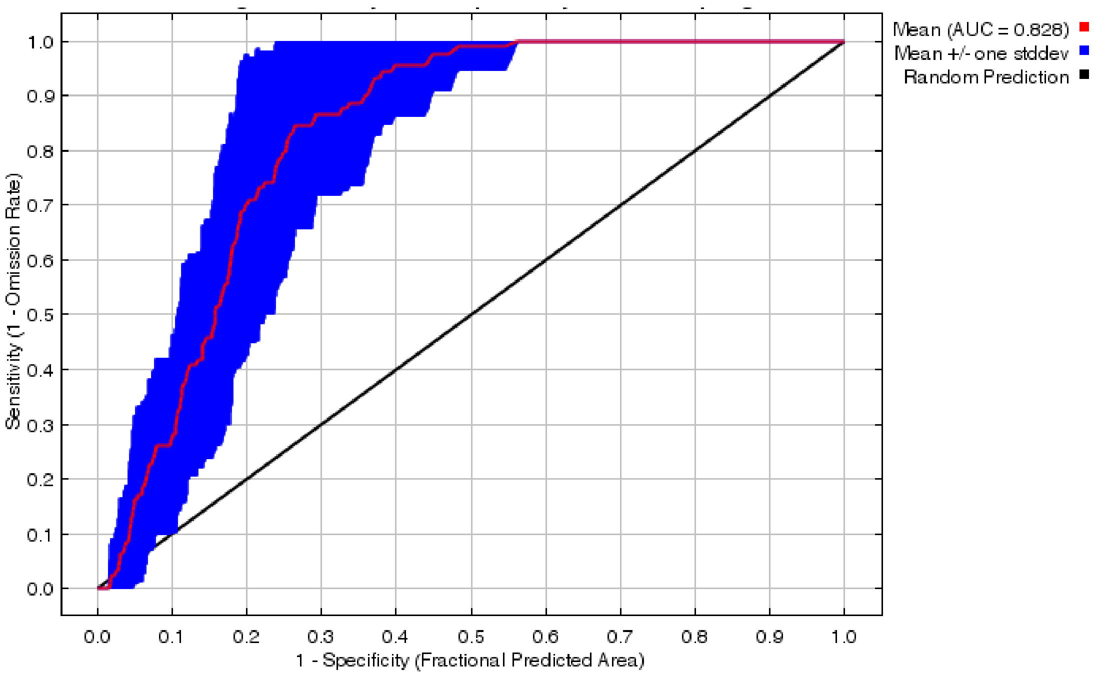

Figure 62: ROC curve for the training test of *L. lithophaga*

Table 31: Relative contributions of each predictor variable to the distribution model of *L. lithophaga*

Predictor variable	Contribution (%)
Bathymetry	78.0
Mean SST	8.6
Kd490	5.5
Primary Productivity	4.8
Chlorophyll concentration	2.5
Maximum SST	0.7

Based on a jackknife test of variable importance (Figure 63a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 63b) confirmed that Bathymetry and Mean SST were the main contributors to the model.

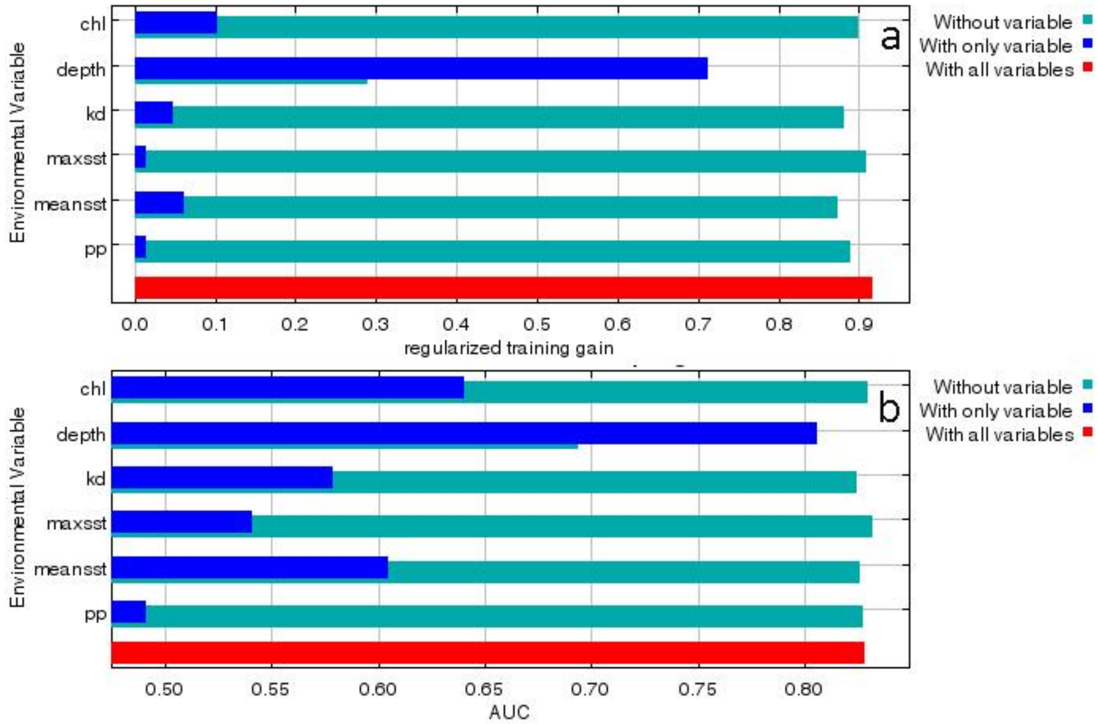

Figure 63: Jackknife of regularized training gain (a) and AUC (b) for *L. lithophaga*

The areas with high probability of suitable conditions for *L. lithophaga* are scattered across the Aegean Sea with the highest probabilities being located in Chalkidiki, central Lesvos, Amorgos, Anafi and central and SW Crete (Figure 64). Figure 65 shows the response curves of *L. lithophaga* to Bathymetry, Mean SST, and Kd490. The most suitable conditions for *L. lithophaga* are at low depths with declining suitability as depth increases *L. lithophaga* prefers areas with mean SSTs between 292.4-293.5K. Regarding Kd490, *L. lithophaga* is most probable to be found at areas with low values of Kd490; the probability stabilizes at around 35% at values greater than $0.3m^{-1}$. Table 32 shows the minimum and maximum values of each environmental variable in the cells where *L. lithophaga* individuals have been recorded.

Table 32: Minimum and maximum values of predictor variables in the cells where *L. lithophaga* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,43	-0,15
Mean SST	291,68	294,20
Maximum SST	297,09	301,28
Kd490	0,03	0,60
Chlorophyll concentration	0,07	2,65
Bathymetry	-79,26	-0,04

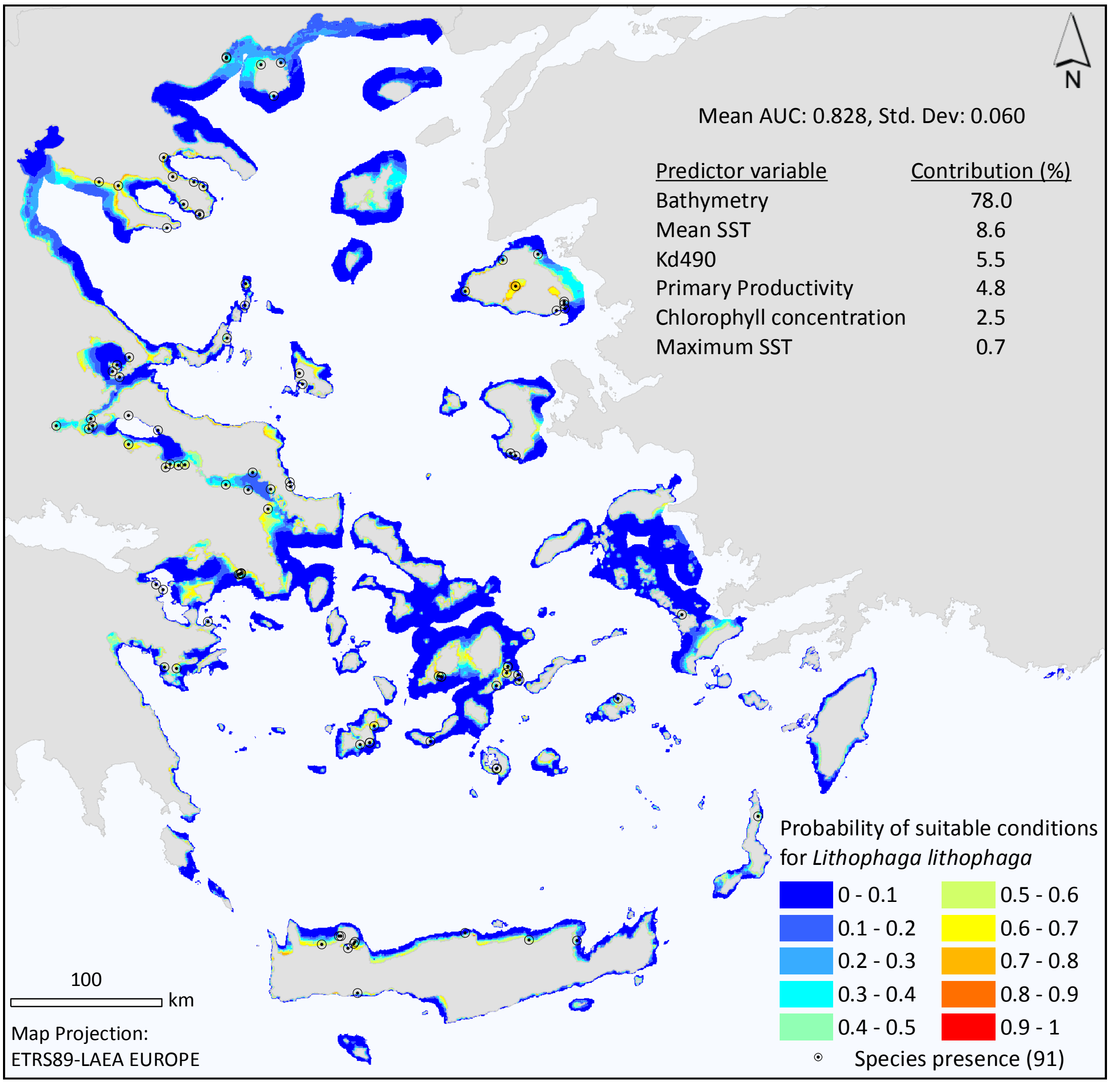

Figure 64: Probability of suitable conditions for *L. lithophaga*

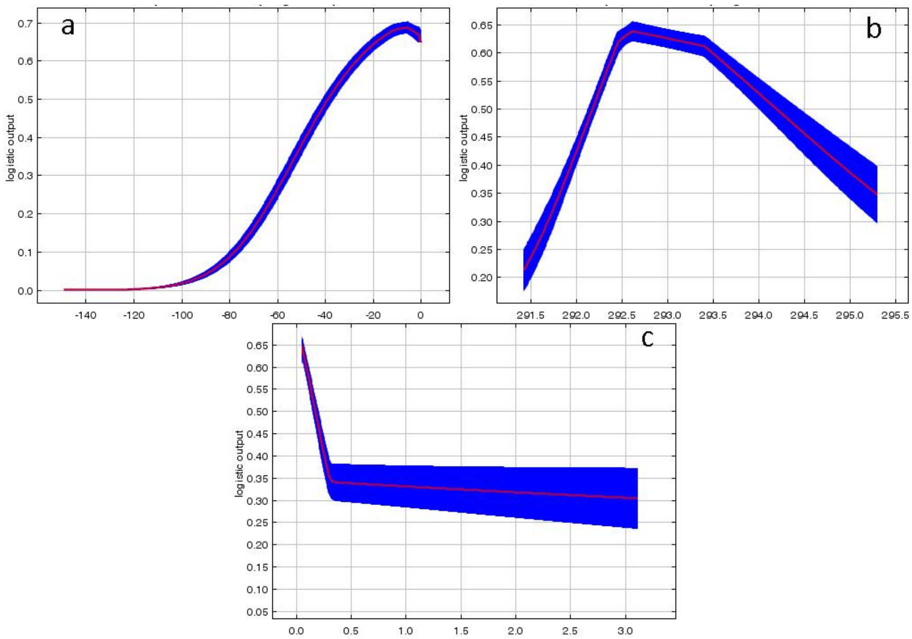

Figure 65: Response curves of *L. lithophaga* to Bathymetry (m) (a), Mean SST (K) (b), and Kd490 (m^{-1}) (c).

3.1.15 *Luria lurida*

A total of 66 presence points were used to model the occurrence of *L. lurida* across the study area. The mean AUC of all models was 0.866 (standard deviation 0.103 - Figure 66). Bathymetry and Maximum SST were the two main contributors to the model (combined contribution of 77.3%; Table 33), whilst the remaining four predictors (Chlorophyll concentration, Kd490, Mean SST and Primary Productivity) had a combined contribution of 22.7%.

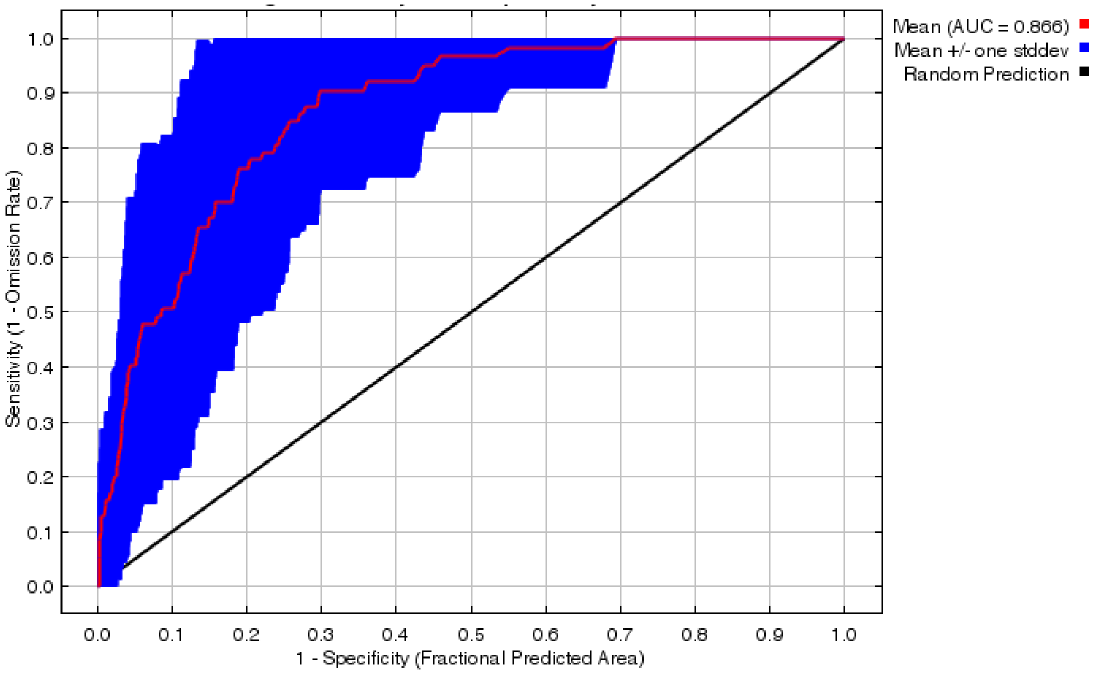

Figure 66: ROC curve for the training test of *L. lurida*

Table 33: Relative contributions of each predictor variable to the distribution model of *L. lurida*

Predictor variable	Contribution (%)
Bathymetry	60.4
Maximum SST	16.9
Chlorophyll concentration	8.3
Kd490	6.2
Mean SST	5.8
Primary Productivity	2.3

Based on a jackknife test of variable importance (Figure 67a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 67b) confirmed that Bathymetry and Maximum SST were the main contributors to the model.

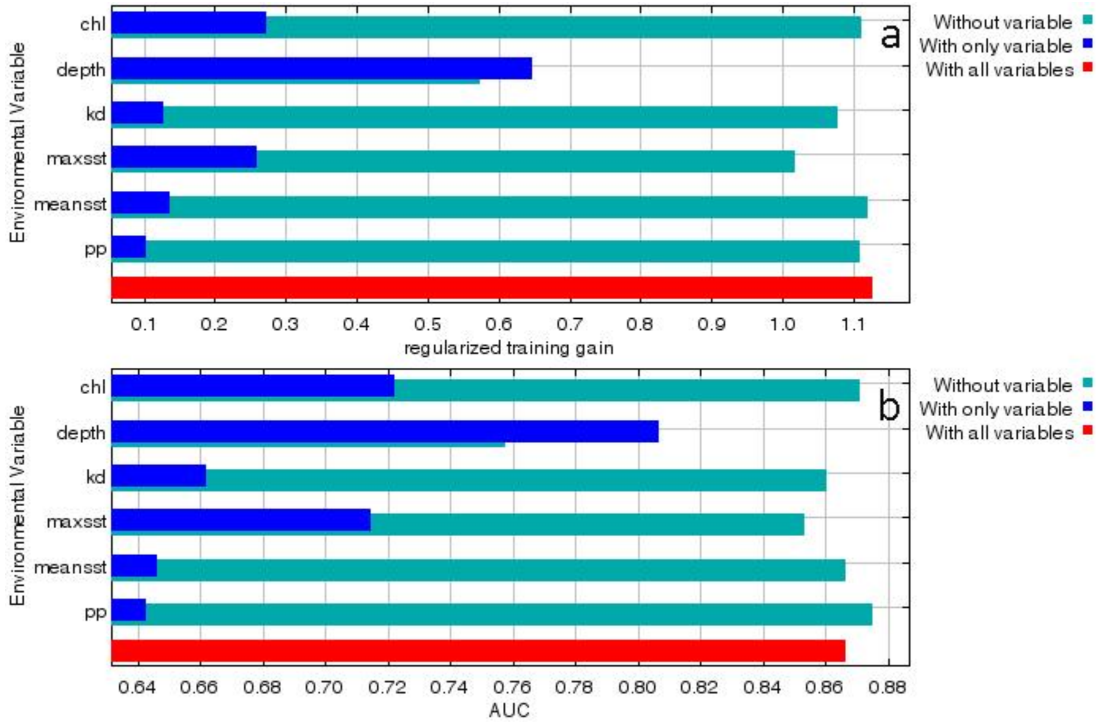

Figure 67: Jackknife of regularized training gain (a) and AUC (b) for *L. lurida*

The areas with high probability of suitable conditions for *L. lurida* are located in Chalkidiki, SW Lesvos, Psara and Rhodes (Figure 68). Figure 69 shows the response curves of *L. lurida* to Bathymetry, Maximum SST, Chlorophyll concentration and Kd490. Concerning depth, *L. lurida* the suitability of conditions decreases with depth up to 12m and then declines. It is rather improbable to locate the species at depths greater than 75m. The most suitable maximum SSTs for the species are above 301K and the less suitable are between 299K and 301K. *L. lurida* has a medium stable response to chlorophyll concentration and low response to Kd490. Table 34 shows the minimum and maximum values of each environmental variable in the cells where *L. lurida* individuals have been recorded.

Table 34: Minimum and maximum values of predictor variables in the cells where *L. lurida* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,43	0,22
Mean SST	292,02	294,93
Maximum SST	297,11	301,71
Kd490	0,03	0,31
Chlorophyll concentration	0,07	2,53
Bathymetry	-85,53	-0,15

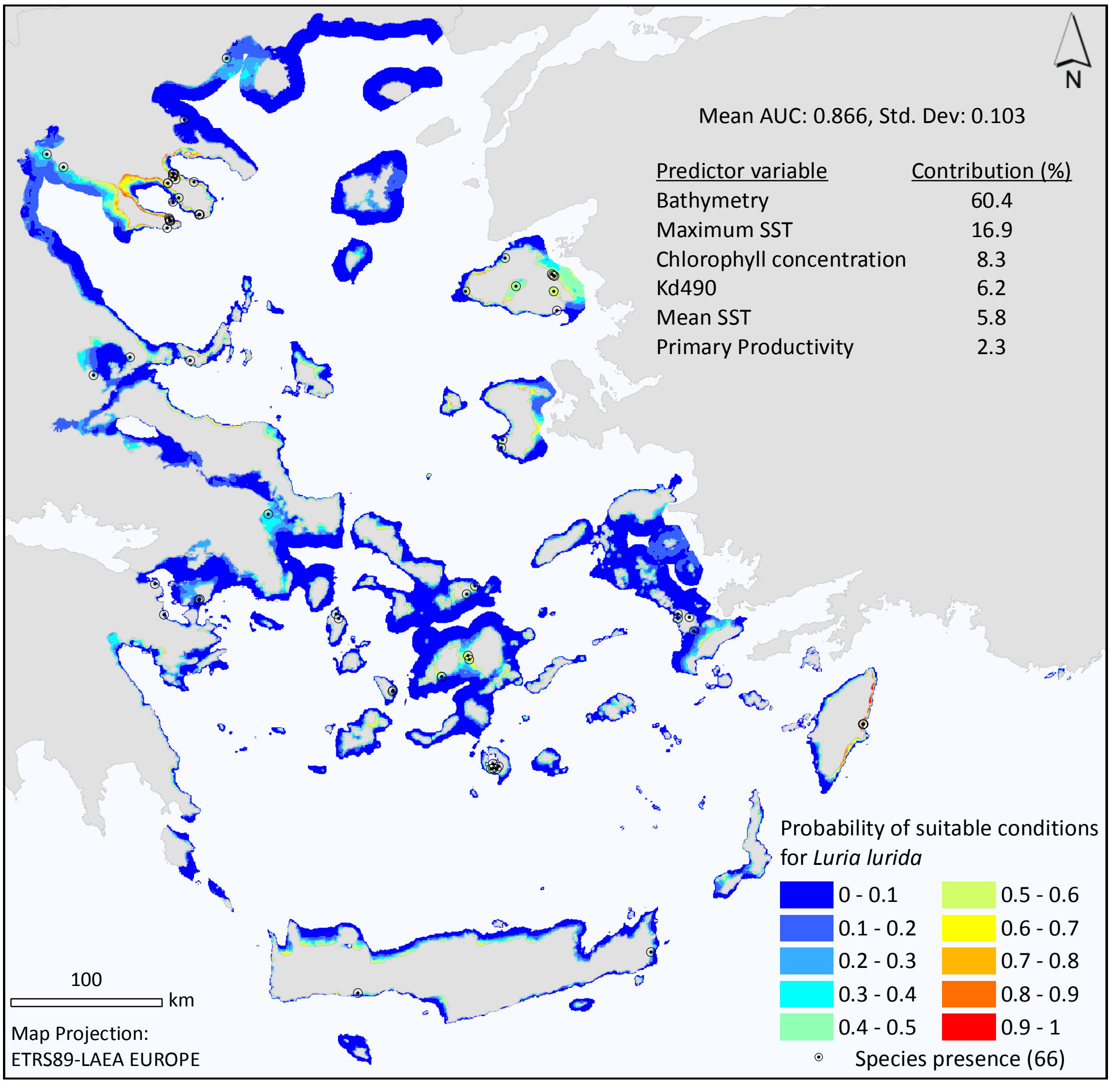

Figure 68: Probability of suitable conditions for *L. lurida*

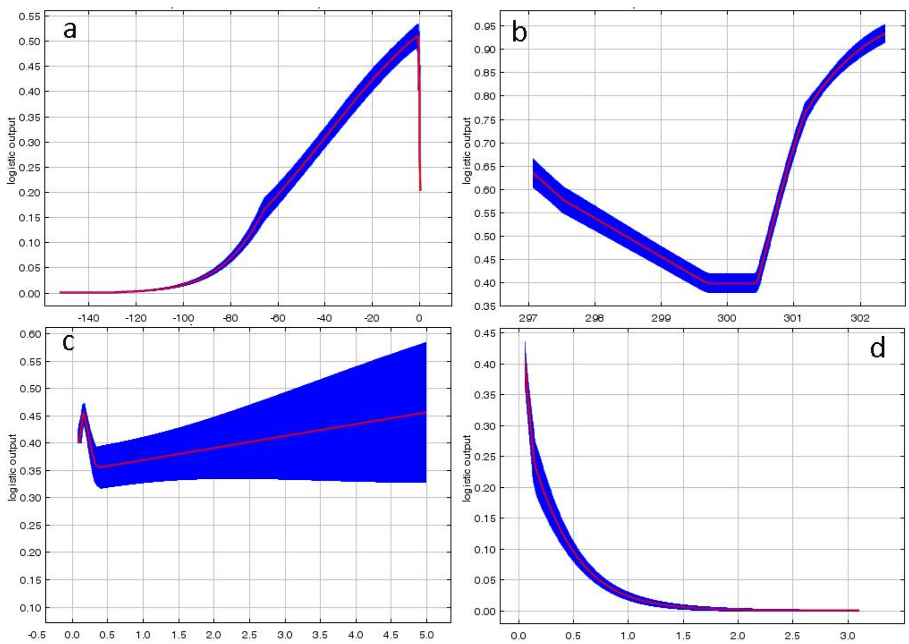

Figure 69: Response curves of *L. lurida* to Bathymetry (m) (a), Maximum SST (K) (b), Chlorophyll concentration (mg/m^3) (c), and Kd490 (m^{-1}) (d).

3.1.16 Pinna nobilis

A total of 460 presence points were used to model the occurrence of *P. nobilis* across the study area. The mean AUC of all models was 0.877 (standard deviation 0.032 - Figure 70). Bathymetry and Maximum SST were the two main contributors to the model (combined contribution of 85.6%; Table 35), whilst the remaining four predictors (Mean SST, Chlorophyll concentration, Primary Productivity and Kd490) had a combined contribution of 14.4%.

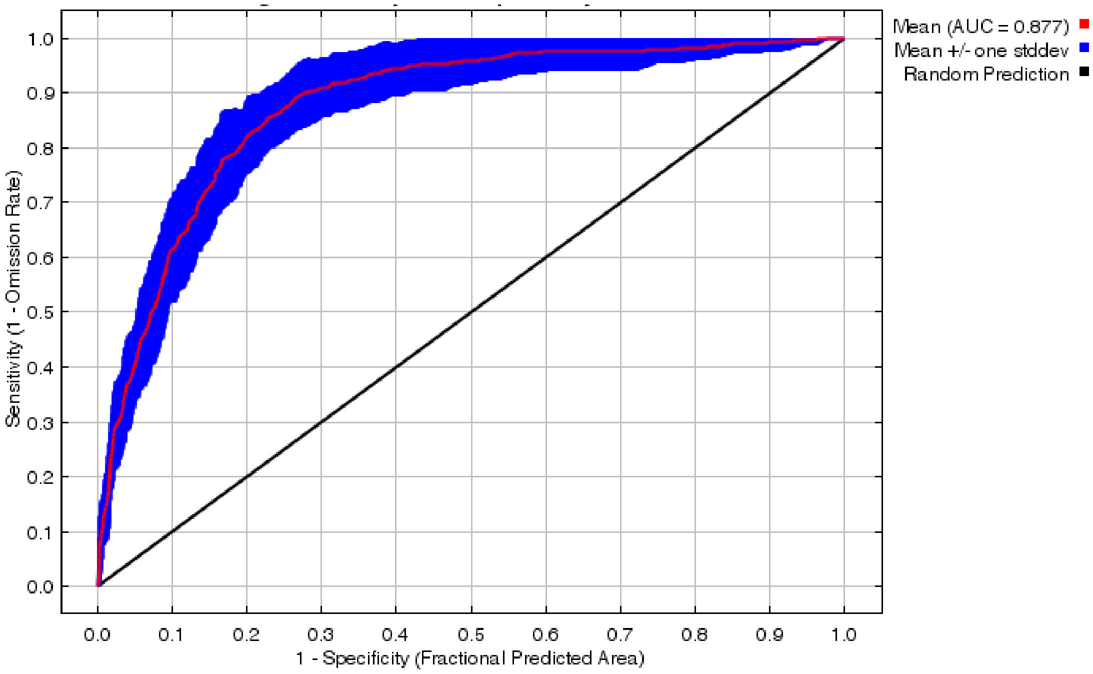

Figure 70: ROC curve for the training test of *P. nobilis*

Table 35: Relative contributions of each predictor variable to the distribution model of *P. nobilis*

Predictor variable	Contribution (%)
Bathymetry	75.8
Maximum SST	9.8
Mean SST	5.5
Chlorophyll concentration	4.4
Primary Productivity	3.3
Kd490	1.2

Based on a jackknife test of variable importance (Figure 71a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 71b) confirmed that Bathymetry and Maximum SST were the main contributors to the model.

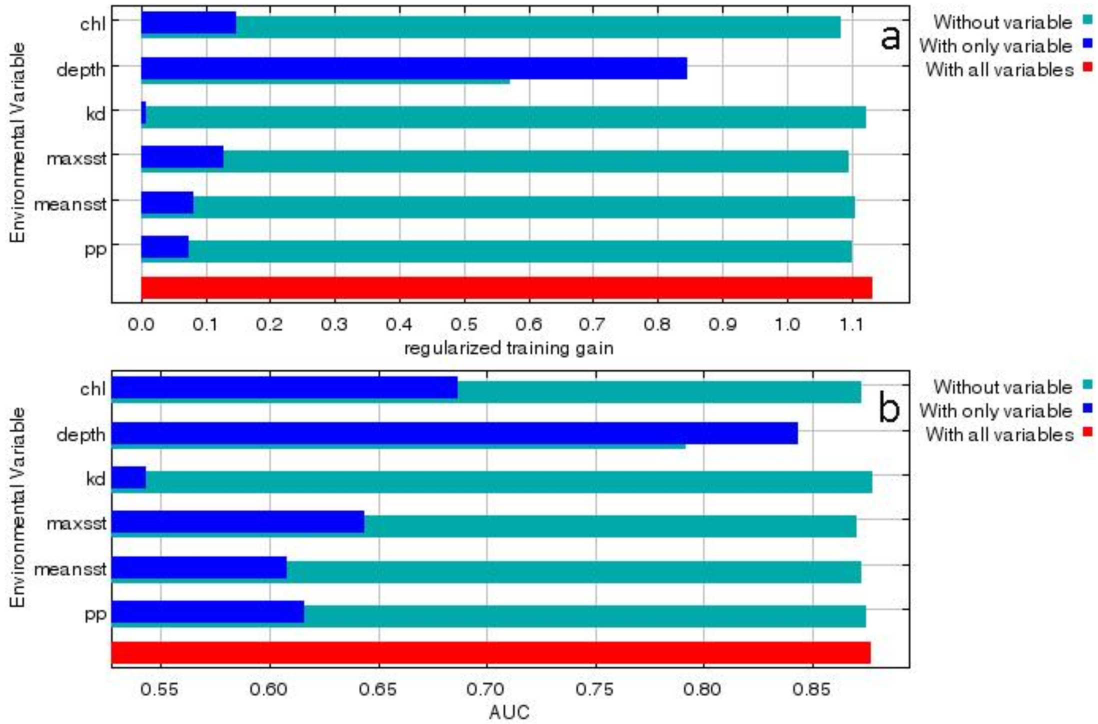

Figure 71: Jackknife of regularized training gain (a) and AUC (b) for *P. nobilis*

The areas with high probability of suitable conditions for *P. nobilis* are located in SW and central Crete and Lesvos (Figure 72). Figure 73 shows the response curves of *P. nobilis* to Bathymetry, Maximum SST and Mean SST. *P. nobilis* prefers depths around 10m. It has a very good response to maximum SSTs around 297K and mean SSTs between 292.3K and 294K. Table 36 shows the minimum and maximum values of each environmental variable in the cells where *P. nobilis* individuals have been recorded.

Table 36: Minimum and maximum values of predictor variables in the cells where *P. nobilis* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	0,23
Mean SST	291,47	294,93
Maximum SST	297,07	301,71
Kd490	0,02	1,34
Chlorophyll concentration	0,07	4,70
Bathymetry	-137,88	0,00

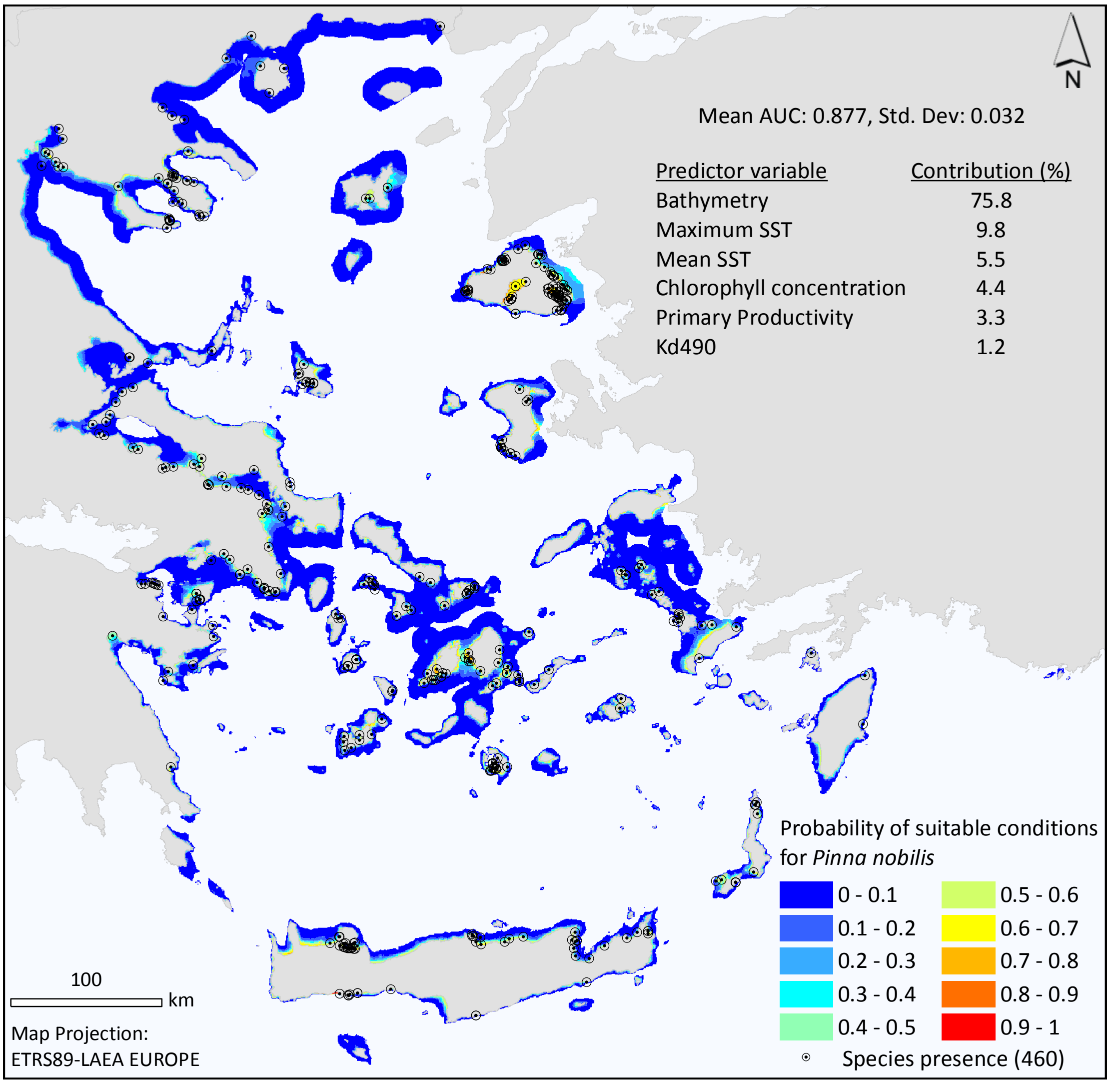

Figure 72: Probability of suitable conditions for *P. nobilis*

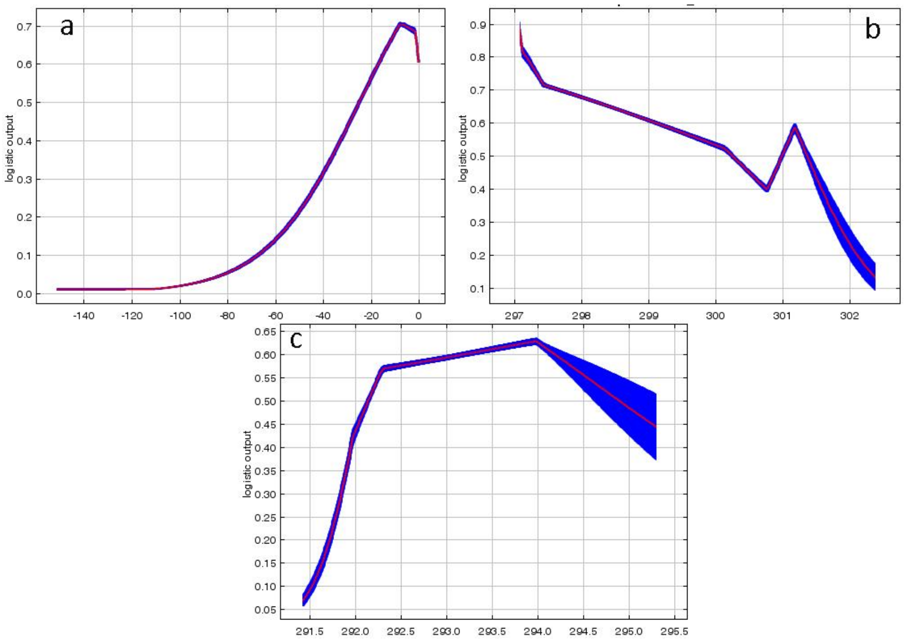

Figure 73: Response curves of *P. nobilis* to Bathymetry (m) (a), Maximum SST (K) (b), and Mean SST (K) (c).

3.1.17 Tonna galea

A total of 95 presence points were used to model the occurrence of *T. galea* across the study area. The mean AUC of all models was 0.882 (standard deviation 0.052 - Figure 74). Bathymetry, Mean SST and Chlorophyll concentration were the three main contributors to the model (combined contribution of 89.4%; Table 37), whilst the remaining three predictors (Maximum SST, Primary Productivity and Kd490) had a combined contribution of 10.6%.

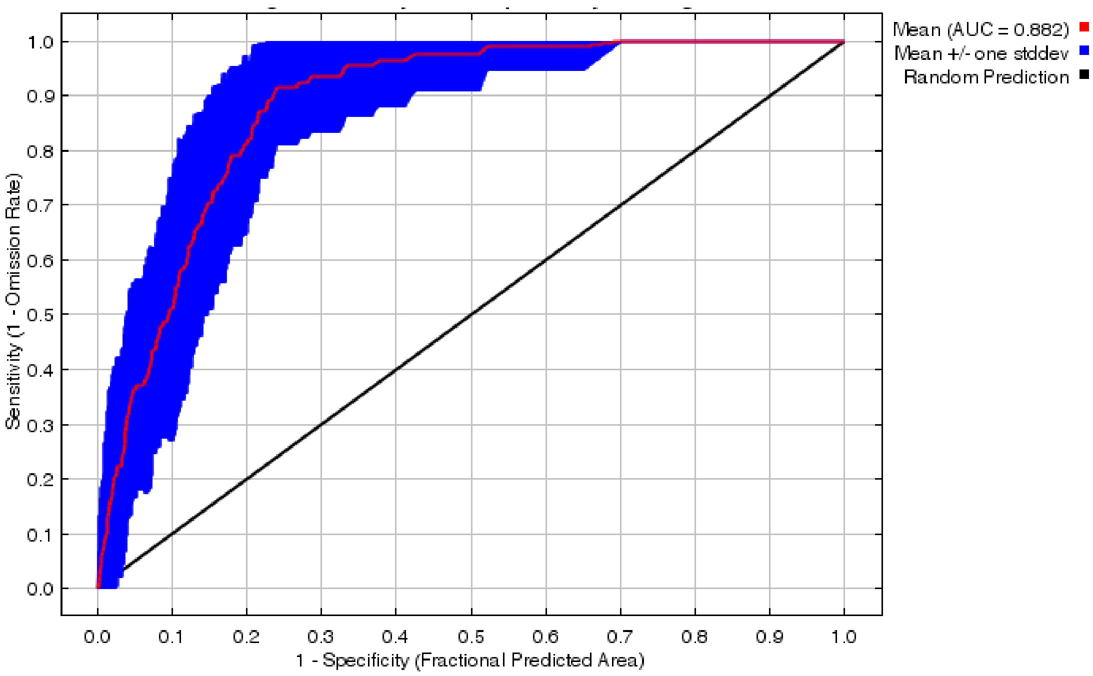

Figure 74: ROC curve for the training test of *T. galea*

Table 37: Relative contributions of each predictor variable to the distribution model of *T. galea*

Predictor variable	Contribution (%)
Bathymetry	74.1
Mean SST	7.7
Chlorophyll concentration	7.6
Maximum SST	4.0
Primary Productivity	3.6
Kd490	3.1

Based on a jackknife test of variable importance (Figure 75a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 75b) confirmed that Bathymetry, Mean SST and Chlorophyll concentration were the main contributors to the model.

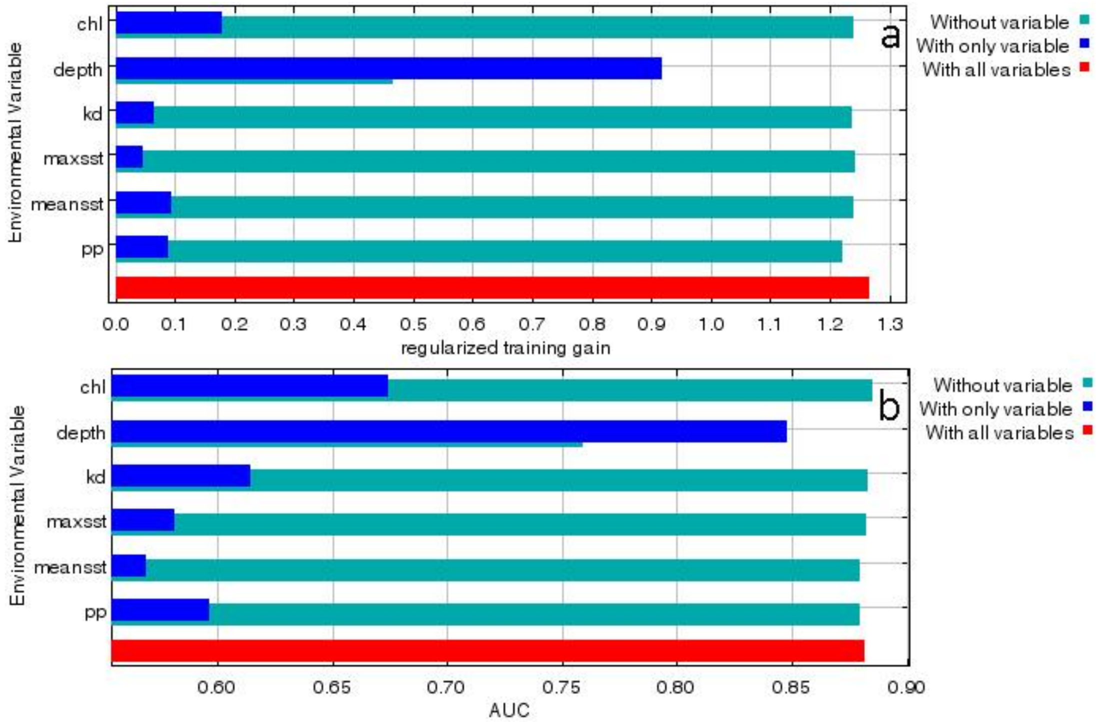

Figure 75: Jackknife of regularized training gain (a) and AUC (b) for *T. galea*

Areas predicted to have the most suitable conditions for the occurrence of *T. galea* are SW and central Crete, Psara and Lesvos (Figure 76). Figure 77 shows the response curves of *T. galea* to Bathymetry, Mean SST, Chlorophyll concentration and Maximum SST. *T. galea* prefers depths around 10m. It has a very good response to high mean SSTs (above 292.3K) and low maximum SSTs (up to 298K). It prefers areas with low chlorophyll concentrations. Table 38 shows the minimum and maximum values of each environmental variable in the cells where *T. galea* individuals have been recorded.

Table 38: Minimum and maximum values of predictor variables in the cells where *T. galea* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	-0,17
Mean SST	291,95	294,89
Maximum SST	297,12	301,83
Kd490	0,02	0,29
Chlorophyll concentration	0,07	2,53
Bathymetry	-102,95	-0,06

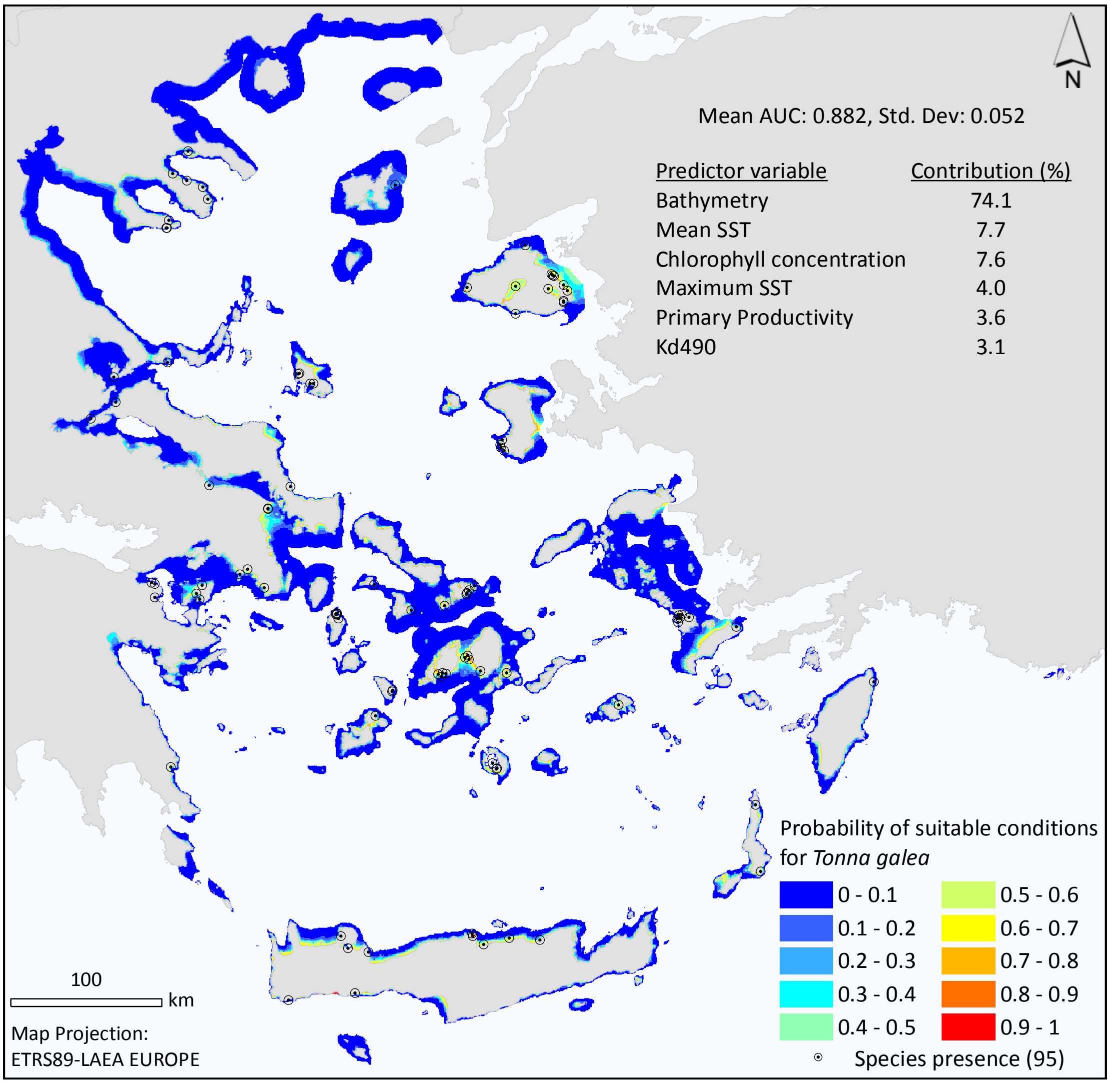

Figure 76: Probability of suitable conditions for *T. galea*

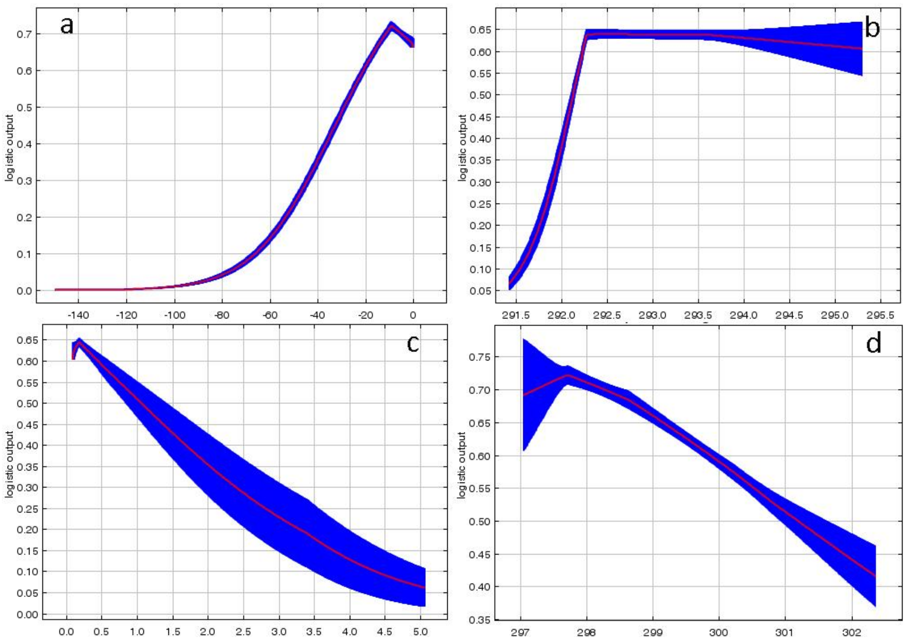

Figure 77: Response curves of *T. galea* to Bathymetry (m) (a), Mean SST (K) (b), Chlorophyll concentration (mg/m^3) (c), and Maximum SST (K) (d).

3.1.18 *Zonaria pyrum*

A total of 19 presence points were used to model the occurrence of *Z. pyrum* across the study area. The mean AUC of all models was 0.909 (standard deviation 0.174 - Figure 78). Mean SST and Bathymetry were the two main contributors to the model (combined contribution of 88.1%; Table 39), whilst the remaining four predictors (Kd490, Chlorophyll concentration, Maximum SST and Primary Productivity) had a combined contribution of 11.9%.

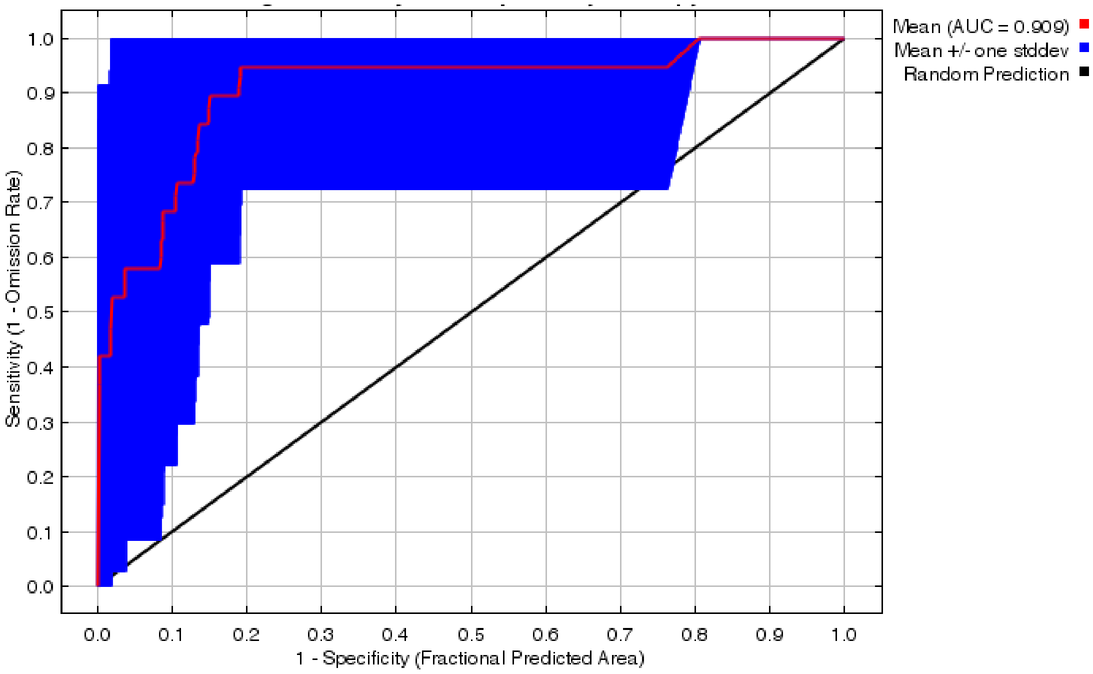

Figure 78: ROC curve for the training test of *Z. pyrum*

Table 39: Relative contributions of each predictor variable to the distribution model of *Z. pyrum*

Predictor variable	Contribution (%)
Mean SST	65.7
Bathymetry	22.4
Kd490	7.2
Chlorophyll concentration	3.0
Maximum SST	1.3
Primary Productivity	0.3

Based on a jackknife test of variable importance (Figure 79a), the predictor variable with the highest gain when used in isolation was Mean SST, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 79b) confirmed that Mean SST and Bathymetry were the main contributors to the model.

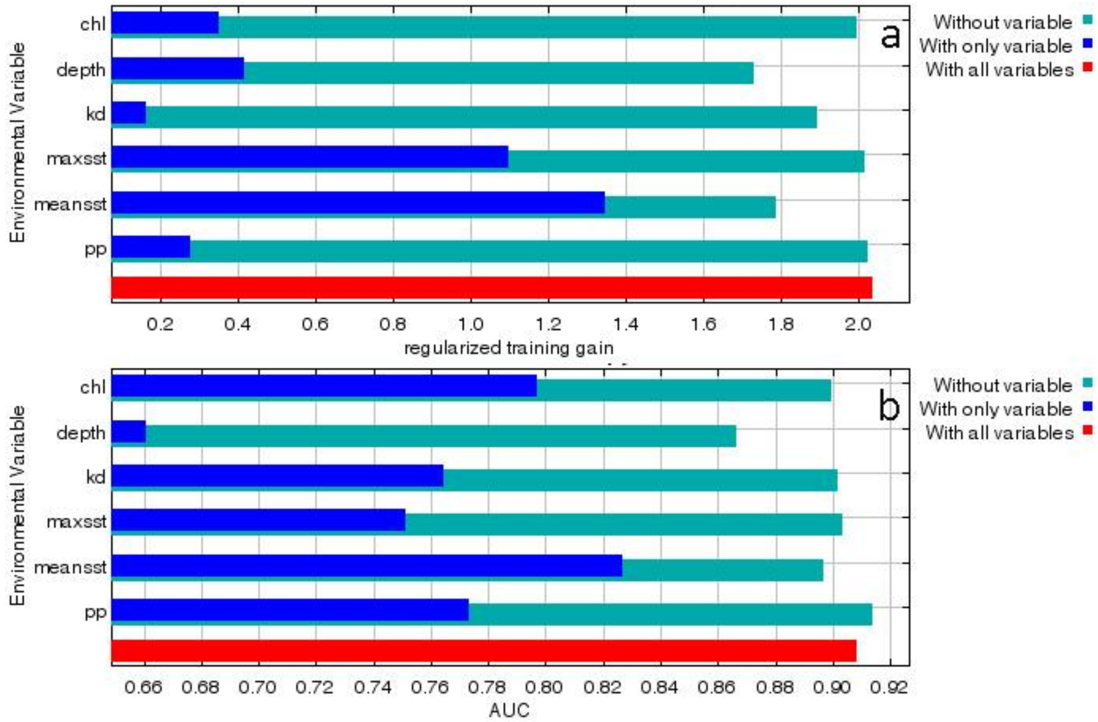

Figure 79: Jackknife of regularized training gain (a) and AUC (b) for *Z. pyrum*

Areas predicted to have the most suitable conditions for the occurrence of *Z. pyrum* are scattered across SE Aegean Sea, with the higher probabilities being located in RHodes and Kastelorizo (Figure 80). Figure 81 shows the response curves of *Z. pyrum* to Mean SST, Bathymetry and Kd490. *Z. pyrum* prefers mean SSTs above 294K. It is more possible to be found at small depths, there is a 50% possibility to be found at depths between 50m and 70m and smaller possibilities deeper waters. *Z. pyrum* is not affected by different chlorophyll concentrations/ Table 40 shows the minimum and maximum values of each environmental variable in the cells where *Z. pyrum* individuals have been recorded.

Table 40: Minimum and maximum values of predictor variables in the cells where *Z. pyrum* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,42	-0,20
Mean SST	292,11	294,93
Maximum SST	298,27	301,71
Kd490	0,03	0,13
Chlorophyll concentration	0,09	0,53
Bathymetry	-65,68	-0,14

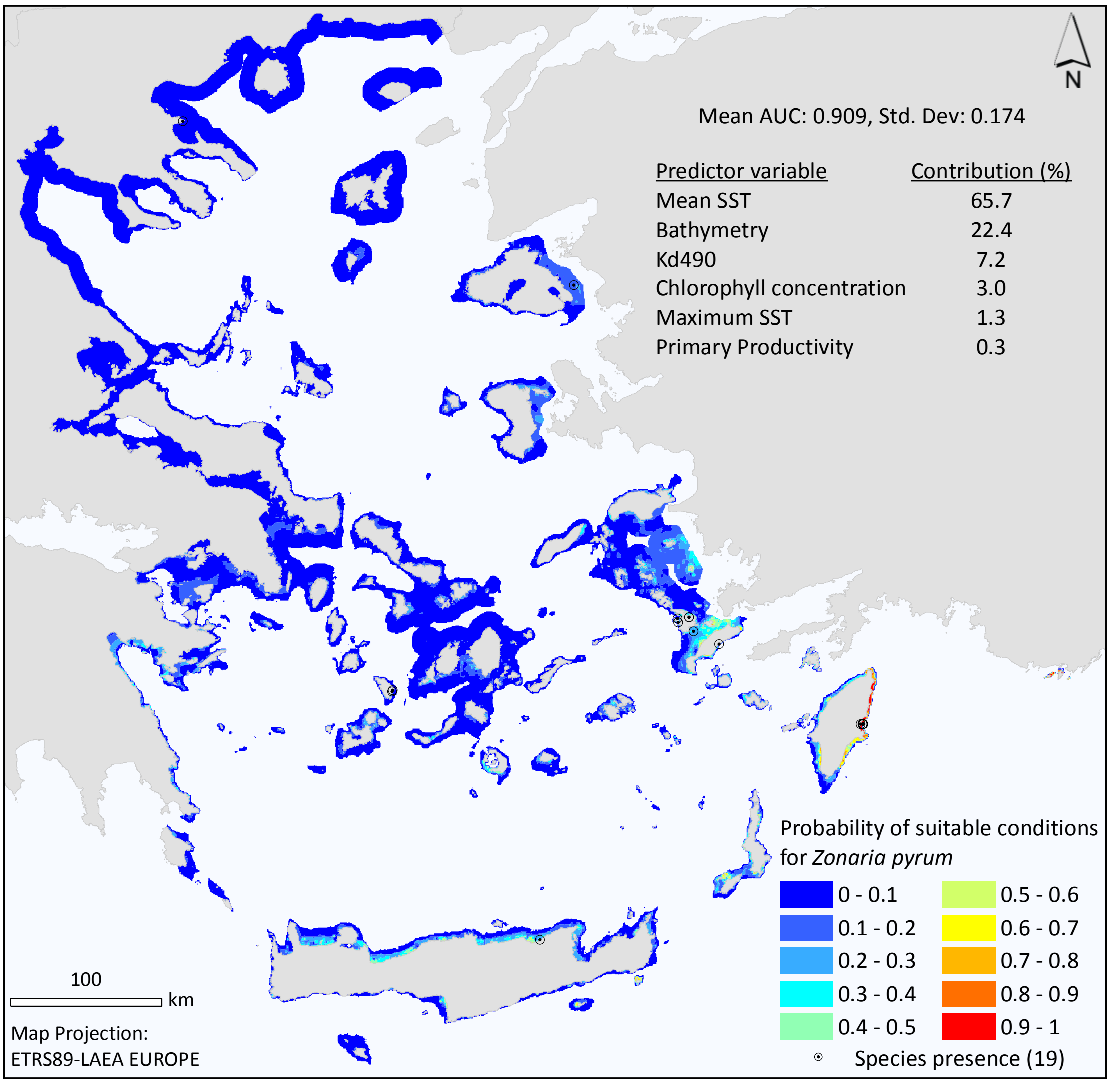

Figure 80: Probability of suitable conditions for *Z. pyrum*

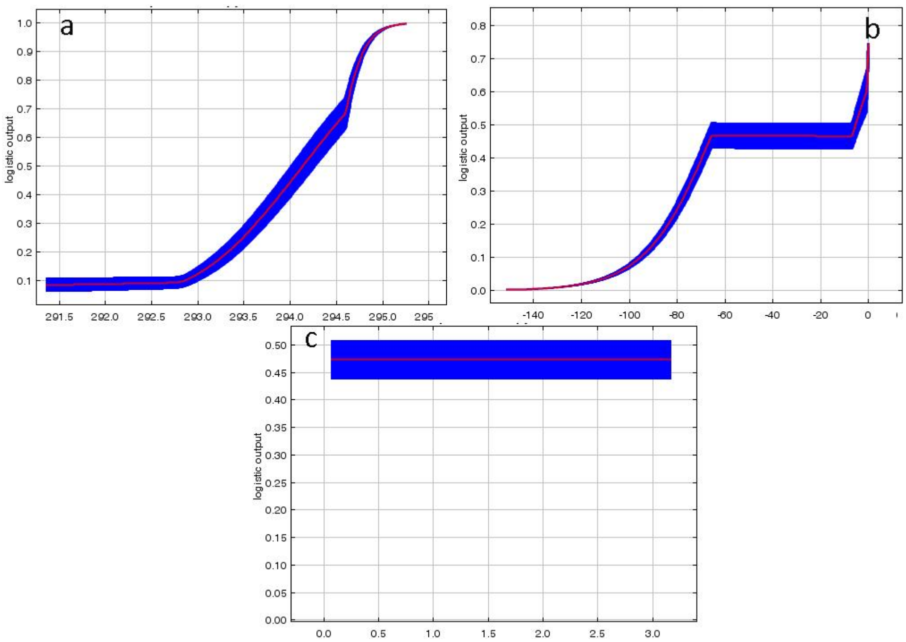

Figure 81: Response curves of *Z. pyrum* to Mean SST (K) (a), Bathymetry (m) (b) and Kd490 (m^{-1}) (c).

3.1.19 *Centrostephanus longispinus*

A total of 85 presence points were used to model the occurrence of *C. longispinus* across the study area. The mean AUC of all models was 0.840 (standard deviation 0.084 - Figure 82). Bathymetry and Chlorophyll concentration were the two main contributors to the model (combined contribution of 76.7%; Table 41), whilst the remaining four predictors (Maximum SST, Primary Productivity, Mean SST and Kd490) had a combined contribution of 23.3%.

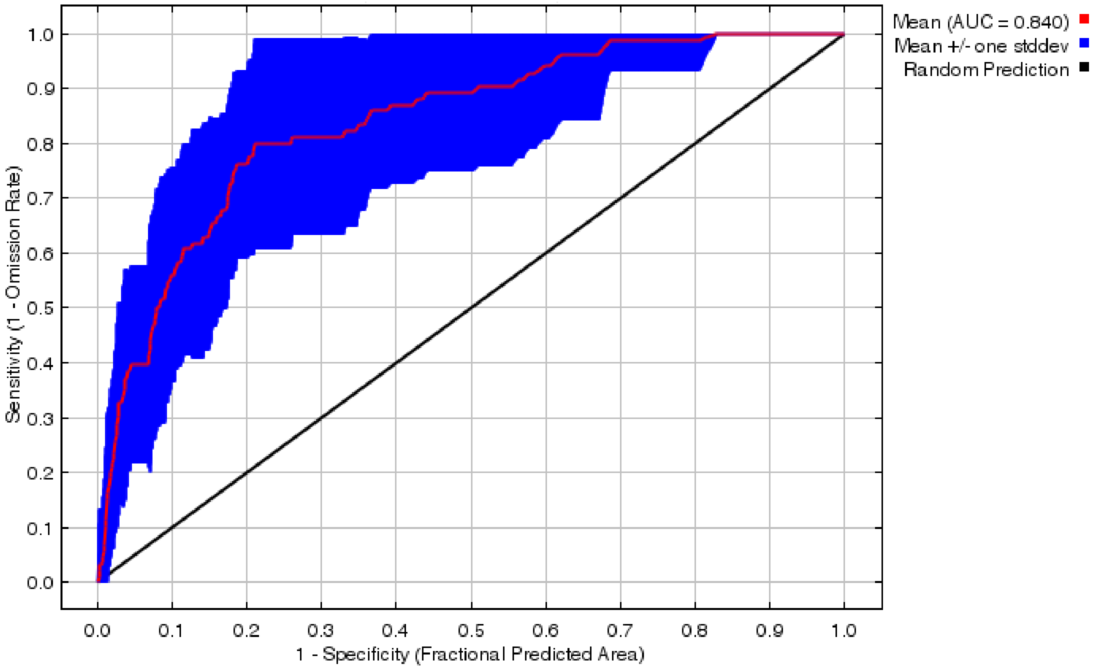

Figure 82: ROC curve for the training test of *C. longispinus*

Table 41: Relative contributions of each predictor variable to the distribution model of *C. longispinus*

Predictor variable	Contribution (%)
Bathymetry	45.5
Mean SST	31.2
Kd490	11.4
Chlorophyll concentration	7.0
Primary Productivity	3.7
Maximum SST	1.2

Based on a jackknife test of variable importance (Figure 83a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 83b) confirmed that Bathymetry and Chlorophyll concentration were the main contributors to the model.

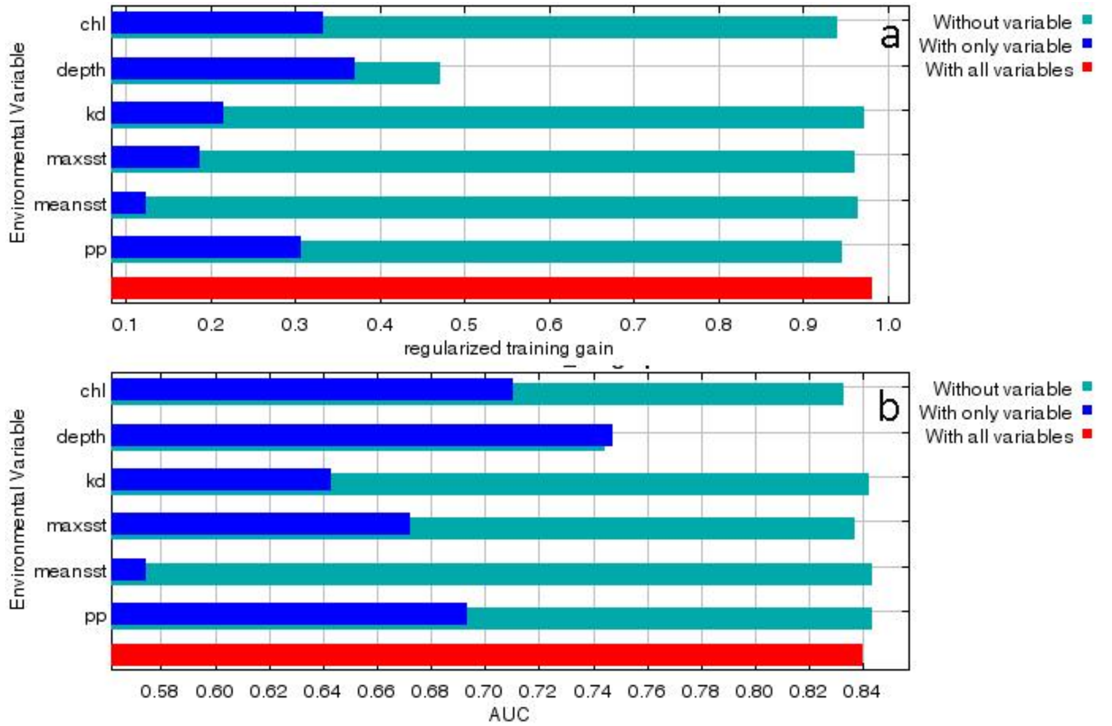

Figure 83: Jackknife of regularized training gain (a) and AUC (b) for *C. longispinus*

Areas predicted to have the most suitable conditions for the occurrence of *C. longispinus* are Lesvos, Chios, Ikaria and the Cyclades (Figure 84). Figure 85 shows the response curves of *C. longispinus* to Bathymetry, Chlorophyll concentration, Maximum SST, and Primary Productivity. The most suitable depths for *C. longispinus* range between 0-30m. The species prefers areas with low concentrations of chlorophyll and it is rather impossible to be found at areas with concentrations greater then 0.5mg/m^3. *C. longispinus.* thrives at low and high maximum SSTs (below 297.4K and above 302K). Finally, it prefers areas with low and high primary productivity (below 0.39[6]gC/m^2/day and above 1.5[7]gC/m^2/day). Table 42 shows the minimum and maximum values of each environmental variable in the cells where *C. longispinus* individuals have been recorded.

Table 42: Minimum and maximum values of predictor variables in the cells where *C. longispinus* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,44	-0,26
Mean SST	292,10	294,89
Maximum SST	297,07	301,83
Kd490	0,02	0,07
Chlorophyll concentration	0,07	0,20
Bathymetry	-136,22	-0,30

[6] log (0.39)=-0.4
[7] log (1.5)=0.17

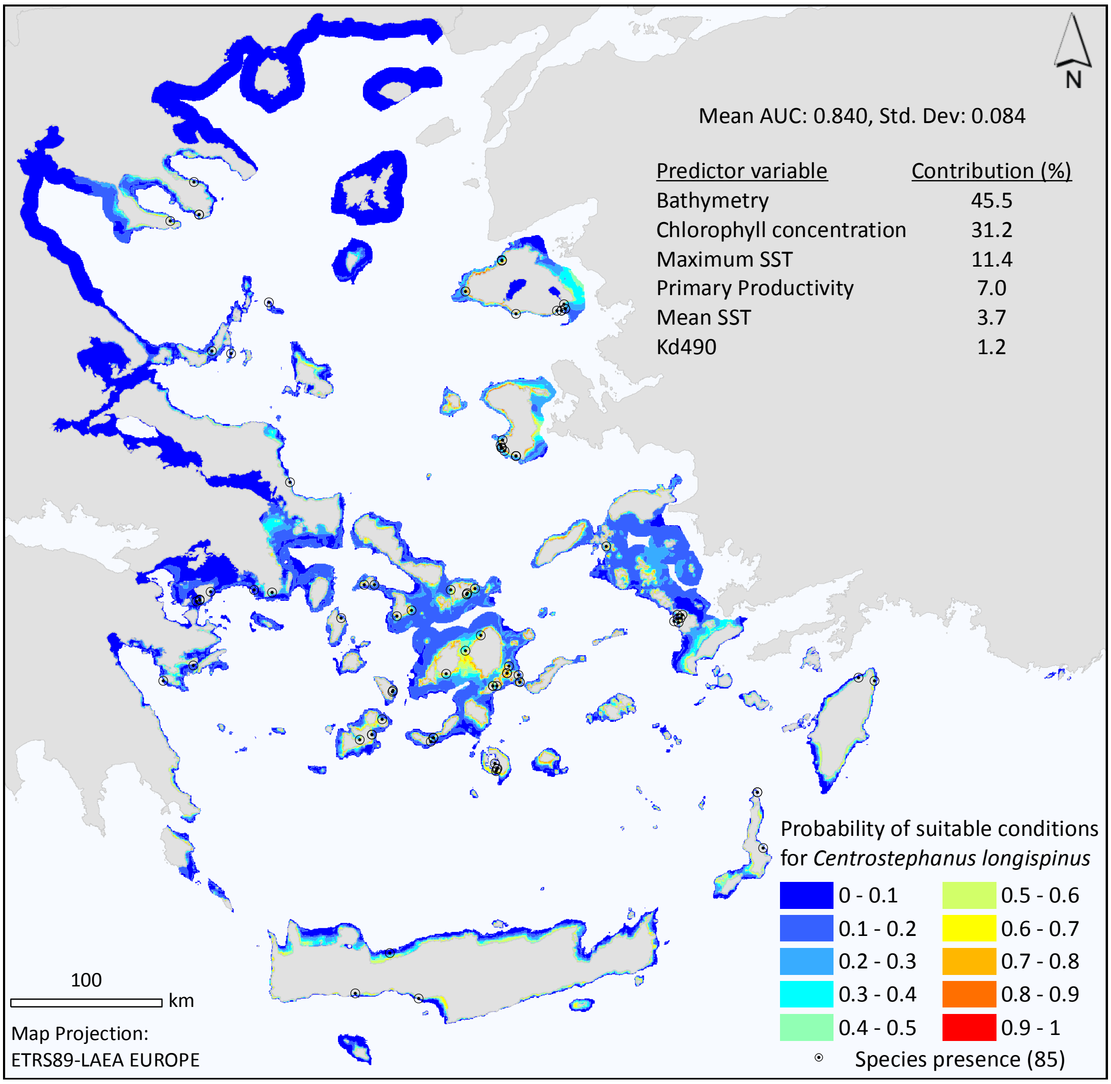

Figure 84: Probability of suitable conditions for *C. longispinus*

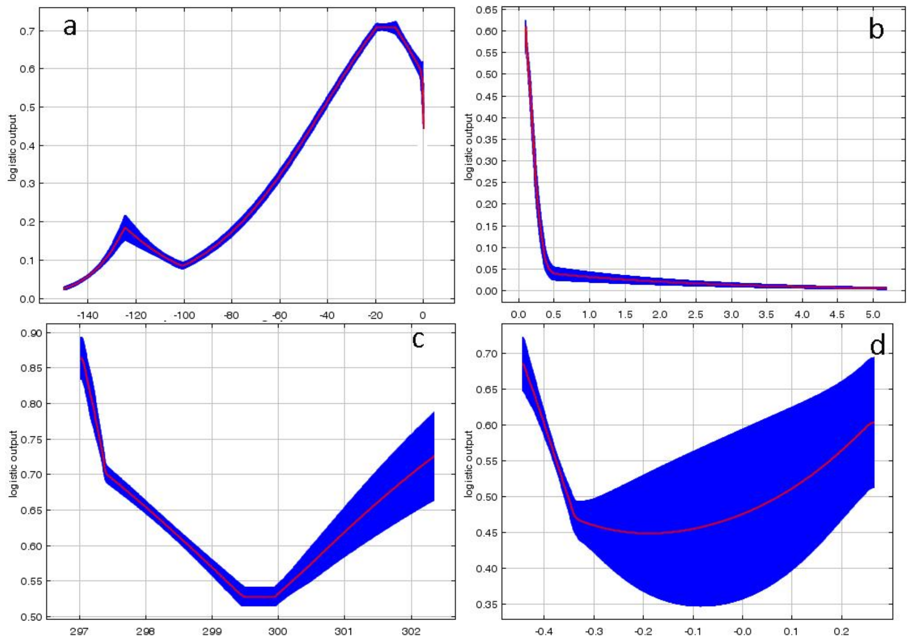

Figure 85: Response curves of *C. longispinus* to Bathymetry (m) (a), Chlorophyll concentration (mg/m^3) (b), Maximum SST (K) (c), and Primary Productivity (log(gC/m^2/day)) (d).

3.1.20 *Ophidiaster ophidianus*

A total of 91 presence points were used to model the occurrence of *O. ophidianus* across the study area. The mean AUC of all models was 0.864 (standard deviation 0.084 - Figure 86). Bathymetry and Chlorophyll concentration were the two main contributors to the model (combined contribution of 79.8%; Table 43), whilst the remaining four predictors (Maximum SST, Mean SST, Primary Productivity and Kd490) had a combined contribution of 20.2%.

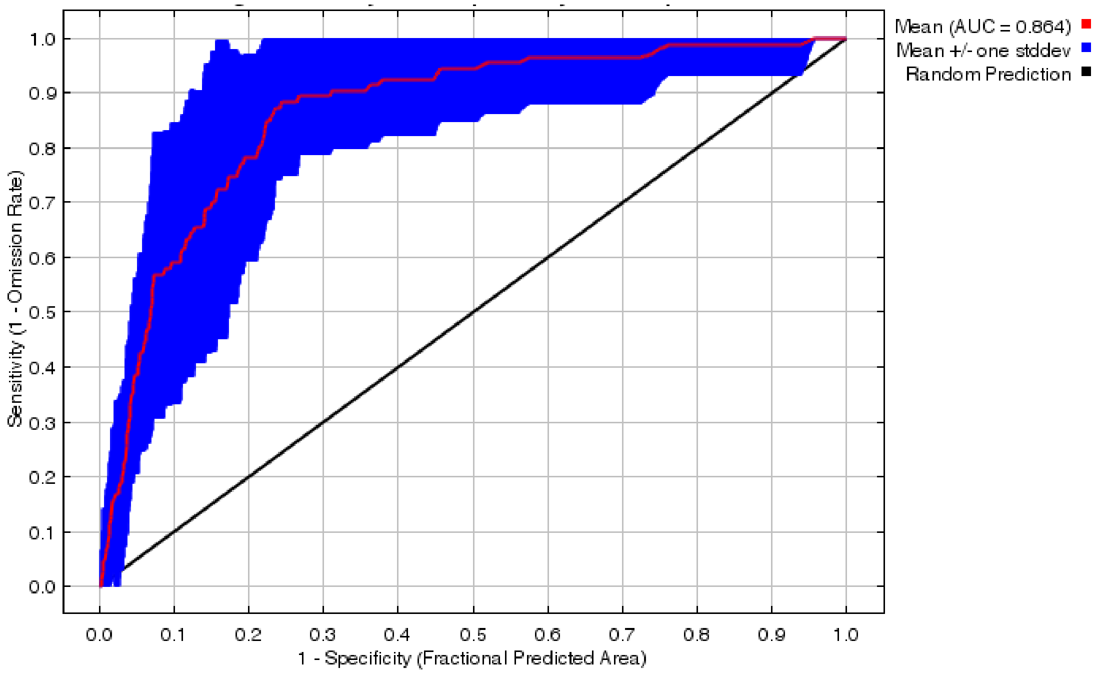

Figure 86: ROC curve for the training test of *O. ophidianus*

Table 43: Relative contributions of each predictor variable to the distribution model of *O. ophidianus*

Predictor variable	Contribution (%)
Bathymetry	61.7
Chlorophyll concentration	18.1
Maximum SST	10.8
Mean SST	4.8
Kd490	3.5
Primary Productivity	1.1

Based on a jackknife test of variable importance (Figure 87a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 87b) confirmed that Bathymetry and Chlorophyll concentration were the main contributors to the model.

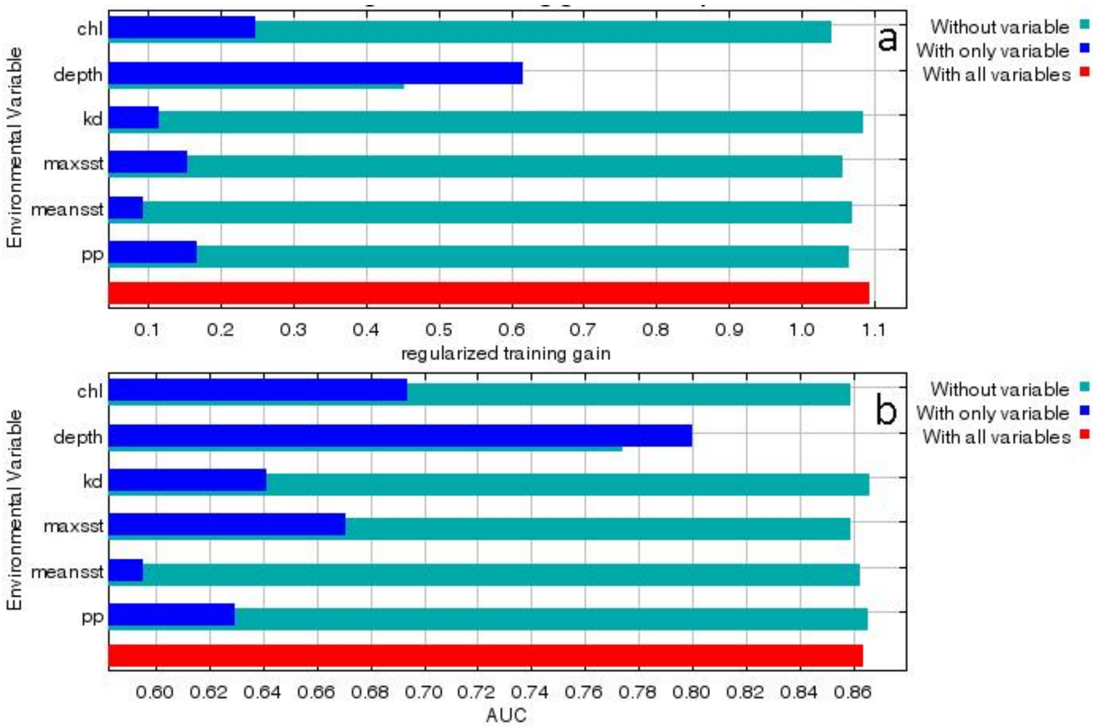

Figure 87: Jackknife of regularized training gain (a) and AUC (b) for *O. ophidianus*

Areas predicted to have the most suitable conditions for the occurrence of *O. ophidianus* are Chios, Psara, Lesvos, Donousa, Chalkidiki and Thermaikos gulf (Figure 88). Figure 89 shows the response curves of *O. ophidianus* to Bathymetry, Chlorophyll concentration and Maximum SST. *O. ophidianus* prefers low depths (0-20m). It cannot be found at areas with chlorophyll concentrations lower than 1mg/m^3. It thrives at high maximum SSTs (>301.6K) and has a fair possibility to be found at maximum SSTs lower than 298K and higher than 301K. Table 44 shows the minimum and maximum values of each environmental variable in the cells where *O. ophidianus* individuals have been recorded.

Table 44: Minimum and maximum values of predictor variables in the cells where *O. ophidianus* individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,43	0,22
Mean SST	292,10	294,89
Maximum SST	297,09	301,83
Kd490	0,02	0,35
Chlorophyll concentration	0,07	1,76
Bathymetry	-137,88	-0,02

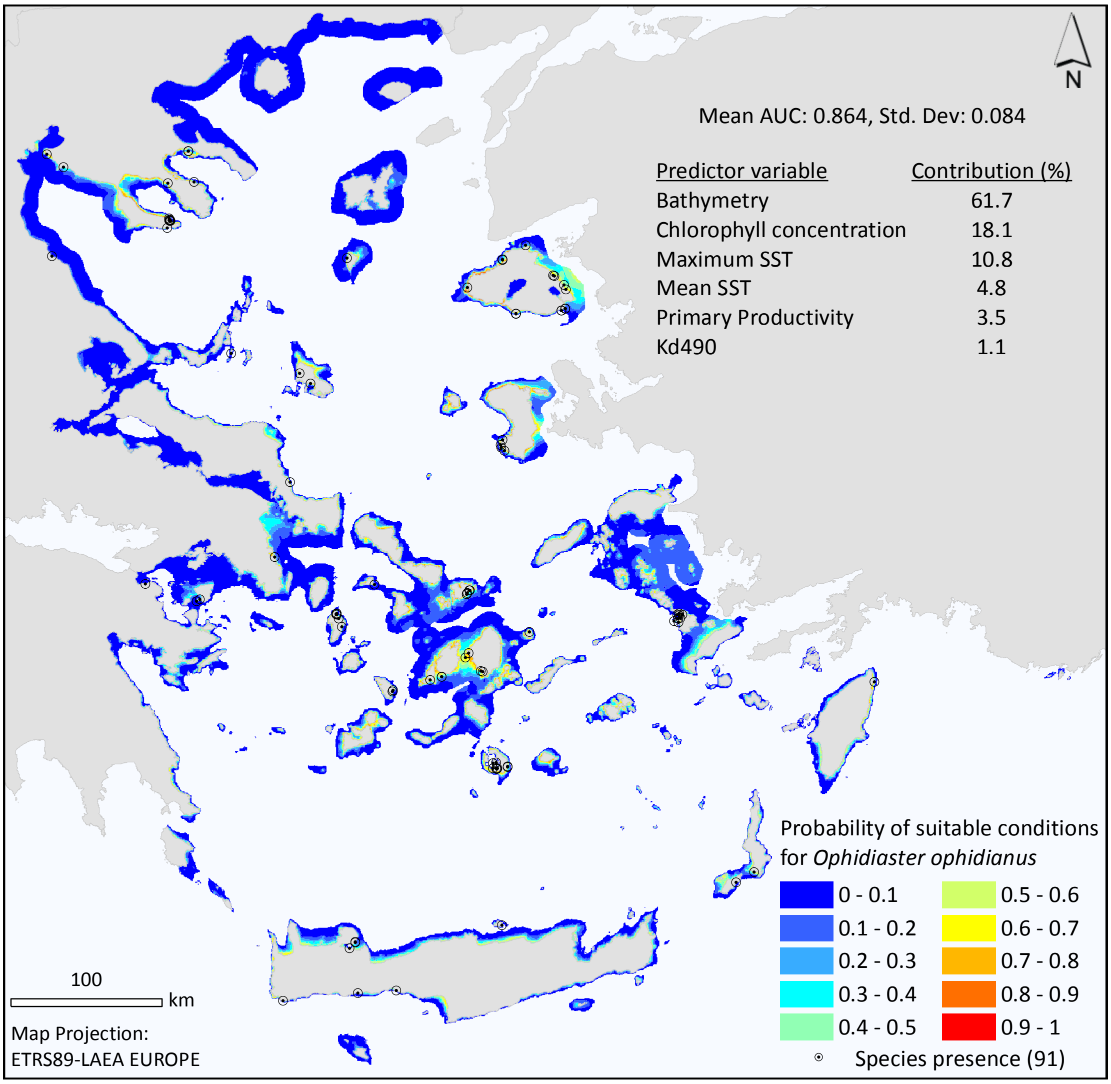

Figure 88: Probability of suitable conditions for *O. ophidianus*

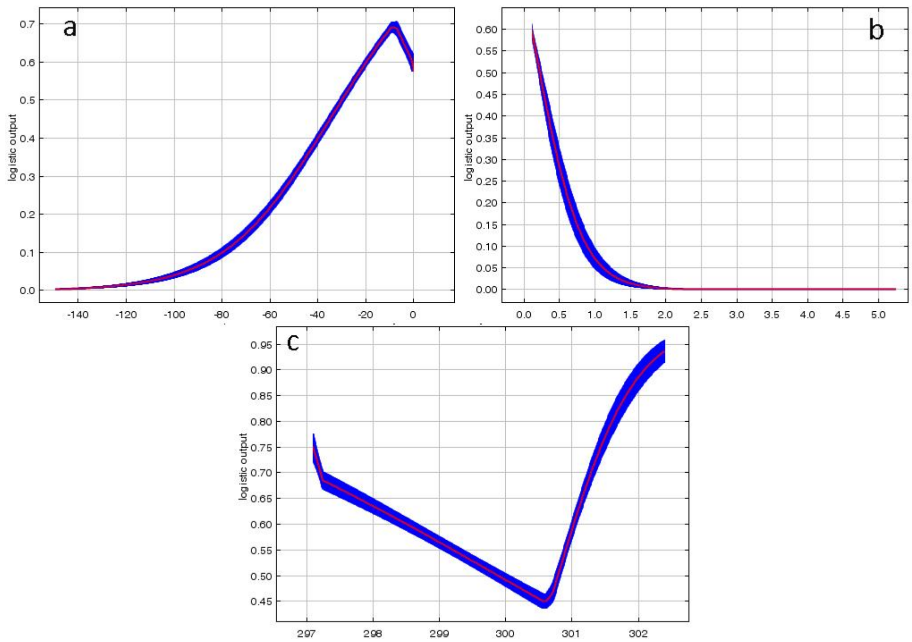

Figure 89: Response curves of *O. ophidianus* to Bathymetry (m) (a), Chlorophyll concentration (mg/m^3) (b), and Maximum SST (K) (c).

3.1.21 *Hippocampus* spp.

A total of 133 presence points were used to model the occurrence of *Hippocampus* sp. across the study area. The mean AUC of all models was 0.801 (standard deviation 0.074 - Figure 90). Bathymetry, Mean SST and Chlorophyll concentration were the three main contributors to the model (combined contribution of 89.6%; Table 45), whilst the remaining three predictors (Primary Productivity, Maximum SST and Kd490) had a combined contribution of 10.4%.

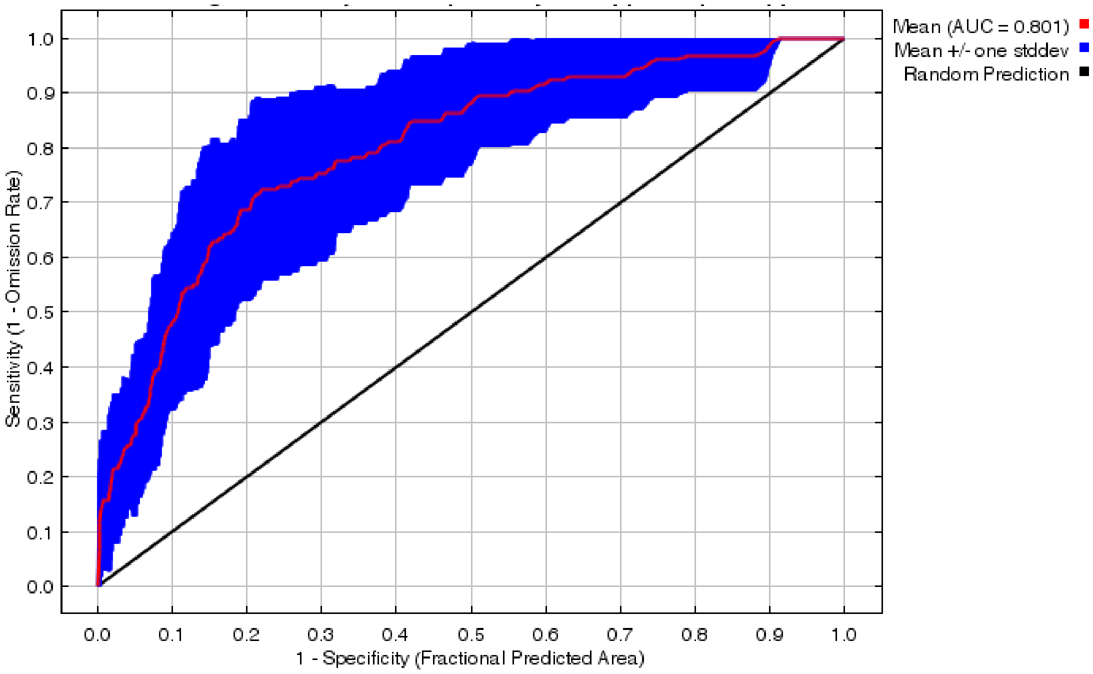

Figure 90: ROC curve for the training test of *Hippocampus* sp.

Table 45: Relative contributions of each predictor variable to the distribution model of *Hippocampus* sp.

Predictor variable	Contribution (%)
Bathymetry	55.1
Mean SST	17.8
Chlorophyll concentration	16.7
Primary Productivity	8.0
Maximum SST	1.6
Kd490	0.9

Based on a jackknife test of variable importance (Figure 91a), the predictor variable with the highest gain when used in isolation was Bathymetry, which therefore appeared to have the most useful information by itself. The jackknife test on the test set's AUC (Figure 91b) confirmed that Bathymetry and Mean SST were the main contributors to the model.

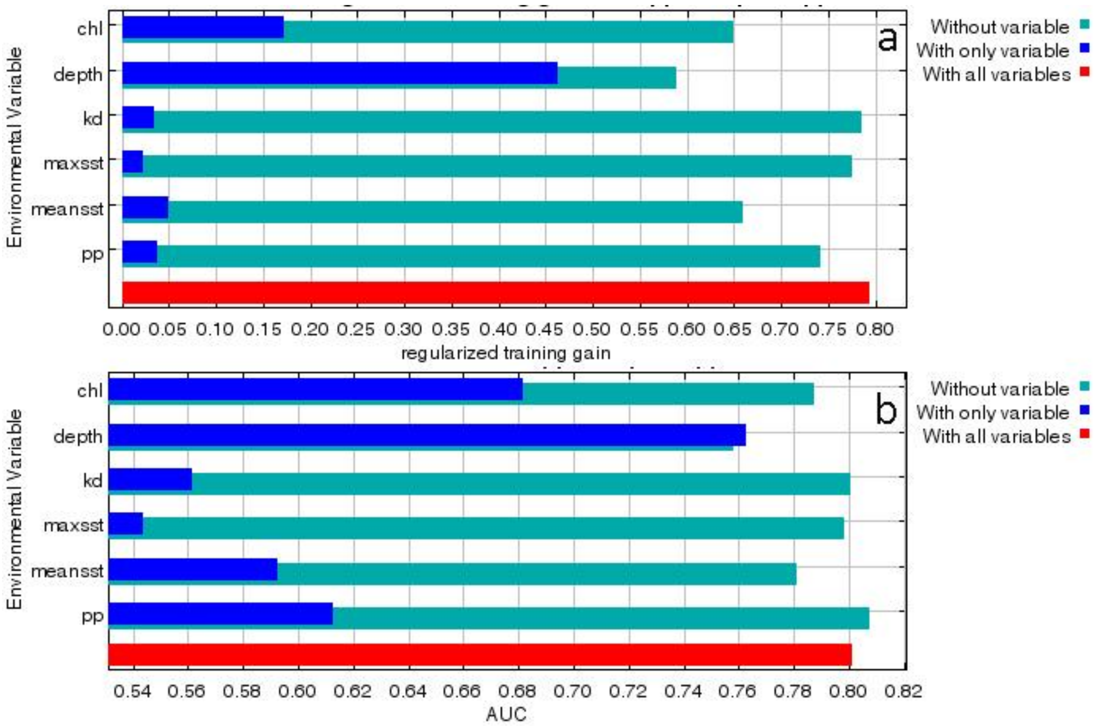

Figure 91: Jackknife of regularized training gain (a) and AUC (b) for *Hippocampus* sp.

Areas predicted to have the most suitable conditions for the occurrence of *Hippocampus* sp. are scattered across South Aegean Sea, with higher probabilities being located in NW Crete and Paros (Figure 92). Figure 93 shows the response curves of *Hippocampus* sp. to Bathymetry, Mean SST, Chlorophyll concentration and Primary Productivity. Seahorses can be found at all depth with the most suitable depth being between 0-60m. They prefer warm waters (Maximum SSTS >293.4K). They are not affected by different concentrations of chlorophyll and they prefer waters with low primary productivity (<0.50[8]gC/m^2/day). Table 46 shows the minimum and maximum values of each environmental variable in the cells where *Hippocampus* sp. individuals have been recorded.

Table 46: Minimum and maximum values of predictor variables in the cells where *Hippocampus* sp. individuals have been recorded.

Predictor variable	Minimum Value	Maximum Value
Primary Productivity	-0,43	0,15
Mean SST	291,64	294,72
Maximum SST	297,80	301,25
Kd490	0,02	0,77
Chlorophyll concentration	0,07	3,44
Bathymetry	-148,44	-0,03

[8] log (0.5)=-0.3

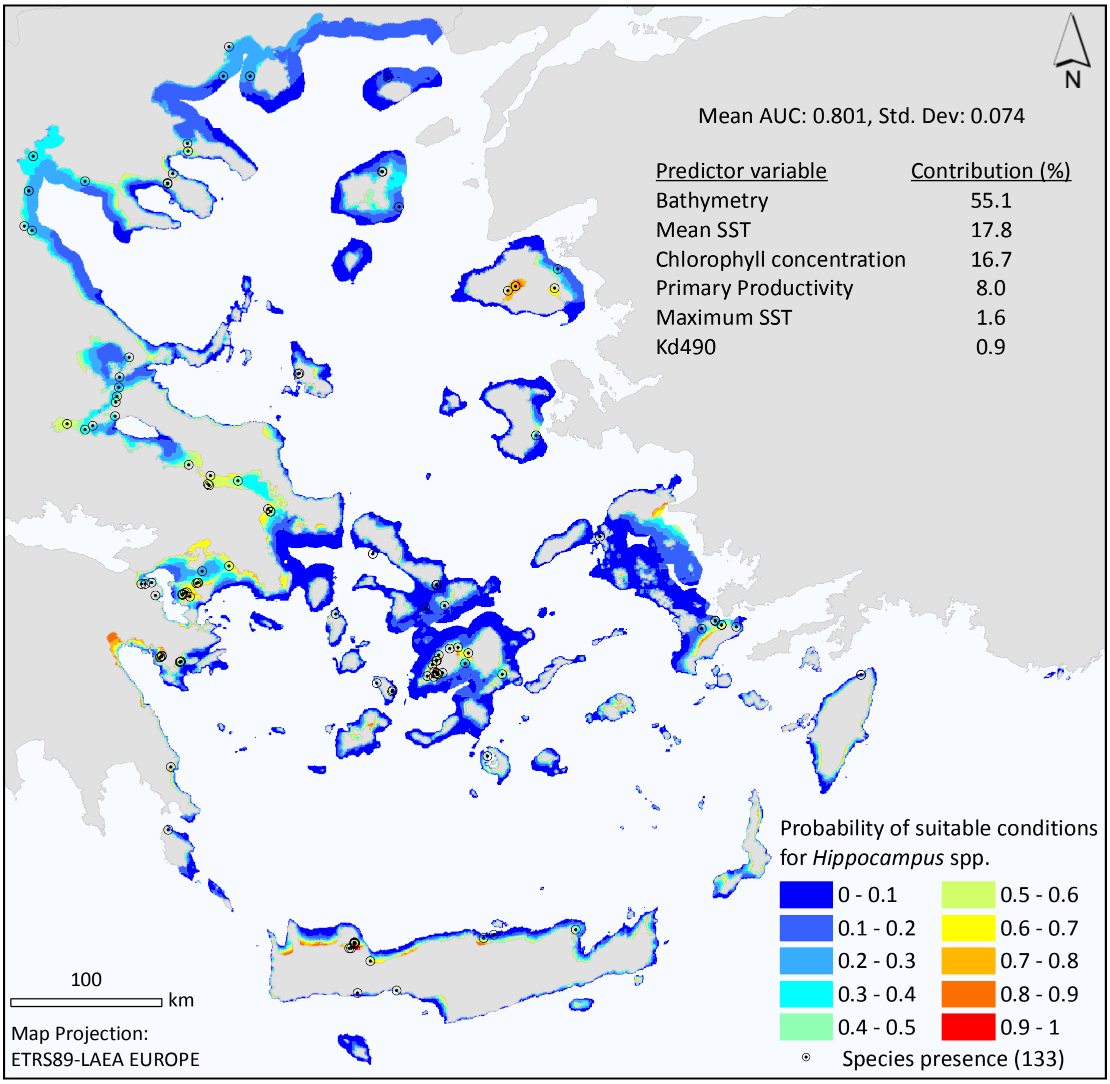

Figure 92: Probability of suitable conditions for *Hippocampus* sp.

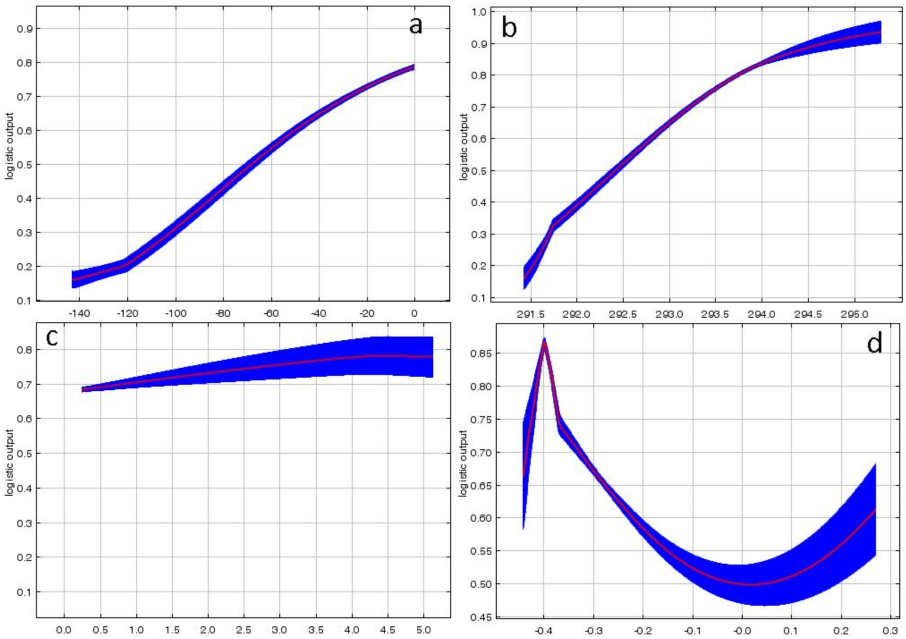

Figure 93: Response curves of *Hippocampus* sp. to Bathymetry (m) (a), Mean SST (K) (b), Chlorophyll concentration (mg/m^3) (c) and Primary Productivity (log(gC/m^2/day)) (d).

3.2 Hotspot analysis

Two different approaches were used to detect potential biodiversity hotspots. The first methodology used was the simple addition of the models for the 21 animal species and key ecological features. Figure 94 shows the cumulative probability of suitable conditions for the 21 ecological features studied; hotspots are identified mainly in Lesvos, Chalkidiki, Skyros, Chios, Psara, the Cyclades and Crete (scores >12; Figure 95) followed by scattered areas mainly in the North Aegean Sea, the Cyclades, East coast of Peloponnese and Karpathos (scores >10;Figure 96). This approach assigns a cumulative probability to all the grid cells of the study area.

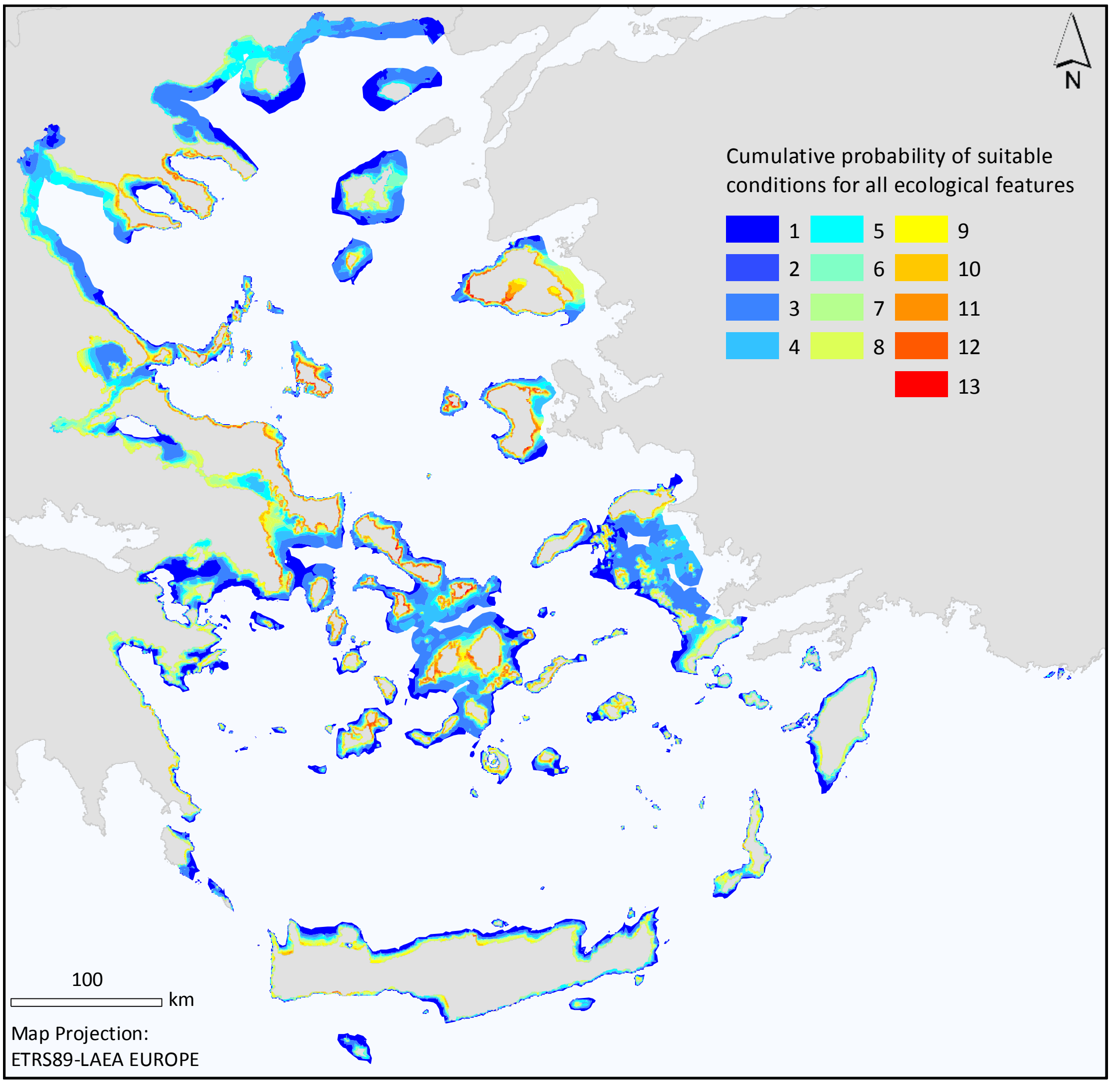

Figure 94: Cumulative probability of suitable conditions for all ecological features

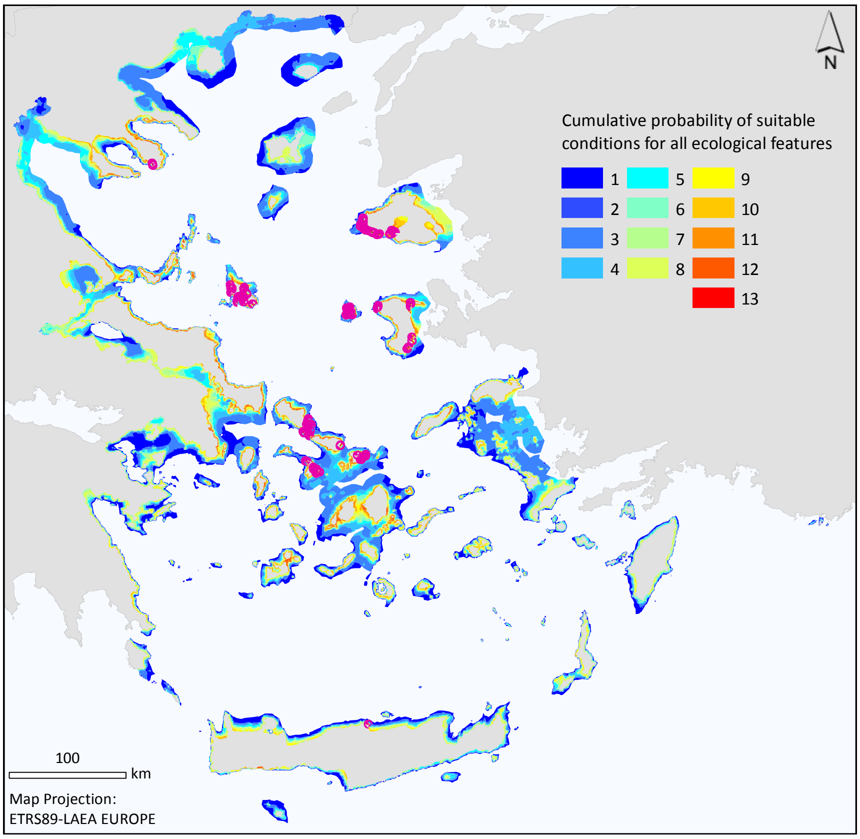

Figure 95: Cumulative probability of suitable conditions for all ecological features; cells with cumulative probability >12 are marked in fuchsia.

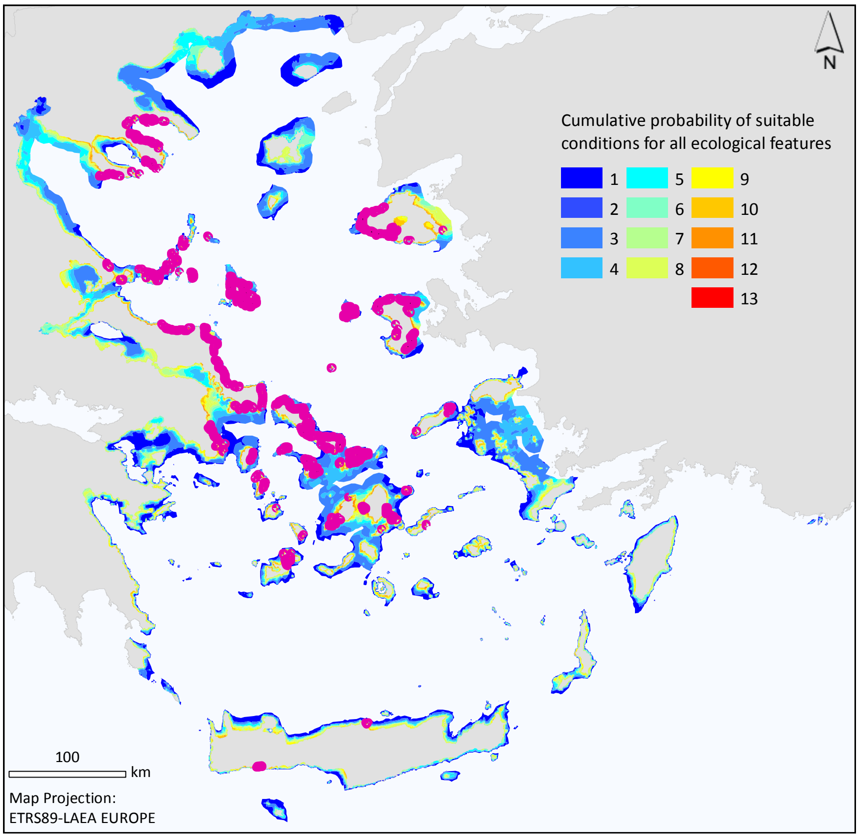

Figure 96: Cumulative probability of suitable conditions for all ecological features; cells with cumulative probability >10 are marked in fuchsia.

In order to limit the regions identified as hotspots, we followed a second approach in which after deciding a universal threshold for all ecological features the distribution probability for each species was differentiated between 1 (presence) and 0 (absence). All cells with probabilities of suitable condition larger than 0.7 were considered as presence. Figure 97 shows areas that were identified as hotpots, the maximum number of species or ecological species identified in a single cell was 13. The western coasts of Lesvos and Chios islands were highlighted as hotspots with 13 ecological features (Figure 98), followed by the gulf of Kalloni in central Lesvos and Psara island with 12 ecological features (Figure 99). Areas with more than 10 species were located in other regions of the aforementioned islands as well as in Amorgos and cental Kriti (Figure 100).

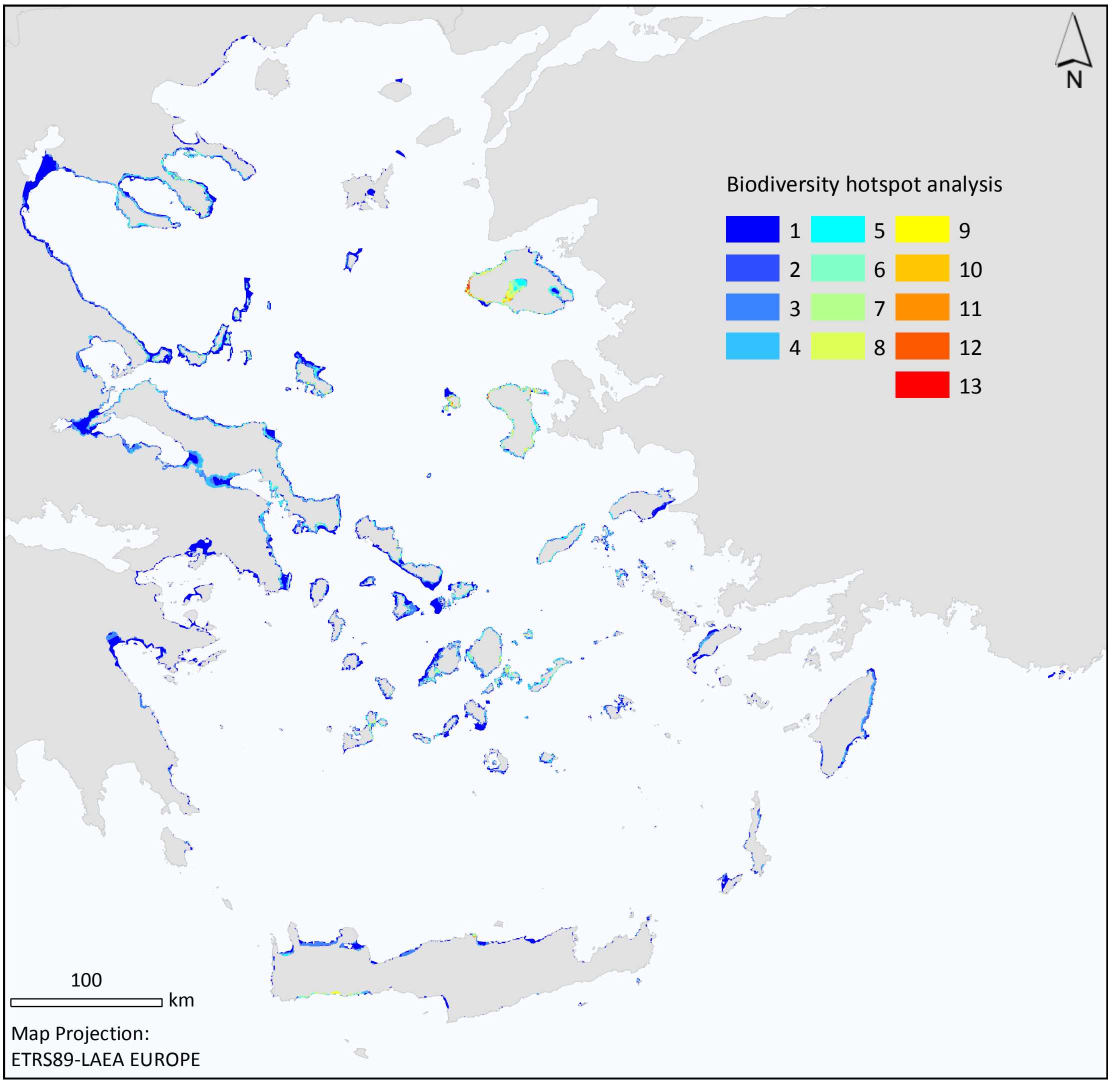

Figure 97: Biodiversity hotspot analysis for all ecological features

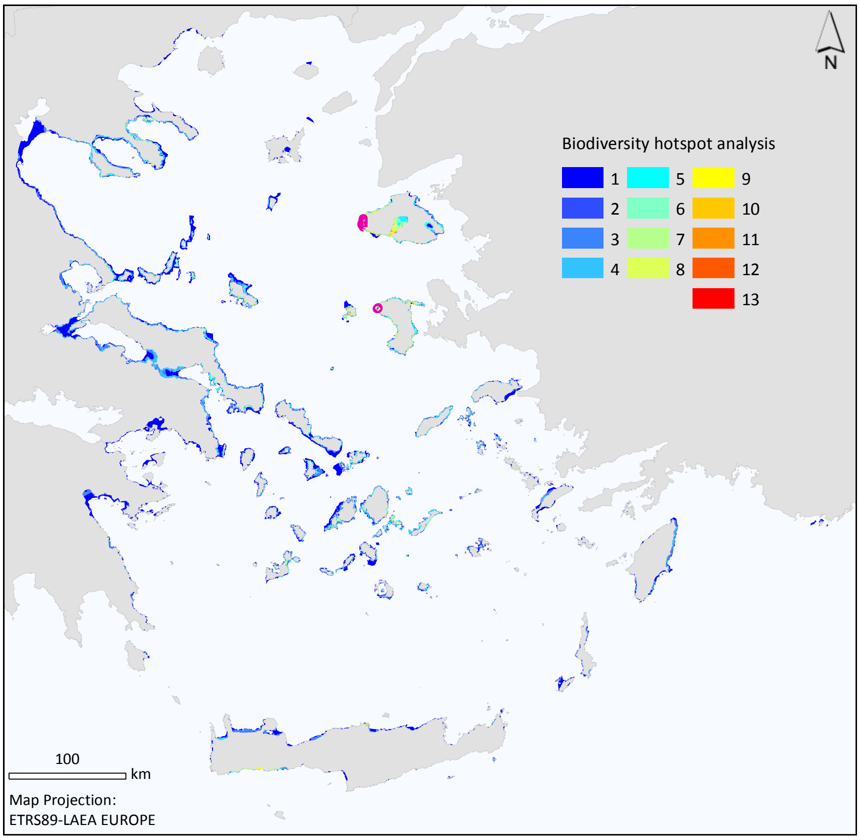

Figure 98: Biodiversity hotspot analysis for all ecological features; cells with 13 ecological features are marked in fuchsia.

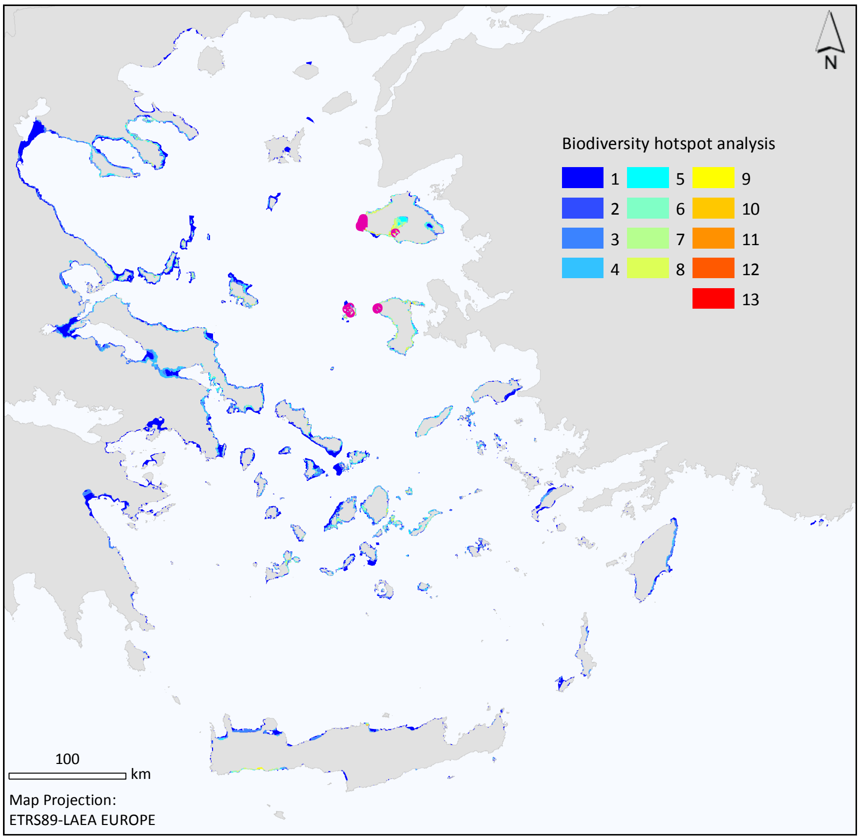

Figure 99: Biodiversity hotspot analysis for all ecological features; cells with more than 12 ecological features are marked in fuchsia.

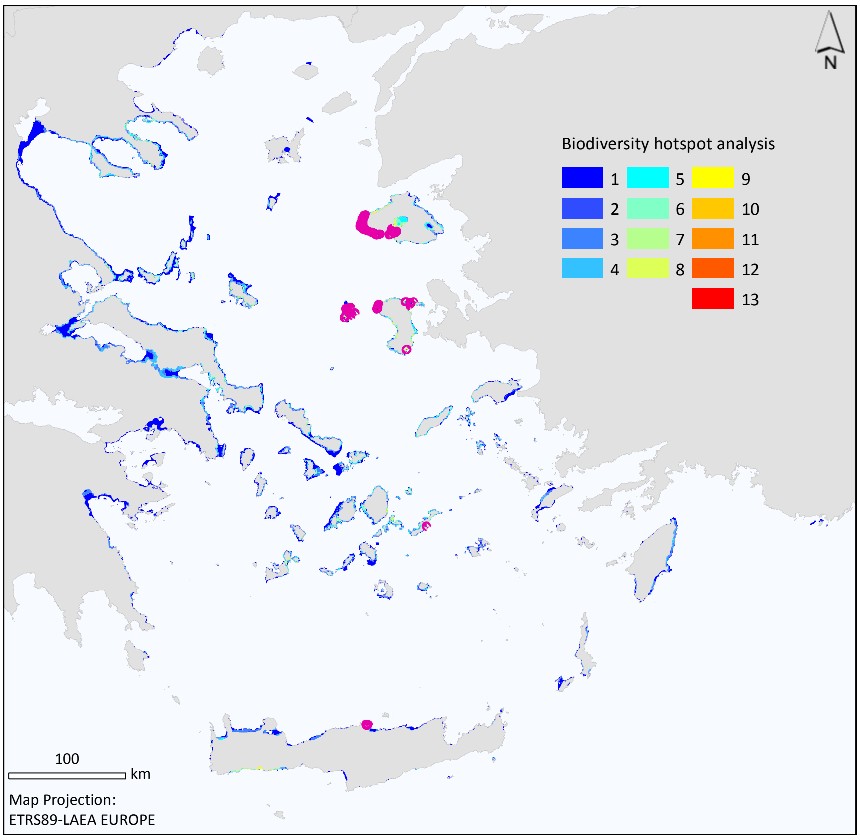

Figure 100: Biodiversity hotspot analysis for all ecological features; cells with more than 10 ecological features are marked in fuchsia.

4 Discussion

In this dissertation we used recently assembled datasets for animal species and key ecological features by Sini, et al. (2017) combined with six environmental variables in order to estimate the probability of suitable conditions for the animal species and key ecological features in the shallow (depth <150m) territorial waters of the Aegean Sea. The datasets came from various sources with various precisions. Considering that when using geographic coordinates, the second decimal place is worth up to 1.1 km and the third decimal place is worth up to 110m we excluded all data with precision less than 3 decimal places.

The environmental variables came in different resolutions and we downscaled them to a 0.5x0.5 km grid. In each cell we assigned the mean value of the area it covered. Considering the bathymetry we used the official dataset given by the Hellenic Navy Hydrographic Service (HNHS) which lacks in accuracy especially in small depths, which in combination to the downscaling and the assigning mean values to each of the cells of our study area leads to large depth values in the coastal cells. An important environmental value that we intended to use was salinity, but there were no available datasets from the Environmental Marine Information System data in closed gulfs such as Pagasitikos and Evoikos gulfs.

Three key ecological features were modeled in this dissertation, Rhodolith beds, Coralligenous formations and corals of the sublittoral zone.

Rhodolith beds refer to mobile substrates largely composed of variably-sized growth forms of unattached algal species of the Corallinaceae and Peyssonneliaceae families, and are commonly found in association with coarse sands and fine gravels (Sini, et al., 2017). Rhodolith beds grow in dim light conditions (Martin, et al., 2014). Their depth distribution ranges from the upper infralittoral to the lower circalittoral zone (<20-180 m; Sini et al., 2017; Barberá et al., 2003), while their average depth range within the Mediterranean is between 30-75 m (Basso et al., 2016; Sini et al., 2017). Our results showed that their distribution could depend on nutrient inputs but this was not supported by literature.

According to Sini et al. (2017), Mediterranean coralligenous formations refer to biogenic structures made up of encrusting coralline algae and calcareous animal material. They typically develop under dim light conditions at depths ranging from 20 to 120 m, either a) as outcrops of rocky substrates (i.e. coralligenous of the littoral rock), or b) as banks/platforms/minute reefs surrounded by sedimentary substrates or even sandy bottoms. Our results showed that the possible distribution of coralligenous formations depend mostly on temperature ranges, whereas Martin et al. (2014) found that bathymetry, slope of the seafloor and nutrient input were the main contributors to their models.

According to Sini et al. (2017) the corals of the sublittoral zone refer to all arborescent corals whose occurrence in the Aegean Sea is primarily known from waters shallower than 200 m and include nine gorgonian species (*Eunicella cavolini, E. singularis, E. verucosa*, *Paramuricea clavata*, *P. macrospina*, *Leptogorgia sarmentosa*, *Spinimuricea klavereni,* and *Villogorgia bebrycoides*), as well as the red coral *Corallium rubrum.* Our study underlines the significance of temperature; Mediterranean gorgonian species are particularly vulnerable to temperature anomalies (Sini et al., 2015).

The 8 Porifera species modeled in this dissertation were *Aplysin*a sp., *Axinella cannabina, A. polypoides, Geodia cymodium, Sarcotragus foetidus* and *S. pipetta* (modeled together as *Sarcotragus* sp.), *Tethya aurantium and T. citrina.*

*Aplysin*a sp. preferred depth range is consistent to other studies (i.e. 5-20m in Coppari et al. (2016)); the arborescent-shape morphology of this species, which can easily break down in wave-exposed shallower depths (Bell & Barnes, 2000) might explain this preference. Chlorophyll concentration is one of the main contributors to the model since concentration of Chlorophyll *a*(Chl *a*) can be used as a traditional proxy of the abundance of photosynthetic symbionts in sponges (Becerro et al., 2003).

A. cannabina is a warm-water native (Parravicini et al., 2015) which comes to contrast to our findings of less preferred high mean SSTs, it is a typical sciaphilous species commonly occurring in coralligenous habitats and marine caves (Katsanevakis et al., 2017), thus it should be modeled using habitats as an environmental variable.

A. *polypoides* is a warm-water native (Parravicini et al., 2015) and prefers low depths (i.e. 10-70m; Coppari et al., 2016). According to Coppari at (2016) the species removes low quantities of C (0.19 ± 0.02 mg C/m^2/day in spring and 0.42 ± 0.04 mg C/m^2/day in autumn) which justifies our findings for larger probabilities of suitable conditions in oligotrophic or mesoptrophic waters; according to Ignatiades (2005) ‘open oligotrophic’ < ‘offshore mesotrophic’ < ‘inshore eutrophic’ waters are defined for chl-a as 0.5 < (0.5 – 1.0) < 1.0 mg/m^3, and for primary production as 1.5 < (1.5 – 3.0) < 3.0 mg C/m^3/h.

Geodia cydonium is very common in sciaphilous environments (Uriz, 1981) and it has been located at various depths between 0.5 and 35m (Mercurio et al., 2006; Pancer et al., 1997; Batel et al., 1998; Schröder et al., 1998; Pancer, et al., 1996), which is consistent to our findings for depths preferences; the possibilities of suitable conditions in larger depths could be due to its sciaphilic behavior.

Sarcotragus sp. preference to small depths is supported by bibliographic data, since those sponges are most commonly found on shallow rocky reefs(Pérès, 1967). Our findings concerning temperatures are in contrast with other studies showing that

Sarcotragus sp. populations are mainly distributed in warm waters worldwide (Voultsiadou, 2005; Katsanevakis et al., 2017).

In the Mediterranean Sea *T. aurantium* cooccurs with the very similar species of *T. citrina*, but inhabits different niches. *T. aurantium* generally inhabits areas that are more exposed to light and current in depths of 1–40 m, while *T. citrina* prefers more sheltered places (Thiel et al., 2007), which is consistent to our finding concerning Kd490; Kd490 can be used as an indicator for water turbidity. *T. citrina* is usually found in shallow, calm waters between 0.5 and 1 m, though it can be found at greater depths even exceeding 70m (Corriero et al., 1989).

Cladocora caespitosa was the sole Anthozoa species in this study. It can develop on shallow (<10 m) and deeper (>30 m) rocky substrates and is able to thrive in turbid waters at relatively low irradiance mainly between 7 and 15 m depth. However in clear waters this coral can also be found down to 40 m (El Kateb et al., 2016) which is consistent to our findings concerning preferred depth. Our results show that the coral is most likely to be found in areas with temperature around 18-19^{o}C and is not able to withstand elevated or prolonged summer temperatures (Rodolfo-Metalpa et al., 2005) .

The 8 Porifera species modeled in this dissertation were *Charonia variegata, Erosaria spurca, Lithophaga lithophaga, Luria lurida, Pinna nobilis , Tonna galea* and *Zonaria pyrum.*

C. variegata lives in rocky shores of temperate and tropical waters (Katsanevakis et al., 2008) and it is only found in the warm waters of the Eastern Meditteranean (Russo et al., 1990). Our results match most of the areas where the species has been reported, i.e. in the Kyklades, Kriti, Dodekanisos and the N Aegean. Our study suggests that *C. variegata* prefers oligotrophic waters (low values of chlorophyll concentration and primary productivity) which is consistent to other studies (e.g. (Katsanevakis et al., 2017).

Erosaria spurca is a nocturnal animal, remaining hidden during daylight hours, and lives in rocky subtidal areas and in seagrass beds (Katsanevakis et al., 2008), thus it is strongly suggested to use more environmental variables in the modeling process, perhaps the habitat or the substrate. Our results match most of the areas where the species has been reported, i.e. in the Kyklades, the Dodekanisos, Kriti, Rodos, Samos, and the N Aegean (Katsanevakis et al., 2008). The CIESM project “Tropical signals” enlisted *Erosaria spurca* among its macrodescriptors of warm water affinity(CIESM, 2008), which is in contrast to our results for a preference to low maximum SSTs.

L. lithophaga is an inhabitant of hard substrata (limestone rocks) communities in the midlittoral and upper sublittoral zones (Galinou-Mitsoudi & Sinis, 1994) which is in contrast to our findings of a possible depth range of 0-110m. The species inhabits mostly steep rocky shores, areas that in our study are represented with depth values higher than the actual due to use of mean depth for each 0.5kmx0.5km cell. According to Perharda et al. (2015) the range of seawater temperatures recorded by *L. lithophaga* over the period 1987– 2012 is between 12 and 25°C which is consistent to the preference of mean SSTs between 292-293.5K (18.85-20.35°C).

Luria lurida lives in rocky areas of the subtital zone and is a nocturnal animal (Katsanevakis et al., 2008); according to (Poppe & Goto, 1991) it lives in depths between 1-60m. Our findings are consistent to bibliographic references since there are larger possibilities to find the animal in small depths and little possibilities to find it in areas with a lot of light. Our results match most of the areas where *L. lurida* has been reported, i.e.in the Kyklades, the Dodekanissa, Kriti, the N Aegean (Katsanevakis et al., 2008).

P. nobilis shows a preference to low depths which is consistent to previous findings (Koutsoubas et al., 2007; Katsanevakis et al.,2006; Katsanevakis,, 2007). The species is most possible to be found in Lesvos and Crete (Katsanevakis et al., 2008). An environmental variable that should be used to study the possible distribution of *P. nobilis* is the substrate knowing that the mussel grows on soft-sediment areas overgrown by seagrass meadows (Katsanevakis, 2006; Siletic & Peharda, 2003).

Tonna galea is a thermophilic species (Bianchi et al., 2014) and lives in sandy/muddy bottoms and seagrass beds, at depths from a few meters to 120 m (Katsanevakis et al., 2008). It has been recorded in the Saronikos, Korinthiakos, and Evvoikos gulfs, the N Aegean Sea (SE Thermaikos Gulf, Chalkidiki - SE Toronaios Gulf), the Kyklades, the Ionian Sea and the Cretan Sea (Katsanevakis et al., 2008); our results match only few of this areas. More or different environmental variables should be used to model the possible distribution of this species.

Specimens of *Zonaria pyrum* from the N. Aegean were found on rocky substrate with many *Axinella* spp. sponges, at a depth of 25 m (Koutsoubas, 1992). Our results match only few of the areas where the species has been reported, specifically the Dodekanisos, the Kyklades and Kriti and show low possibilities of suitable conditions in other areas where it has been reported, such as the Evvoikos Gulf, along the Peloponnisos coasts and the N Aegean (Katsanevakis et al., 2008). Species of the family Cypraeidae are mostly distributed in tropical and subtropical waters (Katsanevakis et al., 2008) which is consistent to our findings for a preference of *Z. Pyrum* to high Mean SSTs.

Information regarding the distribution of protected Echinoderms, such as *C. longispinus* and *O. ophidianus* presents significant knowledge gaps (Sini et al., 2017). Their preference to warmer waters is justified since both species are warm-water natives (Parravicini et al., 2015). They have similar preferences to chlorophyll concentrations and depth; *C. longispinus* which is a typical sciaphilous species

(Katsanevakis et al., 2017) showed a small preference to deeper waters, around 120m.

The 2 Actinopterygii species studied in this dissertation were *Hippocampus guttulatus* and *H. hippocampus,* which were modeled at genus level. *Hippocampus* sp. inhabits shallow inshore waters, mainly in seagrass meadows and algal beds (Lourie et al., 2004), which is in accordance to our findings. Planas et al (2012) suggest that *Hippocampus guttulatus* growth and survival in juveniles at 15^{o}C are reduced with respect to those grown at 18-21^{o}C, which supports our findings for the preference of seahorses to warmer waters.

Hotspot analysis highlighted areas in Lesvos, Chios, Chalkidiki, Amorgos and Crete. The West of Lesvos and Chios islands were identified as hotspots and are known areas where upwelling processes occur (Androulidakis et al., 2017; Mamoutos et al., 2017). Of course we cannot speak of actual hotspots unless we take into consideration a larger variety of marine species.

The predicted distribution maps for animal species and key ecological features can be of critical importance to guide more-cost effective surveys and monitoring efforts targeting poorly-surveyed areas In turn, the newly collected data, could then be used to improve distribution models, since a systematic survey of Aegean Sea is rather impossible. Model performance will also improve with finer resolution, or more relevant predictor variables, resulting in better predicted distribution maps.

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Maps throughout this dissertation were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com.

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