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## Molluscan indicator species and their potential use in ecological status assessment using species distribution modeling

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## ABSTRACT

Marine habitat assessment using indicator species through Species Distribution Modeling (SDM) was investigated. The bivalves: *Corbula gibba* and *Flexopecten hyalinus* were the indicator species characterizing disturbed and undisturbed areas respectively in terms of chlorophyll *a* concentration in Greece. The habitat suitability maps of these species reflected the overall ecological status of the area. The *C. gibba* model successfully predicted the occurrence of this species in areas with increased physical disturbance driven by chlorophyll *a* concentration, whereas the habitat map for *F. hyalinus* showed an increased probability of occurrence in chlorophyll-poor areas, affected mainly by salinity. We advocate the use of *C. gibba* as a proxy for eutrophication and the incorporation of this species in monitoring studies through SDM methods. For the Mediterranean Sea we suggest the use of *F. hyalinus* in SDM as an indicator of environmental stability and a possible forecasting tool for salinity fluctuations.

### 1. Introduction

The management of aquatic ecosystems through sustainable practices is mandatory under European legislation with policies such as the European Water Framework Directive – WFD (EU, 2000) and the Marine Strategy Framework Directive – MSFD (EU, 2008). Both these directives aim to achieve a “good” ecological status and in this context they use a series of biotic indices (Borja et al., 2000; Dauvin and Ruellet, 2007; Muxika et al., 2005, 2007; Rosenberg et al., 2004; Simboura and Zenetos, 2002) in order to assess the ecological status of coastal and estuarine waters. Studying the benthic ecosystem and the associated benthic communities is a common approach for evaluating the effect of natural or anthropogenic pressures on the marine environment (Zettler et al., 2013). Macrobenthic invertebrates are considered important biological indicators for aquatic ecosystems as their response to a variety of environmental stressors is well established (de-la-Ossa-Carretero et al., 2012; Dimitriou et al., 2015; Moraitis et al., 2013). However, in order to use all the main macrobenthic groups (annelids, crustaceans, echinoderms and mollusks) in relevant benthic ecological indicators, adequate knowledge of their taxonomy is mandatory. Additionally, the most important taxonomic groups, like crustaceans and echinoderms, are often absent from gradients of environmental disturbance while mollusks have a broader range of tolerance

(Nerlović et al., 2011; Pearson and Rosenberg, 1978), making them good candidates for assessing marine ecosystem health.

In aquatic environments, ecological condition often derives from the presence, absence, or abundance of a species that is related to a specific set of environmental requirements and therefore has high indicator power (Zettler et al., 2013). Certain Indicator Species act as proxies of environmental or ecological change due to their sensitivity or predictable reactions to a wide range of environmental stressors (López-Baucells et al., 2017). The contribution of an indicator species to environmental management is important because it is conceptually straightforward and allows the determination of bioindicators for any combination of habitat types or groups of sites based on the outcome of a classification procedure (McGeoch and Chown, 1998). Some of the advantages that characterize indicator species is the fact that they are easily monitored, and they integrate or reflect cumulative effects of environmental changes (Siddig et al., 2016). The indicative ability of an indicator species is determined using an analysis of the relationship between the observed species presence-absence or abundance values in a set of sampled sites and a classification of the same sites according to the study objectives (De Cáceres et al., 2010). An ideal indicator species consistently occurs in a specific habitat type and represents a more accurate ecological indicator than a habitat generalist species (De Cáceres and Legendre, 2009).

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Mollusks have been used as biotic tools for ecological status assessment in the context of WFD status classification (Leshno et al., 2015; Nerlović et al., 2011), as ecological indicators (La Valle et al., 2011) and bioindicators of environmental contamination (Coelho et al., 2014; Mahmoud et al., 2010; Velez et al., 2016). The ecological role of molluscan fauna in the Eastern Mediterranean Sea has been highlighted by various authors (Arvanitidis et al., 2005; Dimitriadis and Koutsoubas, 2008; Koutsoubas et al., 2000; Zenetos, 1996), who have addressed their importance in ecosystem structure and biodiversity maintenance and also, underlined their capability to reflect the total macrofaunal community in terms of ecological status evaluation. The use of benthic mollusks in Species Distribution Modeling (SDM) studies has focused mainly on the impact of climate change (Saupe et al., 2014), biodiversity (Darr et al., 2014), species of socioeconomic interest (Appelqvist et al., 2015; Russell et al., 2012; Vázquez-Luis et al., 2014) and impact of biological invasions (Jones et al., 2013; Raybaud et al., 2014) and less so on studies regarding the distribution of species with high ecological value (Gormley et al., 2013). In the Mediterranean region, molluscan indicator species combined with SDM have not been used for assessing marine ecological status.

The aims of this study were to: (i) identify the benthic molluscan indicator species in areas with different ecological status according to a eutrophication scale developed for the water column in the Eastern Mediterranean, (ii) employ SDMs to generate predictive habitat maps for these species and (iii) evaluate the ecological importance of the indicator species in this study in terms of integration in monitoring studies as ecological indicators. Macrobenthic mollusks were suitable candidates for the purpose of this work due to their ability to reflect the long terms effects of water column conditions and their sedentary life making them unable to avoid deteriorating environmental conditions (Moraitis et al., 2013). We hypothesize that the habitat suitability maps of the indicator species would reflect the overall ecological status of the survey area. It is expected that the distribution of the species associated with environmentally disturbed habitats would be mainly driven by chlorophyll *a* concentration and therefore it/they can be used as a proxy for eutrophication. Accordingly, species that characterize undisturbed marine environments are expected to be influenced by a variety of other environmental factors.

The use of indicator species for habitat characterization is very rare (Zettler et al., 2013) and to our knowledge there are no other studies incorporating benthic indicator species into SDM for this purpose. To this end, we propose a novel approach in marine health assessment by identifying the molluscan indicator species of environmentally disturbed and undisturbed areas and incorporating them in the most relevant SDM techniques.

## 2. Materials and methods

### 2.1. Study design

Environmental gradients tend to affect species sensitivity and indicative value to an environmental stressor (e.g. eutrophication) and whether this particular species can serve as an indicator depends on its relative position along the gradient (Zettler et al., 2013). Due to the well-defined environmental gradients (e.g. primary productivity) from the northern to the southern parts of the Aegean Sea, we also included stations from the Ionian Sea (Fig. 1) in order to fully evaluate the indicative power of the species. This allows a more cohesive approach to understanding the ecological niche of the molluscan species by expanding the value range of the most relevant environmental predictors.

In order to identify the indicator species, first, the sampling stations were assigned into two groups according to their ecological status based on the trophic state of the water column. The immediate response to marine nutrient enrichment is an increase in phytoplankton biomass, a relationship that defines eutrophication. We used chlorophyll *a* concentration (chl *a*), scaled on the eutrophication scale (Karydis, 1999;

Pagou et al., 2002) and modified by Simboura et al. (2005), to assess the ecological status of the sampling locations as chlorophyll concentration represents a simple and integrative measure of the phytoplankton community to nutrient enrichment succession (Spatharis and Tsirosis, 2010). In this scale, chl *a* is used to express an attribute of phytoplankton quantity since phytoplankton is one of the three biological components (together with benthos and macroalgae) assessed in the context of the WFD for coastal waters (Simboura et al., 2016). Chl *a* concentration values based on satellite and *in situ* measured data were obtained from Bio-Oracle, a global environmental dataset designed for marine species distribution modeling (<http://www.bio-oracle.org/>) (Tyberghein et al., 2012). Depending on the monthly mean chl *a*, the sampling stations were divided (Fig. 1) into “acceptable” (Chl *a* < 0.4 µg/l) and “unacceptable” (Chl *a* > 0.4 µg/l) according to the ecological status scale of WFD as defined by Simboura et al. (2005). The term “acceptable” corresponds to the classes that refer to the acceptable boundary values (i.e. “high” and “good”) and the term “unacceptable” corresponds to the classes that refer to the unacceptable boundary values (i.e. “moderate”, “poor” and “bad”) in the WFD context.

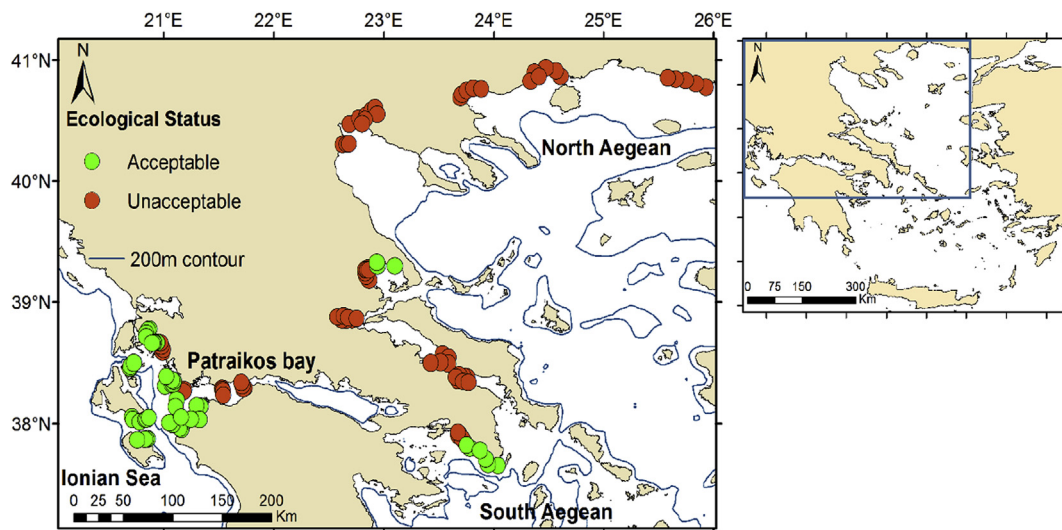
### 2.2. Biological data

Soft-bottom macrofaunal samples were collected from 123 sites located in the Aegean and Ionian Seas (Fig. 1) between April and July 2014, using a Smith-McIntyre grab with a sampling area of 0.1 m<sup>2</sup>. Each sample was sieved first with a 1 mm and then a 0.5 mm mesh sieve. The sieved samples were fixed with 10% formalin, stained with the coloring substance Rose Bengal and transferred to the laboratory for sorting and identification at the species level. The final species list contained a total of 122 species of marine mollusks (3015 individuals), along with information regarding the functional characteristics of each species (feeding type, habitat behavior and the ecological group according to their sensitivity or tolerance to disturbance as was defined using the Bentix index classification (Simboura and Zenetos, 2002)).

Indicator Species Analysis (De Cáceres and Legendre, 2009) was used to identify the representative molluscan species of two groups of habitats with different ecological status classification. Indicator species are determined using an analysis of the relationship between the species abundance values from the sampled sites and the classification of the same sites into groups based on the grouping procedure mentioned. For this analysis, we used the original Indicator Value method (Dufrene and Legendre, 1997), by excluding side group combinations so the species can be associated with the specified ecological conditions. The outcome of the analysis is the product of two components, called “specificity” and “sensitivity”. Specificity is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. Sensitivity is the probability of finding the species in sites belonging to the site group. Finally, the algorithm provides a statistic (Indicator Value) ranging from 0 (not suitable indicator) to 1 (perfect indicator) and the respective *p* - value. The “indicspecies” package implemented in R 3.3.2 program language (R Development Core Team, 2017) was used to perform indicator species analysis.

### 2.3. Environmental data

In the modeling context, the most relevant variables to model benthos distribution were selected. Depth and sediment type are not considered suitable for SDM, the former because it is sensitive to issues of collinearity with other environmental variables (Reiss et al., 2015) and the latter because of its extreme spatial variability (Saupe et al., 2014; Townhill et al., 2017). According to Reiss et al. (2015), the most useful direct variables used in benthic distribution modeling are salinity, temperature and primary productivity and therefore were selected for this work. Incorporating only biologically important environmental factors in the modeling process increases the performance and consequently issues of autocorrelation are avoided (Kotta et al., 2014). For



**Fig. 1.** Sampling stations located in the Aegean and Ionian Sea assigned with the ecological status classification label derived from a modified Eutrophication scale metric by Simboura et al. (2005). (Ecological status: Acceptable corresponds to high or good; Unacceptable: moderate – poor - bad). The 200 m contour is also presented.

molluscan species distribution in this study, sea surface temperature (SST - mean), sea bottom temperature (sbt - mean), surface and bottom salinity (mean), and chlorophyll *a* (Chl *a* - mean) concentration as a primary productivity measure were initially selected as environmental predictors. All environmental predictors were derived from the Bio-Oracle, a global environmental dataset designed for marine species distribution modeling (<http://www.bio-oracle.org/>) (Tyberghein et al., 2012) except for sea bottom temperature (sbt) which Aquamaps database (<http://www.aquamaps.org/>) (Kaschner et al., 2016) was used. In order to avoid multicollinearity and over-fitting issues, the collinearity diagnostic VIF (Variance Inflation Factor, cut-off threshold = 5) based on a stepwise procedure to detect and exclude collinear variables and the Pearson correlation test (threshold > 0.5) were incorporated. Bottom salinity and SST were excluded from the analysis due to collinearity issues. Transformation of continuous environmental variables prior to ecological analysis is known to reduce collinearity effects (Vázquez-Luis et al., 2014). For this reason, chl *a* was  $\log(x+1)$  transformed prior to the modeling analysis as in previous SDM studies (Galanidi et al., 2016). All environmental raster layers were resampled by bilinear interpolation to a resolution of 1 km<sup>2</sup> and cropped using a polygon mask to the extent of the sampling vicinity, i.e. depth up to 200 m. The model prediction surface reflected the environmental layer surface, which was chosen to cover all sampling stations along the continental shelf. Therefore, the set of values used in the training stage of the model defined the extent of the projection on the maps which included only areas within the range of the values for all the environmental variables considered. All spatial analysis and multicollinearity tests were carried out using the packages “raster”, “mapproj” and “usdm” implemented in R 3.3.2 program language (R Development Core Team, 2017) and ArcGIS (Version 10.2). The final dataset of the environmental predictors suitable for SDM (no collinearity issues) is

presented in Table 1 along with the biological importance for each model predictor. An overview of the final environmental predictors employed in the SDM and their respective maps is provided in Fig. S3. Supplementary material.

#### 2.4. Modeling

In order to model the potential distribution of the two molluscan indicator species, *in situ* presence–absence data was used as biological input combined with a set of relevant environmental predictors. The majority of the obstacles regarding the model quality of SDMs are based on the paucity of data, spatial biases, and the lack of valid absences (Guisan et al., 2006; Reiss et al., 2015) that affect presence-only modeling methods (Veloz, 2009). To avoid those shortcomings, we used presence and true absence data collected *in situ* and excluded areas that were not adequately sampled from the modeling analysis. The use of high-quality species presences and species true absences gives the opportunity to accurately evaluate species habitat suitability in predictive modeling (Singer et al., 2016). Species that were not present in at least five spatially unique stations were removed from the analysis as recommended in previous SDM studies (Galanidi et al., 2016; van Proosdij et al., 2016). A wide variety of methods has been proposed for SDM, each with its own advantages and disadvantages (Robinson et al., 2011). To make use of the advantages and avoid the disadvantages of the several algorithms used to create SDMs, one solution is to create an ensemble of predictions derived from multiple modeling approaches (Araújo and New, 2007; Gama et al., 2016; Riul et al., 2013). By merging different model algorithms, this approach accounts for inter-model variability and reduces the uncertainties resulting from a single-modeling method (Araújo and New, 2007; Singer et al., 2016; Thuiller et al., 2009). Since presence and true absence data are available in this

**Table 1**  
Selected environmental predictors suitable for benthic species distribution modeling along with their biological importance.

Predictor	Unit	Abbreviation	Biological Importance
Mean surface salinity	PSS	salinity	Salinity is used to define different water masses and depth zones and is considered as a primary driver for the distribution of benthic invertebrates (Reiss et al., 2015)
Log (x + 1) mean chl <i>a</i> concentration	mg/m <sup>3</sup>	lgchlomean	Primary productivity proxies indicate food availability for suspension feeding mollusks (Rodil et al., 2014)
Mean sea bottom temperature	°C	sbt	Temperature is a limiting factor for marine species distribution that controls metabolic rates and affects physiological functions in all growth stages (Valentine and Jablonski, 2015)

study, an ensemble model was created based on presence-absence techniques. More specifically, two regression-based methods: Generalized Linear Models (GLM), Generalized Additive Models (GAM) and two machine-learning methods: Boosted Regression Tree analysis (BRT) and Random Forest (RF) were developed. Models are built using 10 runs with the data splitting method of subsampling, so for each model, 70% of the data was used for training and 30% percent for testing. The method of subsampling was selected to avoid the inclusion of the same records in both the training and test datasets. The model performance was evaluated according to the receiver-operating characteristic (ROC) curve (AUC) (Fielding and Bell, 1997), and true skill statistic (TSS) (Allouche et al., 2006). Both metrics are calculated via the proportion of “sensitivity” (correctly predicted presences) and “specificity” (correctly predicted absences). The AUC statistic is unsuitable for model evaluation in poorly sampled areas with no observed species absences, and it's been criticized for the imbalance between presences and pseudo-absences generated in presence-only studies (Pearson et al., 2007; van Proosdij et al., 2016). Since there was no *a priori* defined minimum number of sampling records in this study, the resulting sampling size with presences and observed absences is adequate enough to include both widespread and rare species, making AUC a suitable evaluation metric. TSS is a threshold-specific statistic with values > 0.4 indicating statistical significant model performance (Allouche et al., 2006). For variable importance assessment a randomization procedure that measures the correlation between the predicted values and predictions where the variable under investigation is randomly permuted is used according to Thuiller et al. (2009). Ensemble models were created based on a weighted averaging, i.e. weighted using the AUC statistic, and consisting only of high quality models according to the TSS and AUC evaluation metrics thresholds (i.e. TSS > 0.65, AUC > 0.8). All modeling and evaluation analyses were performed using the package “sdm” (Naimi and Araújo, 2016) implemented in R 3.3.2 program language (R Development Core Team, 2017).

### 3. Results

#### 3.1. Indicator species analysis

From the 123 sampling stations, chl *a* concentration beyond the limit of good ecological status was documented at 73, which were labeled with the “unacceptable” ecological status. The remaining 50 were assigned the “acceptable” ecological status (Fig. 1). Indicator species analysis showed a variety of species associated with the two groups of habitats. As can be seen in Table 2, the representative species for the sites with “acceptable” ecological status were characterized by common functional characteristics, i.e. epifaunal suspension-feeding species that are sensitive to environmental stressors. *Flexopecten hyalinus*, a soft-bottom macrobenthic bivalve, topped the analysis and was significantly associated ( $p < 0.007$ ) with the group of stations assigned with “acceptable” ecological status.

The community functional diversity regarding the sites classified as of “unacceptable” ecological status comprised species characterized as either tolerant to environmental disturbance or opportunistic meaning

a successful establishment at environmentally disturbed habitats. The indicator species for the group with the “unacceptable” ecological status was the bivalve *Corbula gibba*, an opportunistic species commonly found in disturbed or organically enriched habitats. The components of specificity and sensitivity present additional information regarding the ecological value of these species. More specifically, almost all the records of *F. hyalinus* are found in sites with “acceptable” ecological conditions (i.e., specificity = 0.9) although not all sites belonging to this group include the species (i.e., sensitivity = 0.14) (Fig. S2. Supplementary material). *C. gibba* occurs in almost all sites with environmental disturbance (specificity = 0.9) and showed a higher sensitivity (0.42) compared with *F. hyalinus* i.e., the species was recorded in almost half the “unacceptable” sites (Fig. S1. Supplementary material). The indicator value for *C. gibba* was higher than that for *F. hyalinus* (0.63 vs. 0.36), making it a suitable indicator for sites characterized with high chl *a* concentration. From the results derived from the Indicator species analysis, *C. gibba* and *F. hyalinus* were considered as species with significant ecological importance and therefore were used in SDM.

#### 3.2. Modeling

Ensemble model run success percentage per species was 100% for all modeling methods, with model performance results from test dataset within the threshold criteria (mean AUC  $\geq$  0.8, TSS  $\geq$  0.65), indicating good model performance (Table 3). Overall, salinity and chl *a* concentration were the most important predictors of the distribution of the two molluscan species in the Aegean and Ionian Seas (Table 3). Chl *a* was the most important environmental predictor in the model performance for *C. gibba*. Salinity was the second important variable affecting the distribution of this species whereas temperature had minimum impact. In contrast, salinity was the primary driver of the modeling performance for *F. hyalinus*. The habitat maps of the two species presented opposite patterns. The *C. gibba* model successfully predicted the occurrence of the species in relatively eutrophic areas validating as expected the indicative nature of the species regarding ecological disturbance. From the results of Fig. 2, the model predicts higher probability of occurrence in the north part of the Aegean Sea, decreasing progressively towards the south part, where it is restricted in all the main enclosed bays. In the Ionian Sea *C. gibba* habitat suitability model recorded high probability of occurrence in the inner part of Patraikos bay. The modeling results of *F. hyalinus* suggest that the species is more widespread in the southern part of the study in the Aegean Sea and throughout the islands of the Ionian Sea, indicating that the species occurs preferably in areas with limited primary productivity (Fig. 3). Overall, the habitat suitability map of *C. gibba* derived from SDM, reflected the “unacceptable” ecological conditions of these sites in terms of eutrophication levels indicating strong relationship of this species with chl *a* concentration. The modeling results showed that *F. hyalinus* occurs preferably in environmentally undisturbed areas (in this case limited primary productivity) affected by salinity concentration.

**Table 2**

Indicator Species Analysis results for two groups of sites of different ecological status (“Acceptable” and “Unacceptable”) based on chl *a* concentration. Diet category: Suspension Feeder (SF), Deposit Feeder (DF).

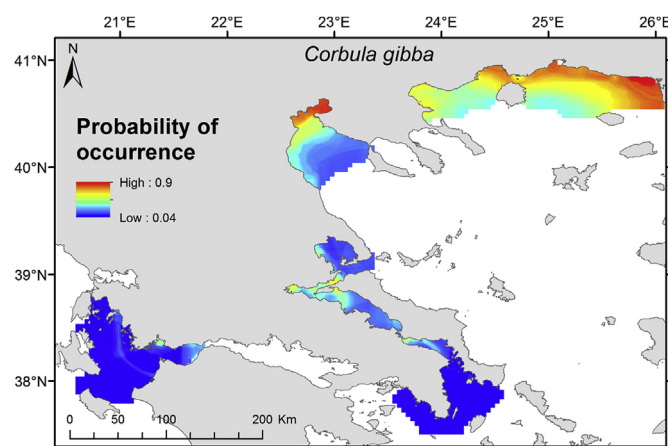
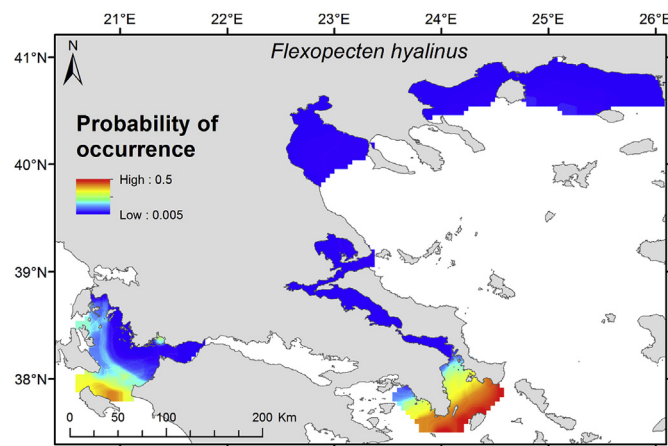
	Diet	Behavior	Bentix	Specificity	Sensitivity	Indicator Value	p.value
<b>Group: ACCEPTABLE</b>							
<i>Flexopecten hyalinus</i>	SF	Epifauna	Sensitive	0.90	0.14	0.36	0.007
<i>Limatula subauriculata</i>	SF	Epifauna	Sensitive	1.00	0.08	0.28	0.003
<b>Group: UNACCEPTABLE</b>							
<i>Corbula gibba</i>	SF	Burrower	Opportunistic	0.94	0.42	0.63	0.001
<i>Kurtiella bidentata</i>	SF	Epifauna	Tolerant	0.91	0.43	0.63	0.001
<i>Abra prismatica</i>	DF	Burrower	Tolerant	0.91	0.35	0.57	0.002



**Table 3**

Environmental predictor importance (mean of ten ensemble runs) for each species. Higher value means higher importance and value close to zero equals to no importance. Mean for area under the receiver operating characteristic curve (AUC) and True skill statistic (TSS) of 10 replicated runs for each model. Models: Generalized Linear Models (GLM), Generalized Additive Models (GAM), Boosted Regression Tree analysis (BRT) and Random Forest (RF).

Predictor importance			Evaluation measures			
Model	Species	lgchlomean	sbt	salinity	AUC	TSS
GLM	<i>G. gibba</i>	0.622	0.029	0.228	0.87	0.70
	<i>F. hyalinus</i>	0.392	0.295	0.744	0.89	0.81
GAM	<i>C. gibba</i>	0.472	0.344	0.509	0.9	0.73
	<i>F. hyalinus</i>	0.437	0.478	0.646	0.88	0.81
BRT	<i>C. gibba</i>	0.322	0.000	0.412	0.87	0.67
	<i>F. hyalinus</i>	0.113	0.168	0.458	0.89	0.79
RF	<i>C. gibba</i>	0.343	0.088	0.317	0.87	0.68
	<i>F. hyalinus</i>	0.223	0.178	0.319	0.81	0.72

**Fig. 2.** Habitat suitability map for *Corbula gibba*.**Fig. 3.** Habitat suitability map for *Flexopecten hyalinus*.

#### 4. Discussion

Our initial hypothesis that the distribution of the species associated the most with environmentally disturbed sites would be driven mainly by chl *a* concentration is met. In this study, the macrofaunal mollusk *C. gibba* was strongly associated with sites that were labeled with moderate, poor, or bad ecological status in terms of chl *a* concentration, which was the most important environmental factor in the modeling analysis affecting the distribution of this species. These results support those of a previous SDM study that addresses the importance of chl *a*

concentration as surrogate of food supply to suspension feeding mollusks and being regarded as the primary driver affecting their distribution (Rodil et al., 2014). Increased chl *a* concentration is often translated into increased food availability for primary consumers such as bivalves, which respond with an increase in abundance, biomass and assimilation efficiency. However, the net effects of nutrient enrichment depend on the balance between positive and negative effects on the ecosystem and resident species (Carmichael et al., 2012). This is more evident in suspension-feeding bivalves such as *C. gibba* and *F. hyalinus*, where, during foraging they filter phytoplankton, zooplankton, algae and other organic particles. In this study, *C. gibba* was found to respond to organic enrichment and high phytoplankton levels, with increased probability of occurrence in areas with elevated chl *a* concentration agreeing with Jensen (1990).

*C. gibba* is considered a species of high ecological importance due to its opportunistic nature and was reported to tolerate anthropogenic and natural disturbance, therefore it is an inhabitant of unstable environments (Hrs-Brenko, 2006). In this study, the habitat suitability of *C. gibba* was high in locations with environmental disturbance, such as relatively eutrophic areas (Fig. 2). Hydrographic conditions characterized with poor food availability and low temperature ( $\leq 12^\circ\text{C}$ ) affect the physiology of the bivalve *C. gibba*, by extending the larvae development period which may lead to low recruitment due to predation and stopping the growth in adult individuals (Hrs-Brenko, 2006). The increased chl *a* levels in the northern part of the study combined with an ideal temperature range that induces shell growth and larvae development create suitable habitat conditions for *C. gibba*. The high probability of occurrence in the northern Aegean Sea is explained by the hydrography that characterizes this marine region. The increased primary productivity in the northern Aegean Sea, where the highest probability of occurrence is found, is not only human-induced locally but also due to the riverine inputs, delta systems and the water inflow from the Black Sea through the Dardanelles Straits high in nutrient loads (Giannakourou et al., 2014; Ignatiades, 2005; Primpas and Karydis, 2011). As expected, the predicted habitat suitability map of *C. gibba* reflects the geographic extent of the stations with impoverished ecological status, as this bivalve is an indicator of environmental disturbance according to the Indicator Species Analysis conducted in this study. The dominance of *C. gibba* over other macrofaunal species in areas with organic enrichment such as enclosed bays is also supported by previous studies using this species as an indicator of environmental disturbance (Cavallini et al., 2005; Crema et al., 1991; Leshno et al., 2015; N'Siala et al., 2008; Solis-Weiss et al., 2004).

In this context, it may be concluded that the response of this bivalve to nutrient enrichment and increased primary productivity is predictable, which is an important requirement for an indicator species. Furthermore, the broad spatial distribution of the species, which extends to all European seas, makes it an ecological indicator applicable beyond the regional scale. It should also be noted that the characteristic asymmetric construction of the shell makes it easy to identify. The taxonomic identification of molluscan species is much easier and faster than any of the other macrobenthic taxa (Nerlović et al., 2011; Zenetos, 1996). Based on the above, it can be concluded that incorporating this species as a eutrophication biotic tool through SDM methods is accurate and time-efficient approach in marine habitat assessment.

The ecological importance of scallop *F. hyalinus* is presented in this study. Unlike *C. gibba*, which is found in almost all European seas, the distribution of *F. hyalinus* is limited to the Mediterranean Sea. Rare species that present a narrow ecological and geographic range are suitable candidates for SDM since model performance is significantly better compared to widespread species (Hernandez et al., 2006; van Proosdjij et al., 2016). Additionally, the SDM results of these species are more informative, as they reveal habitat-specific preferences. For *F. hyalinus*, the narrow spatial extent of the predicted habitat suitability reflected the habitat requirements of the species. High probability of occurrence was documented mainly in the southern part of the study in

the Aegean Sea and through the islands of the Ionian Sea (Fig. 3), an opposite distribution pattern to that of *C. gibba*. This outcome was expected as *F. hyalinus* is the indicator species of areas with “good” ecological status regarding the chl *a* levels, therefore, its habitat suitability map mirrors the spatial extent of these areas. In the case of *F. hyalinus*, salinity contributed the highest to the modeling performance agreeing with previous benthic SDM studies (Darr et al., 2014; Gogina and Zettler, 2010), where salinity outperformed other environmental predictors. The impact of salinity on benthic assemblages is well addressed in previous studies (Lucena-Moya et al., 2009; Sangiorgio et al., 2014; Whitfield et al., 2012), where it was found to induce variation in taxonomic richness, abundance and functional composition. *Flexopecten* species in particular are affected by hyposmotic stress as low salinity concentration affects the composition of the gills and the mantle of the bivalve (Telahigue et al., 2010). The distribution of *F. hyalinus* is affected by the spatial variability in salinity due to the well-defined gradient in the Aegean Sea (from North to South) resulting from the Black Sea water inflow from the Strait of Dardanelles. Salinity gradients have a strong effect on the benthic communities documenting decreased species richness and the overall impact is often paralleled with other environmental stressors such as marine anthropogenic activities (Zettler et al., 2007). In marine regions with minimum fluctuations in salinity, the benthic communities respond with increased species richness and consist mainly of species sensitive to disturbance. In the cases of Ionian Sea and south-central Aegean, the salinity levels remain constantly high compared to the northern Aegean as they are affected by different water masses that determine the hydrographic characteristics of these basins. The south-central Aegean is affected by the Levantine Surface Water (LSW), a saline water mass. LSW is the product of intense evaporation formed in the Levantine, with salinity values up to 39.20 psu during the summer months (Velaoras et al., 2013). Additionally, the Atlantic Water (AW) that flows from the Straits of Gibraltar enriches the Ionian and the south Aegean and elevates the salinity levels (Ciappa, 2014). Finally, the Levantine Intermediate Water (LIW), which is the net result of air-sea interactions in the entire Mediterranean, is a saline water mass affecting both Aegean and Ionian Sea. LIW is formed in the Levantine Sea during winter and sinks to a depth up to 500 m (Menna and Poulain, 2009). Therefore, these regions are constantly fueled by saline water masses in a way that the salinity levels are maintained relatively high throughout the year compared with other marine areas favoring the presence of *F. hyalinus* (Fig. S3A. Supplementary material).

The findings of this study imply that *F. hyalinus* occurs in areas with stable environmental conditions preferably characterized by limited primary productivity, agreeing with Çinar et al. (2015) that *F. hyalinus* is sensitive to environmental disturbance. Even though in our case, *F. hyalinus* was an indicator of locations assigned with “good” ecological status, its lower indicative power compared with *C. gibba* suggests that the species composition in undisturbed environments is more complex and determined by a variety of environmental factors. We didn't expect chl *a* concentration to be the main factor shaping the benthic community structure in the undisturbed areas of this study and this is more evident in the case of *F. hyalinus* as this species did not respond so effectively to increased food supply as *C. gibba*. Indicator species in areas with minimum environmental disturbance may differ among marine regions. In this study, the predicted habitat map of *F. hyalinus* derived from SDM reflected the good ecological status. We suggest the use of *F. hyalinus* in SDM methods as an indicator for environmental stability in the Mediterranean Sea. Due to the strong dependence on salinity, we assume that the incorporation of *F. hyalinus* in studies as a proxy for salinity fluctuations is also possible.

## 5. Conclusions

The habitat maps derived from SDM of the two indicator species used in this study reflected the overall ecological status in terms of chl *a*

concentration in the water column.

We advocate the use of the bivalve *C. gibba* as a proxy of eutrophication and as a biotic tool for marine health assessment and “early alert” protocols mainly because of the broad spatial distribution of the species, which extends in all the main European seas, the easiness of identification and the predictable response of this bivalve to nutrient enrichment and chl *a* concentration, which is an important requirement for an indicator species. In disturbed sites, there is high probability of occurrence for *C. gibba*, since the main driver of ecological change is increased levels of chl *a* concentration and the consequent increased sedimentation of organic material. On the other hand, undisturbed sites are likely to harbor a variety of benthic communities, depending on various habitat characteristics. Although *F. hyalinus* is a good candidate indicator species for such environments, it is likely that many different types of communities may occur in those sites mainly because of other environmental factors (such as salinity) besides chl *a* concentration. Based in the findings of this study, *F. hyalinus* could serve as an indicator of pristine marine areas and as a proxy for salinity fluctuations in the Mediterranean Sea.

Monitoring the health of the benthic ecosystem using benthic invertebrates as a biotic tool is an expensive and time consuming process and requires extensive taxonomic expertise. The workflow proposed in the present study aims to resolve these issues mainly because of these steps: 1) The use of presence and absence data instead of abundance makes the sampling processing faster, 2) Focusing on a limited number of benthic species instead of the entire community structure makes this approach easier for non-experts in taxonomy and 3) The use of online available marine environmental datasets with wide spatial coverage is a popular cost-efficient solution for environmental data collection.

We believe that focusing on specific benthic indicator species and using publicly available global marine environmental data in relevant SDM applications is a new and efficient way of marine habitat assessment.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.marenvres.2018.05.020>.

## References

- Allouche, O., Tsoar, A., Kadmon, R., 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *J. Appl. Ecol.* 43, 1223–1232. <https://doi.org/10.1111/j.1365-2664.2006.01214.x>.
- Appelqvist, C., Al-Hamdani, Z.K., Jonsson, P.R., Havenhand, J.N., 2015. Climate envelope modeling and dispersal simulations show little risk of range extension of the shipworm, *Teredo navalis* (L.), in the Baltic Sea. *PLoS One* 10, 1–16. <https://doi.org/10.1371/journal.pone.0119217>.
- Araújo, M.B., New, M., 2007. Ensemble forecasting of species distributions. *Trends Ecol. Evol.* 22, 42–47. <https://doi.org/10.1016/j.tree.2006.09.010>.
- Arvanitidis, C., Atzigeorgiou, G., Koutsoubas, D., Dounas, C., Eleftheriou, A., Koulouri, P., 2005. Mediterranean lagoons revisited: weakness and efficiency of the rapid biodiversity assessment techniques in a severely fluctuating environment. *Biodivers. Conserv.* 14, 2347–2359. <https://doi.org/10.1007/s10531-004-1668-x>.
- Borja, A., Franco, J., Pérez, V., 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Mar. Pollut. Bull.* 40, 1100–1114. [https://doi.org/10.1016/S0025-326X\(00\)00061-8](https://doi.org/10.1016/S0025-326X(00)00061-8).

- Carmichael, R.H., Shriver, A.C., Valiela, I., 2012. Bivalve response to estuarine eutrophication: the balance between enhanced food supply and habitat alterations. *J. Shellfish Res.* 31, 1–11. <https://doi.org/10.2983/035.031.0101>.
- Cavallini, F., Iotti, M., Simonini, R., 2005. Evoluzione dei popolamenti macro-zoobentonici dell'Adriatico Settentrionale. I. Analisi dei dati storici di Aristocle Vatova (1934–1936). *Atti della Soc. dei Nat. e Mat. di Modena* 2005 135, 145–154.
- Ciappa, A.C., 2014. The controversial path of atlantic water in the eastern mediterranean. *Prog. Oceanogr.* 123, 74–83. <https://doi.org/10.1016/j.pcean.2014.02.001>.
- Çinar, M.E., Bakır, K., Öztürk, B., Katağan, T., Dağlı, E., Açıık, Ş., Doğan, A., Bakır, B.B., 2015. TUBI (Turkish Benthic Index): a new biotic index for assessing impacts of organic pollution on benthic communities. *J. Black Sea/Mediterr. Environ.* 21, 135–168.
- Coelho, J.P., Duarte, A.C., Pardal, M.A., Pereira, M.E., 2014. Scrobicularia plana (Mollusca, Bivalvia) as a biomonitor for mercury contamination in Portuguese estuaries. *Ecol. Indic.* 46, 447–453. <https://doi.org/10.1016/j.ecolind.2014.07.015>.
- Crema, R., Castelli, A., Prevedelli, D., 1991. Long term eutrophication effects on macrofaunal communities in northern Adriatic Sea. *Mar. Pollut. Bull.* 22, 503–508. [https://doi.org/10.1016/0025-326X\(91\)90405-H](https://doi.org/10.1016/0025-326X(91)90405-H).
- Darr, A., Gogina, M., Zettler, M.L., 2014. Detecting hot-spots of bivalve biomass in the south-western Baltic Sea. *J. Mar. Syst.* 134, 69–80. <https://doi.org/10.1016/j.jmarsys.2014.03.003>.
- Dauvin, J.C., Ruellet, T., 2007. Polychaete/amphipod ratio revisited. *Mar. Pollut. Bull.* 55, 215–224. <https://doi.org/10.1016/j.marpolbul.2006.08.045>.
- de-la-Ossa-Carretero, J.A., Simboura, N., Del-Pilar-Ruso, Y., Pancucci-Papadopoulou, M.A., Giménez-Casaldueiro, F., Sánchez-Lizaso, J.L., 2012. A methodology for applying Taxonomic Sufficiency and benthic biotic indices in two Mediterranean areas. *Ecol. Indic.* 23, 232–241. <https://doi.org/10.1016/j.ecolind.2012.03.029>.
- De Cáceres, M., Legendre, P., 2009. Associations between species and groups of sites: indices and statistical inference. *Ecology* 90, 3566–3574. <https://doi.org/10.1890/08-1823.1>.
- De Cáceres, M., Legendre, P., Moretti, M., 2010. Improving indicator species analysis by combining groups of sites. *Oikos* 119, 1674–1684. <https://doi.org/10.1111/j.1600-0706.2010.18334.x>.
- Dimitriadis, C., Koutsoubas, D., 2008. Community properties of benthic molluscs as indicators of environmental stress induced by organic enrichment. *J. Nat. Hist.* 42, 559–574. <https://doi.org/10.1080/00222930701835530>.
- Dimitriou, P.D., Karakassis, I., Pitta, P., Tsagaraki, T.M., Apostolaki, E.T., Magiopoulos, I., Nikolioudakis, N., Diliberto, S., Theodorou, J.A., Tzovenis, I., Kagalogi, I., Beza, P., Tsapakis, M., 2015. Mussel farming in Maliakos Gulf and quality indicators of the marine environment: good benthic below poor pelagic ecological status. *Mar. Pollut. Bull.* 101, 784–793. <https://doi.org/10.1016/j.marpolbul.2015.09.035>.
- Dufrène, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Monogr.* 67, 345–366. <https://doi.org/10.2307/2963459>.
- EU, 2008. Directive 2008/56/EC of the European parliament and of the Council of 17 June 2008, establishing a framework for community action in the field of marine environmental policy (marine Strategy framework directive). *Off. J. Eur. Union* 2008 19–40.
- EU, 2000. Directive of the European Parliament and of the Council 2000/60/EC Establishing a Framework for Community Action in the Field of Water Policy. *PE-CONS 3639/1/00*.
- Fielding, A.H., Bell, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environ. Conserv.* 24, 38–49. <https://doi.org/10.1017/S0376892997000088>.
- Galanidi, M., Kaboglu, G., Bizsel, K.C., 2016. Predicting the composition of polychaete assemblages in the aegean coast of Turkey. *Front. Mar. Sci.* 3, 1–14. <https://doi.org/10.3389/fmars.2016.00154>.
- Gama, M., Crespo, D., Dolbeth, M., Anastácio, P., 2016. Predicting global habitat suitability for Corbicula fluminea using species distribution models: the importance of different environmental datasets. *Ecol. Modell.* 319, 163–169. <https://doi.org/10.1016/j.ecolmodel.2015.06.001>.
- Giannakourou, A., Tsiola, A., Kanellopoulou, M., Magiopoulos, I., Siokou, I., Pitta, P., 2014. Temporal variability of the microbial food web (viruses to ciliates) under the influence of the Black Sea Water inflow (N. Aegean, E. Mediterranean). *Mediterr. Mar. Sci.* 15, 769–780. <https://doi.org/10.12681/mms.1041>.
- Gogina, M., Zettler, M.L., 2010. Diversity and distribution of benthic macrofauna in the Baltic Sea: data inventory and its use for species distribution modelling and prediction. *J. Sea Res.* 64, 313–321. <https://doi.org/10.1016/j.seares.2010.04.005>.
- Gormley, K.S.G., Porter, J.S., Bell, M.C., Hull, A.D., Sanderson, W.G., 2013. Predictive habitat modelling as a tool to assess the change in distribution and extent of an OSPAR priority habitat under an increased ocean temperature scenario: Consequences for marine protected area networks and management. *PLoS One* 8, 1–16. <https://doi.org/10.1371/journal.pone.0068263>.
- Guisan, A., Broennimann, O., Engler, R., Vust, M., Yoccoz, N.G., Lehmann, A., Zimmermann, N.E., 2006. Using niche-based models to improve the sampling of rare species. *Conserv. Biol.* 20, 501–511. <https://doi.org/10.1111/j.1523-1739.2006.00354.x>.
- Hernandez, P.A., Graham, C., Master, L.L., Albert, D.L., 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography (Cop.)* 29, 773–785. <https://doi.org/10.1111/j.0906-7590.2006.04700.x>.
- Hrs-Brenko, M., 2006. The basket shell, Corbula gibba Olivi, 1792 (Bivalve Mollusks) as a species resistant to environmental disturbances: a review. *Acta Adriat.* 47, 49–64.
- Ignatiadis, L., 2005. Scaling the trophic status of the Aegean Sea, eastern mediterranean. *J. Sea Res.* 54, 51–57. <https://doi.org/10.1016/j.seares.2005.02.010>.
- Jensen, J.N., 1990. Increased abundance and growth of the suspension-feeding bivalve corbula gibba in a shallow part of the eutrophic Limfjord, Denmark. *Neth. J. Sea Res.* 27, 101–108. [https://doi.org/10.1016/0077-7579\(90\)90038-1](https://doi.org/10.1016/0077-7579(90)90038-1).
- Jones, M.C., Dye, S.R., Pinnegar, J.K., Warren, R., Cheung, W.W.L., 2013. Applying distribution model projections for an uncertain future: the case of the Pacific oyster in UK waters. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 23, 710–722. <https://doi.org/10.1002/aqc.2364>.
- Karydis, M., 1999. Evaluation Report on the Eutrophication Level in Coastal Greek Areas. University Of Aegean, Mytilini February 1999 (In Greek).
- Kaschner, K., Kesner-Reyes, K., Garilao, C., Rius-Barile, J., Rees, T., Froese, R., 2016. AquaMaps: Predicted Range Maps for Aquatic Species. World wide web electronic publication. [www.aquamaps.org](http://www.aquamaps.org) Version 08/2016.
- Kotta, J., Möller, T., Orav-Kotta, H., Pärnoja, M., 2014. Realized niche width of a brackish water submerged aquatic vegetation under current environmental conditions and projected influences of climate change. *Mar. Environ. Res.* 102, 88–101. <https://doi.org/10.1016/j.marenvres.2014.05.002>.
- Koutsoubas, D., Tselepidis, A., Eleftheriou, A., 2000. Deep sea molluscan fauna of the Cretan Sea (Eastern Mediterranean): faunal, ecological and zoogeographical remarks. *Senckenberg. Maritima* 30, 85–98. <https://doi.org/10.1007/BF03042958>.
- La Valle, P., Nicoletti, L., Foino, M.G., Arduzzone, G.D., 2011. Donax trunculus (Bivalvia: Donacidae) as a potential biological indicator of grain-size variations in beach sediment. *Ecol. Indic.* 11, 1426–1436. <https://doi.org/10.1016/j.ecolind.2011.03.005>.
- Leshno, Y., Benjamini, C., Edelman-Furstenberg, Y., 2015. Ecological quality assessment in the Eastern Mediterranean combining live and dead molluscan assemblages. *Mar. Pollut. Bull.* 104, 246–256. <https://doi.org/10.1016/j.marpolbul.2016.01.014>.
- López-Baucells, A., Casanova, L., Puig-Montserrat, X., Espinal, A., Páramo, F., Flaquer, C., 2017. Evaluating the use of Myotis daubentonii as an ecological indicator in Mediterranean riparian habitats. *Ecol. Indic.* 74, 19–27. <https://doi.org/10.1016/j.ecolind.2016.11.012>.
- Lucena-Moya, P., Pardo, I., Álvarez, M., 2009. Development of a typology for transitional waters in the Mediterranean ecoregion: the case of the islands. *Estuar. Coast. Shelf Sci.* 82, 61–72. <https://doi.org/10.1016/j.ecss.2008.12.011>.
- Mahmoud, N., Dellali, M., Bour, M. El, Aissa, P., Mahmoudi, E., 2010. The use of Fulvia fragilis (Mollusca: Cardidae) in the biomonitoring of Bizerta lagoon: a biomarkers approach. *Ecol. Indic.* 10, 696–702. <https://doi.org/10.1016/j.ecolind.2009.11.010>.
- McGeoch, M.A., Chown, S.L., 1998. Scaling up the value of bioindicators. *Trends Ecol. Evol.* 13, 46–47. [https://doi.org/10.1016/S0169-5347\(97\)01279-2](https://doi.org/10.1016/S0169-5347(97)01279-2).
- Menna, M., Poulin, P.M., 2009. Mediterranean subsurface circulation estimated from Argo data in 2003–2009. *Ocean Sci. Discuss.* 6, 2717–2753. <https://doi.org/10.5194/osd-6-2717-2009>.
- Moraitis, M., Papageorgiou, N., Dimitriou, P.D., Petrou, A., Karakassis, I., 2013. Effects of offshore tuna farming on benthic assemblages in the eastern mediterranean. *Aquat. Environ. Interact.* 4, 41–51.
- Muxika, I., Borja, A., Bald, J., 2007. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. *Mar. Pollut. Bull.* 55, 16–29. <https://doi.org/10.1016/j.marpolbul.2006.05.025>.
- Muxika, I., Borja, A., Bonne, W., 2005. The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. *Ecol. Indic.* 5, 19–31. <https://doi.org/10.1016/j.ecolind.2004.08.004>.
- N'Siala, G.M., Grandi, V., Iotti, M., Montanari, G., Prevedelli, D., Simonini, R., 2008. Responses of a Northern Adriatic Ampelisca-Corbula community to seasonality and short-term hydrological changes in the Po river. *Mar. Environ. Res.* 66, 466–476. <https://doi.org/10.1016/j.marenvres.2008.08.002>.
- Naimi, B., Araújo, M.B., 2016. Sdm: a reproducible and extensible R platform for species distribution modelling. *Ecography (Cop.)* 39, 368–375. <https://doi.org/10.1111/ecog.01881>.
- Nerlović, V., Doğan, A., Hrs-Brenko, M., 2011. Response to oxygen deficiency (depletion): bivalve assemblages as an indicator of ecosystem instability in the northern Adriatic Sea. *Biologia (Bratisl)* 66, 1114–1126. <https://doi.org/10.2478/s11756-011-0121-3>.
- Pagou, K., Siokou-Frangou, I., Papathanassiou, E., 2002. Nutrients and their ratios in relation to eutrophication and HAB occurrence. The case of Eastern Mediterranean coastal waters. In: Second Workshop on “Thresholds of Environmental Sustainability: The Case of Nutrients.” 18–19 June, Brussels, Belgium.
- Pearson, R.G., Raxworthy, C.J., Nakamura, M., Townsend Peterson, A., 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *J. Biogeogr.* 34, 102–117. <https://doi.org/10.1111/j.1365-2699.2006.01594.x>.
- Pearson, T., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Annu. Rev.* 16, 229–311.
- Primpas, I., Karydis, M., 2011. Scaling the trophic index (TRIX) in oligotrophic marine environments. *Environ. Monit. Assess.* 178. <https://doi.org/10.1007/s10661-010-1687-x>.
- R Development Core Team, 2017. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.r-project.org/> Version: 3.3.2.
- Raybaud, V., Beaugrand, G., Dewarumez, J.M., Luczak, C., 2014. Climate-induced range shifts of the American jackknife clam Ensis directus in Europe. *Biol. Invasions* 17, 725–741. <https://doi.org/10.1007/s10530-014-0764-4>.
- Reiss, H., Birchenough, S., Borja, A., Buhl-mortensen, L., Craeymeersch, J., Dannheim, J., Darr, A., Galparsoro, I., Gogina, M., Neumann, H., Populus, J., Rengstorf, A.M., Valle, M., Hoey, G. Van, Zettler, M.L., Degraer, S., 2015. Benthos distribution modelling and its relevance for marine ecosystem management. *ICES J. Mar. Sci.* 72, 297–315.
- Riul, P., Targino, C.H., Júnior, L.A.C., Creed, J.C., Horta, P.A., Costa, G.C., 2013. Invasive potential of the coral Tubastraea coccinea in the southwest Atlantic. *Mar. Ecol. Prog. Ser.* 480, 73–81. <https://doi.org/10.3354/meps10200>.



- Robinson, L.M., Elith, J., Hobday, A.J., Pearson, R.G., Kendall, B.E., Possingham, H.P., Richardson, A.J., 2011. Pushing the limits in marine species distribution modelling: lessons from the land present challenges and opportunities. *Glob. Ecol. Biogeogr.* 20, 789–802. <https://doi.org/10.1111/j.1466-8238.2010.00636.x>.
- Rodil, I.F., Compton, T.J., Lastra, M., 2014. Geographic variation in sandy beach macrofauna community and functional traits. *Estuar. Coast. Shelf Sci.* 150, 102–110. <https://doi.org/10.1016/j.ecss.2013.06.019>.
- Rosenberg, R., Blomqvist, M., C Nilsson, H., Cederwall, H., Dimming, A., 2004. Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. *Mar. Pollut. Bull.* 49, 728–739. <https://doi.org/10.1016/j.marpolbul.2004.05.013>.
- Russell, B.D., Connell, S.D., Mellin, C., Brook, B.W., Burnell, O.W., Fordham, D.A., 2012. Predicting the distribution of commercially important invertebrate stocks under future climate. *PLoS One* 7. <https://doi.org/10.1371/journal.pone.0046554>.
- Sangiorgio, F., Quintino, V., Rosati, I., Rodrigues, A.M., Pinna, M., Basset, A., 2014. Macrofauna in Mediterranean and Black Sea transitional aquatic ecosystems: a comparative study of the benthic populations sampled by box corer and leaf bags. *Ecol. Indic.* 38, 159–169. <https://doi.org/10.1016/j.ecolind.2013.10.009>.
- Saupe, E.E., Hendricks, J.R., Townsend Peterson, A., Lieberman, B.S., 2014. Climate change and marine molluscs of the western North Atlantic: future prospects and perils. *J. Biogeogr.* 41, 1352–1366. <https://doi.org/10.1111/jbi.12289>.
- Siddig, A.A.H., Ellison, A.M., Ochs, A., Villar-Leeman, C., Lau, M.K., 2016. How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in ecological indicators. *Ecol. Indic.* 60, 223–230. <https://doi.org/10.1016/j.ecolind.2015.06.036>.
- Simboura, N., Panayotidis, P., Papatthanassiou, E., 2005. A synthesis of the biological quality elements for the implementation of the European Water Framework Directive in the Mediterranean ecoregion: the case of Saronikos Gulf. *Ecol. Indic.* 5, 253–266. <https://doi.org/10.1016/j.ecolind.2005.03.006>.
- Simboura, N., Pavlidou, A., Bald, J., Tzapakis, M., Pagou, K., Zeri, C., Androni, A., Panayotidis, P., 2016. Response of ecological indices to nutrient and chemical contaminant stress factors in Eastern Mediterranean coastal waters. *Ecol. Indic.* 70, 89–105. <https://doi.org/10.1016/j.ecolind.2016.05.018>.
- Simboura, N., Zenetos, A., 2002. Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new Biotic Index. *Mediterr. Mar. Sci.* 3, 77–111. <https://doi.org/10.12681/mms.249>.
- Singer, A., Schüchel, U., Beck, M., Bleich, O., Brumsack, H.J., Freund, H., Geimecke, C., Lettmann, K.A., Millat, G., Staneva, J., Vanselow, A., Westphal, H., Wolff, J.O., Wurpts, A., Kröncke, I., 2016. Small-scale benthos distribution modelling in a North Sea tidal basin in response to climatic and environmental changes (1970s–2009). *Mar. Ecol. Prog. Ser.* 551, 13–30. <https://doi.org/10.3354/meps11756>.
- Solis-Weiss, V., Aleffi, F., Bettoso, N., Rossin, P., Orel, G., Fonda-Umani, S., 2004. Effects of industrial and urban pollution on the benthic macrofauna in the Bay of Muggia (industrial port of Trieste, Italy). *Sci. Total Environ.* 328, 247–263. <https://doi.org/10.1016/j.scitotenv.2004.01.027>.
- Spatharis, S., Tsiirtsis, G., 2010. Ecological quality scales based on phytoplankton for the implementation of water framework directive in the eastern mediterranean. *Ecol. Indic.* 10, 840–847. <https://doi.org/10.1016/j.ecolind.2010.01.005>.
- Telahigue, K., Rabeh, I., Chetoui, I., Romdhane, M.S., EL Cafsi, M., 2010. Effects of decreasing salinity on total lipids and fatty acids of mantle and gills in the bivalve *Flexopecten glaber* (Linnaeus, 1758) under starvation. *Cah. Biol. Mar.* 51, 301–309.
- Thuiller, W., Lafourcade, B., Engler, R., Araújo, M.B., 2009. BIOMOD - a platform for ensemble forecasting of species distributions. *Ecography (Cop.)* 32, 369–373. <https://doi.org/10.1111/j.1600-0587.2008.05742.x>.
- Townhill, B., Pinnegar, J., Tinker, J., Jones, M., Simpson, S., Stebbing, P., Dye, S., 2017. Non-native marine species in north-west Europe: developing an approach to assess future spread using regional downscaled climate projections. *Aquat. Conserv. Mar. Freshw. Ecosyst.* <https://doi.org/10.1002/aqc.2764>.
- Tyberghein, L., Verbruggen, H., Pauly, K., Troupin, C., Mineur, F., De Clerck, O., 2012. Bio-ORACLE: a global environmental dataset for marine species distribution modelling. *Glob. Ecol. Biogeogr.* 21, 272–281. <https://doi.org/10.1111/j.1466-8238.2011.00656.x>.
- Valentine, J.W., Jablonski, D., 2015. A twofold role for global energy gradients in marine biodiversity trends. *J. Biogeogr.* 42, 997–1005. <https://doi.org/10.1111/jbi.12515>.
- van Proosdij, A.S.J., Sosef, M.S.M., Wieringa, J.J., Raes, N., 2016. Minimum required number of specimen records to develop accurate species distribution models. *Ecography (Cop.)* 39, 542–552. <https://doi.org/10.1111/ecog.01509>.
- Vázquez-Luis, M., March, D., Alvarez, E., Alvarez-Berastegui, D., Deudero, S., 2014. Spatial distribution modelling of the endangered bivalve *Pinna nobilis* in a Marine Protected Area. *Mediterr. Mar. Sci.* 15. <https://doi.org/10.12681/mms.796>.
- Velaoras, D., Kassis, D., Perivoliotis, L., Pagonis, P., Hondronasios, A., Nittis, K., 2013. Temperature and salinity variability in the Greek seas based on POSEIDON stations time series: preliminary results. *Mediterr. Mar. Sci.* 14, 5–18. <https://doi.org/10.12681/mms.446>.
- Velez, C., Pires, A., Sampaio, L., Cardoso, P., Moreira, A., Leandro, S., Figueira, E., Soares, A.M.V.M., Freitas, R., 2016. The use of *Cerastoderma glaucum* as a sentinel and bioindicator species: take-home message. *Ecol. Indic.* 62, 228–241. <https://doi.org/10.1016/j.ecolind.2015.10.051>.
- Veloz, S.D., 2009. Spatially autocorrelated sampling falsely inflates measures of accuracy for presence-only niche models. *J. Biogeogr.* 36, 2290–2299. <https://doi.org/10.1111/j.1365-2699.2009.02174.x>.
- Whitfield, A.K., Elliott, M., Basset, A., Blaber, S.J.M., West, R.J., 2012. Paradigms in estuarine ecology – a review of the Remane diagram with a suggested revised model for estuaries. *Estuar. Coast. Shelf Sci.* 97, 78–90. <https://doi.org/10.1016/j.ecss.2011.11.026>.
- Zenetos, A., 1996. Classification and interpretation of the established mediterranean biocoenoses based solely on bivalve molluscs. *J. Mar. Biol. Assoc. U. K.* 76, 403–416. <https://doi.org/10.1017/S0025315400030630>.
- Zettler, M.L., Proffitt, C.E., Darr, A., Degraer, S., Devriese, L., Greathead, C., Kotta, J., Magni, P., Martin, G., Reiss, H., Speybroeck, J., Tagliapietra, D., Van Hoey, G., Ysebaert, T., 2013. On the myths of indicator species: issues and further consideration in the use of static concepts for ecological applications. *PLoS One* 8. <https://doi.org/10.1371/journal.pone.0078219>.
- Zettler, M.L., Schiedek, D., Bobertz, B., 2007. Benthic biodiversity indices versus salinity gradient in the southern Baltic Sea. *Mar. Pollut. Bull.* 55, 258–270. <https://doi.org/10.1016/j.marpolbul.2006.08.024>.