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# Understanding relationships between conflicting human uses and coastal ecosystems status: A geospatial modeling approach

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ABSTRACT

Human use of ecosystem resources and services is increasing worldwide, generating pressures that alter ecosystem structure, functioning and provision of services. Unexpected ecosystem change is becoming frequent, and the complex ways through which multiple human pressures may interact leave conservation practitioners and natural resource managers faced with high uncertainty. We developed a geospatial approach for modeling the complex relationships between multiple human pressures and coastal ecosystems status. This framework was then used to produce maps of the expected status of marine coastal ecosystems resulting from variation in the cumulative human pressure. The geospatial modeling approach we developed was tested on an emblematic study case requiring marine spatial planning, i.e. a recently established marine protected area (MPA) that will have to coexist with the expansion of a close commercial harbor. In the study case presented, our modeling approach was used to predict the status of coastal ecosystems resulting from different management alternatives. Results showed that should Port Authority support MPA in reducing human pressures in the area, coastal ecosystems would not be expected to further deteriorate as a consequence of harbor expansion. Our approach proved effective in modeling complex interaction among multiple pressures (e.g. synergisms) and predicting potential future scenarios. The implementation of this approach into geographical information systems (GIS) allows managers to represent the expected outcomes of their planned conservation efforts, thereby representing an important decision-support tool for finding efficient management solutions in the face of complex interactions and high uncertainty.

## 1. Introduction

Marine ecosystems are challenged worldwide by a vast set of potentially interacting human uses. The human 'footprint' on the oceans is so pervasive that many scientists have proposed that no ocean region can still be considered pristine (Jackson and Sala, 2001; Stachowitsch, 2003; Halpern et al., 2008b). Human influence is particularly profound in coastal ecosystems (Vitousek et al., 1997; Halpern et al., 2008b). Here, conflicting human uses generate multiple pressures that act simultaneously often producing unexpected ecosystem responses (Crain et al., 2008; Darling and Côté, 2008; Doak et al., 2008; Halpern et al., 2008a).

The recognition of the necessity for increased marine conservation has motivated a worldwide establishment of marine protected areas (hereafter MPAs). Despite playing a pivotal role in marine ecosystem protection, MPAs may not be sufficient alone (Agardy, 1994; Montefalcone et al., 2009). Globally, MPAs rarely cover an adequate extent and representation of different ecosystems and in most cases are too small to protect adequate portions of habitats and populations (Mora et al., 2006). Moreover, MPAs do not address the multiplicity of human pressures along coastal zones and cannot prevent the impacts of coastal pollution or the expansion of invasive species (Agardy, 1994; Halpern, 2003). For these reasons, recent conservation literature calls for the implementation of ecosystem-based-management (hereafter EBM) emphasizing that multiple pressures have to be explicitly accounted and addressed in comprehensive, spatially explicit management plan (Ruckelshaus et al., 2008; Thrush and Dayton, 2010).

Human pressures and coastal ecosystems have, by definition, a spatial component. This is why cartography is traditionally considered essential for the analysis and management of natural environments (White et al., 1992; Bock et al., 2005). In the marine environment, however, cartography is less developed and less frequently applied compared to the land because of the

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reluctance to consider the sea as a ‘territory’ and the evident operational difficulties involved (Bianchi et al., 2004). Early approaches emphasized the need to integrate ‘naturalistic’ maps with ‘socio-economic’ maps for coastal zone management (Bianchi and Zattera, 1986). Modern tools for spatially-explicit planning stem from the long-standing cartographic tradition and use in environmental management and are viewed as fundamental for implementing EBM (Stelzenmuller et al., 2010a). Understanding the relationships between multiple human pressures and the status of ecosystems is crucial to develop spatial plans whose main goal is the cartographic visualization of the results of different management alternatives (Douvere, 2008).

Yet, understanding the relationships between multiple human activities and the status of ecosystems is difficult for two main reasons: (1) multiple pressures may interact in complex non-additive manners (Shears and Ross, 2010) and (2) spatial information on both ecosystem status and potential sources of impact is scarce (Halpern et al., 2008a; Fraschetti et al., 2009).

While disentangling complex interactions among multiple pressures (e.g. non-additive behaviors) can be effectively done in factorial experiments manipulating stressors both separately and in combination (Crain et al., 2008), this remains challenging in the real world, where pressures are typically more than two and their direct manipulation is often unfeasible. However, such information is needed and represents the base-knowledge to implement EBM (Thrush et al., 2008). In the real world, scientists are faced with a suite of information gaps and statistical challenges, including missing data, lack of normally distributed variables and with spatial correlation among different human pressures. Flexible approaches and modeling tools capable to highlight multiple stressors interaction and to cope with uncertainty are necessary to implement spatial plans; waiting for the ideal conditions to understand pressures/status relationships is a luxury that marine ecosystems and their managers can hardly afford (Parravicini et al., 2010).

In spite of the objective difficulties mentioned above, information on human pressures distribution by means of surrogates (e.g. presence/absence of relevant human activities or weighted distance from these activities) have been successfully used to mapping potential risks of human impact (Eastwood et al., 2007; Petrosillo et al., 2010; Stelzenmuller et al., 2010b; Mensa et al., 2011). In addition, gaps of knowledge of coastal ecosystem status are being, at least in part, filled by the huge amount of data made available by national and international initiatives (e.g. the Water Framework Directive and the Marine Strategy Directive of the European Union, and the Clean Water Act in the USA). All these instruments require the adoption of appropriate monitoring plans aimed at assessing ecosystems status through ecological indicators (Olsson et al., 2008; Hering et al., 2010).

We developed and tested a spatially-explicit and flexible modeling approach to quantifying and visually representing interactions between a suite of human pressures and the status of different ecosystem types across intensely-utilized coastal seascapes. Here, we use this approach to visualize the expected outcomes of alternative management scenarios for an emblematic case study from coastal Italy: a coastal zone where a newly established marine protected area will have to coexist with the planned extension of a close commercial harbor.

## 2. Methods

### 2.1. Conceptual framework

The primary goal of marine spatial planning is assessing the effects of different management alternatives on the state of coastal ecosystems (Douvere, 2008). Most techniques developed in this field are based on expert-judgment surveys or literature reviews. Both methods are used to assess the vulnerability of different habitats to selected human pressures (Selkoe et al., 2009; De Lange et al., 2010). If the spatial distribution of both marine habitats and human pressures is known, then a measure representing the potential risk of impact can be computed and represented on maps, thereby helping identify the most efficient management solution, i.e. the one capable to minimize the risk of impact (Halpern et al., 2009; Stelzenmuller et al., 2010b). These approaches have the invaluable advantage that spatial plans can be implemented when data on ecosystem status are missing or scarce, e.g. over large scales allowing a synoptic view of the territory to be managed (Bianchi, 2008). The main drawback of such approaches, however, is that multiple pressures are generally assumed arbitrarily to play additively (Halpern et al., 2009). This is a limitation when considering that almost three-quarters of studies on multiple pressures effects detected significant non-additive interactions (Crain et al., 2008; Darling and Côté, 2008). Without using data on ecosystem status, in fact, expert- or literature-based techniques can hardly detect and understand the complex interactions that may exist among pressures (e.g. synergisms or antagonisms). In addition, these behaviors are spatially variable and extremely site-specific, making it difficult, if not impossible, to extrapolate general rules to be used *a priori* over vast spatial scales (Crain et al., 2008).

Considering field data, our approach enables the modeling of the relationships between multiple pressures and ecosystem status and to use such information to predict the results of different management alternatives. The geospatial modeling tool presented comprises four main steps: (1) the GIS (geographical information system) mapping of human pressures and their intensities, (2) the GIS mapping of marine ecosystem status, (3) the modeling of the relationships between human pressures distribution and marine ecosystem status, (4) the use of the model calibrated in the step (3) to build maps of expected ecosystem status according to different management alternatives – i.e. expected or planned variations in human pressures distribution and intensities (Fig. 1). Within the framework of this geospatial approach, once a efficient solution is found, appropriate monitoring plans must be implemented to allow for future more accurate calibration of the model.

### 2.2. Study area and field data

We applied our geospatial modeling approach to the coastal zone surrounding the “Isola di Bergeggi” MPA, established in 2007 and located in the Ligurian Sea, NW Mediterranean (Fig. 2). This study case is emblematic of the importance that marine spatial planning and EBM may represent for conservation. The area is embedded within a human-dominated landscape, characterized by a twofold scenario of economic exploitation of the marine environment: westbound the area borders with the tourist center of Spotorno, eastbound with the commercial harbor of Vado Ligure. Although they are currently protected, the coastal ecosystems of the Bergeggi MPA pay the legacy of various past and ongoing human uses such as finfish fishing, date-mussels harvesting, coastal urbanization, SCUBA diving and anchoring (Parravicini et al., 2006, 2008, 2009; Montefalcone et al., 2009, 2010). In addition, the MPA is bordered by two large beaches, one of which was created *ex novo* between 1969 and 1971 (Fierro et al., 1975), and is maintained through almost annual nourishments. The area is an important tourist destination and, despite the presence of the commercial harbor nearby, belongs to the best water quality class according to WFD (water framework directive) standards (Asnaghi et al., 2009). Other protection measures include the presence of one SCI (site of community importance) whose management plan, implemented in 2009, prohibits anchoring and further coastal development within its boundaries. The MPA comprises three

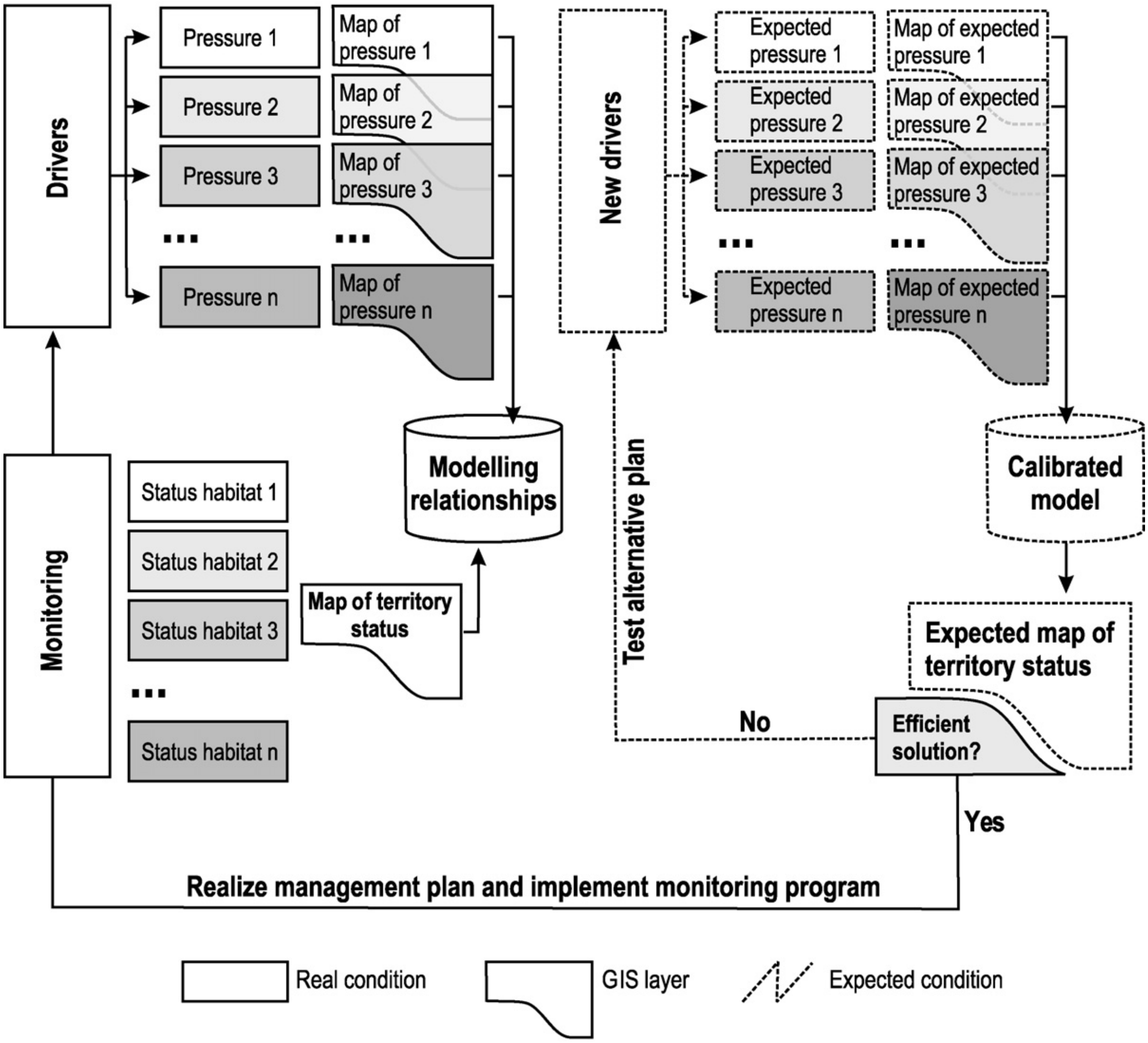

**Fig. 1.** Conceptual diagram of the steps used to develop the geospatial modeling approach presented. The approach comprises four main steps: (1) mapping human uses and their intensities, (2) mapping marine territory status, (3) modeling the relationships between human uses distribution and marine territory status, (4) use of the model calibrated in the step (3) to build maps of expected territory status according to different management alternatives – i.e. expected or planned variations in human uses distribution and/or intensities.

distinct zones: (1) a “no-take” zone in which SCUBA diving and tourist access are the only activities allowed (A zone); (2) two partial reserve zones in which anchoring is forbidden and fishing is allowed only for local residents (B zone); (3) a buffer zone in which anchoring is forbidden and fishing is allowed for local residents and tourists after being authorized (C zone).

In this environmental context, the extension of the Vado Ligure commercial harbor has been planned to start in 2011, and there is an urgent need to: (1) quantify the expected impact of the extended harbor on the MPA and (2) understanding whether the present management plan by the MPA will be able to maintain current ecosystem condition or even allow for ecosystem recovery from past impacts. The planned harbor expansion will consist in the construction of a multipurpose platform of 700 m in length and a surface of 200,000 $m^2$. The structure will lead to a conspicuous increment in ship traffic (i.e. the number of containers per year is foreseen to increase by an order of magnitude by 2020; from ca. $10^5$ containers at present per year up to ca. $10^6$ containers by 2020).

Information about marine ecosystems in the study areas was scarce, and limited to soft bottoms and seagrass meadows. The former had been studied by a combination of towed underwater video-camera surveys and Van Veen grab samples (Somaschini et al., 1998), the latter by side scan sonar and remotely operated vehicle (Bianchi and Peirano, 1995). To enhance and complement pre-existing knowledge, we conducted field studies in 2004 and 2005, a few years before the establishment of the MPA and the implementation of SCIs. Direct observations by SCUBA diving were conducted to assess the present status of soft bottoms and seagrass meadows, and especially to fulfill the gap of information on rocky reef habitats (see Rovere et al., 2010 for details on field activities). Maps of benthic habitats and their status were produced (Bianchi et al., 2007), thereby providing a description of the marine seascape status before protection was implemented.

### 2.3. *Maps of pressure*

The map of the study area was divided into parcels of 250 $m^2$ each (for a total of 480 parcels) and for each parcel we quantified the intensity of each human pressure acting in the study area applying a modeling framework that considers, for each parcel, the types of pressure present and the distance from their sources (as a proxy of pressure intensity abatement). The size of parcels (250 $m^2$) was chosen because it represents a good compromise between

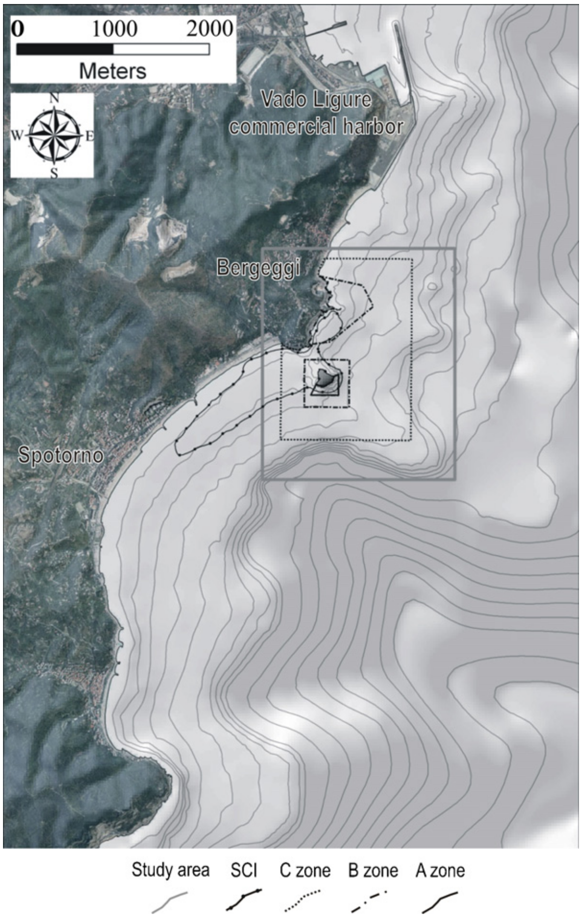

**Fig. 2.** Environmental context in which the study area is located. Although being protected, the MPA (established in 2007) borders westbound with the tourist center of Spotorno and eastbound with the commercial harbor of Vado Ligure, which extension consists in the building of a multi-purpose platform, planned to start in 2011.

resolution and availability of information on pressures and ecosystems. Eight different pressures were considered: anchoring, commercial harbor, storm drain pipes, coastal outfalls, urbanization, SCUBA diving, beach nourishment and fishing.

The assessment of the intensity of each pressure at its source was obtained by eliciting 12 experts who were selected based on their knowledge of the study area and the planned extension of the commercial harbor. All the experts were environmental scientists with direct experience on the area and knowledge of the official technical document on the harbor extension provided by the port Authority. Experts were asked to give a score of intensity for the selected human pressures by means of a 7-point scale.

The quantification of the intensity of each human pressure on marine territory parcels was then obtained considering its assessment as a problem of decision theory where a decision-maker has to find efficient solutions depending on a certain finite number of criteria (i.e. in our case experts evaluations). Following Chen (2000) a multi criteria decision making (MCDM) problem can be concisely expressed in matrix form as:

$$D = \begin{array}{cc} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \cdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \end{array} \qquad W = \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_m \end{bmatrix}$$

In our case, decision (D) is the determination of the intensity of a given pressure acting on the marine territory where, $A_1, A_2, \ldots, A_m$ represent the parcels of marine territory and $C_1, C_2, \ldots, C_n$ (i.e. criteria) are the intensities of each considered pressure at its source according to the different evaluation of the elicited experts. The final scores obtained were then multiplied by $W$, i.e. a weighting factor that is the inverse of the distance of each parcel from the source of each pressure. For simplicity, the weights were chosen taking into consideration a linearly decreasing influence of human activities with space and a maximum influence spreading of 10 km according to the practice of ICZM (Lau, 2005), except for pressures considered punctual (e.g. SCUBA diving, fishing), in which case the pressure was considered extinguished in 100 m.

The aim was to aggregate all the information here reported in matrix form into a comprehensive map of pressures. We applied the fuzzy extension of the TOPSIS (technique for order preference by similarity to an ideal solution) method for MCDM. The detailed procedure and calculations are reported in Chen (2000). The fuzzy extension of the TOPSIS method was used because it incorporates the multiplicity of expert evaluations solving the MCDM problem under a fuzzy environment.

### 2.4. *Map of marine territory status*

To quantify marine territory status, we divided the map of marine habitats into the same number of parcels of 250 m$^2$ used for the maps of pressure. Within each parcel, we computed an index of status for each habitat inspired by the methodology proposed by Bellan et al. (1985) and similarly to what is done to assess quality status according to the WFD (Rosenberg et al., 2004). Thus, the following scores, which represent the distance of a habitat from its reference, unperturbed condition, were attributed to each habitat within each parcel: 1, when the observed habitat is not different in term of structure and taxonomic composition from reference conditions; 2, when it exhibits high abundances of stress-indicator species and/or invaders without, however, drastic changes in community composition; 3, when a severe reduction in species richness occurs; and 4, when no affinity with reference conditions is still detectable. Historical descriptions of Mediterranean marine habitats were used as reference conditions (Pérès and Picard, 1964; Augier, 1982). The index of the status of the marine territory was calculated by averaging the scores of the habitats present in each parcel and was later standardized and mapped through GIS. Since the index represents the distance from reference conditions, high scores of the marine territory status index correspond to degradation while low values correspond to a healthy condition.

### 2.5. *Modeling relationships*

The information contained in the two types of maps was used to model the relationships between coastal ecosystems status and the spatial distribution of human pressures. The same model was then used to quantify the expected effects of the expanded harbor on the MPA and to test whether the present management plan by MPA and SCI will be enough to cope with the increased human pressure or whether further consultation between the MPA and the Port Authority is needed to define a reasonable strategy to balance conservation needs and commercial interests.

As mentioned above (see Section 1), ecological data often show nonlinear and complex interactions among variables so that traditional statistical methods based on linear models can be inadequate for analyzing such data (De'ath and Fabricius, 2000; Grenier et al., 2010). For this reason, to model the relationships between seascape status and human activities, we used Random Forests, hereafter RF (Breiman, 2001). RF is a machine learning based approach that consists of models in which multiple classification or regression trees are fitted to the data and their predictions are combined in a final result. RF has been shown more effective in building predictions than other commonly used techniques such as regression models (Cutler et al., 2007). In addition, RF is capable to highlight complex interactions and to handle non parametric data, collinear predictors and missing values (Siroky, 2009).

In the present paper, RF was built using 120 regression trees to model the relationships between the marine territory status score and the scores of each human use. The number of trees was chosen after testing the number required to minimize prediction errors expressed as “out of the bag” errors (Siroky, 2009). RF was made spatially-explicit by appropriate weighting obtained by a geospatial variogram (Bel et al., 2009). The accuracy of the model was then evaluated by calculating the Pearson correlation coefficient between the observed status scores and those predicted by the model. To rank the priorities for protection, the importance of each human use in altering the marine territory status was computed (Cutler et al., 2007). In RF, the importance of a predictor variable is measured by comparing the accuracy of the predictions by the model using the original variable with the accuracy of the same model using a randomly permuted variable (Siroky, 2009). The effect of each human use on marine territory status was then visualized through univariate partial dependence plots, whereas potential interactions were visually assessed through bivariate partial dependence plots (Liaw and Wiener, 2002).

### 2.6. Scenarios building and representation

In order to visualize the effects of harbor expansion on the MPA, four scenarios were developed by eliciting experts’ judgment.

Experts were asked to quantify: (1) expected intensity of the harbor pressure after its expansion; (2) intensity of the pressures regulated by the present management plan of the MPA and SCI (i.e. anchoring, fishing, SCUBA diving); (3) expected intensity of pressures in the event that the Port Authority will solve conflicts with stakeholders allowing MPA manager to minimize human pressures in the area. The latter effort was defined as follow: (1) beach re-nourishments are no longer performed; (2) fishing is completely forbidden within the no-take zone and the partial reserve zone and allowed only to residents within the buffer zone; (3) the SCI boundaries are extended to the whole area, implying the complete prohibition of anchoring.

In the case of the expected impact of the harbor after its expansion, both the maximum and the minimum values of impact obtained via experts elicitation were considered in order to verify the model sensitivity to potential errors made by experts in the quantification of the expected influence of this particular pressure.

Then, the following four scenarios and the relative maps of the expected status of the marine territory were built:

- **Scenario O-ME**: the optimistic condition (O) in which the influence of the extended harbor will be the minimum expected by the experts, and the Port Authority will do its maximum effort (ME) in sustaining MPA to reduce human pressure in the area
- **Scenario O-DN**: the optimistic condition (O) in which the influence of the extended harbor will be the minimum expected by the experts, and MPA will maintain the present management plan (do nothing, DN)
- **Scenario P-ME**: the pessimistic condition (P) in which the influence of the extended harbor will be the maximum expected by the experts, and the Port Authority will do its maximum effort (ME) in sustaining MPA to reduce human pressure in the area
- **Scenario P-DN**: the pessimistic condition (P) in which the influence of the extended harbor will be the maximum expected by the experts, and MPA will maintain the present management plan (do nothing, DN)

The relationships between the seascape status predicted by the model under the four scenarios were assessed by computing the Pearson correlation coefficient.

## 3. Results

### 3.1. Map of pressures

Maps of human pressure intensity displayed different patterns of potential influence on the coastal area (Fig. 3). Some pressures influenced specific areas with few parcels presenting very high intensity arranged in well-recognizable spots (anchoring, SCUBA diving, beach re-nourishment and fishery). In contrast, pressures due to other coastal activities (mainly urbanization and outlets) affected a wide coastal area by impacting a vast set of parcels, albeit with different intensities.

Most of the considered pressures acted with the maximum intensity within the Bergeggi MPA borders, indicating a number of possible threats to the conservation of the habitats under protection.

### 3.2. Map of marine territory status

The map of the marine territory status highlighted evident signs of habitat degradation (Fig. 4). In particular, parcels close to the coastline, where most of the human pressure are acting, exhibited high scores (i.e. unhealthy conditions). A better picture emerges when looking at the parcels far from the coastline (Fig. 4).

### 3.3. Pressures/status relationships

The status of the marine territory predicted by the model was almost identical to the status quantified through direct surveys (Pearson $r = 0.97$ when testing the relationship between observed and predicted territory status).

The most important human pressures impacting the marine territory were: urbanization of the coastline, fishery and the presence of the commercial harbor. The other pressures had a smaller role in deteriorating the marine territory (Fig. 5). The univariate partial dependence plots for the three most important pressures showed that urbanization and the commercial harbor had an evident threshold effect on the marine territory status (Fig. 6). On the contrary, the relationship found between fishery and the marine territory status showed a marked tendency to increase even at low intensities indicating that low fishing pressure is capable to have noticeable effects.

Bivariate partial dependence plots obtained between each pair of the human pressures considered showed that almost all couples of pressures tended to interact mainly additively (see for example Fig. 7a). The only evident multiplicative effect was the clear synergistic interaction between beach re-nourishment and the commercial harbor (Fig. 7b).

### 3.4. Predicted scenarios

The main outcome from the maps of the four scenarios is that the Port Authority, if capable to solve conflicts with stakeholders in order to minimize human pressures in the area, may have an active role in guaranteeing conservation (Fig. 8). Considering either the maximum or the minimum expected intensities of the extended harbor, scenarios that envisage a strong effort by the Port Authority to sustain the MPA are markedly different from the parallel do-nothing scenarios. In the case that the commercial harbor will have the minimum intensity expected by experts, the overall status of the marine territory will result ameliorated by active management. However, even in this optimistic case, the marine territory status

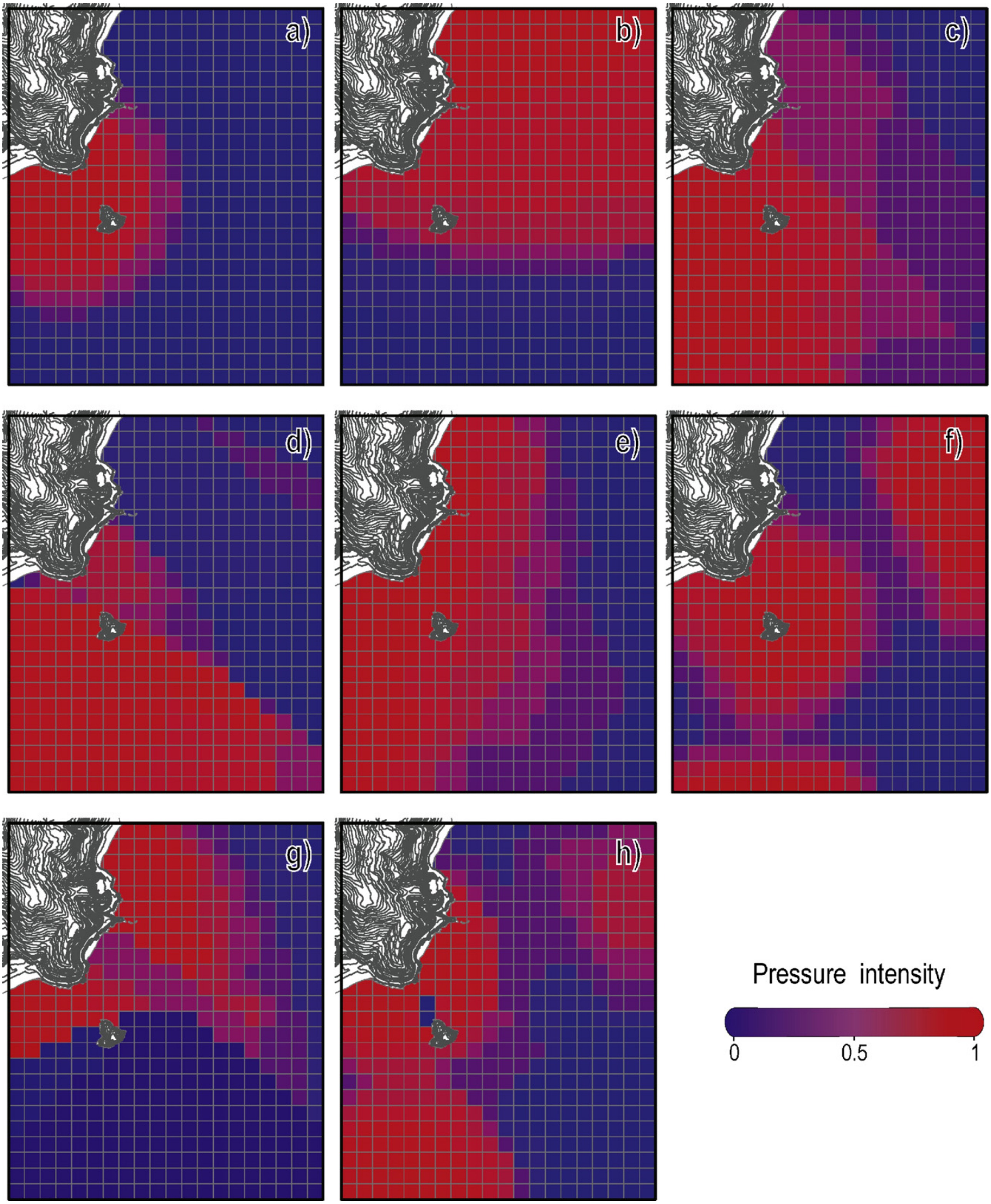

**Fig. 3.** Maps of human use intensity obtained for the following selected pressures: (a) anchoring, (b) commercial harbor, (c) pipe outlets; (d) coastal outfalls, (e) urbanization, (f) SCUBA diving activity, (g) beach re-nourishment, (h) fishery.

will show extensive portions with high scores (i.e. no affinities with reference conditions), especially along the coastline. Using either the minimum or the maximum expected intensity of the extended commercial harbor did not profoundly affect the outcomes of the model, thus highlighting that territory status predictions are robust to possible errors made by the elicited experts (Fig. 9).

## 4. Discussion

This study aimed to develop a standardized framework allowing scientists and managers to compare the results of different management alternatives on marine ecosystems status. This is crucial for implementing EBM that is expected to provide managers with

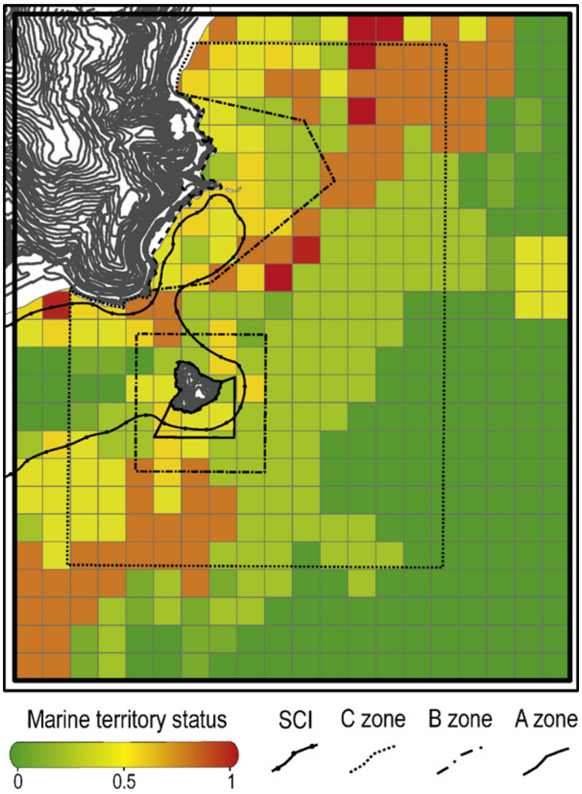

**Fig. 4.** Map of the marine territory status obtained by field data collected through direct surveys.

valuable instruments to reduce uncertainty, the risk of ecological surprises and the consequent risk of failing to achieve conservation goals (Doak et al., 2008). The implementation of our modeling approach into a geospatial environment allows not only to predict but also to visually represent the results of different practices upon seascapes that managers are entrusted by society to protect. This aspect is important to help policy in solving the dilemma of finding the appropriate balance between conservation and use of natural resources (Thrush and Dayton, 2010). In this study, the Port Authority effort to support the MPA in reducing fishery, beach nourishment and anchoring within its boundaries is expected to represent a good balance between the exploitation of the area and its conservation. In this regard, the visual representation of the expected effect by different management alternatives will facilitate the consultation process between the MPA and the Port Authority that is needed to achieve the goal of a win-win strategy.

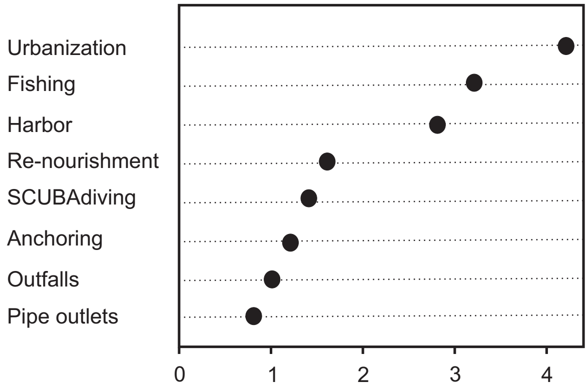

**Fig. 5.** Importance of the explanatory variables (pressures) used in the models in shaping the status of the marine territory. Importance is quantified as the mean decrease of accuracy of the RF model when each explanatory variable is removed.

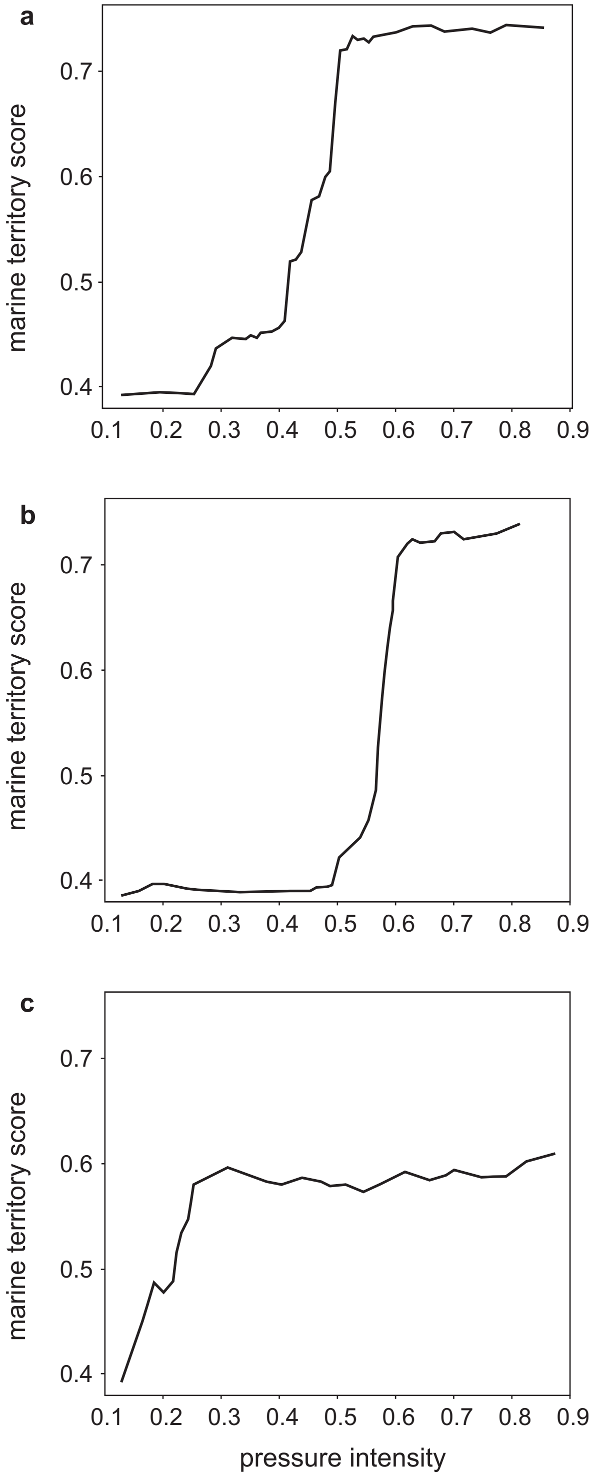

**Fig. 6.** Univariate partial dependence plots of the three most important pressures in the study area: (a) urbanization, (b) harbor and (c) fishery.

Although many studies on the implementation of spatial planning in the marine realm are mainly conceptual (e.g. Gilliland and Laffoley, 2008), applied examples do exist (Ball et al., 2009; Halpern et al., 2009; Stelzenmuller et al., 2010b). These examples used mapping of potential pressures and assessment of the potential risk of impact by eliciting experts to quantify the vulnerability of dif-

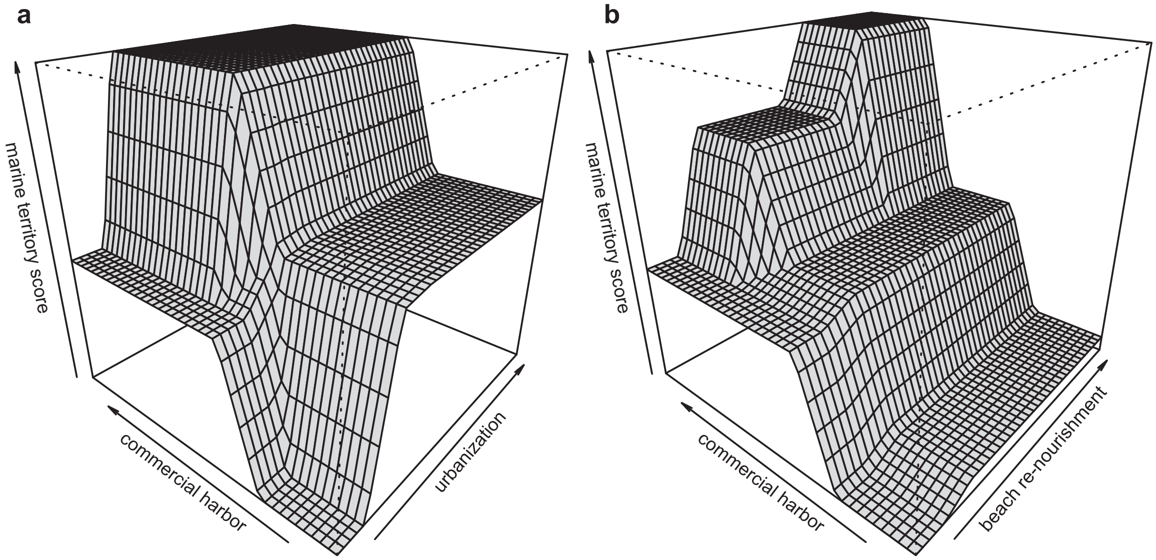

**Fig. 7.** Examples of bivariate partial dependence plots showing the interaction between pressure intensities: (a) commercial harbor and coastal urbanization (i.e. additive effect), and (b) commercial harbor and beach re-nourishment (i.e. synergic multiplicative effect).

ferent habitats to specific pressures. Such an approach has a high potential since it can be applied over large scales and is, therefore, absolutely necessary for the planning of marine territory uses. Moving from planning to decision, however, requires information on how multiple human pressures interact (Lenz and Peters, 2006). Human pressures can interact additively, synergistically, antagonistically and these behaviors are extremely context dependent (Crain et al., 2008). The only way to detect such interactions in the real world is to model pressures/effects relationships (Thrush et al., 2008). With expert- or literature-based approaches, the way through which multiple human pressures interact is chosen *a priori*. This is why we introduced modeling in our geospatial approach. Expert knowledge was in fact used to quantify the intensity of different pressures, process in which the knowledge by environmental scientists resulted important.

When modeling relationships, RF technique resulted particularly efficient. RF is based on multiple individual classification and regression trees (CART), already successfully used for environmental mapping and management (Pesch et al., 2011). CART stems from techniques called automatic interaction detectors (AID) and are particularly appropriate in identifying and modeling complex interactions among multiple human pressures (Loh, 2008). Moreover, RF handles the common problem of collinearity among predictor variables through their random selection when building individual trees and are not challenged by response variables not filling the assumption of normality (Siroky, 2009). Another advantage is that RF can be applied using categorical response variables (Cutler et al., 2007). This is an important aspect because most ecosystem-status indicators are categorized into classes (e.g. indicators used by the WFD). Our approach allows status or quality classes to be modeled and predicted according to different management alternatives without the need of recovering the original numerical information or when using indicators that are *a priori* categorical (e.g. Orfanidis et al., 2003). In addition, RF can be applied to multivariate datasets and may be thus particular useful in the case that different indicators are utilized to assess the status of different components of coastal ecosystem as in the case of the European WFD (Borja et al., 2009).

While the knowledge of the status/pressures relationships may reduce the uncertainty that managers have to face when taking decision (Polasky et al., 2011), the accuracy through which such relationships are assessed strongly depends on the amount of available information. In this regard, a strong effort is being spent by national and international monitoring programs aimed at evaluating coastal ecosystems status (Douvere et al., 2007; Olsson et al., 2008; Hering et al., 2010). These data can be rationally organized within the framework of our geospatial modeling approach in order to extract the maximum amount of information for conservation managers.

The availability of field data to implement our approach, however, remains a necessity. While our tool demonstrated to be effective in predicting scenarios of marine territory status resulting from variations in the intensities of existing pressures, such an approach cannot predict the expected effects of “new” and unknown pressures. Large scales assessments may partially overcome such limitation by reducing the number of the unknown pressure/status relationships. However, a major future need will be that of integrating geospatial approach based on field data and modeling with systems based on expert judgment. While models can inform on the way through which multiple pressures interact, expert elicitation may reduce uncertainty when the effects of new pressures are to be taken into account. In this regard, the integration of the information made available by our geospatial modeling approach and experts may be possible within networks that are capable to probabilistically represent correlative and causal relationships among variables (Stelzenmuller et al., 2010a).

Despite efforts made by ecologists to develop techniques and approaches to provide tools to assist conservation managers' decisions, some degrees of uncertainty remain (Thrush and Dayton, 2010). For instance, all existing approaches will tend to predict an amelioration of ecosystems status when management plans imply a reduction of human pressures. Ecological theory and field evidence, however, suggest that coastal ecosystems may profoundly pay the legacy of past impacts, and show hysteresis (Parravicini et al., 2010). The predicted trajectories and timing of recovery are then to be considered extremely cautionary (Lauck et al., 1998). Long-term monitoring will remain the best way to obtain good knowledge of the system to be managed. These data, if available, can be easily implemented within our geospatial modeling tools and will help refine its predictions by incorporating information on ecosystem trajectories and resilience.

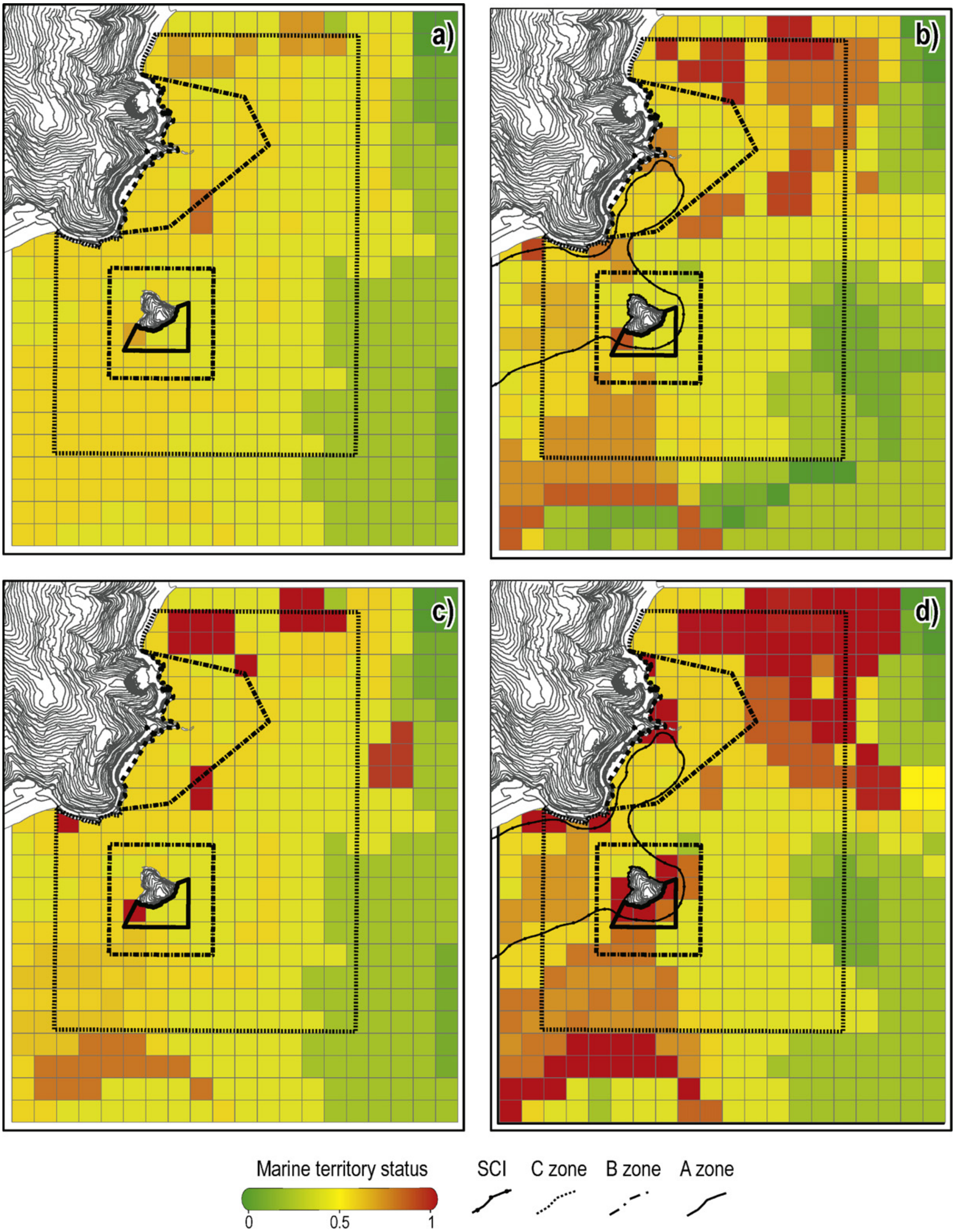

**Fig. 8.** Maps representing the status of the marine territory predicted by the RF model considering the following scenarios: (a) Scenario O-ME, where the influence of the extended harbor will be the minimum expected by the experts, and MPA will do its maximum effort to reduce human pressure in the area; (b) Scenario O-DN, where the influence of the extended harbor will be the minimum expected by the experts, and MPA will maintain the present management plan; (c) Scenario P-ME, where the influence of the extended harbor will be the maximum expected by the experts, and MPA will do its maximum effort to reduce human pressure in the area; (d) Scenario P-DN, where the influence of the extended harbor will be the maximum expected by the experts, and MPA will maintain the present management plan. Maximum effort by MPA will imply the prohibition of fishery in both the no-take zone (A zone) and the partial reserve zone (B zone). Fishery will be allowed only to residents in the buffer zone (C zone). In addition, beach re-nourishment will be avoided and the boundaries of SCI will be extended to the whole area thus implying the prohibition of anchoring.

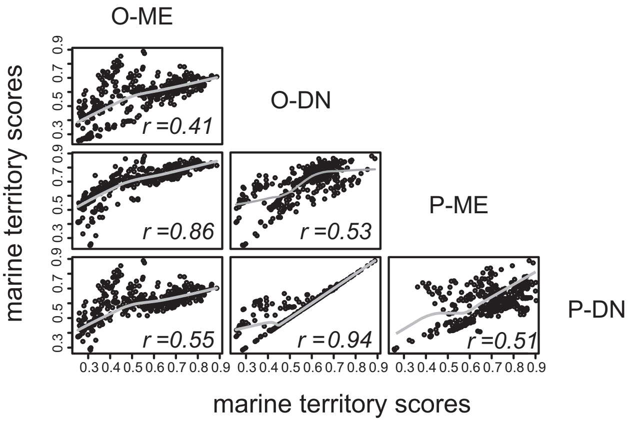

**Fig. 9.** Pair-wise correlations between the marine territory status predicted according to the considered scenarios (numbers in italic indicates the Pearson correlation coefficient). O-ME: the influence of the extended harbor will be the minimum expected by the experts, and MPA will do its maximum effort to reduce human pressures; O-DN: the influence of the extended harbor will be the minimum expected by the experts, and MPA will maintain the present management plan; P-ME: the influence of the extended harbor will be the maximum expected by the experts, and MPA will do its maximum effort to reduce human pressures; P-DN: the influence of the extended harbor will be the maximum expected by the experts, and MPA will maintain the present management plan.

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