Bringing geoheritage underwater: methodological approaches to evaluation and mapping

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1. Introduction

The valorisation of the natural heritage (here intended as the complex of biotic and abiotic elements of nature worthy of conservation) assumed a growing importance in the last years, leading to place biodiversity and geodiversity concepts side by side (Brilha, 2002). This in turn channelled efforts to protect not only biotopes, but also the associated physical landscape or environment through the identification of geosites or geomorphosites (Panizza & Piacente, 1993; Panizza, 2001; Reynard, 2004, 2005). In the field of abiotic heritage evaluation, various methods have been proposed for the recognition of scientific and additional values of relevant geological and geomorphological sites (Panizza, 2001; Coratza & Giusti, 2005; Pereira et al., 2007; Reynard et al., 2007; Serrano & Ruiz Flaño, 2007; Zouros, 2007). Natural heritage studies cover most types of environments, from mountain and subterranean areas to plains and coasts. Nevertheless, while many approaches to valorisation of natural heritage are reported for emerged shorelines (e.g. Carobene & Firpo, 2005; Zouros, 2007), research on coastal submerged areas (Orrù & Ulzega, 1988; Orrù et al., 2005) still lacks common schemes and approaches when compared with studies dealing with marine ecological resources (Bianchi, 2007 and reference therein).

Inspired from a methodological approach developed in France for the evaluation of terrestrial natural spaces in the framework of the EU Habitat Directive (Bardat et al., 1997), the Regional Activity Centre for Specially Protected Areas RAC SPA (UNEP) (Relini, 2000) obtained evaluation indexes for 148 ecological units (biocenoses, associations or facies), which correspond to the main marine habitats of the Mediterranean Sea. The combination of these criteria led to the realisation, in the last decade, of marine territorial cartographies in some Italian protected areas (Bianchi, 2007, and references therein). From these experiences, Bianchi (2007) defined "marine natural emergences" as species, habitats or landforms of high conservation interest, achieving the result of a territorial cartography displaying these three typologies of marine natural emergences. Applying this approach, Rovere et al. (2007a) argued that "adding the abiotic values to the biotic ones appears of importance in the evaluation of the natural heritage", but pointed out the discrepancy between the definition of biological and ecological values and the abiotic ones, the former being codified, the latter lacking common evaluation schemes.

The development of underwater abiotic heritage assessment approaches demands for a greater effort with respect to the terrestrial environment (e.g. costs of boats and SCUBA equipment) and faces several limits, such as logistics of field activity (time and depth limitations for diving) and adverse environmental conditions (e.g. scarce visibility due to reduced water transparency). These limits are flanked by the conceptual difficulty, for administrators and policy managers, to conceive the marine environment as "territory" (Bianchi, 2007), as its perception is low with respect to the terrestrial environment and the tools for its management are not always defined. Due to these considerations, evaluation of scientific and additional values of abiotic heritage should be coupled with the evaluation of the inherent accessibility to users of the underwater natural heritage due to the aquatic medium itself (need of swimming skills or diving licenses to access sites).

Approaches to the valorisation of the underwater abiotic heritage should be developed using several distinct but interrelated kinds of inputs. Firstly, direct and indirect surveys, together with published information, provide the baseline maps to implement the conceptual framework for the evaluation of the abiotic heritage. Secondly, a conceptual framework, comprising of the categories and criteria to assign values to the landforms inside a given area, has to be developed and applied. Merging the baseline data and the conceptual framework into georeferenced databases will allow maps of the abiotic heritage to be obtained. Thirdly, accessibility values must be considered, as they represent the potential use of the heritage values, and accessibility maps need, therefore, to be produced. Finally, the abiotic heritage maps should be integrated with other information, such as ecological and socio-economical values or environmental degradation and risk assessment in order to obtain a complete territorial cartography, which is the base for the management of the natural heritage as a whole (Bianchi, 2007).

In this study, we propose a methodological approach that integrates the inputs mentioned above. In particular, the direct surveying techniques and the conceptual framework for the evaluation of the abiotic marine heritage together with its accessibility to use will be applied to a case study in the *Isola di Bergeggi*, a recently established Marine Protected Area (MPA) in Liguria (Italy).

2. Study area

The MPA *Isola di Bergeggi* (Fig. 1), located in the central part of the Ligurian Sea (NW Mediterranean), is characterised by the alternation of sandy and rocky coastlines, the latter being composed of Triassic dolomitic limestones of the "Brianzonese" domain ("Dolomie di S. Pietro dei Monti"). The presence of calcareous cliffs in the area allowed the formation of karst features, among which the best known is the *Grotta Marina*, a cave of karst origin whose shape has been subsequently modified by sea ingressions during the Late Quaternary period (Bianchi et al., 1988; Carobene & Firpo, 2004). According to the morphobathymetric and sedimentological map produced by Rovere et al. (2007b), the underwater coastal part of the study area is characterised by submerged cliffs cut by tidal notches and abrasion platforms, and of sand, pebble and rockfall deposits at their foot; the deeper part of the continental shelf (ranging from ca. 10 to more than 80 m depth) is mostly characterised by seagrass meadows, loose sediments and deep cliffs and rocky outcrops.

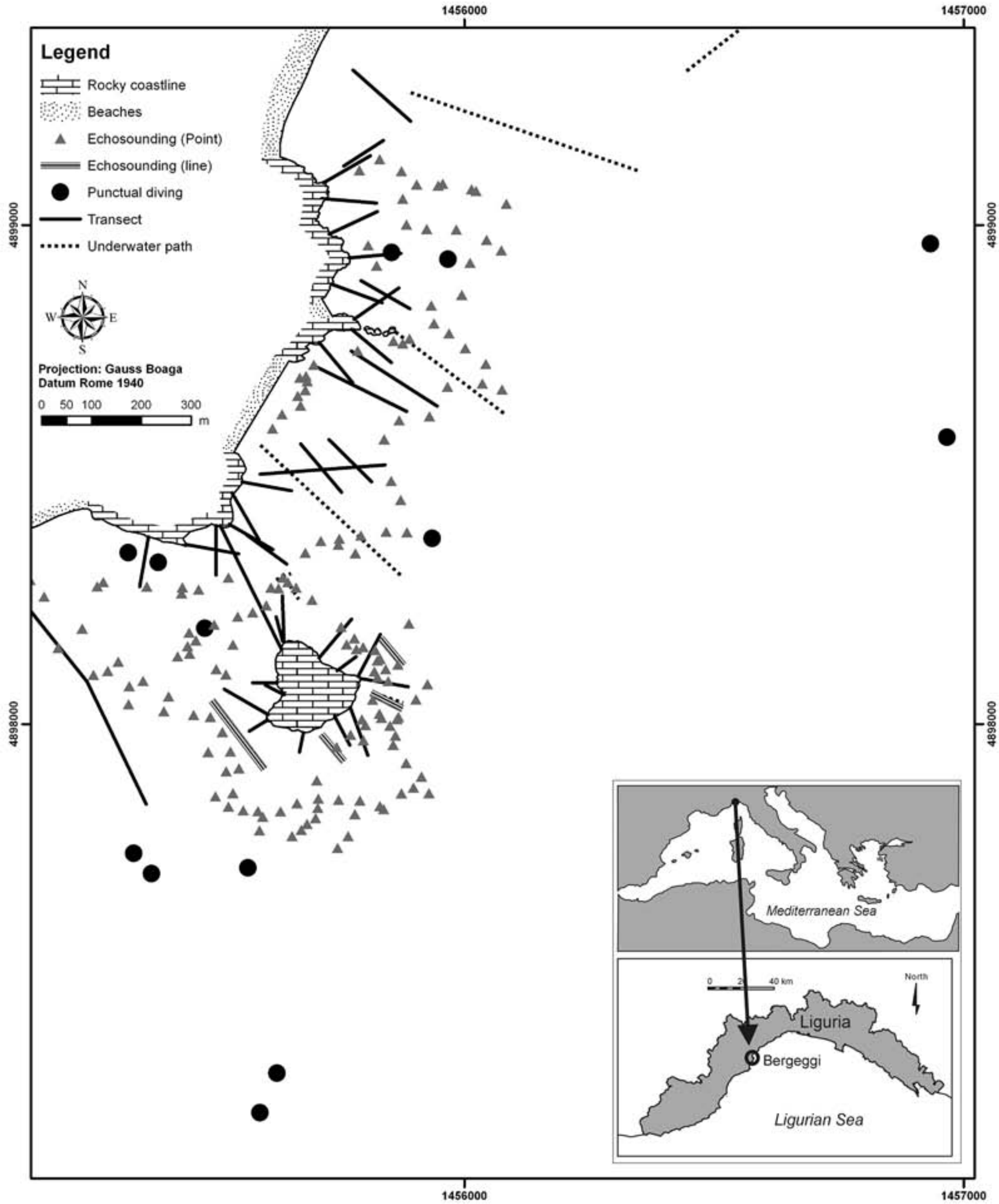

Fig. 1 Location of the study area with direct and indirect surveys.

3. Methods

Assessment of the underwater abiotic heritage was carried out using both indirect and direct surveys (Fig. 1). Indirect surveys consist in remote sensing techniques for mapping marine bottoms (aerial photography, satellite images and acoustic records from side scan, single or multi beam sonars). In general, these techniques have the advantage of mapping larger areas than direct surveys, allowing us to obtain georeferenced data at landscape scale useful for providing the cartographical basis for detailed mapping. Indirect surveys made in the study area included echo sounding (points or lines), as well as data from side scan sonar sonograms and aerial and photographs (Diviacco & Coppo, 2006). Nevertheless, in coastal marine environments, implementation of indirect surveys with direct ones is needed because of some critical issues dealing mainly with the interpretation and ground-truthing of aerial images and geophysical surveys and with the need for detail. Depth transects, underwater paths and punctual surveys were, therefore, carried out using scuba diving techniques (Bianchi et al., 2004). Depth transects consist of marked lines positioned on the bottom, along which the topography, relevant morphologies and types of sediments are measured. Underwater paths are similar to transects, except that they are done without reference lines and the distances are estimated with Personal Diving Sonar (PDS) and compass navigation. Underwater paths are the simplest type of polygonal survey, a method that proved to be efficient in mapping submerged shoals and caves (Colantoni, 2007).

In order to evaluate abiotic heritage and accessibility, the study area was divided into territorial units (hereafter called TU), defined as parts of the territory that: i) should give a sufficiently detailed territorial information; ii) can be compared from the point of view of the value and function that they have in the framework of environmental evaluation; iii) can be easily and uniformly represented in a GIS, allowing the building of relational databases to extract information for territorial management (Bianchi, 2007). These units are typically submultiples of the UTM grid, and can have various dimensions according to both the scale of baseline maps and the objectives of the study (in general, maps for environmental decisions require higher scales than those for environmental planning). In this study, the dimension of the TUs was set to 100 × 100 m due to the high detail (1:2000) of the baseline maps: the morphobathymetric and sedimentological map (Rovere et al., 2007b), the marine biocenose map (Parravicini et al., 2007a), and the marine emergence map (Parravicini et al., 2007b).

The Total Abiotic Heritage values (hereafter referred to as TAH) were divided into two categories: scientific and additional (Reynard et al., 2007). Scientific values are referred to as the sum of the geomorphological significances that a process or landform may assume in terms of four subcategories: integrity (INT), representativeness (REP), rarity (RAR) and paleogeographic value (PAL). Additional values refer to the aspects that have a link with a process or landform, but that cannot be directly ascribed to the field of geomorphological sciences. The subcategories identified for these values are: cultural (CULT), ecological (ECOL), economic (ECON) and aesthetical (AEST). These subcategories were described and adopted in terrestrial environments by Reynard et al. (2007).

The TAH values of each TU were assigned as follows (Tab. 1, 2):

- for each subcategory, a score was assigned to each landform, ranging from 1 to 5;
- additional and scientific values were obtained for each landform averaging the scores of the relative subcategories (Tab.1, 2);
- the TAH value of a landform was obtained averaging the scores of its additional and scientific values;
- the values at TU level were obtained by averaging the relative values of the landforms contained in the TU (Fig. 2);
- the TAH values at TU level were re-classified into five classes, which were represented into thematic maps as different colours of the TUs (Fig. 3);
- the accessibility of a TU was similarly scored in five classes (Tab. 3) ranging from 1 (high accessibility) to 5 (low accessibility). In the TUs where more than one value of accessibility was eligible, it was decided to retain the lower accessibility value allowing for the use of the higher abiotic heritage value (see Fig. 2 for an example).

Subcategory description / Criteria for the evaluation	1	2	3	4	5
SCIENTIFIC VALUES					
Integrity (INT): state of conservation of a given landform	Bad conservation due to both natural and human causes	Bad conservation due to human causes	Damage can occur in some parts of the landform but landscape integrity is preserved	Good conservation due to human intervention	Good conservation due to natural conditions
Representativeness (REP): exemplarity of a given landform	No exemplarity	Bad example of process or landform	Fair example of process or landform	Good example of process or landform	Reference site (in scientific literature) for the description of a process or landform
Rareness (RAR): rareness of a given landform at national, international or global level	Common or rare only at local scale	Rare at regional scale	Rare at national scale	Rare at international (e.g. continental) scale	Rare at global scale (e.g. few examples worldwide)
Paleogeographical (PAL): importance of a given landform in defining processes or environments that have characterised the Earth history	No paleogeographic value	Scarce paleogeographic significance	Good representation of a paleoprocess	Good representation of a paleoenvironment	Good representation of a paleoprocess and a paleoenvironment

Tab.1 Description of subcategories and criteria for the evaluation of scientific values.

Subcategory description / Criteria for the evaluation	1	2	3	4	5
ADDITIONAL VALUES					
Cultural (CULT): cultural values in a site (according to Pereira et al., 2007)	Without cultural features	Cultural features with no connection to landforms	Immaterial cultural features related to landforms (e.g. legends)	Material cultural features related to landforms	Anthropic landform with high cultural relevance
Ecological (ECOL): importance of a habitat for the national or regional natural heritage, as defined by document UNEP (OCA)/MED WG 149/5 Rev.1 (Relini, 2000)	Scarce ecological value		Intermediate ecological value		High ecological value
Economical (ECON): assessment (e.g. number of visitors, benefits) of the products generated by the landform.	No economical value	Scarce economical value	Economical values related mainly to biological heritage	Economical values related mainly to abiotic heritage	Economical values related to natural (biotic and abiotic) heritage
Aesthetical (AEST): the value of the landform in terms of emotional impact on users, partially following and adapting the scheme proposed by Reynard et al., 2007	Where Ec is the aesthetic relevance of an habitat (as defined by document UNEP (OCA)/MED WG 149/5 Rev.1: Relini, 2000); Int the integrity derived from the INT subcategory; Ver the contribution of the landform to the verticality of the landscape; Str the presence of three-dimensional structures in the landform. Each value is assigned a score from 1 to 5, so the AEST subcategory can vary between 0 and 5. The AEST score was divided into 5 classes according to the results of the AEST index: 1: 0-1 2: 1-2 3: 2-3 4: 3-4 5: 4-5				

Tab. 2 Description of subcategories and criteria for the evaluation of additional values.

Description	Accessibility
Accessible from the coast, snorkelling	1
Accessible with snorkelling, need of a boat	2
Accessible with scuba diving I level	3
Accessible with scuba diving II level	4
Accessible with technical diving or speleo diving	5

Tab. 3 Description of the criteria for the evaluation of accessibility of territorial parcels.

The evaluation of the TAH was made not only on the data source derived from the baseline map (Rovere et al., 2007b), but also on the field notes taken during direct surveys, in order to obtain a greater detail. As an example, in some zones of the study area during field mapping, a strong human impact due to date mussel harvesting was recorded on both cliffs and deposits at the cliff foot (Parravicini et al., 2006; Rovere et al., 2009), but it was not included in baseline maps. The use of field notes during the evaluation led to a reduction of the integrity of these zones, and hence the TAH value of the related TUs.

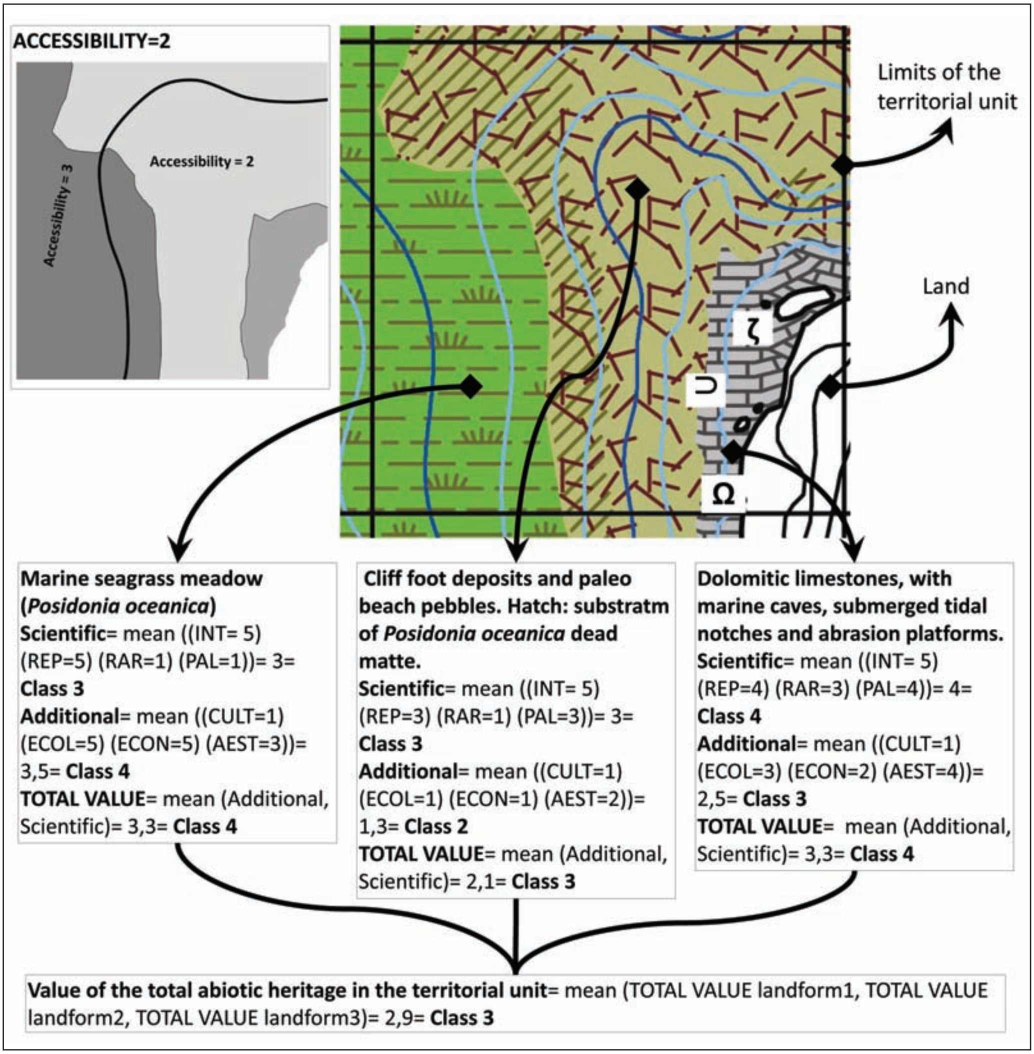

Fig. 2 Example of scoring procedure of a territorial unit.

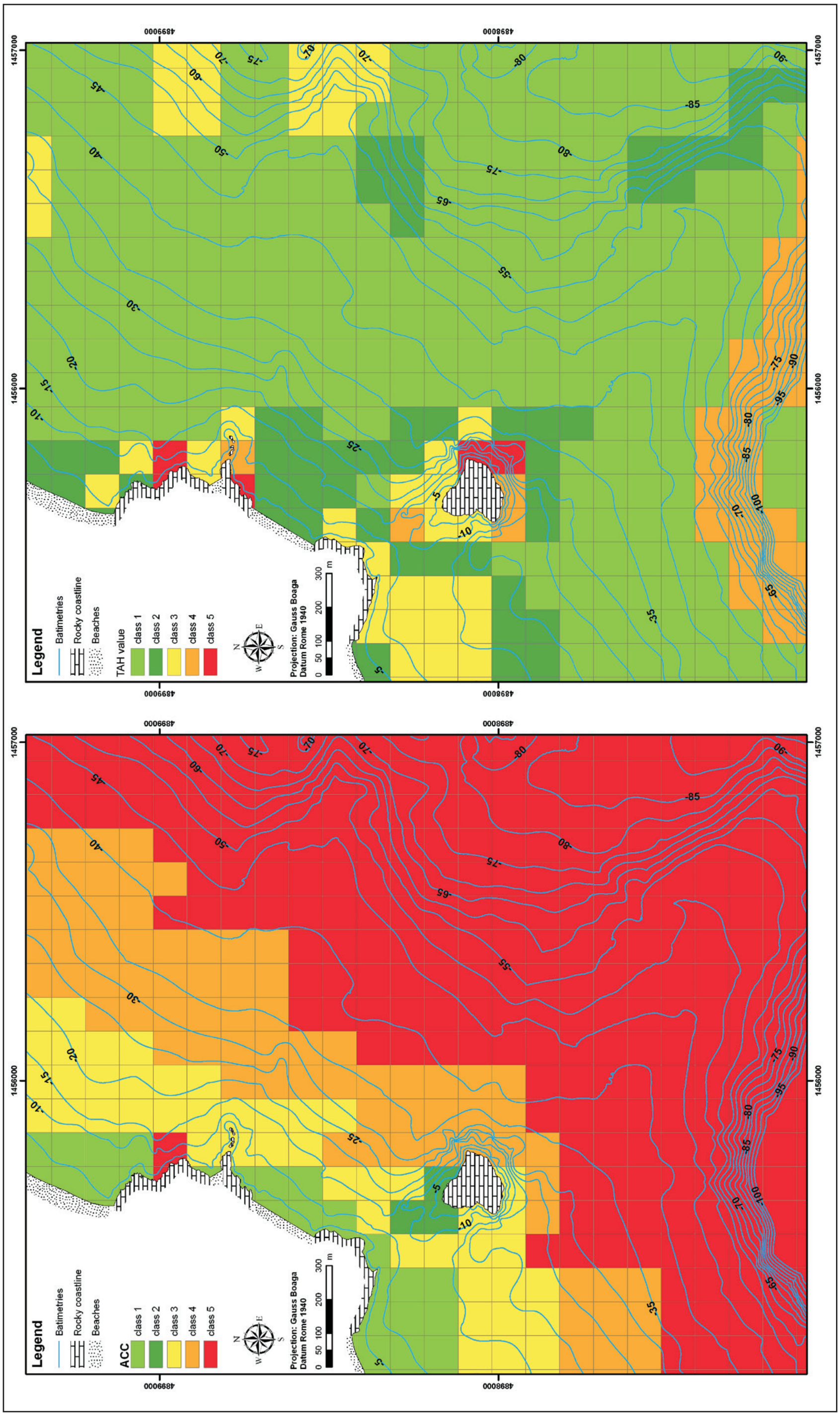

Fig. 3 Left: accessibility map; Right: total abiotic heritage values (mean of scientific and additional values).

4. Results and discussion

This study produced two main orders of results. The first one is represented by the refinement of the methodological approach, which was adapted in part from similar terrestrial studies dealing with the valorisation and conservation of geomorphosites, and in part from parallel approaches for the evaluation of ecological values. The second order is represented by the direct implications for the valorisation, conservation, and, finally, management of the MPA *Isola di Bergeggi.*

4.1 Methodological approach

Although indirect survey techniques were essential for the realisation of a cartographic basis (e.g. bathymetry, limits of *Posidonia oceanica* meadows), data from direct surveys proved invaluable to obtain the details for the comprehension and spatial representation of the morphologies. The availability, during the evaluation procedure, of the dataset obtained from direct surveys also helped in assigning values to each landform. In general, this consideration suggests that direct surveys must be planned not only with the typical aims of a geomorphological survey (e.g. description of landforms, processes) but also taking into account their successive use for the TAH evaluation, and should, therefore, include data, which usually are not surveyed (e.g. the integrity and the cultural values associated to a landform).

A major problem with the evaluation of TAH is subjectivity, which can also affect the choice of the number and typology of subcategories. In fact, while the distinction in categories that can be ascribed to the "scientific" and "additional" ones adopted here is well established in literature, different authors propose various supplementary subcategories to the ones adopted in this study (e.g. Zouros, 2007 and reference therein). This is a key point in the evaluation of TAH, and can be solved using three approaches. The first is a bottom-up approach, where an expert board is asked to determine subcategories and criteria, based on the comparison of many specific study cases. The second is a top-down approach, where an expert board is asked to determine, a priori, which are the subcategories and criteria to give to each landform in a hypothetical condition, independently from local contexts, and then test the definitions in study cases. The third is a no-uniformity approach, implying that it is simply impossible (or too difficult and time-consuming) to choose a common evaluation scheme for the evaluation of abiotic heritage in the marine environment and, even if the division into categories of "scientific" and "additional" values is maintained, the choice and evaluation of subcategories should be done following site-dependent considerations.

None of these approaches can be considered as the best, but they are intertwined and could represent three different steps in the evaluation of TAH. In fact, studies using no-uniformity approaches in different environments may provide the base for bottom-up choice of subcategories and criteria, which should necessarily be revised, implemented and generalised by expert boards, in a top-down perspective in order to enhance and improve further studies dealing with TAH and the comparison between different areas.

Another source of subjectivity resides in how the shift from landform-level to TU-level values is realised, as yet advanced by Bianchi (2007) during the compilation of ecological territorial cartography. Three main methods can be identified, each with their own pros and cons (Tab. 4): none can be considered as the best in absolute terms. In this study, the value of the TU was calculated by averaging the values of the landforms contained in it (third method in Tab. 4). The confrontation of the concordance/discordance of values obtained with these three methods would be particularly helpful in the choice of the correct methodology.

Method	Pros	Cons
The value of the parcel corresponds to the sum of the values of the landforms contained in it	It takes into account the value of geodiversity	Many low-value landforms are not equivalent to a single high-value one
The value of the parcel corresponds to the maximum value of the landforms contained in it	Landforms with high values are put in evidence	It does not take into account geodiversity
The value of the parcel corresponds to the mean of the values of the landforms contained in it	Many landforms of low value give a low value of the TU as a result	Averaging low values with high values produces mediocrity

Tab. 4 Three main methods, which can be used for the passage from landform-level values to those at TU level, with their respective pros and cons.

4.2 Management implications

In the study area, almost 80% of the TUs are located in the deeper continental shelf (Fig. 3) and have low values of TAH (classes 1 and 2) and accessibility (classes 4 and 5) (Fig. 4a, b); exceptions to this pattern occur in the SSW part, characterised by a wide submerged cliff and several rocky outcrops ranging from 50 to almost 90 m depth (Fig. 3). Coastal territorial units usually have high accessibility, exception made for the SE part of the Bergeggi Island and the Bergeggi Marine Cave (Fig. 3).

The comparison of TAH and accessibility values (Fig. 5) suggests three possible scenarios of tourist use of TUs having intermediate or high (class ≥ 3) TAH values: i) 7% of these TUs can be used for the development of snorkelling trails (Fig. 5, square A); ii) 5% is suitable to be used for the development of underwater trails for both experienced and first-level divers (Fig. 5, square B); iii) 11% of these TUs are suitable to be used as sites for technical diving (Fig. 5, square C).

The comparison between classes of values of scientific subcategories (Fig. 4c) shows that a significant percentage of the TUs have high (classes 4 and 5) values of INT, RAR, PAL and REP subcategories. For the additional values (Fig. 4d), 19% and 14% of the TUs have high values of respectively ECON and AEST subcategories. Scores of additional values show the absence of cultural features but point out the presence of TUs with high ecological importance, suggesting the opportunity of developing further multidisciplinary studies focusing on the links between abiotic and biotic values in this area.

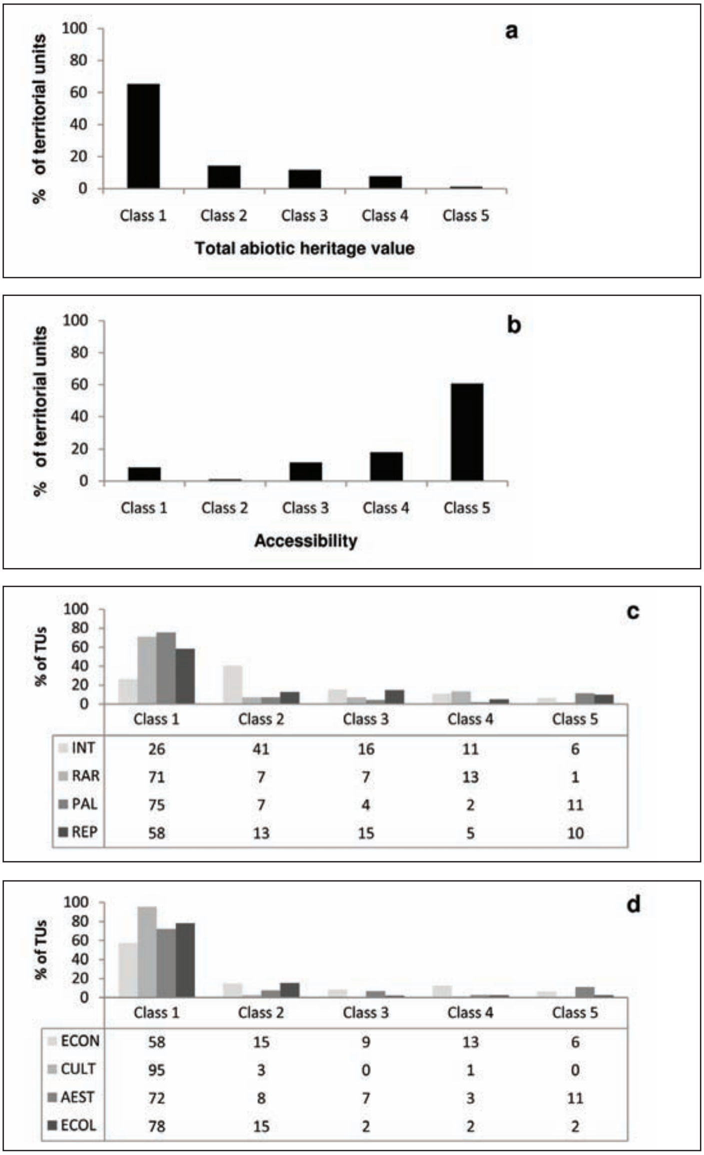

Fig. 4 Histograms representing the frequency distribution (%) of the scores of the territorial units according to: a) total abiotic heritage (TAH); b) accessibility; c) subcategories of scientific values; d) subcategories of additional values.

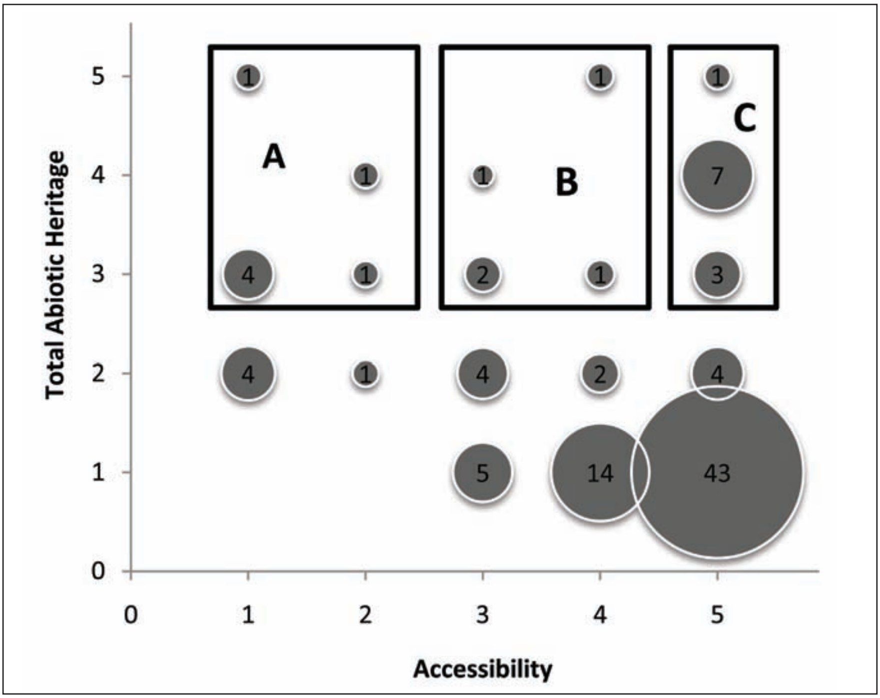

Fig. 5 Bubble diagram representing the values of Accessibility vs Total Abiotic Heritage (TAH). The diameter of the bubbles represents the percentage of territorial units with the associated values. The squares represent TUs, which can be used for: A) the development of snorkelling trails; B) the development of underwater trails for both experienced and first-level divers; C) site for technical diving.

The study area is characterised by a significant number of TUs with high scientific, additional, or both values located mainly in the coastal part, which is the most accessible for tourist use. In particular, the TUs characterised by high aesthetical values will allow for a use of the marine natural heritage based on the simple perception of the submerged seascape. Hence, aesthetical values may act as a "flag" for the scientific values of the area, shifting underwater tourism from an unaware and merely recreational use of the sea to the conscious use rooted in the knowledge of the marine natural heritage. This twofold possibility of valorising the natural heritage, together with the status of MPA, enhances the economical values of the TUs with high scientific and additional values inside the Bergeggi area.

5. Conclusion

What lessons can be learnt from this study for the future applications of methodological approaches to mapping and evaluation of the abiotic heritage underwater? The adoption of direct field techniques allowed us to include, in the planning of underwater geomorphological surveys, the assessment of values related to the submerged abiotic heritage. A common methodological approach is needed to define which are the subcategories and the criteria to adopt for the evaluation of abiotic heritage values. This is a critical point and each of the solutions discussed (top-down, bottom-up or no-uniformity) have their own pros and cons, but, in all cases, would be effective in reducing the subjectivity of the evaluation. At present, studies on different environments with different subcategories and criteria are being carried out, providing the "no-uniformity base", but an effort should be done in the near future to generalise the results of these studies and to adopt common schemes for the evaluation of TAH. Once a common evaluation scheme is chosen and adopted, common criteria will be necessary to shift from the assignment of values at landform level to that at TU level (sum, maximum, mean). The methodology developed and applied in this study represents the first attempt to face, and try to solve, these issues.

In perspective, the methodological approach proposed in this study proved to be efficient in providing indications for the assessment and evaluation of the marine abiotic heritage. Once integrated with input from other disciplines (such as biology and ecology), the proper valorisation of the abiotic components will concur to define a complete conceptual framework to be adopted for the management of underwater natural heritage as a whole.

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