Chapter 17
Seascape Integrity Assessment: A Proposed Index for the Mediterranean Coast

Sébastien Thorin, Pascaline Bodilis, Thibault Schvartz, Eric Dutrieux and Patrice Francour

Abstract Landscape ecology is a multidisciplinary field that combines the spatial approach of geography with functional ecology. Concerning marine environment, a submerged landscape, called seascape, is defined as a spatially heterogeneous area of coastal environment (i.e. intertidal, brackish). Measurement of spatial patterns plays a central role in monitoring environmental change and for studying the multi-scale processes that drive organism distributions and biodiversity. The aim of this paper is to propose a relevant seascape index focusing on Mediterranean littoral areas, moreover rocky habitat that constitutes one of the most important and characteristic habitats of the north-western Mediterranean coastal areas. The methodology proposed to score marine sites addresses three factors: biological, geomorphologic (i.e. 3D complexity) and anthropogenic. The goal was to build a functional and relevant tool that could eventually be used for a large scale geographical analysis of submarine landscapes along the north-western Mediterranean coast. The proposed index can qualitatively assess the value of the seascape within a site. Statistical tests showed that the proposed index is an accurate and relevant proxy of the seascape complexity value. The seascape integrity index we developed can then be a new tool that could complement other existing biological indices.

Keywords Seascape index · French Mediterranean · Habitat complexity · Management

S. Thorin (✉) · T. Schvartz · E. Dutrieux
Creocean, Languedoc-Roussillon Agency, 128, Fès avenue, 34080 Montpellier, France
e-mail: thorin@creocean.fr

T. Schvartz
e-mail: schvartz@creocean.fr

E. Dutrieux
e-mail: dutrieux@creocean.fr

P. Bodilis · P. Francour
Université Nice-Sophia Antipolis, EA 4228 ECOMERS. Parc Valrose,
06108 Nice Cedex 2, France
e-mail: Pascaline.BODILIS@unice.fr

P. Francour
e-mail: francour@unice.fr

O. Musard et al. (eds.), *Underwater Seascapes,* DOI 10.1007/978-3-319-03440-9_17,

17.1 Introduction

Landscape ecology is a multidisciplinary field that combines the spatial approach of geography with functional ecology (Boström et al. 2011). Landscape ecology has been widely applied in the terrestrial environment to understand the relationships between spatial patterns and ecological processes at a range of spatial and temporal scales (Wedding et al. 2011). But while landscape ecology started out as primarily a terrestrial discipline, it is increasingly applied to explore organism–habitat relationships in aquatic environments. Initial studies applying landscape approaches to tropical marine systems indicate that landscape structure (cover and pattern of surrounding habitat types) likely play an important role in determining fish community composition, abundance and species richness (Yeager et al. 2011). As highlighted by Pittman et al. (2011), landscape ecology concepts have recently emerged as theoretical and analytical frameworks that are equally useful for evaluating the ecological consequences of spatial patterns and structural changes in the submerged landscapes of coastal ecosystems. Thus, since the early 1990s, the landscape ecology approach has been applied in several coastal subtidal and intertidal biogenic habitats across a range of spatial scales (Boström et al. 2011).

A submerged landscape, called seascape, is defined as a spatially heterogeneous area of coastal environment (i.e. intertidal, brackish). Seascape structure is commonly represented as a patch matrix, with focal patches (e.g. vegetation) viewed as 'islands' embedded in a matrix (e.g. sediment) that affect animal movements and survival depending on relative isolation (Boström et al. 2011). Measurement of spatial patterns plays a central role in monitoring environmental change and for studying the multi-scale processes that drive organism distributions and biodiversity (Pittman et al. 2011). Moreover spatial heterogeneity is now recognized as a central driver to many ecological processes (Wedding et al. 2011; Yeager et al. 2011). Spatial pattern metrics offer great potential for ecological research and environmental management in marine systems (Wedding et al. 2011).

Habitat structure likely drives a large part of spatial variability in the distribution and abundance of Mediterranean organisms, especially when abundance is assessed at small spatial scales. Habitat complexity can thus be measured at each scale using different variables (e.g. number of boulders classified by size, rugosity, *etc*.; see Ruitton et al. 2000). If we consider habitat structure from a functional perspective, such that habitat refers to any physical or biological environmental attribute that offers some resource like food or shelter to the organisms of interest at a given scale, then it is pertinent to ask what features of this habitat are important to those organisms, and what the responses of those organisms are to the spatio-temporal heterogeneity of a feature of this habitat (Garcia-Charton et al. 2000).

One of the most important and characteristic habitats of the north-western Mediterranean coastal areas is the rocky substrata (Harmelin 1987). Mediterranean rocky bottoms are generally formed by boulders of several sizes (from small stones to huge blocks) resulting from coastal erosion, flagstones, plates or large areas of bedrock with varying degrees of architectural complexity. The complexity of coastal rocky bottoms is enhanced by habitat 'formers', defined as 'those species that characterize a habitat' which provide additional resources such as physical refuge and food items to target species (Garcia-Charton et al. 2000). Moreover, marine rocky habitats commonly exhibit complex spatial patterns that can be viewed, at any scale, as mosaics of interacting patches (e.g. organisms) (Garrabou et al. 1998).

A better understanding of faunal-seascape relationships, including the identifications of threshold effects, is then urgently needed to support the development of more effective and holistic management actions in restoration, site prioritization, and forecasting the impacts of environmental change (Boström et al. 2011). The lack of knowledge on seascape patterns and their ecological consequences represents both a major void in our understanding of marine and coastal ecology and an exciting new frontier for research (Pittman et al. 2011).

The European Water Framework Directive or WFD (2000/60/EC Council Directive 23th October 2000) imposes the assessment of the European water quality and establishment of management plans for those waters. Several water quality indices have been developed to fulfil this obligation of water quality evaluation (e.g. Ballesteros et al. 2007). The Marine Strategy Framework Directive UE (2008/56/EC of the European Parliament and the Council Directive of 17 June 2008) extended the principles of quality assessment to several components of the marine environment with the overall aim of promoting sustainable use of the seas and conserving marine ecosystems. The Member States are mandated to make an analysis of the essential features and characteristics and current environmental status of those waters based on an indicative list of elements that cover physical and chemical features, habitat types, biological features and hydro-morphology. In particular, one of the qualitative descriptors for determining good environmental status is the "sea-floor integrity" which has to be "at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems are not adversely affected" (Official Journal of the European Union, 25.6.2008).

The aim of this paper is to propose a relevant seascape index focusing on Mediterranean littoral areas. A first study was carried out in 2002 in Languedoc-Roussillon (French Mediterranean north-western coast, France), at the request of the Rhône-Méditerranée-Corse Basin Agency, to implement a landscape index specifically devoted to rocky substrates (Créocean 2002). The aim was to obtain better knowledge of the regional seascapes, and to develop a new tool that can qualitatively assess the seascape integrity. In 2008, this experiment was extended to the Provence-Alpes-Côte d'Azur Region (Créocean 2009) using an adapted index incorporating both the geomorphologic and biological specificities of this region. The goal was not to make a simple inventory of the various seascapes of the PACA Region and to characterize their value, but to build a functional and relevant tool that could eventually be used for a large scale geographical analysis of submarine landscapes along the north-western Mediterranean coast. We present here the tool developed to score marine sites and assess their seascape integrity.

17.2 Methods

17.2.1 The Proposed Seascape Integrity Index: Basic Concepts

The methodology proposed to score marine sites addresses three factors: biological, geomorphologic (i.e. 3D complexity) and anthropogenic. As most of the littoral habitats within a landscape are now affected by human activities (e.g. tourism, urban development, industries), we considered that the development of such a landscape integrity index should take into account the anthropogenic pressure.

A landscape is a heterogeneous environment wherein spatial and temporal limits are determined by the observer's sight. The explored environment is then dependent on the perception and the position of the observer, and is variable due to the environmental conditions. To address the underwater visibility problem and the seascape spatial scale, the only possible option is to consider the submarine observer as mobile. The landscape scale is thus assimilated into what a diver can perceive during a 40-minute course which corresponds approximately to the average duration of a classical dive. Even with restricted underwater visibility, the observer can visit several different environments or habitats, similar to the progressive landscape reading described by Musard et al. (2007).

17.2.2 Major Landscape Criteria

The architecture of submarine bottoms is of prime importance to highlight the habitat mosaic which forms them: relief variations, structural diversity and the nature of the architectural elements are directly linked with habitat diversity. This criterion then needs to be fully exploited, with an evaluation of the sea bottom quality which specifies the value of various relief types that can be encountered when diving. The landscape quality could also be evaluated through the population richness that colonizes and sometimes constitutes sea bottoms: "the landscape appearance of this submarine space is largely conditioned by the existence of fauna which, occasionally, becomes a structuring element of the landscape" (Musard et al. 2007). We then specifically focused on species noteworthy for their size, colour or abundance, which are constitutive landscape elements. These species are considered as contributing to the aesthetic and/or landscape value of the marine natural heritage (Francour and Bellan-Santini 2007). The biological quality of a landscape can also be linked to the presence of structuring species in the community, i.e. species that create by themselves new habitats such as coralligenous bottoms or *Posidonia oceanica* meadows.

The Relief factor corresponds to physical descriptors structuring the sea bottoms' relief. For every descriptor, the quotations are defined from zero (lack of relief) to a maximal value which varies, depending on its landscape potential (Table 17.1).

The Biological factor focuses on species that can be observed during diving (large enough and easily recognizable underwater) and that can influence the landscape (large size species, forming abundant populations or with outstanding shape or colour

Table 17.1 Quotation grid for Relief criterion

Physical descriptor: Nature and structure of the Relief	Lack	Max quotation
Shallow rocky bottoms and lower part of cliff	0	+2
Flat rocks (rocky plateau, slabs)	0	+2
Blocks/sparse block field	0	+2
Isolated large blocks	0	+3
Coastal or isolated pinnacles	0	+4
Submarine walls	0	+4
Faults, breaks, small hollows	0	+2
Rocky shoals, small overhangs	0	+2
Large hollows that can be visited by SCUBA divers (caves, arches, tunnels, very large overhangs, etc.)	0	+5
Deep crevices	0	+4
Coralligenous in its physical structure	0	+2
Posidonia oceanica meadows as habitat	0	+2
Sandy areas	0	+2

Table 17.2 Quotation grid for Biological criterion

Biological criterion	Lack	Max quotation
Large erected species (Sea fans, axinellid sponges, alcyonids, large bryozoans, large erected algae. . .)	0	+4
Colorful surfaces covered with encrusting species	0	+3
Diversity and global abundance of forms and colors	0	+3
Permanent or regular presence of abundant open water fish species	0	+4
Permanent or regular presence of abundant necto-benthic fish species	0	+2
Permanent or regular presence of abundant emblematic and/or rare fish species (grouper, brown meager, barracuda, red coral, long-spined sea urchin . . .)	0	+2

characteristics). Submarine landscape valuation remains very subjective, particularly underwater. This is the reason why another criterion has been added for mediated or rare species because they can significantly impact the landscape perception of the diver (Table 17.2).

The Anthropogenic factor is sorted into two categories: (i) elements that are part of the landscape and that do not distort it; this category includes buildings on the sea (e.g. dykes, artificial reefs, etc.), as well as wrecks; and, (ii) elements that indicate an uncontrolled, or undesired at the minimum, degradation of the environment (e.g. large solid wastes, excessive siltation, turbidity induced by discharge, physical destruction of sea bottoms, etc.). The first category has a positive effect on the landscape while the second has a negative effect (Table 17.3).

17.2.3 Calculation of the Final Index

The global note is calculated by summing the physical, biological and anthropogenic factors according to the following formula:

$$Seascape\ integrity\ index = 2x Physical + 2x Biological + 1x Anthropogenic$$

Table 17.3 Quotation grid for Anthropogenic factor

Anthropogenic criteria	Lack	Max quotation
Linear structures (dykes, rockfill . . .)	0	+3
Isolated structures (artificial reefs, moorings . . .)	0	+3
Wrecks	0	+3
Presence of large solid waste	0	−2
Invasive species, algal turf largely covering the substrate	0	−3
High turbidity/siltation	0	−4
Globally poor population	0	−4
Mortalities of different species	0	−5
Signs of physical destruction of the environment (erosion, trawling)	0	−5

17.2.4 Data Acquisition

A total of 71 sites in the PACA Region were explored by SCUBA diving. The sites ranged from well preserved areas (national park, no-take areas) to highly human-impacted areas (large harbours) or even totally artificial substrates (dykes, piers). The censuses were conducted from February to October 2008. Each site was explored once by 2 SCUBA divers. Geomorphologic, biological and anthropogenic data were recorded on underwater diving slates during a 40-minute dive.

17.2.5 Statistical Analysis

To analyze the landscape value data, we applied two cluster analysis methods: joining and K-mean clustering. The joining clustering or tree clustering was performed using Euclidian distance and Ward linkage rules. The K-Mean clustering was performed after analysis of the tree resulting from the previous joining clustering; 4 a priori groups were selected. According to the different values of R, Band A factors, all the data (factor values) were standardized before cluster analysis. Both standardization and cluster analysis were performed using Statistica 6.1 (StatSoft).

17.3 Results

The two cluster analysis yielded similar classification using 4 a priori groups for the K-Mean clustering (Table 17.4). Only 4 sites among the 71 analysed were not classified in the same cluster by either the joining or the K-Mean clustering (Gorgones Noires, La Vesse, Rague St Louis, and Beauduc artificial reefs).

Cluster 1 (Ward, Table 17.4) is characterized by high R values, similar to cluster 2 (average R = 22). B values are average, lower than for cluster 2 but higher compared to clusters 3 and 4 (average B = 15). The highest values for A are observed in this cluster, as also for clusters 2 and 3. This cluster includes protected sites, such as Sec de Montrémiant, and non-protected sites, such as Le Village. Most of the

Table 17.4 Scoring values for the 71 sites of the PACA Region and results of the two cluster analysis methods used, joining tree clustering (Ward: tree clustering, Euclidian distance and Ward linkage rules) and the K-mean clustering (*KM4* clustering with 4 *a priori* groups). Scores are given for the three criterion retained by the method (*R* Relief or Geomorphologic, *B* biological, *A* anthropogenic). The coefficients (2 or 1) used to compute the final index (see text) have been already applied on the values for the three factors

Name	R	B	A	Ward	KM4
Calanque de l'Oulle	30	12	0	1	4
Grand Salaman	22	13	– 2	1	4
Grotte du Veyron	25	17	0	1	4
Le Village (Agay)	23	12	2	1	4
Lion Mer	25	16	– 0.5	1	4
Petit Ribaud	17	14	0	1	4
Pierres à Joseph	26	16	0	1	4
Pierres du Châ teau	21	15	– 1	1	4
Pigeonnier	20	17	0	1	4
Pointe de la Galère	17	15	0	1	4
Pointe de l'Etoile	18	17	0	1	4
Pointe Fauconnière	23	13	0	1	4
Prieur	22	14	2	1	4
Sec de Montrémian	23	13	0	1	4
Tombant à Dudu	17	12	– 3	1	4
Tombant du Planier	20	15	1	1	4
Tombant du Veyron	19	17	0	1	4
Balise du Rabiou	24	21	0	2	3
Cap des Mèdes	29	20	0	2	3
Cassidaigne	18	23	– 1	2	3
Deux frères	29	22	– 0.5	2	3
Donator	9	26	3	2	3
Enfer de Dante	22	24	0	2	3
Faille du Moulon	29	18	0	2	3
Farillons	23	32	0	2	3
Fourmigues Antibes	19	22	3	2	3
Fourmigues Giens	22	23	– 0.5	2	3
Gabinière	15	26	0	2	3
Gorgones Noires	15	19	– 2	2	4
Grotte à Corail	26	20	0.5	2	3
Impérial du milieu	22	29	0	2	3
Les Rosiers	21	24	0	2	3
Pierre à Sica	17	23	– 1.5	2	3
Pierres tombées	20	22	0	2	3
Pointe du Rascas	27	20	– 0.5	2	3
Pyramides	24	19	0	2	3
Sec de la Gabinière	32	26	0	2	3
Sec du Gendarme	24	21	0	2	3
Sec du Langoustier	34	26	0	2	3
Sèche des pê cheurs	26	26	0	2	3
Trois Ilots	17	21	– 1	2	3
Vengeur	23	20	0	2	3
Calanque du Mugel	11	9	0	3	1
Cap Caveau	17	8	0	3	1
Coralligène Cote Bleue	8	14	– 1.5	3	1
Dalles de Bagaud	14	8	0	3	1

Table 17.4 (continued)

Name	R	B	A	Ward	KM4
Digue Toulon	8	7	0	3	1
Est Ile Rousse	11	13	1	3	1
Fourmigues BM	13	8	1.5	3	1
Gradins Monaco	4	6	1	3	1
Herbier du Larvotto	6	7	3	3	1
Herbier St Tropez	7	3	0	3	1
La Patate Monaco	12	12	0	3	1
La Vesse	20	10	– 0.5	3	4
Péniches d'Anthéor	3	13	0.5	3	1
Pointe d'Endoume	12	5	– 0.5	3	1
Port Monaco	5	9	0.5	3	1
RA Côte Bleue	5	9	0	3	1
Rague aux Corbs	14	9	– 1	3	1
Rague St Louis	15	13	0	3	4
SM Côtes Bleue	10	13	– 1.5	3	1
Tombant Spélugues	12	12	– 1	3	1
Aquaculture	3	5	– 10	4	2
Baie de Carteau	1	4	– 6	4	2
Emissaire Marguerite	2	2	– 3.5	4	2
Galets Beauduc	1	3	– 3.5	4	2
Golfe Beauduc	0	2	– 4	4	2
Mouillage grandes unités	5	4	– 3	4	2
Pieux du Lazaret	0	5	– 3.5	4	2
Plage des Corbières	2	2	– 11	4	2
RA Beauduc	2	9	– 2	4	1

RA artificial reefs, *BM* Bormes-les-Mimosas, *SM* underwater track.

sites are characterized by an important relief and good biodiversity, such as Grotte du Veyron caves and Calanque de l'Oulle (Fig. 17.1).

Cluster 2 is characterized by high values for R (maximum R = 34; average R = 23) as in cluster 1. The highest B values is observed in this group (average B = 23). The A values are equal or close to zero, similar to cluster 1 and 3 but higher than cluster 4 (average A = 0). This cluster includes sites known for their impressive landscapes and highest biodiversity, such as the sites of La Gabinière and Sec de la Gabinière of the national park of Port-Cros.

Cluster 3 is characterized by intermediate R (average R = 10) and B values (average B = 9). B values are slightly higher than in cluster 1 but lower than those observed in clusters 2. The A factor reached low values, close to zero, similar to clusters 1 and 2, but the values were still largely higher than cluster 4 (Amoy = 0). Many sites influenced by anthropogenic activities are present in this cluster; however, they have a low damage level: all sites of Monaco (Port Monaco harbor, Gradins Monaco), Digue Toulon (a pier), Pointe d'Endoume and Artificial Reefs (RA) of the Côte Bleue Marine Park. This cluster also encompasses shallow natural sites: Dalles de Bagaud, Fourmigues BM, Calanque du Mugel, Rague aux Corbs, Herbier Saint-Tropez, SM Côte Bleue. This cluster thus grouped (i) anthropogenic sites with low or no damage, (ii) shallow sites (mainly seagrass meadows) submitted

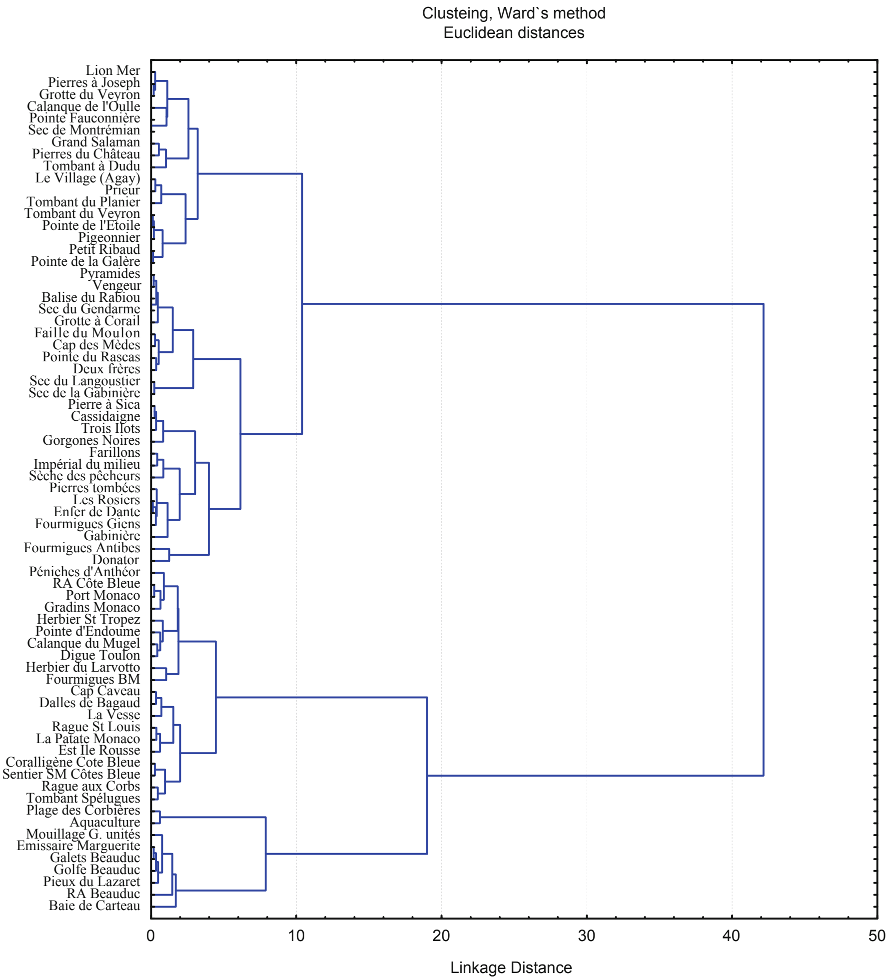

Fig. 17.1 Classification of all the stations by a hierarchical clustering method using Ward's method and Euclidian distance. A K-mean clustering method gathered the same stations according to four clusters (1, 2, 3 and 4; see Table 17.4)

to anthropogenic pressures that limit biological richness; and, (iii) monotypic areas with low diversity both in relief and in species.

Cluster 4 shows the lowest R, B and A values (average $R = 2$; $B = 4$; $A = -5$). These sites are the areas most impacted by human activities: Aquaculture (under this site the seagrass meadows has totally disappeared), Carteau Bay (within Fos harbor), Pieux Lazaret, Mouillage Grandes Unités (within Antibes harbor), Emissaire Marguerite (i.e. outflow of Sainte-Marguerite, Toulon), Plage des Corbières (beach with the presence of dead *Posidonia oceanica*, muddy bottoms, low diversity and a dirty general aspect).

17.4 Discussion

The development of indices to underpin the implementation of directives, conventions, statutes and other more informal national and international initiatives remains a challenging approach in marine environments (Rovere et al. 2011). The assessment of ecosystem quality relies mainly on biodiversity assessment (e.g. Warwick and Clarke 1998) but rarely involves geomorphologic features (Rovere et al. 2011). Consequently, the elaboration and use of landscape pattern indices are still infrequent in Mediterranean community ecology (Garrabou et al. 1998).

The seascape integrity index proposed in this study is based on three factors: biological, geomorphologic and anthropogenic. Each of these factors provides a particular information linked to ecological functions, aesthetic or nature heritage values, and habitat or disturbance intensity. It can be globally computed by summing the physical, biological and anthropogenic quotations. We hypothesized that the anthropogenic factor has a lower weight than the biological or relief factors to characterize the seascape integrity index. Even if we have no theoretical model to sustain this unbalanced model ($2B + 2R + 1A$), the clear and consistent splitting of the stations in clusters for both joining tree and K-Mean clustering seems to validate this initial choice.

The proposed index can qualitatively assess the value of the seascape within a site. Two of the components of this index, the Relief and Biology factors, can be directly linked to the diversity and richness of invertebrates or fish assemblages. Several studies have highlighted a clear correlation between the substratum complexity and the diversity or richness of fish or invertebrates (e.g. Harmelin 1987; Francour 1997; Ruitton et al. 2000; Harmelin-Vivien et al. 2001; Bonaca and Lipej 2005). The addition of the anthropogenic factor to the definition of the index allows us to take into account the extra value due to human activities. This value could increase the complexity of the substrate (e.g. dykes; see Harmelin-Vivien et al. 1995) or decrease it (e.g. Harmelin et al. 1981; Airoldi and Beck 2007; Mangialajo et al. 2007).

The classification of the different sites into well differentiated clusters is consistent with the previous knowledge of the authors on these sites (not presented in this paper). The similarity and good correspondence between the two clustering methods suggests that the proposed index is an accurate and relevant proxy of the seascape complexity value. In addition, one of the main advantages of this index is its simplicity, such that it can be used by non specialized divers. The proposed index can then be utilized to conduct a rapid, qualitative evaluation of the state of seascapes, be easily tested on a large number of sites, and rapidly generate a consistent database.

Although it would be useful to generate a large database, the development of guidelines to interpret the computed value (addition of the three weighted factors) should be pursued as the next step. One approach could be the calculation of a theoretical value for a given habitat (e.g. *Posidonia oceanica* meadow or coralligenous formations) and the comparison of the computed value to the theoretical maximum value. Another approach is by setting up a complete and large database, encompassing few disturbed sites (even if the notion of pristine site is a chimera in the north-western Mediterranean), to substitute computed clusters with groups of sites defined by a mean seascape integrity value (or a range of values), and then be able to "classify" a given site according to the computed value without previous cluster analyses.

The proposed seascape integrity index is also particularly adapted to rocky environments, where relief and biodiversity are directly linked. At present, the lack of suitable biological index for rocky substrata is obvious, despite numerous scientific studies for that purpose (e.g. Capo 1998; Harmelin et al. 1981; Hereu et al. 2004; Pérez et al. 2000; Pérez 2001; Pérez et al. 2002; Pérez et al. 2003). The seascape integrity index we developed can then be a new tool that could complement other existing biological indices, especially those used for the Water Framework Directive (WFD) implementation, such as CARLIT (CArtography of LITtoral and upper-sublittoral rocky-shore communities; see Ballesteros et al. 2007), or for the monitoring of fish assemblages, such as FAST (Fish Assemblages Sampling Technique; see Seytre and Francour 2008, 2009). Moreover, as recommended by Garcia-Charton et al. (2000), this index could be used to characterise heterogeneity in relation to the management of fish assemblages within Mediterranean MPAs. In addition, because the proposed index only entails a low cost for data collection, the seascape integrity value of a large number of sites can be analysed. If a deep and important change of seascape occurs, it will then be possible to have a reference value before and after the modification. In the past, the introduction of invasive species, such as *Caulerpa taxifolia* (Meinesz et al. 1993; Meinesz et al. 2001), or habitat destruction caused by a strong storm like the one that occurred in 2008 along the Spanish Mediterranean coast (Garcia-Rubies et al. 2009) resulted to a probable, but not quantified, change of seascape integrity value. Habitat restoration for such disturbed ecosystems is possible, and previous knowledge of the seascape integrity value before the disturbance will be useful in assessing the effectiveness of the restoration process. Lastly, the ability to quantify seascape complexity allows us to calculate a degradation function (i.e. as human frequentation increases, habitat stress increases and habitat complexity decreases), and to assess the carrying capacity of an ecosystem as proposed by Dixon et al. (1993).

Acknowledgments We sincerely acknowledge Valérie Rico-Raimondino (PACA Region), Nathalie Quelin (Direction Régionale de l'Environnement et de l'Aménagement du Littoral, PACA Region) and Pierre Boissery (Agence de l'Eau Rhône Méditerranée Corse) for their permanent support during the implementation of this study.

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Editors
Olivier Musard
Agence des aires marines protégées
Brest
France

Laurence Le Dû-Blayo
Université de Rennes 2
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France

Patrice Francour
Université Nice Sophia Antipolis
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France

Jean-Pierre Beurier
Université de Nantes
Nantes
France

Eric Feunteun
Muséum National d'Histoire Naturelle, Station Marine de Dinard
Dinard
France

Luc Talassinos
Provence-Alpes-Côtes d'Azur
Direction Régionale de l'Environnement de l'Aménagement et du Logement
Aix-en-Provence
France

ISBN 978-3-319-03439-3 ISBN 978-3-319-03440-9 (eBook)
DOI 10.1007/978-3-319-03440-9
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014931370

Printed on acid-free paper

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