Olivier Musard · Laurence Le Dû-Blayo
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Underwater Seascapes

From geographical to ecological perspectives

Springer

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A Step Forward

The underwater landscape is an engaging issue. Can the underwater world be described as landscape within the meaning of the European Landscape Convention as discussed at this Seminar?

The Convention states that it applies to “the entire territory of the Parties and includes land, inland water and marine areas”. It defines “landscape” as “an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors”. Each Party thus undertakes to “recognise landscapes in law as an essential component of people’s surroundings, an expression of the diversity of their shared cultural and natural heritage, and a foundation of their identity”.

Obviously, populations do not generally live in marine areas (the intertidal environment, at the interface of land and sea) or submarine spaces. People can, however, travel, discover and “perceive” the landscapes they hold, in a variety of ways such as walking, swimming, diving, sailing, flying, etc.

Seascapes and underwater landscapes are also deeply anchored in the collective imagination: Greek myths, the works of Virgil, tales of towns engulfed, Jules Verne’s books, fairytales (The Little Mermaid), documentaries by Commandant Cousteau, films (The Big Blue, Océans, etc.), comic strips and other media have made a great contribution by marking entire generations.

The papers presented at this Seminar held in Brest in March 2010 about Underwater Landscape demonstrated concern for understanding and discovering the spatial structures of seabeds by geology, geomorphology, bathymetry, etc. Other presentations of underwater areas focused on an analysis of once populated territories, through the natural or cultural riches they contain.

With their sensitivity and detailed knowledge of ecosystems, landscape designers show that the seascape and underwater landscape can also be assessed as part of a project, i.e. knowing what we are doing and assessing the impacts. Work on underwater landscapes engaged at the Landscape School in Versailles will provide insight into this topic.

Inter-disciplinary work is now necessary to minimise the impact of activities or projects on these fragile environments and to manage both land and marine areas as intelligently as possible, building on our knowledge of the environment and with full respect for natural processes.

The underwater landscape must therefore be tackled by both hard and soft science, since it is of public interest, at ecological, environmental, cultural, social and economic levels. From time immemorial, writers, poets, artists, photographers and musicians have found inspiration in the formidable wealth of natural, cultural and landscape resources that these areas form. We must now further our knowledge and recognition of them.

The European Landscape Convention stipulates that appropriate protection, management and planning of the landscape can contribute to job creation. We must therefore promote the marine environment, in accordance with its values and with a sustainable development approach. The Convention states that we must respond to the public's wish to enjoy high quality landscapes and play an active part in their development.

The Parties to the Convention therefore undertake to protect, manage and/or plan their landscapes by adopting both general and specific measures. They undertake to:

- define and implement landscape policies aimed at landscape protection, management and planning;
- establish procedures for the participation of the general public, local and regional authorities, and other parties with an interest in the definition and implementation of landscape policies;
- integrate landscape into regional and town planning policies and into cultural, environmental, agricultural, social and economic policies, as well as any other policies with possible direct or indirect impact on landscape.

The Parties further undertake to promote landscape awareness, training and education, identification and assessment, as well as the definition of landscape quality objectives and landscape policy implementation.

Awareness must be raised in civil society, private organisations and public authorities of the value of landscapes, and their role and changes; photography competitions are in this respect particularly useful. The Parties are required to promote training for specialists in landscape appraisal and operations; multidisciplinary training programmes in landscape policy, protection, management and planning for professionals in the private and public sectors and for other interested organisations; and school and university courses which, in the relevant subject areas, address the values attaching to landscapes and the issues raised by their protection, management and planning. The attention of future generations must also be drawn to the value of the marine environment. The relevant players must be involved with a view to improving knowledge of landscapes and landscape identification and assessment procedures must be guided by sharing experience and methodologies. Landscape quality objectives must be determined for the landscapes identified and assessed, after consulting the public. Lastly, instruments aimed at protecting, managing and/or planning the landscape must be introduced.

The European Landscape Convention is an appeal to the collective intelligence. It acknowledges the landscape as an important part of the quality of life for people everywhere: in urban areas and in the countryside, in degraded and high quality areas, in areas recognised as being of outstanding beauty as well as everyday areas. It expresses concern to achieve sustainable development based on a balanced and harmonious relationship between social needs, economic activity and the environment.

Even if we do not see them directly and continuously, we know that underwater landscapes are there, under our responsibility, ready to reveal themselves and fill us with wonder. May this be sufficient to awaken our imagination and spur us into action.

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Grand Témoin/Key Observer of the
Seminar "Paysages sous-marins"
2011, 29-31 March, Brest, FRANCE

Preface

The European Landscape Convention was adopted on 20 October 2000 in Florence (Italy) and came into force on 1 March 2004 at European level and on 1 July 2006 in France. It provides a framework for discussion and reflection to promote the protection, management and planning of European landscapes, in their every dimension. Pursuant to the terms of the Convention, landscapes must be identified and assessed. It is therefore vital that we turn our attentions today to the concept of **underwater seascape** or underwater landscape: the epistemological and scientific issues are extremely important, particularly because, if we want to take this notion into account, it will combine various disciplines, involve widely accepted concepts (ecosystem, habitat, biocoenosis, biotope, facies, population) and open up new avenues to be explored with new currents of thought and topics of research or work (photographic observatories of underwater seascapes for example).

Reference to the "underwater seascape" dates back at least to the nineteenth century. It swiftly became a term used by deep-sea divers in the 1940s–1950s and has been employed increasingly by French scientists since the 1990s. Branching back to a process of territorialisation and individuation of the underwater littoral fringe, it is gradually gaining ground through portrayal by image, film and photography, but also by new three-dimensional mapping technologies. Such representations offer continuous overviews of an area to which we often take a fragmented approach. The sea is no longer represented like a completely isotropic area; it is discovered, in every sense of the word, revealing a mosaic of habitats, shapes and reliefs and their related wildlife components, figured and figurative objects in interaction with environmental, social and economic issues and in need of management and protection.

The concept of underwater seascape or landscape is a growing subject of study, as scientific literature attests. Publications on the topic have multiplied in recent years, addressing both the question of scalar levels and interaction with key ecological concepts, as well as connectivity within landscape ecology. The appeal of underwater landscapes and the soar in leisure and tourist activities also raise issues of social representation, access and value. The challenges in terms of research are therefore real and important. Similarly, we can question the way public policies on environmental and landscape protection take underwater seascapes into account. At the bridge between materiality and immateriality, between nature and culture, marine areas call for a pluridimensional approach wherein every element must be appropriately protected and managed. Landscaping and territorialisation can undoubtedly contribute to the obligation to protect biodiversity and ecosystems, and will furnish a vital corpus for the development of collective empathy for the sea and the seabed.

In France, the *Agence des aires marines protégées* (Marine Protected Areas Agency) is a public undertaking established by law in 2007, placed under the governance of the French Ministry of Ecology. Its main role involves supporting public policy for marine protected area establishment and management. As such, we felt impelled to address this topic and explore its many conceptual, legal and technical facets, in the light of the protection, management, knowledge and mediation issues surrounding coastal and marine areas. To do so, the Agency established a steering committee which greatly insisted on the need to develop and drive a cross-cutting approach. During this seminar held in Brest (29–31 March 2011), thanks to multidisciplinary expertise and through extensive debate, we identified various leads to support and structure the emergence of the underwater landscape. The following pages aim to reflect the full wealth of the discussions held.

Lastly, we must add that the seminar initially took place in French only, since French research into the topic of landscapes boasts an abundance of literature. It has been marked by intensive periods of debate, punctuated with sacralisation and dismissal: this is such a specific subject in the history of science and ideas that an independent analysis, disconnected from foreign currents of thought, is possible. Organising reflection on underwater seascapes exclusively in the French language was in line with that tradition. When Springer suggested publishing the proceedings in English, the question of the title obviously arose. While the term "*paysage*" used in French is polysemous and devoted to interdisciplinary reflection, in English, application of the word "landscape" to the marine and submarine world gives rise to an array of possible terms which do not necessarily cover the same object: possible variations include *seascape*, *marine landscape, underwater landscape*, *submarine landscape*, and *submarine scenery*. Although Underwater Seascape was selected, several authors of chapters have nonetheless preferred to use Underwater Landscape. The matter was in fact never completely settled, but the seminar left no doubt that this work should pave the way to broader reflection at European and international levels, or provide guidance for more specific topics of research. These proceedings therefore also seek to initiate future cross-disciplinary debate on an essentially polysemous subject.

We would once again like to extend our warm thanks to all the contributors, to Editions Springer, and particularly to Maguelonne Dejeant-Pons, Executive Secretary of the European Landscape Convention-Council of Europe, for accepting the role of Grand Témoin (key observer) and for allowing us to share in her expertise on European Landscape Convention implementation.

Olivier Musard
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Chapter 1
Introduction: Towards a Shared Language: Semantic Exchanges and Cross-disciplinary Interaction

Laurence Le Dû-Blayo and Olivier Musard

Abstract Any interdisciplinary undertaking demands a comparison of the paradigms and vocabulary specific to each scientific corpus involved, particularly where the concept—landscape—is complex and applied to a difficult environment—the underwater world. For this first cross-disciplinary work focussing exclusively on "underwater landscapes", certain methods and epistemological reference frameworks must therefore be put into perspective in order to mitigate the impact of partitioned and partitioning cultural schemas on this combined approach to the "underwater landscape". This general introduction thus establishes a preliminary basis for the subsequent chapters herein but also provides illustration of a complex, cross-disciplinary pathway of reflection transcending the three-part development selected.

Keywords Paradigm · Epistemology · European Landscape Convention · Landscape ecology · Coastal zone · Mountain · Representations · Connectivity · Mapping · Scuba diving

1.1 Introduction

There is no shortage of questions[1] surrounding such a complex concept (Antrop 2013): is the landscape approach within the meaning of the European Landscape Convention appropriate in the underwater world? Can the underwater environment

[1] This introduction builds on reflection initiated in Olivier Musard's thesis (2003) and the article written in 2007 in collaboration with Jérôme Fournier and Jean-Pierre Marchand (Musard et al. 2007).

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be a "landscape" in the sense of an area appreciated by society? Should we restrict the meaning to that of a physical description? To put it plainly: is there an underwater landscape and if so, are the concepts and methods the same as for terrestrial landscapes? How then, should the disciplinary approaches to landscape, both terrestrial and underwater, be organised? What are the prospects in terms of public policy? We must therefore attempt to build lexical bridges and develop correspondences between subjects of research to avoid, where possible, cross-disciplinary debates confined to their specific frameworks of reflection and analysis.

Prior to paradigms and their implications in terms of methods and public policies, the authors are faced with the concrete question of terminology and particularly of the French–English translation. The term *paysage sous-marin*, in French, is not problematic per se. Only the word *paysage* is used both in everyday and scientific language to describe the area perceived by an observer. The generic term *paysage* is frequently associated with an adjective which specifies either the spatial scope of application (*paysage rural*, *paysage urbain*, *paysage littoral*, etc.), or the methodological scope: *écologie du paysage*, *pédopaysage*[2], etc. (Le Dû-Blayo et al. 2008a, b). The phrase *paysage sous-marin* is therefore immediately understood (even if it subsequently criticized) as a reference to and consideration of the landscape, limited to areas underwater.

The situation is more complex in English, as *landscape*, used to refer to landscape in general, is completed by specific vocabulary based on a spatial qualification: *townscape* (urban landscapes), *seascape* (coastal and marine landscapes); *landscape* is thus more precisely understood to mean *countryside landscapes*, i.e. exclusively rural. The term *seascape* is developing particularly in public policy, through reflection on the protection of marine landscapes[3], within the framework of off-shore wind farm establishment for example. It is used in everyday and scientific English to refer more particularly to marine and coastal landscapes, i.e. the sea seen from its surface. It may be completed by an adjective to specify its use for a sea view, beneath the surface: *undersea seascape, underwater seascape,* thus encompassing all views within the body of water, therefore in the three-dimensional entirety of the *Big Blue*. But the term *landscape* itself can be specified in an underwater application as evidenced by Kirill M. Petrov's work in Russian titled *Underwater landscapes: theory, methods and research* (1989). The reference *Underwater landscape* (also including fresh water) is in fact widely used alongside other references such as *undersea landscape* or other more specific terms like *seafloor landscape* or *seabed landscape*. Underwater landscape is therefore taken to be the continuation of a landform beneath the water's surface with, in the same way as on the surface, a relief, geology, patterns of erosion, plant coverage, habitats and related human activities, particularly the exploitation of resources found on this underwater topography. English law does not therefore establish the same divide as French law between *undersea landscape* and *landscape*, and the water level is a fluctuating limit on a fixed topographic continuum. In this

[2] *Landscape ecology, soilscape*.

[3] For example "Dorset coast landscape & seascape character assessment", 2010 www.cscope.eu/_. . . Dorset/Land-and_Seascape_Character_Assessment.pdf.

sense, the term *seascape* can be regarded as a landscape in relation to the sea's surface, seen from above and/or below, whereas *landscape* is relative to a landform, above and/or below the water. Joshua Nash uses the phrase *underwater landscape* in his article on underwater toponymy, demonstrating the link between the denomination of underwater reliefs and that of neighbouring terrestrial landscapes (Nash 2013). In this work, the translation *underwater seascape* has nonetheless been chosen, to emphasize the maritime specificity. This choice also corresponds to current research (Pittman et al. 2011; Teixidó et al. 2011) but does not in any way fundamentally call into question the reference "Underwater landscape" also used by several authors of chapters.

1.2 Landscape Within the Meaning of the European Convention

1.2.1 Is There an Underwater Landscape?

From a social standpoint, the term "underwater landscape" or "underwater seascape" is employed in various lines of work and leisure, particularly among divers, and therefore raises fewer questions than in the scientific world, where its use is contested and was discussed at the symposium in 2011. More precisely, if landscape is conceived as defined in the Florence Convention, i.e. "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (European Landscape Convention: ELC)[4], can it be applied to the underwater world? If it can, how can this particular landscape be given recognition in public policies? Here we see the full extent of the methodological issues and political constraints that recognition of underwater land- or seascapes can engender.

The fact that the landscape's character "is the result of the action and interaction of natural and/or human factors" poses no problem in terms of application to the underwater seascape, and numerous studies and practices have already analysed these factors, particularly via the exploitation of deep sea geological or food resources and the management of resulting conflicts (Trouillet et al. 2011).

The question of "area/ *territoire*" is slightly trickier, as it obviously cannot be a human living environment beneath the surface of the sea. Three particular points must nonetheless be underlined: first, coastal inhabitantscan often develop a considerable sense of 'ownership' of the undersea environment, and particularly the near undersea area, as a result of its resources such as fishing zones. The near undersea environment is therefore indeed an area in the sense "a portion of the land surface, taken over by a social group to ensure its reproduction and meet vital needs" (Le Berre 1992). The development of names specific to underwater areas demonstrates that more or less visited places and emblematic sites are created (Musard 2008). This

[4] The French version reads: "partie de territoire telle que perçue par les populations, dont le caractère résulte de facteurs naturels et/ou humains et de leurs interrelations".

is confirmed by J. Nash (2013): "Place-naming creates links between previously unmapped landscapes and represents how through the naming of landscapes, and even underwater landscapes, places are created, remembered, and travelled to". Secondly, not all terrestrial areas regarded as landscapes are living environments or even everyday landscapes, one striking example being the parallel with high mountain areas we draw below. Lastly, we should point out that the definition of landscape given in the French version of the European Landscape Convention uses the term *territoire* (territory). The difference in the translation is quite strong, *area* being much more neutral than *territoire* since it does not necessarily imply any social ownership.

The key remaining questions are a matter of perception by people. This opens up the field of research to the sensory perception of underwater seascapes, to representations (aesthetic, scientific, professional, etc.) of underwater seascapes, and to human access to such areas.

The first area of reflection relates to the visibility of the underwater seascape: the depth of vision of underwater seascapes is generally smaller than in air and can, in very turbid water, be limited to a few dozen centimetres. The notions of panorama, or even quite simply perspective, viewpoint, belvedere and background are therefore somewhat inoperative in the undersea environment. Such reduced visibility is a major obstacle to the installation of certain landscape monitoring tools, such as photographic observatories for example. Is the scale of vision in the submarine world compatible with the notion of landscape? Obviously, in the right conditions, undersea views do exist and provide matter for spectacular photos or films. Conversely, we must emphasize that many terrestrial situations are difficult to put in perspective (very partitioned urban landscapes, thick forests or groves) and there can be little or no visibility (landscapes in fog or heavy rain, landscapes by night). But more radically, we must reassert that landscape is not solely perceived by our eyesight but by all the other senses too. Now, acoustic atmospheres and tactile perceptions increase ten-fold in water, and this clearly enhances the emotions we feel when visiting underwater seascapes and thus the enjoyment of diving (Straughan 2010). The study of underwater seascapes is therefore a stimulating and promising area of research in the light of theoretical advances in emotional geographies (Davidson et al. 2005).

The question of representations is also often raised. In the debate on the *artialisation* of land, it emerges as a primary condition of the landscape's very existence; but it is also part of the historical approach to interrelation between cultural media and landscape enhancement.

Lastly, access to this landscape is a recurring question: there is no doubt that the undersea environment is not a human living environment and that relatively few people have had the opportunity to see these seascapes *in situ*. But this question applies equally to all terrestrial environments hostile to man, such as cold deserts, which not only cannot be a lived in but are only seldom travelled to, as part of rare expeditions. Yet, the Antarctic does offer landscapes and people everywhere are fascinated by pictures of it. To exist, a landscape need not be a living environment for people; it must merely have been perceived and recounted by someone, like the highest mountain peaks.

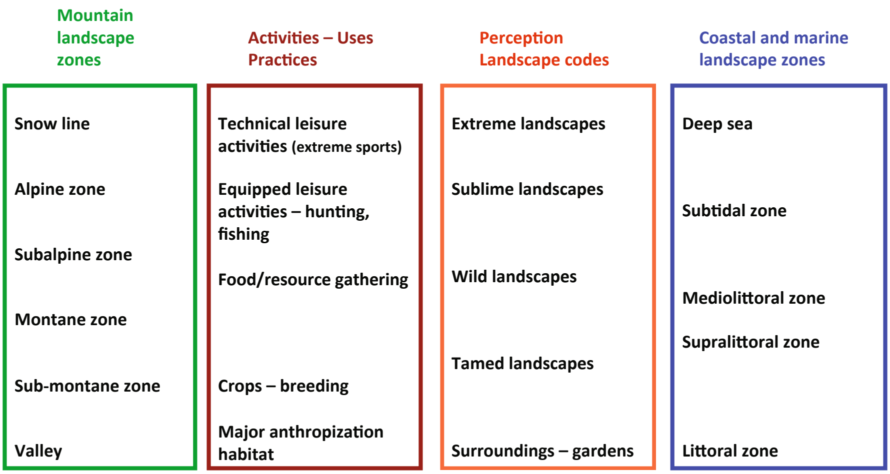

Fig. 1.1 Mountain and coastal landscapes: symmetries in the gradients of natural constraints, degrees of anthropization and landscape recognition

1.2.2 Similarities Between Mountain and Coastal Landscapes

Mountain landscapes are similar in many ways to coastal landscapes and we can use this comparison to better identify the characteristics of the latter (Fig. 1.1).

From the bottom of the valley to the mountain top, and irrespective of the landscape's morphology, mountain landscapes are structured in zones due to the gradient of constraints, namely the drop in temperature. Similarly, from the surface to the depths, underwater seascapes are structured in zones primarily due to the reduction in light. The foreshore itself is structured in zones (supra, mid and subtidal) based on the length of submersion.

In the mountains and on the coast and the near undersea environment, human societies have developed a sense of ownership of these landscapes as a result of their characteristics (limits, exposed or sheltered slopes, etc.), the way they function (transfers, complementarity, etc.) and the socio-cultural specificities that define or attach to them. In addition to the natural gradients, there are the human-induced gradients: the village zone in both valleys and on the coast is associated with crop farming and breeding or marine breeding on the foreshore (particularly mussels and oysters listed as farming activities in the French inventory of economic activities). These activities gradually give way to the hunting or fishing zones and then to the less accessible and seasonal zones. Lastly, the highest- or deepest-zone is only accessible after much effort and very specific and costly technical preparation. Everyday uses of coastal or valley surroundings gradually give way to extreme recreational and professional activities which, by definition, are but occasional forays into environments hostile to man.

Above and beyond their uses, perception of these landscape zones has in certain respects followed a similar pattern, as already mentioned (Corbin 1988): far from the vast farming plains, these landscapes were late to be brought to light; attention then turned to picturesque valleys and rocky coastlines, and subsequently to the sublime frozen or maritime horizons; lastly, in the twentieth century, human societies developed a fascination for untamed, rebellious nature.

Thus, very close to our towns and cities, high reliefs and sea beds offer a gradient of environments, areas and perceptions producing a gradient of landscapes which paradoxically function and are structured in a similar way. Such similarities argue in favour of greater recognition of underwater seascapes, within the meaning of the European Landscape Convention.

1.3 Culture and Nature

1.3.1 Social Emergence of a Term

The terms *underwater seascape* or *landscape* immediately became part of the language used by the very first deep-sea divers (Diolé 1954), particularly those keen to take underwater pictures during their dives, such as L. Boutan in 1893 (Boutan 1893; Weinberg et al. 1993), and J.-Y. Cousteau ("Silent Landscapes", 1947 film). This representation is in line with a process already initiated by Jules Verne in his novel "Twenty Thousand Leagues Under the Sea" (1870). The undersea walks and travels take place in a luxuriant setting and the fauna and flora are described in great detail. The narrative employs the full array of landscape description terms and pours forth a taxonomic classification, as if the liquid element were a totally transparent expanse, as if the sea had opened up, offering the human observer the spectacle of its depths, and their diversity and particularities. Jules Verne describes his characters' travels amidst underwater forests and landscapes with unquestionable literary rotundity. Yet, he achieves an amazing feat since the term "underwater landscape" is never used in the text except for the title of the famous and no doubt one of the most well-known engravings captioned "*Underwater landscape of Crespo Island*" showing divers walking along a path lined with seaweed and cnidaria, and a few jellyfish swimming above.

The representation of this underwater space to which Jules Verne's characters take us is not that of the ocean deeps but a near undersea environment, discontinuous and shallow, with different features, characterised by its relief, the texture of the ground, the fauna and the vegetation. In fact, this further confirms the territorialized nature of the "*Underwater landscape of Crespo Island*": "We at last arrived on the borders of this forest, doubtless one of the finest of Captain Nemo's immense domains. He looked upon it as his own, and considered he had the same right over it as the first men had in the first days of the world. And, indeed, who would have disputed with him the possession of this submarine property?" Insofar as Captain Nemo, his men and his three guests are the only visitors, it is a proto-territory, a sort of frontier. This approach does not bear the hallmark of Jules Verne, a positivist writer developing half-fiction, half-scientific novels. It marks a turning point, even a break, in the conception of the undersea world, which was explored with increasing frequency at the turn of the nineteenth century, the French novelist in fact predicting the invention of these areas in the second half of the twentieth century (Marchand 2000). Observed from a general view point, better studied from a specific angle, the underwater world, or at least the way it was portrayed, at last became a more attractive reality.

In parallel to the dissemination of books and magazines on deep-sea diving, undersea pictures gradually emerged, according to J.-P. Montier (1998), as a medium creating and stemming from a certain emotional and sensory vision of what divers regard as landscape, a beautiful underwater landscape. This aesthetic landscape characterisation, which remained relatively limited in terms of pictorial works until the 1970s, is closely linked to an area of practice that divers call a dive site; by transposition, it extends the reflection of F. Tremblay and Ph. Poullaouec-Gonidec (2002): "By belonging to a recreation group [. . .] an individual acquires specific knowledge (interpretation keys) which, through the combination of various distancing tools (literature, painting, photography), allow him to mediatise his intimate experience of the site".

In the 1990s, various authors of diving books thus used the term "underwater landscape" to encourage discovery of the subaqueous environment and underwater species (Weinberg 1993; Dutrieux et al. 1999). Furthermore, in recent years, this principle of progressively reading the underwater landscape and the characteristic and emblematic species its holds has led private and public operators to develop global diagrams or representations of the undersea site to be explored. Building on the mapping procedures used in science, these cross-sectional, three-dimensional, perspective, or flat reproductions suggest standard trails via outstanding points. They reproduce the mosaic of topographic and wildlife features that are representative and characteristic of the site. The observer thus sees the site globally and spatially as if the sea had withdrawn, as if the body of water had disappeared. Such use of pictorial representations contributes to the recurring use of "underwater landscape" by divers. This system of representation is undeniably in line with a process of understanding and consuming undersea areas in general, and sites of underwater practices in particular. It becomes an educational and tourist tool fostering faster recognition and knowledge of a site and its essential components. These landscape transcripts and the trails they propose are a combination of the biotic and abiotic features taken into account and of consumer logics seeking to define the most "interesting" things to see, thus extending to underwater landscapes the tradition of tourist guides and excursions popularised since the nineteenth century.

Thanks to the extension of protection measures, this sensory discovery and characterisation of underwater seascapes has recently begun to gain ground among managers of undersea protected areas, giving rise to state orders in respect of underwater seascapes. Landscape design approaches are thus applied to the underwater landscape with the whole battery of site and landscape atmosphere descriptions: different views, main features, block diagrams, sketches, photographs, etc. (Aubinet 2012). This voluntary process of discovering, assessing, sharing and managing underwater landscapes thus reaches beyond analysing visitor impact on the protection of seascapes and the undersea environment (Barker and Roberts 2004). Underwater landscapes become the object of broader consideration, within the meaning of the European Landscape Convention.

1.3.2 The Necessary Interdisciplinary Articulation

Landscape is a cross-cutting concept that demands an interdisciplinary approach to be understood in its entirety: questions will thus be addressed from landscape construction (physical and anthropic factors), to the description of shapes (spatialization, characteristics), through to perception (social and cultural filters). The ongoing stream of programmes, works and interdisciplinary seminars on the topic since the 1980s[5] and the interdisciplinary broadening of specialized journals like *Landscape Research,* clearly illustrate the emergence of landscape as a special ground for cross-disciplinary research and exchanges between researchers, stakeholders and citizens.

Works span four key areas of thinking, that are open and in constant interaction, i.e. cultural approaches, planning approaches, environment-based approaches and economic and legal approaches (Fig. 1.2).

Regarding the underwater seascape, there is a clear imbalance between these fields in both scientific production and public policy implementation. Natural sciences have indeed extensively studied the sea depths and the way they work: underwater reliefs, sedimentary flows, currents, thermal and salinity gradients, animal populations, phytosociology, etc. There is close interaction here with areas of economics either for the purpose of exploiting resources (fish stocks, mineral and energy, etc. resources) or to protect biodiversity (marine protected areas), but also in the legal field through exploitation rights, including in respect of tourist resources. However, between underwater seascapes and ecocomplexes or habitats, the scientific community is still hesitant as to the terminology to be employed and approved. How can we avoid confusion in use of the word "landscape", while harnessing its heuristic potential? Beyond underwater seascapes, the interrelation between ecology, landscape and landscape ecology is a topical issue, as in the terrestrial area (Kirchhoff et al. 2013).

Arts and literature have long explored this strange, oneiric and mysterious underwater world which lends its fantastic scenery to all dreams, introspections and intrigues. The underwater fringe of the coast becomes an area in its own right and is represented, travelled through and observed. Its recreational and tourist

[5] 1982: *Mort du paysage? Philosophie et esthétique du paysage,* Champ Vallon, Mâcon, p. 238.
1984: *Lire le paysage, Lire les paysages*, Ed. C.I.E.R.E.C. Université de St-Etienne, p. 314.
1985: *Paysage et Système—de l'organisation écologique à l'organisation visuelle,* Editions de l'Université d'Ottawa.
1986: *Milieux et paysages. Essai sur diverses modalités de connaissance*, Paris, Masson, p. 154.
1989: *Composer le paysage: construction et crise de l'espace 1789–1992*, Champ Vallon.
2008: *Landscape: from knowledge to action,* Berlan-Darqué M., Luginbühl Y., Terrasson D. (Dir*)* Ed Quae, p. 311.
2010: *Paysages*, Recueil des résumés, 135ème congrès des sociétés historiques et scientifiques, Neuchâtel, p. 359.
2013: *Paysage et développement durable*, Luginbühl Y., Terrasson D. (Dir) Ed Quae, p. 311.
2013: *The routledge companion to landscape studies*, Howard P., Thompson I., Waterton E. (Dir.), ED., Routledge.
2013: *Landscape & Imagination, towards a new baseline for education in a changing world*, Newman C., Nussaume Y, Pedroli B. (Dir.), Ed; Bandecchi&Vivaldi, p. 718.

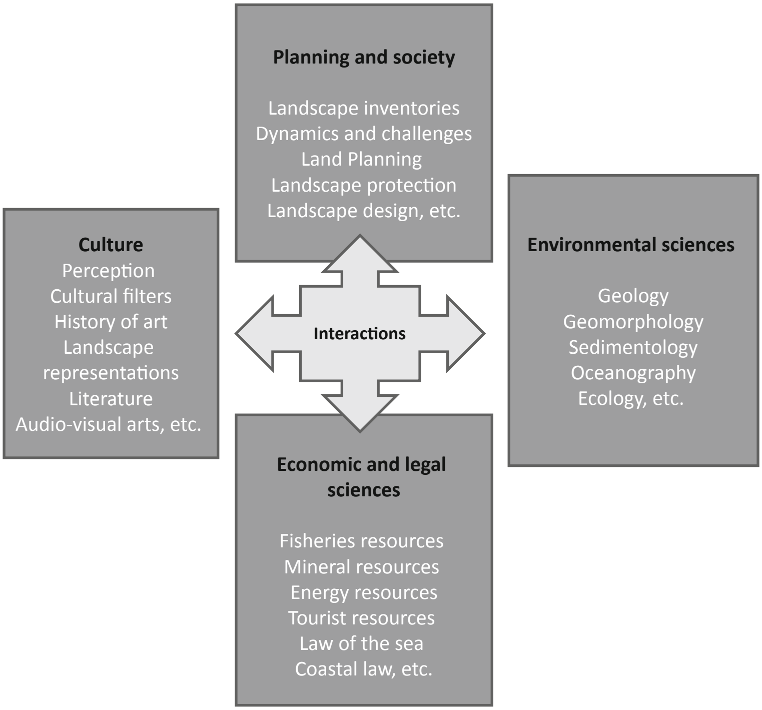

Fig. 1.2 For an interdisciplinary approach to underwater landscapes

vocation is confirmed. It is socially and economically structured through images and representations in which emotion, sensitivity and aesthetics merge against a cultural backdrop of films and literary works. The unknown is therefore fully mediatised and socialised by the omnipresent image. This realm, tackled at last from its best angle, thus arouses interest among divers and non-divers alike.

Social sciences have, on the other hand, been very hesitant in addressing this landscape (Parrain 2012): inventories and maps are incomplete, irregular and often restricted to a biogeographical approach (Fournier 2000); monitoring of uses is very limited, as is knowledge of social representations. Coordination of economic activities is still very often based on a short-term predation model, through to resource depletion. Management of the undersea area fluctuates between state responsibility and individual practices; underwater seascape protection measures remain concealed behind measures to protect biodiversity, often limited to marine protected areas. The underwater landcape is an exploratory ground, both for social sciences and landscape policies.

While economics (wind energy, aquaculture, etc.) and social (underwater tourism) or cultural practices are moving into the field of underwater landscapes and make growing use of the relevant terms, recent publications on landscape in social sciences greatly evade the question. P. Howard's work (2012), which explores sonorous or olfactory landscapes, contains no occurrence of an underwater landscape term in its five-page index. In a very learned approach to geography and vision, Denis Cosgrove (2008) explores the vision of the land in history, according to the hemispheres, on the ocean and even in cosmography, but does not break through the water's surface. Similarly, in the introduction to his summary on the landscape, Y. Luginbühl (2012) touches upon the water's surface in an ambiguous manner: "It—the landscape—thus refers to contemplation and to a specifically terrestrial area excluding the sea, unless the word *land* means the planet".

Yet, social sciences have conceptual designs and methodological tools that are quite capable of standing the test of underwater landscape analysis. This is a new area of research that social and natural sciences must explore, as part of an interdisciplinary approach.

1.4 Studying the Underwater Landscape

1.4.1 Which Reference Terminology for Which Landscape Approach?

In this interdisciplinary approach to landscape, vocabularies intersect and complete or contradict one another. Admittedly, the European Landscape Convention established a definition of the landscape, providing a framework for all contracting states' public policies in respect thereof. However, firstly not all disciplines have acknowledged landscape as being rooted in people's perceptions and secondly, each discipline retains its own methods, tools and descriptors. Furthermore, in the case of underwater landscapes, or seascapes, the specific constraints exacerbate questions concerning dialogue between disciplines.

Words are associated with images and the construction of representations of the underwater world is a core aspect here. We individually assess the degree to which such representations and images help to forge the collective construction of underwater seascapes, not solely by sharing a corpus of films or novels, but also by sharing maps, block diagrams, sketches, sections and scientific charts.

To open up reflection as an introduction to this work, and without claiming to do so completely, we can here suggest a correspondence between terms and concepts that interlink and ultimately form a corpus to be shared in the approach to underwater landscapes (Fig. 1.3).

The question of representations is no doubt one of the key aspects of an interdisciplinary approach to underwater landscapes: representations stemming directly from the emotions that underwater landscapes arouse, developed within a framework of personal and social filters; but also all representations, i.e. images, produced through work on the underwater world and which, from a bathymetric chart to a film, via a photograph of a protected site, help build a collective representation of underwater seascapes. Thus, permeability is high between representations of terrestrial landscapes and those of the underwater world, because the same techniques (maps, block diagrams, cross-sections, etc.) and very often the same vocabulary (plain, shelf,

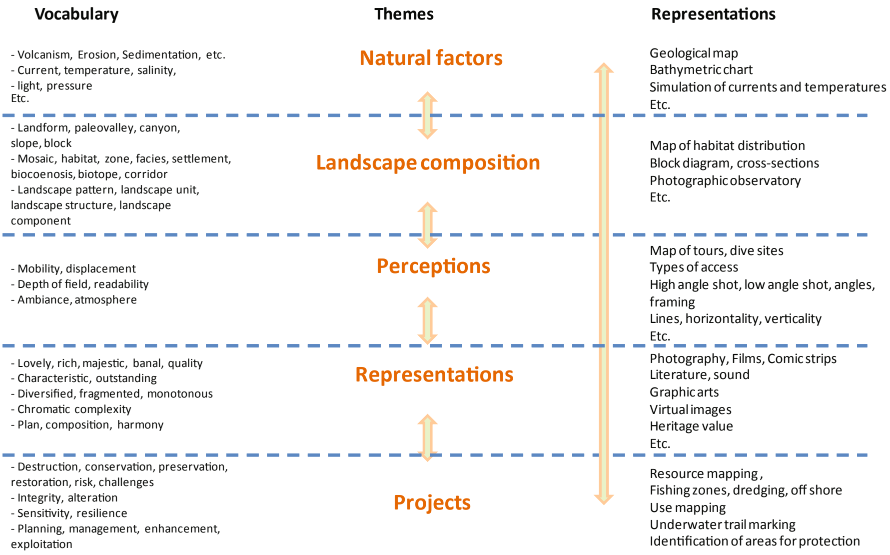

Fig. 1.3 Which terms for which representations?

valley, kelp forest, Posidonia bed, etc.) are used. There is also considerable cross-influence and iteration between approaches, from the scientific to the imaginative representation, as social recognition of underwater seascapes is fuelled by scientific knowledge, but is also a pre-requisite to the development of scientific research.

Yet, the whole question of landscape conceptualisation does not amount solely to the representation thereof. Simple or simplistic representation of certain concepts can even result in deviations in their use, as an easily understandable representation spreads faster in people's minds and in practices to the detriment of a deeper and necessary analysis of the complexity of landscapes. This may be the case with the connectivity concept and its corridor representation, which justified the contribution of landscape ecology to preserving biodiversity in the face of fragmentation. Now, the tracing of corridors and the diktat of connectivity are not an adequate answer to all problems of ecological quality, nor necessarily to all environments, as we have seen through studies on the ocean environment where exchanges and movements of species differ totally compared to land. Thus, reducing the question of ordinary biodiversity to the establishment of green corridors across the territory can be counter-productive. *A fortiori*, the cross-disciplinary application of one concept (connectivity) and one type of representation (corridors) to social or human sciences can create exaggerated simplifications. This tendency can become dangerous when the force of a representation is considered to offset the understanding of complex relationships existing within a landscape and claimed to be a lever for public policy *via* the design of simplistic tools (Mikusinski et al. 2013).

Therefore, the aim is not necessarily to use the same descriptive categories in all disciplines, since the content described is not the same, but rather to build bridges and connections (Fig. 1.4) to facilitate cross-disciplinary landscape reading. Thus, the

Landscape mapping	Landscape ecology	Planning / ELC	Landscaping
Descriptors and scales	Matrix Corridor Patch	Unit Structure Component	Atmosphere Structure Feature
Title	Typology of habitats	Landscape atlas	Landscape design
Objectives	Good environmental status Biodiversity	Landscape quality Diversity / identity	Landscape amenities

Fig. 1.4 Correspondence between reference terms specific to scopes of research

question here is not so much that of underwater landscapes, but of interdisciplinarity in the study of landscapes in general.

However, the comparison of underwater seascape images developed by researchers from various disciplines is quite a direct and pragmatic point of entry in the joint construction of a subject of research.

1.4.2 The Operative Question of Scales

If we are to apply the recommendations of the ELC and draw up inventories of underwater landscapes, the transcription, particularly cartographical, raises numerous questions: how do we represent this three-dimensional space in which most movement takes place in the body of water and not on the bottom? Can we transpose the scales and vocabulary specific to terrestrial landscape mapping?

On a methodological and operational level, scale is inherent in the observer's position, field of vision, in the depth of field and in the biotic and abiotic factors taken into account and mapped (Collina-Girard 2002). In this case, underwater landscapes are assessed by an underwater observer who, by definition, moves around. He moves on the surface, in a water column and near a substratum, allowing him to view a variable portion of surface area and volume. The observer moves within a "sphere" whose radius defines the visual depth of field, itself contingent on highly variable factors such as the clearness or turbidity of the water, amount of light, depth, colour of the bottom or even the shapes of the reliefs (Aubinet 2012). The retinal perception of the elements seen over a trail takes place by gradually and selectively reading planes or "arranged" homogeneous units, which follow one another like a streaming landscape. For research by scuba diving, the fact that invisible expanses are gradually revealed without the help of any pre-existing global representation like aerial photographs for the terrestrial environment, seriously complicates the reproduction

Terminology	Surfaces	Description
Component	n x 1 m	Abiotic, biotic or anthropic element covering a small surface area
Location	n x 10 m	Limited area with a particular use or perception
Site	n x 100 m	Special areas, often around an emblematic feature
Landscape structure	n x 100 m	Characteristic organisation of a unit, consisting of components
Type of landscape	n x 1km	Homogeneous area in terms of relief, plant coverage, occupation (sequence)
Landscape unit	n x 10 km	Has a certain homogeneity compared to neighbouring units but a varying degree of internal complexity (mosaic, gradient)
Landscape group	n x 100 km	Grouping of units, regional overviews

Fig. 1.5 Reading and analysis scales

and assembly of the successive features and structures, in order to recreate the underwater mosaic and represent an underwater landscape in its entirety. This difficulty, together with the question of access, explains why maps of underwater landscapes are so rare, and why their content is often limited to certain data accessible from the surface (such as bathymetry) or capable of being extrapolated from samples (like geology). For obvious reasons of resources, only certain protected species have been completely mapped on detailed scales (Gourmelon 1996). However, technological progress is being achieved.

Having said that, the landscape inventory categories proposed in French legislation based on scales (components, structures, units) and those possibly added by landscape players and researchers (places, sites, set, etc.) are fully adapted to underwater landscapes and to studying the diversity, the mosaic or the fragmentation of landscape (Fig. 1.5).

There is therefore no major methodological reason to abandon land-sea continuity in coastal landscape mapping. Such Landscape Atlases, in which underwater landscape units extend terrestrial landscape units with which they partly share the same characteristics, particularly from a topographic and geological point of view, would naturally be of great benefit in understanding dynamics and uses but also in defining focuses for landscape management and protection.

1.5 Conclusion

The questions addressed in this introduction provide insight into areas of research, some of which will be explored in greater depth by researchers in the following chapters. One thing is however certain: underwater seascapes, or underwater landscapes do exist within the meaning of the ELC and they represent an increasingly common social challenge that must lead to appropriate public policies. These landscapes further represent a tremendous scientific challenge as not only can they complete our reading of the landscape continuum, but also and above all drive new approaches, particularly in the physical perception (embodiment) of landscapes.

Like certain types of terrestrial landscapes, particularly urban, underwater landscapes compel us to move away from traditional frameworks of countryside landscapes to develop methods that are not necessarily specific, but more innovative and favourable to renewed landscape theories. We therefore hope that underwater landscapes will be a stimulating field of research and one that will revive both landscape and disciplinary approaches.

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Chapter 2
Underwater Seascapes in the Eye of the Diver

Olivier Musard

Abstract Photography is one of the ways in which to study underwater landscapes. Using this medium gives the opportunity to view the sensitivity of photographers and in particular that of divers to underwater seascapes. From this realisation, a national photography competition on this topic was held in 2011. A selection of the very best pictures offers an interesting overview of the representation, materiality and poetry of the submarine world's landscapes.

Keywords Réunion island · French polynesia · Port-Cros island · Coral polyp · Zooxantella · Kelp forest · Ripplemarks · Posidonia · Land-sea continuum.

As part of this seminar and thanks to a partnership with the *Fédération française d'études et de sports sous-marins* (French Federation of Underwater Studies and Sports), the *Agence des aires marines protégées* decided to organise a national photography competition on underwater seascapes in mainland France and French overseas territories.

The aim of the competition was two-fold:

- gather material to outline a semiological analysis through a set of questions: Which angles of view are preferred? What effects do the light and perspectives produce? What are the most recurrent forms of relief? Is an underwater seascape static or dynamic?
- illustrate the materiality of underwater seascapes, combining aesthetics and ambiance, reflecting the words of J.M Besse (1992): "Landscape representation is the continuation and transformation of what, since the Greeks, has been the subject of philosophy: contemplation (theoria) of the way of the world. Landscape is the way of the world revealed [. . .]".

For these proceedings, some of the photographs are presented to illustrate this double aim.

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We once again extend our thanks to everyone who took part in this national competition and especially to the photographers who accepted to contribute to this portfolio.

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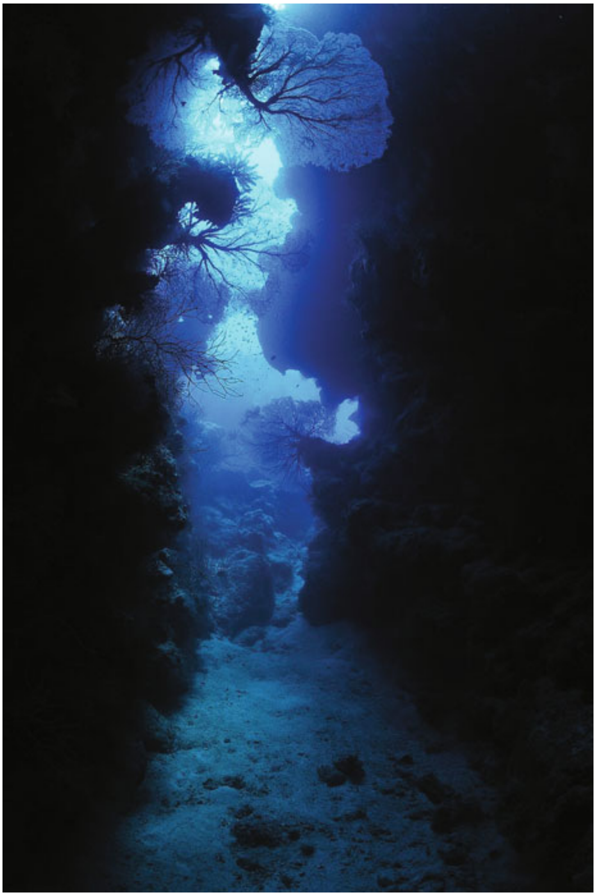


1st Prize, category: Underwater Seascape, Overseas territories

New Caledonia, Pacific Ocean

Playing on light, embracing the verticality, the photographer catches the instant delivering the underwater seascape from within like an eternal blue cocoon.

2nd prize, category: Underwater Seascape, Overseas territories

Réunion Island, Indian Ocean

Land-sea continuum, half-air half-water, at twilight, the landscapes reveal a harmony that global change is successively disrupting: here, the branching corals, the structuring pattern of this underwater seascape, don a white colour pointing to the landscape imbalances that lay ahead.

Category: Underwater Seascape, Overseas territories

Guadeloupe Islands, Caribbean Sea

Ideal transposition of a bucolic landscape: first image of a photographic tour setting out to discover hidden parts where the promise of new horizons lies at each twist and turn?

2nd prize, category: Underwater Seascape, Metropolitan France

Marseilles, Mediterranean Sea

Leaving nothing to chance, the organised patterns evoke a structural complexity in which landscape and wildlife become one, denying access and inviting the diver to remain on the edge of this impenetrable, fragile scenery.

2nd prize, category: Underwater Seascape, Metropolitan France

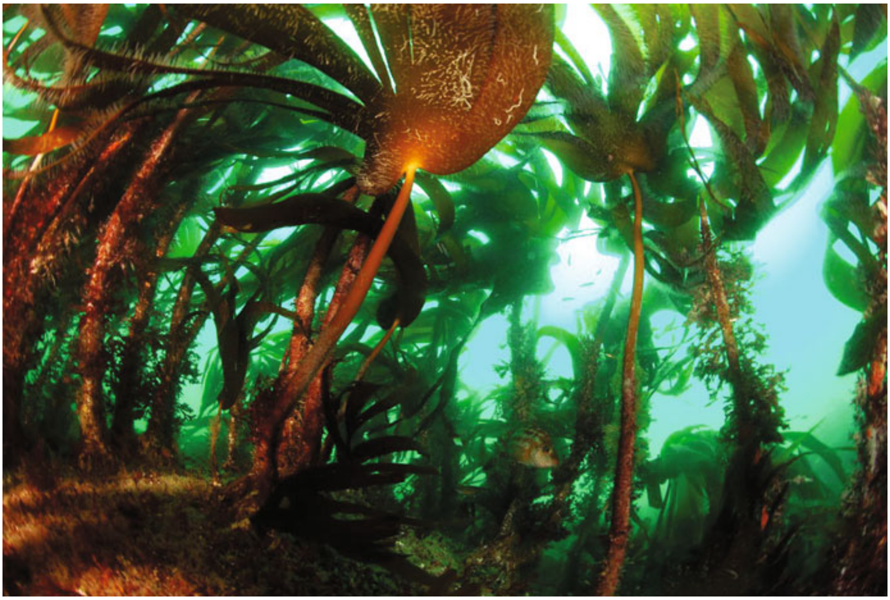
Port-Cros Island (National Park), Mediterranean Sea

Panoramic view of a rocky ledge portraying the geological forces at work thousands of years earlier and revealing a diversity of shapes in which the Posidonia grass beds, bathed in the sun's rays, and the school of breams suggest a perfect, enveloping harmony between water, rock and plant life.

Special Prize, "landscape of life", category: Underwater Seascape, Overseas territories

French Polynesia, Pacific Ocean

Mobilis in Mobili: driven by the compelling need to move as the daytime and night-time tidal streams dictate, these fish are as intimate with this reefal seascape as the symbiosis of a coral polyp and a zooxanthella.



All Categories Prize

Trebeurden, Brittany, English Channel

The canopy of this dense kelp forest filters a light captured solely by the epiphytes of the stipes and the grassy layer on the substratum, magnifying the impression of a vertical and mazelike plant landscape with no immediately possible horizons.

Category: Underwater Seascape, Overseas territories

Réunion Island, Indian Ocean

Oblong shapes, traces of life, the gaze across the mellow landscape is lost in the languor of the ripple-marks and a diffuse horizon that the next tide or storm will restructure to build a new geography of shapes.

Part I
Exploring the Diversity of Underwater Seascape Representations and Frameworks

Chapter 3
Landscape Emerging: A Developing Object of Study

Olivier Musard, Laurence Le Dû-Blayo, Camille Parrain and Christine Clément

Abstract The emergence of underwater and marine areas is a gradual, ongoing process. It has gained speed in recent years particularly with "underwater landscapes", which illustrate and stem from shared concern to manage marine areas. Yet, reference to the "underwater landscape" has merely been an echo to artistic or scientific currents of thought: confined to a handful of individual or original initiatives in specific fields, there has been no sufficiently substantial basis to allow any development. Bringing into perspective certain sequences relative to its emergence and formation will consolidate a reference base for greater expression and consideration of this geographic emergence of underwater landscapes and areas, having regard for what it reflects.

Keywords Landscape observatory · Marine habitats · Scuba diving · Mapping · Ecumene · European Landscape Convention

3.1 Introduction

Pragmatically speaking, reference to the "underwater landscape" can appear to be a misuse of language if we go by the generic definition whereby landscape is "*all the visible features of an area of land*" (*Oxford Dictionary*, British and World

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English) or if we apply a strict interpretation of the European Landscape Convention (Convention Européenne du Paysage 2000) around the notion of "surroundings". It cannot truly be applied to the underwater world as this term has developed solely on the socio-spatial organisation of mankind (Pinchemel and Pinchemel 1997). Furthermore, much controversy and numerous analyses (Roger 1995; Le Dû 1997) have punctuated the history of the term "*landscape*" and landscape studies are underpinned by many currents of thought and disciplines (Rougerie and Beroutchachvili 1991). Yet, researchers in human and social geography have taken little interest in these subjects, only briefly addressing the topic of underwater landscape or the materiality of the underwater littoral fringe (Corlay 1998; Pinot 2002; Musard 2003; Musard et al. 2007). For about a decade, active, cross-cutting research has focused on the theoretical, technical, practical and epistemological foundations of the underwater landscape, creating a corpus that is more than a mere transposition, adaptation or application of terrestrial landscape to the sea world.

3.2 Terrestrial Fundamentals for Traditional Geography of the Sea?

To geographers, the landscape is an area observed that cannot be fundamentally reproduced in map form. Y. Lacoste (1977) reasserted this difference, insisting on the fact that from the point of observation, some parts of a landscape are invisible or concealed. This synoptic statement applies to underwater landscapes, but in French physical geography of the sea, embodied by A. Guilcher, F. Verger, R. Paskoff, J.-R. Vanney or J.-P. Pinot, this underwater space is above all defined through the projection of its geological, topographic and morphological nature. The influence of rocks on the relief, which was a regular question in the 1960s, led to the underwater world being considered basically as an extension of the coast (Nonn 1972). Such retranscription of the sea bed in a schematic cross-section or a vertical map allows geographers to identify the relief and dynamics of the coastal system and render visible and readable something that, in essence, escapes the human eye: "*there is no interpretation if there is no landscape to interpret and, beneath the sea, there is no landscape provided by nature, only landscape reproduced by cartographic analysis*" (Pinot 2002).

Yet, this analysis clearly confirms the confusion between landscape and cartography and there are several reasons why. Physical geography of the sea dates back to the second half of the nineteenth century (in 1855 M.-F. Maury published *The physical geography of the sea*) but it only really developed in the 1950–1960s, at a time when "*geomorphological study conceals and devitalises the landscape*" (Bertrand 1995). Such geography of the sea studied the relief of the sea bed and its many shapes, the "*underwater landscape*" having no veritable existence here. This unknown space was only rendered on small or mean scale maps and was described using land terminology, for want of better (Bourcart 1949). Furthermore, as M. Roux (1998) recalled, there was a tendency to represent the Ocean "*as a perfectly isotropic area*". New technologies and new instruments gradually enabled geographers of the sea who, apart from the odd researcher, did not directly observe the sea beds, to improve their scales of interpretation (Augris and Gourmelon 2002). Data was interpreted and transposed onto a vertical plane in order to reproduce a *continuum* in one or three dimensions, providing a general view of the underwater topography and a detailed analysis of coastal dynamics in the form of locatable abiotic units.

Nonetheless, the phrase "*underwater landscape*" was still used little in coastal geography and French geomorphology. Either the underwater landscape was considered "*banal*" (Pinot 1998), or it "*greatly* [. . .] *bears the stamp of man*" (Pinot 2002). This second conception does not in any way reflect a territorialising study of the geographic object. It can be explained by the scalar level taken into account, by the cartographic projection of the data obtained and by a maximalist assessment of the impact of human activities on the deep sea. As fundamental as it may be, this physical geography has therefore recently evolved to adjust these three parameters to a scientific approach which, in terms of cognitive and interpretive processes in coastal zone management, was overly restrictive. Interdisciplinarity and new tools such as Geographic Information Systems used by geographers have also fostered this move towards a global, dynamic conception of the littoral for geography (Bartlett and Carter 1988; Wedding et al. 2011). LIDAR tools used to map the coastal strip encompassing both land and underwater dimensions respond for example to this concern. But underwater landscape is no longer exclusively a matter for geography; it is part of particularly fundamental and essential cross-disciplinary reflection.

3.3 Technical Constraints and Conceptual Stages: A Slow Process of Recognition by the Naturalist and Scientific World

There are reasons why the French scientific community lacked interest and a clear vision of the underwater landscape on a semantic, conceptual and methodological level (Palmisani 2002). Broadly speaking, from the seventeenth century, considerable work was done to develop inventories and taxonomic classifications. Prior studies had to be deciphered and confirmed, as samples were often taken at random without any real apprehension of the environment and with sometimes hazardous extrapolations (Déléage 1992). There was also a move away from eloquent vernacular terminology to scientifically classify more or less successfully distinguished elements which triggered recurring fantasies in the collective imagination (Geistdoerfer 1995). With the advent of diving apparatus, and the development of diving and *in situ* research, scientists experienced a minor revolution: this tool helped them better conceive the reality and complexity of the underwater world (Doukan 1954; Fournier 2004), and gradually begin to see what could be an underwater landscape. In fact, in one of the first approaches, researchers rediscovered the concept of zonation and applied it to the vertical organisation of seaweed and fish (Rougerie 1993).

The term was not, however, part of the established terminology. For over a century and before diving masks enabled scientists to observe species for themselves, other terms were coined to understand submarine life. Scientific objectivity thus gained recognition over the subjectivity of the human eye filled with sensitivity and marked by excessive cultural references. These semantic and conceptual developments marked the start of *Ökologie* (1866) and its succession of fundamental concepts including "*biocoenosis*" introduced into scientific language in 1877. Most of the concepts invented at the turn of the twentieth century were nonetheless replaced in 1935 with the emergence of a new word coined by Tansley: "*ecosystem*" (Dury 1999; Drouin 1993; Deléage 1992). This strong concept of ecology was gradually shaped by various currents to give rise to the theory of ecosystems. Other questions then incorporated the human dimension into the ecosystem concept and examined ecology in the light of society issues (De Montgolfier and Natali 1987; Lefeuvre 1989; Barbault 1996; Zacharias and Roff 2000).

In fact, although marine biologists had decided not to develop research on the topic of underwater landscapes, use of the expression became necessary to refer to the environmental deterioration caused by human activity: in 1990, a definition was put forward, based more on "*participants personal, non-written experience than on written data*" (Boudouresque (Coord.) 1990). In substance, it considers the "*underwater landscape*" as a "*particular aspect of a population or a set of populations capable of being perceived as such by a non-specialist observer on a small and medium scale*". The authors associate the "*underwater landscape*" with the reign of plant life, expanding a scientific analysis of the coastal and marine zonation (Picard 1985), from the surface down to the farthest depths. Within these zones, algal distribution or more generally plant coverage breaks down into strata and sub-strata and real algal "*belts*" or "*horizons*" can be seen. This analysis of the plant coverage ties in with the concerns of biogeographers and phytosociologists thus allowing a descriptive vocabulary, specific to landscape study, to be used; by transposition, the notion of underwater landscape acquired scientific legitimacy, although the world "habitat" was preferred.

3.4 Toward Global Apprehension of an Area, Between Habitat and Ecosystem

Many inventory, mapping, study and monitoring procedures indeed developed from the standard reference of habitat including Corine, Eunis and Natura2000. By associating biotope and biocoenosis, knowledge of the structure, distribution and functionality of these habitats greatly improved. More complex figures such as geomorphology and topography were thus incorporated into studies, illustrating a multiplicity of possible combinations around questions of heterogeneity, texture and biodiversity. Yet, these habitats tended to be studied separately, the question of assembly of habitats or more generally the representation of a mosaic of habitats being given little recognition until recently. The change occurred in the 1990s, through the concepts of "geosystem" (Beroutchachvili and Bertrand 1978) and "ecocomplex".

To Blandin and Lamotte (1988), the reality of human-induced pressure and the problem of land planning called for reflection with greater integration of the population, settlements and ecosystems. Between geosystem, which involves a strong perceptive and subjective dimension, and ecocomplex, they suggest using the latter for its degree of integration allowing "*an assembly of ecological systems in interaction in an area*" to be studied. This notion of ecocomplex encompasses, jointly and outside all cultural filters, a natural and human history in a given area. However, these three references -landscape, geosystem and ecocomplex- are apparently still little in use in the various branches of ecology, except for those claiming to take their roots in landscape ecology (Rougerie and Beroutchachvili 1991; Burel and Baudry 1999).

In fact, according to P. Dury (1999), while the two words landscape and geosystem only seldom appear in ecological publications and only since the 1990s, they both represent a conceptual and semantic enhancement and a scientific opportunity. The change of perspective accelerated in the years 2000 (Zacharias and Roff 2000; Roff and Taylor 2000; Roff et al. 2003; I.C.E.S 2005; Pitmann et al. 2011; Teixidó *et al.* 2011), reasserting with conviction the benefit of landscape ecology-related concepts based on the association of landscape spatial structures with ecological processes, particularly *via* the combined matrix—patch—corridor model. This development narrowed the gap between ecology and geography and provided a better response to social and environmental challenges. Hesitations in terms of conceptual references are inherent in the formation of emerging references but they emphasize the extent to which it is sometimes important to define a clear corpus leaving no room for subjective interpretation. Objectively expressing the subjectivity of the landscape and its components is a real scientific challenge, particularly in terms of systemic approach.

3.5 The Landscape System, an Effective Synopsis

Landscape study led the THEMA laboratory (Théoriser et Modéliser pour Aménager) to propose a combined integrated analysis based on four aspects, "production", "visible landscape", "perception" and "use", representing the four keys to understanding the system. Each one consists of structuring variables expressing the various aspects of apprehending the landscape, such as its materiality through biotic, abiotic or anthropic features or the cultural filters involved in the study of perceptions (Fig. 3.1). This matrix is an operational synopsis used to convey every dimension of the landscape object and to convey it a broader context.

To test this model against the underwater landscape, greater regard must be had for the observation framework required to tackle the marine and more precisely the submarine world. Observation takes place in a constantly multidimensional space that invariably follows a vertical, ascending-descending, and horizontal course. As the landscape unfurls, the biotic and abiotic components are the principal attractions as in the case of Gorgonians (Fig. 3.2).

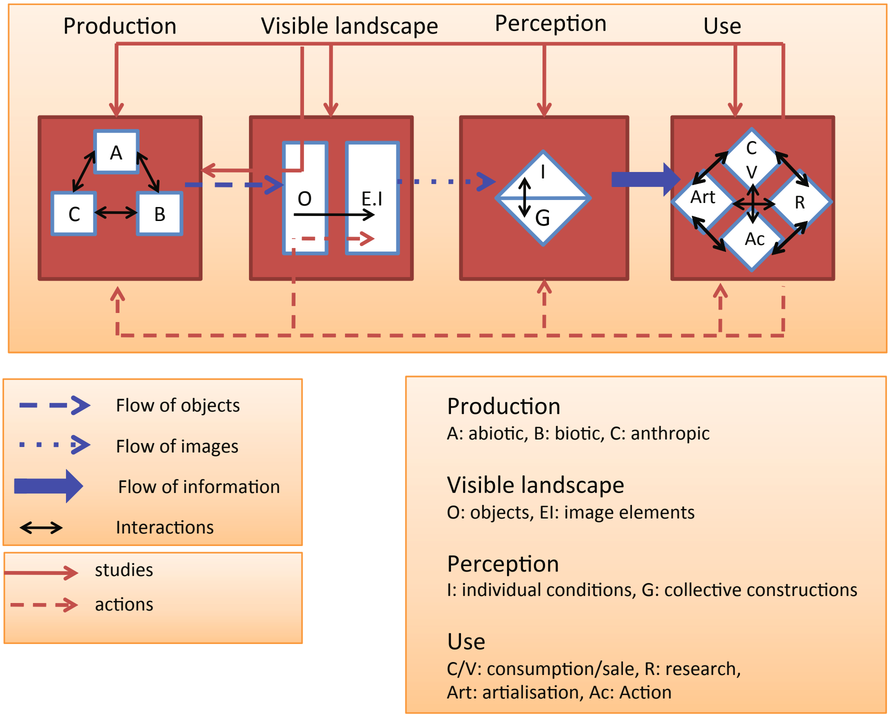


Fig. 3.1 A holistic matrix for landscape analysis. (Source: UMR THEMA website, landscape and living environment team: http://thema.univ-fcomte.fr/IMG/pdf/Paysage.pdf)

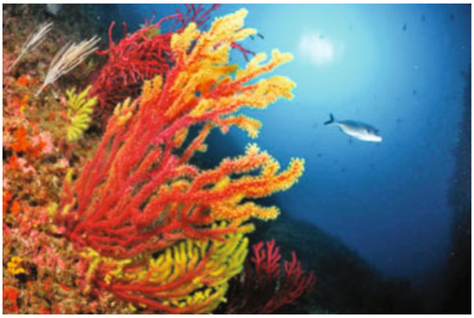
Landscape features	THEMA Matrix
	GORGONIAN CORAL - Production: biotic - Visible landscape: clearly individualised objects and images - Perception: collective construction of the gorgonian as a symbol of the beauty and fragility of the sea's depths - Use: artialisation (photography contest, etc.); research; catcher image for developing underwater leisure activities

Fig. 3.2 The THEMA matrix and Gorgonian coral, a landscape symbol and feature. © Jean-Louis Ferretti, All rights reserved

It is true that, generally speaking, many slopes in the Mediterranean particularly (but also in some other areas such as the Channel and the Atlantic), are adorned with more or less dense, majestic and colourful gorgonians (*Paramuricea clavata* or *Eunicella sp.* for example). When deep-sea diving first began in the 1950s, gorgonian corals revealed their aesthetic power as principal features of a landscape: they have been key illustrations leading to the development of a collective frame of reference in terms of perception of a beautiful landscape, i.e. its structure, shapes and colours. With the development of scuba diving, the appeal of these landscapes and landscape features have engendered excessive diver numbers in sites like the Gabinière, in Port Cros National Park (Musard 2003) or at the *Pellu* in Bouches de Bonifacio Nature Reserve (Musard 2008), to mention but examples of French marine protected areas. With the help of scientists, managers have focused research and monitoring projects on diver impacts on gorgonians in order to develop management solutions. The deterioration of these landscape features was not the only question as, for the two dive sites mentioned above, divers are also interested in a highly emblematic species, the grouper, which as J.-A Foëx (1954) pointed out, is only "*found in the most splendid landscapes*".

By using the THEMA analysis system, the various underwater landscape objects can be examined and interrelated. Through this example of integrated analysis, problems of inter-visibility and integration of mobile features emerge as vital. They are not easy to solve prima facie, particularly in view of what can be seen along the trail, as shown by Table 3.1 in the case of a diver. Initiatives to develop knowledge of and monitor underwater landscapes must operationally and technically integrate these factors, in order to consolidate the benefits and scope thereof.

3.6 Object and Practice: Towards Underwater Landscape Photographic Observatories and Atlases

The socialisation of the coastal underwater fringe leads, simultaneously and consistently, to the progressive development of both images and growing responsibility. This process gradually raises the question of the benefit of developing underwater landscape atlases and observatories, in the same way as for the terrestrial environment, particularly to reinforce marine environment monitoring and protection measures (Clément 2012). Integrated into public policies on terrestrial landscape since the French "Landscape" Law (1993) and the European Landscape Convention, these tools are references in landscape diagnosis and policy, in three key focus areas: description and mapping of landscape units; study of landscape dynamics; and study of social practices and perceptions. The transposition of these tools into the underwater world raises several questions regarding the transfer of methodologies in terms of area breakdown, adaptation of scales, anthropogenic markers, cultural representations and use of space, observation conditions (starting with the problem of turbidity), and involvement of the public (Table 3.1). Although underwater landscapes atlases and observatories are developing, the question of their benefits in

Table 3.1 Underwater landscape readability and interpretation based on scalar levels. (Source: Musard et al. 2007)

Dimensions	Diver observation configuration	Diver interpretation scale	Diver readability
1,000–100 m	Trail with global apprehension of the landscape and the components forming the mosaic	Open underwater area that may include a dive or observation site	Random, superficial and depending on the trail
100–10 m	Distinction and identification of homogeneous populations and structures forming the landscape mosaic	Defined underwater area such as a dive or observation site	Gradual and in sequences
< 10 m	Distinction and identification of differentiated populations and structures forming the dive or observation site	Particular, characteristic landscape unit forming the dive or observation site	Between progressive and immediate, depending on the clearness of the water and the relief
< 1 m	Identification of unevenly distributed species, in interaction and in competition for the sea on very irregular surfaces	Structured composite components structuring a portion of a characteristic unit	Immediate (almost no hidden areas)

terms of monitoring, mediation, management or knowledge, must be examined. The technologies to be rolled out also represent a critical challenge in the implementation of such tools, because the approach is centred on what is to be observed and studied (Métailié 1986; MEDDTM 2010; Sevenant and Antrop 2011). Photo comparison does not, for example, make an observatory, just as a picture cannot serve as an analysis. Photography involves a partly objective breakdown of space: images must therefore be considered in their context and reconsidered with a view to developing knowledge of an area (Beringuier et al. 2010).

The exploratory approach carried out in Mayotte Marine Nature Park by C. Clément (2012) identified leads for reflection and elements of methods for the implementation of such tools (Table 3.2) building on existing frameworks (Luginbühl et al. 1994). Local materials gathered for the study (illustrations, representations based on tales and legends, local community perceptions, names of fishing and diving locations) revealed little reference to underwater landscapes since, to the people of Mayotte, the lagoon symbolizes the kingdom of "djinns", the kingdom of all dangers. Conversely, a survey of monitoring and protection measures showed that experts (scientists, managers and other protection agencies) were involved. It further revealed the institutionalization of underwater landscapes. Being daily users, diving club managers were able to indicate priority underwater landscapes (representative, under threat, preserved) of interest for the photographic observatory. They also positioned themselves as potential contributors to the atlas and the observatory. A study of the scientific bibliography (fundamental oceanographic parameters) and the compilation of local data and survey results enabled the lagoon to be divided into landscape units despite the lack of knowledge and typological references of

Table 3.2 Proposed methodology protocol for underwater landscape identification and characterisation. (Source: Clément 2012 amended, according to Luginbühl et al. 1994)

Objectives	Methodology	Data output
Identify the landscape units	– Observation in the field from itineraries – Interpretation of scientific studies (oceanographic parameters) and existing maps	– Differentiated maps – Written report offering several points of view on the current status of underwater landscapes
Locate institutionalised underwater landscapes	Inventory of current protection measures (MPA, etc)	– Diagrams and sketches of the key features of underwater landscapes
Identify iconographic representations of landscapes	Search in literature (tales and legends), pictures, photographs and lists of place names	– Collection of photographs
Identify landscapes of interest	Survey among underwater observers to gain insight into the atmosphere	
Proposed methodology protocol for landscape dynamics assessment		
Identify visible signs of change to landscapes	– Observation in the field – Establishment of a first typology of changes	– Differentiated maps of changes – Summary map of pressures
Update trends	Interpretation of statistics from monitoring bodies	– Interpretive report of changes and pressures
Check and clarify landscape changes	Meetings with relevant local managers and underwater observers	
Proposed methodology protocol for underwater landscape observatory implementation		
Delimit the study area and define the project's objectives	Organisation of a steering committee and appointment of a professional photographer Statement of the challenges and topics	– Renewal of photographs overtime – Map of photography points – Debates with stakeholders (cultural events)
Create a sample of observation points	Approval by the steering committee Choice of technical and operational options Selection of photography sites	– Web-based interfaces for public participation and dissemination of data
Encourage publicparticipation	Reflection on a participative methodology, dissemination of the information, collection of existing pictures	
Data processing	Data encoding, interpretation and analysis	

the underwater world in overseas territories. This exploratory initiative in Mayotte to develop underwater landscapes atlases and photographic observatories above all confirmed the potential of these tools as relevant mediation and monitoring instruments (an innovative approach to the study of ecosystem interaction and connectivity).

Within the framework of a marine protected area, this approach is all the more founded. These tools can naturally provide guidance for the development of conservation and management actions. In addition to providing evidence of underwater landscape dynamics and transformations, they bring the issues of natural heritage conservation to light and can be integrated into decisions for marine biodiversity action. Apart from Mayotte, other overseas territories are interested in this approach. In a context of integrated coastal area management, various coastal and marine protection players in Réunion, Martinique and Guadeloupe regard these tools as a way of establishing a land-sea continuum, by linking it to their existing territorial landscape photographic observatories and atlases. Internationally, the development of methods such as the Catlin seaview survey (http://catlinseaviewsurvey.com) further reflects this process of establishing landscape references for knowledge, mediation or management purposes. The development of landscape indicators also contributes to this overall reflection as does the integration of landscapes into ecosystem service assessment (David et al. 2012).

3.7 Conclusion

As a reality structured around physical, environmental and human processes, the underwater area naturally echoes issues surrounding landscape within the meaning of the European Landscape Convention, while often demanding greater regard for the associated conceptual fields. The operative issue of scales, the paradigm shifts made possible by technological developments and, more generally, collective interest in pushing back the limits of the ecumene to move into new "territories of emptiness" (Corbin 1988), offer a basis which will undoubtedly continue to expand. Such territorialisation and concomitantly, such landscape representation, logically extend a process of littoralisation from which an underwater dimension was missing. The underwater landscape thus fits into a broader framework of reflection on marine landscape (Parrain 2012) integrating the many dimensions of the marine area (surface, volume, sea beds) and belonging to the new forms of territorial construction (Musard et al. 2007; Parrain 2010), in the manner of frontiers.

At the first World Congress on National Parks, this now undeniable mental and material recognition of the underwater landscape was anticipated: "human-induced pressure will gradually cause man to turn to the sea, and especially to the underwater "theatre", for cultural and recreational reasons" (cited by Beurier and Le Morvan 1980). The theatrical dimension is crucial in that, although the underwater landscape invariably appears to serve as decorum, it particularly demonstrates the need for cross-disciplinary interaction in order to assemble a mosaic that is far too scattered for the purpose of studying and managing the marine environment.

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Chapter 4
Underwater Landscape Put to the Test of Law

Jean-Pierre Beurier

Abstract Landscape is "what we see of the land"; it is the human view of the world. For a long time, law recognised landscape indirectly: for example the 1930 French law on the protection of sites protects our view of a listed site as a supporting measure. International law has also contributed indirectly to protecting landscapes (1940 Washington Convention and the 1972 Paris Convention). The visual quality of a natural site is part of the legacy we must leave for future generations. Since the French law introduced in 1993 and the Florence Convention of 2000, law now protects landscapes *per se.* But can that protection be extended to underwater landscapes that we do not directly see?

Keywords Montego Bay Convention · European Landscape Convention · Coral reef · Natural heritage · Wrecks

Landscape can be defined as "what we see of the land", an expanse presenting a general view. Landscape is defined according to our human perception of it. It represents the human view of the world (Beurier 2002). During the twentieth century, landscape was indirectly recognised by law through the protection of sites, but it was not expressly mentioned by the lawmaker until the end of the century. French law of 2 May 1930 on the protection of natural sites and monuments set the tone: the law must protect outstanding sites from all intentional or other forms of destruction, owing to their artistic, historic, scientific, legendary or picturesque nature. Listed sites are subject to restrictions such that no change may be made to their appearance and their character may not be impaired by advertising or camping facilities for instance. In addition to preserving sites themselves, the law clearly protects our view of them by establishing urban planning restrictions. The landscape of which a site is part must also be preserved. International law subsequently addressed the question more directly and on 12 October 1940, the Washington Convention on the protection of nature and the panoramic beauty of America was signed. The convention creates protected areas in which wildlife and "nature monuments" are protected and any form of trade controlled (Art. 2); but it also provides that outside such areas, rules

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may be adopted to protect the fauna, flora and the scenery, geological formations and natural objects of aesthetic, historic or scientific value (Art. 5). Here, the law directly integrates the landscape concept and seeks to prevent its impairment. This is also the case of the Paris Convention of 16 November 1972 concerning the protection of world cultural and natural heritage. This instrument recognises natural features (physical and biological formations, natural sites or areas) of outstanding universal value from an aesthetic or scientific point of view as world natural heritage. Together with the natural beauty of sites, it is this value that must be transmitted to future generations (Art. 2). Although the Convention does not include the word ‘landscape’, we understand that the visual quality of a site is an intrinsic part of the “natural heritage”. More recent conventions are more explicit and require the Parties to protect landscapes (Apia Convention of 12 June 1976 for the conservation of nature in the South Pacific; Benelux Convention of 8 June 1982 on nature conservation and landscape protection). The convention on the protection of the Alps signed in Salzburg on 7 November 1991 goes a step further, providing not only for the protection of landscapes but also for their restoration where necessary. The Convention uses the relatively non-legal and subjective phrase “beauty of nature and landscapes” (Art. 2- f) to require the conservation, promotion and upkeep thereof owing to their aesthetic character, but also because they have been shaped by man.

Specific legislation on landscape came into force in France on 8 January 1993 with the law on the protection and enhancement of landscapes, and at European level, with the European Landscape Convention of the Council of Europe adopted in Florence on 20 October 2000[1]. Whether they implicitly or explicitly include landscape protection, all these pieces of legislation have been devised and developed by landsmen for territories on land. Since there is now no doubt that landscape is an object of law, the question arises of whether such texts can be applied to maritime or marine areas, under State rule or jurisdiction. Can landscapes formed by submerged territories be taken into account by law and, if so, which legal system can we apply to conserve them, and even ensure their restoration and transmission to future generations?

We will therefore begin by exploring legal recognition of underwater landscapes, and secondly the management thereof by law.

4.1 Legal Recognition of Underwater Landscapes

We have seen (Beurier 2002) that underwater landscapes exist and are extremely varied; they are primarily located in the sublittoral zone, within reach by scuba diving, where eight main types have been inventoried (Fig. 4.1), plus wrecks and artificial reefs. In the open sea, cliffs and canyons of the continental slope, sea mounts, hydrothermal springs, and hard grounds of cold-water coral are identified. Lastly, beyond the polar circles, there are ephemeral landscapes of ice and subglacial reliefs.

[1] Council of Europe, Series of European Treaties 176 (in force since 1 July 2006, 29 ratifications in 2011).

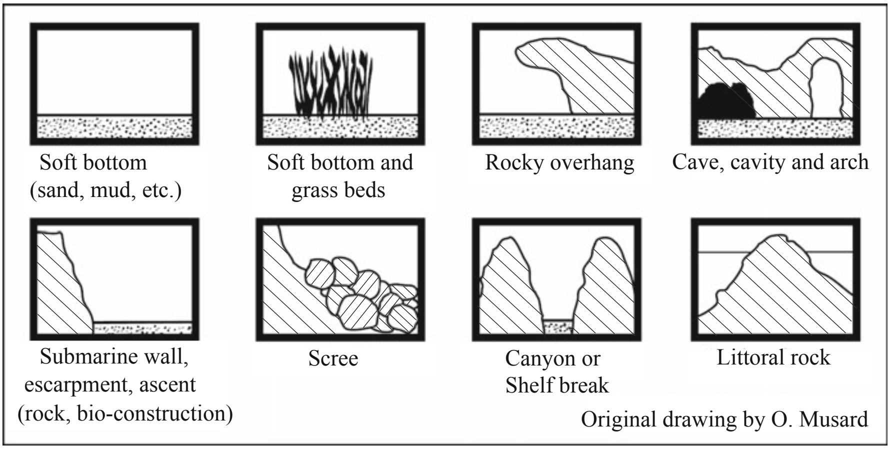

Fig. 4.1 Schematic cross-sectional drawing of the principal types of "natural" underwater landscapes. (Source: Musard et al. 2007)

Admittedly, a landscape implies surveying a panoramic view, which is impossible in the underwater world due to the turbidity of water. A diver, however, or a submariner can easily and gradually discover the landscape (Musard et al. 2007). On a legal level, no instrument recognises underwater landscape *per se*. We must therefore reason by analogy and determine the law-maker's or plenipotentiaries' actual intent.

4.1.1 An Ambiguous Definition

Today, instruments are in force to protect landscapes both in international law, and in Community and domestic law. As this legislation was developed for terrestrial landscapes, can the criteria be transposed without distorting the content of their provisions?

Landscapes in the sublittoral zone are all located in national waters or possibly in the territorial waters of the coastal State, therefore in areas over which the government exercises control. It has full authority to lay down rules for the conservation, protection, restoration and enhancement of such sites. An outstanding underwater landscape will consist of an area of high ecological quality and extensive biodiversity, and could therefore come within the scope of "national natural heritage" defined by the Bern Convention of 19 September 1979 on the conservation of European wildlife and natural habitats. That Convention requires States "to maintain the population of wild flora and fauna at a level which corresponds in particular to ecological, scientific and cultural requirements, while taking account of recreational requirements" (Art. 2). As we have seen, the 1972 UNESCO Convention also provides for identifying the elements of world heritage and requires States to take conservation measures (Art. 3). The United Nations Convention on the law of the sea of 10 December 1982 requires State Parties to protect and conserve the marine environment (Art. 192), which means both maintaining the status of living stocks and preventing all impairment of habitats. As for the European Landscape Convention signed in Florence on 20 October 2000, it acknowledges the importance of protecting landscapes for the quality of life of populations and for local cultures as well as ecosystem protection. It aims to promote the protection, management and planning of landscapes and to organise European cooperation in this area (Prieur et al. 2006). The Florence Convention therefore renders the protection of aesthetic, cultural and ecological values indissociable.

In European Community law, among the priorities of the Sixth Action Programme (2001/2010), express provision was made for protecting, conserving and restoring landscapes. The "Habitats" Directive of 21 May 1992 promoting the conservation of biodiversity already contributed to landscape protection by creating a network of protected areas (Natura 2000); the 6th Action Programme extended that network to marine habitats and the coast. This remarkable Directive expressly refers to the link between landscape and biodiversity (Art. 3 and 10) but only refers to elements of nature on land; it further specifies that such provisions are not mandatory. EC Directive 2008/56 of the Parliament and the Council of 17 June 2008 establishes a framework for Community action in marine environment policy (Marine Strategy Framework) (OJEU L 164/19 of 25 June), seeks to restore the marine environment to a good ecological state, to curb loss of biodiversity, and to guarantee the capacity of marine ecosystems to provide goods and services. The Directive urges Member States to establish special conservation areas, special protection areas or marine protected areas (involving different stages of conservation or protection (or both)). The strategies further apply to the management of human activities which must be maintained at levels compatible with achieving good ecological status (Art. 1°). The Directive's scope covers the water column, the seabed and the subsoil to the outer limit of the territorial sea. The fight against deterioration aims to sustain economic activities including tourism but also to safeguard the amenity and recreational value of the environment (Art. 3).

French law is not to be outdone. Under Article 1° of the law of 10 July 1976 on nature conservation, landscapes are of public interest. And the law of 2 February 1995 (adopted in addition) states, in Article 30, that a departmental inventory of natural heritage will be drawn up to list natural sites, landscapes and environments. Meanwhile, the "littoral" law of 3 January 1986 directly addresses the protection of outstanding landscapes (Art. L 321-1 of the French Environment Code). Admittedly, there again, the law targets the land aspects of the coast while further referring to uninhabited islands, headlands and rias, as well as coral reefs. Particularly worthy of attention is law 93/24 of 8 January (amended and incorporated into the rural, urban planning and environment codes; JO 9 January p. 513) on landscape protection and enhancement. Introduced to complete the "mountain" and "littoral" laws, it does not contain any definition of landscape and primarily aims for landscape protection, management and enhancement. Its implementing decree of 11 April 1994 (94–283) establishes landscape guidelines and sets out principles and directions for landscape management. An implementing order of 8 December 2000 (JO of 15 December)—an essentially urban planning law—establishes a National Landscape Council with the task of proposing measures to improve landscape quality. Article 18 provides for a land policy to safeguard the littoral area but it is of no direct concern to our topic here. It should also be noted that the landscape law totally ignores biodiversity, focussing primarily on urban planning. Positive law therefore remains ambiguous about the scope in which the definition of landscape applies, yet it does not expressly preclude marine territories.

4.1.2 Compatible Content

We can see that the various levels of law integrate the concept of terrestrial landscape, laying down measures to protect this heritage in a context of private property and urban development from which the underwater world is excluded.

However, the main instruments are often drafted in broad and imprecise terms, leaving room for extrapolation in order to include the marine environment. The scope of the European Landscape Convention is thus transposable to the marine environment. The preamble is written in very general terms: the landscape is of "public interest"; it is a component of our "natural heritage"; and this new instrument is devoted to "all landscapes in Europe". Article 1 defines landscape as "an area" and Article 2 stipulates that the provisions apply to the entire territory of the parties and includes "land, inland water and marine areas" whether the landscapes are considered outstanding or everyday landscapes. In addition (Art. 5), landscape is an expression of "people's heritage and a foundation of their identity". The Parties must therefore identify landscapes in "their entire territory". Nothing in the Convention prevents a State's underwater territory from being included in the scope of application. It is no doubt by misuse of language that the text refers to "inland water" rather than "continental waters", and in the writers' minds, marine areas are those on the surface, but nothing precludes the sea bed from being taken into account, since it is an integral part of the State's territory.

In European Community law, Annex I of the 2008 Marine Strategy Directive defines, as a descriptor of good environmental status, the level of integrity of the sea floor ensuring that the structure and functions of the ecosystems are safeguarded; it considers the topography and bathymetry of the seabed to be physical features to be preserved, along with all habitats. Indeed, the word "landscape" is not used directly in the Directive, but these geomorphologic characteristics do constitute key elements of an underwater landscape.

Moving now to French law, the Environment Code provides (Art. L 322-1) that the *Conservatoire de l'espace littoral et des rivages lacustres* (Coastal protection agency): "In order to promote the integrated management of coastal areas, may [. . .] carry out missions in the public coastal area it has been allocated or entrusted with". As for the littoral law, it does not refer to the marine environment by name, but the "littoral" includes maritime land elements (islands, headlands and rias) as well as coral reefs, even though they are, by assumption, underwater. Furthermore, the “landscapes” law is designed, *inter alia*, to complete the “littoral” law. There is therefore evidence to contend that, although legal provisions protecting landscapes do not expressly provide for the underwater relief, they can, if necessary, apply to the sublittoral zone, particularly as maintaining landscape quality contributes to building environmental corridors (Stein 2003) the importance of which is upheld by the Council of Europe.

4.2 Underwater Landscape Managed by Law

While nothing prevents landscape protection law from applying to the underwater relief, we must still determine how such protection would be managed. We must first determine the legal nature of the target territory, before drawing conclusions as to the legal system applicable to it. In France, we first have the seabed and subsoil of inlands waters and the territorial sea, forming a portion of the natural maritime public property; there are then outstanding areas located beyond that, in the exclusive economic zone or on the continental shelf over which the coastal State has exclusive economic jurisdiction. Lastly, with regard to the Montego Bay Convention (MBC), the territory includes the soil of the international area, described as common heritage of mankind and managed by the International Seabed Authority.

4.2.1 Specific Territories

Law distinguishes between several types of territory based on their distance from the coast. Wrecks are a special case considered separately.

1. For areas under national sovereignty (inland waters and territorial sea), the seabed and the subsoil are incorporated into the natural maritime public property. They are therefore non-conveyable, inalienable and freely accessible to the public unless the area in question is allocated to a public service. Although incorporated into the territory of coastal towns (Council of State ruling, Saint-Quay-Portrieux, 1983), the Government directly manages its non-allocated property. However, maritime public property is not excluded from the application of general urban planning and environmental protection rules. Decisions concerning the use of such property therefore integrate requirements for safeguarding coastal sites and landscapes as well as biological resources (French Environment Code Art. L 321-5). Specific coastal land planning and protection policy aims, *inter alia*, to protect biological and ecological balances, to fight erosion, and to conserve sites, landscapes and heritage (Environment Code Art. L 321-1, 2°). Thus, even though the Government strives to manage maritime property to serve its economic interests (marine culture, pleasure boating, harbours, material extraction, energy production), the goal of preserving the natural environment remains essential. Moreover, containment grants have become an exception (Decree of 29 June 1979) and can no longer give rise to conveyance.

2. For areas under national jurisdiction (economic zone, and continental shelf beyond 200 nautical miles), the seabed and subsoil do not belong to the coastal State which only has economic jurisdiction. This means that it has exclusive rights of exploration, exploitation and management of the natural resources (whether living or not as far as the EEZ is concerned; for the continental shelf, such resources may be non-living and living but must be in permanent physical contact with the seabed). This exclusive jurisdiction is extremely broad and encompasses the conservation and protection of these areas. Therefore, while the coastal State cannot restrict navigation and fly-over, it may restrict use in certain particularly fragile parts, after approval by the IMO (MBC Art. 211, § 6). It may, in any case, fight all form of pollution or destruction that would adversely affect its resources in order to ensure the protection and preservation of the marine environment (MBC Art. 56, 1, b, iii). The coastal States are required to publish the limits of such particular areas and must inform the IMO of the additional laws and regulations adopted for the prevention, reduction and control of pollution. Such rules must correspond to generally accepted international standards.
3. The international seabed area under the high sea is governed by a specific system as it is declared "common heritage of mankind" (Art. 136 of the MBC). Economic activities are carried out therein through the International Authority whose Council has jurisdiction to issue mineral titles. States or economic entities authorised by the latter must take the necessary measures to effectively protect the marine environment. The Authority adopts rules to address risks threatening or interfering with the ecological balance and to prevent damage to the fauna and flora (MBC, Art. 145).
4. Wrecks of any kind are a specific case, irrespective of the area in which they lie. In areas under national sovereignty, wrecks are protected by the Sovereign State's domestic law. A distinction is very often drawn firstly between modern and historic wrecks and secondly, between civil and State-owned vessels. In all cases, a wreck has an owner whose interests are protected by law (law of 24 November 1961) but who may be required to refloat or move the vessel if it creates a danger for navigation or the environment. Wrecks represent a particular landscape that is both artificial and natural. A wreck landscape may be protected by measures introduced by the Government in the area in which it is located. Beyond areas under national sovereignty, only historic wrecks can be protected by the 2001 UNESCO Convention (in force 2007) but solely to avoid plundering. Beyond the limits of sovereignty, modern wrecks are only subject to special protection rules where they are considered tantamount to burial places (Titanic, U171 for example).

4.2.2 Specific Protection Standards

As current law has been developed for terrestrial landscapes, the first specific protective measures relate to urban planning. French law 94/112 of 9 February 1994 amending the law of 8 January 1993 establishes landscape guidelines and requires urban planning programmes to take landscapes into account. This legislation establishes a methodology for landscape identification and typology leading to the development of landscape plans. French circular 95/23 of 15 March 1995 relative to landscape protection and enhancement instruments seeks to provide guidance for landscape policy between the Government and local authorities. A landscape charter may be drafted for this kind of project and a landscape contract signed. Prior to such contracts, studies and a diagnosis are required, and a draft is prepared (circular 95/24 of 21 March 1995). Such measures prove that landscape quality is recognised as a key factor of territorial development. Safeguarding underwater landscapes could therefore involve making an inventory of the most outstanding aesthetic, but also scientific, historical or picturesque sites. A site located in State-owned property is listed by a decree issued by the Minister in charge of sites (Environment Code Art. L 341-4). The new legislative provisions offer decision-makers new tools with which underwater landscapes could be protected.

1. French law 2006-436 of 14 April 2006 (JO of 15) relative to nature parks recognises the landscape as a possible criterion for the establishment of a park (Environment Code Art. L 331-1). Chapter 4 of the law introduces marine nature parks. The codified legislation is incorporated into the Environment Code. This new type of park is established in waters under national sovereignty and even under national jurisdiction (Environment Code Art. L 334-3). The Code specifies (Art. L 334-7) that any loss of integrity or damage to the conservation of public property within the perimeter of the park, or liable to compromise use thereof, is a public infrastructure offence. The law-maker thus contributes to the establishment and management of marine protected areas designated at international level (Art. L 334-1), with the primary aim of maintaining marine and coastal biodiversity. Activities altering the marine environment are subject to authorisation and may be banned. Paradoxically, Chap. 4 of the law does not expressly integrate the protection of marine landscapes and the implementing decree of 16 October 2006 did not fill that gap. It was not until the law of 23 February 2007 on the general principles of nature parks that landscape gained recognition as an element of biodiversity (Prieur 2008).
2. Nature reserves have been in existence for longer: their system was established by the nature conservation law of 10 July 1976 (76–629, Chap. 3). The complex Council of State decree procedure applies for the establishment of a nature reserve as it aims to protect an environment of national interest. This legal tool mainly targets wildlife or geological heritage, but through the "protection of natural environments" (Environment Code Art. L332-2), the aesthetic or scientific quality of a landscape could easily be included. This is perfectly illustrated by the first marine nature reserves created in France (Cerbère-Banyuls in 1974 and Scandola in 1975) where sea fan cliffs, red coral cavities, submarine walls of hydroids, marine sponges and tunicates form sumptuous landscapes with the surrounding vagile fauna. The same is true of all other marine nature reserves established

later (Lavezzi and Cerbicales in Corsica, La Caravelle in Martinique, and Entrecasteaux reef in New Caledonia). Under the measure, once the site is classed as a reserve, the territory's status and appearance may no longer be altered (L 332-9). This latter provision indeed shows that landscape is part of the protected elements. Thanks to highly restrictive provisions, nature reserves have achieved excellent results and have even helped restore environments and thus landscapes. But the Environment Code is silent on the importance of landscape integrity within a reserve and ironically, the French Urban Planning Code is more advanced, combining provisions for the preservation of biological balances and the protection of outstanding coastal landscapes (Urban Planning Code, Art. R 146-1).

3. The French biotope protection by-law (Rural Code, Art. R 211-12) stemming from the Decree of 25 November 1977, is a much less restrictive and also less effective instrument, but nonetheless useful since it is much less complex to create. It protects a biotope necessary to the conservation of a species threatened with extinction. In maritime public property, these by-laws come within the remit of the Minister responsible for fisheries. The relevant authority may take measures restricting use, following an opinion issued by the Commission for nature, landscapes and sites (Environment Code Art. R 411-15 to 17). A biotope protection by-law only concerns landscapes indirectly and the measures may not even concern the view we have of the area in question; in most cases, however, the landscape will be protected by measures aiming to protect a given species' biotope.
4. "Natura 2000" areas under the "Habitats" Directive 92/43 of 21 May 1992 are designed to contribute to the conservation of natural habitats and biodiversity. The European Union has selected priority natural habitats, both terrestrial and aquatic. The aim is to establish a European network of protected areas taking account of the vulnerability of spaces and species. Member States must therefore designate sites of community importance. After designating a site, the Member State takes the necessary measures to protect special areas. Protecting vulnerable species and their habitat is the key aim, but again such protection of habitats helps maintain the landscapes that correspond to particular biotopes.
5. Marine protected areas are also established to protect particularly outstanding fauna, flora and biotopes. They are areas delimited at sea for which long-term protection goals are set. These areas are scientifically monitored to check application of an action plan, regulations or at the very least a code of conduct. The main aim is to protect biodiversity and habitats, but also to protect rare species or to restore an environment or fisheries resources. An MPA does not refer to any particular legal type of protection measure, and even less so to a specific legal system. The State having territorial jurisdiction or the relevant States in the case of measures taken by agreement in areas beyond national jurisdiction may choose any solution regarded as effective. States establishing MPAs form networks with a view to implementing coherent and complementary protection measures. The IUCN has defined six MPA categories based on the objectives pursued. Landscapes are included in Category V, a choice that is difficult to comprehend, as if landscape did not require protection in the other categories. The concept became

widespread with Agenda 21 which proposed conserving and restoring critical habitats (Chap. 17 A, h) and urged States to identify marine ecosystems with high levels of biodiversity in order to designate protected areas (Chap. 17, 85). This idea was taken up in numerous regional conventions (OSPAR 92; Barcelona, 2008 ICZM protocol) or already existed in embryo (Lima, 1989 MPA convention). None of these documents, however, made any reference to landscapes until the "biological and landscape diversity" protocol of the Antigua Convention (North-East Pacific) in June 2002. On the other hand, many non-binding texts already drew connections between MPAs and landscapes, such as the IUCN WCPA Marine Plan of Action of 2006[2] (5th MPA category = protected landscape and seascape: developing initiatives for seascapes); and the 2010 United Nations General Assembly resolution[3] (Micronesia Eastern Tropical Pacific Seascape project); or the 2007 report by the Secretary General[4] (protected area management tools may have a variety of objectives such as the protection of "beautiful seascapes"); or lastly the 2002 report by the SG[5] (marine protected areas may be established for the purpose of protecting [. . .] "beautiful seascapes").

Whether the management tools stem from international or domestic law, these fragile ecosystems should be protected by restrictive measures to avoid damage caused by human activity. All measures aiming to fight pollution and particularly land-based marine pollution are necessary, like those restricting the use of certain fishing practices (trawl nets on hard coral grounds, on grass beds, and on the edges of sea mounts, etc.) or banning ocean mining on hydrothermal springs in activity. These vital measures will not however suffice; in the sublittoral zone, areas open to recreational diving should also be laid out. The most outstanding sites have suffered from their success (Shadwan in Egypt; Les Médès in Spain; the "Pigeon reserve" in Guadeloupe, the "Donator" on the Var coast in France, etc.). Not only should mooring areas be created, divers selected, rules established to govern supervision (Musard 2003, 2009) and use, and boat numbers restricted, commercial operators must also be required to comply with charters of conduct (Musard 2009) and the competent authority must introduce appropriate prohibitions and penalties.

4.3 Conclusion

A report from the Secretary General has no legally binding value, no more than a General Assembly resolution. Yet this provides evidence of two things: firstly, current legislation does not prevent underwater landscapes from being integrated into nature conservation concerns, and secondly a consensus would seem to be emerging to take all forms of landscape into account in environmental protection measures.

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[2] www.iucn.org/themes/wcpa/biome/marine/programme.

[3] A/64/L.18– A/RES/64/71 of 12 March 2010 § 157.

[4] "Oceans and the law of the sea" A/62/66/Add 2 of 10 September 2007. p. 36.

[5] "Oceans and the law of the sea" A/57/57 of 7 March 2002. p. 84.

In France, the "Grenelle de la mer" meetings should have been an opportunity to work on underwater landscapes and encourage use of the many tools available to give them substantial recognition as environmental components and values requiring protection, as part of ecosystem conservation. This would, if necessary, have proved the great interdependence between biodiversity and landscape (Prieur 2008). It's high time the National Landscape Council established by law on 8 December 2000 addressed the issue.

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Chapter 5
Underwater Landscapes and Implicit Geology. Marseilles and the National Calanques Park

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Abstract The implantation of the new national park in the Marseilles Calanques requires a juridical framework to protect these exceptionally attractive coastal and underwater landscapes. In order to analyze the reasons behind the spectacular nature of these submerged landscapes, it is essential to evoke the geological and climatic specificity of this coastal karst, submerged at the end of the last glaciation. The keys to understanding these formations are the lithology, the intense fracturing and intersecting of the massif determining coastal dissections and the eustatic factor. Besides these geological factors, the underwater landscape bathes in fluctuating light linked to the instability of winds and tides. The biological occupation completes the makeup of an underwater landscape specific to the Marseillse region. The Marseilless example demonstrates that underwater landscapes are the result of interlocking reasons, from the fundamental and determining geological structuration to the adaptive modalities of biological and human occupation, from the prehistoric artists of the partially submerged Cosquer cave to wrecks from the last war and Antique wrecks excavated by archaeologists.

Keywords Underwater landscape · Karst · Marseilles · Geology · Underwater diving · Eustatism

The first modern pressure regulator, invented by Georges Comeinhes in 1934, was used for the inaugural exploration of underwater landscapes in Marseilles during a dive from Frioul Island at a depth of − 53 m, well before the use of the first Cousteau-Gagnan diving-suit in 1943 on the Var coast. Thanks to these pioneers, the Marseilles region (Fig. 5.1), which boasts some of the most spectacular Mediterranean landscapes, is widely known to divers. This notion of landscape is certainly not objective. It is implicitly pictorial and viewed through artistic subjectivity. Through reductionist and scientific work, the naturalist confers a scientific coherence to a puzzle which, for the profane, does not appear to have any.

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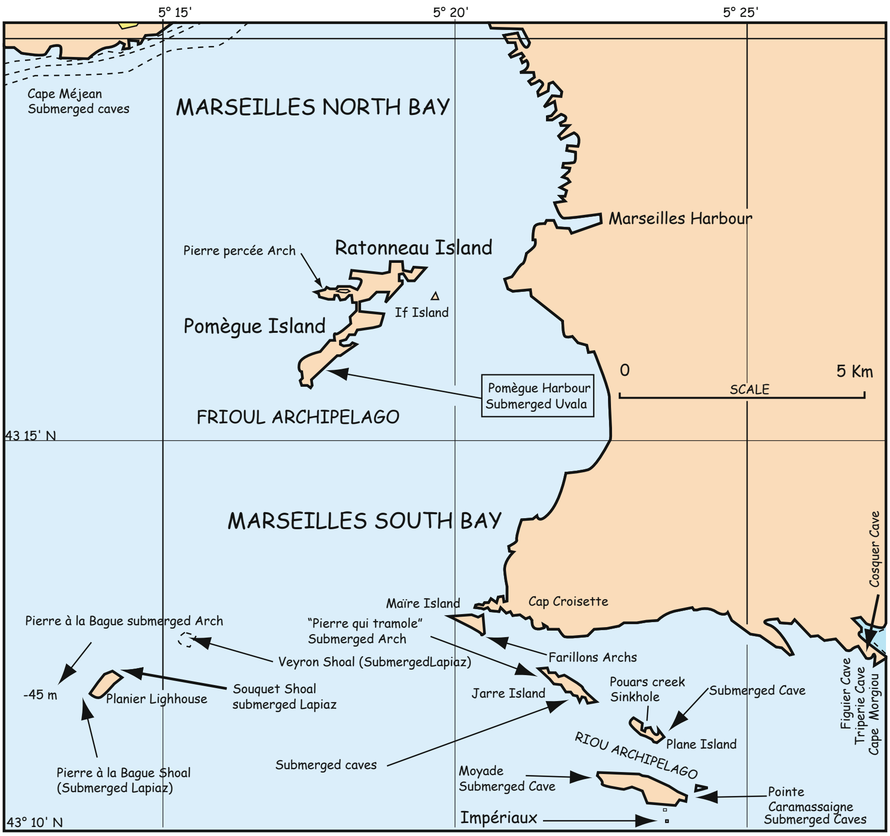


Fig. 5.1 The most spectacular diving spots in the Marseilles inlet and the Calanques Massif. (Collina-Girard 2012)

The specificity of the terrestrial and underwater landscapes in the Marseilles region is based on geological and climatic regions. Four discriminatory factors sum up the fundamentals of the landscapes: a lithology and a specific structural grid, an obvious eustatic heritage and particular wind conditions and surface currents designed around these physiographic factors (Collina-Girard 2012).

5.1 Lithology and Underwater Landscapes

Granitic and metamorphic regions contrast with limestone regions in very divergent landscape styles (Fig. 5.2). Rocks from the ancient metamorphic bedrock dominate the regions east of Cap Sicié: schists and phyllites from the shores of the Maures Massif from the archipelagos of Porquerolles and Port-Cros, or volcanic rocks and gneiss from the shores of Esterel and the Tanneron Massif. To the west of Toulon

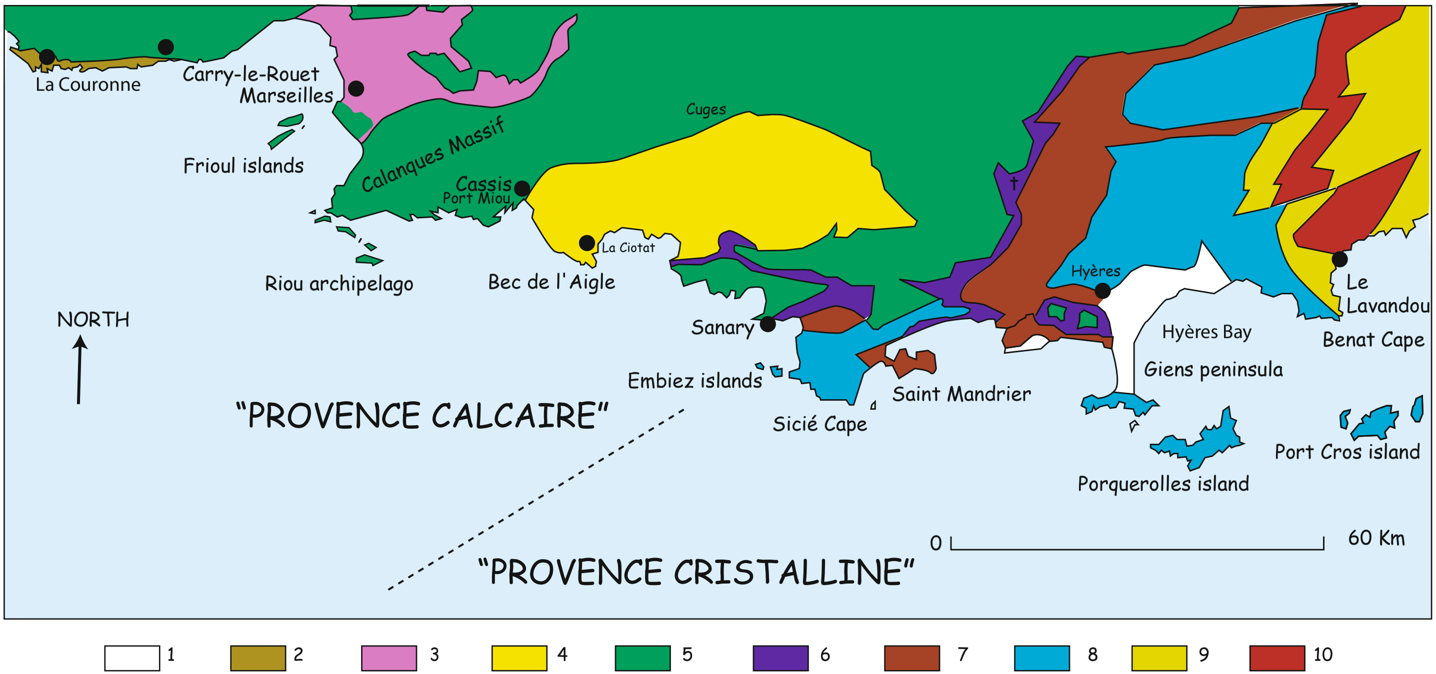


Fig. 5.2 Simplified geological map of the coastline between Cap Couronne and the Porquerolles-Port Cros archipelago. *1* Recent (Quaternary) sands of the Giens peninsula. *2* Tender shelly Tertiary (Miocene) sandstone (Carry-le-Rouet "molasses"). *3* Consolidated pebble and sand sheets of Tertiary age (Oligocene) filling in the Marseilles basin (ancient delta). *4* Pebble and sandstone sheets at Cap Canaille and the Ciotat from the secondary era (*Upper* Cretaceous, Turonian stage). *5* Massive limestone bars of secondary age (*Lower* Cretaceous, Urgonian facies). *6* Red clays with salt and gypsum, of secondary age (Trias). *7* Primary clays and red sandstones ("Permian"). *8* Mica schists (phyllites from Porquerolles-Port Cros archipelago and Giens). *9* Micaschists. *10* Gneiss and granites

Fig. 5.3 Morgiou Calanque carved into Urgonian limestones. (© J. Collina-Girard, All rights reserved)

and Cap Sicié, divers from the area of Ciotat, at the foot of the Bec de l'Aigle and Verte Island, explore ruin-shaped landscapes carved in resistant Upper Cretaceous conglomerates. Further to the west, Jurassic and Cretaceous compact limestone dominates the Marseilles coast. On the Blue Coast, around Carry-le-Rouet, Miocene "molasses" outcrop with rounded shapes organized in rock bars separated by deep crevices, popular among underwater hunters.

The underwater karstic landscapes of "limestone Provence", which are very conducive to the fixing of fauna, contrast with the "crystalline Provence" landscapes, where metamorphic and siliceous rocks are more resistant to chemical corrosion but less favourable to biological incrustation. Two national parks on either side of Cap Sicié present these two distinct types of underwater landscapes perfectly: the Porquerolles islands and Port-Cros Park, representative of the "crystalline Provence" seabeds, and the future Calanques National Park between Marseilles and Cassis, a typical example of a "limestone Provence" underwater landscape.

5.1.1 "Urgonian" Limestone Karstic Landscapes

The underwater landscapes of the future Calanques National Park are mainly a continuation of the white compact Lower Cretaceous limestones ("Urgonian" facies). The Calanques landscapes sway between the blue Mistral swept sky and the immaculate white of the "Urgonian" limestones (Fig. 5.3). These rocks are bioclastic limestones issued from the dismantling of rudist colonies. These extinct bivalves, organized in “spud-like” reefs make the fine mud seabed very uneven, and reflect a shallow underwater landscape on a carbonated platform which evokes the present-day Bahama Islands. The current underwater morphology is essentially dominated by these compact but fractured limestones, which are particularly vulnerable to karstic dissolution (Fig. 5.4). This karstification of limestones deriving from extinct underwater landscapes exhibits characteristic morphologies. These normally terrestrial shapes, arches, caves, karrenfelds, dolines and resurgences, are still easy to recognize beneath the sea as the landscapes were submerged very quickly during the last glacial period and were thus not eroded.

- **Landscape of underwater arches**:
  At the southern extremity of Maïre Island, just off the Farillons Skerries, a series of spectacular underwater arches forms a grandiose landscape, famous among divers (Fig. 5.5). There are similar isolated arches on Jarre Island, at a depth of − 30 m, at the foot of the “Pierre de Brégançon”, but also off the shore of the “Tombant de la Pierre à la Bague”, between − 35 and − 45 m west of Planier lighthouse.

- **Cave landscapes and karstic galleries**:
  Underwater caves are another element of the karstic landscape. They are well known to divers because of their obscure ceilings conducive to the development of red coral which has been exploited in the region since Antiquity (Fig. 5.6). Cosquer cave is now famous for its prehistoric paintings. The upper third of the cave was spared by the Tardiglacial rise in sea level. This cavity is part of a network of submerged galleries associated with a typical karstic pocket valley, which is now submerged. This network opens up under the sea (Cosquer Cave at − 37 m, Triperie Cave at − 17 m, Figuier Cave at − 20 m). Other caves exist at the foot of the deep wall (− 35 to − 60 m), between Caramassaigne Point (at the eastern extremity of Riou Island) and the Grand Conglu Skerry. One of these caves, with the floor currently at a depth of − 58 m, is located at the foot of this wall which dominates the sand plain extending seaward. Further east, at the Cassis Port outlet, the vast porch of Trémie Cave, at a depth of − 9 and − 20 m extends through a secondary room into a landscape of stalagmites and stalactites. A survey conducted by the prehistorian Eugène Bonifay yielded several flint prehistoric tools, evidence that humans lived in these now totally submerged landscapes.

- **Karrenfeld landscapes**:
  Offshore, between the Croisette Cap and Maïre Island, the Veyron Plateau is a typical karrenfeld landscape, covered with a spectacular network of galleries, between − 15 and − 20 m (Fig. 5.7). These galleries, formed by aerial karstic dissolution have yielded ferruginous sediments and continental limestone floors. To the west of Planier lighthouse, the “Plateau de la Pierre à la Bague” is a karstic karrenfeld plateau at a depth of − 1 and − 15 m with pinnacles and typical karstic incisions (Fig. 5.8). Similar submerged karrenfeld landscapes are present around the eastern point of Planier Island towards the Souquet shoal. Karrenfeld and

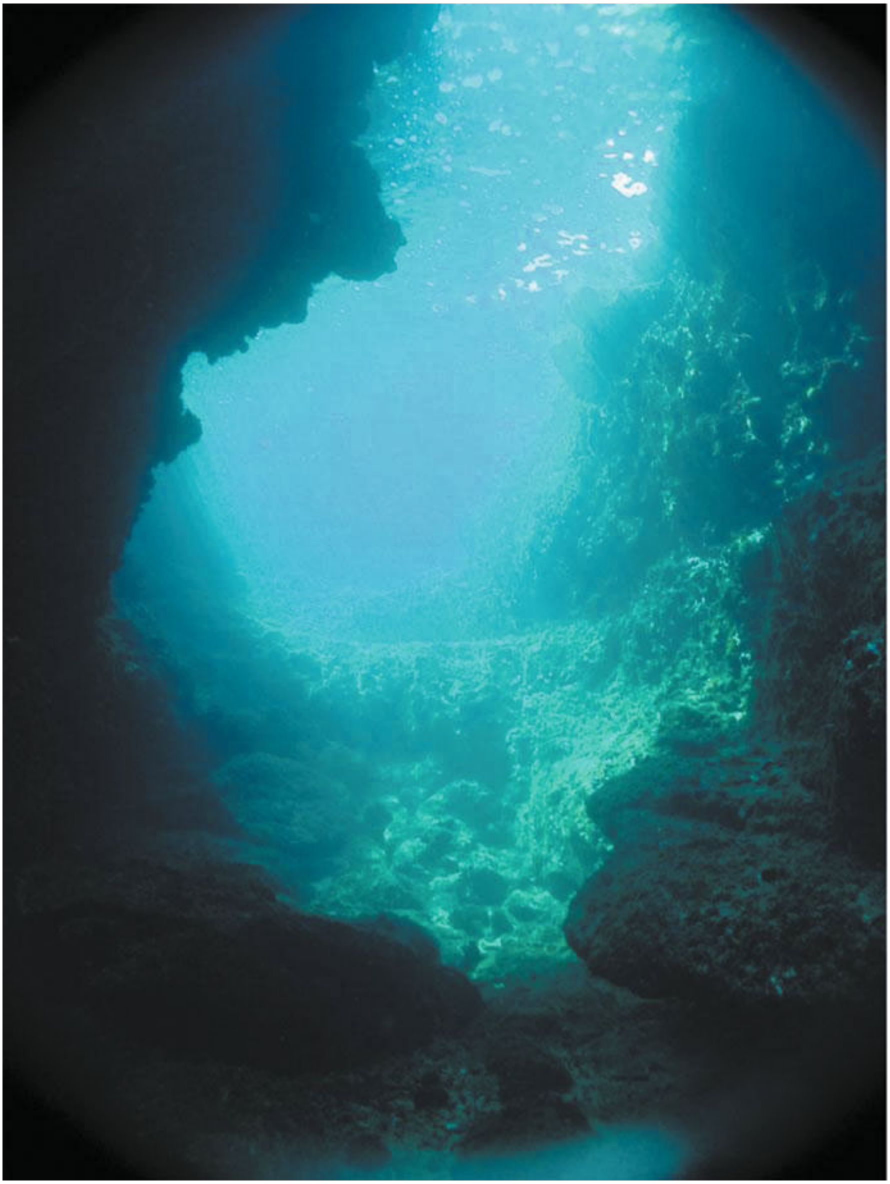


Fig. 5.4 A collapsed and submerged cave on the coast of Plane Island (– 15 m). (© J. Collina-Girard, All rights reserved)

pinnacle shaped landscapes are also visible at the extremity of Lucques Point, on the west coast of Pomègues Island.

- **Landscapes with "doline" fields and "poljes"**:
  The continental plateau off Marseilles and the Frioul islands, at a depth of 60–200 m, (Fig. 5.9) presents us with currently immersed landscapes from the last

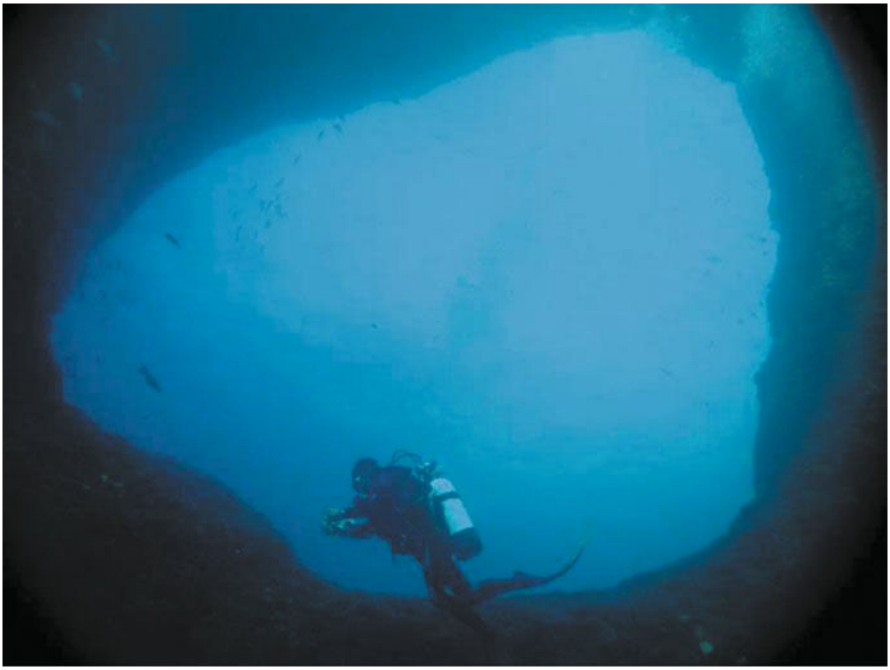


Fig. 5.5 A large underwater arch (– 5 to – 20 m) under the middle Farillon reef. (© J. Collina-Girard, All rights reserved)

glacial maximum (Collina-Girard 2012). The underwater topography of this plateau is typically karstic with many dissolution hollows and dolines, which are generally aligned following known structural directions. A dive off one of these dolines near Château d'If, at a depth of 30–35 m, allowed us to directly observe one of these half-sanded up, truncated cone-shaped hollows. These partly immersed dolines, forming sheltered creeks, can be observed on the coast of the Archipelago islands of Frioul and Riou. One of these creeks, the Pomègues Calanque (known to divers as the "Calanques aux pipes") is an "uvala", formed by the coalescence of three karstic hollows. The Pointe Marlet Calanque on Pomègue Island and that of Triperie on Cap Morgiou are submerged karstic "pocket valleys". Half immersed dolines also cut into the coastlines of the Plane and Jarre islands. Between Frioul Archipelago and Carry–le-Rouet, the underwater landscape is dominated by a large flat-bottomed hollow (– 72 m), a polje reminiscent of those observed in the Marseilles hinterland (Cuges-les-Pins poljé near Aubagne and Plan d'Aups in the Sainte Baume Massif).

- **Landscapes of resurgences and underground rivers**:
  The presence of immersed resurgences in the Cassis region, in the Port Miou calanque and Bestouan completes the portrait of these submerged karstic landscapes. The porch of the Port Miou resurgence, which is at a depth of – 20 m,

Fig. 5.6 Ceiling covered with coral in the underwater cave (− 20 m), in Moyade creek, western extremity of Riou Island. (© J. Collina-Girard, All rights reserved)

accedes to a freshwater river currently explored by divers for over 1,400 m to a depth of − 147 m. This network was carved during the Messinian and does not stop here. It drains a considerable hinterland and probably extends towards immersed outlets, to a depth of about − 200 m, somewhere in the Cassidaigne pit (Cavalera et al. 2010). Beyond these abyssal landscapes observed in diving saucers, submarines or wire guided devices, lie structurally oriented large canyons, inherited from Messinian landscapes contemporary with a low Mediterranean level of more than − 1,500 m which was refilled some 6 million years ago.

5.2 Fracturing and Landscapes

The Massif des Calanques limestones are compartmentalized by a network of fractures, with the main fractures following two intersecting directions; NW-SE and NE-SW. These directions (Fig. 5.10b) form a structural pattern visible at all levels of observation, from metric outcropping to landscapes perceptible on aerial or satellite photographs or on bathymetric maps (Collina-Girard 1995, 2005). The coastline of Marseilles Bay, the Massif of the Calanques and the archipelagos follow this structure (Fig. 5.10a). On the coast, fractures and NW-SE or NE-SW subsidence faults

Fig. 5.7 Karstic galleries in the Veyron plateau, at a depth of about − 20 m, off Marseilles between Cap Croisette and the Planier lighthouse. (© J. Collina-Girard, All rights reserved)

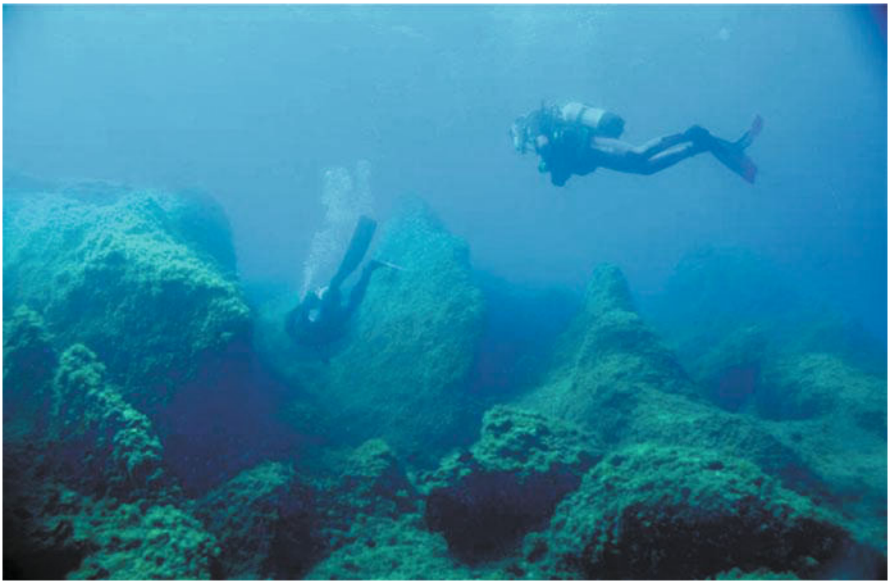


Fig. 5.8 The submerged "karrenfeld" of the "Pierre à la Bague", west of Planier Island (between 0 and − 15 m deep). (© J. Collina-Girard, All rights reserved)

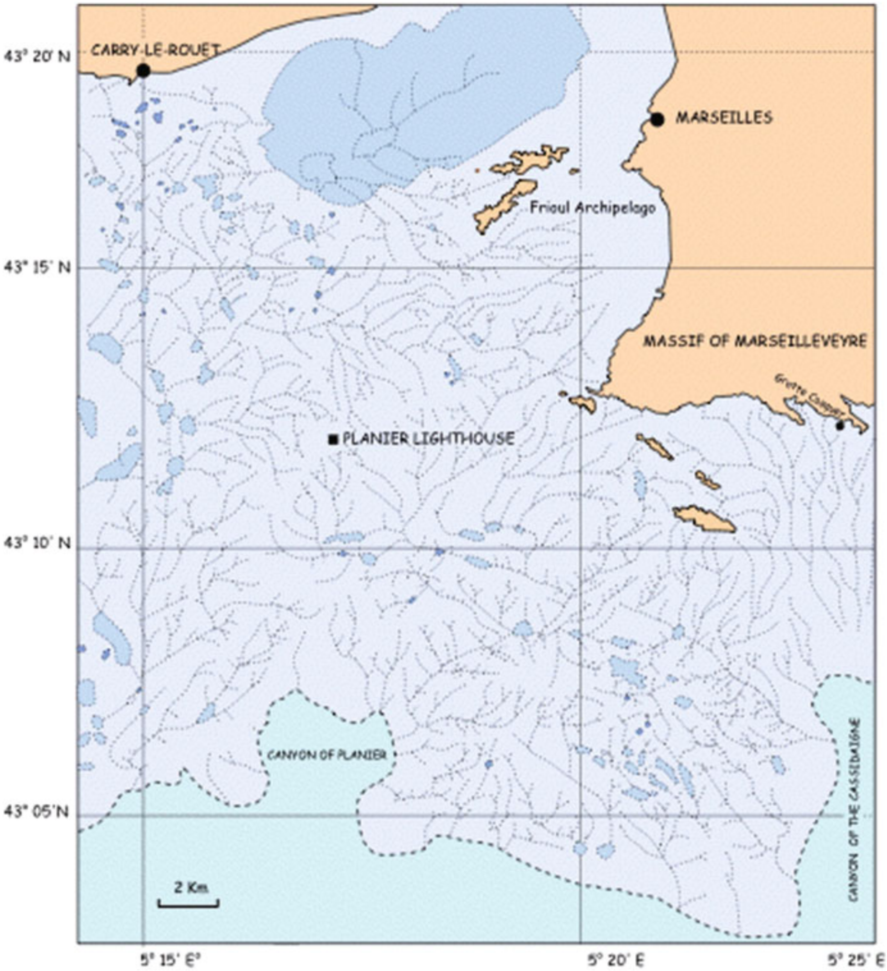
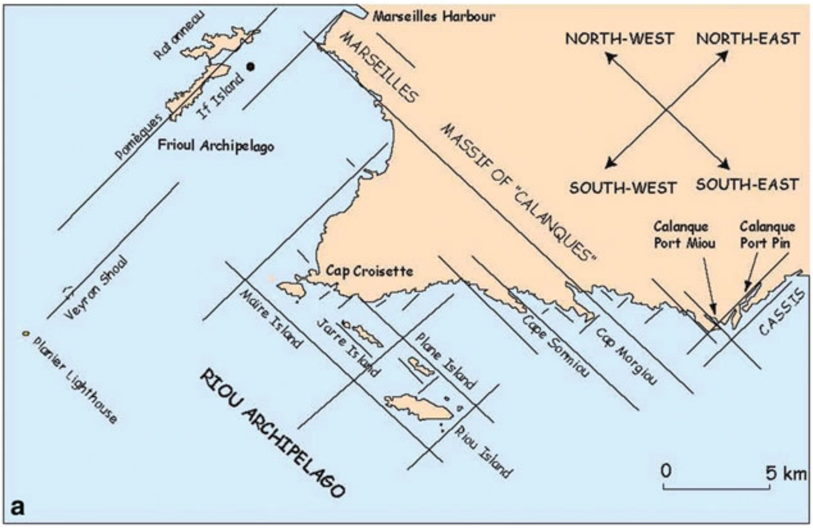


Fig. 5.9 The continental plateau and its swallowed landscapes off Marseilles and the Massif des Calanques

determine the position and the orientation of the "calanques", these drowned valleys which cannot be dissociated from the Marseilles landscape. At Cassis, for example, the two calanques near En-Vau and Port-Pin respectively follow these two main directions. This structural determinism of the coastal landscapes (Fig. 5.11) is also present underwater, particularly with regard to the position and the orientation of the large vertiginous walls and their vertical landscapes (Fig. 5.12) so appreciated by divers.



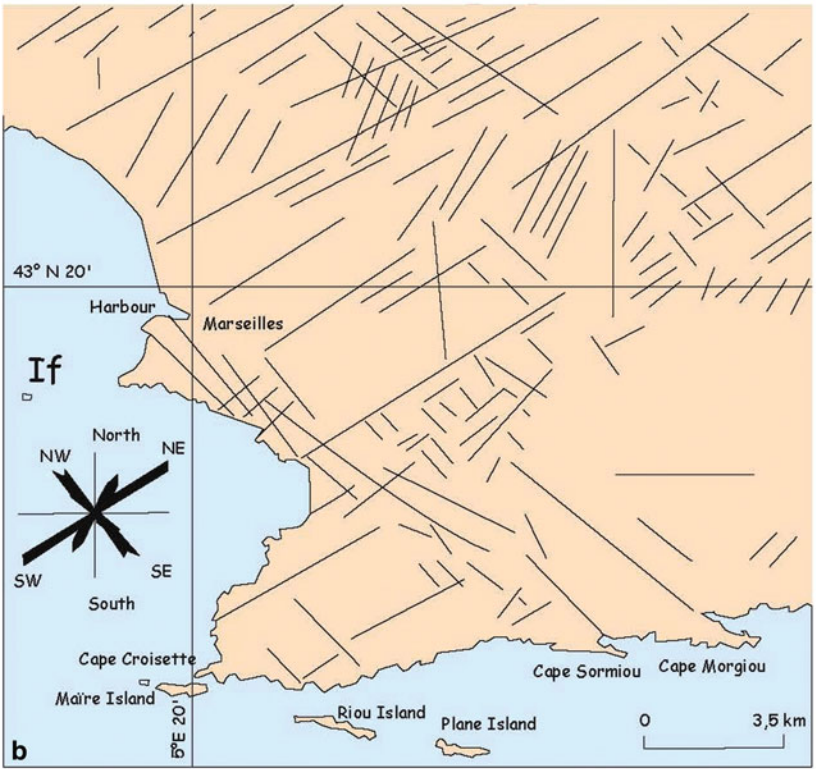


Fig. 5.10 Breakdown of the Marseilles coastline and the Massif des Calanques. **a** Orientation of the Marseilles coast and in the Massif des Calanques. **b** Orientation of the fracture networks as identified on aerial photographs (after Dupire 1985)

Fig. 5.11 Fracturing in the Massif des Calanques, the Grande Candelle fault and Sugiton Calanque, in a large crushed zone south of the scientific Luminy Campus in Marseilles. (© J. Collina-Girard, All rights reserved)

5.3 Eustatism and Underwater Landscape

The famous calanques landscapes appear as a karst structured by tectonics and submerged (Fig. 5.13) at the end of the last glaciation since 19,000 B.P until the end of Antiquity (Lambeck and Bard 2000, Laborel et al. 1983). Under the sea, the verticality of the wall is interrupted by erosion ledges. This step-like morphology is another component of these underwater landscapes. The statistical study of this tiering was carried out in Provence, Corsica and on Elbe Island and brought to light a typical sequence with ledges centred around the following depths: − 11 m, − 17 m, − 25 m, − 35/− 36 m, − 41 m, − 46 m, − 50/55 m. This tiering was interpreted as a series of palaeoshores carved during the Finiglacial transgression and the Holocene (Collina-Girard 2002), represented in Marseilles by a barrier beach cored at − 100 m south of Planier Island. Mussel shells from this barrier beach were radiocarbon dated to 13,800 years B.P (Collina-Girard and de Giovanni 1996). A sequence of coastal stepped notches was observed near Bandol (Alon Port) by the biologist Jacques Laborel at depths of − 7, − 25 and − 35 m.

At Cap Morgiou, the half immersed Cosquer Cave, which is only accessible by diving, owes its fame to prehistoric charcoal drawings and engravings (Clottes and

Fig. 5.12 Farillon wall (Maïre Island, Marseilles). (© J. Collina-Girard, All rights reserved)

Fig. 5.13 Riou Archipelago, summit of a drowned karst. (© J. Collina-Girard, All rights reserved)

Courtin 1994; Collina-Girard 2004). The represented horses, ibex, bison, aurochs, Saiga antelopes and cervids depict the hills and plains swallowed up during the Last Glacial Maximum (18,000 B.P.), but also the coastal landscapes (seals and penguins) which stretched out about fifteen kilometres south of the cave. Archaeology shows that the exploitation of fish and shell food is at least as old as the Upper Palaeolithic (Carry-le-Rouet Rockshelter) and continues during the Neolithic (Riou Island sandpit and excavations in the Butte Saint Charles in Marseilles).

Geological factors determine the main makeup of the coastal and underwater landscape. Yet these landscapes are also affected by more fluctuating factors such as wind conditions and marine tides. These atmospheric factors influence the immediate perception of the observer on a very short timescale (light, hygrometry, cloud cover) and seasonal and cyclical climatic rhythms also add a temporal touch.

5.4 Wind Conditions

5.4.1 Wind Conditions and the Light of the Landscape

The Marseilles region is influenced by two wind types; the Mistral, from the north or northwest sector and the southeast or east wind (Fig. 5.14a). These winds blow all year round with lulls between the 14th of July and the 15th of August, and during the autumn. The atmosphere of the maritime scenery is directly dependent on these wind conditions. There is marked opposition between the Mistral landscape with a short, choppy and violent swell beneath a pastel blue sky and mountain light. This wind can blow up suddenly, blow out just as suddenly and make way for the much longer and more regular east swell, beneath a cloudy and storm prone sky. This wind change is accompanied by variations in the light bathing these terrestrial and underwater Provencal landscapes.

When the Mistral blows, hygrometry is particularly low and the air is bright like in the mountains. The sea is capped by short waves topped with white tufts, the sky is pastel blue and it is bitingly cold. The surface of the sea is azure and the light penetrates deeply beneath the sea in cold and crystalline water which refracts the sun's rays. When the east wind blows, the air is much moister, the sky is greyer and cloudy with the possibility of stormy showers. The temperature is milder and the swell is ample. The sea's surface can take a dark blue, almost black hue. For the diver, the light is less intense and the more clement water is often deep dark blue with more filtered sunlight.

5.4.2 Wind Conditions, Geology and Navigation

By a happy coincidence, the coastlines, which are oriented by the directions of geological fractures, are exactly opposed to the direction of the prevailing winds

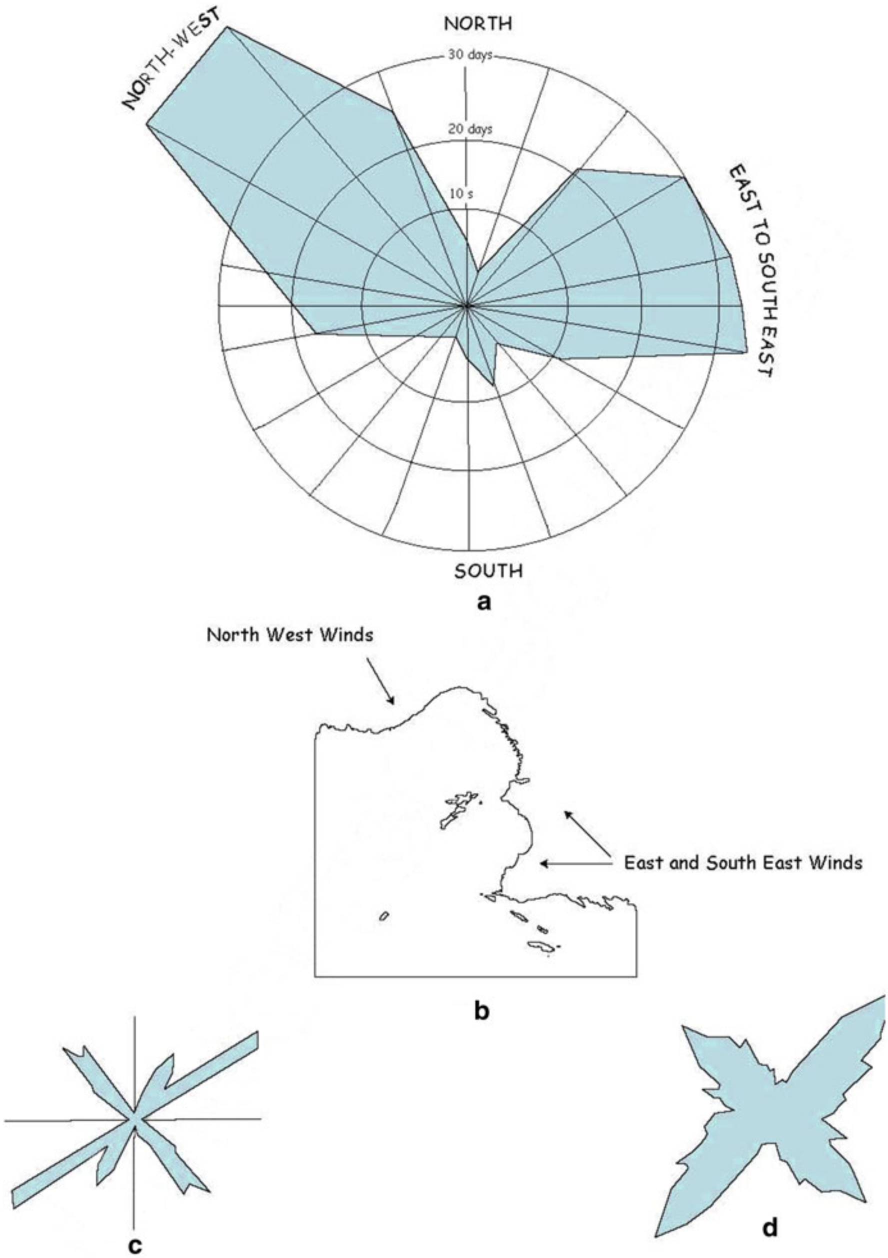


Fig. 5.14 Wind direction in the calanques. **a** Length of the winds in Marseilles, example from 1969 (after Castelbon 1972). **b** Orientation of the shoreline of the Marseilles inlet and the Calanques in relation to prevailing winds. **c** Orientation of the fractures in the Massif des calanques identified on aerial photographs (Dupire 1972). **d** orientation of the small valleys in the Massif des calanques

(Fig. 5.14b). On the coastline or on the islands, the fortunate conjunction of geology and meteorology thus provides the opportunity of all-weather refuge anchoring. There is no doubt that this did not escape the Greeks marines during Antiquity when they settled in Marseilles in the sixth century before our era.

5.4.3 Wind Conditions and "Thermal Landscape"

During the fair season, wind conditions cause the displacement of warm water fronts (23–24 °C) brought in by the east wind and pushed out by the Mistral. This surface warm water lies on much colder deep waters (13 °C). When the Mistral blows, this water column is pushed out behind Sicié Cap while the cold and deep waters rise to the surface, causing the water temperatures in diving locations to plummet rapidly. When the wind changes, the surface warm water is no longer pushed seaward by the Mistral and flows back into the Bay above the deep cold water, creating a violent surface current. The thermocline between superficial warm waters and deep cold waters moves vertically with these wind patterns, thereby modifying the diver's "thermal landscape". These rapid variations in temperature also affect others, such as the pelagic fish that follow the movements of this tepid surface water.

5.4.4 Temperature Patterns and Landscape

The seasonal temperature variations associated with the Mistral and northeast wind frequency changes are accompanied by changes in water temperatures. Certain phenological events, which are remarkable for the diver, set the immersed landscape in a seasonal calendar through the cyclical perception of the underwater landscape (Dupuy and Harmelin 2000; Collina-Girard 2012).

In spring, the onset of the fair season is initiated by the proliferation of the *asparagopsis* alga which carpets the seabed and walls. The disappearance of this alga then marks the imminence of summer warming. At the same time, shellfish such as sea spiders migrate towards the coast in the spring while the first octopuses put in an appearance.

The summer and early autumn mark the arrival of abundant pelagic fish, rare during the winter: "dentis", bream, zebra seabream, liches, tuna. New species to these waters have appeared on a regular basis in the past twenty years, such as the barracuda, which was uncommon west of Toulon up until recently. During midsummer and the autumn, the electric blue fry damselfish hatch (*chromis chromis*). At the same period we can observe *murex* hatches, piles of eggs similar to expanded polystyrene. Erect holothurians ejecting their gametes during reproduction are also characteristic of this season, during which warm water temperatures stabilize at around 20 °C or more.

The octopuses weaken and die at the end of the autumn, a season which can extend until mid-November in Marseilles. The summer and winter fish; large seabream,

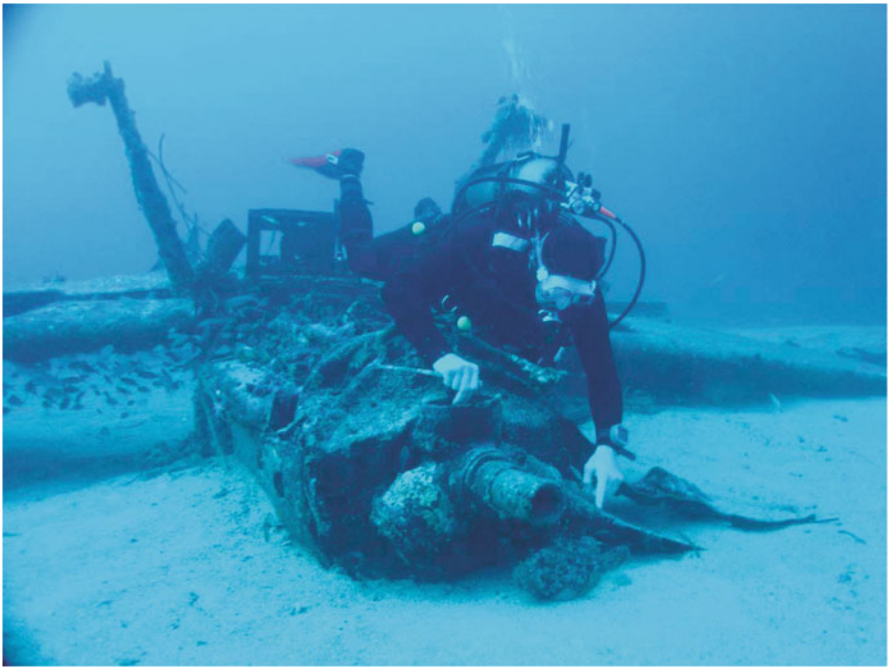


Fig. 5.15 Anthropisation of underwater landscapes, a wreck from the last war, the remains of a "Messerschmidt" type airplane at the foot of Planier lighthouse at a depth of -42 m. (© J. Collina-Girard, All rights reserved)

dentis, liches and tuna, tend to rarify when the waters begin to cool towards mid-November.

This rarefication of tepid water fish from the beginning of the cold season continues until only the bass remain. During winter, when water temperatures are stabilized at about 13 °C, it is not rare to come across an anglerfish or a shoal of squid.

All these biological signals affect the diver's "biological landscape" and "phenological landscape"... And the diver's mood also changes with the winds and the seasons.

5.4.5 Meteorology and "Mental Landscapes"

In many respects, the "geopsyche" (Hellpach 1943) of our mental landscape seems to be under meteorological control in Marseilles. We could allude here to common figurative expressions such as; to be depressed, to be "pumped up", "under pressure", "a storm is brewing", "a breeze of optimism". The reputed versatile and whimsical mood changes associated with the Marseilles population seem to be very much in keeping with this variable weather which can change in all respects in less than a few hours; wind direction and intensity, cloud cover, light and population moods...

5.4.6 Anthropisation of the Underwater Landscapes

Modern shipwrecks inherited from the 20th century world conflicts now form attractive artificial reefs for fish (Fig. 5.15). Recently, several artificial structures were sunk off the shores of the Prado beaches in order to create new settlement cores on sandy beds. The domestication of wild underwater zones has thus begun on Riou Island, off the Massif des Calanques, some 6,000 years after the arrival of the first Neolithic farmers. This landscape domestication began in 1989 with the setting up of an aquaculture farm on the east coast of Pomègue Island, and continued with the creation of a reserve of a small coastal portion in the Marine Park of the Blue Coast, near Carry-le-Rouet, about twenty years ago. Currently, the National Park project aims to protect terrestrial and underwater landscapes from Marseilles to the Ciotat.

5.5 Conclusions

Just as pschoanalysis could be considered as a geology of mental landscapes, the "geoanalysis" of underwater landscapes reveals an object resulting from stratified and embedded reasons. In Marseilles, it is the lithology, inherited from marine landscapes from the beginning of the Cretaceous era and the structural breakdown, inherited from stress due to the formation of the Pyrenean-Provencal and Alpine ranges which make up most of the landscape, later modelled by the eustatism affecting landscapes at the end of the Quaternary period. The reciprocal relations between the geological substratum and the prevailing winds determine and then channel the logic behind biological cover implantations and human activity.

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Chapter 6
Boreal Submerged Black Sea Landscapes

Gilles Lericolais

Abstract In 1999 William B. F. Ryan and Walter C. 3rd Pitman suggest in their book: "*Noah's Flood: The New Scientific Discoveries about the Event that Changed History*", that the Black Sea, once a much smaller land-locked freshwater lake, was deluged about 7,500 years ago with salty water destroying the fertile plains around the once-shallow freshwater lake. For them, this would have happened when sea levels rose beyond a Bosporus critical point letting the Mediterranean Sea overflowed into the Black Sea basin. In this, Ryan and Pitman proposed that such a catastrophic event is likely to have remained in the collective memory leading to the creation of the story of Noah and the great flood. Since then, a vigorous debate arose between researchers in this region and the scientific community. As this debate concerns more the question of flood myths that are common in many early cultures, most of concerned researchers get to a point where they can't see the wood for the trees meaning they did not consider the scientific results obtained from observations collected by a series of expeditions and showing that outside the cultural concerns, the Black Sea encountered a late major sea level rise during the Holocene. Here a synthesis on the assessment of the last sea-level rise in the Black Sea is presented. Numerous underwater surveys had collected data which interpretations evidence recent submerged landscapes somewhere around—100 m depth on the western Black Sea shelf consistent with a major low stand level witnessing that the Black Sea shelf was emerged at the beginning of the Holocene. Such important collections of data bring highlights to the debate regarding the precise timing and amplitude of the reconnection between the Black Sea and the Mediterranean Sea about 9,000 years ago.

Keywords Holocene · Rapid sea-level rise · Bosporus · Underwater surveys · Flood

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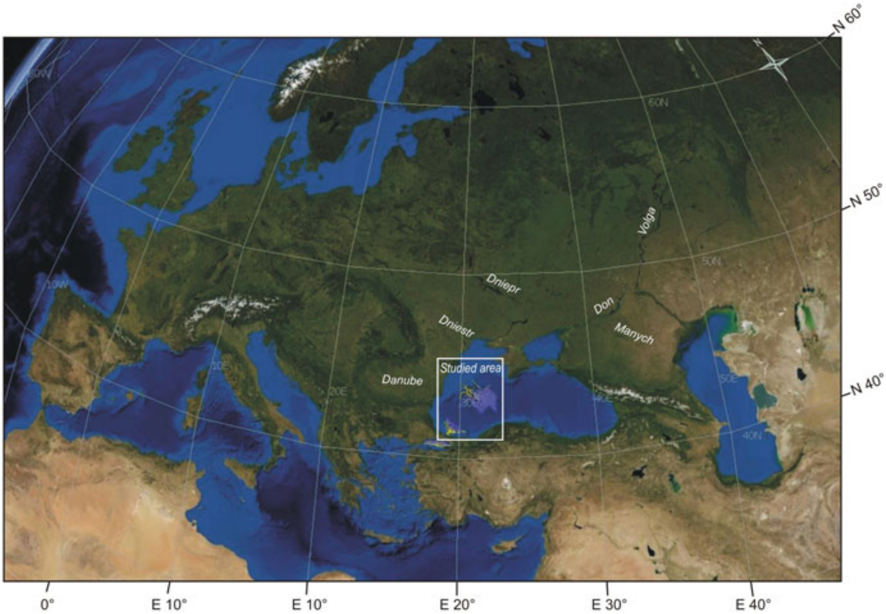

Fig. 6.1 The Black Sea and the area were important dataset was collected

6.1 Introduction

The Black Sea semi-enclosed basin (Fig. 6.1) is a unique laboratory for paleo-climatic studies as its water level fluctuations are directly linked to the climate variability without any hysteresis effect compared to the global ocean. This European landlocked Sea is connected to the World Ocean by a chain of two shallow straits, the Dardanelles and the Bosporus. Global sea level and the Earth's climate are closely linked. The Earth's climate has warmed about 6–8 °C since the Last Ice Age (ca. 20,000 years BP). As the climate has warmed following the end of this last cold period, sea level has been rising about 120 m.

Throughout the Quaternary Ice Ages that dominated the human history of Europe over the past 2 million years, sea levels were mostly lower than present by as much as 150 m, creating extensive coastal landscapes attractive to human settlement. Between 16,000 and 6,000 years ago, most of this territory was drowned by sea level rise following the last Ice Age, transforming the geographical and environmental context of human development. This drowned landscape preserves valuable sedimentary archives of long-term environmental and climatic changes, and an increasing number of submerged archaeological remains that document human response to this rapidly changing environment (Flemming 2004). The beginning of the Holocene (i.e. the completely recent geological era) is set at around 10,000 years BP and represented a marked climatic warming phase which is the beginning of the present interstadial (warm period between glaciations). This Holocene Climate Optimum was a warm period during roughly the interval 9,000 to 5,000 years which consisted of increases of up to 4 °C near the North Pole (Davis et al. 2003). This change is well established in a number of sediments and corresponds to the boundary between the Younger Dryas/Preboreal, and also the Late Glacial/Postglacial. The Holocene in contrast is distinguished by being the Age in which human activities have had a marked, and for the most part extremely detrimental, effect on the rest of the biosphere. Yet at the same time this age has witnessed the rise of civilization and the exponential development of human activities.

As consequences of such fundamental climatic changes were modifications of landscapes and ecosystems including into the Carpatian-Danubian-Pontian space. Human population was compelled to adapt to these new conditions. This period known as the Epipalaeolithic was followed by the Neolithic period, beginning with the rise of farming, which produced the "Neolithic Revolution". The Neolithic is not a specific chronological period, but rather a suite of behavioural and cultural characteristics, including the use of wild and domestic crops and the use of domesticated animals. This is thought to have started in the Middle East and in Egypt around 11,000 years BP. Then the "Neolithic Revolution" appeared around 10,000 years BP in Anatolia and the Southern part of the Black Sea linked probably to successive migration of population from Anatolia (Ivanov and Avramova 2000).

The North-Western Black Sea shelf has been as well as the European shelves exposed during sea level low-stands This now submerged Black Sea shelf provided a crucial arena for the survival and dispersal of Europe's earliest inhabitants during the Stone Age, the early development of prehistoric societies, the initial spread of agriculture from the Near East, and the foundations for the earliest civilizations. The key evidence relating to these early developments now lies buried on the sea floor. But, the water level fluctuations of the Black Sea had behaved independently from the global sea level during its period of disconnection from the Global Ocean. In the aftermath of the Ice Age, water levels in the Black Sea and the Aegean Sea rose independently until they were high enough to exchange water. The exact timeline of this development is still subject to debate. One possibility is that the Black Sea filled first, with excess fresh water flowing over the Bosporus sill and eventually into the Mediterranean Sea. There are also catastrophic scenarios, such as the "deluge theory" put forward by William Ryan and Walter Pitman in their book: "Noah's flood: The new scientific discoveries about the event that changed history" (Ryan and Pitman 1999).

Actually, Long decades of work carried out by scientists from Russia and other eastern European countries (Andrusov 1893; Arslanov et al. 1978; Balabanov 1984; Fedorov 1963; Kvasov 1968; Muratov et al. 1974; Nevesskiy 1961; Ostrovskiy et al. 1977; Shimkus et al. 1980; Yaranov 1938) led to the publication of different hypotheses and curves for the Holocene sea level changes of the Black Sea. Using these different works a first synthesis effort was realised by Pirazzoli (1991). But, Ryan et al. (1997) published a hypothesis according to which a massive flood through the Bosporus occurred in ancient times. They claim that the Black Sea was a vast freshwater lake, but then about 7,500 years BP later corrected to 8,400 years BP (Ryan 2007; Ryan et al. 2003), the Mediterranean spilled over a sill at the Bosporus, creating the current communication between the Black and Mediterranean Seas.

Subsequent work has been done both to support and to discredit this hypothesis, and archaeologists still debate it (Aksu et al. 2002; Aksu et al. 1999; Algan et al. 2007; Balabanov 2007; Ballard et al. 2000; Giosan et al. 2009; Gorur et al. 2001; Hiscott et al. 2007; Kerr 2000; Lericolais et al. 2009; Lericolais et al. 2010; Major et al. 2006; Major et al. 2002; Ryan et al. 2003; Uchupi and Ross 2000). Such a late reconnection will lead to a longer exposing of the Black Sea shelf allowing the population to settle near the coast. This has led some to associate this catastrophe with prehistoric flood myths and became one of the highest scientific debates of recent years and one that has fascinated the public imagination. Debate regarding the precise timing and amplitude of the reconnection between the Black Sea and the Mediterranean Sea about 9,000 years ago is as vigorous today as when it started about a decade ago. This controversy was one of the triggers for the installation of IGCP Project 521. "Black Sea-Mediterranean Corridor during the last 30 ky: sea level change and human adaptation". The resulting book edited by Yanko-Hombach et al. (2007b) is a good recorder of the state of research from geology to archaeology carried out in the Black. However, many conclusions of studies presented in the volume should be considered cautiously as it is evident that the debate is vividly going on and a lot of research remains to be done.

In this paper, we present a synthesis corresponding almost to an essay on the assessment of the last sea-level rise in the Black Sea obtained from observations collected by a series of expeditions carried out between 1998 to 2005. Especially, the evidence of recent submerged landscapes which erosion was due to wave action around 9,000 years BP. Before this work, numerous Russian authors indicated a sea level lowstand at about -90 m depth, based on the location of offshore sand ridges described at the shelf edge south of Crimea. The unique wave-cut terrace on the outer Romanian shelf presenting an upper surface varying between -95 and -100 m is therefore consistent with a major lowstand level situated somewhere around -100 m depth and witness that the Black Sea shelf was emerged at the beginning of the Holocene. These expeditions were realised in the frame of two main projects: BlaSON (Lericolais et al. 1999) and the European project ASSEMBLAGE (EVK3-CT-2002-00090) (Lericolais and Assemblage partners 2006) although not all of the 4,20,000 km^2 of the Black Sea have been surveyed using modern scientific equipment and interpretation light at modern ideas.

6.2 Oceanographic Surveys: Tools and Methods

The underwater archaeological research that has been carried out in pursuit of archaeological goals has often been fragmented, conducted outside the academic and scientific mainstream, or by museums, national parks and heritage organisations. Most of these works have been conducted in a depth range of 0–20 m, well within range of efficient Scuba diving (Flemming 2004). Unfortunately, archaeologists usually lack access to equipment such as ships, ROVs (Remotely Operated Vehicles), submersibles, and acoustic survey devices, or the technical skills or interdisciplinary partners to apply them.

Conversely, marine geologists and geophysicists have produced many detailed studies of underwater features relating to sea-level change, coastal sediment dynamics and palaeoclimate across the full depth range of potentially habitable landscapes on the continental shelf, but rarely with archaeological goals and issues of prehistoric social change in view. This is why for instance, the objectives of the FP5 European project ASSEMBLAGE was to use most advanced geophysical techniques to asses the sedimentary system of the Western Black Sea since the Last Glacial Maximum. Modern high-technology equipment was used and ground truthing was carried out to determine the geophysical features recognized. At present, important analyses such as stable isotope measurements as well as AMS ^{14}C age determinations from core samples at a small sampling interval are undergone.

Most important results used in this paper are coming from interpretation of data acquired during surveys realised in the framework of two main projects; (1) BlaSON: a French-Romanian bilateral project for which two surveys coordinated by IFREMER were carried out on board the French RV “Le Suroît” in 1998 and 2002, (2) ASSEMBLAGE: a FP5 European project for which two surveys on board the French RV “Le Marion Dufresne” in 2004 and the Romanian RV “Mare Nigrum” in 2005 were carried out. For all these surveys a differential GPS system was deployed for accurate (about 1 m) positioning and every vessel was equipped with swath bathymetry systems. Very high-resolution seismic lines were shot simultaneously using a Chirp sonar system. All data acquisition were synchronized and digitally recorded. The navigation profiles presented here are displayed in Fig. 6.2.

Together with geophysical surveys, ground truthing was obtained from cores. Sediment cores have been recovered using Kullenberg-type piston corers. More than 100 cores were collected among which, some reach more than 40 m long of sediment recovery. Studies are still ongoing on the analyses of the samples.

6.3 Results

6.3.1 Morphological Information

Prior to these important Black Sea campaigns, work and publications reported presence of terraces on many Black Sea margins, from the narrow Caucasus shelves (Ostrovskiy et al. 1977; Shimkus et al. 1980) to the Northern Turkish shelf (Algan et al. 2002; Ballard et al. 2000). Among these terraces, shells belonging to past littoral environments were dated between 19,000 to 9,000 years BP (Chepalyga 1984; Dimitrov 1982; Ostrovskiy et al. 1977; Scherbakov et al. 1978). On the Romanian continental shelf, Popescu et al. (2004) and Lericolais et al. (2007b) have noticed the absence of incised river channels below − 90 m water depth where a wave-cut terrace like morphology was mapped about 100 km far from the Danube delta (Fig. 6.3).

Wave-cut terraces are erosion surfaces created by erosion from wave action indicating the vicinity of the shoreline. Since rivers do not always generate continuous incised valleys all along the shelf (Lericolais et al. 2001; Talling 2000; Wescott

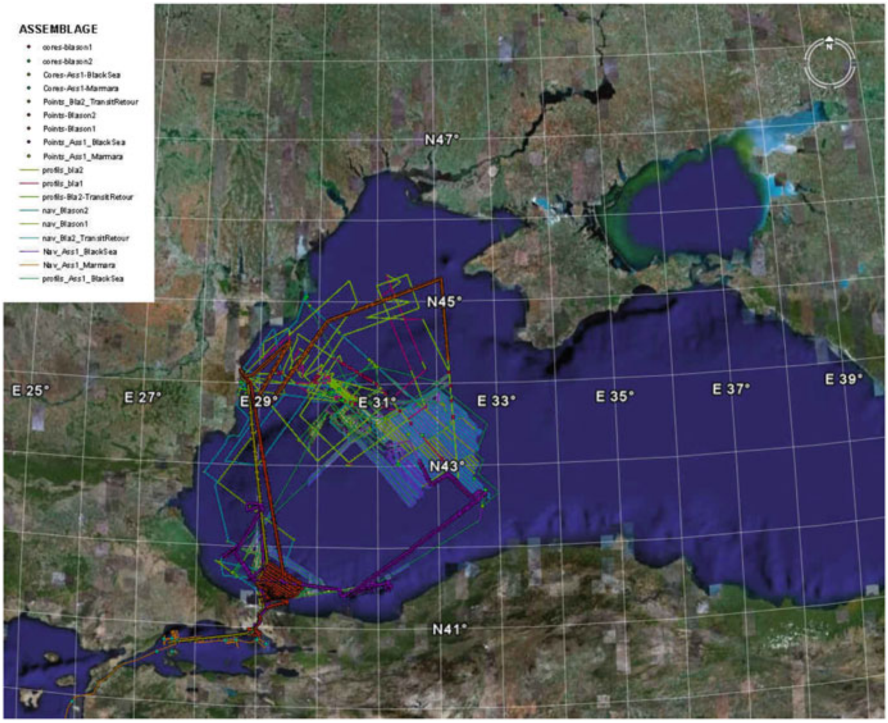

Fig. 6.2 Bathymetry of the semi-enclosed Black Sea basin and BlaSON and ASSEMBLAGE survey route locations

1993), their absence below the isobath − 90 m does not necessarily indicate location of the paleo-coastline. A good indicator of the paleo-coastline is the wave-cut terrace wrapping around the head of the Viteaz canyon (VC on Fig. 6.3) and present between isobath − 90 and isobath − 110 m (Popescu et al. 2004). Northward of the Viteaz Canyon the terrace deepens again to − 97 m while the height increases to 10–15 m, and splits into two distinct steps. The last lowstand paleo-coastline should thus have been situated between this submerged terrace and the deepest buried fluvial channels

At the top of this coastal feature recognized on the Romanian shelf is a set of coastal dunes or delta mouth bars described by Lericolais et al. (2007a, b). But, are this morphology of features on the seafloor inferred to drowned beaches or wind generated dunes? In a recent paper, Lericolais et al. (2007b) have interpreted the linear ridges mapped on the Romanian shelves in studying their possible origin of formation (Fig. 6.4). After analysing the different possibilities ranging between sand waves or longshore bars or delta mouth bars, Lericolais et al. (2007b) interpreted such features as coastal dunes resulting of accumulation of sand transported along the shore by combined action of winds and waves (Carter et al. 1990a) in littoral environnements (Carter et al. 1990b). For the linear ridges on the Black Sea's shelf to be coastal dunes, they had to have been constructed during a regression that exposed the surface upon which they grew, and they had to survive intact any subsequent shoreface erosion as they became submerged.

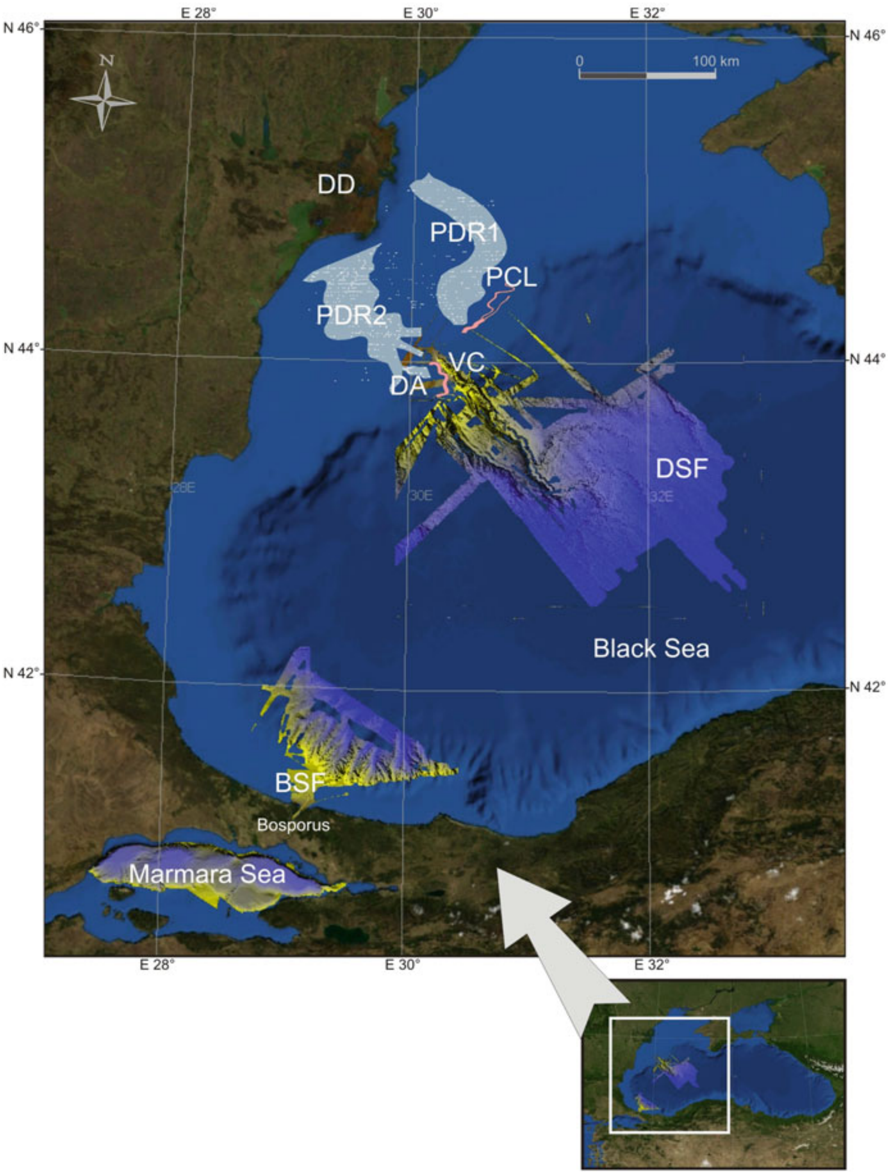

Fig. 6.3 Western Black Sea shelf presenting the location map of the geomorphologic interpretation issued from previous work. *DA* Dune Area, *DD* Danube Delta, *PDR1* and *PDR2* Paleo-Danube River 1 and 2, *PCL* Paleo Coastline, *VC* Viteaz Canyon, *DSF* Danube Deep Sea Fan, *BSF* Bosporus Shallow Fan-Delta. (Lericolais et al. 2007b; Popescu et al. 2004; Popescu et al. 2001)

These submerged shorelines characterized by the presence of a wave-cut terrace at depths between − 80 to − 100 m are key elements in supporting a recent low level of the Black Sea. The analysis of the very high-resolution seismic data in pseudo3D mode (Lericolais et al. 2009) demonstrates that this shelf deposits form an important

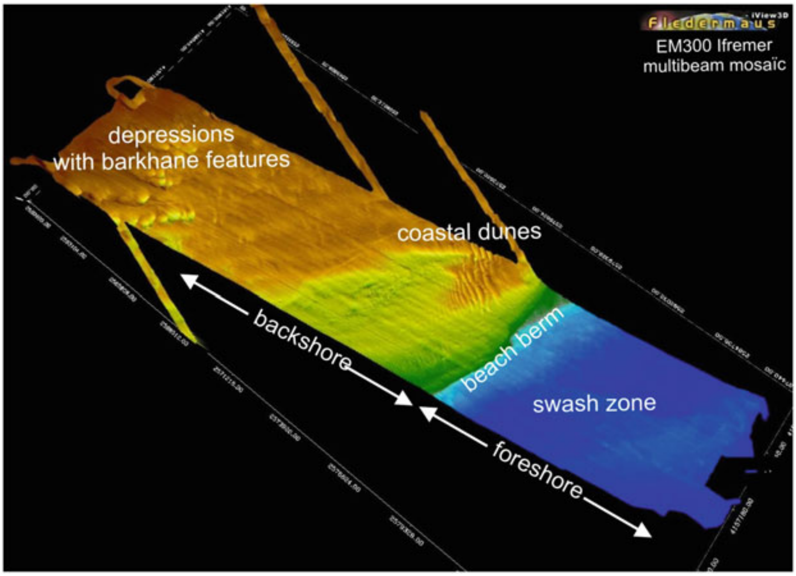

Fig. 6.4 Data terrain model obtained from multibeam data collected on the Romanian shelf (DA on Fig. 6.3)

basinward-prograding wedge system interpreted as forced regression system tract eroded at the distal part by a wave cut terrace (see Fig. 4 and 5 of Lericolais et al. 2009). Analyses of cores retrieved from the dune field area demonstrate that the prograding wedges are lacustrine in origin and dated of the PreBoreal (Lericolais et al. 2010). Here too, the hinge point corresponds to the wave erosion surface mapped around the − 100 m isobath. The ages returned by the core analysis range between 11,000 to 8,000 years ^{14}C BP with the formation of dunes being around 8,500 years ^{14}C BP. The prograding reflectors deepen seaward and are truncated by an erosional surface described as the wave cut terrace.

On the western part of the Black Sea continental shelf, a shelf-wide ravinement surface is always present and can be recognized both on high-very high resolution seismic reflection profiles and in all the collected cores. In the cores this surface corresponds to the described "hash layer" of Major et al. (2002). This "hash layer" is constituted of debris of whitened *Dreissena*. This is equivalent to the present day surf zone where the washed wave zone is marked by debris of whitened mollusc shells.

All the area is covered by a drape of less of 1 m thick inside which *Mytilus edulis* are described in all the cores recovered in the Black Sea (Giunta et al. 2007). *Mytilus edulis* lives in poorly-sorted muddy sand or muddy gravel shores in water depth from 0 to 30 m (Westerbom et al. 2002) but can be present in deeper water depth know as specific "niche". As these mussels dated from 7,500 to 5,000 years BP are encountered everywhere in the recovered cores at a water depth ranging between 70 to 100 m, one can say that the water level at that time was at least between 80 to 50 m lower than today. This mud drape covering the dunes is confirming that the dune system is not any more active. Everywhere across the mid and outer shelf the ridges, mounds and depressions are draped by this thin layer of sediment with a remarkably uniform thickness of no more than a meter (Lericolais et al. 2010).

6.3.2 Core Sample Information

Before the evidence of the above described wave cut terraces no reliable sea level markers were described to allow a good sea level reconstruction (Giosan et al. 2006; Pirazzoli 1991). More the lack of radiocarbon ages on in situ materials and the difficulty in calibrating radiocarbon ages in a setting with variable reservoir ages (Giosan 2007) led to ongoing discussion about the Black Sea level fluctuations. Recent publications (Balabanov 2007) have proposed unrealistic Black Sea level curve leading to an obvious controversy with the so far published sea level curves of the Mediterranean Sea. Brückner et al. (2010) demonstrate that both water bodies had reacted synchronously on glacio-eustatic changes at least since 7,500 BP, when the Black Sea and the Mediterranean were connected. Brückner et al. (2010) documented that none of the Mediterranean sea level curves shows the major wiggles postulated for the Black Sea by Balabanov (2007) which are supposed to reflect transgression and regression cycles.

Using sediment cores to reconstruct the Black Sea level fluctuation with accurate dates is challenging. One of the reasons for this is the uncertainty existing to resolve the reservoir age of the Black Sea. Actually, if at least for the more recent period, Siani et al. (2000) have proposed a reservoir age of 415 ± 90 years BP for the Black Sea, a different reservoir age of about 1,280 years deduced from the occurrence of the Santorini Minoan ash in several south Black Sea cores recovered in deep waters was proposed by Guichard et al. (1993). If we include documentation from Jones and Gagnon (1994), Bahr et al. (2005) and Kwiecien et al. (2008), then reservoir ages are extending from 0 to 1,280 years. The question of which reservoir age could be given to old water of the "Black Lake", depending on depth in the water column is still a matter of debate. Recently, radiocarbon activity of dissolved inorganic carbon has been measured in the north-western Black Sea and a contribution to sedimentary organic carbon estimated at $< 15\,\%$ of the photosynthetic primary production could explain ^{14}C reservoir ages greater than 1,300 years (Fontugne et al. 2009).

Another controversy lies in the knowledge of the salinity of the Black Sea during the New Euxinic Stage ($\sim$20,000 years BP). Wall and Dale (1974) demonstrated that sediments whose ages did not exceed 23,000 years in the cores they analysed contain a unique dinoflagellate assemblage that comprises essentially two species, *Tectatodinium psilatum* and *Spiniferites cruciformis*. These dinoflagellates apparently lived in the almost freshwater "lake-sea" of the New Euxinic Stage and were displaced abruptly 7,000 years ago when saline water from the Mediterranean began to flow into the Black Sea (Wall and Dale 1974). Although, other authors (Marret et al. 2009; Mudie et al. 2002; Yanko-Hombach et al. 2007a) prefer to speak of a brackish body for the Black Sea at that period. Therefore, determining the salinity of the isolated Black Sea is of interest in the ongoing discussion about the impacts of the last reconnection. Accurate salinity estimation is also desired to better understand paleo-environmental proxies of the isolated Black Sea since currently there is no analogue of this ancient giant lake. Soulet et al. (2010) using an advection-diffusion model for pore water collected into Black Sea cores during ASSEMBLAGE cruise compared different scenario models of bottom water chloride and $\delta^{18}O$ variations and simulated the impact of a catastrophic reconnection and a smoother reconnection. The comparison suggests that the glacial Black Sea was a homogeneous freshwater lake (with a $\delta^{18}O$ of $\sim -10\,\%$ and a salinity of ~ 1 psu). Modern hydrologic conditions would only have been reached at ~ 2,000 years BP, concomitant with the onset of coccolith-rich thin layers that characterize modern basin sediments (Giunta et al. 2007). This recent results obtained from pore water analyses precise the results obtained by Manheim and Chan (1975) and confirm that the Black Sea was a fresh water lake prior to its reconnection with the Marmara Sea.

6.4 Discussion and Conclusion

The assessment of the north-western part of the Black Sea sedimentary systems from the continental shelf and slope down to the deep sea zone provided by the ASSEMBLAGE European Project bring important highlights to the debate regarding the precise timing and amplitude of the reconnection between the Black Sea and the Mediterranean Sea about 9,000 years ago. The results obtained from geophysical data and core analyses provide a solid record of the Black Sea Last Glacial Maximum (LGM) water level fluctuations and shed new light on the controversy concerning the Black Sea water level fluctuation since the Last Glacial Maximum. ASSEMBLAGE project has attempted to assess the last sea-level rise in the Black Sea and provide scenarios quantifying the processes governing the transition of Black Sea system from a low-salinity lake to a marine state while addressing the variability in this system.

One important fact obtained by this extensive mapping of the western Black Sea shelf is the evidence of a water regression evidenced by the forced regression features (Lericolais et al. 2009) which took place during the PreBoreal period. In a recent paper (Lericolais et al. 2010) propose a scenario for the transition of the Black Sea system from a lacustrine to a marine environment. Six major observations have documented this Black Sea behaviour: (1) Existence of two lowstand wedges one dated from the LGM and covered by a second one dated from 11,000 year BP to 8,000 year BP and located at a water depth ranging from − 100 to − 120 m; (2) a Danube prodelta built up at − 40 m after the post LGM melt water pulses was also documented; (3) a set of meandering river channels capped by a regional unconformity and extending seaward across the Romanian shelf to the vicinity of the − 100 m isobath was recognized; (4) evidence of submerged shorelines with wave-cut terraces and coastal dunes, or delta mouth bars at depths between − 80 to − 100 m, below Holocene Bosporus and Dardanelles Strait outlet sill to the global ocean; (5) observation on the western part of the Black Sea continental shelf of a shelf-wide ravinement surface visible in high-very high resolution seismic reflection profiles; (6) presence of a uniform drape of sediment beginning at the same time above the unconformity with practically the same thickness over nearby elevations and depressions and with no visible indication of coastal-directed onlap across the outer and middle shelf.

As the Black Sea was in a very close vicinity to the Scandinavian-Russian ice cap, the supply of the melting water from the glaciers into the Black Sea through the major drainage system constituted by big European rivers (Danube, Dniepr, Dniestr and Bug) was sufficient to raise the water level between − 40 m to − 20 m just after the Melt Water Pulse 1A (MWP1A) at approximately 14,500 years BP. The − 40 m upper limit is interpreted from records deduced from the Danube Pro-delta building (Lericolais et al. 2009) which are not exhaustive, and the 20 m limit is certified by (Yanko 1990).

Palynological studies conducted on BlaSON cores (Popescu 2004) show that from the Bölling/Alleröd to the Younger Dryas a cool and drier climate prevailed. North-eastern rivers converged to the North Sea and to the Baltic Ice Lake (Jensen et al. 1999), giving reduced river input to the Black Sea are resulting in a receding shoreline. The post Bölling/Alleröd climatic event had favoured the lowering of the Black Sea water-level and the presence of the coastal sand dunes and wave-cut terraces confirmed this lowstand. The anastomosed buried fluvial channels described by (Lericolais et al. 2009; Popescu et al. 2004) that suddenly disappear below − 90 m depth and a unique wave-cut terrace on the outer shelf, with an upper surface varying between − 95 and − 100 m is therefore consistent with a major lowstand level situated somewhere around − 100 m depth. Precedent studies have already proposed a depth of − 105 m for this lowstand according to a regional erosional truncation recognised on the southern coast of the Black Sea (Algan et al. 2007; Demirbag et al. 1999; Gorur et al. 2001) but also based on a terrace on the northern shelf edge (Major et al. 2002).

On the Romanian shelf, preservation of the sand dunes and buried small incised valleys is to be linked with a rapid transgression where the ravinement processes related to the water level rise have no time to erode sufficiently the sea bottom (Benan and Kocurek 2000). Around 8,500 years BP, the surface waters of the Black Sea suddenly attained present-day conditions owing to a rapid flooding of the Black Sea by Mediterranean waters, as shown by dinoflagellate cyst records (Marret et al. 2009; Popescu 2004; Wall and Dale 1974). This can also be related with the beginning widespread and synchronous sapropel deposition across slope and basin floor. This inflow of marine waters is confirmed by the abrupt replacement of fresh to brackish species by marine species. Further more, the model developed by (Siddall and Kaplan 2008) shows that about 60,000 m^3 of water per second must have flowed into the Black Sea basin after the sill broke and it would have taken 33 years to equalize water levels in the Black Sea and the Sea of Marmara. Such a sudden flood would have preserved lowstand marks on the Black Sea north-western shelf.

Besides the strong controversy about the conditions of the last reconnection of the Black Sea, its salinity just prior to the last reconnection is also a matter of debate (Burkhard et al. 1998). On one hand, a fresh Black Sea “Lake” (e.g. Ballard et al. 2000; Major et al. 2002; Ryan et al. 1997) would have allowed coastal farming

Fig. 6.5 Recently discovered dugout canoe made most probably of oak. (Photo courtesy of Bozhidar Dimitrov, head of the National Museum of History of Bulgaria)

on exposed shelves. As a consequence, a catastrophic flood would have accelerated dispersion of Neolithic farmers into the interior of Europe forming a historical basis for the widespread Deluge myths (Ryan and Pitman 1999). On the other hand, a brackish or salty Black Sea (e.g. Mudie et al. 2002; Yanko-Hombach 2007) would have prevented any massive settlement along the Black Sea coast. The recent results obtained from pore water analyses (Soulet et al. 2010) confirm that the Black Sea was a fresh water lake prior to its reconnection with the Marmara Sea and allow so to think that early Neolithic population could have lived near the Black Sea "Lake" and encountered the rise of the water at the late reconnection of this water body with the Global Ocean. If the level of the Black Sea felt down to 100 m depth from the present level during the PreBoreal to the Holocene, it is strongly conceivable to expect to find some buried Neolithic artefacts on the shelf of the Black Sea.

The Black Sea has a great potential, since it's anoxic (anaerobic, no oxygen) below *ca.* 200 m depth. With no oxygen, deep-sea wrecks can be preserved for millennia. Also, the Black Sea pre-reconnection remains of prehistoric settlements could be found underwater. To support such expectation, recently a well-preserved ancient wooden dugout canoe has been discovered at the bottom of the Black Sea by fishermen trailing nets along the sea bottom more than 30 km off the coast (Fig. 6.5).

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Chapter 7
Gaze into the Landscape: Can Sensory Immersion, Landscape Reading and Design, and Landscaping Methods be Adapted to the Underwater Landscape?

Charles Ronzani and Alain Freytet

Abstract Underwater landscape nowadays becoming a field of action for landscape designers: Politicians and natural marine parks are starting to resort to it. Contrary to what we could think, not only do landscape designers set up the land, they also carry out researches seeking to understand how a natural and/or cultural landscape can be seen by an audience, and managed at its best. They "read" the landscape. They can rely on science, but above all, this reading is for them an art; the art of "immersion." Intuitively, artistically, graphically soaking up the place's atmosphere bringing a new look upon it, understanding and conveying its emotion and specificity: this is the modern practice used by the French landscape designers of the Versailles school. However, can these methods, usually terrestrial, be applied to the underwater landscape? Do underwater characteristics (which are completely different from the terrestrial ones, starting with the visual water filter that questions an essential part of the definition of landscape itself) impose a change of method? What new tools and practices does the landscape designer have to invent in order to study the underwater landscape, and eventually act on it? The development of this quite new job is allowing new and unseen management perspectives for underwater landscapes. The landscape designer (alongside scientists), beside knowledge and protection, can facilitate coexistence between delicate marine environments and the audience, in terms of sensitization, cultural mediation, underwater museography, adjustments, and communication tools that are attractive and fitted into landscape. "Make understand rather than defend": The "ecology of perception" is a substitute to the purely protective ecology present in the exotic laboratory of underwater landscape. All of this is, once out of the water, in favor of the terrestrial landscape to which we might have gotten accustomed too easily and not see all the beauty it offers us...

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7.1 Introduction

Landscape study is an art of immersion. This belief underpins our methods and ethics as landscape designers—a term we will explain below—and has led us to explore the new dimension of our profession as it expands into underwater landscapes. The first issue relates to natural spaces and their management. Today, marine area management policies have yet to recognise the sensory, "aesthetic" dimension and the concept of landscape heritage as full fundamentals, on a par with the environment. Current protection measures and frameworks (reserves, parks) lend little weight to landscape as the prime *raison d'être*, and often overlook the powerful lever it can be as a showcase, a medium and a scenography, for cultural mediation with the public in natural spaces. The second issue concerns landscape designers and landscape in general. From metaphor, we move to reality. We naturally sense that the shift from terrestrial to marine landscape research and design impacts both the theory and practice of our profession. Our profession has in fact hitherto largely ignored the underwater landscape, or even denied it landscape status full stop, perhaps because with underwater landscapes the difficulties inherent in landscape study and work increase tenfold. Or maybe because conventional landscaping methods and concepts are put to the test? We nonetheless view the link between a landscape designer's specific art of sensory immersion and actual immersion in the underwater landscape as an opportunity to successfully adapt landscaping practices and concepts to the underwater world. The magnifying mirror of underwater landscapes may well reveal the definition, ideal or future transformation of "landscape" and landscape design, including on dry land. We will attempt to answer these questions in two stages. Before addressing the question of the underwater landscape, we will first explore the landscape designer's epistemological stance in relation to landscape on land and in general. We believe this is primarily based on "landscape reading". This prior journey through sometimes arid territories of theory is necessary to understand the vision with which a landscape designer tackles the novelty of the underwater world, and the disorientation and questioning the process engenders. We will then turn our attentions to this confrontation, and the solutions to be found, through concrete examples of studies and action.

7.2 An Ongoing Effort to "Read" Terrestrial Landscape Indicators

7.2.1 Landscape: Inner Reflection of an Outer Reality?

There is a constant threat to anyone undertaking to study a landscape, landscape designers being the first ones to confront it. The risk is that of missing the point of one's research, because landscape is a complex notion: it is an area, as perceived[1]. Not the theoretical, measurable area of science, but an area which, in the eyes of anyone visually embracing the world, is a living tableau, a complete and adequate spectacle, an everyday setting for life, or what ancient philosophies called "world"[2]. At the time of contemplation, be it supreme from the top of a mountain or by chance at the corner of a street, a landscape noticed and admired suspends judgement and arouses emotion. In a glance, the spectacle we refer to as "landscape" thus becomes a whole, as confirmed by the attempts made to "set" it. Exclamations, written descriptions, painting and photography, or the popular expression in picture postcard form, present the landscape as a work of art, with an invitation to lose oneself in it as if nothing else existed, as if it contained everything of importance, sufficient within itself, the organic parent of our being[3]. Yet, instantly, any study or attempt to understand the inner mechanisms that prompt the emotion of landscape enters a process of deconstruction: the subjectivity on which space imprints landscape emotion. Whereas by definition, the landscape is above all "within us"[4], we hasten to give the external elements of space those objective qualities that will spark off our inner emotion, rather than deciphering and breaking down their subtle arrangements into single components to find the formula of the emotional alchemy prompting our admiration. Landscape designers themselves do not escape this natural tendency to break down and analyse the organic whole that our perception would appear to create when we come into contact with things.

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[1] Today, there is a consensus on the definition. Refer to the *European Landscape Convention of Florence*, Council of Europe, 2000, and A. Berque, *Médiance, De milieux en paysages*, Belin, 2000.

[2] For the epistemological difference between the concepts of area and world, we refer to the doctrines of the philosophical school of phenomenology represented in particular by Husserl, Heidegger, Gadamer, and Merleau-Ponty. World is "*that always-nonobjectual to which we are subject*" in Heidegger's "The Origin of the Work of Art", *Off the beaten track*, translated by Julian Young and Kenneth Hayes, Cambridge University Press.

[3] With landscape, we are "caught up" like a child forgetful of adjacent realities. Our gaze is like the sixth side closing up a cube forming the scenery of a play. Cf. H.G Gadamer, *Vérité et Méthode* (Truth and Method), 2nd edition. Seuil, Paris 1996.

[4] This is the "discovery" of philosopher Thoreau during his retreat to the woods at the end of the 1840s. Cf. H.D. Thoreau, *Walden; or, Life in the Woods*, Ticknor and Fields: Boston, 1854.

7.2.2 The Landscape Designer: A Landscape "Reader"?

Landscape designers do indeed willingly refer to themselves as landscape "readers". "Read" the landscape? "You should scan the entire site and surrounding areas in every direction, observe and record each and every configuration and thing right down to the slightest and least significant; you must not miss the slightest element on this page of writing"[5] recommends Michel Corajoud, one of the founding fathers of the profession, to students at the École Nationale Supérieure du Paysage de Versailles. This comparison with reading metaphorically likens landscape to text, a metaphor now well established in both land planning and landscape design[6]. In one respect, it is legitimate: it expresses the ambiguous nature of the landscape concept, i.e. the objective subjectively perceived. Therefore, a landscape designer's exercise not only involves perceiving, taking in and recording like everyone else, but perceiving "better", grasping the visible shapes of the landscape and beyond, the structure or significant shapes at work in the landscape. In so doing, the comparison with text also reflects awareness of the illusory character of perceptive omniscience, awareness that the sight we see is in fact a space built and theatrically portrayed by the structure of our body and mind. Awareness that its stimuli closely depend—from an objective point of view—on the elements and factors specific to space, its structure and its laws. Because, from this perspective, isn't the fabulous feeling of giddiness and strength we experience when contemplating a gigantic mound of rocks ultimately the unexpected result of interaction between very precise fragments of matter? Linked to a particular geology? Pawns now frozen that could also be described as the result of movements determined by implacable physics, for which geologists and geographers would find a mathematical explanation by reducing them to simple numbers? The metaphor of text and reading introduces the idea of units, letters, words and phrases, assembled according to known rules of grammar which, if we know how to "read", we can understand by identifying all those relations—provided we have broken down and isolated each piece. Many official guidelines, professional training courses and ministerial orders have, both in landscape design and "space management", undertaken to teach landscape designers to "read", by identifying and interpreting the "landscape units" that make up the immense landscape text. Failing a consensus in this scramble for precious units, each learner-reader uses the methods and tools he has chosen or acquired during training, with varying results. Units are identified in space, underscored, pinned on maps and used in planning, but are they really "pieces of landscape"? Even if zones are marked out, limits established between mapped areas and elements of the visible space possibly photographed and retained for typology purposes, this is not necessarily a definition of the landscape, i.e. an area as perceived. And there is no certainty that landscape and perception can be

[5] Michel Corajoud, "Le projet de paysage: lettre aux étudiants", in Jean-Luc Brisson, *Le Jardinier, l'artiste et l'ingénieur, Éditions de l'imprimeur, 2000.*

[6] See for example the article by B. Folléa "Le paysage comme relation", in *Les Carnets du Paysage* no 21, Actes Sud, Arles, 2011.

segmented: "in landscape, no boundary is too hard or closed to split open and connect to surrounding areas. There is no real distinction between different places"[7].

7.2.3 How Does Landscape Differ in Structure to Text?

Excessive use of the metaphor with text would nonetheless be fallacious for two reasons, and inevitably based on a double misunderstanding: firstly, the idea that perception functions according to the same model; and secondly, an incomplete and erroneous conception of the word "text". Strictly speaking[8], a text, like a language, is an instrument of voluntary communication between several given players. Structurally, it is a precise, codified breakdown of discontinuous units in the continuous flow of the possible sounds of speech (phonemes, words) or its written transcription (graphemes). These units correspond to units of meaning (semes[9]), broken down into the fields of meanings we give things in the world. A *sign* can thus be the association of signifier and signified. Signs are structured into systems relative to human groups, governed by strict rules (alphabet, dictionary or index, spelling). And everything is intentionally produced—to communicate. Without testing a set of examples against this model, there is no doubt that lending any of these characteristics to landscape or its components would be a misuse of language.[10]

7.2.4 "Immersive" Landscape Reading

Conversely, a landscape designer does not decode or apply any prejudged grammatical rules to the landscape; he designs his own way of "reading" as a sensory and intuitive immersion into the area perceived. The metaphor is rightly aquatic: "*first, 'free-floating attention' should be given, to absorb the site and its surroundings during long visits, at various times of day and in all weather conditions. We 'soak it in', from the ground to the sky, almost to boredom*"[11]. Thus, reading through immersive absorption *in* or *by* the landscape should be understood to be the same as immersion

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[7] Michel Corajoud, op.cit.

[8] Meaning in terms of communication systems science, semiology.

[9] To use Prieto's term in *Messages et signaux*, Presses Universitaires de France, Paris 1966.

[10] For development on the critical examination of the textual model applied to landscape, and the interpretation of landscape from a semiological point of view, as a structure and signifier system (particularly on landscape units and indicators), see C. Ronzani, *Se fondre dans le paysage. Le camouflage, lecture avertie des signes paysagers, ou mise en question des méthodes paysagistes? Analyse sémiologique de l'oeuvre camouflée de Pierre Gatier à la batterie des Mèdes, Porquerolles*. PhD thesis in Landscape sciences and architecture, École Nationale Supérieure du Paysage de Versailles, 2013.

[11] Bernard Lassus, "Pour une poétique du paysage", in Maîtres et protecteurs de la nature, dir. Alain Roger, François Guéry, Éd. Champs-Vallon 1991.

in reading a novel or a poem. And there is no need to be a grammarian for that. To avoid the risks of reading in fragments, i.e. deciphering and dismantling minimal units in the landscape, a landscape designer's method is subjective, an empirically intuitive choice. Because the object leaves no other choice. A landscape designer does not practice a landscape science. Landscape design aims to run counter to scientific method, even though, in other respects, perception and the perceptive phenomenon that landscape represents may be studied scientifically.

7.2.5 Landscape Designer: A Scout and Reader of "Landscape Indicators"?

This standpoint as intuitive readers deprives landscape designers of a comfortable "specialist" position based on developed knowledge or an instantly transmissible or imitable method. They are rather like a special kind of observer and scout. Since the perceived area that we call "landscape" generally contains no organised sign or conveys no intentional message in the shapes visible, and that we could "read" if only we knew the codified rules or "words", then what do we actually read? At worst, nothing. At best, "indicators". The words of landscape designer Corajoud speak for themselves: "*each and every configuration and thing right down to the slightest and least significant*"[12]. In landscape, certain elements *can* make sense to someone looking for some particular thing or seeing into them. They are not stable, conventional units like words. So what is an indicator? "*An immediately discernible fact, that suggests something about another fact which is not immediately discernible*"[13]. A footprint in the mud is an indicator of an animal, the Northern Star of the north, and smoke of fire. An indicator is a "natural sign"[14] outside all pre-established code; it only makes sense in a given situation, to a given observer: in landscape, only hunters, naturalists and herbalists for example see certain elements, specific to their knowledge of the area and their aim. Each one "reads" something in their particular register, allowing them to choose from the realm of possibilities they know. The specific tracks of an animal, the nest of a bird, the soil propitious to certain plants, etc. The same is true of the "signs" that landscape designers try to "read" in the landscape. Elements indicate things that may still be invisible in the immediate landscape, but are decisive for the future or elsewhere (a substratum, the inclination of a rock, the recent or former presence of water, etc.). These indicators refer to others which will lead not only to the most unusual places of a landscape but also to the origin, the future or the key principles of the appearance or dynamics determining the space or the resulting

[12] Cf. supra.

[13] Cf. G. Mounin, "Sémiologie de la communication" in *Introduction à la sémiologie*, Éditions de Minuit, Paris 1974.
And Prieto, op.cit.

[14] The word, by Greimas, is obviously contradictory as its challenges the limits of the concept of sign. Refer to J. Greimas, "Conditions d'une sémiotique du monde naturel", in revue *Langages* no 10. Paris 1968.

perception of the landscape. Indicators seldom mean only one thing. They create patterns and are repeated in the landscape[15]. Identity, characteristics and names depend on them, based on the cultural background that local people share. For example, the landscape of Fontainebleau forest lies in the bracken, the sand, the sandstone, etc. Necessary, although not sufficient, these visually or physically interconnected landscape indicators had to be harnessed by an array of practices, views and illustrations to achieve status as a picturesque "landscape"[16]. Sometimes, in culturally anonymous landscapes, indicators are already at work but have not been named by inhabitants. They must therefore be dug out, explained. For example, which landscape indicators "portray" the landscape specific to Brest? The cranes? Or the piers?

7.2.6 Bringing the Landscape's Features to Light: The Vital Mediation of Drawing

The landscape is the fruit of individual perceptions, although built on a common, shareable basis (the actual area), attaching to the here and now of a given place. It must therefore be rendered singular, unique. With the appropriate indicator, it is thus the distinctive "quality" of an area, the elements to which people can and do give meaning, that a landscape designer will seek to capture. And he will do so both in the literal (epistemological and semantic) and figurative sense: a landscape designer's drawing, his core practice, is the most appropriate "operational scheme"[17] not only to detect but to bring out the subtle indicators of the landscape. The drawn line does not have the deceptive objectivity of a dot or precisely plotted zones. Fleeting singularities temporarily detached from the spatial, perceptive background, these landscape units emerging through the pencil are not predefined: they are provisional segments emerging from the continuity of space seen by the eye. Whichever cognitive criteria (contrast, shape) may be responsible for their detection, it is important to know what crosses the threshold of sensory detection beyond which "something" appears in the world like a complete object, is noticed and is therefore noticeable. Landscape features and the drawn line are open to the realms of possibility, to the peripheral, to extending beyond the scope. Other indicators, and alternative meanings and perceptions remain possible. In drawing, no truth is imposed, only a vision proposed. This is made evident in the refusal to close the drawing, to finish the strokes, to mark the limits specific to sketches. These lines are part of and greatly depend on the attention given, the scale, the moment, and the spatial and psychological

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[15] Cf. infra note 10.

[16] Historically through the role of the Barbizon school of painters in particular.

[17] Or "schema of practice": social anthropologist Philippe Descola demonstrated the relevance of this concept to describe efficient cognitive operations using know-how acquired in non-scientific cultures (crafts, hunting), without recourse to the traditional, European, modern-day concept of "idea" preceding the action, and therefore outside the intellectual presupposition of the theory-practice model. Cf. Ph. Descola, *Par-delà nature et culture* (Beyond Nature and Culture), Gallimard, Paris, 2005.

coordinates. Changing a parameter changes their meaning, or even makes them vanish as pertinent landscape indicators. Yet, the drawn line makes a clear choice in the possible representations of the landscape, the choice of what is seen, a specific interpretation open to collective judgement. The drawn line renders the landscape indicator visible, whereas a photo will too often be a jungle of indicators, leaving the observer with as much to do as when he actually contemplates the area.

7.2.7 Rediscovering Landscape As a Sensory Filter by Plunging into the Underwater Landscape?

To detect and "read" units in the landscape, they must correspond to the subtle cultural combinations that associate meaning with places, open to interpretation by others. The authenticity with which a landscape is "read" hinges on the "depth" and the degree to which perception acts as a filter between the subject and the area. The temptation to develop analyses with no regard for this subjective relativity specific to landscape perception is great. Where does this risk arise from? Should we challenge the predominant landscape model based on what we see? The conception of landscape as a supreme, objective view of the land, excluding the other senses, greatly heightened in the satellite era, asserting perceived space to be consistent, measurable and divisible in every respect as it is objectively, physically, on a map or in a snapshot? Exacerbated by the deceptive transparency of the open air as the eye's medium? Causing us to overlook the fact that the gaze passes through a distorting medium, and is matter itself? The opacity and relative blur of underwater landscapes and their multisensory aspect may make the reality of the senses less easy to forget; perhaps it will be a revelation, and an opportunity to reassert and deepen the notion of landscape. But the risk may be quite the opposite—that of "excessive" perception, extreme sensory immersion preventing all interpretation. Landscape designers have already evoked this risk in respect of certain terrestrial landscapes: "*on site, you would be swamped by the profusion of data and quite unable to make any decision*[18]". In our opinion, this problematic interrelation between perceptive transparency and opacity, between immersive reading and distraction, will challenge a landscape designer's ability to decipher the underwater world, and the latter's potential status as "landscape".

7.3 Submersion and a Radical Change of Scenery: Does Underwater Landscape Challenge our Landscape Reading Practices?

Beneath the water's surface, our sensory relationship with space differs completely from the way we relate to nature on land. Land is so much our world that, despite being a blue planet, we call it "earth" rather than sea. Under the yoke of language, we are

[18] Michel Corajoud, Op.cit.

"earthlings", not people of the sea. As we have seen, a description of actual experience is the most appropriate method to determine our relationship with the world we call "landscape". So we will begin by describing the specific situation of the underwater landscape. Using our imagination, we will undertake a brief phenomenology of the body submerged, with a view to understanding the challenges inherent in the tools we must invent to adapt to this new landscape.

7.3.1 Water as a Perceptive Filter and the Submerged Body: Two Fundamental Features of the Underwater World

The first striking difference in perception compared to terrestrial landscape is the body submerged. We float, often horizontally. The second radically new and patently obvious factor is water. In "air", we seldom feel the need to specify that this gaseous environment is the usual setting of what we call landscape. The air's relative homogeneity allows light to diffuse and coincides with our primary sense—our eyesight—, leading us to believe that space is "transparent". To the best of our knowledge, Gilles Clément is the only landscape designer to have taken an interest in the "clouds" that blur and populate sky and landscape[19], fighting ignorance of the weather and of the passage of time, reclaiming the hours of the day, the seasons and other atmospheric variables. While we know little about the relative opacity of air (mist, polarisation, humidity), the materiality of water and its role as a perceptive filter are evident. It is, incidentally, approximately a thousand times denser than the mixture of gases we breathe on earth. The effects on the observer's body are naturally considerable.

7.3.2 "Moving Being in Moving Space"

With no fixed anchor point, diving puts us in total motion, under the effects of external flows (current, swell) and our own movements (kicking flippers, swimming, breathing). We even move *by* breathing. Freed from weight, the body's own lift provides our fragile bearing on the water's fleeting surface. But for the weight of the cylinder, our lungs would bring us back to the surface, like air-filled balloons. A diver's centre of gravity merges with the Archimedean point. Everything hinges on the balance point around which, like an airship, the slightest impulse changes our direction. Only biology counters the dream of modulating the body's floatation with precise measurements of air. The interplay between our inner breathing and our vertical (the more the lungs are filled with air, the more we are drawn to the surface, and vice versa) and horizontal movements is such that, when mastered, our quiet, serene displacement impacts our very perception of the landscape. With every buoyant movement, however slight, we feel carried through time and space.

[19] Gilles Clément, *Nuages*, Bayard, 2005.

The peaceful silence and kinetic effect of the spectacle "streaming" past are like a travel shot in slow motion. Landscape and movement, movement and emotion appear as one, magically attesting to the etymology and the very nature of emotion: since Aristotle[20], being moved has meant a movement of the soul; it is here a real movement in the landscape. In this situation worthy of Captain Nemo's motto ("*mobilis in mobile*", moving in a moving thing[21]), only one thing is missing. There are no points of reference. To find out where we are, we must endeavour to read the landscape.

7.3.3 Alone and Speechless, in the Sonorous, Tactile Landscape of the Body, the Horizon Tilts and Disappears

Reference points do lack when in movement under water, and yet our five senses are disoriented in relation to land. Our eyesight is not alone. There is perceptive synaesthesia[22] with the smell and taste of plastic of the mouthpiece or diving mask and salt. The sound of our own breathing prevails over all other[23], turning our attention to ourselves much more than in free air. As spoken language is not possible, and sign language limited, the underwater world becomes a solitary experience, silence being imposed on words. While generally unnoticed, it finds expression here in what we see: the bubbles we make rise to the surface in strings. The attraction of floatation acts in the same but opposite way to gravity on earth, indicating verticality, the point of reference in space. Our balance, on which our sense of direction depends, is upset. The horizontal swimmer is like the upright walker, but finds his bearings in relation to the vertical gradient of depth. In the landscape, the horizon is usually our main point of reference[24]. Underwater, not only is the horizon blurred by the water's turbidity; it is twofold: sea bed and the mirror surface merge in the blue of water, and nothing about them is definite. Verticality is therefore the horizon and reference axis of the underwater landscape, and this alone would almost suffice to explain the radical disorientation it creates in people now accustomed to a world of transport where the horizon is a hackneyed frontier[25]. In addition, kicking and swimming demand intense effort: we become active spectators, far removed from the amateur painter

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[20] See the treatise by Aristotle, *On the soul*. It is a discussion of the outer and inner movement of beings. The Latin translation of the text "*De Anima*"—also meaning "from movement"—also conveys this notion.

[21] Jules Vernes, *Twenty thousand leagues under the sea*, Captain Nemo's motto.

[22] The best definition of synaesthesia is summed up in the words of Baudelaire: "*all colours, scents and sounds meet as one*" (C. Baudelaire, "Correspondences", in *Les Fleurs du Mal.*

[23] A whole analysis of the underwater landscape as an invisible (or only potentially visible), but sonorous landscape, with both a topology and a topography that are directly or indirectly perceptible, could be developed but does not come within the framework of this article.

[24] Cf. Michel Corajoud: "I willingly associate the idea of horizon with the particular status of the limits that make landscape". Op cit.

[25] Should we see the underwater landscape as a current form of the imagination's migration to "the incommensurable vertical", akin to the starry sky and lunar landscapes, which B. Lassus calls the

or opera lover comfortably and passively seated in a velvet chair[26] or a romantic rambler contemplating a sea of clouds from a belvedere. In two respects, those of perceptual change and of struggle, the reference point zero from which all possible landscape reading proceeds, is no longer the horizon, but the body itself.

7.3.4 A Landscape Above all Structured by its Colours?

Our eyesight is also altered under water, and we perceive the colour range, so vital on land for our depth perception, differently. Warm colours occupy the foreground; cold colours take over the background. In this way we give paintings depth. Underwater, the palette soon shrinks. Red disappears at a depth of five metres and blue takes over, growing increasingly dark the further down we go. Yellow, a rare colour in nature, save in exotic fish, is the last to remain deep down, before the blues and greys gain control. It's the famous colour of the mythical "yellow submarine"[27], the costume of deep-water exploration craft. Thus remain only the (big) blues. Cold and blackening, they detach us from the near and attach us to the far. Diving therefore always creates the impression of having travelled far. Through the illusion of infinity and absence of warmth, the sea's depths echo the vertical abyss of the sky at night to which we sometimes turn our gaze from the earth's surface (Fig. 7.1).[28]

7.4 Inventing Approaches and Tools for "Reading" the Underwater Landscape: A Major Facet of Presenting and Communicating Through Landscape in Parks, Trails and Reserves

7.4.1 Attempting to Read via Colour: Painting the Underwater Landscape

How can aquatic chromatism be represented to better read and make sense of it? Jules Verne asked the question: "And now, how can I convey the impressions left on me

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new and only remaining space of dreams now that planes and cars are shrinking the world? Cf. B. Lassus, *Couleur, lumière paysages, instant d'une pédagogie*, Edition du patrimoine, May 2004.

[26] Except on the Nautilus submarine with its large glass panels, as Jules Verne wrote from an apartment and had never dived: "Suddenly, through two oblong openings, daylight appeared on both sides of the lounge (. . .) We were separated from the sea by two panes of glass (. . .) On both sides I had windows opening over these unexplored depths. The darkness in the lounge enhanced the brightness outside, and we stared as if this clear glass were the window of an immense aquarium". (Jules Vernes, Twenty thousand leagues under the sea, Chap. 14 "The Black Current"). On the conditions in which he wrote the book and his reveries, see Christian Chelebourg, Jules Verne, L'Oeil et le Ventre. Une poétique du sujet, Lettres modernes Minard, Paris 1999.

[27] Expression made popular by the 1966 Beatles' song and the eponymous 1968 film.

[28] Which reinforces the vertical nature of underwater landscape. Cf. infra note 25.

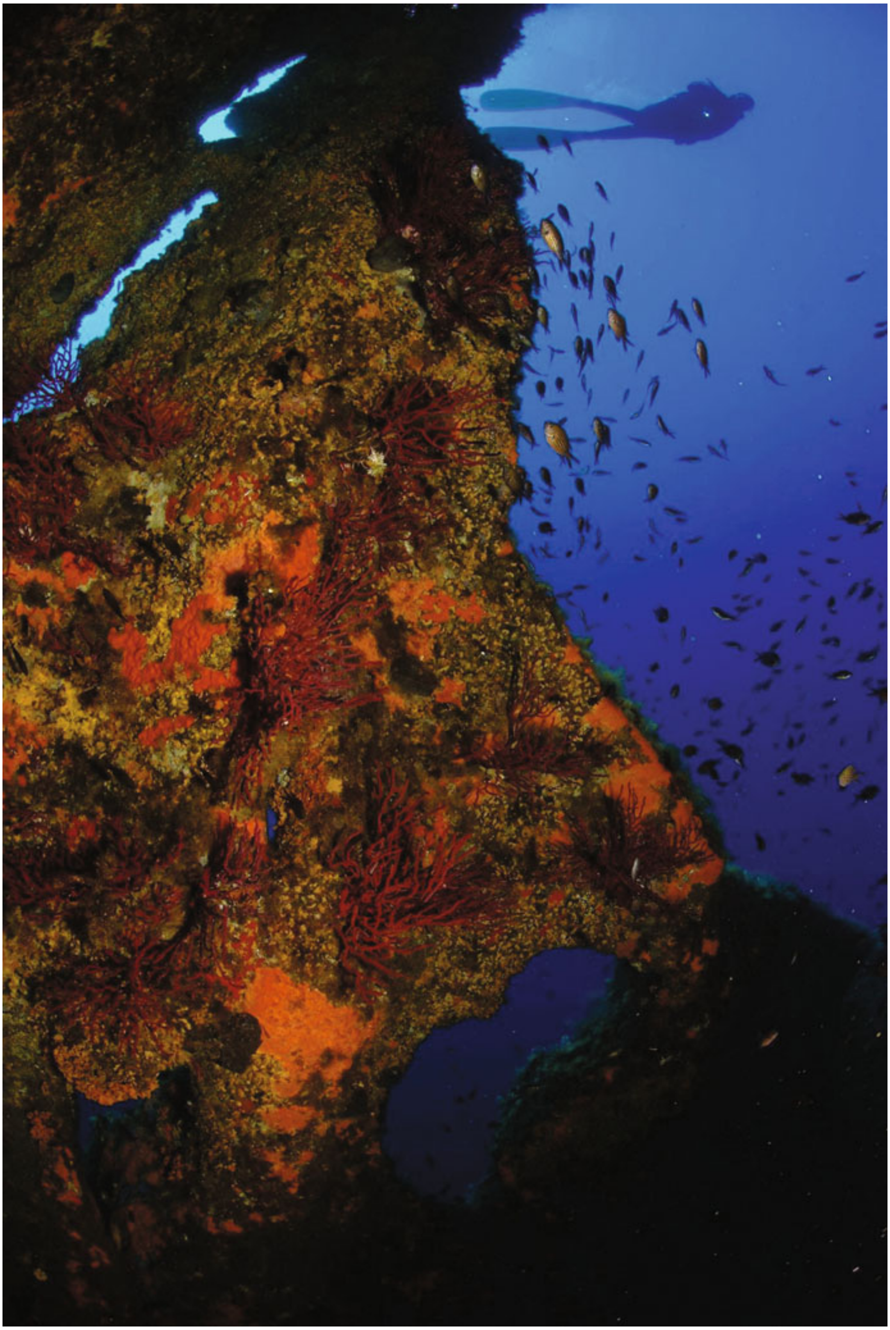

Fig. 7.1 Roche Percée Site in Corsica (© Gilles Diraimondo, All rights reserved)

by this stroll under the waters. Words are powerless to describe such wonders! When even the painter's brush cannot depict the effects unique to the liquid element, how can the writer's pen hope to reproduce them? [. . .] Who could paint the effects of the light through those transparent sheets of water?"[29]. Maxime Aubinet is a student at the Ecole Nationale Supérieure du Paysage de Versailles. As part of his course, and under the supervision of Alain Freytet, he uses sketches drawn underwater as material for a specific pictorial production. He dives alone and without breathing apparatus. His dives can last up to 1 min 30 s, which is quite short for doing sketches. At a depth of 5–7 m, he finds a spot worthy of reproduction and during several dives, he makes a note of physical indications. He also uses video, filming with a very high quality camera. Using a heavy camera stand, he can place the camera on the seabed to take fixed shots and make optimal use of the short dive time. Using this material and written notes describing the atmospheres he encounters, he then paints in very large formats. The representation does not seek to be figuratively exact; it is more impressionist in style (Fig. 7.2a and 7.2b).

So what possibilities does such a representation offer? Great attention is paid to the shades of the submarine spectrum, producing works of unusual beauty. But his ability to render every feature of the underwater landscape visible would appear to be restricted by the very criteria of its authenticity, close to the ambiance *in situ*. By being overly true to the shades of the aquatic spectrum perceived, paint reproduces the same perceptive blur as the water filter. By definition, it only plays on the chromatism and contrasts, restricted by the cold, underwater range[30]. What about the shapes, volumes, textures, planes and objects? From this perspective, painting, like photographs, exploits sensory proximity, faithfully reproducing the specific underwater "blur" and blends. It appears, however, to be one of those representation methods that prevent other features of the underwater landscape from emerging, thus restricting the extent to which it can be read.

7.4.2 Drawing Underwater Landscape: Ignoring the Misleading Colours of the Depths to Reveal Structures?

A line sketch drawn under water differs in nature from painting (Fig. 7.3). Far from proceeding in swathes of solid colour and relying on their contrast to create relief, it seeks to create depth through a series of planes distinguished solely by their outline. The simple, black-line drawing delimits, differentiates and accentuates while retaining continuities. It sorts and selects by nature. It attempts to abstract without misrepresenting. It can therefore transcend the poor visibility of the aquatic scene. While less precise than a photograph, it is paradoxically less misleading. By disposing of sensory confusion, a sketch serves as an investigative tool: the landscape designer must decide, on the spot, how to interpret the shapes and nature of objects

[29] Jules Vernes, *Twenty thousand leagues under the sea*, Chap. 16 "Strolling the plains".

[30] By virtue of the optical law of Chevreul's simultaneous contrast of colour.

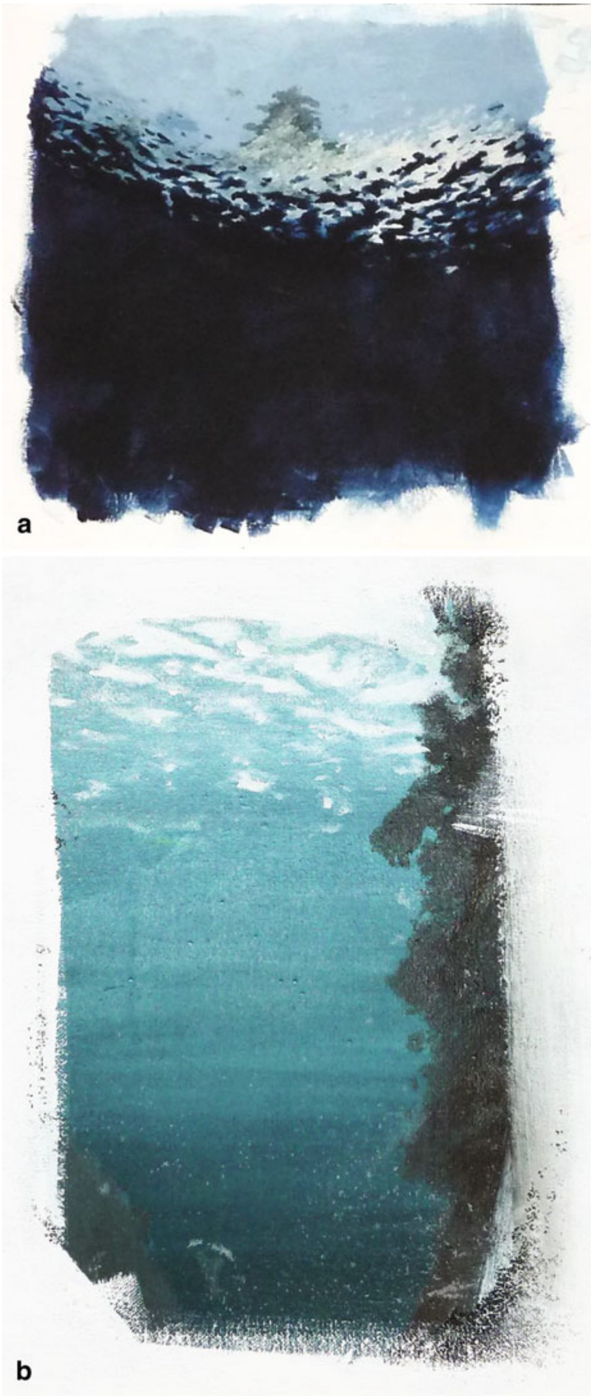

Fig. 7.2 **a** Acrylic painting (© Maxime Aubinet, All rights reserved). **b** Idem

Fig. 7.3 Drawing in water with groupers, at the place of Pellu, Natural Marine Reserve of the Bouches de Bonifacio/project of International Marine Park of Bonifacio, Corsica. (© Florian Freytet, All rights reserved)

(Fig. 7.4). "The probity of art"[31], drawing can be an instrument of knowledge. It is, *inter alia*, what allows the landscape designer to remain in the objective sphere, with a hold on reality that can be shared with other disciplines and the scientific world.

7.4.3 Capturing and Representing Underwater Landscape: An Opportunity for the Museographical Potential of Marine Sites. the Example of Taffonu, a Submerged Natural Sculpture?

By paying attention to the verticality of underwater landscape, the door opens to three-dimensional perception of a landscape feature. The example of *tafone* or *taffonu* in Corsica is highly instructive. *Tafone* is a block of granite weathered by wind and salt crystallisation into an unusual silhouette. *Taffonu* once sculpted by wind erosion in the past may now be underwater. An underwater encounter with the particular geomorphological pattern of "taffonu" is striking. Ordinarily shaped into compact balls or full, rounded masses cut through by sharper joints, the granite is weathered

[31] The phrase is from Aristotle, in his *Poetics* treatise.

Fig. 7.4 Port Cros sea bed. (sketch by Alain Freytet for Port Cros National Park)

into more or less spherical cavities of every dimension. Floatation allows a diver to discover these veritable sculptures in three dimensions. If only we could explore great contemporary sculptures in the same way, rather than rooted to the ground as if paralyzed by their size. We would swim in a mobile by Calder or float around one of Paul Reyberole's monumental figures. Above and beyond their dramatic history, the fascination with shipwrecks no doubt lies in the possibility of swimming above them and discovering every facet, from every angle. The cavities of the largest *taffoni* can be as big as houses. A *taffonu* located at a depth of 10 m is a direct evocation of the changing sea level: this is terrestrial landscape now underwater. Like an Atlantis of geological time, these shapes render underwater landscapes readable by suggesting what they were when the *taffoni* formed (Fig. 7.5). A similar situation can be found off the shores of Marseille where submerged karstic reliefs render major eustatic movements perceptible.

Before the recent, sophisticated technical processes that museums and interpretive centres now use (3D, virtual panoramas and other interactive "streaming" simulations) and describe as "museographical immersion", and following the era of museum furnishings (frames, stands and display cases), only underwater landscape offers quality museographical conditions. Water is a very good, natural picture frame. The equivalent of what air would be if museum walls were made of gas that could bear paintings without being seen[32]. Conversely, when exhibited in air, in museums or interpretive centres, the question of moving freely around an aquatic object arises[33]. Displaying the underwater object is also a challenge we address in documents and interpretation media relative to a specific underwater landscape.

7.4.4 Developing Underwater Block Diagrams: "Bird's Eye" or "Fish Eye" View?

There is no doubt in the profession that the block diagram is one of the best instruments for representing landscape in volume. A three-dimensional drawing of an area, it shows the topographic contours crowned with the elements covering the surface (vegetation, constructions, hydrography, etc.) and relevant to the perception that makes it a landscape. It is "sensory", as this is neither axonometry nor digital modelling, no projections calculated according to laws of perspective and a rigorously exact scale. It is a subjective representation of an objective space, just like the landscape it reveals. A block diagram combines the real measure of shapes, distances and scales with subjective quantities. Without being exact, it can be precise, through the attention paid to detail. It can be true to the atmospheres experienced on site. And exhaustive? It is not designed to be: although reproducing the actual relief in broad outline, this is to bring out the *character* of a given landscape and represent the *characteristic* components. For example, while the tall, mast-like posidonia sea grass is an indicator and a characteristic feature of the Mediterranean underwater landscape, there is obviously no need to represent the entire population in the area drawn. In landscape design, a block diagram does not claim or aim to have scientific

[32] The managers of the Isla Muejeres National Marine Park in Mexico made no mistake in deciding to work with artist Jason de Caires Taylor: he submerges sculptures which become gradually covered with coral. They can be visited by snorkelling and the profits co-fund the nature reserve.

[33] This aspect was carefully addressed at the *Ozeanum* sea museum in Stralsund, Germany: the architecture was designed after the scenography, so that full-scale sculptures of whales could be hung in a huge area ideal for acoustics and visitor flows via a network of walkways.

Fig. 7.5 Large summital taffonu in the Géode site, Corsica. (© Gilles Diraimondo, All rights reserved)

value, although it can help scientists suggestively locate the sites of their action. This is the case today at the STARESO research station near Calvi in Corsica. On the contrary, it has an aim that exact bathymetric modelling cannot necessarily achieve, with its excessive accuracy and lack of physical perception: it aims to share the full wealth of a site, making it fully readable and giving real direction through simplified representation of things. A terrestrial block diagram is generally cut into a three-quarter view, from an angle "plunging" down onto the surface of the ground represented. It also clearly shows the ground section in profile, allowing geological data to be integrated. Above ground level, the axes "in air" are generally softened or removed: there is nothing material, no concrete portion of land to be cut out and framed in the air forming the sky above the land. Although drawn, a block diagram thus works like a mock-up; in fact, where possible, it is often based on a mock-up (either made of clay in a workshop or of sand on the beach). It is a "bird's eye" view, an old, metaphorical phrase once used for methods of representing strategic military ground. But how appropriate is a "bird's eye" view for the underwater landscape? Whether it's a view from the eye of a seagull, a shearwater or an albatross makes no difference. Flying over the seas and oceans is possible and even a widespread practice. But a problem of surface, or rather double surface arises: there is the sea bottom—the topographic relief—, and the water's surface. We could disregard the surface like we disregard the representation of air on dry land, if we are aiming to show the seabed landscape. But what if the aim is precisely to show the foreshore, a coastline, the position and sides of an island or a reef? Or even show the site of a wreck without any land surface, for example? The graphic challenge therefore lies in the transparency: representing the surface without distorting the underwater landscape to be read below (Fig 7.6a).

So, how do we develop an underwater block diagram? How have methods been adapted and tested to date? One method has gradually emerged from comparing the experiences of Fabien Garoste, manager of the *Torra Plongée* diving club, an experienced diver and expert on the underwater sites found along the Corsican coast in Propriano bay and the Sartenais, and those of Alain Freytet, an artist, diver and landscape designer familiar with block diagram representation of terrestrial landscapes, the subject he teaches at the Landscape School of Versailles. The representation is developed in seven steps:

1. *A general presentation* of the site is provided by the "pilot fish" who knows the area well. The description is sensory and presented orally, drawing connections between the relief's major structures and the terrestrial landscape. This gives a basic idea of the landscapes likely to be found. Some place names are included and will be used throughout the process.
2. *A first survey dive* gives a feel of the atmosphere and determines the overall volume of the site. Singular spots—both mineral (caves, walls, overhangs, cracks) and living (gorgonian wall, groupers' valley, Pinna Nobilis grass beds, etc.)—are identified. Sketches are made of these places on site, in the water, and are completed with notes once back on dry land. Through discussions about these spots we begin to outline the overall plan.

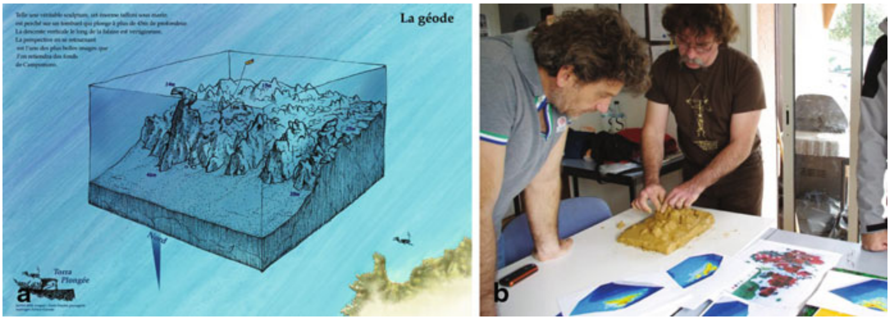

Fig. 7.6 **a** Block diagram of the Géode site, Campomoro, Corsica. (sketch by Alain Freytet for Torra Plongée) **b** Making of a clay model of the “Pellu” place, reproduction from memory of a 1 ha hilly landscape, Corsica. (© O. Bonnenfant/Environnement Office of Corsica)

3. *A model made of sand on the beach or of clay* provides a volume representation of the entire site. The use of volume is important for sharing and exchanging ideas, and to represent the site’s morphology. Using wet sand on the beach or clay, a satisfactory shape gradually emerges through the successive layering of various touches. Unique spots are also located on the mock-up and assigned names, either a name they already have or one they are now given. The mock-up usually varies in scale from 1/500 to 1/200. We then plot the itinerary covered during the first survey and the future trajectory to register the landscapes to be represented under water. Occasionally, sounding operations are carried out, producing a plan view of the underwater relief. These technical documents are then used to back up the “sensory” model (Fig. 7.6b).
4. *The block diagram sketch* is drawn based on the model. The angle of approach of the sketch is a fundamental choice. The block will give a partial representation of the site, as certain sides are hidden from sight. To make the block diagram as complete as possible, the perspective and location of certain areas are sometimes slightly altered where the representation permits. The diagram is most often a “bird’s eye” view, drawn from a point located above sea level and with a slight perspective to facilitate recognition. This structural sketch is then reproduced on a fairly large board (50 × 50 cm) on which drawings can be made during diving.
5. *The return dive* to the site is done with the large board on which the block diagram is sketched. The itinerary often differs from the exploratory dive to combine various points of view. This second dive is guided by the orientation of the block diagram and the singular spots to be represented. Changes in light, visibility, temperature and wind will sometimes give the landscape slightly different aspects. The sketches done underwater allow detail to be added to the outlines. The main shapes are thus drawn accurately according to the chosen angle. Depending on the readability, several trips backwards and forwards may be needed to get an overall idea while carefully studying the mineral textures (rock fracturing, size and shapes of blocks or stones, size and distribution of sand, etc.) and plants (Posidonia, Gorgonians, etc.). Not all details can be shown due to the scale of

the representation, as this could alter the document's reading scale. A few details are noted in box form to avoid "overcrowding" the general block diagram. A few quick drawings of a fish or cetacean may be added if they are encountered.

6. *The block diagram drawing* is a black and white line drawing in A4 or A3 format, based on the notes taken during the dive. The final perspective is chosen and textures are sketched to distinguish the various typical environments. Appropriate shading is used to emphasize the relief and bring out the textures. Places that have not been thoroughly explored are shown in as much detail as the rest based on advice provided by the pilot fish. Colour is then added to the black and white diagram using software to emphasize depth and perspective. Behind the overlay shaded in increasingly intense blue for depth, the colour and light of certain designs (rocks, Posidonia grass, etc.) distinguish the environments. When the site is near the coast, the representation and colouring of the land surface serve as a measure. A miniature representation of a boat and its mooring point mark the water's surface and will be important reference points for reading the diagram.
7. *The final touches and last corrections* are added through successive discussions. Changes are often made on the computer file (an extra crack, a change of angle of a rocky peak, a Posidonia grass bed that needs expanding, etc.). The main depths are indicated on the diagram itself to allow divers to plan their dive and the relevant stages. The North is marked next to the block based on the perspective. The situation map locates the site in relation to the coast and the boat's departure point. A text that is both geographic and poetical presents the site overall and in detail, highlighting the specific and outstanding features of the dive. This sensory description of the underwater landscapes goes beyond a mere description of the environments and the actual setting, giving the sketch a true landscape dimension.

This kind of representation has been produced using this method for several sites. In Campomoro in Corsica, the Torra Plongée diving club, where the method was developed, uses it to explain sites to amateur divers before they dive. The explanation is often given on the boat once the diving teams have been formed and just before they plunge (Fig. 7.7).

On the Galite Islands in Tunisia, a block diagram was developed as part of a landscape design assignment conducted by the Coastal Protection Agency for the marine protected area project initiated by the Tunisian Ministry of the Environment and Sustainable Development's Coastal Protection and Planning Agency (C.P.P.A.). Surveys were provided for the work by the Andromede Oceanology Thétis office. The data remained very general across the underwater trail (Fig. 7.8).

For the STARESO scientific research centre, an experiment is being conducted with Pierre Lejeune to represent the Revelatta headland site in two complementary forms: a conventional "bird's eye view" block diagram and another "fish eye view" diagram, closer to what a diver perceives. The diagram is drawn from a viewpoint located under the water's surface. A diver is immediately "in his element" and can plunge into the representation as if in water. However, being more inspired by the context, such a representation is more difficult to develop and to read. It is less complete, and conceals entire sections of the site explored (Fig. 7.9a and 7.9b).

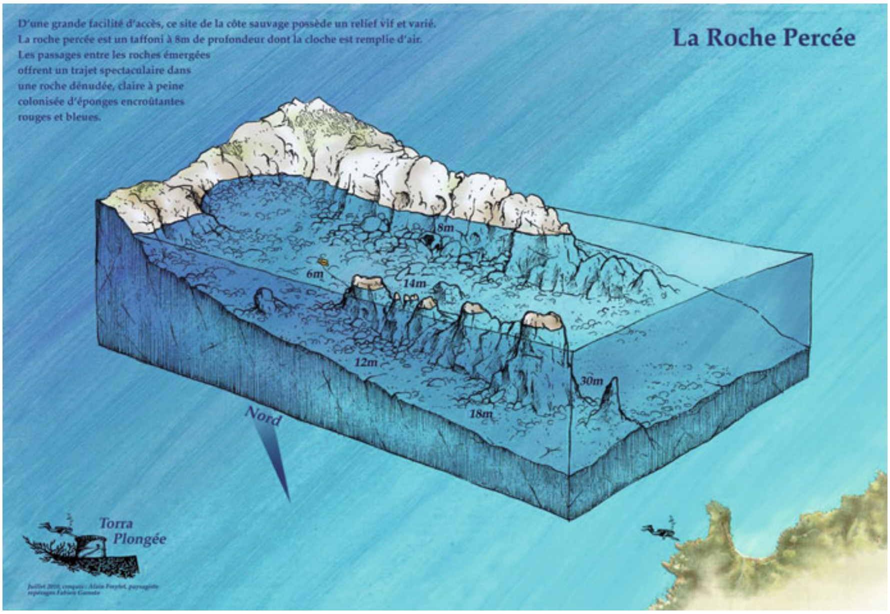

Fig. 7.7 Block diagram of the Roche Percée site, Campomoro, Corsica. (sketch by Alain Freytet for Torra Plongée)

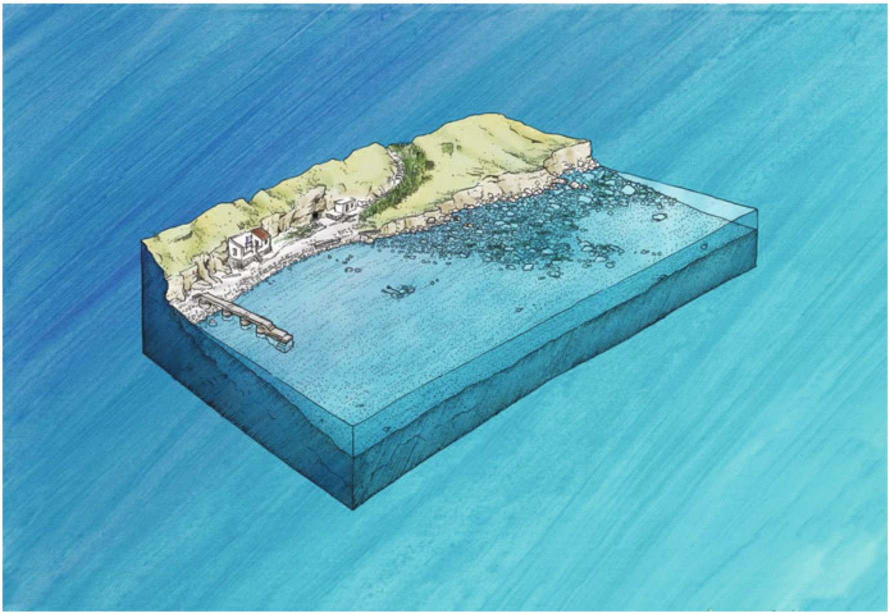

Fig. 7.8 Block diagram of the Galite Islands underwater trail, Tunisia. (sketch by Alain Freytet for the C.P.P.A.)

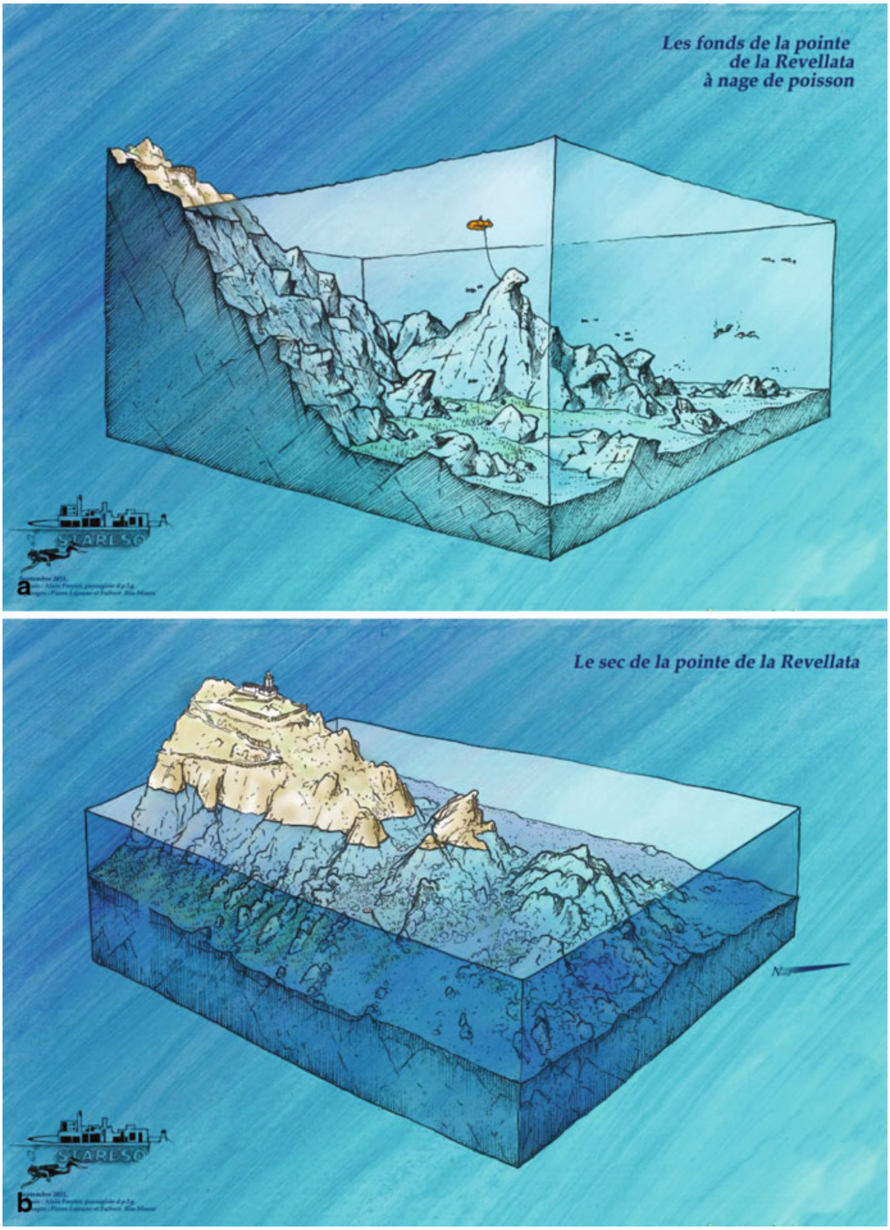

Fig. 7.9 **a** "Fish eye view" block diagram of the Revelatta headland site, Corsica. (sketch by Alain Freytet for STARESO) **b** "Bird's eye view" block diagram of the Revelatta headland site, Corsica. (sketch by Alain Freytet for STARESO)

7.4.5 Reference Points for the Invisible Underwater World: Figuring and Transfiguring the Marine Toponymy

Landscapes are also given existence by naming places and sites. We cannot talk about a nameless landscape, so naming sites is a process of recognition. A good part of a landscape designer's work thus involves determining and naming places (very often by collecting names used by people who have invented them or who frequent the sites), so that they gain recognition in people's minds, in political debates and in management schemes. In this way, names are given to useful places (by fishermen for example), or those that people like (by divers). Underwater toponymy is a specific field. It is primarily developed by fishermen who, without ever seeing them, know the seabeds well and name their principal fishing sites, any dangerous spots and any irregular features that catch their nets or attention. Such hands-on knowledge acquired through fishing nets produces a first set of names which will gradually take on the local accent and spelling. Then come the names given by divers who actually see, albeit only partially, the underwater sites. Several sources offer inspiration, the first being the relief (Fig. 7.10). We therefore find names such as "dome", "barrel", "cathedral" or "lion's rock". Architectural and urban metaphors are often used. Animals and plants found on site are another source of inspiration, e.g. "groupers' valley". Lastly, where they are present, wrecks will predominate. Very few maps contain all of these names. A map is a group of small, separately known areas interspersed with large unknown parts. We are not yet able to name vast geographic expanses of underwater landscapes like we do in an atlas of terrestrial landscapes. This approach will expand, particularly through systematic coastal surveys on several different scales.

7.5 Enhancing, Promoting, Revealing and Planning Underwater Areas: Towards "Marine Museographical Immersion"

If any landscape, particularly underwater, is a matter of perceptive immersion, then all cultural mediation, education, popularisation or communication in natural areas can be museographical and scenographic immersion where landscape is used. More than an enclosed space or a plain mediation object (a board set up in the landscape), the forms and nuances of the landscape can be mobilised to reach out to the observer. Confining landscape to photos, picture postcards, boards, galleries or showcases on dry land would deprive us of a valuable and sometimes rare resource in France, Europe and the rest of the world; this is also true if we settle for "interpretive centres" and museums designed solely as architectural objects rather than places (outdoors or in water). Wouldn't "in situ" scenography be better than these *"ex situ"* means delocalised from their subject matter?

Fig. 7.10 Illustration for the Tonneau (barrel) and Cathedrals sites in Campomoro, Corsica. (sketch by Alain Freytet for Torra Plongée)

7.5.1 Landscape as a Natural Means of Mediation: From "Sensory Marketing" to Public Awareness?

Visitor numbers and types can be high and varied in certain marine heritage sites and not limited to an "initiated" or "aware" audience (such as divers, naturalists or fishermen). People from all horizons can be found, with the management problems this brings. Moreover, in our consumer world rife with media immersion, new technologies apply increasingly spectacular means to plunge and keep the audience in our artificial worlds. To appeal, the virtual realm can and must be hyper-real, provoking intense perception through speed and giddiness, soliciting all five senses. With reference to the landscape, sociologists have described this media immersion as "*mediascape*"[34]. Tactile or interactive surfaces occupy our technical and recreational space and, like a second Nature, form a landscape, imprisoning the real landscape in the images they contain. Sales strategies have made no mistake: "sensory marketing" is today an explicit concept, and "immersion" has become a paradigmatic notion in designing settings conducive to buying. In shopping centres, trade fairs and airports for example, lighting, materials, sound and olfactory design, as well as packaging, attempt to convey the diversity of sensations and experience that natural environments once offered. These artificial places harness the full impact of our relationship with the landscape. Couldn't we restore balance and awaken the public's senses to natural areas by designing immersion in the natural landscape as effectively as we do in the artificial consumer world? Immersion has already revolutionised museums,

[34] An obvious neologism based on the word "landscape". On the concept of "mediascape", a mental landscape created by media which influences representations of social groups, and their consumer, planning and policy-making practices, refer to the analysis by Indian sociologist Arjun Appadurai, *Modernity at Large: Cultural Dimensions of Globalization*, Minneapolis: University of Minnesota Press, 1996.

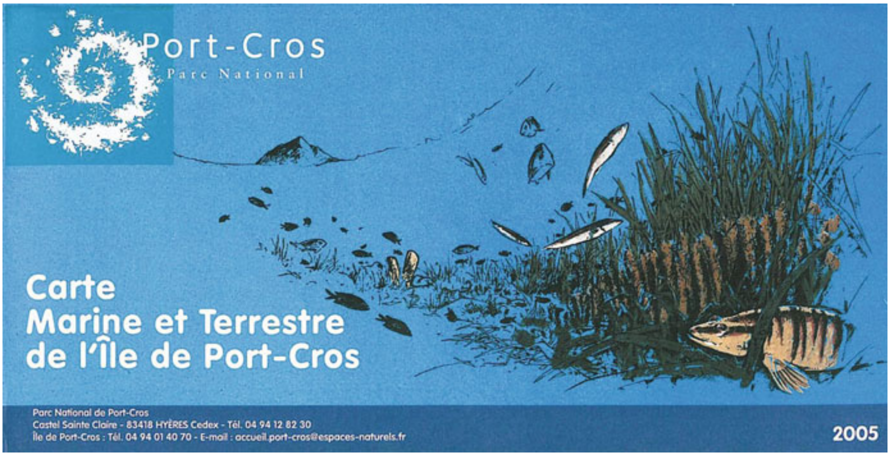

Fig. 7.11 Reference box of Port Cros Island land and sea chart. (sketch by Alain Freytet for Port Cros National Park)

but has not extended to the landscape[35]. With its wealth of shapes, colours and textures, the landscape is a sufficient medium in itself. But we often clumsily attempt to replace it with explanatory buoys and boards, designed to be adequate educational projects, whereas they should simply be supporting tools. The landscape is sufficient as it is the message to be conveyed: a natural space capable of arousing emotion and therefore of value. It is both medium and message[36]. This analysis is valid both for images of landscape (on documents[37]), and the actual landscape, the best "representative" of natural areas in our eyes. A choice made by Emmanuel Lopez, former director of Port Cros National Park, provides a good example of the first aspect. To illustrate the island's landscapes on the reference box of Port Cros sea and land chart, he opted for a drawing done underwater along the underwater trail. Regarding the second aspect, more points of contact with the water should be created to reveal the "underwater landscape". Rather than relying on heavy scuba-diving equipment, snorkelling offers much easier and more affordable access. Underwater trails appear to be less complicated and very effective creations to encourage this change. They often consist of small changing facilities on the shore, some prior guidance to dispel any fears, and a water trail (which may or may not be marked out) revealing the full diversity of landscapes beneath the surface (Fig. 7.11).

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[35] Cf. Florence Baelen, "L'immersion comme nouveau mode de médiation au musée des sciences. Étude de cas: la présentation du changement climatique", in *Sciences, médias et société,* and "L'immersion dans les musées de science, culture ou séduction?" in *Cultures et Musées* no. 5, 2005. Also "Les expositions, une technologie de l'immersion" in *Mediamorphoses.*

[36] According to the phrase coined by media thinker Marshal Mc Luhan, i.e. the self-referential aspect of a medium. In semiology or information theory, we would refer more precisely to equivalence between message and channel.

[37] What Alain Roger calls the "in visu" landscape, particularly in his *Court traité du paysage*, Gallimard 1997.

7.5.2 From "In Vitro" Landscape to "Showcase Landscape": The Landscape Challenge of Dioramas and Aquariums

Who does this concern? In addition to protected areas, "park houses" and exhibition venues, more or less connected with the outdoor landscape sites, also face this strategic challenge. Aquariums raise questions. Their principle and forms stem from an old spatial system based on an *in vitro* importation of the landscape. Like a screen, panes of glass can be used to adjust the manner in which a landscape object is presented to the public. However, there appears to be some opposition between the "distancing" show cases found in traditional museums and the "immersive" show case of aquariums and dioramas. Where the object is exhibited alone and enclosed, it is isolated from its original network of living structures by the glass, leading to observation and scientific abstraction of an object of study. A diorama aims to do quite the opposite. Its promoters, the founding fathers of ecology Alexander von Humboldt and Ernst Haeckel[38], aimed to figuratively reproduce a landscape and all of its features. In "De l'utilité de la peinture de paysage en sciences de la vie", Humboldt, who himself drew both sensory and artistic sketches[39], explains his vision in favour of cooperation between artists and ecologists. With the "diorama", he wanted to establish a visible connection for the public between landscape and biological causality. As Director of the Museum of Berlin, he oversaw the very first dioramas developed for a museum, while Haeckel devoted himself to aquariums. A museographical process from the nineteenth century, the principle of aquariums has changed little ever since. Semi-decor containing real landscape components, it is unfortunately always technically limited in volume and richness. Its status in relation to the landscape is ambiguous, particularly with recent technical advances[40]. Presented as genuine fragments or isolates of threatened natural habitats and species, there is no certainty that the scenographic or museographical process at work offers anything new. The public still finds itself facing an enclosed, limited world. Conscious of the scenographic problem, their managers attempt to "break" this glass shell and include more evocation of the outdoor world and each aspect of the landscape (plants, but also light, sound and movement) for the public's experience. In our opinion, this trend demonstrates the new paradigm of museographical "immersion" through closer connection with the landscape. As a result, scenographers, lighting specialists and landscape designers are increasingly in demand on the museography market. So when will the same effort be made for museographical immersion into the underwater landscape?

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[38] Haeckel invented the notion of biocoenosis, based on a study of oysters and their environment. A biologist and painter, he was Director of Hamburg Natural History Museum and had the very first modern aquarium built, following the example of Humboldt's terrestrial dioramas.

[39] See his highly famous watercolour diagram of the Chimborazo volcano in the Andes, which he climbed with the botanist Bonpland. Their floristic inventory was a founding document of phytosociology.

[40] Even though recent improvements in materials now allow scenes to be embraced in large panoramic windows.

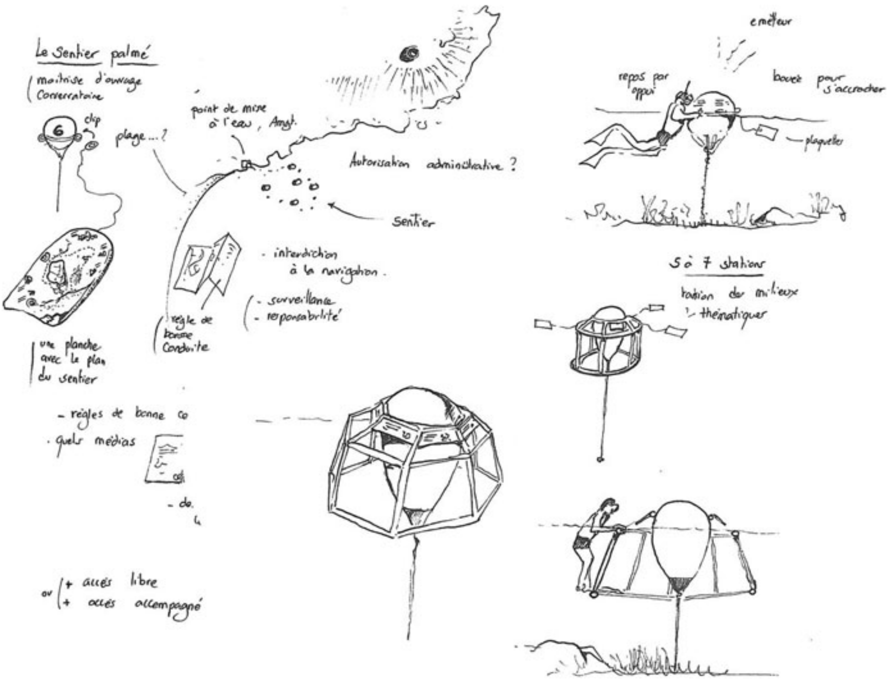

Fig. 7.12 Sketch for the Campomoro snorkel underwater trail. (sketch by Alain Freytet for Torra Plongée)

7.6 Maximum Landscape Immersion, Minimum Intervention: Serving and Preserving the Underwater Landscape

Despite the risk of reducing the underwater world to a commonplace by responding to demand for standard educational equipment with strictly terrestrial and technical objects such as boards or buoys, landscape design services are still seldom used (Fig. 7.12). Rather than heavy, interventionist interpretation projects, we adopt a minimal, mimetic intervention approach on land. This is illustrated by wild lands and urban parks where, since Gilles Clément's "*jardin en mouvement*"[41] (garden in motion), the idea is to give nature a little helping hand, rather than domesticate it or create landscapes from scratch. The less we invade a site with objects and visual information, the more visitors experience direct, strong emotion. Many projects therefore aim to serve sites by avoiding all excessively visible or out-of-place filters between the visitor and the landscape. This trend is now being adopted in underwater landscapes. Projects involving buoys, posts or beacons are often scrapped to leave the site clear, and guided dives with carefully prepared supporting documents are

[41] Cf. Gilles Clément, *Le jardin en mouvement*, Pandora 1991. Re-ed. Sens and Tonka 2006. Concept embodied in the wild lands at Parc André Citroën in Paris which he designed.

Fig. 7.13 A group of children with their Campomoro underwater trail discovery boards. (sketch by Alain Freytet for Torra Plongée)

preferred. For example, as part of the underwater trail project on the *Conservatoire du Littoral Domaine du Rayol* site, the initial and no doubt overly pregnant ideas based on a garden were aborted in favour of guided tours leaving from the beach house, a painted marine fresco in the diving shed, and live underwater images broadcast by camera in a beach-level room. Such minimalist intervention argues for ceasing all reference to these natural environments as “gardens”. We now see them as places with their own dynamics and their own laws independent of all human intervention and policy. Along the coast of Campomoro, in Corsica, the first outlines of the quite interventionist underwater trail involving the installation of underwater buoys and markers were dropped in favour of work on transportable information media. A board that helps swimmers float on the surface also provides information and educational material. It particularly features a very precise map, developed from decametric measurements, together with the itinerary, rules of good conduct, and pictures of animals that may be encountered. Children play with the boards like shields. Visitors thus become active landscape readers while other still rare “landscape media” form the missing pieces in the sensory puzzle between the world and ourselves. But above all, landscape action does not introduce human features to weigh on these fragile areas. They are preserved by shifting the focus to an intermediate object accommodated at the heart of what the landscape really is: a dialogue between our imagination and the area. The very discovery and concept of such tools and methods, working as “levers” in people’s minds, are sufficient justification for all the efforts we, as landscape designers, deploy to read the underwater world (Fig. 7.13).

What do we learn from a landscape designer's visual foray into the underwater world? That, being difficult to read, underwater landscape demands invention. Not solely under water, but also on land, for management and mediation of natural areas *through* the landscape. The conditions in which we perceive underwater landscapes compel us to observe from within and temporarily abandon all objective, scientific vision of space and its ecological functioning. By naturally appealing to the sensitivity of an amateur audience, underwater landscape reveals great potential for fostering awareness which must not be missed. Our vision as landscape designers also, we hope, reflects the need for a multidisciplinary approach to managing marine areas like natural spaces. "*At the outset, nature was wild. This first nature has progressively become 'second', through human conquest of the horizontal line. It must now become 'third' by reinventing its every layer and exploring its full depth...*", suggests Bernard Lassus in a foundational publication[42]. In other words, to protect untamed nature from excessive anthropization, we must now seriously consider what we might call the ecology of human perception. Lastly, the underwater landscape itself shows us that a dual effort is required in landscape design. Firstly, successful reading and immersion in the literal and figurative sense, and secondly effective emergence of the underwater landscape's specific features through the graphic choices made. The underwater landscape brings new horizons in how we conceive and study landscape in general, including above water. Landscape is a tricky subtle notion, floating on sometimes disconcerting and as yet unexplored depths. It would thus be perilous and contemptible to allow routines and methods to take root as automatic procedures. Because the object of landscape design is the human gaze that gives the world meaning, and we will forever look to new horizons.

[42] Op. cit.

Chapter 8
Underwater Landscapes in Comic Books

Laurence Le Dû-Blayo

Abstract The perception of landscapes is expressed through practices and uses, as well as through social and cultural representations. In the case of underwater landscapes, this perception has a very specific history associated with the technical developments of deep-sea diving and the exploration of the sea bed. This exploration, which dates mainly from the 20th century, is a recent development in the history of humanity, relayed in contemporary media, in particular the cinema and the comic book. We discuss here the interplay between underwater landscapes and the comic book, to put a new slant on the way our contemporaries view landscapes.

Keywords Comic book · Bande Dessinée · Cultural representations · Underwater landscapes · Exploration

8.1 Introduction: Landscape and Representation

The debate on the concept of underwater landscape inevitably involves the representation of underwater landscapes because, for some authors, the existence of these representations is a major argument for validating the perception of an environment as a landscape. This is the theory developed in particular by Augustin Berque, who gradually drew up a list of criteria proving that feeling for landscape[1] really does exist. According to the author, the first role of these criteria is to differentiate societies according to their awareness or not of the landscape. Consequently they also

[1] "In increasing order of discrimination: 1 literature (oral or written) celebrating the beauty of places; which includes toponymy (e.g. French place names such as: Bellevue, Mirabeau, Beloeil etc.); 2 ornamental gardens, 3 architecture arranged to make the most of a beautiful view; 4 paintings representing the environment, 5 one or more words to say "landscape", 6 an explicit thought about the landscape" Augustin Berque, 2013, an introductory conference to the international seminar "landscape and imagination", Paris, 2 May 2013.

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define environments which are landscapes for these same societies, either in the way in which they are written, sung, named or painted, or in the way in which they are arranged or ordered, or even in the way people think about them. Alain Roger summarises this in the notion of *artialisation in situ* (e.g.: the art of gardens) and *artialisation in visu* (e.g.: painting) (Roger 1997), a notion which offers interesting prospects for analysing the appearance of new landscape models.

But it should be stressed right away that these approaches have no supremacy in research; they consider contemplation to be the very purpose and existence of landscape and the aesthetics of its representations to be the access to its analysis. Not denying the major contributions that culturist approaches have made, landscapes can also be perceived by analysing social representations, the daily activities which fashion the landscapes but which also determine our way of seeing them. "The process of *artialisation* proposed by Alain Roger is operational when it applies to academic culture, that of canonical aesthetics, recognized by the world of Art. But culture is also knowledge of the surroundings, organised and thought by individuals and societies, in their relationship with the materiality of nature and with others, as in the test of the sensitivity of each one to the living environment and the search for wellbeing" (Luginbühl 2012). Thus, art is not an essential intermediary in the perception of the landscape; there are other professional practices and other everyday uses which also give proof of poetic appreciation of the environment. This reinstates the craftsman and the inhabitant as sensitive participants in the physical and mental construction of landscapes.

By placing the question of the perception of landscapes in the area of social relations and not simply in cultural representations, we slip into approaches which in human geography come under the geography of the emotions, and its non-representational thinking which has been developing for the past ten years or so (Thrift 2007; Wood and Smith 2004). The objective here is (i) to recognize the emotional and affective dimension of human beings as an essential element of individual and collective human experience, and (ii) to take into account the reality of this emotion without its being necessarily translated into any kind of representation, in particular artistic. "Emerging over the past ten years from a set of post-structuralist theoretical lineages, non-representational theories are having a major impact within Human Geography. Non-representational theorisation and research has opened up new sets of problematics around the body, practice and performativity and inspired new ways of doing and writing human geography that aim to engage with the taking-place of everyday life" (Anderson and Harrison 2010). Divers are not necessarily great consumers or producers of images of the sea bed, even though these landscapes inspire in them intense feelings and emotions and their experiences discovering these surroundings can mark their lives. So, as a preliminary to this modest study of underwater landscapes in comic books, let's suppose that the existence of representations of underwater landscapes, even if it is central to the subject, is not an essential condition for considering the underwater environment as a landscape.

8.2 The History of Landscape Models

The perception of landscapes is the result of an interaction between what is offered to our senses by the territory (object) and the interpretation we are able to make via our sensitivity (subject). This sensitivity is modelled by global level filters (history of landscape models), local level filters (built in the memory of social relations) and individual filters (from individual experiences).

Landscape models give a general framework to the perception of landscapes in a given geographical and historical context: in Europe, considerable research has shown the evolution of models from the 16th century to the present day[2], from the pastoral model of fertile countryside, to models of the magnificence of mountains and coastline, then the picturesque model of natural curiosities, and finally the model of the wilderness (Le Du-Blayo 2007). This wilderness model stands out very clearly in contemporary interviews with populations in Europe, whatever the age and social category of the person interviewed, as a counterpoint to agricultural, urban or industrial landscapes, often perceived as degraded by mankind. "It will be observed that the reference to the virginity of the landscape is presented more precisely according to two major models:

- The stereotype of paradise [. . .]
- The model of unpopulated wide open spaces (deserts, the high Arctic) which exalt the passion of the pioneer, the confrontation with danger, the search for solitude, and which comes back to the model of the sublime" (Luginbühl 2012).

Underwater landscapes come fully within the framework of the natural wilderness model, forming a concentration of its principal criteria: the permanent absence of human beings makes it a territory of exploration, and the strangeness of the surroundings and the difficulty of access associated with the underwater environment result in a hazardous, even perilous landscape, where the excitement of discovery and curiosity about the unknown are mingled with the thrill of fear.

The historian Alain Corbin has explained in detail why at a certain period (1750–1840) the coastline, once considered to be ugly and repulsive, became in a few decades the perfect setting for holidays (Corbin 1988). The history of the underwater landscape has still to be written.

8.3 The Emergence of Underwater Landscapes

Like desert landscapes or those in regions of extreme cold, underwater landscapes are constructed over the course of time by the combination of scientific explorations, their economic development, and their use in the arts and leisure.

[2] Landscapes and Modernity, Texts collected and presented by Aline Bergé and Michel Collot, 2007, Ed. Ousia, p 393. Landscapes in the plural, An ethnological approach to landscapes, 1995, Ed. de la Maison des sciences de l'homme, Ethnology of France Collection, Book 9, p 240.

Underwater exploration has been fantasized about since time immemorial. More than 23 centuries separate Alexander the Great diving to the bottom of the Persian Gulf from James Cameron diving into the Mariana trench. But it must not be forgotten that the history of manned voyages to great depths beyond the continental shelf is relatively recent. The craft developed by Lethebridge, Halley, Beebe and Barton reached greater and greater depths but was still attached to the end of cables (Riffaud 1988). It was the Swiss Auguste Piccard who was to succeed in making the first independently steered submarine designed to explore at great depths, launching the race for record descents: 2,100 m in 1953 for the FNRSIII, 10,916 m in 1960 for his son Jacques Piccard and the bathyscaphe TRIESTE (Piccard 1954; Houot and Willm 1954; Piccard 1961). The path was now open, and scientific explorations were to revolutionise knowledge of the seabed. For example, the French American Mid Ocean Underwater Survey (F.A.M.O.U.S. 1972–1974) confirmed the existence of oceanic ridges, then the expedition of the American *Alvin* and the French *Cyana* in 1977 discovered the famous underwater oases, where life develops outside of any photosynthesis process (Laubier 1992).

The exploration of sea beds without a motorised machine developed at the same time, but it was really in the 18th and 19th centuries that a diving-suit was improved which still only allowed movements on the seabed (Millot 1987). The air was pumped from the surface in Auguste Siebe's version, or carried by the diver in the Rouquayrol-Denayrouse self-contained equipment which inspired Jules Vernes for his novel "20,000 leagues under the sea". It was not until 1926 that Fernez-Le Prieur's aqualung appeared (Le Prieur 1956). This apparatus used the flippers invented by De Corlieu in 1914 and enabled the diver to abandon the vertical walking position to swim and explore the whole volume of the water in three dimensions.

This fascinating technical and scientific period, with all its discoveries and also its dramas, is an inexhaustible source of inspiration for literature and the cinema. Scientific discoveries associated with the exploration of completely new and astonishing environments, submarine military history related to the Second World War or the Cold War, or the economic colonisation of the seabed, such as the history of the laying of telecommunication cables: all these topics are abundantly exploited in contemporary cultural creations.

8.4 The History of Representation Media

The scientific and technical history of the discovery of certain land territories intersects with the social and cultural history of landscape models, as with the history of the cultural media.

"The invasion of the audio-visual, the acceleration of speeds, the conquests of space and the abyss have taught us and obliged us to live in new landscapes, underground, underwater, in the air [. . .] and many other registers still unexplored, if not unsuspected, of more aggressive landscapes too, imposed on us by the cinema, contrary to the Arcadian myth, dear to old Europe" (Roger 1997).

The pastoral model of countryside landscapes has been deployed through landscape paintings since the 16th century and is still associated with the brilliance of Impressionist painting; after that, the models of mountain and coastline landscapes were to be popularised at the same time as photography; but it was only in the second half of the twentieth century that the model of the wilderness was to explode with aerial photography (see Yann Arthus Bertrand) and in the cinema (Schama 1995; Baetens 2012).

Underwater landscapes come completely within this dynamic which associates new media and new landscapes: "Not forgetting, of course, all the landscapes that microphysics and space exploration reveal to us, or rather invent for us, and which, undoubtedly reveal, essentially, technical progress. But none of this would ever come within the collective orbit if they were not popularized through the media, and artialised, as clearly shown, for underwater landscapes, by the films of Cousteau and the *Grand Bleu* of Luc Besson, or, for planetary landscapes, the productions of American space art and the work of science fiction" (Roger 1997).

Admittedly, the comic book, which starts to become accepted as the "ninth art", is not such an influential medium as the cinema, and its diffusion via magazines does not have the same impact in the construction and sharing of a common corpus of images as films seen throughout world. But, like the cinema, it has adopted the field of the underwater world and contributes to the popularization of its landscapes.

The inventor of the comic book is often considered to be the Swiss writer Rodolphe Töpffer, famous for the publication in 1944 of the *Voyages in Zig and Zag* which for decades was read by French schoolchildren as an introduction to the landscapes of their country. Töpffer broke new ground in 1933 with the first history album in prints: *The story of Mr. Jabot,* circulated in 1935 (Groensteen 2009; Moliterni 1980). The comic book spread in the 19th century to the United States then in the 1930s it had a great success in Europe in periodicals for children and teenagers, some of which still exist today (*The Mickey magazine*, *Spirou*). In the 1970s, there was a revival in Europe with comic books for adults, exploring all the narrative genres and all styles of comics (Baetens 2008b). A few great authors then emerged, who were to become benchmark classics, such as Moebius, Hugo Pratt and Enki Bilal. So the history of the comic book, like the cinema, is contemporaneous with the history of underwater discovery and scuba diving.

The comic book has much in common with the cinema in the construction of a scenario and the succession of settings, as well as great flexibility in the succession of visual angles (low-angle shot, high-angle shot, close-up). As for the more specific aspects of the underwater environment, for a long time the comic has had the immense advantage of not having to go underwater to create its images. It is free from all the technical and economic constraints to which the cinema is subjected, including studio reconstructions or synthetic images (for example STARWARS episode I). With the stroke of a pen, the comic can confront the deepest abysses such as the sea beds of the antipodes, and the authors have made the most of this advantage (Fig. 8.1).

Vocabulary inside *air bubbles* in the water often converges with the *text bubbles* in the drawings, and it is interesting to note the significant number of comic book festivals whose posters refer to underwater landscapes. Here are a few examples:

Fig. 8.1 Poster of the 9th comic book festival of Perros-Guirec (Author Olivier Boiscommun). Here is one of the many examples of the universe of the comic book placed in direct relationship with the universe of the underwater world. This poster illustrates certain features of underwater landscapes: a sea floor where the relief is a dominant feature, a variety of fauna, the effects of light presenting the surface as the landscape horizon. The presence of the two characters is highly significant of the omnipresent ambivalence in underwater landscapes between animal and human, real and imaginary, breathing on the surface and breathing under the water

- 2001: Abracada bulles, Comic book Festival of Olonne sur Mer
- 2002: 9th comic book festival of Perros-Guirec
- 2002: Tonnerre de Bulles, Comic book Festival of Brest
- 2006: Festival Quai des Bulles at St Malo
- 2007: 6th Comic book Festival of Roquebrunes/Argens
- 2007: Des calanques et des bulles, 9th Comic book Festival of Marseilles

8.5 Underwater Landscapes and the Comic Book

The ambition here is not to cover the whole question, but simply to make some observations and open up some lines of thought. The corpus studied consists of approximately 3000 books by all types of authors published since the 1930s and which cover all the styles to be found in Europe (comic books for children and adults, humour, science fiction, novels . . .), other than American comic books and Japanese manga.

On initial examination, it is striking to see how often the underwater environment appears in comic book scenarios. Naturally, for an author eager for his hero to live over time, the settings for his adventures have to be renewed. Throughout the twentieth century, the majority of comic book heroes have had their underwater adventure. This includes the "classic" comics of the 1940s: Hergé explored underwater landscapes with his various characters, in particular in "The adventures of Jo, Zette and Jocko" *Le rayon du mystère* published in the weekly magazine "Coeurs Vaillants" in the years 1936–1937 and the adventures of Tintin the deep sea diver in *Tintin in the Land of the Soviets* (Hergé 1952). But it was of course with *Red Rackham's Treasure*, the book of the adventures of Tintin published in 1944, that Hergé created his finest underwater landscapes, and produced a popular icon[3].This image of Tintin walking in a diving-suit towards the wreck of the Unicorn is an explicit homage to the image of Captain Nemo walking in a diving-suit towards the island of Crespo, illustrating Jules Vernes' novel *20,000 leagues under the Sea*.

As the ocean floors were being explored, underwater landscapes were as essential in the comic book as in other narrative media and became standard settings for adventure. This was very frequent, in comics mainly intended for very small children, as well as in comics aimed at an older, even adult audience. Since they first began, *Les pieds nickelés* (Pellos 1958) or *Bob and Bobette* (Vandersteen 1950, 1967, 1970) have had several underwater adventures, in association with real expeditions by Cousteau or Piccard. *Spirou* (Franquin 1957), *Les petits hommes* (Seron and Mittei 1980), *Les 4 as* (Craenhals and Chaulet 1964), regularly go under water. The adventures of Bob Morane (Vernes and Forton 1995) followed the evolution of diving equipment. Some series are particularly suited to adventures requiring advanced diving techniques, such as the young *Yoko Tsuno*, an electronics engineer who drives all kinds of machines in the air and in the seawith great skill (Leloup 1979, 1983). Even the *Smurfs* (PEYO 1994) revived the adventure of underwater explorations at their own scale (a small lake) and the author created some very fine plates with this episode, once again reproducing the iconic image of walking in a diving-suit in underwater landscapes popularized by Jules Vernes and then by Hergé (Fig. 8.2). Mention has to be made, of course, of the humour of *Achilles Talon* (Greg 1984), the poetry of *Isabelle*, (Will et al. 1979, 1986), and the romantic adventures of *Blake and Mortimer* (Jacobs 1957) and *Corto Maltese* (Pratt 1992).

In some adventures the underwater environment is an integral part of the scenario as in the series *Submerman* (Lob and Pichard 1979) in which the heroes live in the ocean, *Le Narval* (Supio and Beuzelin 2010) in which the hero is a professional diver, or again in *Hauteville House* (Duval et al. 2004, 2011) where the action very often takes place in the air, underground or under the sea, all the frontiers of the planet being explored for a fantastic background to the action. However in most of the books, underwater landscapes are the setting for occasional adventures (Chaulet-Endry 1985).

[3] The books 'The secret of the Unicorn' and its sequel 'Red Rackham's Treasure' are the two world best-selling episodes of the adventures of Tintin.

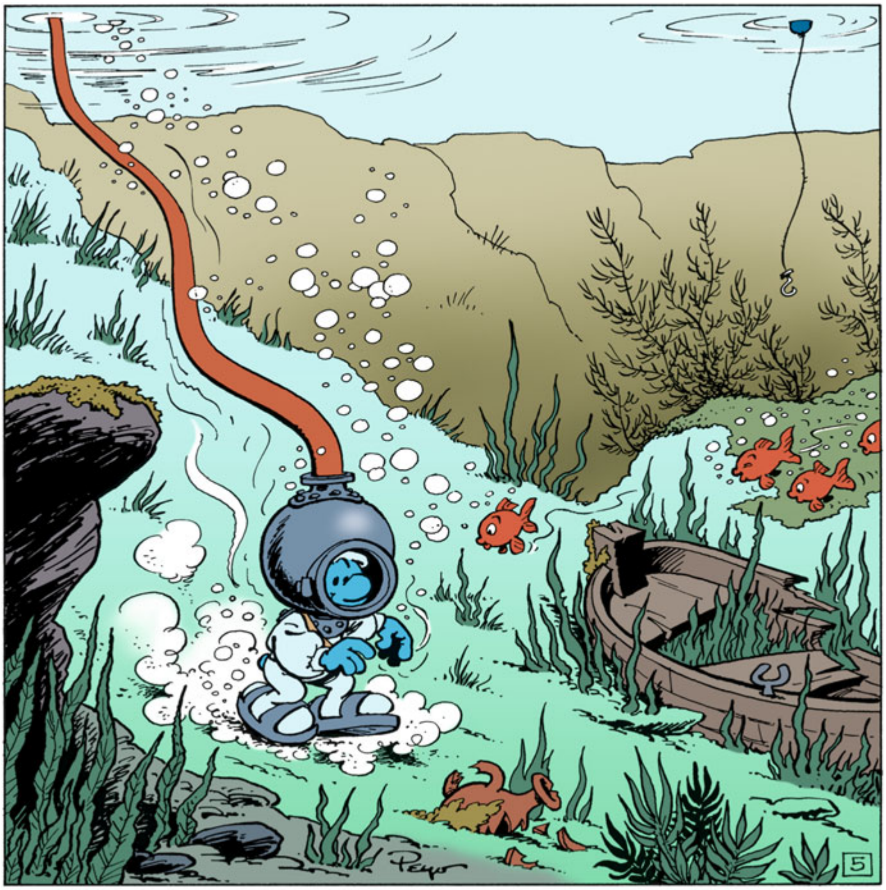

Fig. 8.2 (© Peyo, all rights reserved) Extract from "The Smurf who walked under water" (Peyo 1994). Walking on the sea bed in his diving-suit, the little Smurf here reproduces the image of a man in underwater landscapes popularized by Jules Vernes then Hergé. Worth noting is the direct link between these underwater landscapes and terrestrial landscapes via anthropic objects: the wreck of the boat, the archaeological vestige of an amphora, the fishing line with its hook, and of course the tube which makes it possible for the Smurf to breathe

8.6 Characters of Underwater Landscapes

To tackle the ways underwater landscapes are evoked in the comic book, we extracted 60 books from the whole of this corpus that are representative of various times and different styles, and in which underwater landscapes occupy an important place in the sense that they can be clearly distinguished and therefore analysed, sometimes on several plates. A statistical approach began with a few simple questions:

8.6.1 Access to Underwater Landscapes in the Comic Book

In the vast majority of the books, the characters in the story move IN water, and they observe the underwater landscapes *in situ*. Mobility around the landscape is unrestricted, expressing the desire to explore this underwater territory in all its dimensions: movement on the sea floor, diving into the ocean depths, but also all kinds of journeys in the body of water. Water does not restrict movement; on the contrary it is made easier in three dimensions. The underwater landscape is not a passive background: the characters walk across it, they experience it, and it is often tested with intense physical involvement.

To achieve this, a very large variety of techniques is used: standard diving dress, diving with a breathing apparatus, submarines . . . all existing machines are used (more or less faithful to reality . . .) or invented by the screenwriters. This is the case of the individual submarine invented by the Count of Champignac in the book of Spirou and Fantasio (Franquin 1957) in order to explore a wreck lying at a depth of 200 m.

What is perhaps more astonishing, is that in 20 % of the comic books studied, the characters move under water with no specific breathing apparatus. The Marsupilami created by André Franquin in 1952 is amphibious and therefore moves with great ease under water and in the air. In *L'astragale de Cassiopée* (Will 1979), Isabelle and the other characters go from the air to the water environment and back again with no problem, as if the change of environment did not affect them. At least Calendula says "You can breathe Isabelle, the water in this pool is not like others . . .", obviously because magic is everywhere. In the *Donito* series, created by Didier Conrad (Conrad 1991, 1992, 1993, 1994), the hero spends most of his time diving, thanks to an alga; only he has the secret of this "Twindlin" alga, which enables him to breathe under water. In the book *l'Or caché du cachalot* (Conrad 1996), the excessive consumption of this Twindlin alga by Donito will gradually make it impossible for him to breathe on earth (Fig. 8.3).

Thus in nearly a quarter of the scenarios, the heroes are amphibious and can live in both air and water. The limit between the terrestrial and the underwater worlds disappears; the marine interface is no longer an insuperable frontier for man.

8.6.2 The Vision of Landscapes in the Comic Book

In the comic book, the aquatic environment is not a problem for moving or for breathing, and even less for seeing. In 75 % of the albums, the water is very clear and limpid, and the landscapes as well as the characters are therefore clear to see, even from a distance. In 65 % of cases, the landscapes are presented with panoramic views and great depth of fields of vision, which is obviously not true of real underwater visibility. It is worth noting that the main exception, where water turbidity limits the diver's visibility to a few dozen centimetres, is an action which does occur under water, but in a lake (Houot 1994).

In addition, the cartoonists use all possible settings, and in particular low-angle shots (30 % of the books) to emphasize the vertical dimension of the medium. This

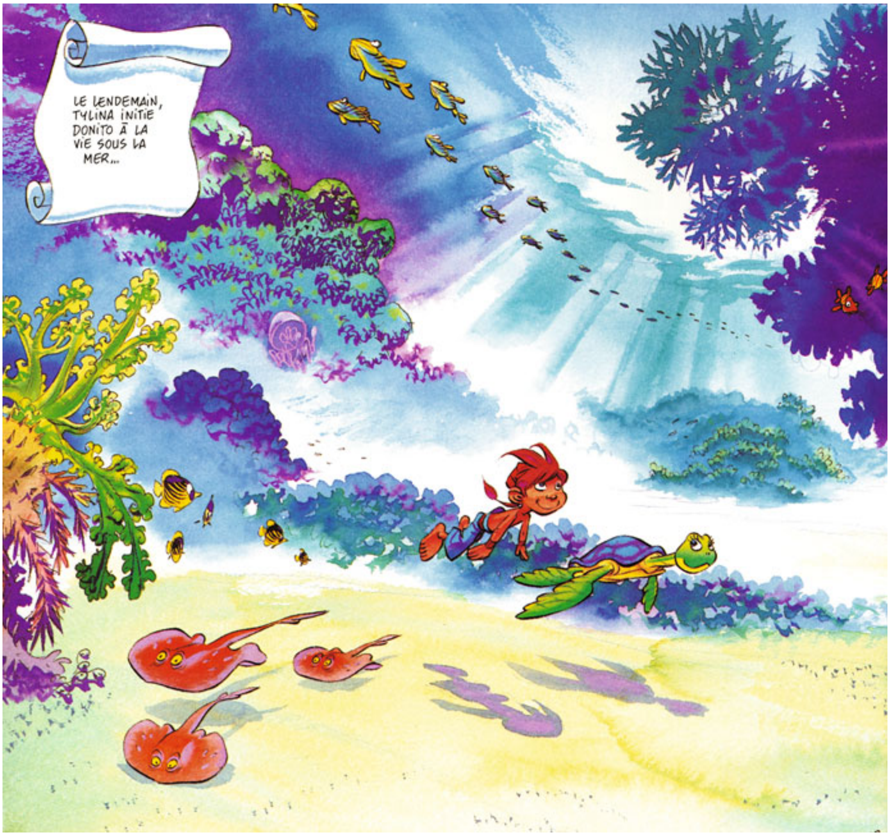

Fig. 8.3 Extract from the Donito series, "Le grand secret", p. 20 (© Didier Conrad & Wilbur, all rights reserved). This image is representative of the aesthetics of the underwater landscapes developed in the comic, via the explosion of the shapes and colours of the ecosystem, the plays of light from the surface, but also the fluidity of movements. The character of Donito moves very freely in this underwater landscape: warm water, limpid and luminous, with no problem for breathing. The underwater landscape here is an idyllic playing field for the little boy, with his pet: the tortoise

vertical dimension is generally very well represented by the effects of luminosity from the surface and the progressive darkening of the landscapes towards the bottom, as well as the fading of colours. The plays of light in water, which contribute in a major way to the beauty of underwater landscapes (Hanna 2007) are therefore very much used in comic book images, as for example in the series *Hauteville House* (Duval et al. 2004, 2011).

8.6.3 Typology of Underwater Landscapes in the Cartoon

The comic book gives a magnified view of the specific features of underwater landscapes, in the sense that cartoonists exploit to the maximum the most easily identifiable characteristic of landscape elements or structures to immerse the reader in the underwater world.

Archaeological landscapes are one of the essential parts, with the recurring theme of the wreck which is present in 50 % of the books studied.

These wrecks relate to all kinds of boats, galleons, trawlers, submarines etc. But they also relate to all the flying objects which might possibly sink to the bottom of the sea: plane, seaplane . . . As in the case of real sea beds, wrecks are varied habitats with a rich variety of flora and fauna. Wrecks are also linked to a more or less mysterious history which is obviously exploited in the comic scenario, in this way reflecting the interest and attraction that wrecks have for divers (Larn 1993; Carre et al. 1994; Feige 1998).

Submerged cities are the second characteristic theme, to be found in 25 % of the books. The myth of Atlantis is very often used (Pratt 1992; Jacobs 1957), as is the story of the town of Ys in Brittany. But it can also be elements of a real city that are transplanted, such as the Sagrada Famillia of Gaudi in Barcelona which on the ocean floor becomes the palace of the king of the fishes in the comic book *Marine* (Tranchand 1990). In comic as well as cinema scenarios, there are many imaginary cities, old and futuristic, where life under water is possible. The underwater world serves as an imaginary, ideal, creative and fantasized world. The theme of the anachronistic landscape where time has shifted is often exploited for mystery or humour, with the incongruous presence under the water of surface objects (a plane for example); but it can also be the setting for inappropriate behaviour (for example a little snooze underwater, or a bicycle ride along the seabed . . .).

Generally speaking, these archaeological landscapes enable the authors to structure the scenario around the limits that fluctuate between the worlds above and below the water. In fact, the hills and valleys and some objects do not move, it is the sea level which changes. The status of the objects and landscapes (terrestrial/underwater) is uncertain, which creates strangeness (Savey 1987). This instability, this confusing blur often refers back to other limits, like that between life and death, and the possibilities of passage or exchange of status. In this sense, underwater landscapes have the same *frontier runner* role as night landscapes, establishing a link between the real world and the imaginary world, between the world of the dead and the world of the living.

The reliefs of the sea bed are represented explicitly in 75 % of the books. They are of great diversity: hills, valleys, gorges, faults, blocks, cliffs, plains, deep trenches. This variety of landscapes is of course exploited both in the scenario and for the aesthetics of the illustrations. These reliefs are often approached very scientifically, as the comic book directly exploits the topicality of scientific discoveries on polymetal nodules, underwater volcanic activity and the tectonic plates.

In the series *The adventures of Spirou and Fantasio—Le repère de la Murène*, the drawing of the shipwreck “le Discret” (Franquin 1957) is representative of the vision of very deep underwater landscapes: dark landscapes, exclusively mineral, difficult to reach, where the human presence is often associated with mystery and danger, even with the morbid (wrecks, submerged cities). The influence of the model of the sublime landscape, very much present in the representation of mountain peaks in the eighteenth and nineteenth centuries, is very obvious here.

Fauna and flora are landscape elements also present in 75 % of the books. Underwater landscapes are not presented as deserts; on the contrary, they are places full of life, and the rocks are bright with colour and shapes which contribute directly to the aesthetics of the landscapes. In this biodiversity, some themes play a predominant role as markers in the underwater landscapes. This is the case of the Gorgons, cnidarians living in colonies of fan-shaped polyps, often brightly coloured in red (paramuricea clavata) and yellow. Their silhouette is easy to recognise and often appears in images of the underwater landscapes. Fauna is often presented as fearful, even dangerous for man. The shark of course often makes his presence felt, as Tintin finds to his cost in his first expedition in a diving-suit to the wreck of the Unicorn (Hergé 1944). But other animals are stars of the seas, in particular the grouper (*Epinephelus marginatus*) which, in the adventures of Bob and Bobette (Vandersteen W.), becomes Prosper, the hero whom all the divers come to visit, prefiguring the present status of the grouper in the protected marine areas of the Mediterranean. This figure of the grouper takes us back to JOJO, the grouper popularized by Captain Cousteau in his film "silent world".

The imagination is stimulated by the potential of species that scientists and fishermen continue to discover every day, and by the strangeness of underwater life, compared to the familiarity of our countryside animals. 30 % of the book corpus refers to fantastic animals or characters, which is quite easy to integrate into underwater landscapes. The siren of course is to be placed in this category, but she is not a major figure, as there is a wide variety of imaginary creatures.

8.7 Conclusion: Underwater Landscapes and Societies

Underwater landscapes are frequently to be found in comic books, whatever the genre or the times. These landscapes are accessible and varied, and can be observed with great clarity. A close link can be detected between the exploration and dissemination of underwater landscapes and the discovery and popularization of comic images. From this preliminary approach, there emerges a parallel between terrestrial landscapes and underwater landscapes, which are shown as a sort of reverse shot. The underwater landscapes have hills and valleys that are similar to terrestrial hills and valleys; they are strewn with objects from the surface, they even reproduce a submerged city. In the way the settings are drawn and the scenarios are organised, the underwater landscapes are in constant interaction with their terrestrial counterparts. This interaction is in offset mode, causing humour, mystery, dream or fear. Ambivalence between what is under/over the water enables the authors to create resonance between other interfaces: the real/the imaginary, animal/human, life/death, past/future . . .

The representation of underwater landscapes in the comic book frequently refers to the scientific discoveries which punctuated the twentieth century. Comic book scenarios call directly on technological progress in diving, archaeological discoveries, seabed biodiversity, understanding the formation of reliefs. For the general public the best known figure of the "scientist" is certainly Captain Cousteau, and it is not surprising that he decided to use films and comics to communicate about his expeditions. Dominique Serafini created for him a presentation of *The adventure of the Cousteau team* in a series of 10 comic books published between 1985 and 1991 (Serafini 1985a, b, 1986a, b, 1987a, b, c, 1989, 1990, 1991). These books take the reader to all the seas of the world, with a very accurate and realistic presentation of the underwater landscapes, and share with him all the themes explored by the Cousteau team; the aim was obviously to inform the audience, and it was extremely effective. There was a sometimes excessive cult of the man with the red bonnet which provoked an interesting parody in a recent comic book, *The ghost of Captain Cousteau* (ISA 2009). In her depressingly spoilt underwater landscapes, she draws a caricature of the classic markers of the underwater landscape: the grotto (assimilated to the grotto of Lourdes), the gorgons . . . and the groupers. The author casts a humorous but critical glance at the pollution of the ocean bed and the media coverage of ecological thinking.

Thus the comic book accurately reflects the complexity of our feelings for these underwater landscapes: the exaltation of discovery but also the reality of the degradation of natural environments by man, the imagination of fantastic worlds but also the projection of our everyday universe. The variety of underwater landscapes is perceived via very different landscape models. The model of wild and sublime landscapes has a powerful influence on the representation of the abyss and the deep sea depths: a very mineral vision, with no anthropisation, inaccessible and often distressing. But the model of the park, even the garden, is closer to the representation of landscapes in shallow waters: in an environment of colourful and welcoming biodiversity, with the occasional wreck, and with decorative structures or follies to be visited; a very popular landscape where people can spend their leisure.

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Chapter 9
The Underwater Landscape: A Vernacular Term? Reflections Through the Eyes and Experiences of Divers

Eva Bigando

Abstract This article is based on the results of a preliminary survey carried out with divers to analyse what the underwater landscape means for them. It aims at defining the contours of this concept in terms of their experience and their mental representations. Without claiming to offer an in-depth response to this question, this article sets out to establish a better understanding of the relationship between man and the accessible part of the underwater world, by defining the ways in which this specific environment is grasped, especially through the experience of landscapes it offers—from the understanding of their material and physical nature, to sensations and emotions involved—drawing on those who have first-hand knowledge of these subaqueous spheres—underwater divers. We will first discuss the precise terms of the survey itself, before going on to show how usage of the concept of underwater landscape is indeed replete with meaning for divers, by shedding light not only on the different connotations and denotations the term has for them, but also on the experiences it offers.

Keywords Underwater landscape meanings · Divers · Experiences · Mental representations

9.1 Introduction

While research scientists in the French-speaking world are still debating about the pertinence of the 'underwater landscape' as a valid concept (Musard 2003; Musard et al. 2007; Chap 1 infra ; Chap 4 infra), those who frequent underwater environments, especially the community of recreational underwater divers, have long adopted the term into their everyday language. Is its usage, then, inherently vernacular?[1]

[1] An allusion to John Brinckerhoff Jackson and his notion of the 'vernacular landscape' (1984), even if the term 'vernacular' is not used with entirely the same meaning here, where we refer more to the notion of a vernacular language, i.e. spoken only within a given community.

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It was during the 1980s in France that recreational diving, practised almost exclusively as a sport, became a ‘natural environment’ leisure activity, spurred on by the growing popularity of ‘American style’ diving, and a growing concern for environmental matters. Diving was no longer a mere end in itself, but a way of discovering the undersea world, as well as a nature-lovers’ consumer activity (Musard 2003). This raises the question of the role played by the underwater landscape in this activity—in terrestrial outdoor activities the landscape’s role is an essential one—and the ways in which divers grasp the ‘underwater landscape’, both in terms of their experiences (emotions and sensations) and symbolic representations.

The late 1980s also saw the massive democratisation of scuba diving (Musard 2003), which opened up the subaqueous world for ordinary people, rather than the (sporting) elite alone, in the same way as the ‘joys’ of discovering far-flung terrestrial environments, originally the prerogative of an initiated privileged few with a taste for landscape aesthetics, are now accessible for society at large. If we add to this the current rise in the number of underwater trails, accessible for those equipped with flippers, a diving mask and snorkel, and the boom in the number of glass-bottom boats and semi-submarines, then it is quite clear that the underwater environment may now be discovered at first hand; in other words, without an intermediary medium, whether that medium be virtual or not (drawings, photos, videos, etc.). Our relationship with the underwater environment is therefore changing, no longer based solely on imaginary constructions, but rooted in tangible reality. Does that mean, however, that the underwater world can be considered as a landscape? Is that the way divers themselves experience that world?

We shall not let ourselves be drawn into the sterile debate as to whether we may legitimately refer to the underwater environment as a ‘landscape’, especially if we consider the term’s original meaning[2]. Use of the word has evolved greatly since it first came into common parlance in contemporary western society, and experiencing the landscape has now become an integral part of how we apprehend our environment, be it our everyday surroundings or not (Bigando 2006). Popularisation of the term ‘landscape’ has extended its dominion far beyond the sphere of everyday usage, and it has now become part and parcel of how we live our lives and interpret the world around us, a world whose frontiers we are forever pushing back. Using the term to refer to the submarine environment should not then be considered as a misuse of language (or of concept, for that matter), all the more so when one observes that underwater diving is increasingly being enjoyed as a contemplative activity, motivated by naturalist concerns. Could we envisage, then, that some individuals seek to immerse themselves beneath the water’s surface for reasons similar to those of others who scale mountain tops, trek across deserts, journey deep into tropical rainforests, conquer the poles or perhaps, in a more or less distant future, will take their first steps on the moon, all to experience the natural, unspoilt beauty of other, less routine, landscapes?

[2] It should not be forgotten that, initially, the term landscape, generally defined as an expanse of country that offers itself to our gaze, referred to the pictorial representation of that scenery.

We must not forget either the growing use of the expression 'underwater landscape' in narratives penned by divers and in written texts relating to underwater diving (Dutrieux and Michel 1993; Apnéa 1995; Dutrieux et al. 1999). Olivier Musard (2003) considers that 'this is the result of the rising number of observers now exploring the underwater world and needing stable markers in their quest to discover and understand the submarine environment through which they travel. This process of anthropomorphizing the sea that we discover inevitably leads to semantic cross-overs, as we seek to express the unknown.' What better notion than that of a landscape to express the encounter between the attentive gaze of a human observer and a specific portion of space, associated with the individual experience born from the relation between a given moment in time, the human eye and the area of space abandoned to his or her gaze? The emergence of a landscape implies not only what the eye may behold—its physical components and the biophysical processes it supposes—but also the manner in which our gaze is exercised, a combination of socio-cultural factors and the psychological state of the individual experiencing the landscape. The landscape may then, in this light, be defined as a 'social construction possessing a material dimension in which biophysical processes take place and an immaterial dimension composed of social representations, aesthetic, emotional and symbolic value systems' (Luginbühl 2005).

While emerged landscapes (i.e. above water, whether terrestrial or not) have frequently been studied by academics, submerged landscapes have enjoyed far less attention and a whole host of questions remain unanswered. How do we apprehend underwater environments? Is there a landscape-centred apprehension of that underwater space, both as regards the object being observed or the observing subject? And do underwater landscapes evoke the same idea as terrestrial landscapes, or are they different? Are they experienced according to the same patterns of experience, practice, perception and representation that pertain to emerged landscapes? Are underwater landscapes compared and contrasted, differentiated or assimilated in terms of terrestrial landscapes?

Without claiming to offer an in-depth response to all these questions, this article sets out to establish a better understanding of the relationship between man and the accessible part of the underwater world, by defining the ways in which we apprehend this specific environment, exposing a prism of how we interpret and understand the world about us through our experience of landscapes (between material and physical components, social constructions, sensorial and emotional appraisals), drawing on those who have first-hand knowledge of these subaqueous spheres—underwater divers.

Our analysis of this question, although preliminary in nature and merely intended to provide pointers for further investigation in a particularly vast field of study, is based on the results of a survey carried out within the framework of a scientific and technical symposium organized by the Agence des Aires Marines Protégées (Agency for Protected Marine Areas) on the theme of underwater landscapes in March 2011 in Brest. As part of a research cooperation agreement between the Agency and the ADES laboratory (CNRS), the survey was intended to do the 'spadework' and provide the foundations for an overview of how the underwater landscape is perceived through the eyes and experiences of divers. The results of this preliminary survey were intended to fuel a far-reaching exploration of the notion of 'underwater landscape' and provide the building blocks of more specific research projects into representations of such landscapes in the Arcachon Basin, where a project for a Natural Marine Park is currently under way.

This article will first discuss the precise terms of the survey itself, before going on to show how usage of the concept of underwater landscape is indeed replete with meaning for divers, by shedding light not only on the different connotations and denotations the term has for them, but also on the experiences it offers.

9.2 Questions on the Underwater Landscape: General Considerations About the Diver Survey

In order to better define the concept of 'underwater landscape', a preliminary survey was addressed to a number of divers. The aim was to gauge the pertinence and define the meaning of this concept for them as first-hand users, perhaps the only ones, of the submarine world.

The survey was carried out as part of a cooperation agreement between research laboratory ADES and the Agence des Aires Marines Protégées (under the aegis of the assignment manager, Olivier Musard), and received the support of the FFESSM (Fédération Française d'Etudes et Sports Sous-Marins) and MNHN (Muséum National d'Histoire Naturelle). It was addressed to divers during two events, held simultaneously in Paris, during the weekend of 16–17 January 2011—at the FFESSM stall at the Paris International Dive Show, and during a two-day course organised by the MNHN on the theme of 'Discovering and Protecting the Marine Environment through Diving.'

In order to encourage a maximum number of divers to answer the survey, we decided that the questionnaire should contain only two open questions (Fig. 9.1), and encouraged them to complete their answers in situ.

A total of 78 people answered the survey—28 during the two-day course run by the MNHN, and 50 at the International Dive Show. There were 76 divers (the 2 non-divers were removed from our analysis), with 16 of them being underwater photographers. Ages ranged from 17 to 77, gender distribution was practically equal, and all levels of diving proficiency were represented.

As for the profile of the participants, three main points are worthy of note. While the women who participated in the survey were generally younger than the men (with an average age of 43 for the women, and 50 for the men), the overall average age was relatively high (Table 9.1), the majority of the participants having had extensive diving experience. Indeed, despite a marked difference in the age at which men and women had taken up the activity (on average the women had been diving for 16 years, and the men for 23 years), it is important to highlight the fact that almost 80 % of the total number of participants had been diving for over 10 years, and 46 % for more than 20 years (Table 9.2). All levels of proficiency are represented, with a majority of survey participants having attained a level of competency equal or superior to Level 3 (Table 9.3).

Agence des aires marines protégées

FFESSM

ADES UMR 5185

ENQUETE

About Underwater Landscapes

As part of a research project on underwater landscapes organised by the Agence des Aires Marines Protégées, we would like to learn more about your vision of underwater landscapes. Thank you for taking part.

1/ Indicate, in a few words, what is an underwater landscape for you.

2/ Does the underwater landscape represent, for you, a diving objective? If so, what exactly are you looking for?

In order to help us with our data processing, could you please tell us :

- your age :

- your gender : Male - Female

- whether you practice underwater diving ? Yes – No

- if so, how long have you been doing that ?

- where (principle sites) ?

- your level of diving proficiency :

Fig. 9.1 The questionnaire

Table 9.1 Distribution of divers by gender and age

	Women			Men				No information	Total
	– 40 years	40/59 years	60 and over	– 40 years	40/59 years	60 and over	?		
Number by gender and age	12	20	1	7	23	10	2	1	76
Total by gender	33 (44 %)			42 (56 %)				1	76

Table 9.2 Distribution of divers by number of years they had been diving

	Women			Men			No information	Total
	– 10 years	From 10 to 20 years	+ 20 years	– 10 years	From 10 to 20 years	+ 20 years		
Number by gender and number of years	6	17	10	9	8	24	2	76
Total by gender	33			41			2	76

Table 9.3 Distribution of divers by diving proficiency

Level	P1	P2	P3	P4	E1	E2	E3	E4	Bees1	Bees2	Bees3	Other	Total
Women	2	3	11	2	5	4	4	1	1	–	–	–	33
Men	1	6	6	4	4	4	5	5	2	2	1	2	42
TOTAL	3	9	17	6	9[a]	8	9	6	3	2	1	2	75

The different levels of diving proficiency specified in the table correspond to the way in which the divers who participated in the survey indicated their level of proficiency, with variations from one individual to another. We chose not to simplify the grid so as to respect their specific precisions
[a]8 of them at level 3 'initiator'

The results of the survey brought three major observations to the fore. The first concerns the fact that the concept of the 'underwater landscape' is rich with meaning for all the divers who participated. Only one person answered that this was not the case, an answer mainly motivated by fear of the encroaching 'touristification' of the underwater environment which might result from the more widespread social dissemination of this concept, leading to an inevitable degradation of the sea world.

> A touristic sort of concept. No scientific pertinence. As I do not wish to be involved in subaqueous 'meat transport', I do not wish either to use this term or see its use gain ground. (quotation from survey participant)

Apart from this single case, the concept of underwater landscape seemed meaningful for the other participating divers. However, we might wonder whether only those who had something specific to say—those for whom the notion of underwater landscape held a particular signification—chose to participate in the survey. In this light, the negative result discussed above may also therefore be considered as presenting a certain vision of landscape, albeit indirectly. Moreover, the interpretation of what exactly constitutes an underwater landscape varies from one individual to another.

Our second observation concerns a more surprising fact. Despite a relatively well-balanced sample population, statistical analysis did not shed light on meaningful correlations between the way in which the divers defined the underwater landscape and other variables differentiating the various categories within the sample. Age, gender, level of diving proficiency, and the fact of being a photographer or not, were not proven to have any significant effect on the results. Therefore, no distinction could be made between different groups within the sample from a statistical point of view, despite good chi-squared variance. We did identify certain parallels drawn with representations of terrestrial landscapes (Bigando 2006), for which once again no direct correlation of any real significance could be made with sociological categories.

Our third and final observation concerns the importance of the imaginary world conjured up by the divers, and the necessarily subjective way in which each of them actually experiences the subaqueous world itself. When evoking underwater landscapes, the divers refer frequently to the sensations and emotions stirred up by their submarine experiences, and these more personal elements rub shoulders with more ‘objective’ factors, especially those concerning the purely physical nature of the landscape.

9.3 Defining the Underwater Landscape: Sense and Significance for the Divers

‘Indicate, in a few words, what is an underwater landscape for you?’ was the first of the two open questions we asked divers.

Some answers concentrated on describing the landscape and attempted to depict a given underwater landscape, generally that individual’s favourite underwater landscape. Others, in what they no doubt considered to be a less subjective manner, tried to put their finger on the defining elements of underwater landscapes in general. Finally, a handful of participants chose to talk about what underwater landscapes evoke for them, and expressed the impressions and emotions aroused by specific moments spent exploring the undersea world.

From an overall perspective, the elements evoked by the divers in their definition of what an underwater landscape is for them, may be brought together in six main categories (which we defined a posteriori, based on the results of the survey):

- material components (physical relief, bedrock, flora, stationary and/or moving fauna, etc.),
- atmosphere, in an almost architectural acceptation of the term,
- sensations and emotions aroused,
- visual aspects (references to what the eye may see and the angle of vision the diver adopts in observing the landscape),

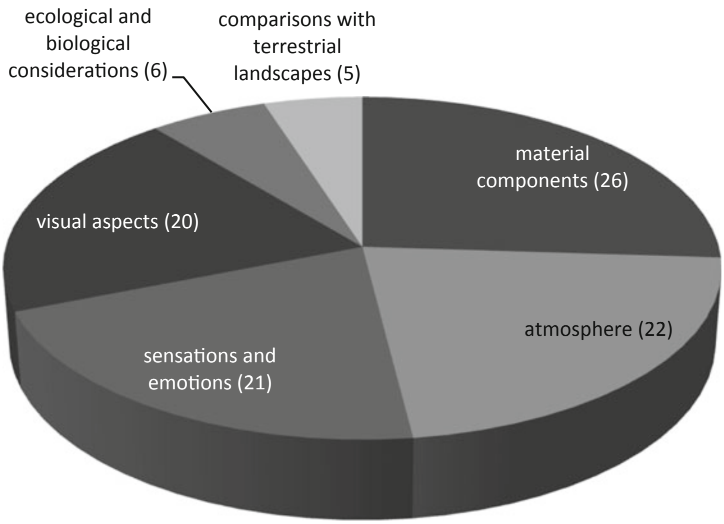


Fig. 9.2 Distribution by category of elements divers use to define the underwater landscape (the figures given represent the number of divers for each category)

- ecological and biological considerations (in the light of such notions as the ecosystem, biotope. . .),
- comparisons established with terrestrial landscapes.

Each participant used one or more of those elements in their definition, combining them in multiple ways according to their own individual logic.

The pie chart (Fig. 9.2) provides an overview of the ways in which survey participants defined the underwater landscape. It should be noted that no dominant manner of doing this emerges. Rather, the participants referred (with varying degrees of uniformity, but never exclusively) to the landscape's material components (26 divers out of 76), to atmosphere (22 divers), the emotions and sensations triggered (21 divers) and a description of the field of vision that observation of the landscape supposes (20 divers). Only after this, in more incidental manner, did the participants refer to the ecological and biological dimensions (6 divers), or feel the need to compare underwater landscapes with terrestrial ones (5 divers).

As far as the material components of the environment were concerned (referred to by 26 out of 76 divers), the most commonly mentioned ones included forms of physical relief (15 references), the nature of the bedrock (11 references), the presence of flora and stationary or moving fauna (19 references), all in greater or lesser detail and in multiple combinations. In other words, they provided a '*geographical description of the diving site*', i.e. '*the combined effect of the differing elements of the relief, the nature of the bedrock and what is grafted on to it*' (quotation from the survey)[3].

[3] Quotations from the corpus of answers provided by survey participants appear in italics and within inverted commas.

Among these components, little mention is made of artificial elements such as wrecks or breakwaters (mentioned by only 3 divers). Moreover, water, unquestionably the main element of the subaqueous environment, is rarely presented as a defining ingredient of the underwater landscape. Neither the body of water as a unique ingredient of the landscape's composition (i.e. without referring to the seafloor), or the water column (a conceptual column of water from surface to bottom sediments), is ever perceived as a landscape *per se*. One of the participants even pointed out that the notion of the water column as a landscape without mentioning the sea floor had no meaning for him, '*For me, a landscape within the water column, without the sea floor has no meaning*.' Yet while the body of water and water column are not then considered as landscapes in the strictest sense of the word, water obviously greatly influences the divers' perception of the landscape. When water is mentioned as a component of the landscape, it is always in terms of its opacity or clarity, and the visibility it provides. This manner of characterising the underwater landscape is in fact closer to what we could define as the underwater 'place atmosphere'.

Indeed, the atmosphere created by the landscape beneath the water is also referred to by the divers (22 out of 76), in what amounts to an almost architectural acceptation of the term. Such questions as colour, form, volume, size and texture are raised. '*An underwater landscape is a fine architectural composition of forms, volumes and colours...*' By atmosphere, some divers also refer to the physical nature of the atmosphere, in terms of clarity and opacity, the play of light and shade, the motionless tranquillity of the surrounding scene or its lively animation. '*An underwater landscape is first and foremost an atmosphere of shifting light and shade*.' Colour and light are the main ingredients referred to (17 divers in total). The question of visibility was far less frequently mentioned in any explicit way. Only one participant thought it necessary to point out that the underwater landscape is '*a general atmosphere which, depending on the relief and composition of the sea floor (whether it be sandy, rocky, plant-covered or a reef), directly determines what is likely to be seen*.' The question of visibility as such, apart from this one exception, was hardly mentioned at all.

The underwater landscape is '*first and foremost an ensemble of elements, ranging from colour, volume and size, whose juxtaposition arouses emotion*.' The divers, in fact, placed great importance in their definitions on the sensations, impressions and emotions triggered by diving (21 out of 76 divers). These emotions are generally pleasant ones and evoked in terms of '*delight*', '*unique*' *or* '*intense pleasure*', arousing a sense of '*wonder*' and '*bliss*.' Strong emotions indeed, and sought after for their rarity by divers, who express a desire to experience a sense of '*freedom*', '*splendour*' and '*escape*.' (This, in turn, is reminiscent of the aesthetics of the sublime, to which we will return later.) The beauty of the landscape is often referred to explicitly. Indeed, 7 divers described the underwater landscape in terms of its '*beauty*.' Yet the overriding feeling triggered was that of well-being, in association with the sense of '*peace*' and '*tranquility*' of the underwater world, and the '*pleasant*', '*restful*', '*appeasing*' and '*relaxing*' nature of the divers' time spent within it.

A further point worthy of note is the reference to what the eye may see, and to the angle of vision the diver adopts in observing the landscape that this supposes. This point is not mentioned systematically (only 20 out of 76 divers made specific reference to it), despite the fact that the definition of the term 'landscape' implies an expanse of scenery that may be seen in a single view, and the fact that the divers' experience of the underwater world is necessarily correlated with the question of visibility and field of vision. However, when reference is made to the opportunity given to divers to 'survey' or 'lay their eyes' on the underwater world, the notion of landscape is more widely associated with the '*general vision one might have of a submerged place*', whether this be qualified as an '*overall view*' or as an '*ensemble of features offered to our gaze*.' Some participants insisted on the fact that appraising the underwater landscape supposed or necessitated '*a certain distance*' or '*depth of field of vision*', a '*wide-angle view*' or '*open field of vision*.' While the underwater landscape is most frequently defined through conventional concepts such as a '*wide shot*' or '*panoramic view*', some divers were more original in their evocation of their subaqueous visual experiences, speaking in terms of a panorama '*in the round*', of vision in '*three dimensions*' or, for some even, '*in four dimensions*.' For every diver, perception of the underwater world as a landscape necessarily implied a certain distance, favouring a global appraisal rather than a detailed, close-up, observation. We should equally point out that certain references to photography were also made (some survey participants had indicated that they were professional photographers), along with pictorial depictions (3 divers). They described the underwater landscape as being '*a painting of open vistas*', '*a painting full of colour and life*' or even '*a painting brought alive with touches of vivid colour*.' Yet, however the participants chose to bear witness to their subaqueous experiences, and whether the notion of their gaze was mentioned explicitly or not, the concept of underwater landscape necessarily involves the way the individual views his experience, the way he "poses his regard on" his surroundings. It is also clear that the 'site' where the diving takes place and which the diver encompasses in his or her gaze, is the underwater equivalent of the terrestrial 'expanse of land" which the eye embraces.

Finally, but to a lesser degree than for the preceding categories (since only 6 divers refer to this), the notion of underwater landscape has equally been defined in terms of ecological or even biological considerations. This manner of characterising the underwater landscape is always exclusive, with the notion of landscape evoking an ecosystem or biotope, and is done so in three different ways. Either these terms are totally assimilated, in which case the landscape becomes a synonym for the biotope ('*the underwater landscape is for me, currently, synonymous with the biotope*' or '*it is a specific biotope*'); or the landscape represents one particular way of exploring a specific ecosystem ('*it's a snapshot of the marine ecosystem, with its fauna, flora and history...*', '*it's an overview which enables one to explore the whole ecosystem of a site without necessarily being able to identify different species, but more globally the environment in which they live and how they move about within it.*')*.* In some cases, the notion of landscape has an added value, in that it operates a change in scale ('*a place composed of ecosystems and biotopes*', '*a site in the broadest sense of the term, composed of different biotopes to observe*')*.* In the last instance, the landscape is considered as being part of a logical arrangement of interlocking scales formed by '*different ecological strata*.' This provides an even broader vision, one that encompasses a whole network of ecosystems or biotopes. We should also remember that when divers spoke of landscape, they never once chose to refer to 'habitat', thereby confirming their intuitive avoidance of the landscape-habitat equation.

The final way in which the underwater landscape was characterised (present in the answers of 5 out of 76 divers) established a comparison with more familiar forms of landscape, generally terrestrial. This comparison is, at times, the reflection of an identification process by assimilation. In some cases this is explicit, '*Like a terrestrial landscape, the underwater landscape is a coherent assembly of forms and colours forming the relief.*' '*As on land, there are valleys, hills and many marvels on which to feast the eye...*'. At other times, the comparison is indirectly suggested, '*It's a place with blue skies beneath which the relief unfolds, at times rugged, at others less so, and which could give rise to mountains, meadows and plains.*' In this example, the language used to describe the underwater landscape could well be used to describe landscapes on solid ground (blue sky, mountains, meadows, plains, etc.). Yet the comparison also serves to highlight a distinction: in this light, the underwater landscape is '*another way of seeing things, unlike on terra firma.*'

Over and above the six specific categories defined here concerning the terms in which the divers define the underwater landscape, our analysis of the results of the survey also sheds light on three elements for cross-disciplinary reflection—the importance of the imaginary world, a specific bond with nature and the desire to protect it, and a highly individual relationship with time.

The language used by the divers confirms the way in which the imaginary world is omni-present when they seek to define the undersea world. The use of such adjectives as '*magical*' or '*marvellous*' bear ample witness to this. For example, the underwater landscape is described as being '*an extraordinary voyage*', '*a magical place in which to let the imagination run free*', '*a fabulous backdrop*' triggering an '*imaginary world*'... The reference to '*tiny and sometimes ENORMOUS multi-coloured creatures*' also harks back to fabulous beasts of old and the sea monsters, so firmly implanted in the collective unconscious. The only difference here is their colourful nature, which renders them less terrifying.

Describing the underwater landscape also provided an opportunity for many divers to express their particular bond with nature, so clearly present for them in the undersea landscape. The chance to observe that landscape means '*contemplating nature in submerged worlds.*' These worlds are the '*expression of a natural beauty*' (non-artificial) imbued with '*wildness*' to be explored. '*Virgin territory, devoid of all trace of human existence*,' '*nature in its raw state.*' The divers' emotional investment is all the stronger when they experience their exploration of the underwater landscape as an ephemeral but possible quest to return to '*nature in her original state*,' like some '*lost paradise*', '*fragile paradise*', '*extraordinary garden* [of Eden] *we must strive to protect*', '*a wonder of creation of which we are the privileged guests, filling us with a sense of respect and the ephemeral nature of these moments of cohabitation.*' The question of conservation inevitably raises its head: '*It's a joy we must protect at all costs.*'

Finally, the way in which the divers describe the underwater landscape bears witness to a particular relationship with time. This is sometimes expressed through references to contrasting timescales (the 'slow' pace of the surrounding landscape *versus* the 'short' length of the dive, for example). The words of one apnoea diver bear eloquent witness to this idea. For him, the landscape is '*a snap shot of the marine ecosystem with its flora, fauna and history, its present and its future as the* *seconds tick by*.' The temporal perspective of the underwater landscape emerges, in fact, from these conflicting timescales. Indeed, however short, dives may be repeated regularly, enabling the diver to gain a sharper vision of the dynamics of the underwater landscape as time passes. Many divers confess a pronounced interest for '*observing changes in the underwater landscape as time goes by—season after season, year after year*.'

9.4 Experiencing the Underwater Landscape: the Quest for a Really Singular Experience

'Does the underwater landscape represent, for you, a diving objective? If so, what exactly are you looking for?' These were the terms of the second question in the survey.

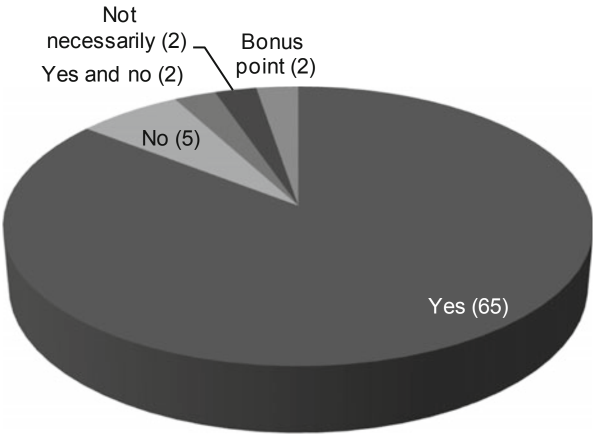
The vast majority of participants (65 out of 76) replied 'yes' to this question (Fig. 9.3). For 54 divers, exploring the underwater landscape was their main objective. For the remaining 11, it was one of their objectives. Only 5 divers replied 'no', but they did not explain why. Two divers replied both 'yes and no', arguing that their answer would depend on the place where the dive was to take place and what the site had to offer. They pointed out that it was easier to see the landscape in some places than in others. '*The underwater landscape in the Atlantic or Channel is difficult to see because of the* '*fog*.' *However, I find that landscapes in the Mediterranean are a delight for the scope and depth of vision they offer, and the way I can see up to the surface*.' Two other divers indicated that the landscape was '*not necessarily*' a diving objective, even if on some occasions it had an immediately noticeable presence. They were more interested in observing the underwater fauna. The last two divers considered that the landscape was a 'bonus point', i.e. not their principle diving objective, but there to be enjoyed if underwater visibility allowed.

When the underwater landscape is envisaged as a diving objective, what exactly are divers looking for?

We must point out here that our analysis of the results of our survey with regards to this question only supplies a partial inventory of the variety of answers given. The initial elements gathered require validation and further completion through more detailed follow-up interviews. The initial corpus of results does, however, shed light on some essential information, thereby opening up a series of fertile questions for further reflection and study.

The participants did not all respond to this question in the same manner. Some identified their underwater landscape quest as a desire to experience strong emotions and sensations. Others were more specific about the 'objects' they were actually seeking to explore—particular types of relief, bedrock, species, environments, wrecks, etc. For a few divers, their quest was accompanied by a second specific activity, generally photography. Some divers, sometimes the same ones, were seeking to experience specific, extraordinary atmospheres. In other cases, specific approaches, like those of exploration or contemplation, were involved. The remarks were not of course mutually exclusive, and often combined several different levels of response.

Fig. 9.3 Pie-chart representing divers' different responses



The desire to uncover underwater landscapes was first and foremost motivated by the desire to experience strong emotions and sensations (15 people). In this case, the landscape becomes both a source of surpassing oneself and a reflection of that. Fifteen divers also mentioned a series of emotions and sensations which express this. 'The sea is a place full of danger and adventure, epitomising models which place value on the idea of surpassing oneself, of reigning supreme over the natural elements, of discipline and asceticism, values on the increase in our technological society in which the environment and our bond with nature are themes around which people will rally' (Ordioni 1992). For the purposes of our study here, analysis of responses in our survey sheds light on six semantic fields:

- surpassing oneself via self-emptying, bareness, and solitude;
- surpassing oneself via the extreme, the vertiginous, what is spectacular and grandiose;
- surpassing oneself via the exotic, surprise, awe, the unexpected;
- surpassing oneself via freedom, escape and distancing;
- surpassing oneself via wonderment;
- surpassing oneself via access to 'supreme beauty'.

These different emotions are the very building blocks of the aesthetics of the sublime, a concept encapsulating a sense of extreme power and breadth of feeling as a means of transcending beauty. A sublime landscape is at once grandiose and awe-inspiring, and implies an encounter between self and the spectacular. The sublime is generally associated with a sense of inaccessibility or incommensurability, and arouses in the individual concerned a mixture of both wonder and dread.

The divers also referred to their desire to experience a specific or unfamiliar atmosphere (12 people), with stress being laid on the role played by colours (5) and the play of light and shade (4).

Next come the desire for vistas, panoramas, composed images, perspective views or deep fields of vision (8). For the most part, this desire is motivated by the diver's interest in underwater photography (6 out of 8).

Some divers also mentioned their desire to observe natural elements of the underwater landscape, such as the relief or the nature of the bedrock (7), or else specific species of flora and fauna, either stationary or moving (7). This desire is motivated by naturalist concerns.

Finally, we identified an underlying desire for diverse/varied experiences (6). Some divers are eager to explore new landscapes (5), like the sea-discoverers of old, and this is more or less explicitly expressed contrast with the stale, less adventurous landscapes dry land has to offer. Others are in search of contemplation (3) or simply keen to expand their minds (3). Whatever the case may be, the resulting effect is generally one of '*absolute bliss*', of '*consummate pleasure*' and a '*feeling of intense satisfaction*.'

By way of a conclusion on this point, we might quote one diver who referred to the underwater landscape with a pun on the French word *dépaysement* (a change of scenery), calling it as a *dépaysagement* (a 'de-landscaping'). In other words, for that individual, the underwater landscape really is a means of plunging into the unknown. . .

9.5 Conclusion

This survey is a preliminary exploration of the subject, and its results should be regarded with a certain reservation. Nonetheless, the content and quality of the answers gathered in the survey provide us with important information with which to fuel future reflection on how those portions of the underwater world to which human access may be gained are perceived, and on the role that landscape can play in our understanding of the relationship between mankind and the subaqueous world.

It is our hope that this exploration of the question will contribute meaningfully to a general recognition that the concept of 'underwater landscape' exists by right, so that it may become much more than a hollow expression. We also hope it will draw attention to the importance of looking at how those who frequent this environment do actually see it (the vernacular gaze) so that the notion may be grasped in all its rich complexity.

The concept of landscape, in its general sense, offers the advantage of transcending not only disciplinary frontiers but also the sphere of science. It is a notion that can be understood by everybody, ranging from those in charge of regional affairs to all of us as ordinary citizens. We might then argue that the landscape has a major role to play as a tool for mediation and citizen participation. It has already proved a rallying point on dry land[4]. The challenge ahead concerns the undersea world. It is our belief that the underwater landscape can also offer a response to the challenges of regional and

[4] See, for example, two experiments carried out in (and with) the community of people living in the Pau area (Bigando 2008, Bigando et al. 2010)—two participatory initiatives involving local inhabitants with reference to their daily experience of the landscape. One of these two experiments was associated with an environmental management project concerning the creation of an urban nature park along the banks of the Gave de Pau.

national development, one that encourages participative management and citizens' involvement in marine environment protection policies.

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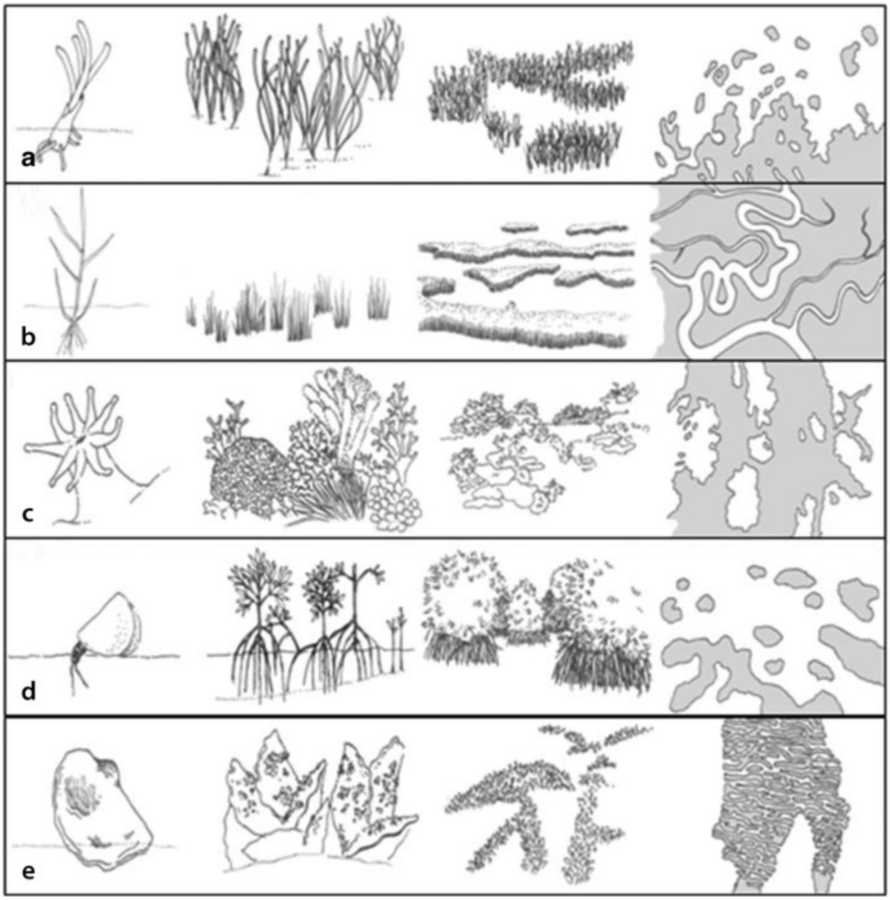
Part II
Towards Landscape Ecology Applied to the Marine Area



Chapter 10
The Concept of Marine Landscapes Within the French Information System on Nature and Landscapes (SINP)

Amelia Curd and Alain Pibot

Abstract Several concepts revolve around the term "marine landscapes": all of them are nourished by aggregating data from multiple sources and disciplines. The SINP (Système d'Information sur la Nature et les Paysages) is the French marine biodiversity and landscape building block in the global marine data infrastructure pyramid. Within this information system marine landscapes have been apprehended in both a pictorial and an ecological manner, therefore the usages of the SINP depend on the adopted definition. Through examples we argue that by increasing the availability of the massive volumes of cross-domain data necessary for apprehending landscapes, regardless of the chosen definition, the SINP can play a role in defining and refining our understanding of marine landscapes.

Keywords Biodiversity · Informatics · Human perception · Cross-domain

10.1 Introduction

It is now widely accepted that, in order to thoroughly understand how environmental features structure potentially large ecological systems, data sets from multiple countries and disciplines need to be made interpretable and pooled. Biodiversity and ecosystem monitoring require data to be organized in a global, integrated infrastructure, such as provided by the Global Biodiversity Information Facility and Ocean Biogeographic Information System (Leadley et al. 2010). Data transmission to these global marine data infrastructures has historically occurred directly from certain data providers, however increasingly countries are structuring their marine

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biodiversity data via national portals. The SINP (Système d'Information sur la Nature et les Paysages—www.naturefrance.fr) is responsible for organizing and structuring marine and terrestrial biodiversity and landscape diversity data within the French territory. Due to its dual management of ecological and landscape data and to the multiple disciplines in which the SINP stakeholders are grounded, an overarching definition of marine landscapes has yet to be fully adopted.

The SINP's mandate, as defined in the state bill published on the 11th July 2007 (http://www.naturefrance.fr/sites/default/files/documents/pdf/circulaire_sinp_et_protocole.pdf), adopts the landscape definition set in the European Landscape Convention (also known as the Florence Convention http://www.coe.int/t/dg4/cultureheritage/heritage/Landscape/default_en.asp), whereby the landscape is an expanse of scenery that can been seen in a single view, whose character is the result of the action and interaction of natural and/or human factors. This definition has hindered the development of a landscape perception in the sub-aquatic environment. Starting from the justifiable principle that the marine environment is uninhabited by humans, the very notion of an underwater landscape, "as perceived by the local population", is fanciful. This is no doubt one of the reasons why landscape terminology in the marine environment, an innovative interdisciplinary concept, has so far revolved far more around notions of landscape ecology than those of human perception of their environment.

During the workshop some headway was made towards an objective definition of marine landscapes, as perceived by the transient populations of SCUBA-divers, a human activity with increasing popularity in coastal waters. New techniques of underwater landscape reconstitution from multiple tiled images help to compensate the lack of depth of field necessary for perceiving a seascape in turbid waters. In Fig. 10.1, the "roches de Coulombray" off the south coast of France in the Languedoc-Roussillon region is impossible to naturally see in its entirety.

Here the diver-photographers of "Andromède océanologie" have reconstituted the seascape by tiling multiple images, an example of how new technologies are allowing us to "discover" previously unobserved underwater landscapes.

10.2 The Legal Context of the SINP

The Convention on Biological Diversity of 1992 (http://www.cbd.int/convention/text/), together with the Florence Convention of 2000 jointly led to the drafting of a French National Biodiversity Strategy. This strategy, both during its 2002–2010 period and in its 2011–2020 revision (http://www.developpement-durable.gouv.fr/French-strategy-for-biodiversity,23446.html), places landscapes on the same level as genetic, specific and ecosystem diversity as a pillar in the preservation and sustainable management of natural heritage.

For the purpose of these proceedings, we therefore consider that there are two ways through which the SINP can help to apprehend landscapes; either via a societal, anthropocentric approach (i.e. via the human perception of scenery), or through an

Fig. 10.1 Coulombray's rocks. (© Laurent Ballesta/Andromède océanologie, All rights reserved)

ecological approach as a multidisciplinary method of describing different ecosystem compartments at different scales.

Created specifically as a mechanism to ameliorate the management of data on nature and landscapes, in such a manner as to serve both of its founding conventions, the SINP has, since its origin and in its very definition, taken into consideration both the societal and ecological acceptations of landscape. Its *modus operandi* allows the delivery to operators working in the development of a landscape approach key elements of knowledge.

10.3 Two Complimentary Landscape Expressions

The SINP contributes towards landscape analysis, both through the scenic acceptation of the concept as well as through its ecological prism. It is therefore possible to illustrate the methodological inputs enabled by the SINP through a few specific examples.

10.3.1 The Ecological Marine Landscape

Because coral reef ecosystems exist as a complex mosaic of habitat patches (e.g., reefs, seagrass patches), they are ideally suited for a landscape ecology approach (Großer-Dunsmore et al. 2007). We therefore used an example in one of France's overseas territories to illustrate how the SINP can act as a tool for one of the many marine landscape perspectives presented during the conference. Searches can be carried out in the SINP via its metadata discovery portal (http://inventaire.naturefrance.fr), with filters both by theme and by biogeographical area. Search results in the southwest Indian Ocean reveal a number of different data sets in and around the Island of la Réunion:

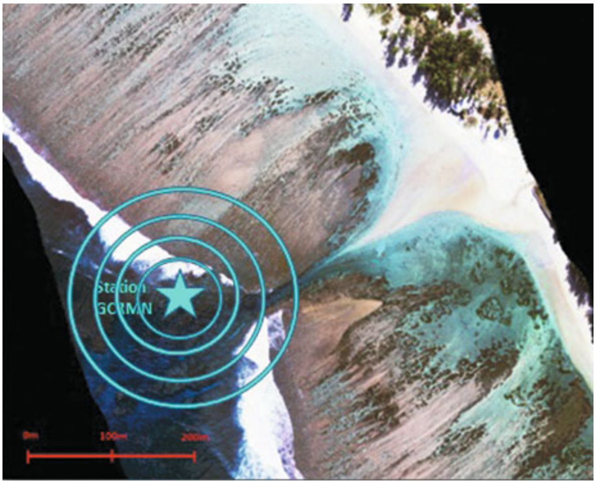

Fig. 10.2 Hyperspectral image of the "passe de l'hermitage" in la Réunion, courtesy of Spectrabent. (© Programme Liteau3D/SHOM-IGN-AAMP-DEAL Réunion-MEDDTL)

- An ongoing hyperspectral imagery program, "Spectrabent" aiming to develop a method to provide a high-resolution map for coral reef ecosystems.
- Several studies of reef fish communities (Reef Check, GCRMN-Global Coral Reef Monitoring Network, an IRD-French Research and Development Institute-PhD thesis,), all using daytime survey transect techniques.

The hyperspectral image mapping of the coastal waters of la Réunion provides a very detailed picture of the mosaic of habitat elements that comprise the benthic seascape (Fig. 10.2). This relatively recent survey (2009) allows for a quantitative investigation of the correlation between fish-communities and seascape parameters, thus going beyond the typical, fine-scale habitat studies that have dominated reef fish ecological studies previously (Kendall 2005).

The concentric circles around the fish transect monitoring point illustrate that, by varying the analysis scale through a range of different size windows, the ecological neighbourhood of the local fish community can be determined (Kendall 2005). The basic idea is that by comparing public data from different programs and organizations on benthic seascapes and fish communities, a correlation between the two at different scales of analysis can be identified in order to determine which scale best fits the relationship. A caveat must be entered in the interpretation of compiled data from heterogeneous sources and above all different initial acquisition goals. The SINP simply allows greater visibility and easier pooling of existing data; the analysis remains the responsibility of the SINP user.

10.3.2 The Pictorial Marine Landscape

The natural heritage value of the marine environment is often confused with the richness of the underwater landscapes. In the specific case of Mediterranean coralligenous habitats (Fig. 10.3), the example is striking: this biogenic structure, due

Fig. 10.3 Coralligenous habitat of the Languedoc-Roussillon coast (© Mathieu Foulquié/DREAL LR, All rights reserved). This image illustrates the aesthetical richness of such an assemblage for which a landscape approach, although advised and used, is still contested as it can yield results discordant with ecological assessments

to its complexity, is firstly perceived through landscape criteria—color, number of strata, volumes. This notion is no doubt partially representative of the habitat's richness, and yet has been largely rejected by the scientific community, who criticize its simplicity. However, if this notion is still questioned in its current state, it will very probably come to serve this complex assemblage which remains difficult to assess. The SINP will then play a key role in the bringing together of numerous data sets which, issued from measurements such as bathymetry, colorimetry and even geomorphology, will help inform at a large scale the distribution and state of health of this priority habitat.

10.3.3 The Succession of Marine Landscapes

The succession and juxtaposition from one landscape to the next is a fundamental approach in the ecological analysis of an area (Frontier 1978; MacArthur and Wilson 1967). This landscape notion here has a mixed acceptation, between perception and ecological function. Identifying entities can be down through an impressionist approach whereas the ensuing functional analysis calls for ecological notions. Here again, the SINP plays a key structuring role by connecting numerous surveys which when pooled together can generate holistic analysis in areas where existing data has often been interpreted only from a single domain. Figure 10.4 is issued from a metadata search on the ecological dynamics of the different landscapes which make up the tropical shore, from the mangrove to the outer reef. The global analysis of these habitats is permissible only by knowing both which cross-field data has been collected in any given area, together with the property rights, status, storage and geographical/taxonomic references of the targeted data sets. Such is the role and function of the SINP.

Name	Name
"Turtle population survey on the feeding sites in Guadeloupe"	"Mangrove inventory of Guadeloupe"
"Survey of egg-laying turtles: beach track counts"	"Seagrass surveying protocols"
"Reef monitoring network in the french Antilles (GCRMN method - University of Antilles-Guyana)"	"Reef Check survey method in Guadeloupe"

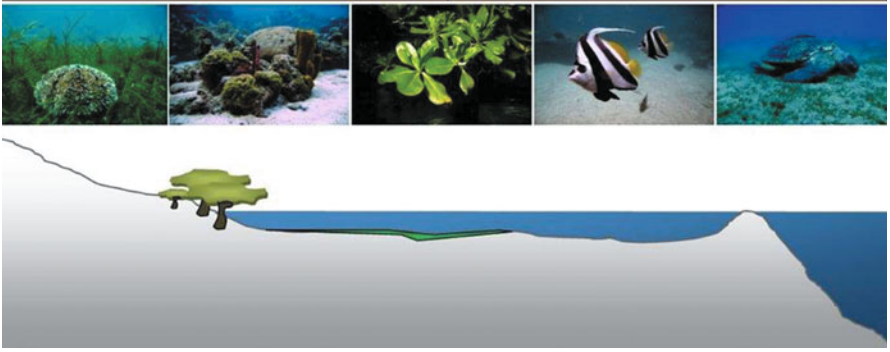

Fig. 10.4 Complimentary survey metadata names assembled via the SINP metadata portal. (www.inventaire.naturefrance.fr)

10.4 Discussion

Practically all the information required in the marine environment in order to allow countries to fulfill monitoring and policy mandates, as well as to pursue their ocean research, is spatial in nature. Therefore both scientific and management users need ready access to spatial data collected and maintained by multiple national agencies, e.g. bathymetry, coastlines, and meteorological data. They must have the right to integrate this data with their own research findings and to disseminate these results to scientific and non-scientific communities (Longhorn 2002). Hinchey et al. (2007) underlined the fact that widely dispersed field or ship-based observations and lack of broad scale data have historically precluded quantification of large-scale patterns and processes. However, relatively recent advances in geographic information systems, remote sensing and computer technologies have begun to address these issues and are permitting assessments of pattern and process in oceans. The global distribution of marine biodiversity has been established—by observation—in broad outline. However, our 'theories' to account for these patterns generally lack explanatory power especially at regional scales (100's to 1000's of km). There has been a paucity of studies to investigate relationships between biodiversity and habitat characteristics (through geophysical factors) at such regional scales. Yet it is precisely at the regional level that nation states exert jurisdiction over their marine resources and can best effect conservation measures (Roff et al. 2003).

In terms of a human, subjective perception of underwater landscapes, in the marine environment the SINP can help to bring together different sets of perceived

Fig. 10.5 Image of a 5000 m^2 site composed of 45 photographs. Ravellata Point, northern Corsica. (© Alain Pibot/Agence des aires marines protégées, All rights reserved)

information (light, morphology, colors, even sound), which are naturally assembled on land but which must be artificially pieced together in the marine environment, a reconstitution which is at the heart of the SINP mandate. Biodiversity and landscape informatics, crossed with new sound and image acquisition technologies and computer analysis, can now give underwater landscapes previously unviewable panoramic images (Fig. 10.5).

It must not be forgotten that although applying the principles of landscape ecology to marine and coastal environments is now technologically possible, accounting for physical and biological characteristics in three dimensions that can vary rapidly in both space and time remains a daunting challenge (Hinchley et al. 2007).

10.5 Conclusion

The transdisciplinary nature of marine landscapes, with respect to both their anthropocentric and ecological definitions, can benefit from a data-driven approach, in which information emerges from the data, which requires a well-designed work flow. For a data-intensive workflow solution to be successful, access to large volumes of data from multiple sources and research domains must be acquired and coordinated (Kelling et al. 2009). Although the SINP does not define any new concepts, it is to the authors' knowledge unique in bringing together through the same portal data from both ecological and societal studies.

On a topic as transversal as landscapes, the SINP plays a key role simply in the identification and access-enabling of datasets issued from multiple fields, simply by facilitating the interdisciplinary and interscalar crossing of information. Let us count on modern subaquatic observation techniques to "discover" marine landscapes, as Jules Vernes drew them, with the same depth of field as in the terrestrial environment, and on the SINP to help us superimpose the different views revealing a largely invisible world.

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Chapter 11
Management of Infralittoral Habitats: Towards a Seascape Scale Approach

Adrien Cheminée, Eric Feunteun, Samuel Clerici, Bertrand Cousin and Patrice Francour

Abstract This study highlighted that the management of coastal fish assemblages still requires to upgrade and involve not only the approach of controlling catches but also in addition the management of all the essential habitats frequented during the different stages in the life cycle of these species. On the basis of a specific case study, the nurseries of the Sparidae fishes of the genus *Diplodus* (white seabream) in the area of the Calanques National Park (Marseilles; north-western Mediterranean), the present article proposes a conceptual scheme to guide coastal managers in following a seascape scale approach while using the tools they dispose of. This case study furthermore enables us to make practical recommendations applicable to the statutory and contractual management of the whole of the Mediterranean coastal zone.

Keywords Seascape · Essential habitats · Connectivity · Nurseries · Coastal management · Statutory protection · Contractual protection

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11.1 Introduction: The Notion of Landscape Ecology and the Management of Coastal Natural Areas

The term Landscape Ecology was first used by a German geographer, Carl Troll (1939). This researcher in geography, botany, physics and geomorphology was interested in the relationships between the heterogeneity of mountain ecosystems, phytogeography and human societies. His work was in particular marked by the use of aerial photography to analyse the heterogeneity of physical environments in relation with the plant cover of mountain environments. If the term was used relatively early in the history of ecology, it was not until the 1980s that the discipline really emerged driven by the fledgling I.A.L.E. (*International Association for Landscape Ecology)*. In contrast to 'classical' ecology, which tended to think in terms of populations and communities living in homogeneous ecosystems, landscape ecology is based on the central notion of spatial and temporal heterogeneity. In the 1980s, the theoretical concepts of the discipline were mainly based on the analysis of agricultural landscapes where agricultural practices played a major role in the fragmentation of ecosystems and the functioning of populations.

The founding concepts of the discipline are undoubtedly derived from the theory of the biogeography of islands developed by McArthur and Wilson (1967), according to which populations of birds were increasingly isolated and vulnerable in function of the extent to which the island was small and isolated from other islands. Thus, from the outset, landscape ecology focused on the relations between the fragmentation of habitats and the structure of populations or communities. This led Levins (1969) to develop one of the essential concepts of landscape ecology: that of 'metapopulation'. This stipulates that in fragmented habitats, the populations living in each of the habitats are more or less isolated from each other, according to their capacity to disperse among each of the habitats separated by other habitats less favourable to the species. The size of the habitats defines the size of the populations. Each of the populations can live and be maintained independently of the other populations as long as its genetic pool is large enough. Below a certain size, the population is in jeopardy unless it is restocked by neighbouring populations. The small habitats are thus often occupied by 'sink populations', the sustainability of which depends on the supply of genes from the larger neighbouring populations which then act as 'source populations'.

Thus, landscape ecology endeavours to understand the mechanisms, most of them of anthropic origin, that lead to the structuring of the landscape by acting on the fragmentation of habitats. These habitats are organised on the basis of a 'matrix' (e.g., cultivated fields) or 'patch' (e.g. woods) architecture. These relictual forest ecosystems may be organized in different ways: a continuum of forest and woodlands interconnected by a bocage network or discontinuously.

The biological connectivity between the forest areas depends on the capacity for dispersion of organisms and on the structure of the landscape network (shapes, organization, etc.), the nature of the plots making up the matrix (e.g. size of the agricultural plots, type of crop) and the distance between the forest habitats. The study of the biological connectivity is thus a fundamental part of the analytical process in landscape ecology: what are the capacities of organisms to disperse through the landscape?

Historically, landscape ecology has been mainly focused on terrestrial ecosystems, with the aim of understanding how biocenosis can be structured in the context of human activities, in particular those related to agriculture and urban development. The transfer of the discipline to marine ecosystems is much more recent, since the term '*seascape*' only appeared in the 1980s (Pittman et al. 2011). The main difficulty lies in the characterisation of seascapes limited technically by a restricted field of vision and by the means of observation available.

When we consider a stretch of coastline, the infralittoral sea bottom has the appearance of a mosaic of geomorphological and biological units characterised by their biotic and abiotic components (Chapman 1995): depending on the scale and on the components under consideration, these units are referred to as ecosystems, biocenosis, habitats or micro-habitats. This mosaic of units makes up a seascape, the scale of which may range from a dozen or so metres to a dozen or more kilometres. In the ecologists' sense, a submarine landscape is thus a sum of habitats of which the emergent properties are different from the simple addition of the properties of each habitat. One of the most significant emergent properties in seascape ecology is the connectivity between these units that depends very strongly, as in terrestrial environment, on the level of fragmentation of the seascape and on the capacity for exchange of individuals between habitats (Basterretxea et al. 2012; Gillanders et al. 2003; Mumby 2006; Cowen et al. 2007; Di Franco et al. 2012).

This pluridisciplinary notion of underwater landscapes has recently reappeared with the current upsurge of public authority management of the marine environment (Musard O. comm. pers.). The necessity for this kind of management is due to the multiplicity of stakeholders, users, pressures and threats that result (over-exploitation of resources, destruction of habitats by over-frequentation or embankments, pollution, etc.). In the littoral zone, the real interface between the marine environment and the continental zone, this range of threats that are facing the seascapes (Coll et al. 2010) represent challenges for the scientific community, management organisations and public authority decision makers.

In order to plan the management of a given coastal marine area, the managing organisation responsible begins by surveying the initial state of that environment, that is describing the natural components of the landscape, the human uses made of it, the pressures and possible threats facing these components, while taking into account the continuity with the terrestrial domain. This provides a basis for identifying the management priorities and for proposing management aims and a plan of action designed, by means of specific measures, to achieve these aims. In the current climate of participative democracy, the issues, aims and actions are defined in consultation with the various stakeholders in the coastal environment (e.g. the Natura 2000 approach). This type of consensus-seeking process is in contrast with the 'private preserve' approach to policy-making prevalent in the 1970–1980s (Francour et al. 2001).

In order to define the priority issues, one of the approaches used consists in identifying within the landscape mosaic the units where the interactions between natural components and anthropic pressures engender impacts (threats) that are particularly

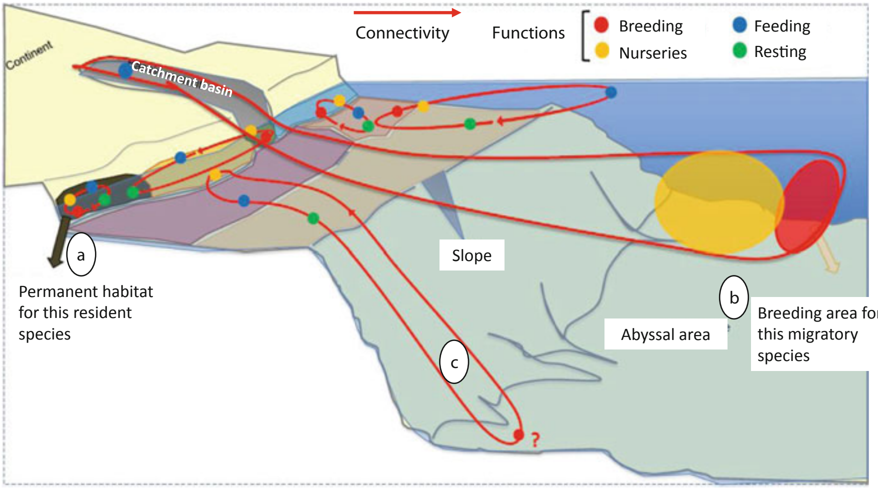

Fig. 11.1 Organisation and connectivity of essential habitats of marine organisms

disturbing. In the course of this landscape survey, the aim is to determine in particular which are the units that have an 'important' function (as much from the social and economic as from the ecological point of view) and which are exposed to pressures likely to endanger this function and thus give rise to a high probable cost (social, economic or ecological). To an ecological scientist's eye, the units (seen as habitats) that should be considered as priority include those that have a key ecological function: in the case of the fishes (Teleosteans), for instance, this would be the adults' spawning grounds (Koenig et al. 2000) and the nursery sites for juveniles (Harmelin-Vivien et al. 1995; Beck et al. 2001; Cheminée et al. 2011), since they are considered as indispensable for the renewal of the populations. In order to manage the 'fishes' resource, the management plan should thus include protection of these key habitats, i.e. essential for the life cycle of the species. There is increasing awareness of the necessity to protect the habitats in order to protect the species and this is increasingly integrated into management processes at international (e.g. the Habitats directive included in the Natura 2000 process) or national level (e.g. *Arrêté* of 29 October 2009 providing a list of protected birds for the whole territory and the means of protection, which stipulates in Art. 3 that the restrictions apply to physical or biological elements necessary for the reproduction or resting of the species under consideration).

However, this approach is at best adopted at the scale of a habitat or only at the scale of habitats that are essential for a single species: the overall dynamic and the interactions between units of the seascape mosaic are today not at all or only rarely taken into account. Yet it is in reality a chain of habitats that should be taken into account for the definition of the management priorities and actions in order to take into account all the habitats that are essential at each stage of the life cycle for each of the species of interest. During their life cycle, living organisms successively occupy the ecological habitats essential to each phase of their existence (Fig. 11.1). The essential habitats habitually taken into account are the spawning grounds (breeding site),

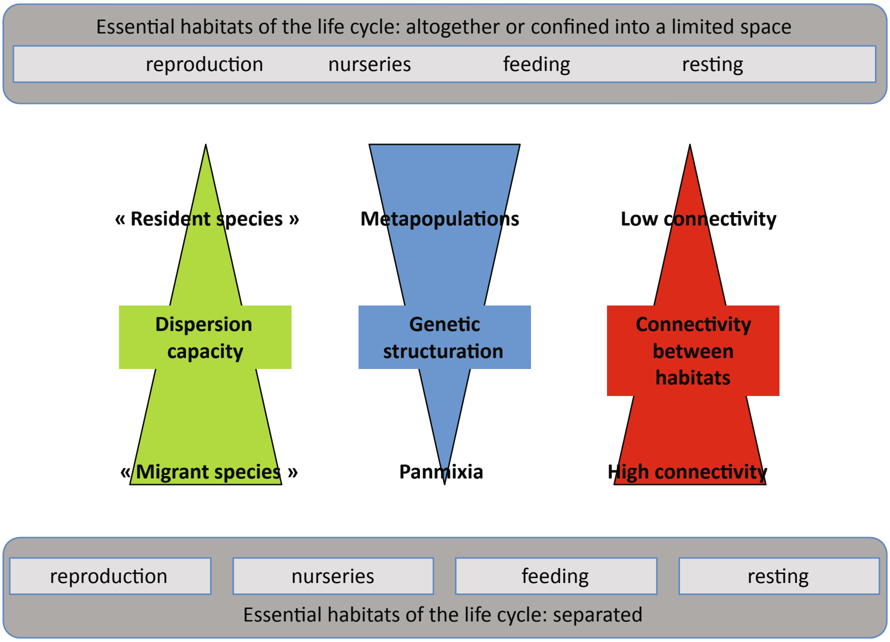

Fig. 11.2 Link between dispersion capacity, genetic structure of populations and their connectivity between essential habitats

nurseries (site of the growth of juveniles), feeding sites (growth of adults), resting sites (summer or winter) and dispersion habitats which become corridors when they are confined. The passage between these habitats will take place according to mechanisms of dispersion which may be diffuse or concentrated within confined spaces. A whole continuum of strategies exist ranging from resident species (Fig. 11.1; point a), where all the phases of the life cycle occur within the same habitat, to migratory species (Fig. 11.1; point b) whose life histories are marked by the passage from one habitat to another in order to accomplish there the different essential stages.

In the case of species with a bentho-demersal cycle, as in the case of many molluscs, or macrophytes and certain fishes such as the gobies, the adult stages are sedentary, or even fixed, whereas the dispersion phase occurs at the larval stage. Thus, generally the dispersion between the essential habitats and the flux of genes between populations depends on the dispersion capability of each of the organisms, and on the distance separating the habitats (Fig. 11.2). The greater the dispersion capability of the organisms, the more weakly are they genetically structured. In general, although it is not an absolute rule, organisms with a bentho-demersal cycle are relatively strongly structured since the dispersion can only occur at the larval stage representing the dispersion phase. Conversely, organisms with a strong swimming capability such as the fishes have a dispersion capability at different stages, from larval or juvenile stage to adult stage. The genetic structure then depends essentially on the characteristics of the biological cycle: a majority of residents (all essential habitats being localised within the same ecosystem) or migrators (movement between essential habitats in the course of the life cycle).

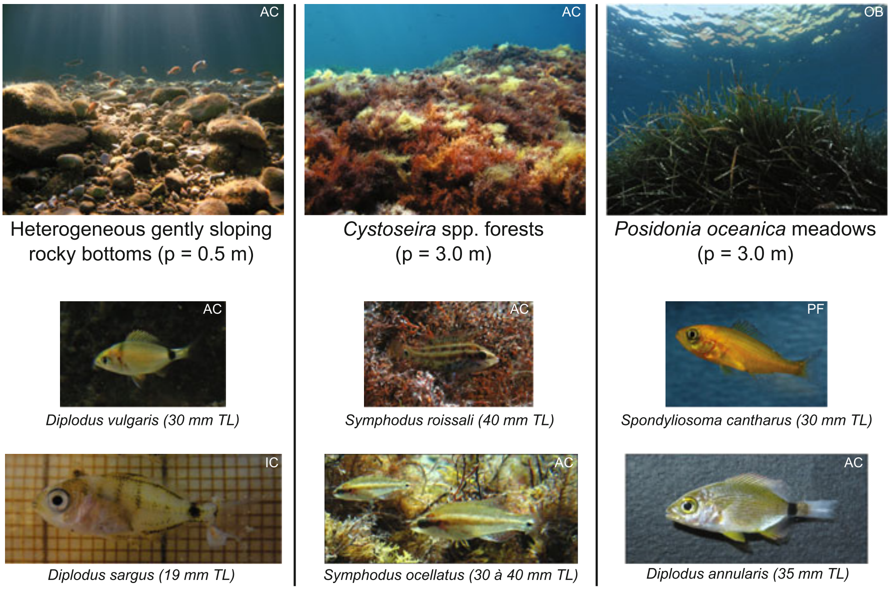

Fig. 11.3 Illustrations of three of the main nursery habitats along the Mediterranean coast (p = depth) and of juveniles of the most characteristic species (Photo credits: AC = Adrien Cheminée; IC = Isabel Amalia Cuadros-Casado; OB = Olivier Bianchimani; PF = Patrice Francour)

11.2 Towards a Strategy for the Protection of Essential Fish Habitats for Conservation Purposes

In the case of fishes, taking into account certain essential coastal habitats is of increasing importance in implementing management policy. For example, international regulations for the Mediterranean (CGCPM) govern fishing for hake by protecting its reproduction habitats situated on the continental slope (Fig. 11.1, point c). With the rapid increase in studies on the rocky coastal habitats of the Mediterranean and the estuaries and salt marshes of the western coasts of Europe, attention is particularly focused on the nursery habitats. It is first and foremost a matter of protecting the different nursery habitats specific to each species of interest (Fig. 11.3). This means taking into account the spatial partition between juveniles of different species within different habitats (Harmelin-Vivien et al. 1995) based on their spatial complementarities and the synergy between them, e.g. through 'edge effect' (Cheminée 2012; Cheminée et al. 2013). It is therefore necessary to know where and in what quantity are to be found the habitats already known to play a nursery role (Cheminée et al. 2011), and furthermore which are the other habitats of the seascape mosaic of the rocky infralittoral that play a nursery role. In addition, it will be necessary to protect parts of the adult habitats, from which the fishing grounds may be resupplied with adults by spill-over effect (Abesamis et al. 2006; Grüss et al. 2011; Goni et al. 2008).

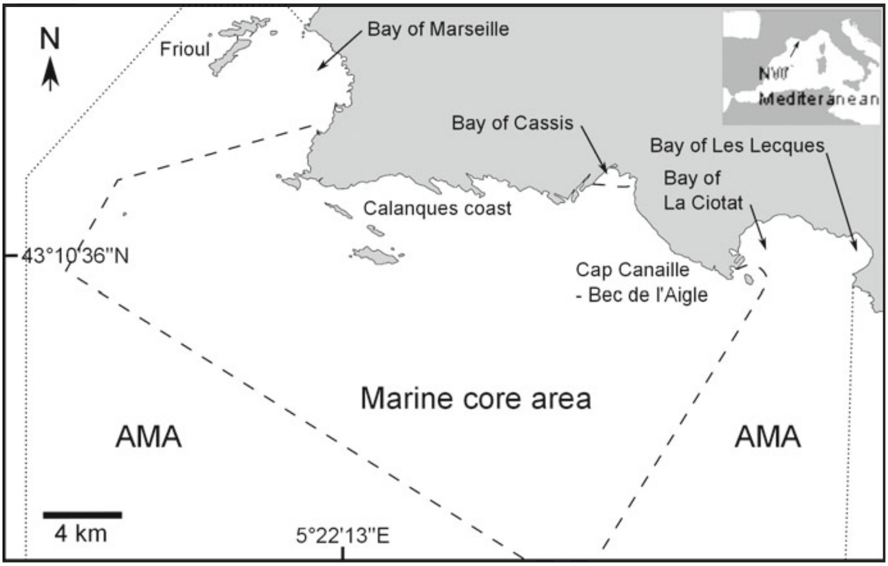

Fig. 11.4 Localisation of the study area—Marine zoning of the Calanques National Park: marine core area (sectors: Calanques coast and Cap Canailles-Bec de l'Aigle); adjacent maritime area ('Aire Maritime Adjacente'—AMA, sectors: Bay of Marseille, Frioul Archipelago, Bay of Cassis, Bay of La Ciotat, Bay of Les Lecques)

Finally, it is also necessary to ensure that the nurseries are present in sufficient number and at the right distance from the adult habitats, in order to guarantee satisfactory connectivity between these habitats and enable ontogenic migration (Cheminée et al. 2011; Di Franco et al. 2012; Gillanders et al. 2003). Each coastal site, because of its specificity, thus requires a specific seascape analysis.

On the basis of a specific case study, the nurseries of the Sparidae fishes of the genus *Diplodus* (white seabream) in the area of the Calanques National Park (Marseille; north-western Mediterranean, Fig. 11.4), we hereafter highlight that the management of fish assemblages should involve not only the approach of controlling catches but also in addition the management of all the habitats frequented during the different stages in the life of these species. In other words, the aim of the present article is (1) to analyse whether the zoning of the management measures in our case study take into account an approach at seascape scale, and (2) to propose a conceptual scheme to guide managers in following this approach, using the tools they dispose of. This case study will furthermore enable us to make practical recommendations applicable to the statutory and contractual management of the whole of the Mediterranean coastal zone.

11.3 Case Study: The Nurseries of *Diplodus* spp. and the Zoning of the Calanques National Park

11.3.1 The Main Issues

The species of the Sparidae belonging to the genus *Diplodus* are the prey of professional and amateur fishers, in particular for underwater fishing (Coll et al. 2004; Guidetti et al. 2008). They are of major economic interest throughout the Mediterranean coastal areas. These fishes, that prey on sea urchins, perform 'top-down' control of these herbivores and thus play a role in the prevention of over-grazing on rocky bottoms (Sala et al. 1998). The renewal of their assemblages is therefore as much an economic as an ecological issue. The habitats that play the role of nursery for juveniles of the white seabream *Diplodus* spp. (*Diplodus* sargus, *D. puntazzo*, and to a lesser degree *D. vulgaris*) are the shallow water zones (0–1.5 m depth), gently sloping, sheltered from hydrodynamic forces and with a heterogeneous substrate of small rocks, stones, gravel and sand (Fig. 11.3). If the substrate is solely made up of homogeneous fine fractions (sand), the nursery value of the habitat is severely reduced (Harmelin-Vivien et al. 1995; Bussotti and Guidetti 2010; Garcia-Rubies and Macpherson 1995; Guidetti 2000; MacPherson 1998; Vigliola and Harmelin-Vivien 2001; Cheminée et al. 2011). In the example of the Calanques Natural Heritage Site ('site classé') from Marseilles (South-east France), Cheminée et al. (2011) have highlighted that the adult populations of *Diplodus* spp. of the Calanques are probably restocked by recruits migrating from nurseries situated not only locally but also, in the majority, in the bays of Marseille, Cassis and La Ciotat, in other words outside the protected area. The Calanques National Park, officially founded at the beginning of 2012, includes a coastline that extends from the southern bay of Marseille to the bay of La Ciotat and Les Leques. To meet the requirements of the management of these species, by taking into account all the essential habitats, the statutory zoning and the contractual protection measures should operate at a spatial scale that goes beyond the habitat to the scale of a landscape covering half of the coastline of the 'Bouches-du-Rhône' district (Fig. 11.4).

11.3.2 Localisation of Nurseries and Presentation of the Zoning of the Calanques National Park

For the whole of the coast of the Calanques National Park, we have localised and quantified the stretches of coastline presenting nursery habitats for juveniles of the white seabream. The coastline studied extends from the roadstead of Marseille (Anse de Malmousque) to the bay of La Ciotat—Les Lecques and includes the Archipelagos of Frioul and Riou and Ile Verte (Fig. 11.4). It represents a total coastline of 151 km. Using the same method as Cheminée et al. (2011), we have analysed the ortho-photographs of the coast (MEDDTL et al. 2012; Google_Inc. 2013) in order to complete the inventory of the previously identified white seabream nurseries (Cheminée et al. 2011). The coastline of each of the nurseries has been measured on the ortho-photographs at a scale of 1:7000. In addition to the ground-truth survey carried out during the previous study (spring-summer 2004, southern roadstead of Marseille, Calanques from Marseille to Cassis), some parts of the nurseries newly identified in ortho-photographs in the Bay of La Ciotat and around Frioul were inspected *in situ* in July 2008 and 2011.

In a second stage, the coastline was divided up according to the zoning based on the existing categories for the management of the natural environment of the 'PACA' regional district, in particular for this sector, as displayed on the internet site of the DREAL(DREAL_PACA 2012; GIP_Calanques 2012): statutory protection, contractual protection and inventories of the patrimony. With regard to the zoning for the Calanques National Park (Fig. 11.4), there is a distinction between (1) the marine core area which contains two sectors, the Massif des Calanques (including the Riou archipelago) and the sector of Cap Canaille and Bec de l'Aigle (including Ile Verte), and (2) the Aire Maritime Adjacente (AMA) (adjacent maritime area) which includes the southern bay of Marseille, the DPM ('Domaine Public Maritime' i.e. state owned maritime area) around the archipelago of Frioul and the bays of Cassis, La Ciotat and Les Lecques. It's worth noting the contrasted types of protection measures (statutory and contractual) applied in these zones of the Park. The core area includes 'special core area' regulations applicable to its whole surface area, including, for example, for the marine resources a ban on trawling and bull trawl fishing. The 'core' status also entails a ban on development work, construction and installations without special authorisation. In places, no-catch or enhanced protection zones (ZNP and ZPR) offer a greater level or protection than the average for the core area. All the other statutory aspects (e.g. the size of catches) come under the authority of the administrative authorities which usually have jurisdiction over the sea (Préfet, etc.). On the other hand, the Park authority can make proposals for (new) regulations to the competent authority. With regard to the adjacent maritime area (AMA), the protection provided by the Park is solely contractual: in general, for the core area and for the AMA, the Park regulation makes provision for the possibility of introducing measures of protection on the basis of partnership (e.g. on the model of the Parcs Naturels Régionaux or Natura 2000 contracts).

The coastline presenting nursery habitats and the proportion of the total coastline that they represent have been calculated for each category of statutory or contractual protection measures of the Park (Table 11.1).

11.3.3 Amount of Nurseries According to the Levels of Regulation of the Park

The table in Annexe 1 presents the list of all the nurseries of *Diplodus* spp. identified within the perimeter of the Calanques National Park and quantifies the corresponding coastline (in metres). Figure 11.5 shows an extract of the cartographical

Table 11.1 Zoning—existing management types and categories in the 'PACA' regional district and the study territory: statutory protection, contractual protection and inventories applicable to the marine environment and discussed in the present paper (DREAL_PACA 2012)—length of coastline, length of coastline of nursery areas and corresponding proportions

Type of protection	Categories	Coastline (m)	Nurseries coastline (m)	Proportion of the total amount of nurseries of the park	Coastline of core nurseries belonging to this category (m)	Proportion of core nurseries belonging to this category	Coastline of AMA nurseries belonging to this category (m)	Proportion of AMA nurseries belonging to this category
Statutory protection	*Core area* (general regulation)	*76425*	4076	*38*	4076	*100*	–	–
	ZNP and ZPR (No-take areas within the core)		81	*1*	81	2	–	–
	'Site classé' (=Natural Heritage Site)		4925	*46*	4076	*100*	849	*13*
Contractual protection	*Adjacent Maritime Area (AMA)* (partnership measures to be organized)	*74584*	6745	*62*	–	–	6745	*100*
	Natura 2000 Site		6244	*58*	4076	*100*	2168	*32*
Inventories	*ZNIEFF-mer I* ('Zone d'Intérêt Ecologique Faunistique et Floristique')		2266	*21*	2266	*55*	0	*0*
	ZNIEFF-mer II ('Zone d'Intérêt Ecologique Faunistique et Floristique')		2178	*20*	66	2	2112	*31*
	Total ZNIEFF-mer		4444	*41*	2332	*57*	2112	*31*
Full National Park		*151009*	*10821*					

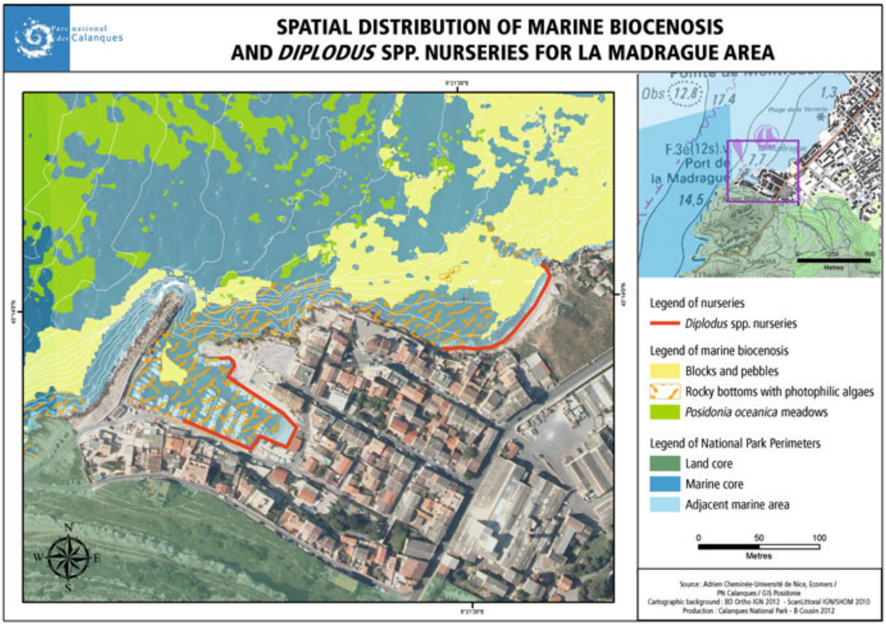

Fig. 11.5 Map of the localisation of nurseries—extract from the 'Atlas des Zones de Nourriceries de Sars (*Diplodus* spp.) et Biocénoses Marines du Calanques National Park' (in prep.). Zone of Madrague de Montredon (Bay of Marseille, cf. Fig. 11.4)

representation localising them more precisely. The full atlas is available at < www.unice.fr/ecomers/ >. The nursery habitats of *Diplodus* spp. occupy only 7.2 % of the 151 km of coastline of the whole park (Table 11.1). In all, 62 % of these nurseries are situated within the AMA and 38 % within the core area. In other words, within the core area, these nursery habitats only occupy 5.3 % of the coastline as against 9 % within the AMA. It is noteworthy that only 2 % of the core area nurseries are included in the 'no-catch area' category (ZNP) and 0 % in the ZPR. Within the core area, the only type of contractual protection finalised to date is the Natura 2000 category: this concerns the whole of the core area and thus 100 % of the core area nurseries. Within the AMA, the only category of statutory protection in force corresponds to 'listed site' areas: only 13 % of the AMA nurseries are covered by this category. Among the partnership-basis measures which could be introduced within the AMA, the category of contractual protection already in force for at least part of the AMA is Natura 2000 (in the process of finalisation) and concerns 32 % of the AMA nurseries. The remaining 68 % of AMA nurseries do not at present benefit from particular contractual protection. Furthermore, in terms of the inventory of the natural patrimony, 41 % of the park nurseries are included within a marine ZNIEFF (I or II). Fifty-seven percent of the core area nurseries belong to a ZNIEFF whereas only 31 % of the AMA nurseries belong to this category.

11.4 Discussion: Applying the Seascape Approach with Regard to Management of the Infralittoral

Over the whole territory of the Calanques National Park, the extent of the nurseries is small (less than 8 % of the total coastline). In addition, most of these nurseries are situated outside the core area, within the AMA, where the anthropic pressures are high (bays of Marseille and La Ciotat) and where the level of protection is by definition lower (cf. 3.2). These data thus confirm those of Cheminée et al. (2011): the white seabream nurseries within the core area of the Calanques National Park would appear to be insufficient in themselves to ensure the renewal of the local adult populations which probably depend on the migration of recruits from the more abundant nurseries situated within the adjacent maritime area (AMA).

The management zoning in our study does not *a priori* take into account all the essential habitats and their connectivity (seascape approach). There are however examples of the management of natural environments that adopt this approach at seascape level and notably the notion of connectivity: the concept of ‘ecological solidarity’ encompasses these principles and is the focus of current discussion within the French national parks authority (Parcs Nationaux de France) (INEA et al. 2009; Thompson et al. 2009; Gabrié et al. 2007). The Ramsar convention (1971) and the recommendations of the various subsequent members’ conferences have also encouraged their members to take into account the functionality of the habitats and processes of connectivity, at landscape scale, for the selection of their ‘wetlands of international importance’ (Direction de l’Agriculture de Mayotte et al. 2002; Cheminée 2002).

We propose here a conceptual schema (Fig. 11.6), illustrated by our case study and applicable in a general way to the management of any coastal site in order to favour a ‘seascape’ approach.

The aim is firstly to manage the habitats of juveniles (Fig. 11.6, point a). To this end, once the characteristics of the habitats of juveniles (nurseries) are known (b) they are mapped (c) for the purposes of localisation and quantification. In a zone under statutory protection (core area of the park in our example; d), the aim is to conserve the nursery value of the habitat: this requires in particular (e) the strict maintenance of the characteristics of the micro-habitat; in the case of the white seabream (*Diplodus*), it has been shown (Cheminée et al. 2011) that it is necessary to respect the heterogeneous character of shallow gently sloping bottoms if they are to perform their nursery function (notion of ‘heterogeneity’ and ‘complexity’, for further details see Box 1). In our case study, the nurseries situated within the core area benefit from a high level of protection: the special core area regulations entails a principle of a ban on development works, construction and installations, concerning in particular the DPM (Domaine Public Maritime—public maritime domain), without special permission, which gives the public authority the means to protect these habitats from direct destruction. In certain cases, if the statutory protection is insufficient (f), the competent public authority can propose (g) additional statutory measures: for example, to specifically list the habitats and their characteristics that

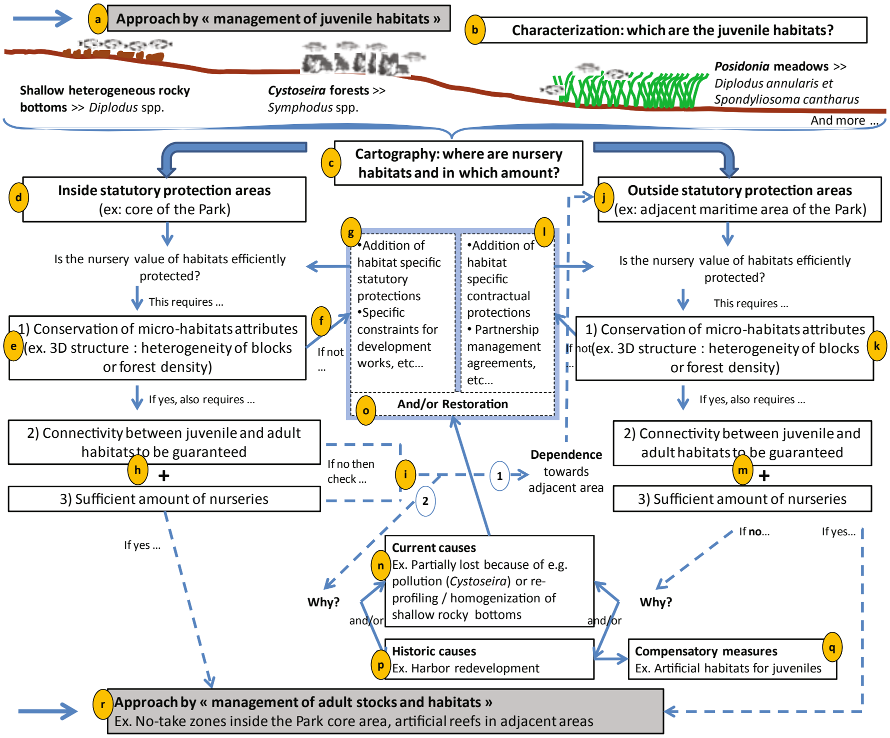

Fig. 11.6 Conceptual schema for a 'seascape' approach for the management of coastal areas

require protection, for example when agreeing to special authorisations for works within the DPM of the core area. Once this stage has been passed, it must be ensured (h) that the nurseries are connected to the adult habitats and present in sufficient quantities to ensure the supply of recruits. In our example, as already mentioned, the nurseries of the Calanques are not sufficiently abundant within the core area (i): the adult habitats of the core area thus depend (j) for the most part on the migration of recruits from distant nurseries, situated outside the statutorily protected area, that is, in our example, in the AMA. It is therefore necessary to apply the same reasoning: within the AMA, it was noted above that 3/5 of nurseries do not benefit from any specific statutory or contractual protection. The integrity of these habitats (maintenance of their characteristics) and therefore of their nursery value (k) strongly depends on the process of contractualisation to come (l), which will define on a consultative basis basis the management actions (partnership based measures) within the AMA. For example, in the case of the white seabream, in application of the principle of heterogeneity mentioned above, there is a need for measures to ensure that both the decision makers and the general public are made aware of the need to preserve on a contractual basis the natural beaches disposing of a heterogeneous substrate, and not to systematically seek to reshape the beaches or fill them exclusively with fine sand. This is a matter of necessary conciliation between environmental priorities and economic priorities linked to bathing activities. Once such guarantees are acquired (k), this seascape approach to management will again require (m) the maintenance of connectivity between the nurseries situated outside the protected area and the adult habitats: the feasibility of these migrations of young white seabream recruits has been confirmed by recent studies (Di Franco et al. 2012) showing the capacity of recruits to migrate from the nurseries towards the adult habitats over distances of more than 10 km. Furthermore, it is necessary to dispose of a sufficient quantity of nurseries (m). If this is not the case, two options may be envisaged, both in the core protected area and in the area without statutory protection: firstly, the causes of the lack of nurseries may be of recent origin (n), for example if they have been partly degraded by pollution events (e.g. alteration of the macrophyte-formed forests of *Cystoseira*) or the reshaping of beaches (alteration of the heterogeneous shallow bottoms with rocks). In this case, the managing authority may envisage measures of restoration (o) in order to re-establish the characteristics of the micro-habitats and thus the nursery value of these habitats. Or the causes of the lack of nurseries may be historical (p) and irremediable, for example in the case of destruction by harbour construction (for details, see Box 2); compensatory measures may then be envisaged in order to replace the lost nurseries (q). At the conclusion of this process, both in areas with and without statutory protection, once the nurseries of each species of interest have been identified (characteristics) and localised (cartography) and their quantity and connectivity with adult habitats is satisfactory and preserved, the next stage is to take care of the management of the adult populations themselves (r); in our case study, within the core area, in addition to the general regulations for the sea (respect of size of catches, etc.), the special core area regulations and the no-catch areas (ZNP and ZPR) provide a basis for managing the adult habitat and populations. In the adjacent maritime area (AMA), operations such as the construction of artificial reefs in the bay of Prado also play a role.

Box 1: Importance of the 'three-dimensional structure' of the seascape and its habitats with regard to their nursery value: examples at various spatial scales

The work of August (1983) offers a basis for defining the structuring of the seascape; the structure of the seascape is the result of several components that may be perceived at different scales: (1) at landscape scale: its 'heterogeneity', which reflects (a) its composition (number of distinct units) and (b) their organization (i.e. the degree of fragmentation and their relative positions); (2) within a given unit (a habitat): its 'heterogeneity' (subdivision in micro-habitats) and its 'complexity', which reflects the three-dimensional architecture of the habitat (e.g. the degree of stratification of the erect macrophytes, or the degree of ramification of the arborescent strata). This structuring of the landscape (heterogeneity + complexity) influences the patterns of abundance of the organisms living there via the processes described by Thiriet et al. (this volume) i.e. essentially the effectiveness of predation and the access to food. The patterns of abundance of juveniles of fishes thus resulting from the structuring of the infralittoral zone at its different scales (habitat and seascape mosaic) may for example be illustrated by: (1) at habitat scale, the homogenisation of the shallow bottoms with heterogeneous granulometry (small rocks, stones, gravel, sand) off artificial beaches by the artificial addition of fine and homogeneous granulometry reduces the nursery value of these bottoms for the *Diplodus* spp. (Cheminée et al. 2011); (2) habitat scale: the arborescent macrophyte-formed habitat (such as the forested assemblages of *Cystoseira crinita* or *C. balearica*) shelter 9–12 times more juveniles of *Symphodus* spp. than the less complex habitat formed by shrubby Dictyotales-Sphacelariales assemblages (Cheminée et al. 2013); (3) at the mixed scale of habitat and seascape: the alteration of a forest of *Cystoseira*, which is reflected by (a) a decline in the density of the forest (reduction of complexity) and (b) its fragmentation (increase in heterogeneity) reduces its nursery value for the juveniles of *Symphodus ocellatus* (Cheminée 2012), but at the same time this heterogeneity (co-occurrence of the two different habitats *Cystoseira* forest and shrubby Dictyotales-Sphacelariales assemblage) is favourable for the juveniles of *Coris julis* (‘edge effect’) and increases for this species the nursery value of these two habitats (Cheminée 2012); (4) at the scale of the seascape mosaic: the co-occurrence of several different nursery habitats (heterogeneity), because of their complementarity will shelter a greater diversity of species of juveniles than a seascape constituted of a single habitat. Indeed, there is a spatial partition of the juveniles of different species (Harmelin-Vivien et al. 1995); (5) at the scale of the seascape mosaic: the homogenisation of the bottoms with meadows of *Caulerpa taxifolia* is harmful for juveniles of *Coris* (Cheminée et al. under review).

Box 2: Historic causes: the case of the major coastal redevelopment schemes of the nineteenth and twentieth centuries in the bay of Marseille

In the bay of Marseille (i.e. partly within the adjacent maritime area of the Park), what has been the degree of fish productivity lost through the irremediable destruction of the nurseries situated at the sites of the major coastal redevelopment schemes of the nineteenth and twentieth centuries? According to Meinesz et al. (2006), in the urban district of Marseille, prior to the main artificialisation of the coast (i.e. before 1800), the initial coastline was 114 km in length; 32 km of coastline were artificialised, resulting in a rate of occupation of the shallow bottoms (0–10 m) of 49 % of their initial surface area (1421 ha). For example, the horseshoe-shaped artificial beaches constructed at Prado (Prado-Plage and Prado Bonneveine, Annexe 1) consist of a homogeneous substrate of fine gravel, separated by sheer, solid rock seawalls. This redevelopment was carried out (late 1970s) over shallow bottom areas including nursery areas for white seabream, that is bottoms with heterogeneous granulometry of small rocks and gravel. This destruction and homogenisation of the habitats probably severely reduced the nursery capacity of the Marseille roadstead area. 3152 m of coastline were thus artificialised (Meinesz et al. 2006). On the basis of the quantities of nurseries currently existing in a relatively pristine control area (Montredon, Annexe 1, Fig. 11.5), it may be estimated that nurseries occupied about 50 % of the coastline of Prado, or 1576 m Today, only 372 m remain (Annexe 1), or a loss that may be estimated at more than 75 %. The case is similar for the area of the Marseilles commercial harbour (‘Port Autonome’, northern bay of Marseille): an examination of the old ordinance survey maps (Fig. 11.7) dating from 1825 to 1866 (MEDDTL et al. 2012) shows that the coast at the level of the location of the basins of the harbour had a morphology that was favourable for the occurrence of white seabream nurseries. The harbour constructed from 1844 to 1975 resulted in the artificialisation of a total of 11533 m of coastline (Meinesz et al. 2006), altering habitats that have irreversibly lost their function as nurseries, given the radical transformation of their morphology (sheer quay walls and greater depth). We estimate that this coast also presented nurseries along 50 % of its length, and that they would have supplied the adult habitats of today’s marine reserve ‘Parc Marin de la Côte Bleue’, situated a dozen kilometres to the west of the harbour, and which present few nurseries, like the core area of the Calanques National Park. The impacts of these transformations are thus considerable.

11.5 Management Perspectives: What Means of Action are Available?

11.5.1 Applying the ‘Seascape Approach’

The application of this ‘seascape approach’ to management involves deciding on plans of action: in terms of practical recommendations for the managing authority, it should be borne in mind that ill-conceived coastal developments that result in the homogenisation of the environment at all scales (from micro-habitat to whole seascape) are harmful in particular with regard to the nursery role of the coastal area. In contrast, well-planned development schemes, purpose-designed on a case by case basis with a view to maintaining the nursery value of the coastal areas, may be envisaged. These theoretical notions should be integrated in practice in the statutory and contractual management of the coast.

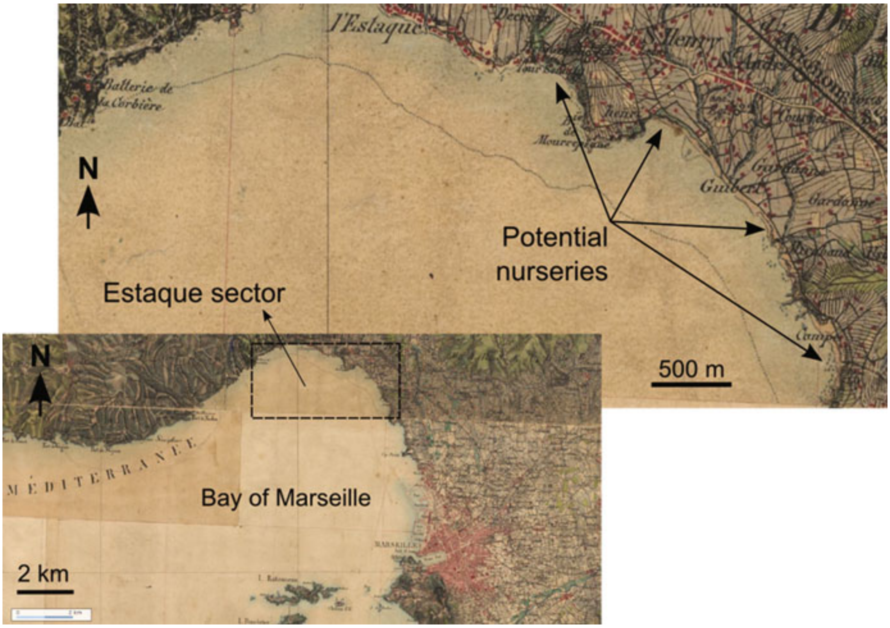

Fig. 11.7 Extract of ordinance survey maps (1825–1866). Bay of Marseille, sector of Estaque—Examples of former nursery habitats destroyed by the harbour redevelopment construction work for the present-day commercial harbour 'Port Autonome'—Source: IGN—Géoportail

11.5.2 The Means of Application of a 'Seascape Approach' to Coastal Management—Knowledge Built on the Case of the Calanques National Park

In order to implement recommendations of this kind, various means of action are available to the Calanques National Park authority. In particular, (1) with regard to protection measures, the park authority has a duty to make proposals for regulatory measures to the competent authority. In parallel, the Park regulation makes provision for the proposal of measures on a partnership basis. These two tools could be used to introduce protection measures specific to essential habitats, notably the nurseries of the Sparidae; that is, measures that explicitly stipulate the intention and the means to preserve their biotic and abiotic characteristics. Indeed, on reading the partnership-based measures of the draft charter, it will be noted that the notion of seascape is used, but that it remains relatively general. Future proposals for additional measures might offer an opportunity to define precisely certain of the high priority habitats, which are at present not specified individually on the maps of the biocenosis such as those of Natura 2000, and which thus have not so far been taken into account in the management plans. This is the case for the heterogeneous nursery shallow bottoms but as well, for example, for the *Cystoseira* spp. forests, nursery habitat for Labridae (Cheminée et al. 2013), included so far without distinction within the 'photophilic macrophytes' biocenosis. In addition, (2) in the core area, the processing of applications for derogations to the banning of works/construction/installations should take into account the recommendations mentioned above. Furthermore, for a given nursery zone, the possible derogations authorised, on the grounds for example that the proposed construction work would not cause the destruction of habitats, should nonetheless specify in the contractual specifications what are the characteristics of the micro-habitat which should also be conserved. Finally, (3) with regard to land ownership, the reclassifying of the maritime space situated directly off land belonging to the Conservatoire du Littoral ('CELRL' = Shoreline Protection National Agency) might be requested, in order to transfer the administrative authority from the 'Préfet de Département' ('DDTM' = national level authority) to the 'Conservatoire' and the Park authorities. This would give the Park authorities additional leverage with regard to the management of habitats and facilitate the application of more suitable and better coordinated management measures at the scale of the underwater landscapes.

Note on harbour development schemes–Harbours constructed on the scale of those of 'Goudes' and 'Morgiou' small villages (shallow depth i.e. <2 m, lower quays, conservation of the heterogeneous nature of the seabed) can conserve a high nursery value for Sparidae, in contrast to the deep and homogeneous basins of the Port Autonome, for example. Is dredging/deepening (i.e. radical transformation of the habitat) systematically necessary for the construction/maintenance of these harbours?

11.6 Conclusion

In general, what is required is (1) to maintain and protect a mosaic of varied habitats both at the scale of a small cove and that of a whole bay in order to ensure the complementarity of habitats for the different species or the different stages in the life cycle of a given species; (2) to respect the morphology of these essential habitats: with regard to coastal development schemes (e.g. harbours), the advisability of certain development works should be rethought in the light of these perspectives, and alternative solutions avoiding a radical transformation of the habitat should be discussed.

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Annexe 1 Nurseries of *Diplodus* spp. within the Calanques National Park—zoning, sectors (cf. Fig. 11.4) and corresponding coastline (meters)—It is specified for each nursery whether its identification is based solely on the interpretation of aerial photographs (O) or whether it was confirmed *in situ* by a 'ground truth' survey (T)

Nursery (local name)	Park zone	Park sector	Aerial photo (O) or survey (T)	Coastline (m)
Port de Malmousque	AMA	Bay of Marseille	*T*	*113*
Quai des Légionnaires	AMA	Bay of Marseille	*T*	*84*
Plage des Légionnaires	AMA	Bay of Marseille	*O*	*31*
Plage Cadière	AMA	Bay of Marseille	*O*	*28*
Anse aux Cuivres bis	AMA	Bay of Marseille	*T*	*14*
Anse aux Cuivres	AMA	Bay of Marseille	*T*	*49*
Plage Station marine	AMA	Bay of Marseille	*T*	*26*
Anse de Maldormé	AMA	Bay of Marseille	*T*	*50*
Plage du Prophète	AMA	Bay of Marseille	*T*	*93*
Base de loisirs du Roucas blanc	AMA	Bay of Marseille	*O*	*481*
Prado-Plage du Grand Roucas	AMA	Bay of Marseille	*O*	*37*
Prado-Plage de David	AMA	Bay of Marseille	*O*	*43*
Prado-Plage de l'Huveaune	AMA	Bay of Marseille	*O*	*51*
Prado-Plage Borély	AMA	Bay of Marseille	*O*	*177*
Prado-Plage Bonneveine	AMA	Bay of Marseille	*O*	*64*
Plage Vieille Chapelle	AMA	Bay of Marseille	*O*	*118*
Plage de la Pointe Rouge	AMA	Bay of Marseille	*O*	*428*
Montredon-Anse des Phocéens et Piscine	AMA	Bay of Marseille	*T*	*184*
Montredon-Anse des Sablettes sud et nord	AMA	Bay of Marseille	*T*	*219*
Montredon-Verrerie sud et nord	AMA	Bay of Marseille	*T*	*188*
Montredon-La Madrague plage	AMA	Bay of Marseille	*T*	*124*
Port de la Madrague	AMA	Bay of Marseille	*T*	*181*
Frioul-port de pomègues	AMA	Frioul archipelago	*O*	*122*
Frioul-calanque de la Crine	AMA	Frioul archipelago	*T*	*94*
Frioul-plage pompiers	AMA	Frioul archipelago	*O*	*50*
Frioul-calanque Morgiret	AMA	Frioul archipelago	*O*	*136*
Frioul-calanque du Berger	AMA	Frioul archipelago	*O*	*10*
Frioul-Eoube	AMA	Frioul archipelago	*O*	*64*
Frioul-calanque de Ratonneau	AMA	Frioul archipelago	*O*	*28*
Frioul-calanque de St-Estève	AMA	Frioul archipelago	*T*	*133*
Frioul-plage des Pilotes	AMA	Frioul archipelago	*O*	*19*
Frioul-port	AMA	Frioul archipelago	*O*	*513*
Samena	Cœur	Bay of Marseille	*T*	*22*
Mauvais Pas	Cœur	Bay of Marseille	*T*	*53*
Escalette	Cœur	Bay of Marseille	*T*	*75*
Blanche	Cœur	Bay of Marseille	*T*	*11*
Port des Goudes	Cœur	Bay of Marseille	*T*	*437*
Maronaise	Cœur	Bay of Marseille	*T*	*35*
Baie des Singes (port)	Cœur	Calanques coast	*T*	*94*
Maire Est	Cœur	Calanques coast	*T*	*27*
Callelongue entrée	Cœur	Calanques coast	*T*	*15*
Callelongue interne	Cœur	Calanques coast	*T*	*144*

Annexe 1 (continued)

Nursery (local name)	Park zone	Park sector	Aerial photo (O) or survey (T)	Coastline (m)
Monasterio plage	Cœur	Calanques coast	*T*	*44*
Mounine	Cœur	Calanques coast	*T*	*12*
Marseilleveyre	Cœur	Calanques coast	*T*	*105*
Queyrons	Cœur	Calanques coast	*T*	*36*
Podestat	Cœur	Calanques coast	*T*	*37*
Sormiou	Cœur	Calanques coast	*T*	*316*
Morgiou	Cœur	Calanques coast	*T*	*396*
Sugiton	Cœur	Calanques coast	*T*	*79*
Pierres tombées	Cœur	Calanques coast	*T*	*206*
Envau	Cœur	Calanques coast	*T*	*67*
Port-Pin	Cœur	Calanques coast	*T*	*65*
Port-Miou	Cœur	Calanques coast	*O*	*982*
Baie de Cassis-plage Bestouan	AMA	Cassis Bay	*O*	*34*
Cassis Bay-portion du port	AMA	Cassis Bay	*O*	*100*
Cassis Bay-Plage du Corton	AMA	Cassis Bay	*O*	*208*
Cassis Bay-Anse de l'Arene	AMA	Cassis Bay	*O*	*565*
Falaises de Soubeyrannes	Cœur	Cap Canaille-Bec Aigle	*O*	*427*
Figuerolles	Cœur	Cap Canaille-Bec Aigle	*O*	*66*
Petit Mugel	Cœur	Cap Canaille-Bec Aigle	*T*	*105*
Grand Mugel	Cœur	Cap Canaille-Bec Aigle	*T*	*109*
Ile verte	Cœur	Cap Canaille-Bec Aigle	*T*	*111*
La Ciotat Bay -Plage de la Clinique	AMA	La Ciotat Bay	*O*	*98*
La Ciotat Bay-Port des Capucins	AMA	La Ciotat Bay	*O*	*193*
La Ciotat Bay-Plage des Capucins	AMA	La Ciotat Bay	*O*	*64*
La Ciotat Bay-Plages de Villa des Tours	AMA	La Ciotat Bay	*O*	*60*
La Ciotat Bay-Plage Lumière	AMA	La Ciotat Bay	*O*	*16*
La Ciotat Bay-Port de St Jean	AMA	La Ciotat Bay	*O*	*271*
La Ciotat Bay-Plage d'Arène Cros	AMA	La Ciotat Bay	*O*	*61*
La Ciotat Bay-Le Liouquet	AMA	La Ciotat Bay	*O*	*92*
La Ciotat Bay-Plage du Liouquet	AMA	La Ciotat Bay	*O*	*356*
La Ciotat Bay-Le Galand	AMA	La Ciotat Bay	*O*	*131*
Baie des Lecques-plage du Nouveau port	AMA	Les Lecques Bay	*O*	*82*
Les Lecques Bay-Vieux port des Lecques	AMA	Les Lecques Bay	*O*	*291*
Les Lecques Bay-plage La Madrague	AMA	Les Lecques Bay	*O*	*95*
Les Lecques Bay-plage Anatole Ducros	AMA	Les Lecques Bay	*O*	*76*
Total nurseries coastline (meters)				*10821*

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Chapter 12
How 3D Complexity of Macrophyte-Formed Habitats Affect the Processes Structuring Fish Assemblages Within Coastal Temperate Seascapes?

Pierre Thiriet, Adrien Cheminée, Luisa Mangialajo and Patrice Francour

Abstract Macrophyte-formed habitats are important components of coastal temperate seascapes. They usually host higher diversity and density of fishes, including both adult and juvenile individuals. Here we synthesized the ecological processes underlying differences in fish assemblage structure among habitats, with an emphasis on the effects of habitat architectural complexity, which results in great part from the state of macrophyte assembalges. At a wide spatial scale, oceanographic patterns affect larval survival and dispersal and consecutive broad patterns of juvenile settlement. At a finer spatial scale, architectural complexities of the habitats affect their quality (basically food availability and predation risk) which drives local patterns of juvenile abundances through differential mortality and active habitat selection. Hence, the analysis and understanding of juvenile/adult abundance patterns have to consider nested sets of seascape features.

Keywords Fish settlement · Food availability · Shelter availability · Predation mortality · Habitat choice

12.1 What Is a Seascape from an Ecological Perspective

A seascape is a wholly or partially submerged landscape. By analogy with terrestrial landscape ecology, a seascape is a heterogeneous area that may be seen as a mosaic of patches, which belong to different types ("Patch mosaic model") (Bostrom et al.

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2011). A seascape has therefore two main features, its composition in term of patch types (e.g. combined total percent cover per patch type) and its spatial configuration, i.e. the spatial arrangement of all the patches, which may be synthesized using metrics such as number, sizes and perimeters of patches, inter-patch distances, contiguity (Wedding et al. 2011).

Patch typology intends to break down the seascape into ecologically meaningful and workable sub-units for facilitating ecological studies of the whole. Hence, each patch-type refers to a given set of environmental conditions, such as depth, type of primary substrate, availability of resources (e.g. food and shelter), and so gives insight on local ecological functioning. Therefore, patch types may be seen as benthic habitats (Fraschetti et al. 2008), the term they are usually referred as.

Ecological functioning of the whole mosaic does not simply rely on the sum of every habitat-specific ecological functioning. Patches interact together and some specific proprieties may emerge by synergy (e.g. edge effect), depending on seascape configuration (e.g. amount of ecotones) (Macreadie et al. 2010; Bostrom et al. 2011). Other environmental factors affect ecological processes (e.g. water temperature, salinity and oxygenation affect growth) and they may vary at a spatial scale distinct from patch scale, usually at broader spatial scales (Ordines et al. 2011). Hence, multiple spatial scales have to be considered for a better understanding of the ecological processes that drive organisms' distribution patterns within a seascape.

12.2 From Macrophyte Assemblages to Seascape Configuration

Some benthic organisms greatly modify local 3D-architectural complexity. They provide habitat to many other organisms and ultimately structure the whole benthic community through "habitat cascade" (Thomsen et al. 2010). Such species are called biogenic habitat formers and include for instance corals, oysters, mangroves, seagrasses and some macroalgae (Bostrom et al. 2011). In coastal temperate seascapes, biogenic habitats include mainly seagrass meadows on soft bottom and macroalgal communities on hard bottom (Fraschetti et al. 2008). Indeed, marine macrophytes (i.e. both seagrasses and macroalgae) are tri-dimensional structures at a spatial scale from 10^{-2} to 10^{1} m (www.algaebase.org). The architectural complexity of a macrophyte-formed habitat often depends on density and complexity of tri-dimensionnal structure of a dominant species/taxonomical group. Macrophyte-formed habitats with high architectural complexity include, for instances in the Mediterranean Sea: 1/the *Posidonia oceanica* meadows due to very high density of shoots (around 600 shoots m^{-2}) (Terrados and Medina-Pons 2011) that are made of ribbon-like leaves, and 2/the *Cystoseira* forests due to the very high degree of branching of *Cystoseira* species (Chemello and Milazzo

2002) that are in medium density (around 20 individuals m^{-2}) (Hoffmann et al. 1992).

It has been reported worldwide that infralittoral habitats are subject to strong modification due to anthropogenic pressures (Coll et al. 2010), such as water pollution, coastal urbanization, boat anchoring, dredging, date mussel fisheries, or invasive species (Claudet and Fraschetti 2010). Macrophytes-formed habitats have not been spared. For instances, Mediterranean *Cystoseira* dominated assemblages have been reported to regress (Thibaut et al. 2005; Mangialajo et al. 2007; Sala et al. 2011). They are generally replaced by habitats with reduced architectural complexity, such as Dictyotales-dominated assemblages (smaller ribbon-like macrophytes), algal turfs or barren-grounds (over-grazed area where dominated by encrusting corallinales). These habitat shifts induce strong modification in compositions and configurations of seascapes, and ultimately in their whole ecological functioning (Ryall and Fahrig 2006; Claudet and Fraschetti 2010).

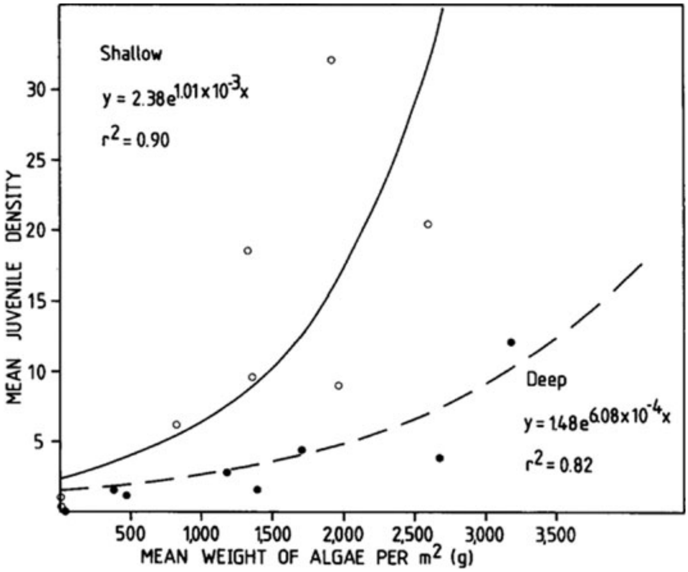
12.3 Complex Macrophyte-Formed Habitats Are Nursery for Many Fish Species

Fish assemblages usually exhibit different patterns of composition and abundances between habitats. Differences are usually larger when focusing only on post-settlement juveniles (hereafter called ‘juveniles’) due to their more specific habitat requirements (Harmelin-Vivien et al. 1995; Cheminée et al. 2013). The habitat(s) that host(s) higher than average densities of juveniles have a nursery role for the considered species (excluding the possible lack of connectivity with adult habitats), and are therefore very important for populations renewals (Beck et al. 2001).

Many studies carried worldwide in coastal temperate seascapes reported that macrophyte-formed habitats play the nursery role for many fish species. Examples include *Ecklonia* and *Carpophyllum* (Phaeophycea) forests of temperate rocky reefs of New Zealand (see Box 1; Jones 1984), *Cystoseira* forests of temperate rocky reefs of the Mediterranean (see Box 2; Cheminée et al. 2013) and the Mediterranean temperate *Posidonia oceanica* seagrass meadows (see Box 3; Guidetti 2000). However, it is worth noting that other less complex habitats play also the nursery role for some other species (e.g. Box 2). Hence, fish juvenile assemblage structure depends on the structure of macrophyte assemblage. We develop in the following sections how architectural complexity of macrophyte-formed habitats can affect the ecological processes structuring fish assemblages.

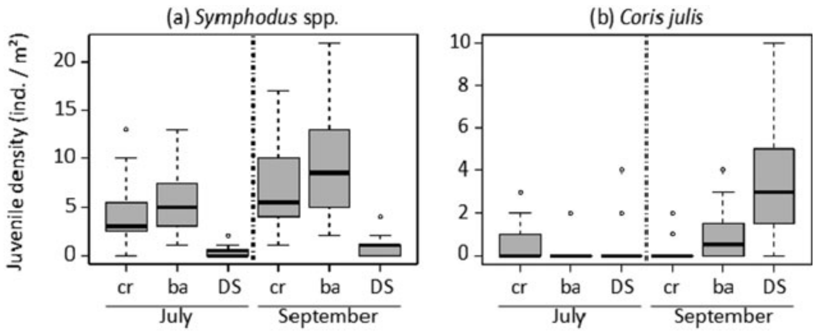
Box 1: The nursery role of a kelp forest in New Zealand—from Jones (1984)

In New Zealand, within the habitat composed by the canopy forming Phaeophyceae *Ecklonia* and *Carpophyllum*, Jones (1984) showed that mean juvenile densities of *Pseudolabrus celidotus* (Labridae) increased exponentially with the mean weight of algae per square meter. This relation was even stronger in shallow (< 8 m) than in deep (> 8 m) areas (see graph). Besides, in the same study, a macro-algal removal experiment resulted in a significantly lower juvenile fish recruitment (6 folds less juveniles per unit area in the cleared area *vs* in the control area). It was confirmed by an increased recruitment observed after the recovery of an algal forest over a previously barren rocky reef (6 folds more intense).



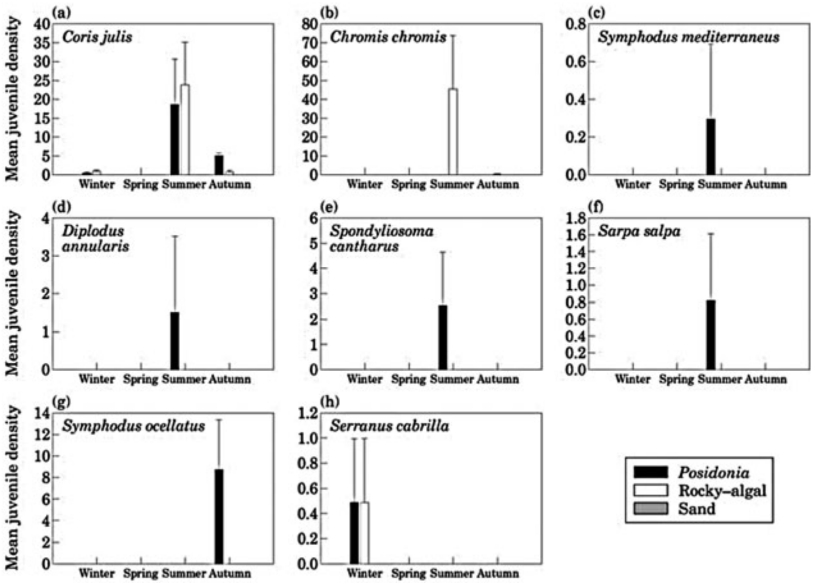
Box 2: The nursery role of Mediteranean *Cystoseira* forests—from Cheminée et al. (2013)

In 2009, Cheminée et al. (2013) compared the nursery value of distinct states of the biocenosis "photophilic macrophytes of the Mediterranean rocky infralittoral biotope". The study considered two *Cystoseira* forests (*C. crinita* [cr] and *C. balearica* [ba]) and the less complex bushy assemblage dominated by Dictyotales and Sphacelariales (DS). Juvenile fish densities of *Symphodus* spp. (box plot "a") were significantly greater in the two *Cystoseira* forests than in the bushy assemblage (DS). These differences were consistent between July (early post-settlement period) and September. They tested if abundance differences resulted from architectural complexity differences using experimental habitat manipulation. Artificially forested substratum (using *Cystoseira*-like plastic structures) had significantly greater densities of *Symphodus* spp. juveniles than the bare substratum. However contrasted response was found for other fish species in function of the considered season (box plot "b")*: Coris julis* juvenile densities were significantly higher in the bushy assemblage (DS) than in both *Cystoseira* forests, but only in autumn.



Box 3: The nursery role of Mediterranean *Posidonia oceanica* seagrass meadows—from Guidetti (2000)

Guidetti (2000) highlighted the higher nursery value for some fish species of *Posidonia* meadows in comparison to some neighboring habitats: juveniles of *Symphodus ocellatus*, *S. mediterraneus*, *Serranus cabrilla*, *Diplodus annularis*, *Spondyliosoma cantharus* and *Sarpa salpa* were significantly more abundant over *P. oceanica* meadows (black bars) than over sand habitat or rocky-algal bottom (i.e. gently sloping hard substrate covered by a dense erect assemblage of articulated Corallinaceae and *Cystoseira* spp.). Contrastingly, juveniles of *Chromis chromis* inhabited predominantly rocky-algal bottoms. Small individuals of *Coris julis* were censused over both *P. oceanica* and rocky-algal habitats. Bare sand did not host any juveniles among these species. The author suggested that differences in fish species richness and abundance are primarily related to habitat tri-dimensional structure.



Mean density (mean number of individuals of juveniles 40 m^{-2}) of common fish species. Bars indicate standard deviations

12.4 Broad Classes of Ecological Processes and Spatial Scales

Evolutionary processes have selected functional and behavioral traits that are adapted to specific environments. The selected pool of functional and behavioral traits is filtered by environments through ecological processes what governs distribution patterns of species within seascape (Morris 2011). Ecological processes may be studied according to three broad classes: (i) differential settlement/recruitment, (ii) differential mortality and (iii) active choice of the favored habitat. None of them is necessary exclusive, difference in composition and abundance of species between habitats could be the result of their combination (Olabarria et al. 2002; Morris 2003, 2011). Moreover, these processes may act at distinct spatial scales.

12.4.1 Differential Settlement Affected by Environmental Conditions at Multiple Spatial Scales

Most of demersal fish species inhabiting temperate coastal waters worldwide experience a complex life cycle. Usually, it is divided into a vagrant planktonic phase (corresponding to the stages egg and larvae) and a relatively sedentary benthic phase (from the stage post-settlers to adult) (Di Franco et al. 2011). During the planktonic phase, eggs and larvae disperse depending mainly on oceanographic patterns. The metamorphosis from larvae to juvenile triggers the transition from planktonic to benthic environment that is called “settlement”. Due to oceanographic patterns (as currents, water temperature etc), juveniles that disperse may settle in greater number to one locality than to others (Di Franco et al. 2011).

In coastal environments, the seascape is usually heterogeneous at a fine spatial scale, and the different habitats are interspersed forming like a mosaic. Considering that difference in larval arrival occurs at a spatial scale that encompass habitat heterogeneity, all habitats composing one locality homogenous in term of larval arrival will exhibit the same settlement rate. According to this point, local difference in post-settlement juveniles between adjacent habitats should be due to differential mortality or movement across habitats rather than difference in larval supply. This however stresses the need to consider multiple spatial scales when studying links between habitat and post-settlement juveniles (Rilov and Schiel 2011).

12.4.2 Differential Mortality and Active Habitat Selection Affected at Finer Spatial Scales

At a finer spatial scale, assuming that the different habitats have been exposed to the same settlement rates, difference in post-settlement juveniles’ densities among habitats may be due to differential mortality and/or active choice of the favored habitat. Considering that this active choice is a behavior that appeared thanks to natural selection, the chosen habitat shall be the one with the highest probability of growing and surviving until reproduction (Morris 2011). Therefore, the two classes of processes, differential mortality and active habitat selection, are both mediated by differential habitat quality in term of food availability and predation rate (Hindell et al. 2000). The highest quality habitat minimize mortality rate by offering the trade-off between foraging and safety (Anholt and Werner 1998; Dahlgren and Eggleston 2000).

12.5 Architectural Complexity of Macrophyte-Formed Habitats Interact with Processes

12.5.1 Foraging Success

Food supply is one of the basic needs for any heterotrophic organism. Food gives the energy, nutrients and vitamin needed to keep body-functioning, growth and development, and reproductive potential. Individuals experiencing starvation lose fat and muscle mass (decrease in condition) in order to keep vital systems. Growth and development of juveniles may be altered (Heck et al. 2003) as well reproductive potential of adults (Ordines et al. 2009). Energy deficiency reduces physical abilities and ultimately results in death. Low food availability may therefore causes direct mortality of post-settlement juveniles or indirect mortality through (a) a reduction of size-at-age making longer the period of vulnerability toward size-selective predation ("the bigger is better" hypothesis, Heck and Orth 1980; Levin et al. 1997), and (b) a reduction of their physical abilities to escape predator attack (Levin et al. 1997).

Availability of food resources depends on their quantity and their accessibility, which are both affected by macrophytes. Plants architecture (e.g. degree of branching) and densities affect the structure of benthic macroinvertebrate assemblages. In several regions worldwide, habitats made up structurally complex macrophytes harbor higher diversity and abundances of macroinvertebrates (Parker et al. 2001; Chemello and Milazzo 2002; Christie et al. 2009; Hansen et al. 2010). These habitats may therefore be particularly suitable as feeding grounds for invertebrate feeders such as many demersal fishes. However, it has been suggested that extremely high structural complexity may alter fishes' foraging efficiency through physical constraint (Stoner 1982; Heck and Orth 1980). Another characteristic potentially affecting invertebrate accessibility is the rigidity of macrophytes. A very flexible canopy is more sensitive to water movement and its constantly back-and-forth may limit access for fishes to understory invertebrates (Levi 2004).

12.5.2 Predation Mortality

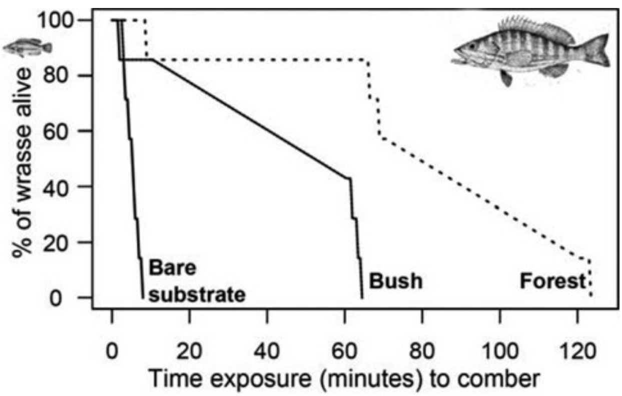
In several regions worldwide, post-settlement juveniles are known to be prey item for various predators. Predation mortality may therefore drive differences in abundance patterns of juveniles between habitats (Hindell et al. 2000; Beck et al. 2001; Heck et al. 2003). Analyzing and quantifying interactions between predators, preys and environmental factors is a quite complex task. For this purpose, the act of predation may be broken into a series of sequential stages which can be treated separately: prey detection and location by the predator, pursuit and attack, and capture (O'Brien 1979).

The predation act may be accomplished following three different broad classes of tactics. The chase (or pursuit) predator actively searches a prey item and uses its superiority in swimming speed for catching. In opposition, the sit-and-wait (or ambush) predator counts rather on the surprise. It waits motionless camouflaged in the environment until one prey enters its attack range, which is small. An intermediate tactic is used by the stalk-attack predator that actively searches for prey item. Once a prey is detected, stalk-attack predator approaches furtively until the prey is within the attack range, which is medium, and makes a speed burst to capture it (Matsuda et al. 1993; Horinouchi et al. 2009; Schultz and Kruschel 2010).

Habitat structural complexity interacts with the different stages of the predation act, what affects predation success accordingly to the tactic. In highly complex habitats, habitat-elements may interfere with prey detection/location for active searchers (chase and stalk-attack tactics), while for ambush predators, encounter rate depends only on prey density and mobility. Moreover, mobility of predators (that are most of the time larger than their prey) may be relatively more constrained by habitat-elements than prey mobility. This decreases the predation success rate sharply for chase predator (long distance pursuit) and slightly for stalk-attack predator (medium distance pursuit). As ambush tactic involves almost no predator mobility, habitat structural complexity should not facilitate prey escape. In some way, it may also be considered that habitat-elements enhance furtive wait of ambush predator and furtive approach of stalk-attack predator, for both tactics the use of camouflage has a paramount role (see Box 4) (Lima and Dill 1990; Lima 1992, 1998).

Box 4: Predation success and habitat architectural complexity—Authors' unpublished data

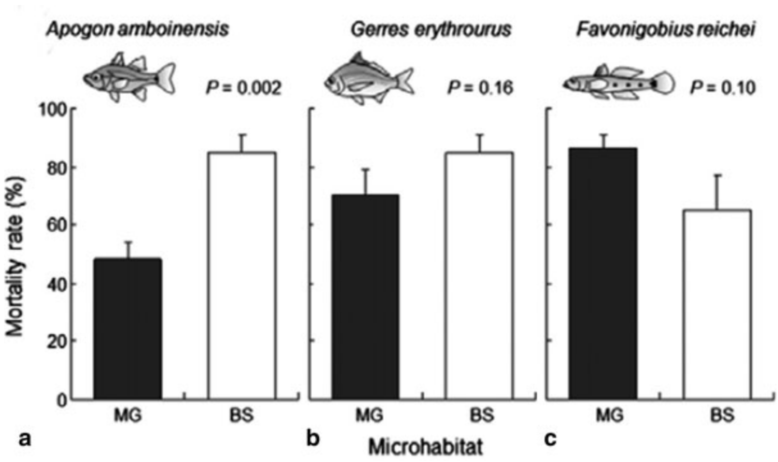
Thiriet et al. studied interaction between predation success and habitat architectural complexity. To avoid confounding effects with food availability, experiments were done in aquariums. Artificial habitats of increasing architectural complexity were constructed using different length of plastic algae: Bare Substrate, Bush (short stems), Forest (long stems). The biological models were two co-occurring demersal fishes in Mediterranean Infralittoral rocky reef: the comber *Serranus cabrilla* preying on post-settlement juveniles of the wrasse *Symphodus ocellatus*. Survival of one prey facing one predator was assessed in the three habitats on seven replicates. In average, survival time in Forest was 1.9- to 16.5-fold greater than respectively in Bush and Bare Substrate (see Figure). These results clearly evidence that high habitat architectural complexity may reduce predation success by providing shelter to prey. But overall predation mortality depends also on predator densities, which may be different between habitats (see Box 5).



Box 5: Predation mortality of juveniles between habitats—from Nanjo et al. (2011)

In order to compare predation mortality of juveniles between 2 different habitats (Vegetated, mangrove roots area-MG; unvegetated, bare sand area-BS), Nanjo et al. (2011) used tethering experiments, that allow to take into account both the efficiency of the predator (habitat and predation-tactic dependent, see box 4) and the density of the predator in a given habitat. The authors studied the predation rates on juveniles of three fish species: the resident, necto-benthic *Apogon amboinensis* (a), the active swimmer *Gerres erythrourus* (b) and the crypto-benthic *Favonigobius reichei* (c). For *A. imberbis*, the predation mortality was significantly lower in the vegetated habitat than in the unvegetated one, although predatory fish were more abundant in the vegetated habitat. No differences in mortality rates were found for the two other species.

These results may be explained by contrasting anti-predator tactics, either associated with mangrove structural complexity offering shelter (in the case of *A. amboinensis*) or independent of mangrove vegetation structure (for the two other species).



From these considerations, chase tactic does not seem to be suitable in highly complex habitats, while ambush tactic does. It is less clear-cut for stalk-attack tactic. Some predators are able to use only one tactic (specialist) while some others are able to use several tactics (generalist) depending on the environment. The relation between habitat and predation tactic suitability is probably a strong driver of distribution patterns of specialist predators among habitats (habitat-specific predators) (Schultz et al. 2009). Dealing with this, predation mortality of juveniles in a given habitat depends on its ability to escape the habitat-specific predators, by using different strategies such as particular microhabitat use (see Box 5). Thus, in general, coevolution between habitat-specific predator and prey juveniles results in specialized escape strategies (see Abrams 1990; Lima 1992). This specialization in escape strategy would lead the prey to actively choose for, and/or to better survive in, the habitat of its coevolved predator rather than another habitats where it has less ability to escape from predators practicing other tactics (Lima 1992).

12.6 Synergy Between Habitats: The So Called ‘Edge Effect’

Previous sections report that each habitat composing the seascape has its own functioning (mediated in part by its structural complexity) what results in differential abundance patterns. However, at the boundary between two habitats (i.e. ecotone), their respective functioning affect each other and particular abundance patterns may appear in this transition area (usually higher diversity and abundance than both sides added), this phenomena is called the edge effect (Ries et al. 2004). Global increase in habitat fragmentation and its propensity to increase the amount of ecotone and consequently edge effects (Smith 2011) stresses the need to better understand underlying mechanisms.

Edge effect may come from emergent physical properties. For instance, at ecotone between marcophyte-formed habitat and bare substrate, current flow and turbulence are reduced. This may cause accumulation of swarming hyper-benthic invertebrates (such as mysids) and therefore offer a great opportunity for juveniles to forage (Macreadie et al. 2010).

Edge effect may also come from the complementarities of resources level proper to each habitat. At ecotone, mobile organisms may regularly switch between habitats and therefore exploit alternatively the optimum habitat as regard to the resource expected (basically food or shelter). For instance, one habitat may be optimum for foraging activities but with a higher predation risk than another habitat. At the ecotone, juvenile therefore can forage efficiently in the risky habitat and switch when a predator is detected. Interaction between predator tactic and structural complexity may also result in positive edge effect for prey juveniles which have developed adaptative anti predator behavior (Matsuda et al. 1993). Positioned close to the ecotone between a highly complex habitat and an open habitat, juvenile may escape in the suitable habitat as regard to the tactic of the predator detected (see section above for details about habitat-specific predators) (Martin et al. 2010; Smith et al. 2011).

12.7 Conclusions

We highlighted that analysis and understanding of juvenile abundance patterns have to consider nested sets of seascape features. At a wide spatial scale, oceanographic patterns affect larval dispersal and consecutive broad patterns of juvenile settlement. At a finer spatial scale, structural complexities of the habitats affect their quality (basically food availability and predation risk) which drives local patterns of juvenile abundances through differential mortality and active habitat selection.

Complementarities and synergies occur between habitats of a seascape. Macrophyte-formed habitats were put ahead in this chapter, because they probably have nursery role for more species than any other habitats do, in coastal temperate seascapes. But the other habitats cannot be neglected even if they have nursery role for only few species. The whole mosaic must consequently be taken into account for management practices. After decades of local-scale habitat-focused management, it is now required to upgrade coastal management at a wider seascape approach.

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Chapter 13
Can We use a Landscape Approach to Assess Natural and Anthropogenic Perturbations of the Rocky Shore Ecosystems?

Christian Hily and Maud Bernard

Abstract Intertidal zone is a marine area which can be reached easily at low tide periods and consequently allows observation at the landscape scale, much larger than that of the subtidal zone. Then an intertidalscape approach can be developed, particularly on the rocky shores where a macroalgal and faunal zonation based on emersion rates help the understanding of structure and evolution of the ecosystem. In this paper, we give the baseline of a new approach of intertidalscape ecology from examples on the Brittany rocky shores and particularly by developing a visual index (Intertidalscape Boulder Field Index, IBFI) using the opportunistic behavior of the green macroalgae to characterize the hand-fishing impacts on the boulder field habitat of the low eulittoral zone, on the rocky shores of Brittany, France.

Keywords Intertidalscape · Rocky shores · Anthropogenic pressure · Boulder fields · Green opportunistic macroalgae

13.1 Introduction

Unlike the subtidal, the intertidal zone is a very original part of the marine environment because it is accessible without scuba diving during low tide periods. These periods vary with tidal magnitude and the time of day when they occur. The consequences of the emersion are numerous and the whole structure and functioning of the intertidal ecosystem are driven by the stressful physical conditions running up and down the shore. Because its accessibility during low periods, the intertidal zone can be investigated with methods close to those of terrestrial habitats. Thus, the measurement of spatial patterns and their temporal variability is possible with the landscape ecology approach (Risser et al. 1984) in such complex environments

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characterized by a heterogeneous mosaic of habitat types, particularly on rocky shores in which the well-known patterns of vertical zonation are fragmented by the microhabitats created by crevices, boulders, pools… Seascape ecology is becoming more and more recognized as a valuable approach of the marine ecology (Turner 2005), but most studies focused on subtidal coastal habitats, mainly on coral reefs and seagrass meadows (Boström et al. 2011). At low tide period, intertidal landscape can be observed in large scale, much larger than subtidal landscapes including in clear waters. Moreover, the *in situ* experiments are easier, and field procedures are close to those developed for sampling vegetation and animals in terrestrial environments. The measurement of heterogeneity and complexity in rocky shores and beaches is possible both at the habitat-landscape scale and at the microhabitats scale. This heterogeneity explains also the great variations of the intertidal landscape over very short vertical and horizontal distances.

The field accessibility of the intertidal zone explains the numerous papers published for decades on the ecology and the diversity of the fauna and flora, and on the structuring effects induced by the physical stress of emersion. However landscape ecology which considers interactions between spatial patterns, ecological processes and scales (Risser et al. 1984) remained few developed in intertidal.

Today, anthropogenic disturbances are dramatically increasing on coastal areas. The intertidal zones are particularly affected by human and agriculture effluents and lots of fishing and recreational activities. The impacts at the landscape scale are almost never considered. Coastal conservation and management need strong bases to evaluate and characterize changing in the marine ecosystems at large scales, to propose valuable management methods to minimize impacts and to restore biodiversity. Consequently, methodological approaches are need to quantify changing and evolution of intertidal habitats both at the local and regional scales (Polis et al. 2004). Landscape approach adapted to intertidal zone would be a new methodological development to evaluate changes, with limited costs, at pertinent scale both in term of ecosystem functioning and environmental management, and to complete protocols based on local sampling which are usually applied in biodiversity measurements in marine environment. In this paper, we studied some rocky shores patterns which can be used in a landscape ecology approach, from examples on the Brittany shores (France). The aims are to look for the opportunities provided by the landscape ecology to characterize rocky shores habitats and, in a feed-back loop, look for opportunities to use the visual changes as indicators of changes in ecosystem structure and functioning under natural and/or anthropogenic disturbances. We present, as an example, a visual landscape index based on the development of the green opportunistic macroalgae to characterize the intensity of the recreational hand-fishing activity in the low eulittoral boulder field habitats (Bernard 2012).

13.2 Structure of Intertidalscapes and their Interpretation

According with classical definition of terrestrial landscape, it is a basic structural unit of the geographic environment (Gudelis 1993), a geosystem which includes a set of interacting and interdependant entities, forming an integrated whole. If each landscape is a set of entities (components), it is also a part (component) of a higher geosystem. Thus, three levels should be considered to understand and interpret the landscape: the level of landscape, the lower level of landscape components and the higher level, the level of the higher geosystem. According Dunning et al. (1992) a landscape is an area of land containing a mosaic of habitat patches, often within which a particular target habitat patch is embedded in a matrix. Many authors consider the landscape as a level which can be seen directly by an observer situated from a specific point of view in a vertical and/or horizontal observation. Because the intertidal zone is a part of the marine environment, we propose to use the term “intertidal seascape” or “intertidalscape”, better suitable than “landscape” for the intertidal zone. Thus, an intertidalscape is the set of structural components of the ecosystem or eco-complex between the low-and high-water tidemarks and can be seen by an observer situated at sea or on land (cliff, dune. . .). The aims here are to characterize the intertidalscape evolution resulting from the ecological processes which control spatial structures (patches and mosaics) in response to natural and anthropogenic disturbances. This approach can answer to questions of connectivity between patches and components of the ecosystems, which correspond with the definition of the landscape ecology as defined by Wu (2006), discipline in which the ecosystem complexity is studied through heterogeneity at various spatial scales. Moreover, in a second step, if dynamics of the ecosystem components are previously well described and explained, some landscape indicators can be developed and used to assess the level of disturbance of these ecosystems. We propose here some considerations for an intertidalscape ecology based on interpretation of the spatial distribution of structural and functional components. For the rocky shores, these components are habitats (biotope + biocenosis) localized in the rocky matrix and characterized with several spatial dimensions based on physical, biological and temporal features (periods of emersion, stochastic events, seasonality. . .).

The first step of a landscape approach on the intertidal zone will be the identification and the specialization of the habitats. At a higher scale, the identification of specific associations of some habitats will be able to define an intertidalscape typology describing the main categories of ecocomplexes based on their geomorphological, physical, biological, but also socio-economical dimensions. Many authors (see Schoch and Dethier 1996; Little and Kitching 1996) defined different variables playing a main role in the rocky shores ecology, variables which could be used to elaborate such a typology. The habitat classifications recently developed at the French national level (“Cahiers d’habitats” Natura 2000; Bensettiti et al. 2004; Rebent, Guillaumont et al. 2010) and European Community levels (Natura 2000, EUNIS (http://eunis.eea.europa.eu)) do not consider the level of landscape. To our knowledge, no one approach is being developed to achieve such an intertidal- sea-scape typology. Consequently, if we can have a landscape reading in the intertidal zone and an analysis based on its habitat composition and distribution—and eventually others dimensions as cultural, aesthetic or socio-economical -, it is not possible to situate this analysis in a reference grid. Such reference classification would integrate all the components but also the interactions between these components. Moreover the concepts developed in terrestrial landscape ecology are today discussed in order to know whether they could apply to sea or if new approaches must be developed for the seascape ecology (Pittman et al. 2011). We consider that if the terminology and concepts developed for the terrestrial applications are equally applicable to the study of intertidal environments and allow to describe their heterogeneity, some processes remain however specific of marine environment such as the connectivity between patches and the role of corridors (Turner 2005), the phase of immersion facilitating the exchanges and connectivity between patches and at higher scales.

13.3 Structure of the Rocky Intertidalscapes

On rocky shores, intertidalscape depends mainly of (1) wave exposure that structures habitats in a horizontal dimension, along a gradient of exposure decreasing from the tips of rocky headlands to coves and sheltered bays, and (2) emersion, that structures habitats on a vertical dimension according the tidal excursion gradient. As a consequence of this second gradient, zonation is the pattern of distribution of the dominant macroalgal and macrofaunal organisms, both in term of abundances and cover rates of the substratum matrix, observable as successive bands from the high to the lower shore (numerous papers have been published on the rockyshore organization from Lewis 1964 to Menge and Branch 2000). Crossing exposure and emersion gradients give the main structuring components of the intertidalscape. For the observer who looks for a landscape reading at a site scale (i.e. a cove, a beach, a little bay), an intertidal zone looks like a mosaic of various colors, structured in a horizontal zonation alterning dark bands dominated by macroalgae (fucoids) and grey bands dominated by macrofauna or bare rock. In the western European coasts, from the high shore to the lower shore, the first level, corresponding to the supralittoral zone under the wave splash and spray influence, is generally characterized by two lichen bands: firstly a yellow-orange-grey band mixing various erected and species (*Caloplaca marina*, *Xantoria parietina*, *Ramalina* spp.) and lower on the shore, a black band mainly composed of the encrusting lichen *Verrucaria mora* species. Under these bands of lichens, different bands of macroalgae (fucoids such as *Pelvetia canaliculata*, *Ascophyllum nodosum*, *Fucus vesiculosus*, *Fucus serratus*, red seaweeds such as *Chondrus crispus*, *Palmaria palmate, Osmundea pinnatifidan* or Laminaria such as *Laminaria digitata*, *Laminaria hyperborea*…) and macrofauna (barnacles, limpets, mussels) are easily identified at the intertidalscape level from exposed to sheltered situations, as three main zones described by authors as: littoral fringe (= high mediolittoral zone), eulittoral zone (= medium and low mediolittoral zone) and sublittoral zone (= emerged fringe of the infralittoral zone). Then, a landscape reading can be based on identification and spatialization of color and rugosity of patches distributed as a mosaic in a rocky matrix. It can give broadly but rapidly the main structure and functioning patterns, and can be the basis of a diachronic analyses to survey the evolution of the relative surfaces of the patches.

If these patterns are recognized since many years, the large possibilities offered by such global landscape analysis remained largely unexploited. However at a larger scale, remote sensing and aerial photographs analysis provided very helpful results to characterize the dynamics of decreasing of the fucoids and kelp beds in Brittany. Nevertheless, if some studies provided good bases for a coastal seascape ecology (Lima and Zollner 1996) future research efforts are needed to link spatial patterning of intertidal habitats and ecosystem functioning. Finally the possibilities given by the landscape ecology to characterize human disturbances on the shore, remained largely unexplored.

In a rocky intertidal seascape, matrix is the rock substratum. This latter can show a heterogeneity at a smaller scale like the occurrence of boulders, crevices or tide pools. Patches are mainly biogenic patches of macroalgal and dense macrofaunal populations of gregarious sedentary species, mostly fixed on the substratum. At the landscape scale, some anthropogenic structures can be present: mainly oyster farms structures. Thus, the intertidalscape is a complex spatial mosaic of heterogeneous habitats, depending both on the heterogeneity of the rocky matrix and of environmental factors including anthropogenic ones. Within this landscape, some mobile macrofaunal species are predators, mainly large crustaceans and fishes at the high tide period and birds at the low tide period. They can induce indirect interactions between the intertidalscape components. Man is also an element of these species which can control some components by a professional and recreational fishing activity or algal harvesting (fucoids and red seaweeds), either from boats or scuba diving at the high tide period or through a hand-fishing activity at the low tide period. These activities do not only concern interactions between species (predator/prey interactions) and connectivity between patches, but can also deeply modify the spatial organization of habitat patches. As an example, the hand-fishing for shellfish (crabs, abalones, clams. . .) on the lower eulittoral boulder fields, can induce strong modifications of the habitat structure that can be rapidly identified at the intertidalscape scale.

13.4 Temporal Scales and Evolution in Intertidalscapes

Intertidalscapes are different from terrestrial landscapes and subtidal seascapes because of the strong visual modifications induced by the daily succession of emersion/submersion periods and its variability in terms of tidal range according the tidal cycles. The periodic changes of intertidalscape are not only visuals but also functional, with drastic modifications of energy and fluxes of matter, metabolism, and moving of the mobile large carnivorous species. On the other hand, intertidalscapes show fewer seasonal changes than temperate terrestrial landscapes.

Moreover, strong changes in the intertidalscape can also be due to stochastic natural or anthropogenic catastrophic events. Storms associated with big waves are also factors which can modify the intertidal seascape more frequently and more deeply than modifications of the terrestrial landscapes under storms. In addition, oil spills are known to deeply modify seascapes and the ecosystem functioning. The ecological successions initiated after cleaning operations have also been described and the processes studied, but recovery of intertidal ecosystems have not been studied in terms of patch dynamics restoration at the landscape scale.

Thus, the different potentialities of an intertidal seascape approach can be summarized as follow:

An intertidalscape approach can:

- **Facilitate the identification of habitats:** a new hierarchical classification of intertidal habitat has been recently proposed. It uses some visual features of patches to differentiate rocky habitats (the REBENT typology, Guillaumont et al. 2010). It is a classification adapted from the Eunis classification to facilitate the habitat mapping. As an example, the mediolittoral habitat type "Rock and boulders dominated by macroalgae" is differentiated from the habitat "Rock and boulders dominated by macrofauna". The edges and the fragmentation of such patches can be easily identified and mapped by GPS.
- **Detect changes**: periodical intertidalscape reading help the detection of temporal changes both at short-term by identifying the spatial amplitude of the dynamic stability (ex: mussel beds), and at long-term by identifying persistent modifications of the mosaic due to a component fragmentation. Short term changes: as underlined by Ellis and Schneider (1997) "more than any other factor, our inability to explain natural variability places a limit on our ability to detect anthropogenic change". This variability is not only effective at the spatial scale but also at the temporal scale. Changes observed in an intertidalscape can be the result of a punctual natural event, visible for a few days or weeks, but with no consequences at a pluri-annual scale. As an example, beaching of drifting kelp uprooted by a winter storm is an event which can totally change the intertidalscape for days and weeks. Easily visible by an observer, the phenomenon induces drastic changes in the ecosystem functioning of the shore. We studied the ecological consequences of the beaching of abundant laminariales (which can reach more than one meter in thickness) on a shore of the Molene archipelago in the West Brittanny (Le Hir 2002). We showed that the structure and functioning of the ecosystem was modified by cascading effects in a bottom up stimulation of the trophic network. The detritus of macroalgal were exploited by detritivorous amphipods and isopods which increased drastically their populations and were further eaten by a diverse fauna of secondary consumers. Such events are a part of the natural annual variability of the intertidalscape and functioning of the intertidal ecosystems.
- **Describe evolution, banalization and homogeneization of the intertidalscape** Kelp beaching events may also be induced by anthropogenic activities resulting from waste of the mechanical harvesting of laminariales during spring and summer. In this case, algae remain accumulated on the substratum for months and the ecosystem cannot assimilate these amounts of organic matter as described previously. As a consequence, anaerobic decomposition induces high mortalities on fauna and flora, associated with strong visual, olfactory and functioning consequences at the scale of the beach site.

Fig. 13.1 Banalization and homogenization of the intertidalscape by the invasive Pacific oyster *Crassostrea gigas*. (© C. Hily, All rights reserved)

Another case study illustrates the helpful potentialities of the intertidalscape approach to describe the evolution of the shores. The pacific oyster *Crassostrea gigas* is an exotic invasive species introduced in the seventy's in the oyster farms in France. Favored by the global temperature increase, this species can spawn in most of the aquaculture sites in which it is introduced in Europe, and develops progressively dense populations in a lot of various intertidal marine and estuarine habitats. We showed that this invasive species is an engineer which creates biogenic reefs, a new habitat on the intertidal zone, which induces drastic modifications on the shores: metabolism, biodiversity, biotic interactions. . . (Lejart and Hily 2011). Today in many sites, a new oyster band occurs in the intertidal zone and covers most of the medium and low mediolittoral zone. As a consequence, the intertidalscape is banalized and homogeneized. The landscape approach is pertinent to characterize areas invaded by *Crassostrea gigas* and to monitor the spatial evolution of this phenomenon which concerns more and more regions in Europe (Fig. 13.1). This example shows once again, that the modifications of some elements of an intertidalscape can be used as useful visual bioindicators, once processes and consequences of changes described and explained.

Surveys in order to detect such perceptible signs of change are very effective at a large regional scale because of their rapidity and their low cost. Further research to identify others visual bioindicators at the intertidalscale would be useful to help in the characterization of ecological health of habitats, needed in the marine EC directives.

13.5 Characterize Ecological Successions

Ecological successions can also be characterized by visual changes at the landscape scale. As an example, the natural cycle of rocky shore biogenic cover, alterning dominance of limpets–barnacles—periwinkle—fucoids (Hartnoll and Hawkins 1985), was recently disturbed on many sites in Brittany. Limpets remained abundant over years, dominating the others species and preventing the renewal of fucoids populations by overgrazing young plants. This process induced a visible decreasing of fucoid cover rates on the shores (both *Fucus vesiculosus* and *Ascophyllum nodosum*). Because fucoids are engineer species, this process induced a shift in mediolittoral habitats. We experimented in the field the control exerted on macroalgae by limpets (unpublished data): we removed all individuals of *Patella vulgata* from 5 × 5 m quadrats ($n = 5$) during one year. Changes in the intertidalscape were visible three weeks after removing with the appearance of a dense cover of green opportunistic macroalgae (*Enteromorpha* spp.) (Fig. 13.1a, 13.1b). Three months later, this first step was followed by a phase of Fucoids settlement (mainly *Fucus serratus* and few *Ascophyllum nodosum* and *Fucus vesiculosus*). This succession was easily visible at the intertidalscape: (1) bare rock with barnacles and limpets; (2) full cover of green algae cover; (3) mixed green and brown algae; (4) brown algae dominant cover. This was a visual example of the consequences of an anthropogenic disturbance (the removing of grazers) which induced an opportunistic peak of green algae, further replaced by a fucoid cover through a facilitation process.

The development of green algae (*Entheromorpha* spp., *Ulva* spp.) is well known to detect and characterize stress and disturbance of the benthic ecosystems, particularly under high nutrient input (Ménesguen and Piriou 1995; Cloern 2001). Consequently, it seems interesting to look for a use of green opportunistic algae as a bioindicator of disturbance for ecosystems at the intertidalscape scale.

13.6 Green Opportunistic Algae (Enteromorpha spp., Ulva spp.) Cover to Characterize Disturbances on the Rocky Shores

Firstly, it must be underlined that we shall consider only the green opportunistic algae (*Enteromorph*a spp., *Ulva* spp.) fixed on the rock substratum and not those which are lying on the sediment or the drifted algae which are beached on the shore. Such beaching events can be very impressive in some sites of Brittany where eutrophication induce a very high green macroalgae production (Fig. 13.3).

Secondly the natural conditions under which green opportunistic macroalgae can develop must be identified to avoid errors of interpretation. Surface of the substratum must be free of dense macroalgal or faunal beds. Proliferations are facilitated on rocks and boulders located under a high flux of dissolved organic matter (Bellan and Bellan-Santini 1972; Raffaelli et al. 1998; Neto et al. 2011). They occur very often at the output of freshwater effluents, sewages and rivers on the shore, their high tolerance to low salinities unlike most of the other species of the shore, is an asset for the colonization. As a consequence, most of the natural situations where the green opportunistic algae are common in dense cover on the shore, are on areas under freshwater flows from small rivers and resurgences. Pebbles which are frequently overturned by waves at the high mediolittoral level of beaches can be also colonized by these algae during their period of stability between two successive storms. Tides pools of the high mediolittoral are also habitats which are naturally and

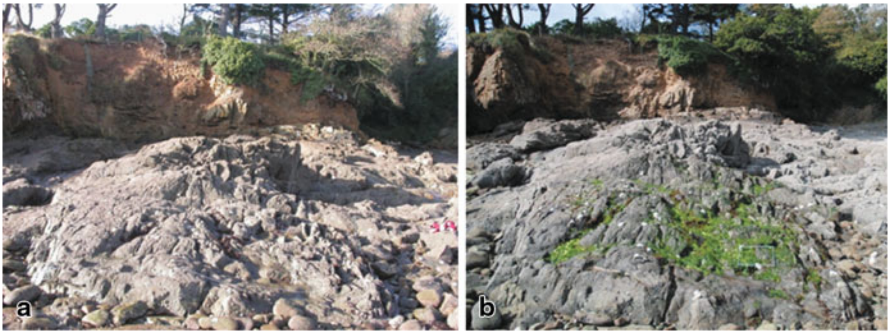

Fig. 13.2 Growth of *Enteromorpha* sp. on rock four weeks after limpets removal in 5 × 5 m quadrats. **a** Rock with limpets and **b** rock with *Enteromorpha* sp. after limpets removal. (© C. Hily, All rights reserved)

Fig. 13.3 Mobiles green algae (*Ulva* sp.) beached on rocks and boulders coming from subtidal sediment offshore. (© C. Hily, All rights reserved)

commonly occupied by green algae because their harsh environment (strong temperature, salinity gradient, oxygen gradients) prevents the settlement and development of others macroalgae. Except these three cases, easily observable on the field, patches of green opportunistic algae are direct consequences of anthropogenic disturbances which have previously destroyed the biogenic cover of the rocky substratum. We used this feature to develop a visual index of hand-fishing pressure on the lower eulittoral boulder fields.

13.7 The Lower Eulittoral Boulder Fields and the Hand-Fishing Activity

Lower eulittoral boulder fields are considered as a specific habitat of high biodiversity (Sousa 1979; Le Hir 2002). Their complexity and heterogeneity are induced by the heap of boulders which creates various microhabitats (overhangs and cavities)

Fig. 13.4 **a** hand-fisherman who overturn a boulder (© F. Delisle, All rights reserved), **b** a line of boulders (*white ones*) recently overturned and not returned to their original position by hand-fishermen—The boulder field is the brown band (*low mediolittoral*) in the foreground, while in the background the grey and white bands are the medium and the high mediolittoral respectively. (© M. Bernard, All rights reserved)

colonized by a large set of species (Takada 1999; Le Hir and Hily 2005). If boulders can occur in the medium mediolittoral, it is the low eulittoral zone and the emerged fringe of the infralittoral zone which are considered as the "boulder fields" habitat. Indeed, their associated biocenosis is different, in term of structure and biodiversity, from the biocenosis of the rocks around at the same level of emersion (Le Hir et Hily 2005). Actually, the cavities and overhangs shelter a large diversity of fixed and mobile fauna, and among them crabs (*Portunus puber*, *Cancer pagurus*), abalones (*Haliothis tuberculata)* and shrimps (*Palaemon serratus*), all harvested by the hand-fishermen. When hand-fishermen forage for these species, most of them overturn the boulders and leave them upside down (Fig. 13.4a, b). Consequently, all the fixed faunal and algal species cannot survive and dead in few days or weeks because they are not adapted to the changes of the environmental conditions.

Boulders which are concerned by the hand-fishing activity are mobile pieces of rock (i.e. Mobile Boulders, MB), with an irregular parallelepiped shape, with two main faces, the lower and the upper faces, whose surfaces are generally $> 500\,\text{cm}^2$, with a thick varying between 5 and 25 cm. Biggest boulders can occur but they cannot be overturned and are consequently not concerned by the hand-fishing disturbance. They can be designed as fixed boulders (FB) regardless to the overturning of boulders by hand-fishermen.

On the upper face of mobile boulders, fixed species mainly correspond to macroalgae (fucoids) or encrusting calcareous algae which cannot survive without light and which are squashed when the boulder is overturned (Fig. 13.5). On their lower face, the fixed species are mainly colonial or encrusting fauna: bryozoans, hydrozoans, ascidians and sponges, very sensitive species to the variations of temperature, desiccation and salinity (Fig. 13.5).This fauna cannot survive in the intertidal zone without the sheltered conditions provided by cavities and overhangs. After the mortality of the fixed organisms, the green opportunistic algae development is facilitated by two processes: (1) rocky substratum becomes free of biogenic cover and (2) the fluxes of particulate and of dissolved organic matter increase, and sometimes anoxia conditions occur (Fig. 13.5). The dense cover of green opportunistic algae growths rapidly after few weeks on the upper faces (which were the lower face before the overturning of boulders) (Fig. 13.5). At the landscape scale of a boulder field that has been prospected by hand-fishermen, the overturned boulders are green points on a brown

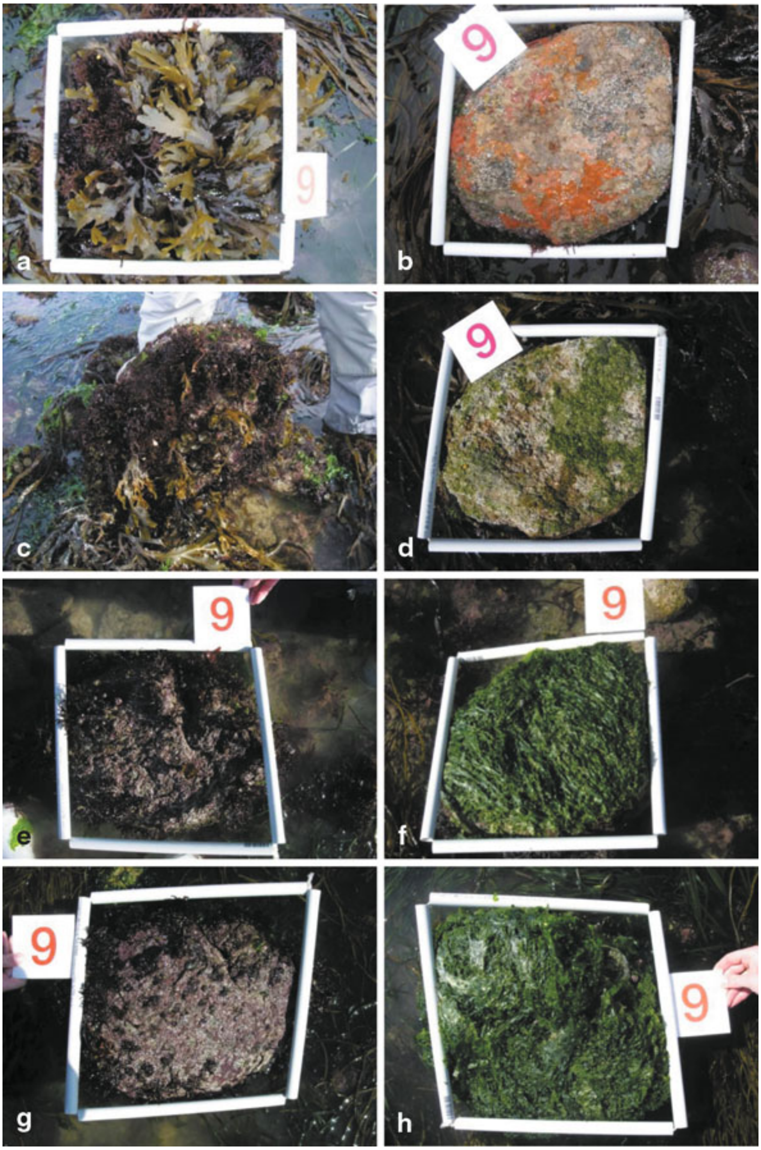

Fig. 13.5 Temporal evolution of the macroalgal cover of the two faces of one single boulder, after have been overturned. **a–b**: initial position of the boulder before over turned experimentally upside down (**a** upper face September 2010; **b** lower face September 2010). **c–e–g**: the upper face which became the lower face (**c** October 2010: upper face upside down since one month (the boulder had been overturned just to the shot, then reversed); **e** February 2011; **g** April 2011). **d–f–h** the lower face which became the upper face (**d** lower face upside down since one month October 2010; **f** February 2011; **h** April 2011). (© M. Bernard, All rights reserved)

matrix. Consequently, at the intertidalscape scale, when the number of overturned boulders increases, the surface of green color increases (Fig. 13.6).

The hand-fishing activity increased considerably in France these last years and many sites are disturbed each spring tide (almost each month). Most of the mobile boulders are overturned and remain upside down at the end of the period of the spring tide (four consecutive days in general). In order to assess the pressure of this disturbance (i.e. the overturning of boulders under the hand-fishing activity) at the boulder field scale, we proposed an Intertidalscape Boulder Field Index (IBFI) (Bernard 2012). It is visual, SMART indicator (Simple, Measurable, Achievable, Realistic, and Time limited) with a protocol calibrated to be operated by non specialists.

1. **Definition of the index**: In the low mediolittoral and emerged fringe of infralittoral of semi-sheltered and sheltered habitats, rocky substratum is covered by erected brown and/or red macroalgae under which encrusting algae and fauna can develop. Without hand-fishing, the intertidalscape of the boulder fields is brown and locally dark red. The rate of green cover increases with the increasing of the overturned mobile boulders number. However, those which were overturned few days ago are light colored (mixed white and pale yellow), due to the fixed fauna. To elaborate such an index, we studied 20 boulder fields in Brittany to obtain various situations on the largest gradient from 100 % brown/red cover to 100 % green cover.
   The aim is to link the relative cover of green color to a level of the hand-fishing pressure. The observations showed that this surface must be related to the area which corresponds to the total of boulders which can really be overturned by hand-fishermen. Actually, the Total Macroalgal Cover (TMC) is composed of algae which grow (1) on the mobile boulders (MB) which can be overturned for shellfish (= algae cover of mobile boulders MBca) and (2) on rocky substrata which are not concerned by the overturning. Among these latter, four categories can occur: small boulders not attractive for hand-fishermen, boulders which are deeply buried in the sediment, boulders which are too big and cannot be overturned and rock. We could gather these four types in a Fixed Boulder (FB) category (Fig. 13.6). Because the FB are never overturned, their algae cover (FBca) remain brown/red. The rate of Green Macroalgal cover (GMC) (including the rate of the white boulders recently overturned) can be expressed relatively to TMC and the MBca. If FBca is 0 %, the cover rate of green algae can reach 100 %. However it is a very rare situation. Thus, the first step is to estimate MBca and FBca values in one boulder field. These values are relatively stable in time, so after this first step and for monitoring the hand-fishing pressure, the green macroalgal cover (GMC) will be the only one variable measured. Our index is referred to the MBca parameter (Fig. 13.6).
   The IBF index is based on a discrete distribution of cover rates in 5 classes; each class is described to facilitate the reading of the landscape (Table 13.1 and Fig. 13.7).
2. **Description of the biocenosis**: to better understand the state of the habitat we described the general feature of the biocenosis (fauna and flora) under these 5 situations (Table 13.1).

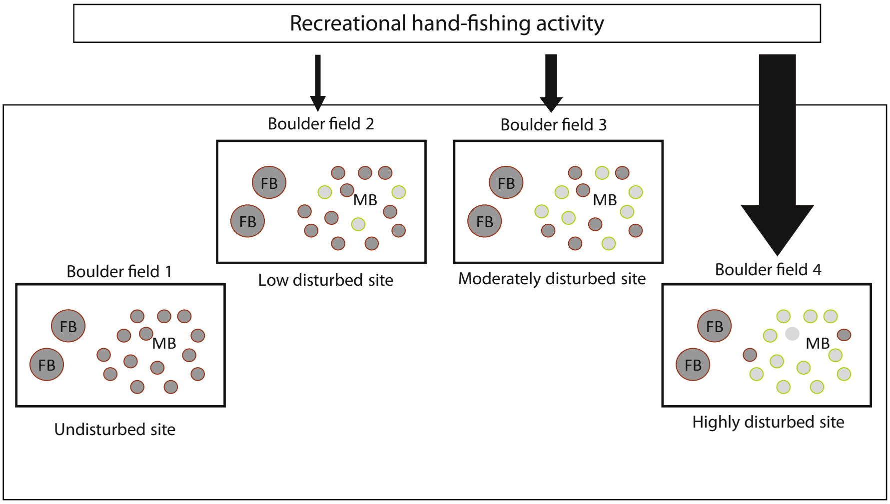

Fig. 13.6 Various theoretical distributions of brown/red (*i.e. dark grey*) versus green/white (i.e. light grey) boulders under increasing intensities of hand-fishing activity (MB = mobile boulders, FB = Fixed boulders). (Modified from Bernard 2012)

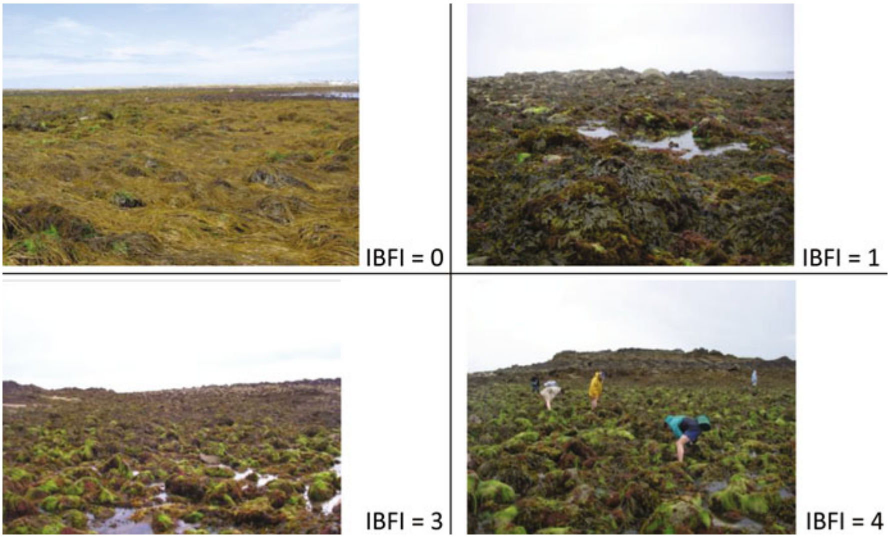

Fig. 13.7 Intertidalscape of four boulder fields under four different pressure of hand-fishing activity. IBFI: 0 = 0–4 % GMC, 1 = 5–24 %, 2 = 25–44 %, 3 = 45–64 %, 4 = 65–84 %, 5 = 85–100 %. (© M. Bernard and M. Lejart, All rights reserved)

3. **Identification of the boulder shape and surface.** Delimitation of the boulder field can be driven by a GPS and localized on an aerial photography to know the total area.

Table 13.1 IBFI: each value of the index is associated with a description at the landscape scale. (Modified from Bernard 2012)

IBFI Values	IBFI = 0	IBFI = 1	IBFI = 2
% "Brown/red" MBca	Between 96 and 100 %	Between 76 and 95 %	Between 56 and 75 %
% "White/green" MBca (i.e. GMC)	Between 0 and 4 %	Between 5 and 24 %	Between 25 and 44 %
Overall description	No visible impact. Uniform coverage of brown/red algae on MB upper surfaces across the boulder field. Exceptional observation of few patches with a white color or a green algae cover	Dominance of brown/red algae coverage on MB upper surfaces. Few sparse patches of white color or green algae coverage on MB upper surfaces	Brown/red color is more two times that of green white color
	No to rare white/green MB, almost exclusive presence of brown/red MB	Strong dominance of brown/red MB and low representation of white/green MB	High numbers of brown/red MB and white/green boulders well represented
IBFI Values	IBFI = 3	IBFI = 4	IBFI = 5
% "Brown/red" MBca	Between 36 and 55 %	Between 16 and 35 %	Between 0 and 15 %
% "White/green" MBca (i.e. GMC)	Between 45 and 64 %	Between 65 and 84 %	Between 85 and 100 %
Overall description	No dominance between brown/red color and white/green color	Dominance of white/green algae coverage on MB upper surfaces. Few sparse patches of brown/red color	Almost no brown/red color at the boulder field scale. It is dominated by white/green color
	Alternance of undisturbed zones of boulders (brown/red MB) and disturbed zones of boulders (white/green MB)	Strong dominance of white/green MB and low representation of brown/red MB. Common characteristics beween the two categories of MB upper surfaces	No to rare brown/red MB, almost exclusive presence of white/green MB. Distinction between brown/red MB and white/green MB becomes ambiguous

4. **Estimation of the index value**: on the field, two options can be developed. (1) A rough but easy estimation of the green cover can be obtained from a fixed point of view (localized by GPS) for a simple monitoring. Photographs must be taken from this fixed position for further diachronic analysis. (2) A better estimation can be obtained by applying a more accurate protocol based on quadrats. Five 5*5 meters quadrats are placed randomly within the boulder field. In each quadrat materialized by a rope, the total number of MB is

counted: TnMB = n(green + white)B + nbrown/red B. Through this method, the rate of green cover is equal to the rate of green boulders. As illustrated on the Fig. 13.5, studies are on the way at the laboratory to better describe the processes of degradation—restoration of the biocenosis and the time required for one boulder to recover a full brown/red macroalgae canopy and to better indentify responses of species and group of species to the perturbation.

13.8 Conclusion

These examples of using opportunistic species behavior to characterize and survey the spatio-temporal variability of an anthropogenic perturbation, shows that the intertidalscape provides large perspectives for further developing the intertidalscape ecology approach. Wu and Hobbs (2002) underlined that the challenge was now to better define and identify strong relationships between spatial distributions and ecological processes. As evocated in this paper we are developing ecological studies to identify the species, functional groups and biotic interactions which are the driving force behind the observed changes at the landscape scales. On the other hand, efforts must be brought at the intertidal ecocomplex level to better understand complexity and heterogeneity of landscape components at different imbricate scales. Because of this high heterogeneity, ecological processes and patterns distributions seem sometimes incomprehensible and biocenoses seem chaotic (Menge and Branch 2000). A new approach of the ecological interactions and processes at the landscape scale should help to understand some patterns which cannot be understood at the smaller scales which are classically used by marine ecologists because the high heterogeneity and complexity of the rocky shores. By developing intertidalscape indicators and landscape ecology concepts which can be applied or adapted to the intertidal zone, it would be further possible to better detect early signs of perturbations, and then this landscape approach could play a main role in the long term monitoring of the environmental coastal quality in the future. Actually, to be robust and to avoid broad interpretation errors because perturbations step in different spatial scales from the global to the local, ecological surveys should be realized at regional scales. Early signal detection given by the intertidalscape indices should be able to activate specific scientific studies to better understand processes and, by helping management and conservation, should be able to prevent strong degradations of the ecosystem quality.

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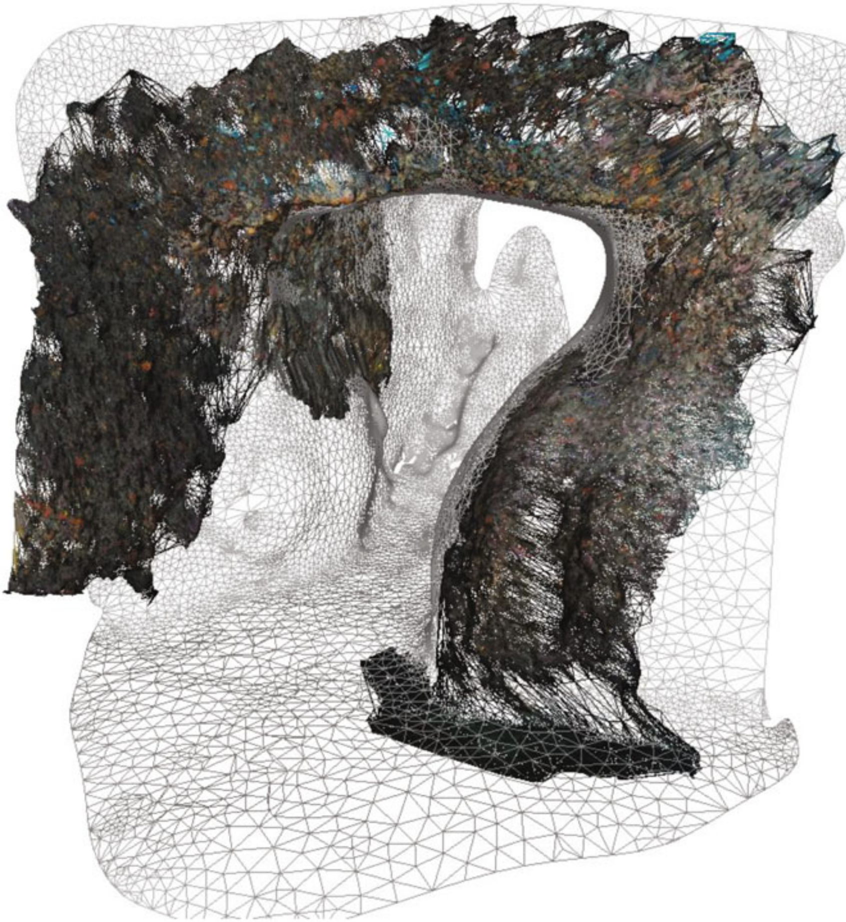
Part III
Tools, Methods and Instruments for Monitoring and Modelling Underwater Seascapes



Chapter 14
Underwater Multimodal Survey: Merging Optical and Acoustic Data

Pierre Drap, Djamal Merad, Jean-Marc Boï, Amine Mahiddine, Daniela Peloso, Bertrand Chemisky, Emmanuelle Seguin, Frederic Alcala and Olivier Bianchimani

Abstract ROV 3D project aims at developing innovative tools which link underwater photogrammetry and acoustic measurements from an active underwater sensor. The results will be 3D high resolution surveys of underwater sites and landscapes useful to keep in memory cultural and natural heritage. The new means and methods developed aim at reducing the investigation time in situ, and proposing comprehensive and non-intrusive measurement tools for the studied environment.

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In this paper, we are presenting a new method of 3D surveys which are dedicated to high resolution modeling of underwater sites. The main met constraints in situ are taken into account and this method leads to a precise 3D reconstruction. Some examples will present both the main obtained results and their limitations. We will end with the perspectives and the necessary improvements to the method, so as to automate the multimodal registration step.

Keywords Photogrammetry · 3D · Wreck · Digital photographs · Automatic Color Equalization

14.1 Introduction and Main Goals

ROV 3D project is partially funded by the European Regional Development Fund and the French Single Inter-Ministry Fund (FUI) for funding research involving both academic laboratories and industry.

The consortium consists of an organization of academic research, LSIS laboratory, and of two industrial partners, COMEX and SETP. COMEX is skilled in underwater scouting and outdoor engineering, whereas SETP is skilled in dimensional control by photogrammetry and topometry.

At the present time, and in the field of high resolution underwater surveys, there is no industrialized automatic treatment. Although, nowadays, certain private businesses propose service charge in underwater sharp metrology by photogrammetry, these offers use traditional methods of close range photogrammetry, based on automatic recognition of coded targets and bundle adjustment. These approaches, precise as they are, need human interference on the object and a site preparation (target laying in the place you want to measure), which, in the underwater context, may be a great handicap.

The project's goal is to develop automated proceedings of 3D surveys, dedicated to underwater environment, using acoustic and optic sensors. The acoustic sensor will allow acquiring a great amount of low resolution data, whereas the optic sensor (close range photogrammetry) will allow acquiring a low amount of high resolution data. From these two surveys, a high resolution numeric structure build 3D modeling of large complex scenes will be proposed to final users, with the production of different type of outputs (SIG 3D, MNT, Mosaic, …). These models can be analyzed and compare at any time and can be used to study sites or landscapes' evolution in time.

In practice, a 3D acoustic scanner will make a large scan of the scene to model, and an optic system will make the high resolution photogrammetric restitution of the different areas in the scene. While our software tools will do the automatic registration of both data sources, other algorithms, developed during the project, will recognize and model objects of interest. Eventually, these data will allow us to establish objects' symbolic representation and their geometry in a precise virtual facsimile, responding to the partners' need in documentation.

The ability to measure and model large underwater sites in a short time opens up many scientific challenges such as image processing, multimodal adjustment, land visualization and offers new opening to marine biology, underwater archaeology and underwater industry (offshore, harbour industry, etc.).

14.1.1 Underwater Image Processing: State of Art

The underwater image pre-processing can be addressed from two different points of view: image restoration techniques or image enhancement methods.

Fan et al. proposed a restoration method based on blind deconvolution and the theory of Wells (Fan et al. 2010). As a first step an arithmetic mean filter is used to perform image denoising, and then an iterative blind deconvolution using the filtered image is carried out. The calculation of the PSF of water is done using the following equations:

$$b = c\omega \tag{14.1}$$

$$H_{medium}(\psi, R) = \exp\left\{-cR + bR\left[\frac{1-\exp(-2\pi\,\theta_0\,\psi)}{2\pi\,\theta_0\,\psi}\right]\right\} \tag{14.2}$$

Where θ_0 is referred to the median scattering angle, ψ is the spatial frequency in cycles per radian, R is distance between sensor and object, b scattering coefficient, c attenuation coefficient and albedo ω.

Image restoration techniques need some parameters such as attenuation coefficients, scattering coefficients and depth estimation of the object in a scene. For this reason in our works, the preprocessing of underwater image is devoted to image enhancement methods, which do not require a priori knowledge of the environment.

Bazeille et al. (Bazeille et al. 2006) proposed an algorithm to enhance underwater image, this algorithm is automatic and requires no parameter adjustment to correct defects such as non-uniform illumination, low contrast and muted colors.

In this algorithm which is based on the enhancement, each disturbance is corrected sequentially. The first step is to remove the moiré effect is not applied, because in our conditions this effect is not visible. Then, a homomorphic filter or frequency is applied to remove the defects of non-uniformity of illumination and to enhance the contrast in the image.

Regarding the acquisition noise, often present in images, they applied a wavelet denoising followed by anisotropic filtering to eliminate unwanted oscillations. To finalize the processing chain, a dynamic expansion is applied to increase contrast, and equalizing the average colors in the image is being implemented to mitigate the dominant color. Fig. 14.1 shows the result of applying the Bazeille et al. algorithm.

To optimize the computation time, all treatments are applied on the component Y in YCbCr space. However the use of homomorphic filter changes the geometry, which will add errors on measures after the 3D reconstruction of the scene, so we decided not to use this algorithm.

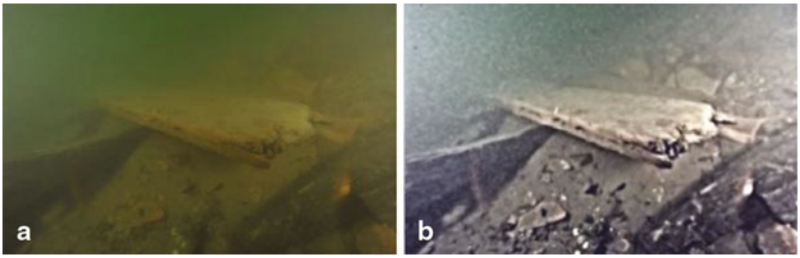
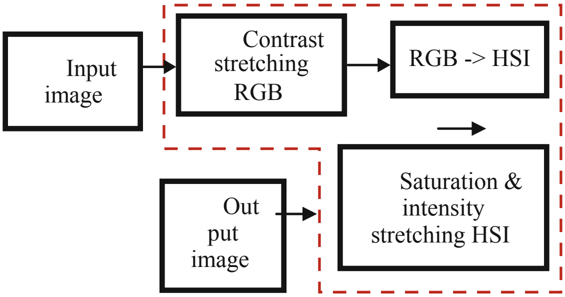


Fig. 14.1 Images before (**a**) and after (**b**) the application of the algorithm proposed by Bazeille et al. (Photo by Olivier Bianchimani (All rights reserved) on the Arle-Rhone 13 roman wreck in Arles, France)

Fig. 14.2 Algorithm proposed by Iqbal et al. (2007)



Iqbal et al. have used slide stretching algorithm both on RGB and HIS color models to enhance underwater images (Iqbal et al. 2007). There are three steps in this algorithm (see Fig. 14.2).

First of all, their method performs contrast stretching on RGB and then it converts the result from RGB to HSI color space. Finally, it deals with saturation and intensity stretching. The use of two stretching models helps to equalize the color contrast in the image and also addresses the problem of lighting.

Chambah et al. proposed a method of color correction based on the ACE model (Rizzi and Gatta 2004). ACE "Automatic Color Equalization" is based on a new calculation approach, which combines the Gray World algorithm with the Patch white algorithm, taking into account the spatial distribution of information color. The ACE is inspired by human visual system, where is able to adapt to highly variable lighting conditions, and extract visual information from the environment (Chambah et al. 2004).

This algorithm consists of two parts. The first one consists in adjusting the chromatic data where the pixels are processed with respect to the content of the image. The second part deals with the restoration and enhancement of colors in the output image (Petit 2010). The aim of improving the color is not only for better quality images, but also to see the effects of these methods on the SIFT or SURF in terms of their feature points detection. Three examples of images before and after restoration with ACE are shown in Fig. 14.3.

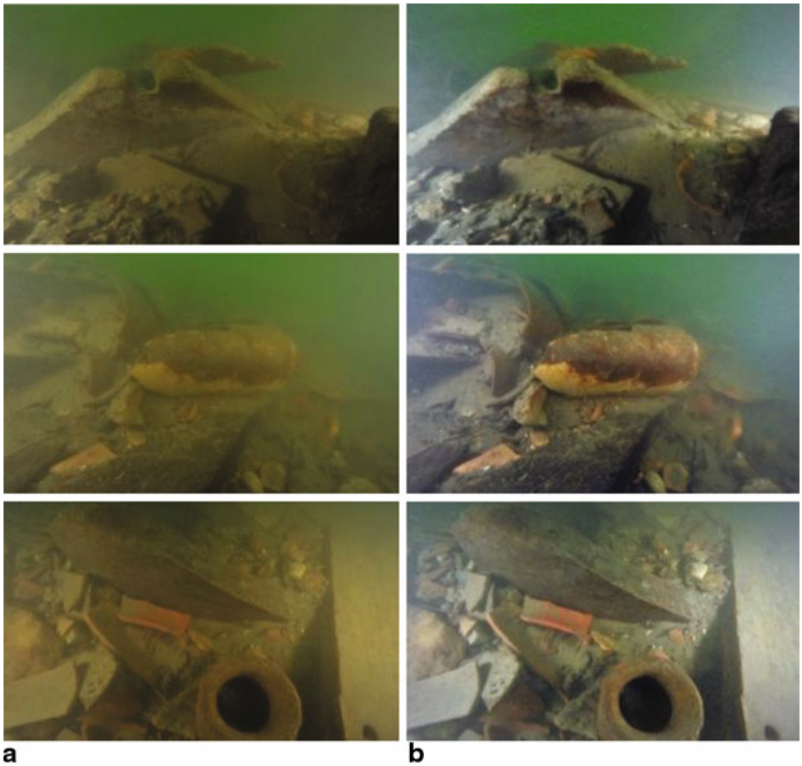


Fig. 14.3 Photographs of the wreck Arles-Rhône 13 (photo Olivier Bianchimani, all rights reserved), before (**a**) and after (**b**) the enhancement by ACE method. (Chambah et al. 2004)

Kalia et al. (Kalia et al. 2011) investigated the effects of different image pre-processing techniques which can affect or improve the performance of the SURF detector (Bay et al. 2008). And they proposed new method named IACE 'Image Adaptive Contrast Enhancement'. They modify this technique of contrast enhancement by adapting it according to the statistics of the image intensity levels.

If P_{in} is the intensity level of an image, it is possible to calculate the modified intensity level P_{out} with Eq. (14.3).

$$P_{out} = \frac{(P_{in} - c)}{(d - c)} \times (b - a) \tag{14.3}$$

where a is the lowest intensity level in the image and equal to 0, b is its corresponding counterpart and equal to 255 and c is the lower threshold intensity level in the original image for which the number of pixels in the image is lower than 4 % and d is the upper threshold intensity level for which the number of pixels is cumulatively more than 96 %. These thresholds are used to eliminate the effect of outliers, and improve the intrinsic details in the image while keeping the relative contrast.

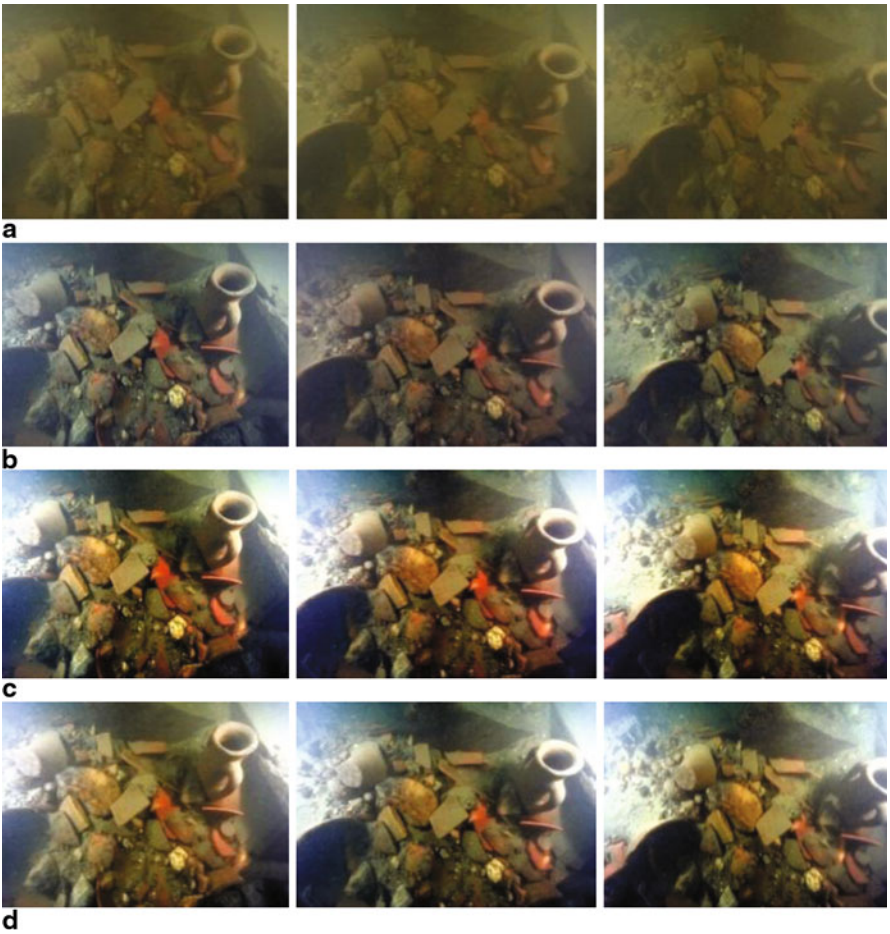


Fig. 14.4 Photographs of the wreck Arles-Rhône 13 (photo Olivier Bianchimani, all rights reserved), **a** original images, **b** results by ACE method, **c** results by IACE method "Image Adaptative Contrast Enhancement", **d** results by the method proposed by Iqbal et al. (2007)

The results of this algorithm are very interesting. One can observe that the relative performance of IACE method is better than the method proposed by Iqbal et al. in terms of time taken for the complete detection and matching process see Fig. 14.4.

14.1.2 Underwater Object Recognition

Pattern recognition process is complex and approaches to solve it are very different, depending on whether we have an a priori knowledge of the object or not, depending on the type and the number of used sensors (one or more 2D cameras, 3D cameras, telemeter, etc.), depending on the type of object to be detected (2D, 3D, random form, etc.). Nevertheless, there are two main families of methods to build a pattern recognition system: structural methods and statistical methods.

The first application related to our project is red coral monitoring. From its tentacular form, we are aiming at developing a structural approach which uses the objects' median (skeleton) axis as form descriptor.

There are many applications for 2D and 3D objects' skeletons in image processing (encoding, compression, . . .) and in vision in general (Merad et al. 2006; Thome et al. 2008). Indeed, we retrieve in the object's skeleton its topological structure; moreover, most of the information which are contained in the form's silhouette can be retrieved in the skeleton. Another advantage that cannot be denied is the fact that, by nature, skeleton have a graph structure. Hence, after the encoding of the coral's form under a graph structure through a 3D skeletisation process, we are going to use powerful skills from the graph theory so as to complete the matching (Shokoufandeh et al. 2005).

The second application consists in archaeologist objects recognition on an underwater site. Because of the a priori information we have, such as the type of the object (amphora, bottle, etc . . .), we will choose a statistic recognition method. (Baluja and Rowley 2005)

In an environment like wreck in 40 m deep, the vision conditions are strongly damaged. It is then necessary to free ourselves from preliminary treatments such as edge detection, line detection and other structural primitive.

Recent works showed the interest in using learning methods like adaboost, see (Freund and Schapire 1997). The advantage of this king of methods is to only need low level descriptors such as pixels' (Baluja and Rowley 2005). LBP's (Ahonen et al. 2006), Haar's (Viola and Jones 2001), etc.

For our problem, we are going to implement an Adaboost classifier; SIFT (Lowe 2004) and/or SURF (Bay et al. 2008) will stand for weak learners. We will check the relevancy of this method by comparing its results to other standard classifiers'.

14.1.3 Merging Optical and Acoustic Data: State of Art

Related Work Optic and acoustic data fusion is an extremely promising technique for mapping underwater objects that has been receiving increasing attention over the past few years (Shortis et al. 2009). Generally, bathymetry obtained using underwater sonar is performed at a certain distance from the measured object (generally the seabed) and the obtained cloud point density is rather low in comparison with the one obtained by optical means.

Since photogrammetry requires working on a large scale, it therefore makes it possible to obtain dense 3D models. The merging of photogrammetric and acoustic models is similar to the fusion of data gathered by a terrestrial laser and photogrammetry. The fusion of optical and acoustic data involves the fusion of 3D models of very different densities—a task which requires specific precautions (Drap and Long 2005; Hurtós et al. 2010).

Only a few laboratories worldwide have produced groundbreaking work on optical/acoustic data fusion in an underwater environment. See for example (Singh et al. 2000) and (Fusiello and Murino 2004) where the authors describe the use of techniques that allow the overlaying of photo mosaics on bathymetric 3D digital terrain maps (Nicosevici et al. 2009). In this case we have important qualitative information coming from photos, but the geometric definition of the digital terrain map comes from sonar measurements.

Optical and acoustic surveys can also be merged using structured light and high frequency sonar as by Chris Roman and his team (Singh et al. 2007). This approach is very robust and accurate in low visibility conditions but does not carry over qualitative information.

Merging Cloud of Points Merging between different sources is also one of the basic problems in computer vision, pattern recognition and robotics.

The fact that the correspondence points between two point clouds are unknown a priori makes the task of merging difficult and interesting in the same time. These points of correspondence are useful to estimate the position and orientation of one point cloud compared to another in the same coordinate system.

The methods used in this topic are often variants of the ICP (Iterative Closest Point) which has been proposed by Besl and McKay (Besl and McKay 1992) and which remains the most used in the majority of software for automatic registration between two models.

This method converges to the first local minimum which is due to the outliers of the matching. Several solutions have been implemented to solve this problem. Chen and Medioni (1991) suggest replacing the measurement of distance between points, which is used in the original method, by measuring the distance between a point and a tangential plane which makes the algorithm less sensitive to local minima.

Rusinkiewicz and Levoy (2001) provide a comparison between several variants of the standard algorithm in terms of convergence time. The authors also proposed an optimized method. The idea behind this method is to classify points in the direction of their normal, then sampling on each class and reject the outliers.

The objective of these methods is to calculate the rigid transformation between two partially overlapping point clouds. Their purpose can be decomposed into two parts; the first part is the matching between points of two clouds. The second part is the estimation of the transformation 3D.

Assuming that we have a set of matching points: $\{P_i\}$and $\left\{P'_i\right\}$ with $i = 1{,}2...N$.

$$\left\{P'_i\right\} = R \times P_i + t$$

where R is the rotation matrix and t is the translation.

To find the correct transformation between the two point clouds, we must find a solution that minimizes the least squares error.

$$err = \sum_{i=1}^{N} RP_i + t - {P'_i}^2$$

To solve this problem we can use the singular value decomposition (SVD) of the covariance matrix C, which is time-efficient and especially easy to use.

$$
\begin{aligned}
C &= \sum_{i=1}^{N} P_i - centroid_p \times (P'_i - centroid_{p'})^T \\
U,S,V &= SVD(C) \\
R &= VU^T \\
t &= -R \times centroid_p + centroid_{p'}
\end{aligned}
$$

With knowledge of how to compute the transformation between the two sets of matching points, the problem of merging data from different sources is summarized in the detection of matching points.

Many techniques have been proposed in literature to find the signature of an object at the scene or description of each point compared to its neighborhood.

Sehgal et al. (2010) proposed to use the SIFT feature detector (Lowe 2004) on 3D data, knowing that the use of this algorithm was reserved only for the detection of interest points in 2D images. They projected each point on a plane to form an image and the intensity of each pixel being the distance between the point and the plane. This method requires dense pixel information to use SIFT whereas the points from data are sparsely distributed.

Johnson and Herbert (Johnson 1997) introduced the notion of spin images to represent surfaces. Each spin image is a local descriptor of a surface to a point defined by its position and normal. This method requires that the two point clouds be of uniform resolution. Mian et al. (2006) used tensors to describe partial surfaces. They showed that this method is more efficient than spin images in terms of recognition rate and efficiency.

Sahillioglu and Yemez (2010) proposed an automatic technique to find correspondences between isometric shapes. They divided the data source and target into surface patches of equal area with each patch represented by the point at its center. This method needs an initial correspondence and the data must be isometric and represented as manifold meshes, which is not the case for data acquired by optical or acoustic sensors.

Rusu et al. (2008) introduced a new point signature which described the local 3D geometry. The signature was presented like a histogram with its invariant to position, orientation and point cloud density. First they estimated the surface normal at each point. Then they computed the histogram using the method proposed in Wahl et al. (2003).

Most of methods in literature use data taken from the same sensors or from CAD tools, but the main issues encountered in our topic are that data which come from different sources (optical and acoustic sensors) have different scales and different resolutions. That is why we try to find a method that will be less susceptible to these issues.

14.2 Photogrammetry: Dense Map

To model the environment by photogrammetry in an unsupervised way it is first necessary to automatically orient a set of unordered images. This orientation phase, which is crucial in photogrammetry, as computer vision, has seen the past three years a great boom. The problem was first solved in the case of ordered series of photographs, for example, made a circle around an object and recently in the case of photographs unordered (Barazzetti et al. 2010; Shunyi et al. 2007). Once all the photographs are oriented several methods are proposed for producing a dense cloud of 3D points to represent the area photographed.

Two major families of methods exist. Those that use solid models as the voxels (Furukawa and Ponce 2010; Zeng Gang et al. 2005) are based on the discretization of space into cells and the goal is to discriminate between full and empty cells to define the boundary between them. The advantage of this method is to use lots of photographs taken from arbitrary viewpoints. In contrast the delicacy of the final model depends on the resolution of the voxel grid can be RAM consuming. On the other hand methods using meshes could adapt their resolution to better reconstruct the details of the scene (Morris and Kanade 2000).

Also the work of Furukawa and Ponce on the dense map generation (Agarwal et al. 2010; Furukawa and Ponce 2010) have also resulted in open source publications. We use this work, merged with our own photogrammetric software in order to use calibrated camera and some constraints on the bundle adjustment, for several months and some examples are presented in this paper.

These developments were coupled with a software bundle adjustment of operating on an unordered set of photographs are based on an implementation of SIFT on GPU due to Changchang Wu, University of Washington (http://cs.unc.edu/ccwu/siftgpu) and implantation of developments PhotoTourism (Agarwal et al. 2010; Snavely et al. 2010). The bundle adjustment used is based on the Sparse Bundle Adjustment of Lourakis (Lourakis and Argyros 2009) and a version of the bundle adjustment of a set of unordered photographs is available in open source: Bundler software (Snavely et al. 2010).

On the other hand, since 2007 IGN (Institut Géographique National, in France) has decided to publish in open source the APERO MICMAC software, dedicated to the automatic orientation of an unordered set of photographs and the calculation of the automatic mapping on a set of photographs oriented. (http://www.micmac.ign.fr) (Pierrot-Deseilligny and Cléry 2011). Their approach is more rigorous from a photogrammetric point of view and allows using calibrated camera.

14.3 Acoustic Survey

The acoustic survey is mainly useful to produce a 3D model of the complete submarine site with a good precision in an absolute coordinate system.

To perform this survey an acoustic scanner 3D is used which can produce multiple 3D points with a same couple (x, y) coordinates, in opposite of standards bathymetric echo sounder.

This particularity is a essential to create a model of complex structures like walls, caves, overhangs . . .

The BlueView BV5000 system used is composed of a high frequency sonar (1,35 MHz), mounted on a pan & tilt system. Both Sonar and pan & tilt are managed from the surface by the dedicated software.

The system works by mechanically scanning a thin vertical sonar slice around the selected area. At each direction, a profile of the surface is taken and added to the other direction profiles to create a final 3D point cloud.

Through mechanical rotation of the sonar head, the BV5000 is capable of producing 3D points from a stationary location

To cover all the structure with enough density of points, multiple stations can be realized around the site and merged after by algorithms like ICP (iterative closest points).

Some reference points can be located with high accuracy in absolute coordinate system to georeferenced the final model.

The sonar head is composed of 256 beams for an aperture of 45 °. The beam width is 1 ° per 1 ° and time resolution is 3 cm. The maximum range is 30 m to be optimal between 1 and 20 m.

14.4 Experimentations

We present here the first experimentations of the ROV-3D project. The first one is merging acoustic data with photogrammetry in a cave close to Marseille (Fig. 14.7). And the second one is a survey of a modern wreck, “le Liban” also close to Marseille. This second survey is done only with photogrammetry with more than 1,00 photographs.

14.4.1 Close Range Acoustic and Optical Survey

Under the ROV-3D project we experimented with the fusion of acoustic data from two sensors, high precision, high frequency acoustic camera sold by Blue View and the photogrammetry system automatically MENCI society (see Fig. 14.5). An experiment was done on the Cave of the Imperial land in Marseilles.

The 3D Scanner is a BlueView BV5000 of active acoustic system that provides a point cloud of 3D high-resolution imagery of underwater sites, see the scanner during the acquisition phase in Fig. 14.6.

Unlike conventional bathymetric measurement systems that retain only the high points, the 3D sonar, installed near the bottom, can acquire and maintain multiple points of elevation Z for a given pair of coordinates (X, Y).

This system “3D Scanner” opens up new possibilities for constructing 3D models of complex structures such as drop offs, overhangs, or even caves.

The “3D scanner” is mounted on a hinged support along 2 axes (horizontal and vertical) allowing rotation from top to bottom and from right to left.

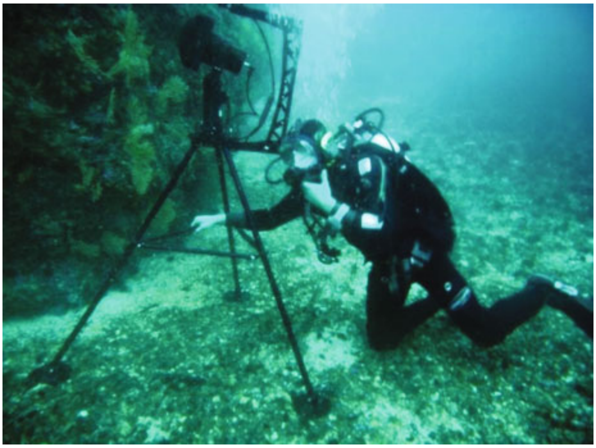


Fig. 14.5 The acoustic camera in situ, just in front of the cave—see next image—(photo Bertrand Chemisky, all rights reserved)

Fig. 14.6 The underwater cave close to Marseille, "L'Impérial de terre" 30 m depth (photo Pierre Drap, all rights reserved)

With an acoustic aperture of 45 ° of the scanner itself and the system is capable of measuring an area of 45 ° or 360 ° on a spherical surface comprising the whole environment surrounding it on the scanner and a range up to **30 m**. In the latter case, the rotation along the vertical axis that accumulated along the horizontal axis allows 4 or 5 scans cover the entire hemisphere to be measured.

Each scan or set of scans are performed in a fixed position and using such a tripod. To obtain a sufficiently dense cloud of points on the stage and studied by size, and multiple stations can be performed and the results merged.

Point clouds generated that were acquired from fixed stations, algorithms such as ICP (Iterative Closest Point) can assemble the sets of points against each other. It then remains to position the merged point cloud in an absolute reference, using reference points whose coordinates can be determined by acoustic positioning systems such USBL (Ultra Short Baseline).

Two dives were devoted to the acquisition of 3D data with the acoustic scanner.

Two more dives were used acchive the photogrammetry survey, see Figs. 14.7 and 14.8. This system consists of a hardware part, three cameras on a linear, calibrated.

Fig. 14.7 The photogrammetric survey using three digital camera synchronized (photo Pierre Drap, all rights reserved)

Fig. 14.8 Merging optical and acoustic underwater data

The shots are processed by a synchronous software house, which on one hand trying to calculate beam by adjusting the largest block possible, i.e. the block containing the most triples as possible, then once the block is calculated, the triplets are used to obtain a depth map of the central apparatus producing a dense cloud of 3D point. The adjustment of the beam is therefore only there to ensure the cohesion of these triplets, the 3D points to them being calculated using a single triplet.

The set of photographs were processed using the software from Menci company and also the pipeleine defined by a SIFT version, the Bundler (Snavely et al. 2010) and finally the dense map process proposer by Furukawe and Ponce.

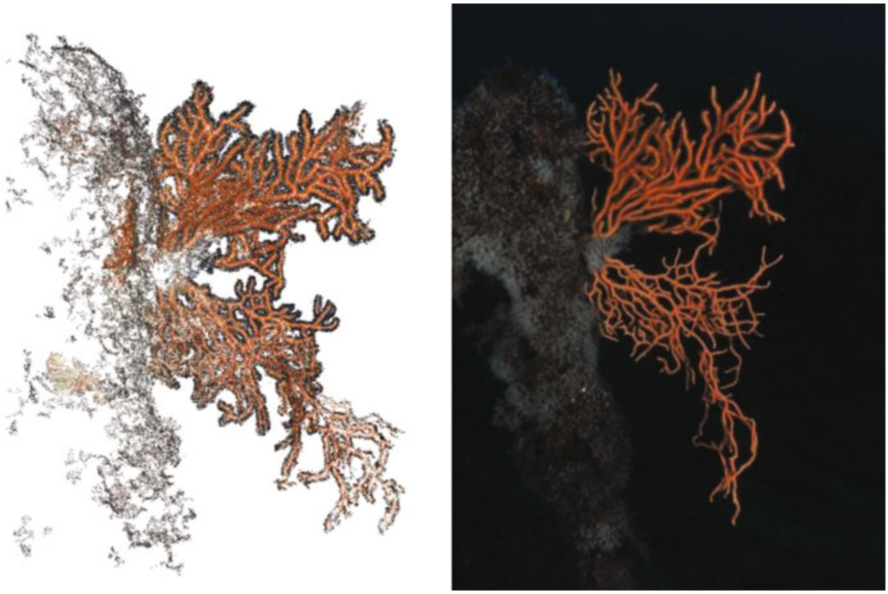


Fig. 14.9 On the right, one of the 64 digital photographs taken (photo Olivier Bianchimani, all rights reserved), on the left, the point cloud automatically computed by the Furukawa method

14.4.2 Large Scale Detail by Photogrammetry

We also tested as part of this mission approach automatic mapping proposed by Furukawa and Ponce (Furukawa and Ponce 2010). We tested this approach on large-scale details, Gorgonaria whose ends were slightly in motion because of the current, see figure below (Fig. 14.9).

One camera was used and sixty photographs were taken for each of the tests that follow. The study of the accuracy and the percentage of coverage was not yet done, that the study dating from April 2011.

14.4.3 The "Liban" Wreck

The Liban is a ship built in 1882 in Glasgow (Scotland), measuring 91 m long and 11 wide. It was equipped with a steam engine. On June 7, 1903 at noon, the Liban left the port of Marseille and less than 1 h later sunk after a big collision with another ship.

Today, the Liban is a very attractive dive site close to Marseilles at 25 m deep. We chose to survey the bow in order to develop and test our approach. Three dives and almost 2,000 photos were necessary to obtain the 3D point cloud visible in the next figure (Fig. 14.10 and 14.11).

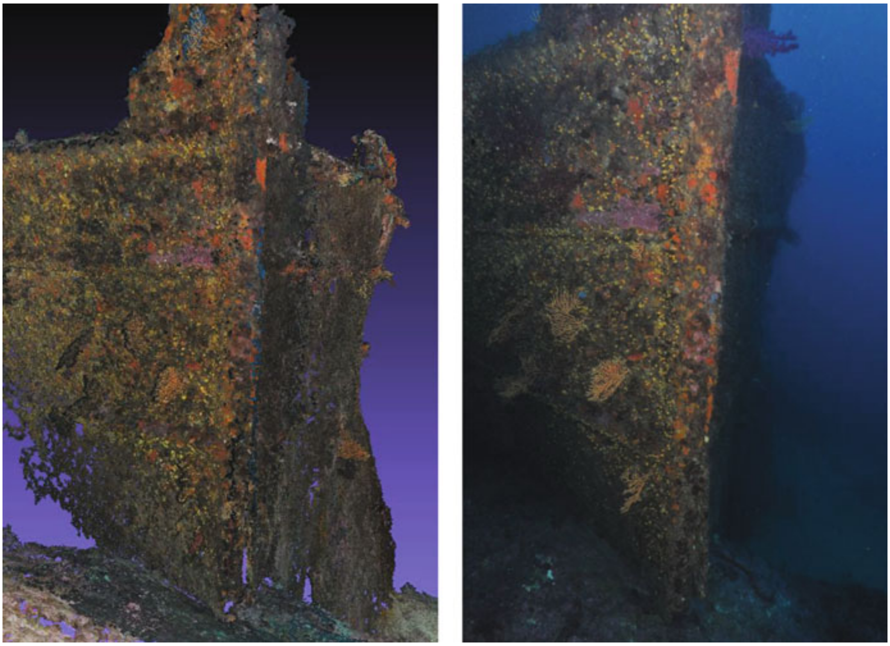


Fig. 14.10 On the right, one of the 1,221 digital photographs taken (photo Olivier Bianchimani, All right reserved), on the left, The "Liban" wreck.: Cloud of 3D points measured by photogrammetry using Furukawa method

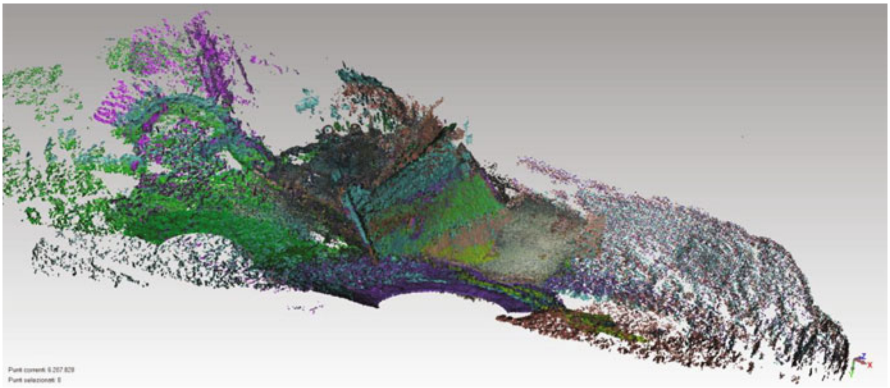


Fig. 14.11 An acoustic survey was done on the same wreck in order to scale the photogrammetric model. Each scan from its own station is represented in a different color

The acoustic survey was done in 1 day and six stations. All survey from these stations were merged using ICP algorithm with an RMS of 0.045 m.

The photogrammetric model, with a high dense cloud of point was scaled and georeferenced (on a local reference system) using the acoustic survey.

In this case, both of the survey see the more or less the same part of the site, the only big difference between them is the resolution and so, the general accuracy.

Merging photogrammetric data on the full acoustic model was done with an RMS of 0.032 m.

We are still working on merging partial photogrammetric survey on acoustic data in an automatic way.

14.5 Conclusion

The ROV3D is an ambitious project, partially funded by the European Regional Development Fund and the French Single Inter-Ministry Fund (FUI) for funding research involving both academic laboratories and industry and also by French regional structure as "Conseil Régional PACA", "Conseil Général des Bouches du Rhône" and "Marseille Provence Métropole". It takes benefit from a strong collaboration between a research laboratory and two private companies in order to be able to test and improve methods and algorithms.

The project aims to produce a complete set of tools and methods for underwater survey in complex and varied environment, for example, real 3D sites as caves, wrecks, walls where a simple type of terrain modelling as DTM is not enough.

Moreover the interest of this project is to produce accurate 3D models with texture information and thanks to the combination between the acoustic and the optical approaches developing specific image processing filters in order to correct photo illumination in underwater conditions.

The project is now quite mature and close to be fully operational. We are still working on marine integration in a small ROV and also on a real-time process in order to have continuous feedback on-board of the survey performed by the ROV. A draft mosaic and a 3D model can be computed on the fly using synchronized video cameras. We are working on a hybrid system, merging high- and low-resolution cameras in order to be able to process results in real-time as well as to be able to process results off-line with a high quality, as presented in Sect. IV of this paper.

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Chapter 15
Application of the Multi-sensor Fusion Method for Underwater Landscape Modeling

Claire Noël, Christophe Viala, Michel Coquet, Simon Marchetti and Eric Bauer

Abstract This paper presents application of multi-sensors data fusion to underwater landscape modeling.

It first deals with multi-sensors mini-oceanographic survey unit devoted to sea bottom mapping and monitoring developed by SEMANTIC TS. Then it presents research tasks conducted by SEMANTIC TS to develop a mapping method for underwater seabed. First stage is to develop methods for characterizing vegetation and sediment on the seabed using the acoustic response from a conventional single beam echo sounder. These new methods are then operated simultaneously with multi-beams sonar producing micro-relief information and side scan sonar providing gray scale levels associated with bottom reflectivity. Then fusion of these data is processed. We show efficiency of these multi-sensors survey unit and multi-sensors data fusion concepts to get very precise 3D bottom mapping allowing monitoring, in a way optimizing truth control (video and diving investigations). Examples are given on diving spot places showing results of these methods for underwater landscape modeling.

Keywords Mapping method · Reflectivity · 3D modeling · Acoustic survey

15.1 Introduction

SEMANTIC TS, is a research and development company in oceanographic acoustic, leading research since 2004 in the fields of mapping and monitoring of subsea areas. The following equipments and methods are operated simultaneously from a small oceanographic ship dedicated to research and mapping of the coastal waters:

- An interferometric side scan sonar (GEOSWATH+) that make possible the acquisition and realization of very well georeferenced side scan sonar mosaics as the same time as the acquisition of high density multibeam bathymetric data in

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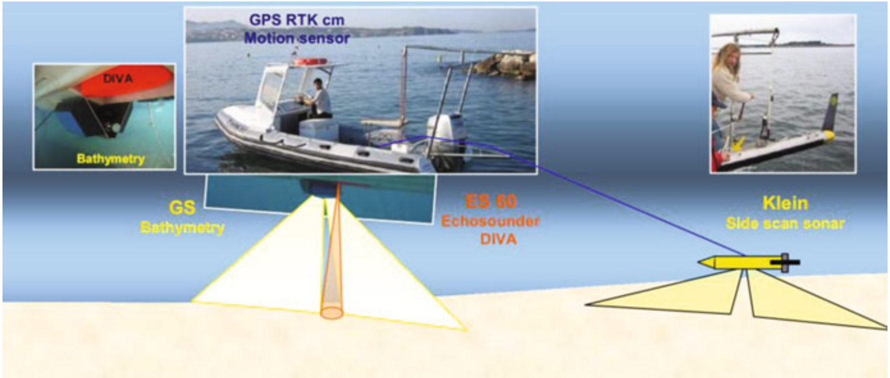

Fig. 15.1 Principle of multi-sensors acquisition

very shallow water environment (0.5–20 m). A towed side scan sonar is used for deeper environment (KLEIN 5000)

- DIVA method and algorithms implemented in 2005. this method uses the back scattered signal from a dual frequency echosounder (SIMRAD ES60—38 and 200 kHz)

An aim research tasks is to realize a reliable method that merge all the dataset from several sensor in order to obtain the most realistic view of the underwater landscapes.

15.2 Materials

Semantic TS has begun the project by setting up a coastal survey vessel devoted to environmental submarine surveys and maps. This survey unit is a small size semi-rigid boat (6.5 m) with removable cabin, allowing moving easily on a road-trailer, boat and all its equipments and instrumentation systems (Fig. 15.1). Mini-survey unit characteristics are:

Professional category; Useful load: 1,000 kg; Draught: 30 cm; Length: 6.4 m; Motor: 115 CV; 220 V in board; Available power 24/24: direct: 500 W/spike: 800 W.

This mini-survey unit is a French professional registered boat, driven by STCW professional pilots. Objectives of this boat are to improve mapping of coastal submarine, harbors, lakes, rivers (zero state area studies and their time evolution), submarine bottom survey for structures establishment, monitoring of submarine vegetation boundaries or sediment movements. Small size is useful to move precisely in narrow sea areas or to strictly follow predefined survey lines, which is a necessary condition for monitoring purposes.

This small size survey unit presents high level of technology, both for platform positioning systems and for acoustic sensors. Boat is able to produced energy to process simultaneously all the instrumentation in 24h/24h. High speed internet aboard is process by 3G to pass on D-GPS RTK corrections, from land reference D-GPS station, in real time.

Instrumentation systems are simultaneously deployed on the mini-survey vessel:

- Interferometric system Geoswath+ NG for multibeam bathymetry
- Interferometric side scan sonar Geoswath+ NG for precisely geo-located mosaic picture at 250 kHz
- Towed side scan sonar Klein 3900/5000
- Frequency 455 kHz/900 kHz
- Resolution 20 cm at 75 m
- Range max: 150 m for high resolution acoustic imagery
- Echo sounding Simrad ES60 high precision (scientific) for bathymetry/biocenoses/sedimentology
- Motion sensor Coda Octopus FS185+ for positioning and motion correction
- 2 D-GPS RTK Novatel for location and motion correction
- 2 D-GPS RTK Leica for land reference station and topography
- Automatic navigation and sailing system POSEIDON (on predefined survey lines)
- Data acquisition station
- Internet and VPN high rate (data transmission/reception)
- Mini-SVS Valeport profiler (Sound velocity profiles acquisition)
- Acquisition and processing data devices
- Geographic Information System—19” shelves available
- Professional divers. Video camera

Methods are operated simultaneously. Figure 15.1 shows principle of multi-sensors acquisition.

To drive all these instruments we have developed a specific software, playing role of an orchestra chef, named POSEIDON. This software pilots data synchronization, acquisition, datation and positioning.

As precise 3D scan pictures of sea bottom could only be obtained with very high accuracy at each step of data acquisition and processing, we have incorporated into POSEIDON, GIS functionalities, processing algorithms and data fusion process.

15.3 Methods

In order to produce help to acoustic imagery interpretation, we have first developed specific methods devoted to vegetation and sediment classification.

Principle of DIVA method (Detection & Investigation Vertical Acoustic), devoted to vegetation is based on single beam data automatic processing. The shape of acoustic bottom impulse response from a scientific echo sounder is recorded simultaneously with centimetric GPS position. As sand and vegetation have different acoustic signature shapes, we have developed a signal processing algorithm based on discriminant analysis and energy level of the bottom reflected impulse response (Viala et al. 2007). The DIVA method initially developed to Posidonia characterization is also efficient for zostera or laminaria localization and cartography. Simultaneous measurement using DIVA method should then increase the performance of multi sensors fusion method.

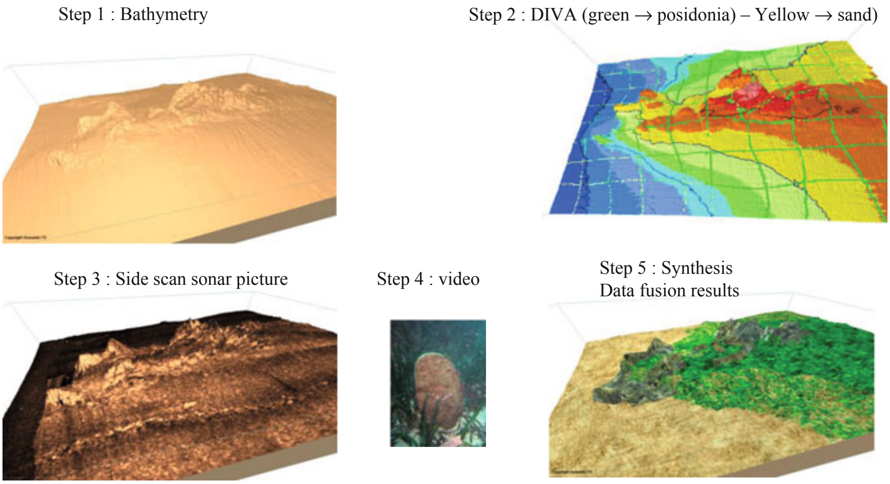

Fig. 15.2 Illustration of multi-sensors data fusion method results to landscape modeling by data fusion process on the "La Vaquette" site (near Cannes)

The DIVA method, developed by SEMANTIC TS, leads to various data, accurate and very well localized, in complement with those recorded from a towed video system which can be considered as "field truth". It also allows a rapid mapping of the vegetation in coastal plain; it can cover about 100 km line of survey per day and can help to georeferenced surface picture. The main inconvenience is the difficulty to find discriminant parameter when rock and vegetation are both present in the survey area. It can be noticed that DIVA method also gives excellent results on kelp mapping (VIALA et al. 2009; Noel et al. 2010). In addition, considering its high accuracy in data positioning (less than 1 m), DIVA method can easily be used in time evolution growing surveys of various species of coastal marine vegetation.

Moreover, we are now working to extend DIVA method into sediment classification (CLASS Method in progress), by the mean of hardness/roughness characterization, based on Chivers and al works (Chivers et al. 1990).

So as to produce precise 3D sea bottom mapping, we have developed on a second stage a method based on the fusion of data provided by acoustic systems (Noël et al. 2008):

- Geoswath bathymetric system
- Side scan sonar systems (Geoswath or Klein)
- Echo sounder

Methods are operated simultaneously, and data fusion is realized by combining, after signal processing, the data collection obtained:

- 3D bathymetric data
- Side scan sonar imagery in grey levels, producing information about reflectivity, and so about bottom nature. New generation of side scan sonars are able to deliver very high resolution picture

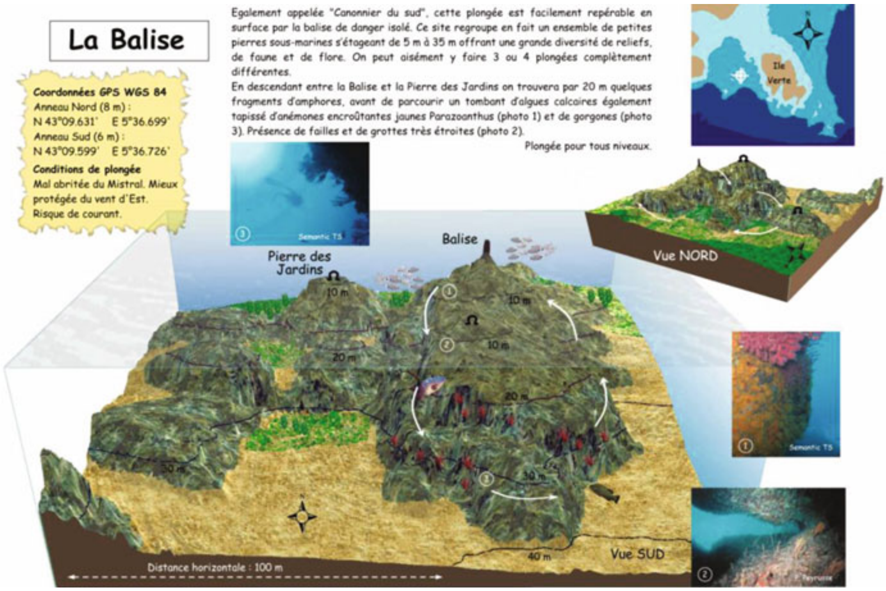

Fig. 15.3 Application of 3D bottom modeling by data fusion process: extract of a diving topo guide

- Micro-roughness derived from precise bathymetry
- DIVA method information about presence and absence of vegetation.
- CLASS method (in progress) information about bottom roughness and hardness

These methods have been successfully applied in French Riviera and Brittany, Guyana, and Corsica).

Figure 15.2 shows steps for 3D bottom reconstitution.

Figure 15.3 shows an application of 3D representation of the bottom, extracted from a diving topo guide realized in collaboration with VIRTUAL DIVE company (http://www.digitalocean.fr/).

Such precise and innovative 3D scan pictures of sea bottom could only be obtained with very high accuracy at each step of data acquisition and processing. For this we had to develop a specific GIS software inside which, we have incorporated processing algorithms.

15.4 Discussion and Conclusion

SEMANTIC TS develops since 2007 fusion methods of acoustic datasets from the previously detailed sensors:

- Bathymetry (underwater topography)
- Bathymetric micro-roughness

- Side scan sonar mosaic, the grey scale giving information about seabed reflectivity and consequently about its nature (vegetal or not)
- Information of presence or lake of vegetation given by the DIVA method

Concept of multi sensors dataset fusion is very powerful and innovative.

It allows producing like in medical applications, very accurate 3D scan pictures of seabed derived from different sources (side-scan, multi-beams, echo sounder) and information (aerial pictures, classification methods results, divers/video observations . . .). Power of data fusion concept remains on the quality of the data and on their complementarities. In this context such a mini-survey unit, able to operate and synchronize several complementary high resolution acoustic sensors simultaneously, and to precisely process motion and geo-positioning, appears as a very efficient tool in the crucial data collection first step of the data fusion process.

It allows realizing biocenotic maps very accurately with very few needs in term of human field observations (divers, camera). Obtained levels of accuracy and resolution are such that these methods allows to realize extremely accurate models of the underwater landscape from which we make diving spot 3D models in order to support environmental issues awareness and to give a help for scuba divers training staffs.

These precise data have also been used, in collaboration with VIRTUAL DIVE company, to make 4D model in the context of ANR "Digita Ocean" research project (video available on http://www.digitalocean.fr/).

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Chapter 16
Reefscape Ecology Within the South Pacific: Confluence of the Polynesia Mana Network and Very High Resolution Satellite Remote Sensing

Antoine Collin, Yannick Chancerelle and Robin Pouteau

Abstract Services provided by coral reef ecosystems are now highly altered by natural and anthropogenic disturbances. The integrated management of marine biodiversity hotspots relies on the description and the evolution of reef landscape at various scales. The network of Polynesia mana ensures punctual and biennial recovery monitoring of Scleractinian corals at a decametric scale resolution over seven countries and territories located in the central area of the South Pacific. Despite the wide regional coverage of such a monitoring, the structure and dynamics of the outer reefs cannot be continuously described. Very high resolution remote sensing overcomes this shortcoming and provides spatial digital models of bathymetry and benthic albedo at 0.5–0.6 m resolution. The synergy of the two methods allowed (1) the structure of Tiahura outer reef (case study, Moorea, French Polynesia) to be represented, (2) the temporal fluctuations that occurred between 2006 and 2010 to be elucidated, and (3) the impact of the joint proliferation of predator *Acanthaster planci* and Cyclone *Oli* to be identified. Coherence and complementarity of *in situ* and satellite data encourage its extension to other sites in the network and its application in the study and management of reef landscapes.

Keywords Coral reef monitoring network · Reefscape · Benthic photography · Very high resolution remote sensing · Multi-scale

16.1 Introduction

Coral reefs represent nearly a third of known marine species and provide valuable ecological services such as disturbance regulation (coastal protection), water recycling, biological control, refugia/habitat, food production (fishing, aquaculture), raw materials, recreo-tourism, and cultural or spiritual stimulation. All of these ecosystem services were estimated at US$ 375 billion worldwide per year (Costanza et al. 1997). However, these systems undergo increased anthropogenic disturbances:

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climate change, rising sea temperatures and acidification, disease, pollution, direct destruction, sedimentation, unsustainable fishing practices (Hoegh-Guldberg 1999; Lesser 2004; Wilkinson 2008).

In response to disturbances, the external areas of coral reefs suffer from large temporal variations (Hughes 1989; Connell et al. 1997; Ninio et al. 2000) both in terms of quantity (coral cover) and qualitatively (coral species richness). This high variability is confirmed by observations made on the monitoring network Polynesia mana. For almost two decades, the network has collected and analyzed the health status of the outer reefs in 15 islands of Eastern and Western Polynesia in the South Pacific. Variations are generally correlated with natural disturbances both physical (cyclones or strong waves) and biological (outbreak of predator *Acanthaster planci*). The direct influence of warmer waters is still a minor threat, in this context, but bleaching events inducing moderate to low coral mortality, however, were reported in French Polynesia in 1992, 2002 and 2003 (Salvat 1992; Adjeroud et al. 2009).

The method used to detect changes in health status in the context of this monitoring is the Point Intercept Quadrat conventionally used in phytosociology, and then adapted to benthic studies (Loya 1978). Like other similar methods (*e.g.* linear transect), it provides, with appropriate sampling strategies, accurate results usable for relevant spatio-temporal reef comparisons. This type of method is dedicated to sampling units at the meter or decameter scale and requires discrete investigations such as snorkelling or scuba diving. This method therefore constrains both the size of the entities studied and the geographical representativeness of coastal observations, not exceeding the linear kilometer. However, quantitative and qualitative benthic variables characterizing a linear outer reef exhibit spatial homogeneity that does not exceed the scale of tens of kilometers. In addition, within the same coastline, the inter-site variability of coral substrates may become significant (*e.g.* Murdoch and Aronson 1999). Of special importance, these methods do not take into account the three-dimensional aspects of sampled entities and therefore do not reveal the landscape changes of structural species, living or dead, which shape most of the reef habitats (Connell 1978). Understanding the variability between sites and mapping the biological morphology of outer reefs over large areas is thereby hardly achievable by manual fieldwork, by definition punctual and disparate. On the other hand, hydrographic and oceanographic campaigns by ship may be dangerous or impossible over shallow reefs. Recent advances in remote sensing can partially address these challenges. Satellite sensors endowed with very high spatial resolution (VHR) now provide spectral information at a sub-meter accuracy, continuously over several square kilometers.

The present work aims to demonstrate, using Tiahura case study (Moorea, French Polynesia), how the VHR spaceborne remote sensing (QuickBird-2 and WorldView-2) can be used to supplement the observations obtained with conventional *in situ* methods implemented in the monitoring network Polynesia mana, so that the temporal variations of parameters characterizing the coral communities and their architecture can be assessed. The long term ambitions of this work are to provide a tool for finely evaluating the health of Polynesian outer reefs on a very large scale, compounded with conventional methods of benthic surveys.

16.2 Polynesia Mana Network

16.2.1 Description of the Network

Polynesia mana coral monitoring network (Fig. 16.1) was initially set up in French Polynesia in 1993, in the context of a long term monitoring of the health of coral reefs. It now covers a dozen sites in the five archipelagos of ten islands, Moorea, Raiatea, Tahiti, Tetiaroa (Society Islands), Nengo Nengo, Takapoto, Tikehau (Tuamotu Archipelago), Nuku Hiva (Archipelago Marquesas), Tubuai (Austral Islands), South Marutea (assimilated to the Gambier Archipelago). This action initiated on the French Polynesian territory has been extended across the southern Pacific in recent years. Node Polynesia Mana (part of the Global Coral Reef Monitoring Network—GCRMN) now includes seven countries or territories (Cook Islands, French Polynesia, Kiribati, Niue, Tokelau, Tonga, and Wallis and Futuna), which represent a total land area 6,000 km^2 for 347 islands and an Exclusive Economic Zone (EEZ) of 12 million km^2. This area of 13,000 km^2 of coral reefs is the main natural resource for 500,000 inhabitants, whether in terms of food, financial resources through tourism, aquaculture, intensive or extensive (black pearls, seaweed, clams, fish) or other forms of exploitation of the environment (*e.g.* collecting shells, aquarium fish for the international market).

During the twentieth century, these countries have undergone rapid development resulting in urbanization, increased population and agricultural and industrial development. This development is concentrated on a few islands (*i.e.* 15 islands on 347 subjects), resulting in degradation of coral reefs in the most populated areas (Gabrié 1998; Guards and Salvat 2008; Wilkinson 2008). The other islands are, for the moment, relatively unaffected by this development. Centralizing industry has increasingly tended to reinforce the flow of people from the remote to the more populated islands to meet the demand for dietary protein and to access a more westernized lifestyle.

16.2.2 Benthic Assessment Methods

The photo-quadrat method is used to measure the permanent percentage of coral cover while distinguishing Scleractinian coral genera in a reproductible manner on the same area. The values obtained on the same reef plot are updated every 2 years. The method involves photographing a 20 m long and 1 m wide (20 m^2) rectangular surface area. A steel cable of 20 m is strongly stretched between two poles by means of a turnbuckle. On this cable, a series of clamps fixed at regular intervals enables for setting an aluminium frame (1×1 m size of internal contours) at 20 successive positions. At each position, the frame is photographed (Fig. 16.2a) so that the band of 20 m^2 can be accurately represented. The method used for data processing is the Point Intercept Quadrat (Weinberg 1981). Eighty-one points are superimposed over each quadrat photographs (Fig. 16.2b) and are systematically distributed offset lines.

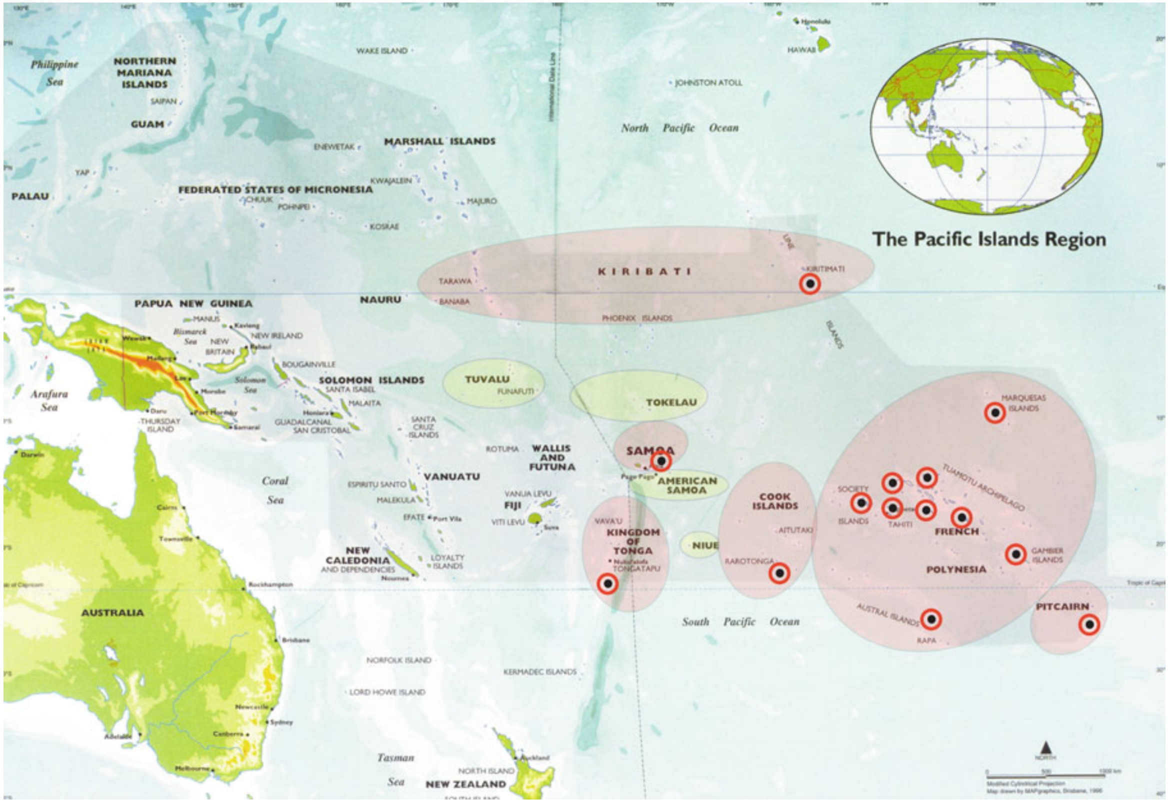

Fig. 16.1 Geographical representation of Polynesia mana network. The *red* areas represent countries or territories where the surveys are periodically carried out and where collaboration agreements have been established with the departments concerned. The *green* areas represent the future facilities. The exact position of the active sites (16 in all) is marked by a *red* cockade

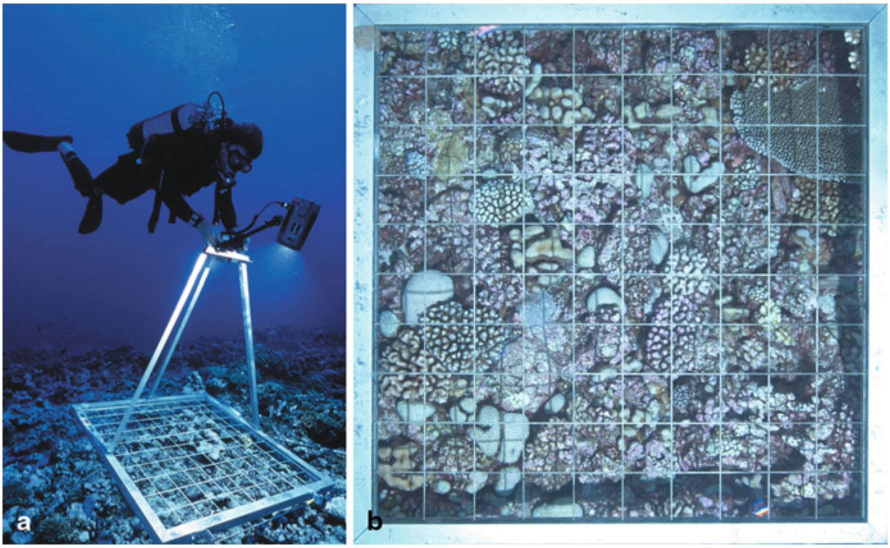

Fig. 16.2 The method of photo-quadrat permanent. **a** Quadrat guided by a cable stretched across the reef is photographed on the same 20 positions once a biennal. **b** Photograph of quadrat grid with rope for counts of live coral

The identification and counting of live coral at each point allows for the estimation of the percentage of total recovery (= 100 × number of points on living coral/81). Partial recovery for each genus is obtained by differentiating the equality in counted points.

The Manta tow technique (English 1994) involves dragging an observer with a boat at low speed. The observer stands on a large wooden plate, which is connected to the boat by a rope. The plate carries a sheet on which the living coral cover is noted as it progresses. The coral cover is assessed according to five categories of area occupied by corals with the following limits: 0–10–30–50–75–100 % (Dahl 1973). The data are taken on four 500 m sections, equally distributed circa the above-mentioned surveyed transect. They are used to validate the representativeness to a larger scale (km) of the results obtained with the photo-quadrat method.

A permanent panoramic photographing method involves capturing a landscape reef portion of the surveyed area from a fixed support using a camera. From a survey campaign to another, the panoramic photographs are shot at a constant angle of view (Fig. 16.3).

16.2.3 Experimental Section

16.2.3.1 Study Site

The study was conducted on Moorea island (17°29′31″ S, 149°50′08″ W), in the archipelago of the Society, French Polynesia (Fig. 16.4). Isolated islands of the

Fig. 16.3 A photographic monitoring of the landscape used on Polynesia mana network sites. At each survey the landscape photograph is taken in accordance with the same angle of view

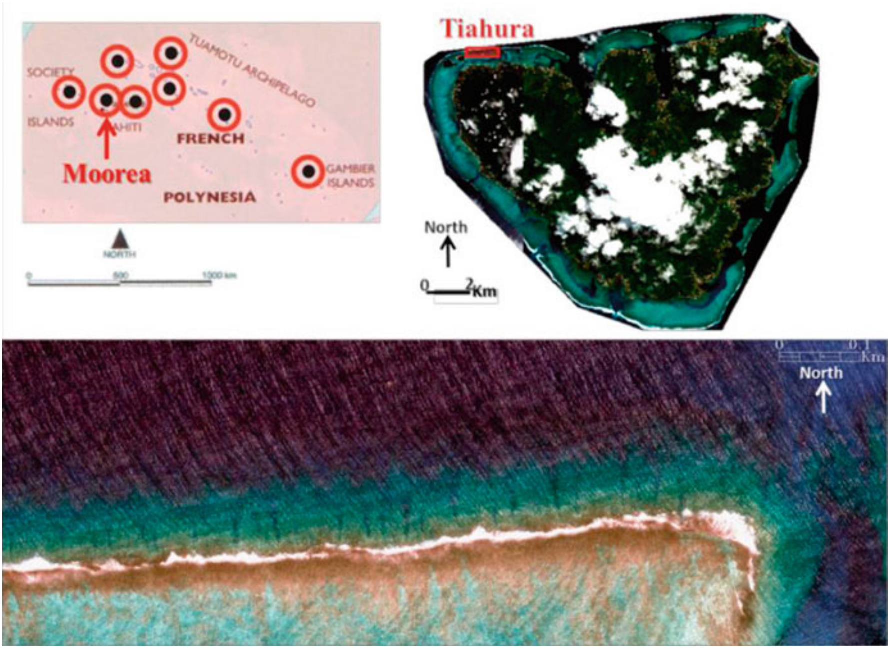

Fig. 16.4 Location of the study site on the island of Moorea, Society Islands, French Polynesia

tropical Pacific are particularly suitable for passive remote sensing studies given the clarity of the water column. The study site is located northwest of Moorea, within Tiahura marine protected area (MPA). The reef health of this area benefits from a monitoring since 1987. Covering 0.4227 km^2, the site includes the barrier reef, reef crest, the outer reef and a pass. Ranging from 0–23 m, the water depth distribution shows a clear distinction between the shallow lagoon and the outer reef-pass system (Fig. 16.4).

Table 16.1 Spectral specificities of the sensors QuickBird-2 (QB-2) and WorldView-2 (WV2)

Band name	Wavlengths QB-2 (nm)	Wavelengths WV-2 (nm)
Purple		400–450
Blue	450–520	450–510
Green	520–600	510–580
Yellow		585–625
Red	630–690	630–690
NIR 1		705–745
NIR 2	760–890	770–895
NIR 3		860–1,040
Panchromatic	450–900	450–800

16.2.3.2 Ground-Truthing

Whilst the coral cover was measured based on the methods of permanent photo-quadrat and manta tow, the landscape structure was identified through the panoramic survey method.

In order to connect the products of remote sensing and bathymetry, the depth measurements were acquired to calibrate and validate the digital depth model (DDM). A 0.1 m accuracy acoustic system (sonar Lowrance LMS-527 CDF iGPS) was mounted on a 5 m length aluminum boat. Each acoustic measurement was collected at mild conditions regarding the swell and wind, to optimize the vertical acquisition. The datum used was the WGS-84 and projection was referenced according to the UTM Zone 6 South.

16.2.3.3 Remotely-Sensed Imagery

Two datasets were used for the purpose of the study, a QuickBird-2 (QB-2) dataset, acquired 9 November 2006, and a WorldView-2 (WV-2) dataset, acquired 17 March 2010. Whilst the QB-2 dataset includes four bands (three in the visible and one in the infrared spectrum) processed at 0.6 m, the WV-2 dataset leverages eight bands (five visible and three infrared) processed at 0.5 m (Table 16.1).

The processing carried out to achieve this very high spatial resolution (VHR) stemmed from the enhancement method called pansharpening. Based on the purple band, showing the highest entropy index and the lowest attenuation by water, the Gram-Schmidt algorithm enabled the QB-2 and WV-2 multispectral bands of 2.4 and 2 m resolution, respectively, to be merged with the panchromatic band of 0.6 and 0.5 m resolution, respectively (see Collin and Planes 2012). Given the obvious roughness of the water surface driven by wind, a sun glint procedure has been applied to the QB-2 dataset (Fig. 16.5). Based on the assumption that only the specular reflection induced by waves is recorded by the infrared channel, it is possible to correct each of the three visible bands (Hedley et al. 2005). This leads to the following equation:

$$L_i(V)_{corr} = L_i(V) - a_i \times [L(NIR) - L_{\min}(NIR)] \qquad (16.1)$$

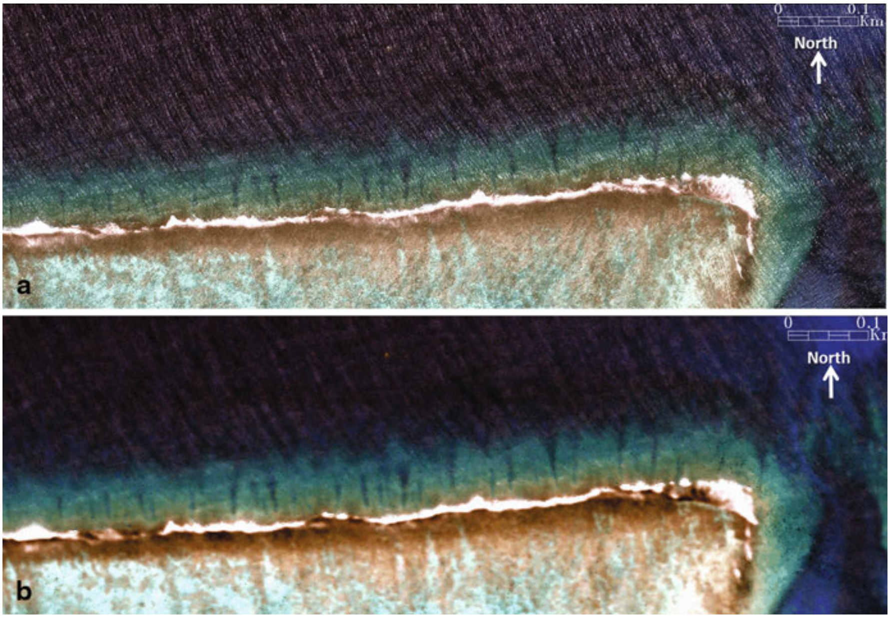

Fig. 16.5 Sun glint procedure applied to the data set QB-2. **a** Initial. **b** Corrected

where $L_i(V)$ is the luminance of the original band i, a_i is the coefficient of the slope, $L(PIR)$ is the luminance of the infrared band and $L_{min}(PIR)$, the minimum of this band.

To compare both datasets, a normalization process was undertaken, using the image processing software IDL-ENVI (Research Systems, Inc.). First, a geometric correction, based on the trigonometry of the sun-scene-sensor system and *in situ* collected remarkable points, yielded mapping products with an accuracy greater than or equal to 0.6 m. Second, a radiometric correction was split into two phases: the radiance calibration and atmospheric correction. The radiance calibration consists of converting a digital value (gray value) into a physical value (in $W.m^{-2}.Sr^{-1}$). The atmospheric correction was applied by adjusting the MODTRAN4 algorithm with the metadata supplied with the imagery. In addition to compensate for the attenuation phenomena inherent to the tropical air column, the algorithm corrects for the adjacency effects. This correction transforms radiance values in reflectance value corresponding to the ratio of the radiance leaving the water surface with the radiance penetrating the water surface (also called the irradiance).

For the sake of meaningful comparisons, the spatial and spectral resolution of WV-2 were degraded to achieve those QB-2, that is to say 0.6 m and 4 bands, *i.e.* blue, green, red and NIR (Fig. 16.6a and d).

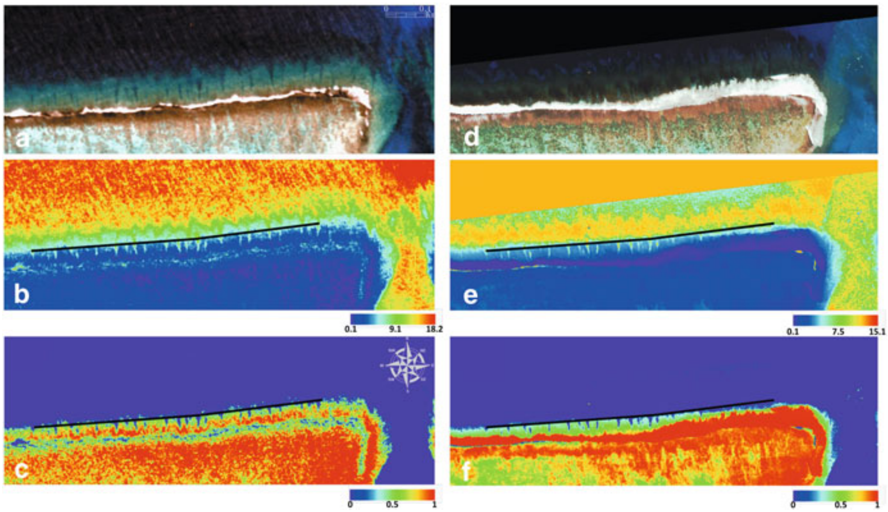

Fig. 16.6 Digital products from the QB-2 and WV-2 datasets. **a** and **d** RGB Images geometrically and radiometrically (atmosphere) corrected from QB-2 and WV-2. **b** and **e** digital depth models from QB-2 and WV-2. **c** and **f** Digital models of the entropy of the bottom albedo from QB-2 and WV-2. Transects (*black* segments **b**, **c**, **e** and **f**) characterize the study area

16.2.3.4 Modeling the Bathymetry

The light direction and propagation are strongly affected by interactions with the constituents of the water column, such as water molecules, dissolved and particulate matter. The attenuation phenomena, such as scattering and absorption, produce an exponential reduction in reflectance with respect to depth. Lyzenga (1981) showed that the relationship between reflectance, inherent to a band, the depth and bottom albedo could be described by:

$$R_w = (A_b - R_\infty)\, e^{-gz} + R_\infty \tag{16.2}$$

where R_w is the reflectance above the water surface, $R_\infty$is the reflectance of the water column (bottom depth > 40 m), A_b is the bottom albedo, g is the attenuation coefficient of light in water, and z the depth.

Attempting to analyze reflectance data that have not been previously corrected for depth can lead to substantial biases. The spectral signatures of shallow benthic components exhibiting strong absorption in the visible might be confused with deeper benthic components endowed with high reflection in the visible. The method of the bathymetry extraction of Stumpf et al. (2003), requiring only a single parameter to be adjusted, was adopted to model the z:

$$z = m_1 \frac{\ln(nR_{wi})}{\ln(nR_{wj})} - m_0 \tag{16.3}$$

where R_{wi} and R_{wj} correspond to the water-leaving reflectances of the bands i and j, respectively, m_1 is a calibration function of the ratio, n is a constant ensuring the logarithm positivity, and m_0 is the offset. For each of both datasets, the function m_0 has been characterized using 122 acoustic samples and the statistical relationship linking the ratio values with those obtained in the field has been correctly modeled by a linear function ($R^2 = 0.69$):

$$Z = 18.2 \times \frac{\ln(nR_{wi})}{\ln(nR_{wj})} \tag{16.4}$$

The above modeling has been implemented and a DDM sampled at 0.6 m was constructed for each of the datasets (Fig. 16.6b and e). Whilst the maximum depth has been estimated at 18.2 m, the minimum depth was about 0.1 m, which may conceivably correspond to the vertical resolution of the DDM.

16.2.3.5 Bathymetric Analysis

The habitat roughness is greatly correlated with the availability of ecological niches (Luckhurst and Luckhurst 1978). Following the modeling of bathymetry, the depth distribution was investigated using the moment theory. A transect, with a total length of 742 m, was plotted in the furrows of the outer reef (Fig. 16.6b and e). This transect provides the basis for diachronic analysis of the bathymetry between 9 November 2006 and 17 March 2010.

16.2.3.6 Modeling the Bottom Albedo

The depth is needed to quantify the light attenuated by the water column. The model is thus to compensate for this attenuation as a function of the spectral bands, thereby obtaining the bottom albedo. By inverting the radiative transfer model (Eq. 16.1), the bottom albedo may be expressed as:

$$A_b = (R_w - R_\infty)\, e^{gz} + R_\infty \tag{16.5}$$

where g (the attenuation coefficient) is $2 \times Kd$. The diffuse attenuation coefficient, Kd, was estimated for each band by referring to a previous study of the inherent optical properties of Moorea water lagoon (Maritorena et al. 1994) (Table 16.2).

Thus, in the presence of the bathymetry z, of the reflectance estimation of the water column without influence, R_∞, and of the attenuation coefficient, g, Eq. 16.4 can be solved for each pixel and each band.

16.2.3.7 Spectral Entropy of the Benthos

Despite careful corrections applied to the datasets, some components, usually detectable at high frequency, convey noise into digital products. These components originate from the sensors' electronic shift or from the three-dimensional variability

Table 16.2 Diffuse attenuation coefficient (Kd) used for modeling the benthic albedo/reflectance

Band name	Diffuse attenuation coefficient (m^{-1})
Purple	0.13
Blue	0.1
Green	0.11
Yellow	0.335
Red	0.5

of aerosols or hydrosols (particles included in the air and water columns) underestimated by correction models. One solution lies in focusing on relative values rather than absolute values. The digital model of the bottom albedo, composed of three visible bands, has been converted into the digital model of its entropy, according to this equation:

$$E_{Ab} = -\sum_{i=1}^{3} pi \times \ln(pi) \tag{16.6}$$

where i is the ranking number of the band and pi refers to the relative abundance of the band i in the sum of the three bands (spectrum). This index is bounded by 0 and 1; when it reaches 0 the spectrum is composed of a single band whilst it equals 1 when the spectrum consists of a strict equality of the bottom albedo of the three bands. A greater diversity of the bands leads to an increase of E. Indicating the relative proportions of the three bands, this index provides a synthetic and relative value of the bottom albedo, offering therefore the possibility to analyze the diachronic evolution. The transect used for the analysis of the bathymetry (total length of 742 m) was also adopted to examine the change in the entropy of the bottom albedo occurring between 9 November 2006 and 17 March 2010 (Fig. 16.6c and f).

16.3 Results

16.3.1 *Time Series of Coral Cover*

The substantial temporal variations of coral cover recorded on Tiahura site between 1997 and 2011, concur with those usually experienced by outer reef communities of a high island in French Polynesia (Adjeroud et al. 2005, 2009). The evolution of the coral cover percentage, regardless the genus and obtained from the method of permanent photo-quadrat at the decimeter scale and confirmed by the manta tow method at the kilometer scale, is shown in Fig. 16.7. It consists of two phases. The 1997–2005 period is characteristic of a stable phase in which the recovery values systematically exceed 30 %. Follows a considerable decline phase (2005–2011) in which the recovery falls from 40 to 0 % in 3 years.

On the other hand, the analysis of panoramic or landscape photographic surveys (Fig. 16.8) indicates a reduction of the structural complexity defined by the reef texture.

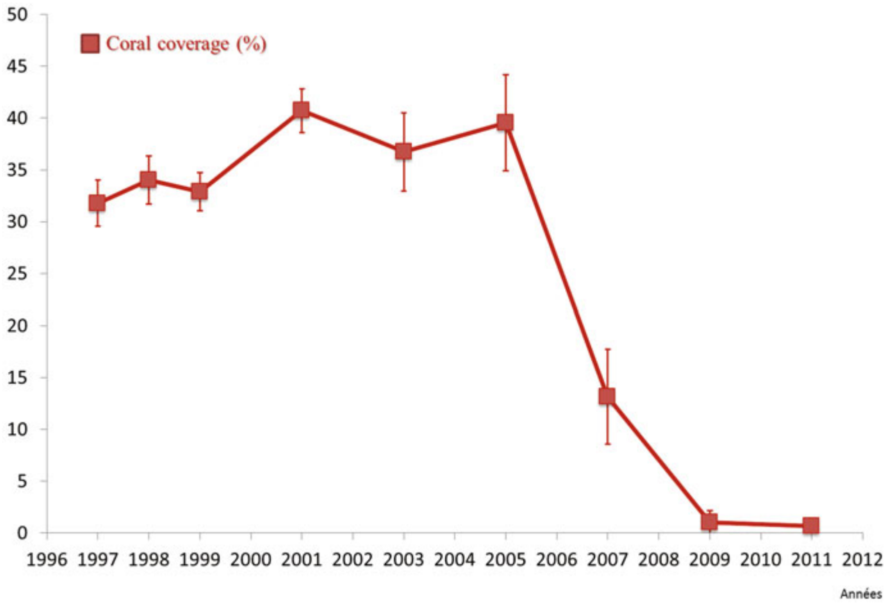

Fig. 16.7 Evolution of the percentage of coral cover of Moorea northern outer reef (Tiahura, depth: 10 m) over the period 1997 to 2011. During this monitoring period, the coral population has suffered two minor coral bleaching events (2002, 2003) and two major phenomena: an invasion by predator *Acanthaster planci* (2006–2010) and a cyclone (*Oli*, February 2010)

16.3.2 Changes in Bathymetry

The spatial pattern of DDM remains unchanged for both datasets, *i.e.* for the two acquisition dates (Fig. 16.9a and c). The shallow (maximum 3 m) barrier reef (south of the reef crest) sharply contrasts with the outer reef (north of the reef crest) and pass (3–18 m). The transect is located on the furrows of the outer reef, ensuring a continuous transition between the reef crest and outer reef (0–10 m). However, a detailed examination of the transect reveals significant differences between the two dates. Although the average depth are identical (8.49 and 9 m, p-value > 0.05, NS), the variances are significantly different (1.53 and 0.12, p-value < 0.01), as evidenced by the aspect of the 2006 curve which is more “rugged” (Fig. 16.9b and d). For example, the profile between 0 and 100 m is steeper in 2006 than in 2010. Similarly, three peaks located between 350 and 450 m, are clearly defined in 2006, whereas a single is still visible in 2010.

16.3.3 Change in Bottom Albedo

The digital models of the spectral entropy of the bottom albedo suggest a constant visual pattern, basically, between 2006 and 2010 (Fig. 16.9e and g). The barrier reef

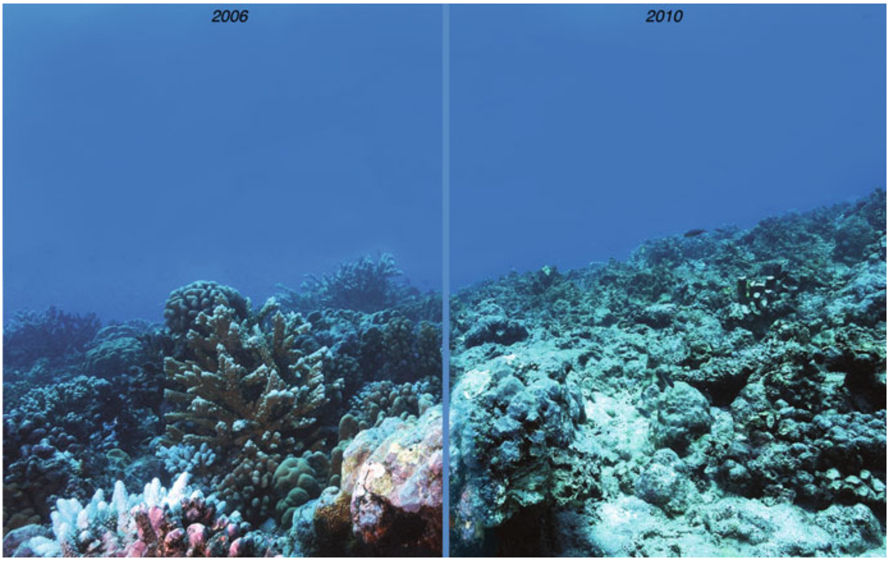

Fig. 16.8 Comparisons of panoramic views on a site monitoring of Moorea northern outer reef (Tiahura) in 2006 (*left*) and 2010 (*right*). Between the two photos, an outbreak of predator *Acanthaster planci* (2006–2009) and the Cyclone *Oli* (February 2010) occurred

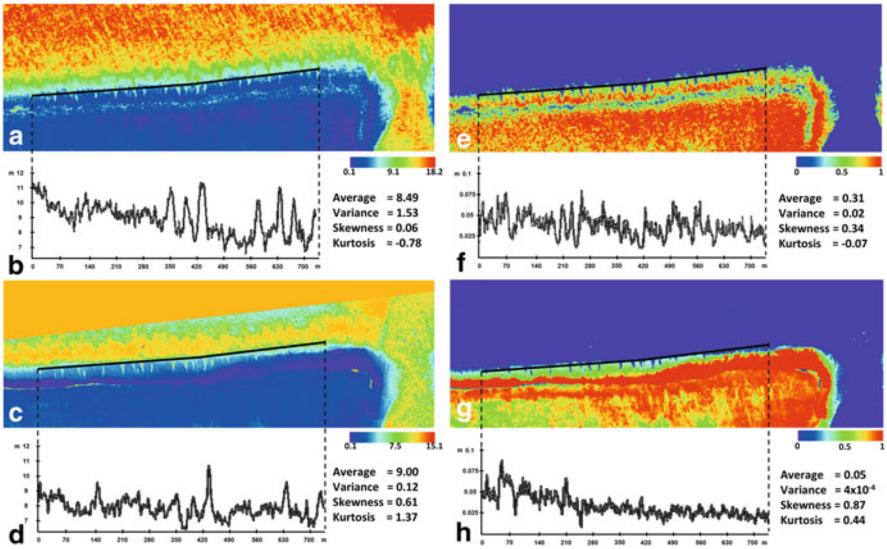

Fig. 16.9 Comparison of digital depth models from QB-2 (**a**), and WV-2 (**c**), using transects (*black segments*) projected along the axis of the depth (**b** and **d**, respectively), and digital models of the entropy of the benthic albedo from QB-2 (**e**), and WV-2 (**g**), using transects (*black segments*) projected along the axis of the entropy of the benthic albedo (**f** and **h**, respectively)

displays a diversity of the three bands obviously superior to this of the outer reef, further offshore, as well as the pass. This result reflects the variability of the spectral reflectance in shallow water, which is, in agreement with water depth, gradually replaced by a dominance of the blue-green, then the blue, thus the diminution and disappearance of the entropy. However it is possible to detect changes between the two dates on the barrier reef which appears less diverse in 2010 than in 2006 in the southwestern study area. Moreover the systematic analysis of the transect tends to establish a manifest differentiation between the two models. Both averages and variances of the entropy significantly diverge (0.31 and 0.05, p-value < 0.01; 2×10^{-2} and 4×10^{-4}, p-value < 0.01, respectively). From 2006 to 2010, the color diversity has decreased by a factor six, and its variability has been strongly eroded. It is also noteworthy that the 2010 curve decreases in average and variability from west to east, whilst this trend is not detectable in 2006.

16.4 Discussion

The coral cover and the structural complexity of Tiahura outer reef have experienced two major disturbances between 2005 and 2010: the invasion of the predator *Acanthaster planci* and the wake of the cyclone *Oli* (February 2010). The frequency of such recurring disturbances on the Polynesian outer reef is in the order of 10 to 25 years (Adjeroud et al. 2005, 2009) and varies according to the type (high volcanic island or atoll) and the geographical location of the island or the site.

16.4.1 Coral Response to Disturbances

The synergy of the three methods (*in situ* and VHR satellite imagery) allows gaining more insight into the response of coral to both the invasion of *A. planci* and the cyclone *Oli*. From 2005 to 2009, the coral cover of Tiahura site surveyed by photo-quadrats has experienced an annual decrease of 10 % until reaching a complete absence of coral cover. This rapid fall may be due to the demographic outbreak of the carnivorous starfish. The impact of the swell generated by the cyclone *Oli* on the coral cover was not significant since it was already close to 0 % before this disturbance happened. The satellite products we derived such as the bathymetry and the entropy of the bottom albedo confirm the rapid fall of the coral cover by providing some further explanatory mechanisms. From 2006 to 2010, two trends were revealed by the remote sensing approach: the erosion of the habitat and the mitigation of the colour diversity. Intuitively, the erosion can be attributed to the wake of the cyclone that produced a powerful and ample swell likely to break the tri-dimensional structure of coral colonies which can explain the smoothing observed throughout the evolution of the mapping products. The benthos discolouration may be related to the mechanical destruction of the colonies by the cyclone but may also be the consequence of the predation by *A. planci*. These two phenomena drive the disappearance of the pigments contained in zooxanthellae (coral endosymbionts) in favour of pigments associated with algal turf and macroalgae. The colour composition reflected by the coral pigments is typically richer than the composition inherent to algae (Collin and Planes 2012). Since the second acquisition is from March 2010, namely after the cyclonic event, the geomorphological and spectral evolution extracted from the satellite images result from the cumulated effect of both disturbances without any chance to dissociate their respective contribution. However, the *in situ* panoramic survey shows a critical simplification of the reef structure at a small scale, as defined in the literature (*e.g.* Chabanet et al. 2005; Murdoch and Aronson 1999). With a higher temporal resolution compared to our satellite data, this survey allows speculating about the relative effect of *A. planci* and the cyclone. In November 2006, the *A. planci* outbreak was already occurring on Moorea island (Clark and Weiztman 2008). The negative influence of coral predation on the deterioration of the coral cover therefore happened from 2006 to the cyclonic event of 2010. This result corroborates the conclusions of Adam et al. (2011) and Trapon et al. (2011). The latter authors also indicate that the impact resulting from the *A. planci* proliferation is more detrimental than the effect of a cyclone. A scene from 2009 would allow confirming that *A. planci* is mitigating the coral colour diversity without altering the structural complexity of the colonies. We can point out upfront that the entropy will show a marked difference from 2006 to 2009 whilst the bathymetric variance will remain unchanged.

16.4.2 Resistance of Coral Fishes and Corals

In addition to the coral cover survey, an assessment of the specific richness of coral fishes was achieved along Tiahura transect (Lison de Loma *pers. comm.*). The evolution of the richness between 2005 and 2011 differs from the evolution of the coral cover (Fig. 16.10). From 2005 to 2009, while the coral cover decreases from 40 to 1 %, the specific richness slightly increases, varying from 41 to 46 fish species. It can be inferred that the predation of *A. planci* acts specifically on the coral cover but has no clear influence on the ichthyologic specific richness. We can reasonably assume that *A. planci* feeds on coral colonies but leaves unaffected their structural complexity and the resulting variety of ecological niches constituting as many habitats for the inherent ichthyologic species. The small increase of the specific richness can also be supported by the results of Adam et al. (2011) indicating an increasing number of herbivorous fishes on Moorea outer reef during a decrease of the coral cover subsequent to a severe event of predation by *A. planci*. This excess of herbivorous species might be fostered by the novel expansion of algal turf and macroalgae they feed on so that algae are not able to outcompete coral cover regeneration. From 2009 to 2011, whilst the coral cover remains around 1 %, the ichthyologic species richness decreases (from 46 to 36 species). These results could be the direct consequence of the cyclone *Oli*. Following the smoothing of the outer reef by the cyclonic swell and the decrease of the complexity of the coral structures as well as the subsequent ecological niches, the number of fish species tends to decline along with habitat loss.

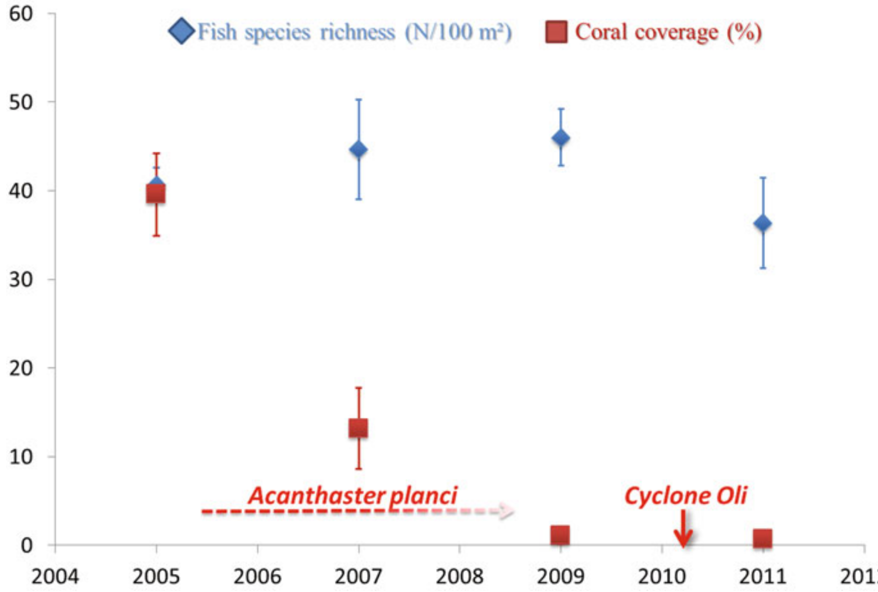

Fig. 16.10 Evolution of the ichthyological richness and coral cover on Tiahura outer reef from 2005 to 2011

After a decline phase due to one or several disturbances, a resilience phase of the coral cover is usually expected as observed between 1996 and 2006 on anterior data from a site adjacent to Vaipahu (*pers. obs*.). The total disappearance of the coral cover induced by the predation and the cyclone may favour the settlement of pioneer coral species excluded from a non-disturbed ecological succession (Connell et al. 1997). The spatial patterns of pioneer species influence the specific composition of the outer reef. After a resilience phase of 12–15 years following an *A. planci* outbreak (Moran 1988), the coral population composition varies among the studies. Adjeroud et al. (2009) show an increase of Porites and Acropora to the detriment of Pocillopora and Montipora (from 1991 to 2006), whereas Trapon et al. (2011) indicate an increase of Porites and Pocillopora to the detriment of Acropora (from 1979 to 2009) over the same study site. The Porites growth, common to both study sites, might be explained by the massive shape akin to the colonies, probably correlated with a higher plasticity regarding hydrodynamic conditions. Assessing the spatial ability of VHR satellites combined with the object-oriented classification is a promising research pathway to detect the evolution of Porites colonies. Determining their dynamic will be useful to better understand and predict the reefscape ecological regimes and shifts. On the other hand, we can notice that the resilience phase of the coral cover had not yet been started in August 2011. This delay is likely attributable to the limit of classical field methods (quadrat and manta tow) for taking into account small coral recruitment (< 5 mm).

16.5 Conclusions

The development of reefscape ecology is based on the consideration of the reefscape structures at multiple spatial scales. The confluence of the scales selected by the Polynesia mana network and the VHR imagery partially responds to this issue. Whilst the Polynesia mana network provides the coral cover rate at a decametric scale over a 20 m^2 area, extended to the metric scale along some km, the VHR mapping covers several km^2 at a sub-metric scale. The 3D reefscape dynamics, the bathymetry and the benthic reflectance extracted from satellite imagery is significantly improved by the 2D *in situ* survey. The joint effect of both the proliferation of the predator starfish *A. planci* and the wake of the cyclone *Oli* is evidenced by a substantial decrease of the bathymetric variance and the diversity of the bottom (entropy of the reflectance) between 9 November 2006 and 17 March 2010. The biennal survey of the coral cover enabled distinguishing the impact of these disturbances: the colour loss is mainly due to the predation of *A. planci* and the smoothing of the bathymetry stems from the wake of the cyclone. The consistency and the complementarity of these tools strongly encourage their use over all the geographic sites of the Polynesia mana network covering seven countries and territories.

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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

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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

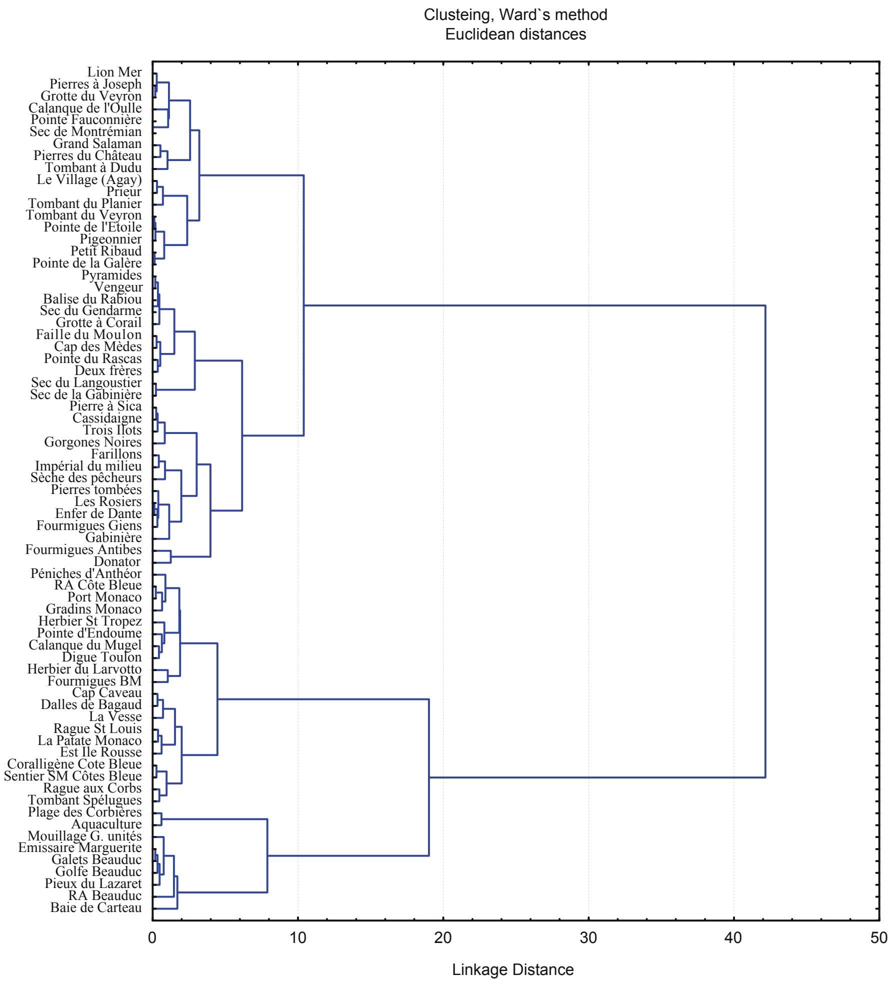

Fig. 17.1 Classification of all the stations by a hierarchical clustering method using Ward's method and Euclidian distance. A K-mean clustering method gathered the same stations according to four clusters (1, 2, 3 and 4; see Table 17.4)

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).

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Chapter 18
The Seascape as an Indicator of Environmental Interest and Quality of the Mediterranean Benthos: The *in Situ* Development of a Description Index: The LIMA

Sylvie Gobert, Aurélia Chéry, Alexandre Volpon, Corinne Pelaprat and Pierre Lejeune

Abstract The LIMA index conveys the environmental interest and quality of the landscape formed by the Mediterranean benthos, ranging from 0 to -40 m, in numerical format. The LIMA index allows a comparison spatially and temporarily between sites. It is a comprehensive index which is easy to implement and is composed of two factors: a topographical description (classification of 15 typologies) and a biological description (the presence or absence of some thirty species or groups of structuring, remarkable and invasive species). The LIMA index has been validated in the Bay of Calvi (Corsica-France) where it varies between 0.31 and 0.79 on a scale of 0.00–1.00.

Keywords Remarkable species · Invasive species · Benthos · Seagrass · Interest and quality index · Corsica

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18.1 Introduction

By definition, a landscape is the arrangement of features, characteristics, and forms of a limited space, it is a portion of territory with a marked identity, modeled by natural abiotic, biotic and anthropogenic factors. The ecology of the landscape studies the spatial and temporal variations, the communications, barriers and fragmentation of zones. Developed more than a century ago in the terrestrial environment, the ecology of landscapes makes it possible to contemplate the effect of planning and its consequences for pre-existing ecosystems.

In the marine environment, the coastal area has an ecological and economic importance which has been amply demonstrated (e.g. Costanza et al. 1997; Hughes et al. 2009), but it is subjected to important modifications due to human pressure (coastal development, urbanization, provision of excess nutrients, release of pollutants…) (Boudouresque 2004; Boudouresque et al. 2009).

Aware of this environmental pollution, the European Community is advocating sustainable exploitation of living resources and protection of biodiversity (www.agriculture.gov.lb/bio_div/tablebio.html, www1.environnement.gouv.fr/article; Aronson et al. 2002). Up to a certain threshold, biodiversity is in correlation with the richness of the environment (Gibson 1994): if this richness diminishes, mainly due to homogenization of the territory, scientists observe an erosion of the specific richness. It is therefore possible to link the environmental quality of an environment with its biological quality.

Corsica, with more than 1,000 km of coastline and a relatively moderate anthropization is a very favorable terrain for the implementation and creation of a reference tool whose aim is to assess the environmental richness and heritage species of the seabed.

The Lima is a regional program that was launched in 2000 by the Office of the Environment in Corsica, devoted to gaining knowledge of the nature and quality of the coastal areas of Corsica at depths of between 0–100 m (Guennoc et al. 2002). This is the context of the present study which was initiated by the agency Eau Rhône Méditerranée Corse, the objective of which is the design of a simple rapid and easily reproducible methodology for the assessment of the attraction and rich heritage species of the Mediterranean benthos in the bathymetric zone from 0–40 m (Chery et al. 2006a, b)

18.2 Material and Methods

18.2.1 Definition of the Sector to be Prospected

Whether in the context of coastal management or the definition of the quality or temporal evolution of a site for scientific reasons, as soon as the sectors to be described have been determined, the bathymetry and sedimentology must be identified. This

Table 18.1 Color code and status of the sites according to the LIMA index

LIMA	Site status	Color code
0.800–1.000	Exceptional richness of species, exceptional site	Blue
0.600–0.799	High richness of species, rich site	Green
0.400–0.599	Average richness of species, attractive site	Yellow
0.200–0.399	Lower richness of species, site low in attraction	Orange
0.000–0.199	Low richness of species, unattractive site	Red

should make it possible to define the length and position (coordinates) of 3 radials to be analyzed in a homogenous zone that is representative of the sector to be explored.

The LIMA index makes it possible to describe sites in the bathymetric zone between the surface and 40 m in depth. However, the distance separating the coastline from the isobath − 40 m varies from one site to another. Therefore all the radials that are in excess of 500 m are divided up into 4 transects of 150 m, distributed in such a way as to describe the deep area (from − 40 m to the coastline), the area of − 30 m (from the isobath to the coastline) the area of − 20 m (from the isobath to the coastline), and the area of − 10 m (from the isobath to the coastline). In the case where the distance separating the isobath − 40 m from the coastline is less than 500 m, the totality of this distance is explored by the divers in order to define the LIMA index.

18.2.2 Data Recording and Calculation Procedures for the LIMA Index

The LIMA index is a comprehensive index calculated from topographical observations and observations on the presence or absence of some thirty species or groups of species of flora and fauna. These observations are carried out by 2 divers and do not involve counting or sample taking. The LIMA index is composed of two factors: a topographical description (TD) and a biological description (BD) of the radials carried out between the surface and 40 m in depth which is the area accessible to an autonomous diver.

$$\text{LIMA index} = (TD + BD)/2$$

All the data gathered during diving is then encoded in a file. The Topographical Description, the Biological Description and the overall LIMA index are then calculated. The LIMA index has values ranging from 0 to 1 and is divided into five classes (Table 18.1). From 0.000 to 0.199, the sector is described as “low in heritage species, unattractive site” (color red); from 0.200 to 0.399, the sector is described as “low in richness of heritage, low level of site attraction” (color orange); from 0.400 to 0.599, the sector is described as “average richness of heritage, attractive site (color yellow); from 0.600 to 0.799, the sector is described as “high in richness of heritage species, rich site (color green); from 0.800 to 1.000, is described as exceptional richness of heritage and exceptional site (Color blue).

Table 18.2 Notes attributed to the different typologies and associated numerical and color codes

Typology	Code	Note
Cavity, large overhang, cave	1	1.000
Sloping, rocky pinnacle, rocky peak	2	1.000
Mediterranean bio-constructed bottom (coralligenous)	3	0.900
Large rockfall	4	0.800
Wreck, artificial reef	5	0.750
Cave: small overhang, depression	6	0.750
Craggy rock colonized or not by macrophyta (magniolophyta, algae. . .)	7	0.700
Isolated rock	8	0.600
Small rockfall	9	0.500
Maerl	10	0.300
Extended sandy stretch colonized or not by macrophyta (magniolophyta, algae. . .)	11	0.250
Rock layer colonized or not by macrophyta (magniolophyta, algae. . .)	12	0.250
Dead matte	13	0.150
Sandy-muddy	14	0.100
Mud	15	0.000

18.2.2.1 Topographical Description (TD)

The diversity and nature of the seabed of a site have been classed and encoded into 15 different typologies; a value of 0 to 1 has been attributed to each typology according to its general structure on a synoptic scale (Table 18.2) (Pérès and Picard 1964; Palmisani 2002).

In a practical way, the TD of a site is calculated from the results of the observations of a diver carried out along the three radials. Each radial, which has a length L, graduated every 5 meters, is covered from a depth of 40 m to the surface and the diver notes the distance (d) while he observes the typology and the corresponding code (c). For each radial a TD is calculated:

$$\text{TDradial} = \Sigma\ (\text{di}/\text{Lradial} * \text{ci})$$

The TD of a sector is the average of the TDs and the three radials explored in the zone:

$$\text{TDsector} = (\text{TDradial1} + \text{TDradial2} + \text{TDradial3})/3$$

18.2.2.2 Biological description (BD)

The biological description (BD) is based on 3 biological indicators: the R index: remarkable species, the I index: invasive species and the S index: structuring species.

$$\text{BD} = (\text{R} + \text{I} + 2\text{S})/4$$

Twenty-nine species or groups of species were taken into account to define the Biological Description. Some species or groups of species are rare or strictly limited

Table 18.3 Species or groups of species which are rare or limited to a particular bathymetric section

Macrophyta
Lithophyllum lichenoide
Magniolophytes
Cnidaria
Corallium rubrum
Mollusc
Patella ferruginea
Fish
Sciaena umbra
Labrus bimaculatus
Shoal
Particular seabed
Coralligenous habitat
Maërl

to a particular bathymetric section, the Biological Description of a sector is therefore directly correlated to their presence along a radial (Table 18.3). Other species or groups of species have a large bathymetric distribution, the Biological Description of the sector is directly proportional to the colonized surface and therefore to the number of times they are listed across the entire radial which is divided into portions of 50 m (Table 18.4).

For those species that are rare or strictly limited to a bathymetric section, the diver notes the presence (or absence) of species or groups of species across the entire radial. A value (v) of 0 or 2 which corresponds to the absence 0 or the presence (2) across the entire radial is attributed. On the other hand, for the species or groups of species which have a large bathymetric distribution, their presence or absence is noted for each portion of 50 m, a value of 0, 1, or 2 is attributed by comparing the frequency of their presence (Σ of presence for the portions i of 50 m/ the number i of the portion of 50 m) with the expected frequency (Table 18.4). This method is applied to all the species or groups of species for the indexes (R and S) in which they occur.

The remarkable species: the R index. The remarkable species considered for the biological description are, on one hand, those that benefit from local legal protection regionally or in the administrative departments, nationally by means of decrees or laws or internationally by means of conventions (Berne, Bonn, Barcelona); and on the other hand, species which are not protected but considered to be regressing or species considered to be vulnerable (Bellan-Santini et al. 1994; Harmelin 1991; Lejeusne et al. 2010; Malak et al. 2011) (Table 18.5). Eleven species or groups of species were considered.

For each radial, the value (v) attributed to each species or group of species is the same as that described above. These values are integrated into the following equation to calculate the R index for remarkable species:

$$R = \Sigma\ \mathrm{v}\textit{Cystoseira sp} + \mathrm{v}\textit{L. byssoides} + \mathrm{vMagnioliophytes} + v\textit{Corallium rubrum} + \mathrm{v}\textit{Cladocora sp.} + \mathrm{v}\textit{Patella ferruginea} + v\textit{Pinna sp.} + \mathrm{n}\textit{Palinurus elephas} + \mathrm{v}\textit{Epinephelus marginatus} + \mathrm{v}\textit{Sciaena umbra} + \mathrm{v}\textit{Labrus bimaculatus}/22$$

Table 18.4 Species or groups of species with a large bathymetric distribution. Expected presence levels

	Zero presence (%)	Average presence (%)	High frequency (%)
Macrophyta			
Cystoseira sp	0.00–0.99	1.00–32.99	$\leq$ 33.00
Caulerpa prolifera	0.00–0.99	1.00–24.99	$\leq$ 25.00
Caulerpa racemosa	0.00–0.99	1.00–32.99	$\leq$ 33.00
Caulerpa taxifolia	0.00–0.99	1.00–32.99	$\leq$ 33.00
Nematochrysopsis	0.00–0.99	1.00–32.99	$\leq$ 33.00
Polysiphonia	0.00–0.99	1.00–32.99	$\leq$ 33.00
Sponges			
Axinella sp	0.00–0.99	1.00–32.99	$\leq$ 33.00
Other sponges	0.00–0.99	1.00–49.99	$\leq$ 50.00
Bryozoa			
Erect bryozoan	0.00–0.99	1.00–32.99	$\leq$ 33.00
Cnidaria			
Cladocora sp.	0.00–0.99	1.00–14.99	$\leq$ 15.00
Eunicella cavolini	0.00–0.99	1.00–32.99	$\leq$ 33.00
Eunicella singularis	0.00–0.99	1.00–14.99	$\leq$ 15.00
Paramuricea clavata	0.00–0.99	1.00–24.99	$\leq$ 25.00
Parazoanthus axinella	0.00–0.99	1.00–49.99	$\leq$ 50.00
Pennatularia	0.00–0.99	1.00–09.99	$\leq$ 10.00
Worms			
Salmacina sp or.Filograna sp.	0.00–0.99	1.00–24.99	$\leq$ 25.00
Fan worms	0.00–0.99	1.00–66.99	$\leq$ 67.00
Molluscs			
Pinna sp.	0.00–0.99	1.00–19.99	$\leq$ 20.00
Crustaceans			
Palinurus elephas	0.00–0.99	1.00–24.99	$\leq$ 25.00
Fishes			
Epinephelus sp.	0.00–0.99	1.00–32.99	$\leq$ 33.00

The R index of a site is the average of the R indexes of the 3 radials carried out in the sector:

$$\text{Rsector} = (\text{Rradial1} + \text{Rradial2} + \text{Rradial3})/3$$

The invasive species index I, for the invasive species is calculated by noting the presence of Caulerpa (ex: *C. taxifolia*, *C. racemosa*) (Belsher and Meinesz 1995; Boudouresque and Verlaque 2002), filamentous algae (*Nematochrysopsis* sp. of the Chrysophyceae family): opportunistic and invasive species, and carpets of Polysiphonia sp: algae with a nitrophilous tendency which proliferate on all types of substratum for longer and longer periods and enter into competition with the benthic species present (Hoffman et al. 2000) (Table 18.6). The I index is calculated by integrating the values into the following equation:

$$\text{I} = \Sigma\ \text{v}\textit{Caulerpa taxifolia} + \text{v}\textit{Caulerpa racemosa} + \text{v}\textit{Nematochrysopsis} + \text{v}\textit{Polysiphonia}/8$$

Table 18.5 List of species or groups of species taken into account for calculation of the R index: remarkable species.—: box to be ticked by the diver according to the presence P or absence A of the species or group of species observed overall or for a portion of the transect

	Total		Portion 1		Portion 2		Portion X	
	Transect		50 m		50 m		50 m	
	P	A	P	A	P	A	P	A
Macrophyta								
Cystoseira sp			–	–	–	–	–	–
Lithophyllum byssoides	–	–						
Magniolophyta	–	–						
Cnidaria								
Cladocora sp.			–	–	–	–	–	–
Corallium rubrum	–	–						
Molluscs								
Patella ferruginea	–	–						
Pinna sp.			–	–	–	–	–	–
Crustaceans								
Palinurus elephas			–	–	–	–	–	–
Fish								
Sciaena umbra	–	–						
Epinephelus sp.			–	–	–	–	–	–
Labrus bimaculatus	–	–						

Table 18.6 List of species or group of species taken into account for calculation of the I index: invasive species.—: box to be ticked by the diver according to the presence P or the absence A of the species or group of species observed over a portion of the transect

	Portion 1		Portion 2		Portion	
	50 m		50 m		X. . .	
	P	A	P	A		
Caulerpa taxifolia	–	–	–	–	–	–
Caulerpa racemosa	–	–	–	–	–	–
Nematochrysopsis	–	–	–	–	–	–
Polysiphonia	–	–	–	–	–	–

The I index of a sector is the average of the I indexes of the three radials carried out in the sector:

$$\text{Isector} = (\text{Rradial1} + \text{Rradial2} + \text{Rradial3})/3$$

The structuring species the S index.

The structuring species enrich the three-dimensional structure, supply a vast range of tints or fill the water column. Nineteen species or groups of species were considered, including plants, sponges, cnidaria, bryozoa, worms, molluscs, fish and particular seabed species like Maerl and corraligenous habitat (Table 18.7).

Table 18.7 List of species or group of species taken into account for calculation of the S index: structuring species.—: box to be ticked by the diver according to the presence P or the absence A of the species or group of species observed in total or for a portion of the transect

	Total		Portion 1		Portion 2		Portion X	
	Transect		50 m		50 m		50 m	
	P	A	P	A	P	A	P	A
Macrophyta								
Cystoseira sp			–	–	–	–	–	–
Lithophyllum byssoides	–	–						
Caulerpa prolifera			–	–	–	–	–	–
Magniolophyta	–	–						
Sea sponges								
Axinella sp.			–	–	–	–	–	–
Large sponges			–	–	–	–	–	–
Cnidaria								
Cladocora sp.			–	–	–	–	–	–
Eunicella cavolini			–	–	–	–	–	–
Eunicella stricta			–	–	–	–	–	–
Paramuricea clavata			–	–	–	–	–	–
Parazoanthus axinella			–	–	–	–	–	–
Pennatularia			–	–	–	–	–	–
Bryozoa								
Erect bryozoa			–	–	–	–	–	–
Worms								
Salmacina sp. Filograna sp.			–	–	–	–	–	–
Fan worm			–	–	–	–	–	–
Molluscs								
Pinna sp.			–	–	–	–	–	–
Fish								
Shoal	–	–						
Particular seabeds								
Coralligeous habitat	–	–						
Maerl	–	–						

As well as the information gathered for these 19 species, the gorgonian populations of *Paramuricea clavata,* typical of the rocky mediterranean seabed, are described based on the presence of dead colonies.

The value v, calculated for *Paramuricea clavata* according to its presence/absence per zone of 50 m, is multiplied by 1 if the average number of colonies encountered is higher than 70 cm and if they carry small quantities of necrosis (estimated to be less than 10 %). The value v is multiplied by 0.5, if the average for the colonies encountered is smaller than 20 cm and if they have a large quantity of necrosis (estimated to be higher than 75 %). The value v is multiplied by 0.75 in intermediate cases.

The *Paramuricea clavata* value, along a transect composed of the portion (i) of 50 m, v*Paramuricea clavata* is equal to Σ (0 or 2 for each portion $i_{(50\,m)}$)/i 50 m * (1, 0.5 or 0.75).

The S index is calculated by integrating the values into the following equation:

$$S = \sum \begin{array}{l} \text{v}\textit{Cystoseira}\ \text{sp} + \text{v}\textit{L. byssoides} + \text{v}\textit{Caulerpa prolifera} \\ + \text{vMagniolophytes} + \text{vAxinella}\ \textit{sp} + \text{vlarge sponge} + \text{v}\textit{Cladocora sp.} \\ + \text{v}\textit{Eunicella stricta} + \text{v}\textit{Eunicella cavolini} + \text{v}\textit{Paramuricea clavata} + \\ \text{n}\textit{Parazoanthus axinella} + \text{nPennatulaires} + \text{nerected Bryozoa} \\ + \text{n}\textit{Salmacina sp}\ \text{and}\ \textit{Filograba sp} + \text{nFan worm} + \text{n}\ \textit{Pinna sp.} \\ + \text{nshoalof fish} + \text{nCoralligenous habitat} + \text{nMaërl}/38 \end{array}$$

The S index for a sector is the average of the S indexes for the three radials explored in the zone:

$$\text{Ssector} = (\text{Sradial1} + \text{Sradial2} + \text{Sradial3})/3$$

18.2.3 Experimentation and Validation of the LIMA Index

The LIMA index was tested and validated in the Bay of Calvi (Corsica-France) (Fig. 18.1) between May and September 2005. This zone has been well studied since 1970 by numerous researchers for the abiotic parameters (e.g. salinity, temperature, nutritive salt content. . .) (Vrancken 1999; Gobert 2002; Lepoint et al. 2004) for the biotic parameters: the gorgonians (Weinbauer and Velimirov 1995; Weinbauer and Velimirov 1996), the seagrasses *Posidonia oceanica* (Gobert 2002), the algal populations (Coppejans and Boudouresque 1983; Demoulin et al. 1980; Demoulin 1987), and the fish populations (Bussers et al. 1976; Lejeune 1984; Pelaprat 2000). . .

Between Punta Revellata and Punta Spano, eight sectors were selected in the Bay of Calvi: Punta Revellata, STARESO, Bibliothèque, Pointe St François, Calvi beach, Punta Caldanu, Bay of Algajo and Punta Spano (Fig. 18.1) and 3 radials per sector representing 24 radials in total were positioned and their lengths were assessed (Table 18.7). The 24 radials were divided into two groups (Table 18.7): the radials lower than 500 m (10 radials) and the radials higher than 500 m in length (14 radials) were described in accordance with the protocol which allows for 4 sections of 150 m, distributed according to the bathymetry (cf. Definition of the sector to be prospected).

18.3 Results—Discussions

Table 18.8 presents the results of the topographical description (TD), the biological description (BD, I, R, and S) and the overall LIMA index for the eight sectors studied in the Bay of Calvi.

In the Bay of Calvi, the LIMA index varies between 0.31 and 0.79 corresponding to sites described as having a low level of richness of heritage species and as low attraction sites (orange) and sites described as having a high level of richness of

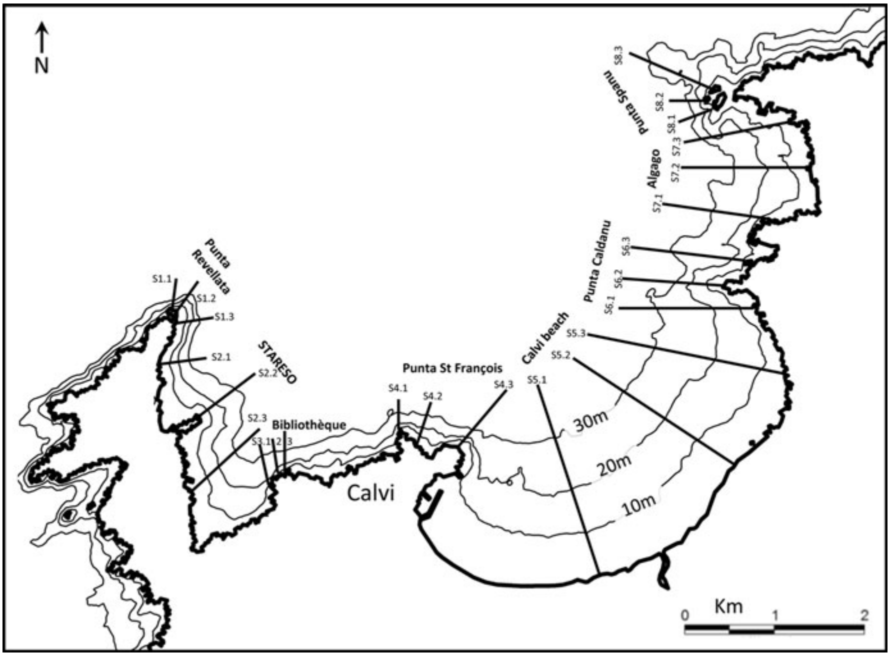

Fig. 18.1 Presentation of the eight sectors prospected in the Bay of Calvi (Corsica) for testing and validating the LIMA index: Punta Revellata (Sector 1), STARESO (Sector 2), Bibliothèque (Sector 3), Punta St François (Sector 4), Calvi beach (Sector 5), Punta Caldanu (Sector 6), Algajo of (Sector 7) and Punta Spano (Sector 8) (24 radials: 3 per sector)

heritage species and as rich sites (green) respectively. A sector is classed as having a high level of richness of heritage species and as a rich site (green class); 4 sites are classed as having an average level of richness of heritage species and as attractive sites (yellow class) and 3 sectors are classed as having low levels of richness of heritage species and as unattractive sites (orange class).

The topographical quality (Table 18.8) varies between 0.25 (Calvi beach sector, radial 1) and 0.92 (Punta Revellata sector, radial 1). The Calvi beach sector is a large covered sandy stretch covered by magniolophyta in certain places. On the other hand, the Punta Revellata sector is an uneven and rocky zone (presence of cavities, overhangs, slopes. . .). This sector of the bay is particularly frequented by sport divers. The detailed results of the Biological Description of radial 1 of the Punta Revellata sector are presented in Table 18.9. Species belonging to remarkable genuses like *Cystoseira, Epinephelus and Palinurus* are frequent there. The colonies of *Eunicella* and *Parazoanthus* colonise the slopes and overhangs and make this sector rich and attractive.

The biological quality varies between 0.21 (S), 0.09 (R), 0.50 (I) for the Calvi beach and STARESO sectors 0.67 (S), 0.81 (R), 1.00 (I) for the sectors of Punta Revellata, Bay of Algago and Punta Spano.

Table 18.8 Lengths, topographical and biological descriptions (Structuring, remarkable and invasive species) for the 24 respective radials of the eight sectors of the Bay of Calvi. Values and color codes (*B: Blauw, O: Orange, Y: Yellow*) of the LIMA index for each radial and for each sector

Sector	Radial (m)	TD	BD		LIMA		
			S	R	E	Radial	Sector
Punta Revellata	1 (197)	0.86	0.61	0.72	1.00	0.78	
	2 (222)	0.92	0.67	0.81	1.00	0.83	*0.79*
	3 (250)	0.84	0.57	0.41	0.75	0.67	*B*
STARESO	1 (390)	0.28	0.24	0.27	1.00	0.36	
	2 (610)	0.33	0.47	0.32	0.63	0.40	*0.33*
	3 (1410)	0.21	0.16	0.15	0.50	0.22	*O*
Bibliothèque	1 (480)	0.32	0.39	0.23	0.75	0.38	
	2 (480)	0.33	0.39	0.36	0.75	0.40	*0.39*
	3 (440)	0.31	0.50	0.32	0.63	0.49	*O*
Pointe St François	1 (280)	0.43	0.58	0.32	0.75	0.44	
	2 (540)	0.35	0.49	0.41	0.63	0.43	*0.44*
	3 (770)	0.35	0.37	0.32	0.63	0.39	*Y*
Plage de	1 (2330)	0.25	0.21	0.09	0.75	0.28	
Calvi	2 (2440)	0.26	0.24	0.09	0.88	0.31	*0.31*
	3 (2520)	0.26	0.24	0.23	0.88	0.32	*O*
Punta	1 (1430)	0.32	0.34	0.23	0.75	0.37	
Caldanu	2 (1630)	0.40	0.47	0.32	0.88	0.47	*0.42*
	3 (1630)	0.36	0.45	0.36	0.75	0.43	*Y*
Baie d'Algago	1 (1160)	0.33	0.50	0.36	1.00	0.46	
	2 (1410)	0.33	0.36	0.27	0.88	0.40	*0.42*
	3 (1160)	0.43	0.47	0.18	0.88	0.46	*Y*
	1 (420)	0.34	0.47	0.32	1.00	0.45	
Punta Spano	2 (490)	0.60	0.47	0.23	0.88	0.55	*0.55*
	3 (1200)	0.63	0.63	0.45	0.88	0.64	*Y*

The classification of the eight sectors of Calvi bay given by the comprehensive LIMA index corresponds to the attraction represented by these sites for experienced sports divers with maximal frequentation at the Pointe de La Revellata and Spano, these same divers, who are used to the Mediterranean coastline, describe sites that are even more attractive in other zones like the area around the Scandola reserve. Access to this reserve would probably result in the highest LIMA classification: an exceptional level of richness of heritage and an exceptional site.

On the rocky substrates (Punta Revellata, Bibliothèque, Pointe St François, Punta Caldanu, Algago bay and Punta Spano sectors), the biological classification given by the BD index reflects the diversity of results obtained by the scientists of different disciplines: ichthyology, algology, zoology (Janssens et al. 1993). On the other hand, the 2 sectors like STARESO and Calvi beach are sandy and are largely colonized by seagrasses (P. oceanica, C. nodosa). These seagrasses are, on first appearance monotonous and not very rich but they are recognized as having a high ecological and economic importance. The LIMA index does not make it possible to describe the magniolophyta. In this type of area, indexes such as PREI (Posidonia Rapid Easy

Table 18.9 Detailed results of radial 1 of sector 1 (L = 197 m) and radial 3 of sector 8 (L = 1200 m)

Punta Revellata Radial 1, Sector 1 (197 m)	Transect total P	A	Portion 1 50 m P	A	Portion 2 50 m P	A	Portion 3 50 m P	A	Portion 4 50 m P	A	Transect value
Cystoseira sp			X		X		X		X		2
Lithophyllum lichenoide	X										2
Magniolophytes		X									0
Cladocora sp.				X		X		X		X	0
Corallium rubrum	X										2
Centrostephanus longispinus		X									0
Patella ferruginea	X										2
Pinna sp.				X		X		X		X	0
Homarus gammarus		X									0
Palinurus elephas					X						2
Scyllarides latus		X									0
Sciaena umbra	X										2
Epinephelus sp.				X	X		X		X		2
Hippocampus sp.		X									0
Labrus bimaculatus		X									0
Caulerpa taxifolia				X		X		X		X	2
Caulerpa racemosa				X		X		X		X	2
Nematochrysopsis				X		X		X		X	2
Polysiphonia				X		X		X		X	2
Cystoseira sp			X			X	X		X		2
Lithophyllum lichenoide	X										2
Caulerpa prolifera				X		X		X		X	0
Magniolophytes		X									2
Axinella sp.			X		X			X		X	2
Large sponges			X			X		X		X	1
Cladocora sp.				X		X		X		X	0
Eunicella cavolini				X	X		X			X	2
Eunicella stricta											0
Paramuricea clavata			X		X		X			X	2
Parazoanthus axinella				X		X		X		X	0
Pennatularia				X		X		X		X	0
Bryozoria			X		X		X		X		2
Salmacina sp.Filograna sp.			X		X			X		X	2
Fab worm					X		X		X		2
Pinna sp.				X		X		X		X	0
Shoal	X										2
Coralligenous habitat		X									2
Maërl		X									2

Index) which describe the state of a given seagrass in a mass of water already exist (Gobert et al. 2009), and are more adapted to the task.

For some years, the accumulated consequences of climate change and anthropic activity have been visible in Corsica and the Bay of Calvi. The gorgonian populations died in massive numbers from 1989 to 2003 but the dynamics of the species has made it possible to recolonize the zone (Poulicek et al. 2007a, 2007b) and the degraded populations which appeared in 2005 are once again actively colonizing.

On the other hand, *Caulerpa racemosa*, which is an invasive species, has appeared in the bay since 2008 (Cariou et al. 2013). The processing of data which is still in progress shows that the LIMA index conveyed these developments between 2005 and 2011; the sector of La Revellata dropped one class to yellow (average level of richness of heritage species and attractive site) due to this species.

The LIMA index conveys the environmental attraction and the richness of heritage species in a defined zone of the Mediterrannean benthos between 0 and – 40 m. The LIMA index makes possible a spatial comparison of the sites and could even demonstrate the temporal evolution of these sites; it could therefore help not only scientists to characterize an ecosystem, but could also help management authorities in their decisions concerning the protection and management of the territory. This comprehensive index which has been validated in the Bay of Calvi, is easy to implement, it could be complemented by other indexes such as the "Fish" index (Payrot 2010) and the ICAR (*Caulerpa racemosa*) (Cariou et al. 2013).

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