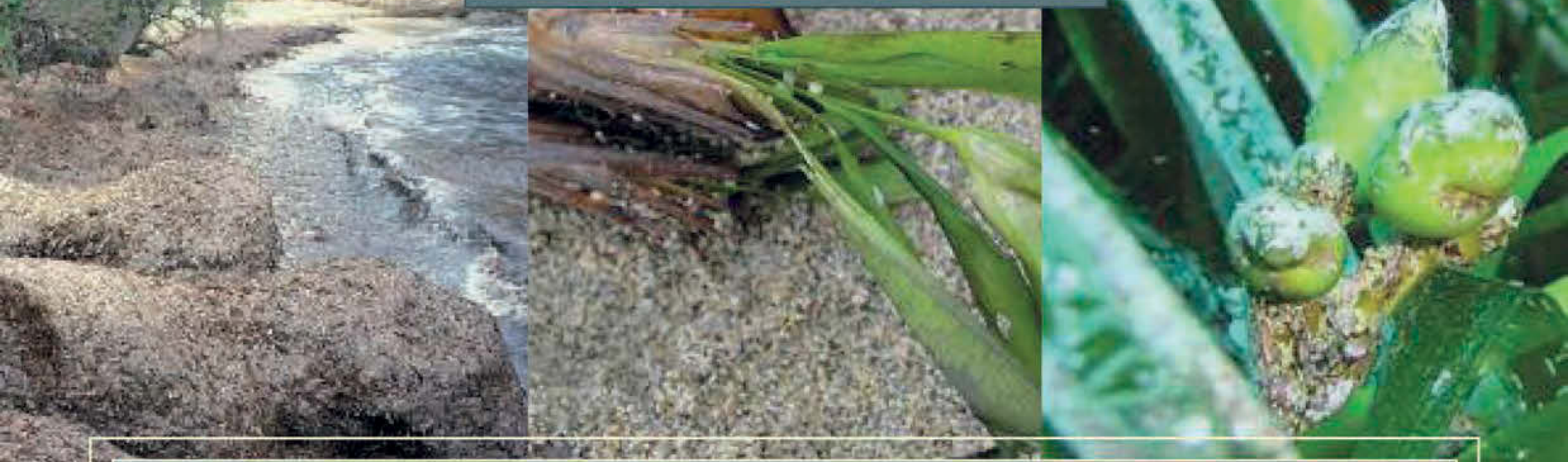
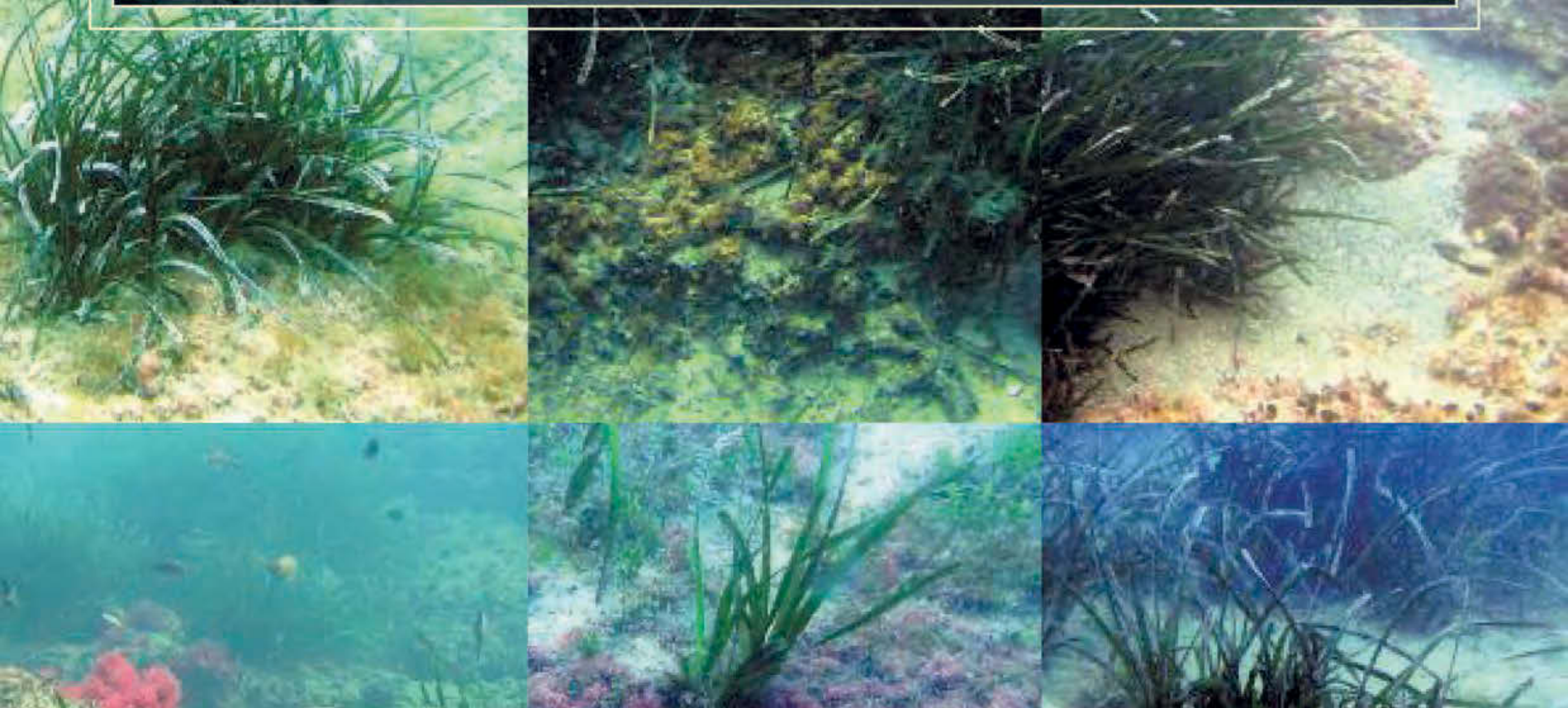


Protection and conservation of *Posidonia oceanica* meadows



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Note: The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of UNEP/MAP, RAC/SPA or RAMOGE concerning the legal status of any State, Territory, city or area, or of its authorities, or concerning the delimitation of their frontiers or boundaries.

THE RAMOGE AGREEMENT

THE RAMOGE AGREEMENT, signed in 1976, is the instrument endowed to the Governments of France, Monaco and Italy for the prevention and combat against pollution in the marine environment and the littoral of the PACA Region, the Principality of Monaco and the Liguria.

THE RAMOGE AGREEMENT facilitates scientific, technical, legal and administrative cooperation for the integrated management of the littoral as well as for public awareness for the respect of the environment.

RAC/SPA

RAC/SPA (Regional Activity Centre for Specially Protected Areas) was established in Tunis, in 1985, by decision of the Contracting Parties to the Barcelona Convention.

THE RAC/SPA's mission is to provide assistance to Mediterranean countries in the implementation of their commitments under the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD Protocol, 1995), especially in regard to developing and promoting marine and coastal protected areas and reducing the loss of biodiversity in the Mediterranean region.

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Chapter 2. ***Posidonia oceanica* meadows: Charles-François Boudouresque.**

Chapter 3. **The role of *Posidonia oceanica* meadows: Gérard Pergent.**

Chapter 4. **The causes of *Posidonia oceanica* meadows regression: Leonardo Tunesi and Charles-François Boudouresque.**

Chapter 5. **Policies applying to *Posidonia oceanica* meadows: Christine Pergent-Martini, Stefano Coppo, Marina Pulcini and Federico Cinquepalmi.**

Chapter 6. **Dead *Posidonia oceanica* leaves, beaches and sand replenishment: Giovanni Diviacco, Leonardo Tunesi and Charles-François Boudouresque.**

Chapter 7. **The *Posidonia oceanica* meadow and management of facilities on the maritime public domain: Charles-François Boudouresque, Guillaume Bernard, Patrick Bonhomme, Eric Charbonnel and Giovanni Diviacco.**

Chapter 8. **The *Posidonia oceanica* meadow and mooring: Giovanni Diviacco and Charles-François Boudouresque.**

Chapter 9. **The *Posidonia oceanica* meadow and the marking of the 300 m strip: Frédéric Bachet, Boris Daniel and Eric Charbonnel.**

Chapter 10. **The *Posidonia oceanica* meadow and trawling: Eric Charbonnel and Leonardo Tunesi.**

Chapter 11. **The *Posidonia oceanica* meadow and fish farms: Gérard Pergent.**

Chapter 12. **The *Posidonia oceanica* meadow and discharge of effluents: Giovanni Diviacco.**

Chapter 13. **The *Posidonia oceanica* meadow and solid waste: Charles-François Boudouresque and Patrick Bonhomme.**

Chapter 14. ***Posidonia oceanica* meadows and the laying of cables and pipes on the seabed: Charles-François Boudouresque and Eric Charbonnel.**

Chapter 15. **Can dead meadows be restored?: Charles-François Boudouresque and Alexandre Meinesz.**

Chapter 16. **Methods of monitoring *Posidonia oceanica* meadows: Charles-François Boudouresque, Eric Charbonnel, Stefano Coppo, Laurence Le Direach and Sandrine Ruitton.**

Chapter 17. **The *Posidonia oceanica* meadow and the Water Framework Directive: Pierre Boissery and Christine Pergent-Martini.**

Chapter 18. **The *Posidonia oceanica* meadow. A summary: Charles-François Boudouresque.**

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This book should be considered as a **"work of authors"** This means that, beyond the scientific data actually published, the authors have used their personal experiences and beliefs (what is known today the **"expert opinion"**). Regardless of the rules and regulations that may govern the management of *Posidonia oceanica* meadows in various countries, the recommendations that are made in the present work are the responsibility of the writers alone. They are not therefore the responsibility of neither the RAMOGE Agreement nor the RAC/SPA (see inserts), or the institutions that helped produce or fund this work (Provence-Alpes-Côte d'Azur Region), or those people who gave information to the writers, and have thus no statutory value.

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CONTENT

1. INTRODUCTION

The seagrass *Posidonia oceanica* and the meadows that it forms have recently become a major issue in marine environmental management and protection in the Mediterranean (Pergent, 1991a; Boudouresque *et al.*, 1995b; Anonyme, 2000; Pergent-Martini, 2000; Anonyme, 2001a; Boudouresque, 2003; Procaccini *et al.*, 2003).

Posidonia oceanica meadows constitute an element that is fundamental for the **quality of the coastal environment** (Boudouresque and Meinesz, 1982; Videau and Merceron, 1992), which is basic to artisanal fishing and tourism development. Its socio-economic importance and the contribution it makes to trade balances make tourism a key element which no Mediterranean country can do without (about 10% of the Mediterranean states' GDP (Gross Domestic Product), except for Algeria and Syria; UNEP, 1999). Artisanal fishing, whose economic importance is more modest, has a major socio-cultural dimension, with positive consequences for tourism (Boudouresque *et al.*, 2005).

The protection and conservation of *Posidonia oceanica* meadows is thus justified not only by their very great heritage value but also for economic reasons. It is thus an textbook illustration of the idea of sustainable development that derived from the 1992 Rio de Janeiro Summit (Boudouresque, 2002b).

SUSTAINABLE DEVELOPMENT

Sustainable development is **the union of the environment and development.** Protecting the environment not only has heritage value, it is not antinomical to economic development, but can be a development tool (Timoshenko, 1996).

The **definition** of sustainable development adopted by the Rio de Janeiro Summit in June 1992 is the following: human activities that enable the present generation of human beings and other species living on the Earth to satisfy their needs without endangering the earth's ability to satisfy the needs of future generations of either men or the other species that people the Earth (*That range of activities and development which enables the needs of the present generation of humans and all other species to be met without jeopardizing the ability of the biosphere to support and supply the reasonably foreseeable future needs of humans and all other species*). The **strengths** of this concept are: **(i)** humans and **all other species** living on Earth are **equal** as regards their rights and requirements; **(ii)** the future is put on an equal footing with the present; **(iii)** there is a **mutualistic symbiosis** between **protection of the environment** and **economic development**.

Furthermore, sustainable development brings together an inseparable trinity: environmental **protection**, **economic development** and **social justice**. There can be no sustainable economic development without environmental protection, no environmental protection without economic development and social justice, and no social justice without economic development and environmental protection.

It is regrettable that the idea of sustainable development is very often betrayed by ecologists, sociologists and politicians – **(i)** ecologists for whom nature takes precedence over man; **(ii)** sociologists who do not agree that animals should be protected while men are endangered; and **(iii)** certain politicians who can only tolerate protection of nature if this does not interfere with their naive, archaic and very (very) short-term ideas of economic development.

Protection and conservation are two similar ideas. But **protection** is a more static idea than **conservation**, for it is particularly based on regulations and their implementation. Now conservation is a dynamic concept, implying management/taking other species and other habitats into account in a context of human usage and conflicts of usage and on a scale that cannot be uniquely local.

A considerable amount of **scientific literature** (over a thousand publications) has been devoted to the protection and conservation of *Posidonia oceanica* meadows. This literature, usually written in English, Spanish, French or Italian, appears in dozens of scientific reviews that are sometimes local and thus not very accessible to non-specialists. Reference lists, classed by subject matter, have been brought out, but are now rather old (Boudouresque *et al.*, 1977, 1979, 1980b; Boudouresque, 1989). One can add to this a summary (Cinelli *et al.*, 1995a).

For the wider public, some **popular works** are available: Ballesteros *et al.* (1984), Flores-Moya and Conde-Poyales (1998), Luque and Templado (2004) and Romero (2004b) in Spain, Boudouresque and Meinesz (1982) and Thébaudin and Cadeau (1987) in France and Mazzella *et al.* (1986) in Italy.

In the field of **managing** *Posidonia oceanica* meadows, information is spread by almost a hundred reports with very small circulations, thus practically inaccessible, and in doctoral theses, also scarcely accessible. Generally speaking, the information contained in these reports is limited and relates to particular sites or situations. The lessons to be learned, likely to become widespread around the Mediterranean, have rarely been summarized, except regarding monitoring tools, legislation and restoration (Boudouresque *et al.*, 1990b, 1995b, 2000; Pergent-Martini, 2000; Boudouresque, 2002a).

All in all, a work that takes stock of the knowledge about *Posidonia oceanica* and the meadows it forms, and that summarizes the information that enables us to best respond to the various problems managers face, does not yet exist.

We have chosen to present **3 levels of reading**: **(1)** the scientific level, **(2)** the level of specialist managers and **(3)** the level of non-specialist managers and politicians.

(1) The **scientific level** corresponds to Chapters 2-5 and the first paragraphs ("the problem") of the other chapters. This information is necessary so that the recommendations contained in the two other levels of reading should not appear as simple, fairly arbitrary formulae. Those who so wish can find basic information there and even go further, referring back to the source (bibliographical references are systematically provided). This information is necessary, for managers increasingly have to justify their choices when these choices are not strictly framed by regulatory provisions. Moreover, this information will enable them to put the recommendations we provide today in their context, when faced with new data to which they may have access.

(2) The **specialist managers' level** corresponds to the "case studies" and "recommendations" paragraphs in Chapters 6-13 and to Chapter 14. In the case studies, managers will find similar situations to those which they are faced. The style of the recommendations, with very clear reference to scientific data, will enable them to justify the choices they will have to propose.

(3) The **non-specialist decision-maker managers' and politicians' level** (Chapter 18) enables quick reading with no scientific references or evidence. The recommendations that appear here are "robust", i.e. it is extremely unlikely that research being done today will lead to them being modified. Managers or politicians who have to make decisions will not run any risks in following the recommendations. Our choice of on the one hand offering several levels of reading and on the other dividing the text into chapters that focus on a specific problem implies frequent cross-referencing between chapters. However, certain ideas **recur** in many chapters; the authors made this choice deliberately to make it easier to use the book.

Despite the care taken in drafting the book, and despite the considerable documentary base which it draws on, the authors are aware that certain documents have been left out, that certain particular cases can be found outside the margins they envisaged, and that their analysis is not above being criticized. They therefore thank in advance all those who wish to point out possible omissions, errors or lacunae.

The present work mainly concerns the coasts of Provence (France), Monaco and Liguria (Italy), i.e. the area covered by the RAMOGE Agreement. However, the writers wished whenever possible to locate it on **a pan-Mediterranean** level. The result is that in any one given country their recommendations may seem unnecessary (according to the existing regulatory texts), naive or possibly unrealistic. They wish to apologize for this in advance..

2. *POSIDONIA OCEANICA* MEADOWS

Some 120-100 million years (Ma) ago, in the Cretaceous period, some continental Magnoliophytes[1] (Plantae) returned to the marine environment. Further back in time, about 475 Ma ago, in the Ordovician (Primary era), their distant ancestors had left this marine environment to go in conquest of the continents (Boudouresque and Meinesz, 1982; Wellman *et al.*, 2003).

By number of their species in today's natural environment, marine Magnoliophytes represent rather a small group: 13 genera[2] and 60 species (Kuo and Hartog, 2001). For purposes of comparison, there are 234 000 Magnoliophyte species (almost all continental) and about 200 000 marine species of fauna and flora together (Fredj *et al.*, 1992; Heip, 1998; Lecointre and Le Guyader, 2001). Why was the **diversification** of marine Magnoliophytes so meagre, while since that time (100 Ma) the continental Magnoliophytes diversified to such an extent? 3 hypotheses exist: **(i)** The predominance of **vegetative reproduction** compared to sexual reproduction for marine Magnoliophytes; sexual reproduction, through the genetic recombination it involves, is a powerful evolutionary motor; moreover, there is often self-fecundation (Romero, 2004a). **(ii)** The absence of **mutualistic** symbiosis with insects (absent in the marine environment) for pollination; in the continental environment this often extremely specific symbiosis has been a powerful motor of speciation (Romero, 2004a). **(iii)** Lastly, **the competitive advantage** the marine Magnoliophytes enjoy over other marine primary producers[3] is so great that competition has not driven evolution.

However, although the marine Magnoliophytes are not numerous, their ecological weight is considerable in coastal environments: many of them are ecosystem engineers[4], or at least key species[5]. The ecosystems they build up or in which they are the major actors play an essential role in many parts of the world. This is so for the Mediterranean.

In the Mediterranean, there are 5 species of Magnoliophytes. As well as *Posidonia oceanica*, there are *Cymodocea nodosa*, *Nanozostera noltii*[6], *Zostera marina*, and a Red Sea species that entered the Mediterranean via the Suez Canal, *Halophila stipulacea* (Hartog, 1970; Por, 1978). Australia seems comparatively much richer, with 30 species, including 8 *Posidonia* species: *P. angustifolia, P. australis, P. coriacea, P. denhartogii, P. kirkemanii, P. ostenfeldii, P. robertsonae* and *P. sinuosa* (Kuo and Hartog, 2001). The fact that the genetic differences (DNA) between the Mediterranean species (*P. oceanica*) and the Australian Posidonia species are relatively great suggests that the separation of the 2 groups happened long ago, certainly in the late Eocene (Waycott and Les, 2000).

1 Magnoliophytes are what used to be called Phanerogams.

2 The following are genera of marine Magnoliophytes *Amphibolis, Cymodocea, Enhalus, Halodule, Halophila, Heterozostera, Nanozostera, Phyllospadix, Posidonia, Syringodium, Thalassia, Thalassodendron* and *Zostera*. Magnoliophytes present in brackish water (e.g. the genera *Ruppia* and *Potamogeton*) are not taken into account here.

3 Here we are talking about the polyphyletic group formerly known as 'algae'. This group is made up of (i) Chromobionta ('brown algae') which belong (with part of what were called 'muchrooms') to the Kingdom Stramenopiles, (ii) Rhodobionta ('red algae') which belong to the Kingdom Plantae, and (iii) Chlorobionta ('green algae') close to the Magnoliophytes, which also belong to the Kingdom Plantae.

4 An ecosystem engineer (engineering species) is an organism which directly or indirectly modulates the availability of resources (other than the resource it itself may constitute) for other species by provoking physical changes in the biotic or abiotic material (Lawton, 1994).

5 A key species is a species whose impact on the functioning of the ecosystem in which it participates is greater than its abundance might lead one to believe (Bond, 2001).

6 *Nanozostera noltii* = *Zostera noltii*.

2.1. GEOGRAPHICAL DISTRIBUTION

Posidonia oceanica is present almost throughout the Mediterranean. In the west, it disappears just before the Strait of Gibraltar, near Calaburros in the north and Melilla in the south (Conde Poyales, 1989). In the east, it is absent from the Egyptian coast (east of the Nile Delta), Palestine, Israel and Lebanon (Por, 1978). It does not penetrate the Marmara Sea or the Black Sea. And it is rare or absent in the far north of the Adriatic (Zalokar, 1942; Gamulin-Brida *et al.*, 1973; Gamulin-Brida *et al.*, 1974) and along the Languedoc coast (France) between the Camargue and Port-la-Nouvelle (Boudouresque and Meinesz, 1982).

In literature there is some mention of *Posidonia oceanica* outside the Mediterranean: the Bay of Biscay (Sauvageau, 1890; Flahault, 1908; Sauvageau, 1927; Fernandez-Casas *et al.*, 1992), Portugal (Daveau, 1896; Flahault, 1908), Canary Islands (Viera *in* Carrillo and Gil-Rodriguez, 1980), the Red Sea (Makkaveeva, 1968), the Indian Ocean (Saporta and Marion, 1878) and even Texas, USA (Correl and Johnston, 1970). These are uncritical citations from very old books, or surprising mistakes due to confusion with *Zostera marina*, *Thalassia testudinum* or *T. hemprichii* (Hartog, 1970; Correl and Correl, 1975; McMillan *et al.*, 1975; Carrillo and Gil-Rodriguez, 1980).

All in all, *Posidonia oceanica* is an endemic Mediterranean species, i.e. strictly confined to this Sea. We know that most of this Sea dried up in the Messinian period, 5.6 to 5.3 million years ago, because of the closing of the Strait of Gibraltar (Krijgsman *et al.*, 1999; McKenzie, 1999). We do not know how *P. oceanica* survived this crisis. One or many refuge areas certainly existed in the Mediterranean or the Atlantic nearby, from which it could recolonize the Mediterranean after the Gibraltar Strait reopened.

2.2. THE PLANT

Posidonia oceanica is made of creeping or erect stems usually buried in the sediment, called rhizomes. Creeping **rhizomes** are called **plagiotropic**, and erect rhizomes **orthotropic**. There is no determined differentiation between plagiotropic and orthotropic rhizomes; according to the available space an orthotropic rhizome may become plagiotropic and vice versa (Caye, 1980). The rhizomes end in groups of 4-8 leaves (shoots) that are 8-11 mm wide and 20-80 cm long. The length may reach 156 cm [7]. Rhizomes also have roots that can grow to 70 cm beneath the surface of sediment (Fig. 1; Giraud *et al.*, 1979; Boudouresque and Meinesz, 1982).

New leaves form all year round. They live for between 5 and 8 months, and more rarely up to 13 months. The leaf's growth zone (meristem) lies at the base. Leaves less than 5 cm long are called **juveniles** and those longer than 5 cm without basal sheath (=petiole) are called **intermediate**; when the growth is over, a petiole is formed and the leaf is said to be **adult** (Fig.2; Giraud, 1979; Ott, 1980; Thélin and Boudouresque, 1983).

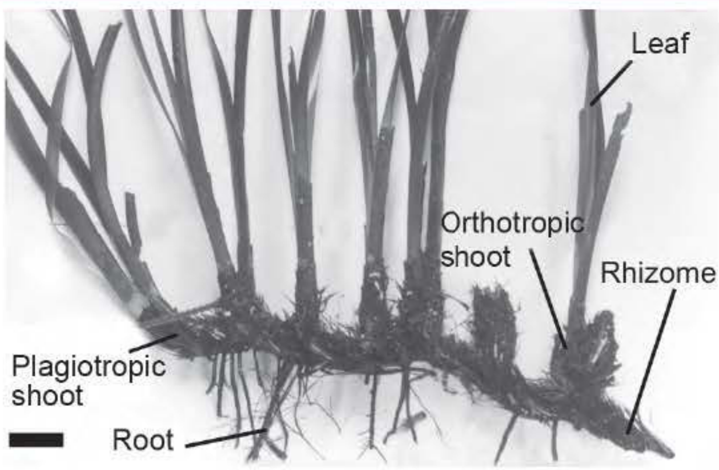


Fig. 1. A plagiotropic rhizome of *Posidonia oceanica*, from which leave upward a half-dozen of orthotropic rhizomes and, downward, roots. Each rhizome bears a shoot of leaves. Frayed scales cover the rhizomes. The scale bar measures 2 cm. From Boudouresque and Meinesz (1982).

When they die, the leaves do

[7] The island of Ischia (Gulf of Naples, Italy), 10 metres depth, in June (Gérard Pergent and Christine Pegent-Martini, unpublished data).

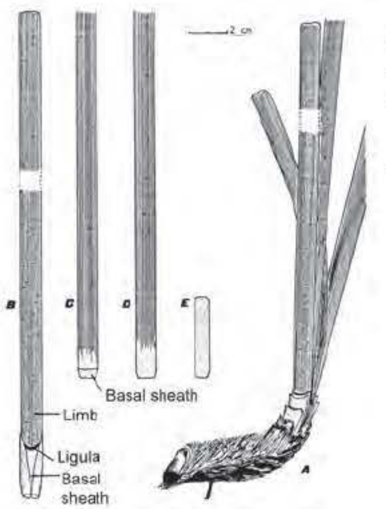


Fig. 2. The different types of leaves in a *P. oceanica* shoot. **A** Shoot of leaves with sheaths (= scales) at the base. **B** Adult leaf with a wrapping petiole. **C** Adult leaf with a basal sheath which begins to form. **D** Intermediate leaf (without basal sheath). **E** Juvenile leaf. After Boudouresque (unpublished).

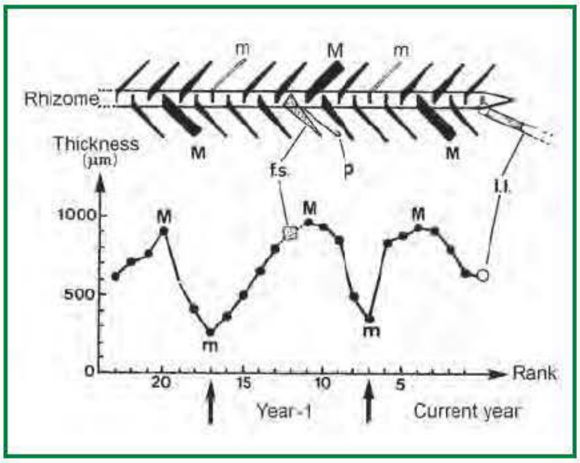


Fig. 3. The lepidochronology. **At the top** Arrangement of scales along a *Posidonia oceanica* rhizome. **Below** scale thickness (in µm). **M** maximum thickness. **m** minimum thickness. **fs** remains of a floral stalk. **p** prophyll (= preleaf) accompanying the floral stalk. **l.l.** the oldest living leaf. **Year -1** previous year. From Pergent *et al.* (1989b).

not fall off: only the limb[8] is deciduous, while the basal sheath (petiole), several centimetres long, remains attached to the rhizome. It is then called a scale or sheath (Fig. 1 and 2). The leaves drop, as they are formed, all year round (Pergent and Pergent-Martini, 1991). The **sheaths** (like the rhizomes) are not very putrescible and so can last for several centuries or even thousands of years. An entire set of parameters of the sheaths (length, thickness, anatomy) varies cyclically during a yearly cycle (Fig. 3). The analysis of these cycles is known as **lepidochronology** (Crouzet, 1981; Crouzet *et al.*, 1983; Pergent *et al.*, 1983; Pergent, 1990a).

Lepidochronology is a powerful tool for measuring the speed of growth of the rhizomes, the number of leaves formed each year, the dynamics of building up meadows, past primary production, old pollutant levels, etc. (Pergent, 1990b; Pergent and Pergent-Martini, 1990, 1991; Pergent *et al.*, 1992; Pergent-Martini and Pergent, 1994; Pergent-Martini, 1998). Much of the data on *Posidonia oceanica* meadows, presented throughout this book, comes from use of the lepidochronological tool.

Posidonia oceanica flowers in the autumn (September-November). The flowers are hermaphrodite, i.e. both male and female at the same time; 4-10 flowers are grouped in an inflorescence at the tip of a 10-30 cm-long stalk (Fig. 4). It does not flower every year, especially in the relatively cold waters of the north-western Mediterranean. Some years there is a particularly intense flowering, throughout the whole Mediterranean, for example in 1971, 1982, 1993, 1997 and 2003 (Giraud, 1977c; Boudouresque and Meinesz, 1982; Mazzella *et al.*, 1983, 1984; Caye and Meinesz, 1984; Pergent, 1985; Thélin and

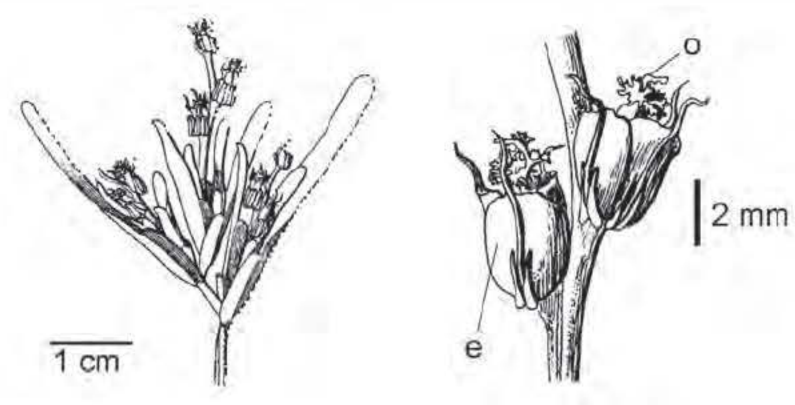


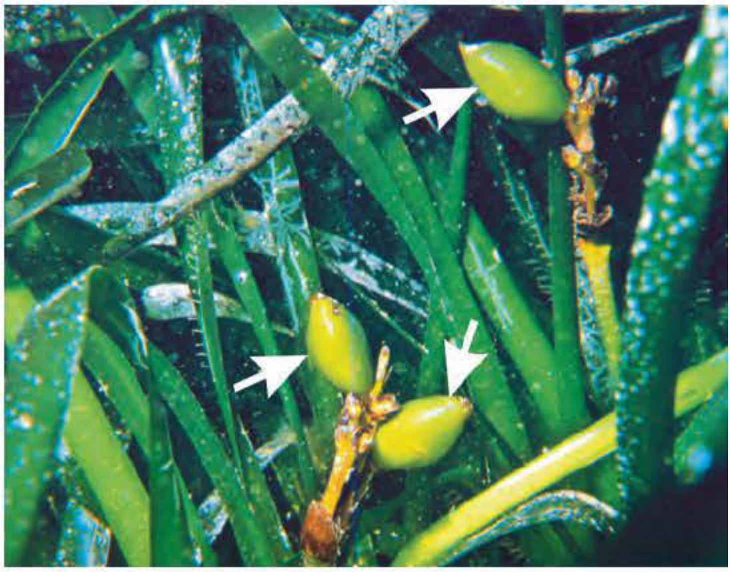
Fig. 4. On the left an inflorescence of *Posidonia oceanica*. On the right two flowers; stamens (e) are situated outside; the top of the ovary (o) is visible. From Hartog (1970).

[8] A leaf has a petiole (base or sheath) by which it is attached to the stem or to the rhizome, and a limb, the part where photosynthesis happens.

Boudouresque, 1985; Pergent *et al.*, 1989a; Acunto *et al.*, 1996; Piazzi *et al.*, 1999; Gobert *et al.*, 2005). Flowering seems to be caused by high summer temperatures and by a temperature of 20°C in October (Caye and Meinesz, 1984; Thélin and Boudouresque, 1985; Pergent *et al.*, 1989a; Stoppelli and Peirano, 1996).

The **fruits** of *Posidonia oceanica* require 6-9 months to ripen. Between May and July, they drop off and float for a certain time. According to the direction of the currents, they may be washed up on beaches in great quantities. The fruits have the shape and size of an olive; they are dark green, dark brown to black (Fig. 5). They have just one **seed** (Hartog, 1970; Boudouresque and Meinesz, 1982). Germination of the seeds has been observed *in situ* on several occasions (Acunto *et al.*, 1996; Piazzi *et al.*, 1996; Balestri *et al.*, 1998; Gambi and Guidetti, 1998; Piazzi *et al.*, 1999; Eric Charbonnel, unpublished observations). However, *P. oceanica* reproduces mainly in a vegetative way, through cuttings (Molinier and Picard, 1952). In the Bay of Villefranche-sur-Mer (Alpes-Maritimes, France), Meinesz and Lefèvre (1984) estimated that in a favourable site (*P. oceanica* "dead matte") the number of cuttings that attach successfully is on average 3/ha/year. *Cymodocea nodosa* and *Caulerpa prolifera* settlements are equally favourable to the attachment of cuttings, and possibly the germination of seeds (Cinelli *et al.*, 1995b). Another form of vegetative reproduction by pseudo-viviparity[9] was recently observed in May 2004 in the Balearic Islands (Ballesteros *et al.*, 2005). Vegetative plantlets form directly on the inflorescences and replace the organs of sexual reproduction. This strategy contributes to short-distance dispersal. For the time being we do not know if this is a very local mode of reproduction or whether it concerns other parts of the Mediterranean.

Fig. 5. Fruits of *Posidonia oceanica* ("sea olives"; arrows), in a meadow. They are 1.5-2.0 cm long and about 1 cm wide.
Photo L. Mazzella.



Posidonia oceanica's **low genetic variability** could be a weakening factor for this species (Raniello and Procaccini, 2002). Indeed, Capiomont *et al.* (1996) highlighted the fact that enzymatic polymorphism between populations of the western Mediterranean (Italy, continental France, Corsica and Algeria) is very low, particularly in the areas of Port-Cros (Var, France) and Nice (Alpes-Maritimes, France). The rarity of the flowering and, especially, seed production, as well as self-pollination, and inversely the frequency of vegetative reproduction (by cuttings) could explain this low variability. It should however be noticed that, based on anatomical, morphological (leaf width) and karyological features, a population of *P. oceanica* presenting original characteristics was found in the area of Algiers (Semroud *et al.*, 1992). Moreover, genetic markers (RAPD, microsatellites) do not confirm the low genetic variability based on enzymatic polymorphism (Reusch, 2001).

9 There are two kinds of viviparity (i) strict viviparity, where the seeds resulting from sexual reproduction germinate on the inflorescence before dropping off the plant and (ii) pseudo-viviparity, when the vegetative propagules (bulbils, plantules) replace the organs of sexual reproduction on the inflorescence. Like cuttings, these plantules give birth to clones of the mother plant.

2.3. ECOLOGY

In calm conditions, *Posidonia oceanica* can develop very near average sea level: its leaves then spread out on the surface. Maximum **depth** depends on water transparency: 15-23 m in the Pyrénées-Orientales, France (Ben, 1971; Pergent *et al.*, 1985; Ballesta *et al.*, 2000), 21-28 m in Liguria, Italy (Bianchi and Peirano, 1995), 20-30 m in Latium, Italy (Diviacco *et al.*, 2001), 28-32 m in the Bouches-du-Rhône, France (Bourcier, 1979; Cristiani, 1980), 28-38 m in the Var, France (Bourcier, 1979; Harmelin and Laborel, 1976), 22-35 m in the Alpes-Maritimes, France (Meinesz and Laurent, 1977, 1978), 30-39 m in Corsica (Molinier, 1960; Bay, 1979; Meinesz *et al.*, 1987; Pasqualini, 1997), 30-38 m in Ischia (Gulf of Naples, Italy; Giraud *et al.*, 1979) and 43-44 m in Malta (Schembri, 1995). In the Var and in Corsica, isolated clumps of *P. oceanica* have been observed up to 45-48 m depth (Augier and Boudouresque, 1979; Boudouresque *et al.*, 1990c). **Light** is one of the most important factors for the distribution and density of *P. oceanica* (Elkalay *et al.*, 2003).

Posidonia oceanica dislikes **low salinity**. It dies off immediately below 33‰ (Ben Alaya, 1972). It is the low salinity that keeps it out of the Marmara Sea (21-27‰), the brackish lagoons of the Languedoc coast and around the coastal river mouths. The absence of *P. oceanica* from the central part of many beaches could correspond to the area where ground water reappears (Leriche, 2004). The species appears to resist high salinity levels more successfully, although Ben Alaya (1972) has shown that 41‰ constitutes its upper tolerance limit. In fact it is present in the hypersaline lagoons of Tunisia (Bahiret el Biban; 46‰ average in August) and Libya (Farwa: 39-44‰ according to the season); in these lagoons its vitality (number of leaves produced per year, growth of rhizomes) seems identical to or above what is observed out at sea (Pergent and Zaouali, 1992; Pergent and Pergent-Martini, 2000; Pergent *et al.*, 2002a).

The extremes of **temperature** measured in a *Posidonia oceanica* meadow are 9.0 and 29.2°C (barrier reef in Port-Cros Bay, Var, France; Augier *et al.*, 1980; Robert, 1988). It is however possible that low (under 10°C) and high (over 28°C) temperatures are only exceptionally borne. *P. oceanica*'s absence from the Levantine coast (eastern Mediterranean) and its scarcity in the northern Adriatic and along the Languedoc coast could be due respectively to the summer and winter temperatures (Boudouresque and Meinesz, 1982). Also, in deep meadows, Mayot *et al.* (2005) suggest that the increase in seawater temperature that is currently observed (Salat and Pascual, 2002) could have a harmful effect on *P. oceanica*.

Posidonia oceanica dislikes too intense **hydrodynamism**. Storms tear off shoots, some of which will constitute cuttings. They can also erode the "matte[10]", either directly, or by leaching the sediment, which weakens the meadows (see below). That is why in rough sea conditions the meadow grows no nearer the surface than 1 or 2 metres. "Dead matte" can thus be a natural phenomenon, as for example in the La Palud Bay in Port-Cros, Var, France (Augier and Boudouresque, 1967). In literature, the presence of "dead matte" has not infrequently been wrongly interpreted as an unequivocal sign of human impact (Moreno *et al.*, 2001).

10 See page 15 for the definition of the "matte".

2.4. THE STRUCTURE OF MEADOWS

The leaves and rhizomes of *Posidonia oceanica* support many flora and fauna, some of which are calcified. When they die, their remains fall off and form an **autochthonous sediment** (debris of sea urchin spines or tests, mollusc shells, corallinales[11], etc.). Moreover, because of their density (up to 5 000/m²) and distribution the leaves of *P. oceanica* reduce the speed of the current; this reduces the kinetic energy of the sedimentary particles carried by the water, which then deposit to the seabed (**allochthonous sediment**).

Posidonia oceanica rhizomes grow in height, even in the absence of sedimentation. To resist being buried, they are capable of speeding up their growth (Molinier and Picard, 1952; Caye, 1980; Boudouresque and Jeudy de Grissac, 1983; Boudouresque *et al.*, 1984; Jeudy de Grissac and Boudouresque, 1985; Boudouresque *et al.*, 1994b).

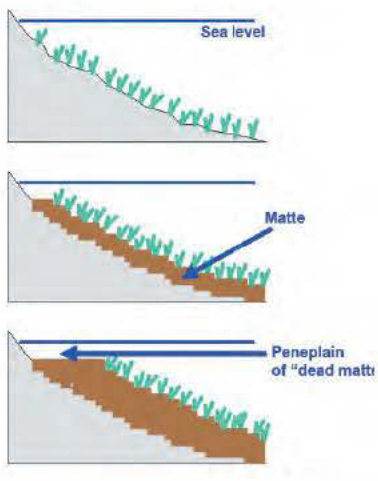
The **"matte"** is the whole mass composed of rhizomes, sheaths, roots and the sediment that fills the interstices. The rhizomes, sheaths and roots are not very putrescible and thus are conserved within the "matte" for several centuries or even thousands of years (Boudouresque *et al.*, 1980d; Boudouresque and Jeudy de Grissac, 1983).

Over the course of time, the "matte" **rises to the surface**. Comparing bathymetric maps of 1839 and 1950 for the Levant-Port-Cros and Bagaud-Port-Cros passes (Var, France), Molinier and Picard (1952) measured a seabed elevation of **1 metre per century**. Certainly, we must probe the precision of these maps. In Catalonia, Spain, over a period of 3 000 years, average growth was **18 cm per century** (Mateo *et al.*, 1997). In the Gulf of Giens (Var, France), a Roman wreck which sank in about 50 or 60 BC is covered with 2 metres of "matte" (Fig. 6; Tchernia *et al.*, 1978; Boudouresque and Meinesz, 1982). In cape Moulin (Port-Cros, Var, France) radiocarbon dating (^{14}C) of the remains of rhizomes indicates an average growth of **10 cm per century** (Boudouresque and Jeudy de Grissac, 1983). A slower average speed was measured in the Bay of Calvi, Corsica (Boudouresque *et al.*, 1980d).

The rising of the "matte" can bring the meadow near the surface. In **exposed conditions**, this rise stops 1 or 2 metres below the sea surface. Hydrodynamism prevents the rise continuing and determines the forming of a peneplain of "dead matte" (Fig. 7; Molinier and Picard, 1952;

Fig. 6. The Madrague de Giens (Var, France) Roman wreck. There is the "matte" (arrow) under which the wreck and the amphorae were buried. From Tchernia *et al.* (1978).

Fig. 7. Dynamics of the *Posidonia oceanica* meadow in exposed conditions. The rise of "matte", over time, stops at 1-2 m deep. The erosion by sea surface hydrodynamism determines the formation of a peneplain of "dead matte". After Boudouresque (unpublished).



[11] Corallinales are calcified photosynthetic organisms which belong to the Rhodobionts (Plantae).

Fig. 8. In a sheltered bay, the *Posidonia oceanica* meadow approaches the sea surface. Photo E. Charbonnel.

Fig. 9. The barrier reef of Port-Cros Bay (Var, France). *Posidonia oceanica* leaves are spread on the surface of the water. Photo S. Ruitton.

Boudouresque and Meinesz, 1982). But in **sheltered conditions**, especially at the innermost part of bays, the rise of the "matte" can continue right up to the sea surface (Fig. 8). The leaves spread out on the surface (Fig. 9). At a first stage, the emersion of the tips of the leaves happens parallel to the coast. This formation is known as a **fringing reef** (Fig. 11). Then the continuing rise of the "matte" widens the fringing reef. Within the fringing reef the leaves and the shallowness hamper water circulation; the temperature may go below (in winter) or above (in summer) the limits of *Posidonia oceanica*'s tolerance. The same holds good for salinity, in times of rain. Between the coast and *P. oceanica*'s emersion front, the shoots die, and a **lagoon** is formed (Fig. 10) (Molinier and Picard, 1952; Boudouresque and Meinesz, 1982).

Posidonia oceanica's emersion front thus constitutes a **barrier reef** (Fig. 10). With time, the barrier reef moves out to sea and the lagoon grows (Fig. 11) (Molinier and Picard, 1952; Augier and Boudouresque, 1970a; Boudouresque and Meinesz, 1982). The barrier reef's movement out to sea is estimated to be 8-10 metres a century (Boudouresque, unpublished data). In the lagoon, the bottom of which is muddy, 2 Magnoliophytes with narrower, shorter leaves than those of *P. oceanica* can establish: *Cymodocea nodosa* and *Nanozostera noltii*.

Many barrier reefs have been destroyed because they were located in bays that have been made into ports. The most spectacular barrier reefs still in existence are those of Port-Cros, Le Brusc and La Madrague de Giens (Var, France) (Molinier and Picard, 1952; Augier and Boudouresque, 1970a; Boudouresque *et al.*, 1975; Boudouresque and Meinesz, 1982; Bernard *et al.*, 2002; Charbonnel *et al.*, 2002). Less typical or less well-known barrier reefs also exist (or did exist[12]) south of Port-Bou (Catalonia, France), in Puerto de Sanitja (Minorca, Balearic Islands, Spain), in Bajos de Roquetas (Almeria, Spain), in Toulon

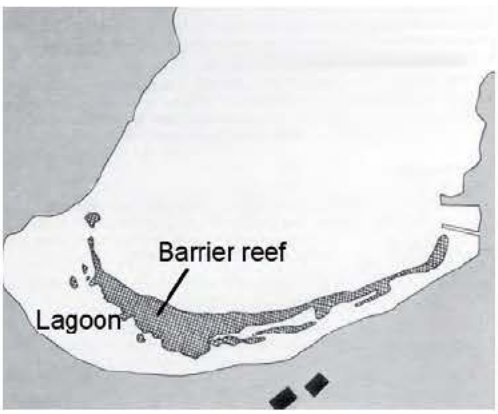


Fig. 10. The barrier reef of *Posidonia oceanica* of Port-Cros Bay (Var, France), in the early 20th century. From Boudouresque *et al.* (1975).

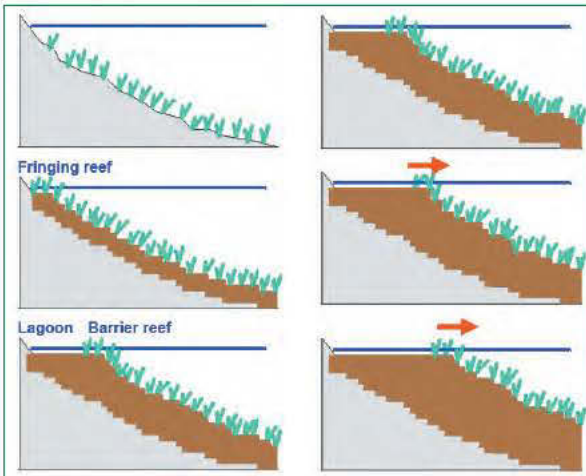


Fig. 11. Dynamics of *Posidonia oceanica* meadow in sheltered conditions. The rise of the "matte", over time, may continue and reach the sea surface. It first forms a fringing reef, then a barrier reef separated from the coast by a lagoon. Over time, the barrier reef expands seaward. After Boudouresque (unpublished).

[12] Some of these barrier reefs, cited below from fairly old sources, have in fact disappeared since then, without this disappearance being recorded by a scientific publication.

(Le Mourillon cove), in Saint-Tropez (Pilon port), in Sainte-Marguerite (continental France), in the Gulf of Saint-Florent and the outer harbour of Centuri (Corsica), in Rapallo and Prelo (Italy), in the Kouali cove and between Bou-Ismaïl and Sidi-Ferruch (Algeria), in La Marsa and Sidi-el-Reiss (Tunisia), in Urla-Iskele (Gulf of Izmir, Turkey) and finally in Abu-Qir (Egypt) (Molinier and Picard, 1954; Aleem, 1955; Molinier and Picard, 1956; Molinier, 1960; Ben Alaya, 1969; Boudouresque *et al.*, 1985b; Pergent and Pergent, 1985; Boudouresque *et al.*, 1994b; Bianchi and Peirano, 1995; Charbonnel *et al.*, 1996; Ribera *et al.*, 1997; Sanchez-Lizaso, 2004).

2.5. TYPES OF MEADOWS

Posidonia oceanica meadows can be of different morpho-structural types linked to hydrodynamism, currents and/or water temperature. However, the type of meadow does not seem to influence density of shoots, length of leaves, number of leaves per shoot or biomass (Borg *et al.*, 2005).

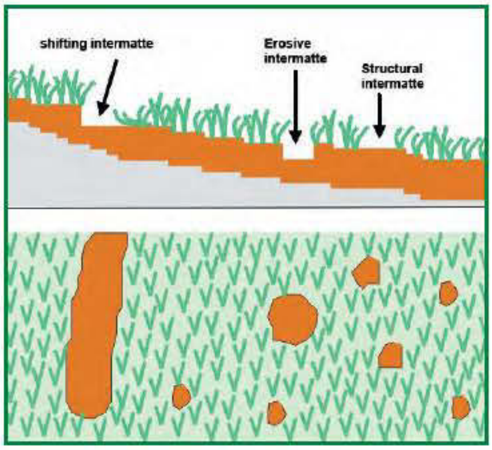


Fig. 12. The plain meadow. At the top, a cross-section perpendicular to the coastline showing a shifting intermatte, an erosive intermatte and a structural intermatte. Below, a top view of the same structures. From Boudouresque (unpublished).

The **plain meadow** is the most usual kind of meadow in the Mediterranean, especially the western Mediterranean. It consists of a fairly continuous, horizontal or gently sloping meadow, broken by erosive structures (erosion scarp, erosive intermatte, shifting intermatte, "return river") and non-erosive "dead matte" (structural intermatte) (Fig. 12; Boudouresque *et al.*, 1980d, 1985a). All these structures are of natural origin (Blanc and Jeudy de Grissac, 1984). **Erosive intermattes** are a sort of circular or ovoid "potholes" dug into the "matte"; when they are deep, *Posidonia oceanica* can start growing again at the bottom of the intermatte (Molinier and Picard, 1952). **Shifting intermattes** are furrows several dozen metres long and several metres wide, lying parallel to the shore. The side of the shifting intermatte that is closest to the shore is made up of an erosion scarp; which is actively eroded. The central part of the shifting intermatte is made up of "dead matte" possibly covered by sand. The side that is furthest away from the shore is made up of a meadow front with plagiotropic rhizomes that tends to recolonize the intermatte. Over time, the shifting intermatte moves along in a parallel direction towards the coast (Fig. 12, 13) (Boudouresque *et al.*, 1980d; Leriche *et al.*, 2004). Typical shifting intermattes have been observed

Fig. 13. A shifting Intermatte in the Bay of Calvi (Corsica). On the left, the erosive scarp. On the right, *Posidonia oceanica* plagiotropic rhizomes recolonizing the intermatte. Photo A. Meinesz.

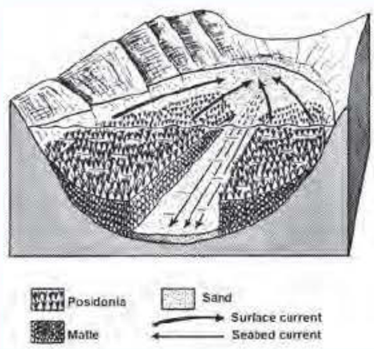


Fig. 14. A return river in a bay. The wind pushes surface waters toward the coast (arrows), and they return to seaward from the bottom (arrows), This circulation movement of water is called undertow. From Boudouresque and Meinesz (1982).

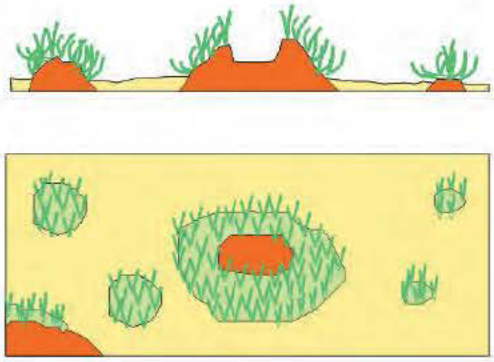


Fig. 15. Cross-section in a hill meadow (at the top) young hills (to the right and left) and an old hill, the destruction of which began (in the center). Top view of a hill meadow (below), with hills of various age, including a hill almost completely destroyed (below on the left). After Boudouresque (unpublished).

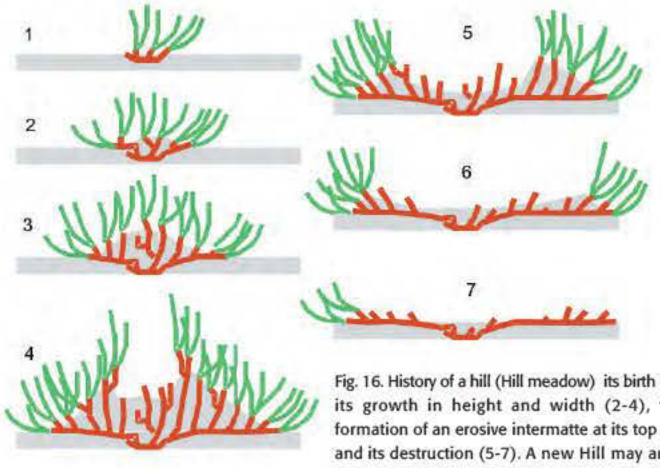


Fig. 16. History of a hill (Hill meadow) its birth (1), its growth in height and width (2-4), the formation of an erosive intermatte at its top (4) and its destruction (5-7). A new Hill may arise from the remains of a hill. Light grey sand. Green leaves. Brown rhizomes. After Boudouresque (unpublished).

in Calvi Bay (Corsica), in the Giens Gulf (Var, France) and in Torre Astura, Circeo and Terracina (southern Latium, Italy) (Boudouresque *et al.*, 1980d; Paillard *et al.*, 1993; Diviacco *et al.*, 1999, 2001). "**Return rivers**", or sagittal channels, are channels cut into the meadow that run perpendicular to the coast, whereby surface water pushed by the wind towards the coast returns to the open sea at the level of the seabed. The return riverbed can be followed up to 10-15 metres depth, more rarely 20 metres; it is 100-300 m wide, sometimes less, and is often bordered by erosion scarps (Fig. 14) (Blanc, 1974, 1975; Boudouresque and Meinesz, 1982; Blanc and Jeudy de Grissac, 1984). The speed of the return current (undertow) can be important during storms, as Blanc (1974) observed rocks weighing 50 kilos carried several hundred metres. Lastly, **structural intermattes** are little stretches of "dead matte" (0.2-0.5 m²) whose origin, which remains to be explained, seems to be natural (Boudouresque, unpublished data).

The **hill meadow** is less frequent. It is encountered between 15 and 30 metres depth, in sectors where there is great hydrodynamism (Boudouresque *et al.*, 1985a). In a hill meadow, *Posidonia oceanica* cuttings give birth to "hills" that grow wider and higher. The hills are usually surrounded by sand (Fig. 15).

When the hills grow higher they are exposed to hydrodynamism: at the summit, the sediment of the "matte" is retained badly and the rhizomes lose their hold. The exposed rhizomes are vulnerable and a kind of intermatte forms. Over time, this intermatte widens until the hill is entirely, or mostly, destroyed (Fig. 15 and 16). The lifetime of a hill between its birth and its destruction is usually about one century (Boudouresque *et al.*, 1985a, 1986a). It seems that the destruction is not always complete and that a new hill can be born from the remains of a former hill. The hill meadow has been described in Corsica (Boudouresque *et al.*, 1985a); it has also been observed in the Var and in Tuscany; it is probably much more widespread in the Mediterranean than these rare mentions suggest, at least in the central-western Mediterranean.

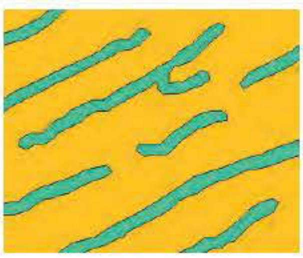


Fig. 17. A striped meadow, seen from top meadow strips, more or less parallel, surrounded by "dead mattes" usually occupied by a *Cymodocea nodosa* and/or *Caulerpa prolifera* settlements. From Boudouresque et al. (1985b), redrawn (Boudouresque, unpublished).

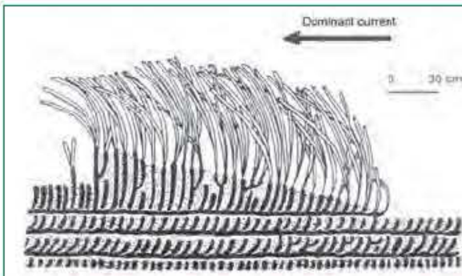


Fig. 18. Cross section in a strip of striped meadow. The progress is made towards the right, whereas the strip is eroded on the left by the hydrodynamism (generated by the dominant current). From Boudouresque *et al.* (1990a).

Fig. 19. Aerial view of a striped meadow in the Gulf of Gabès (Tunisia). From Blanpied *et al.* (1979).

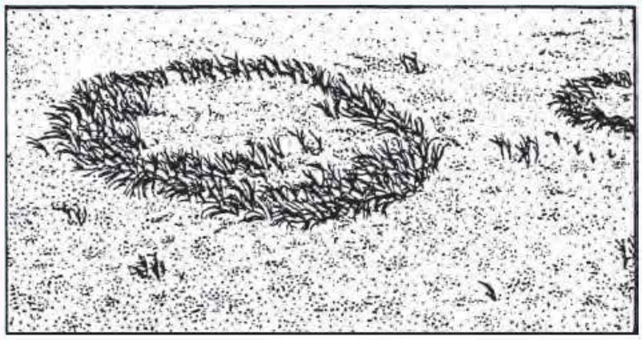


Fig. 20. *Posidonia oceanica* micro-atoll. From Cirik in Boudouresque *et al.* (1990a).

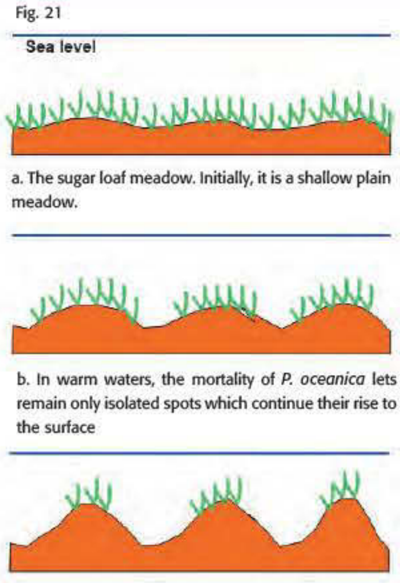
The **striped meadow** consists of 1-2 m-wide *Posidonia oceanica* meadow strips, which are several dozen metres long and separated by "dead matte" occupied by a *Cymodocea nodosa* and/or *Caulerpa prolifera* settlements (Chlorobionta, Plantae) (Fig. 17). Each meadow strip shifts, parallel to itself, against the dominant current, at an average speed of 10 cm/year. A cross section of a meadow strip shows on one side a front of plagiotropic rhizomes that progresses onto the "dead matte", a gentle slope behind the front, and a small erosive scarp where the strip disintegrates (Fig. 18) (Boudouresque *et al.*, 1985b; Boudouresque *et al.*, 1990a; Boudouresque and Ben Maïz, unpublished data).

The striped meadow, which develops in shallow water (less than 10 m depth), is especially present in the Gulf of Gabès, Tunisia, mainly around the Kerkennah Islands (Fig. 19). In a less typical form it is encountered in the Bouches de Bonifacio (southern Corsica) and Marsala (western Sicily) (Blanpied *et al.*, 1979; Calvo and Fradà-Orestano, 1984; Boudouresque *et al.*, 1990a; Boudouresque and Ben Maïz, unpublished).

Posidonia oceanica **micro-atolls** are often associated with the striped meadow. A micro-atoll is originally a more or less circular spot of *P. oceanica* in very shallow water. The Posidonia dies at the heart of the spot while the spot itself grows, thanks to the plagiotropic rhizomes on its periphery, thus giving birth to a Posidonia crown (Fig. 20; Boudouresque *et al.*, 1990a). Micro-atolls have been described in Turkey, in Marsala (western Sicily), and in Saint-Florent, Corsica (Calvo and Fradà-Orestano, 1984; Boudouresque *et al.*, 1990a; Pasqualini *et al.*, 1995).

The **sugar loaf meadow** was described by Molinier and Picard (1954) in Tunisia. At the beginning it is a rather shallow plain meadow. Certainly because of the high water temperature, the meadow dies, except for some more or less circular spots. These spots continue to rise to the surface and simultaneously their diameter decreases, thus forming characteristic "sugar loafs" (Fig. 21). Outside the Tunisian shores, this kind of meadow has been observed in the Gulf of Giens (Var, France).

Fig. 21



a. The sugar loaf meadow. Initially, it is a shallow plain meadow.

b. In warm waters, the mortality of *P. oceanica* lets remain only isolated spots which continue their rise to the surface

c. Finally, only islands of live *P. oceanica* remain at the top of "sugar loaf". After Boudouresque (unpublished).

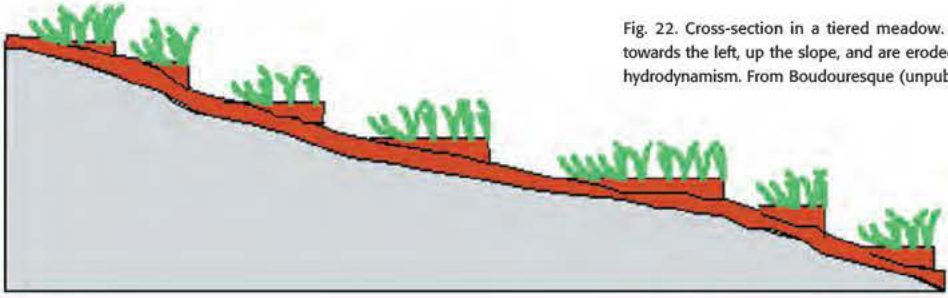


Fig. 22. Cross-section in a tiered meadow. The "steps" progress towards the left, up the slope, and are eroded on their right by the hydrodynamism. From Boudouresque (unpublished).

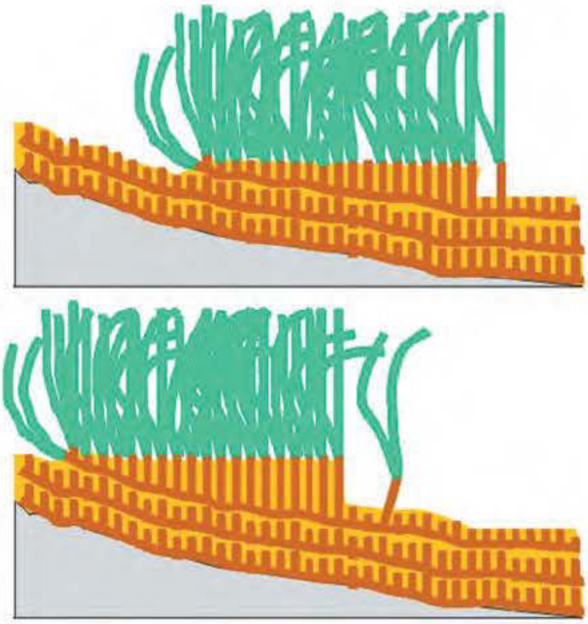


Fig. 23. The tiered meadow. A "step" of Posidonia shifts up the slope and is eroded back by the hydrodynamism. From Boudouresque (unpublished).

The **tiered meadow** (or staircase meadow) develops on hard substrate with a relatively steep slope and descending bottom currents (Boudouresque, unpublished data). Its origin is similar to that of the striped meadow. Parallel strips of meadow, 0.5-3 metres wide, shift up the slope against the current. Upstream of each "stair", plagiotropic rhizomes advance at an average speed of 10 cm/year, whereas downstream the current erodes the vertical part of the "stair" (Fig. 22, 23). In Punta Ciuttone (western Corsica, Parc naturel régional de Corse), where this kind of meadow was discovered, on average several centuries are needed for a "stair" to start from the base of the slope, move up it completely, and finally be destroyed there by hydrodynamism (Boudouresque, unpublished data). The tiered meadow is also present in Port-Cros (Var, France). It is probably present in other parts of the north-western Mediterranean, where it should be sought.

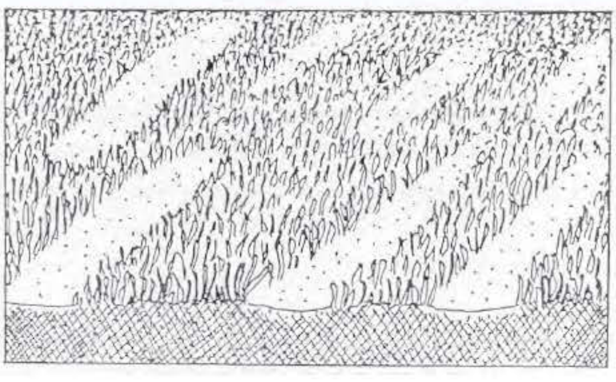


Fig. 24. Cross-section and perspective view of an undulating *Posidonia oceanica* meadow. From Bonhomme *et al.* (1999).

Lastly, the **undulating meadow** develops at the lower limit of *Posidonia oceanica* between 25 and 40 metres depth, on a sub-horizontal substratum (Clairefond and Jeudy de Grissac, 1979). It has, however, also been observed at shallow depths (El Asmi-Djellouli *et al.*, 2000). It is characterized by wide, anastomotic, parallel strips of meadow (up to ten metres), of very slight rise, separated by parallel strips of sand (possibly) covered with "dead matte" (Fig. 24). It has been described between Port-Cros and Bagaud Islands (Var, France) (Clairefond and Jeudy de Grissac, 1979) and found at the entrance to the Galeria Bay (Corsica; Bianconi and Boudouresque, unpublished data), in La Ciotat Bay (Bouches-du-Rhône, France; Charbonnel and Francour, 1994; Bonhomme *et al.*, 1999) and in Tunisia in shallow water (El Asmi-Djellouli *et al.*, 2000). It is probably not very rare. So far its genesis has not been explained.

2.6. HOW THE ECOSYSTEM FUNCTIONS

A basic feature of the *Posidonia oceanica* ecosystem is the juxtaposition of **2 kinds of primary production**. At global level, only marine Magnoliophyte (=Phanerogam) ecosystems present this special feature (Boudouresque, 1996). **(i)** The primary production from *P. oceanica* is rich in cellulose and in lignin, compounds that are not used much by herbivores, and in phenolic compounds, one of whose roles is to dissuade potential consumers (Piovetti *et al.*, 1984). The net primary production of *P. oceanica* is on average 420 g DM/m²/year[13] and may reach 1 300 g DM/m²/year; it drops in relation to depth (Mazzella and Ott, 1984; Romero-Martinengo, 1985; Pergent *et al.*, 1994; Pergent-Martini *et al.*, 1994; Pergent *et al.*, 1997). **(ii)** The primary production from the Multicellular Photosynthetic Organisms (MPOs) leaf epibiota (Fig. 25) is composed of very palatable Rhodobionta and Chromobionta, thus easily usable by herbivores; it is between 100 and 500 g DM/m²/year (Giorgi and Thélin, 1983; Mazzella and Ott, 1984). All in all, the *P. oceanica* ecosystem is one of **the planet's most productive** ecosystems.

Fig. 25. *Posidonia oceanica* leaves covered with MPOs leaf epibiota, in the Bay of Port-Cros (Var, France). From Boudouresque and Meinesz (1982).

Vegetal biomass is very high: up to 900 g DM/m² [14] for the leaves, up to 470 g DM/m² for the MPOs leaf epibiota, up to 50 g DM/m² for the MPOs rhizome epibiota, and up to 5 500 g DM/m² for the rhizomes, sheaths and roots; it decreases with depth (Thélin and Bedhomme, 1983; Pirc, 1983; Libes, 1984; Boudouresque and Jeudy de Grissac, 1986; Ballesteros, 1987; Francour, 1990; Mazzella *et al.*, 1992). No other marine ecosystem, except mangroves, presents such high vegetal biomass. This is due to the storage of the biomass over a long period of time in the "matte". High vegetal biomass and storage are attributes usually associated with continental forest ecosystems.

Animal biomass is considerably lower than vegetal biomass. This is also a feature that the *Posidonia oceanica* ecosystem shares with the continental forest ecosystems. For each taxonomical group or trophic compartment, the values vary considerably from one station to the next and according to depth. For example, the following values (or value intervals) can be seen as common (in g DM/m²): 2-180 g for the leaf epizoans, 2-25 g for fish, 0.2 g for the starfish *Marthasterias glacialis*, 3-6 g for vagile crustaceans and molluscs, 2-33 g for sea urchins (mainly *Paracentrotus lividus* and *Psammechinus microtuberculatus*), 6-9 g for the holothurians (*Holothuria polii* and *H. tubulosa*) and 50-70 g for the "matte" endofauna (Harmelin, 1964; Vadon, 1981; Harmelin-Vivien, 1982, 1983, 1984; Francour, 1984; Ballesteros, 1987; Francour and Paul, 1987; Francour, 1990; Harmelin-Vivien and Francour, 1992; Jiménez *et al.*, 1997). All in all, the fauna usually represents 100-200 g DM/m².

Fig. 26. The fish *Sarpa salpa* (salema) is one of the main consumers of *Posidonia oceanica*. Photo S. Ruitton.

Little (less than **10%**) of the *Posidonia oceanica* primary production is used by herbivores. These are mainly the fish *Sarpa salpa* (Fig. 26, 28),

13 DM = dry mass. Higher values have been mentioned in the literature (e.g. Ott, 1980); their value is local unless due to methodological artefacts.

14 Higher values have been mentioned by several authors (e.g. Drew and Jupp, 1976; Ott and Maurer, 1977; Boumaza and Semroud, 1995; Romero *et al.*, 1998).

Fig. 27. A "banquette" of *Posidonia oceanica* dead leaves on a beach in Corsica. Photo S. Ruitton.

the sea urchin *Paracentrotus lividus*, isopod crustaceans *Idotea hectica*, spider crabs *Pisa mucosa* and *P. nodipes* (Issel, 1918a; Vadon, 1981; Verlaque, 1981; Boudouresque and Meinesz, 1982; Wittmann and Ott, 1982; Chessa *et al.*, 1983; Lorenti and Fresi, 1983; Nédélec and Verlaque, 1984; Velimirov, 1984; Verlaque, 1987, 1990; Pergent *et al.*, 1994, 1997; Rico-Raimondino, 1995; Boudouresque and Verlaque, 2001). The modest grazing role of *Sarpa salpa* could constitute an artefact linked to human action; indeed, in a certain number of Marine Protected Areas (Tabarca and Mèdes Islands in Spain, Port-Cros in France, El Kala in Algeria) overgrazing by *S. salpa* was observed (Laborel-Deguen and Laborel, 1977; Pergent *et al.*, 1993; Sanchez-Lizaso and Ramos-Espla, 1994; Tomàs-Nash, 2004). On the other hand, the leaf epibiota are widely used, in particular by the gastropods *Bittium reticulatum*, *Calliostoma langieri*, *Cerithium vulgatum*, *Columbella rustica*, *Gibbula umbilicaris*, *Rissoa* sp. plur. and *Jujubinus* sp. plur. (Boudouresque and Meinesz, 1982; Templado-Gonzalez, 1982; Chessa *et al.*, 1983; Templado, 1984; Mazzella *et al.*, 1986). Furthermore, macro-herbivores which graze on leaves simultaneously eat the leaf epibiota borne on these leaves; *Paracentrotus lividus* even prefers the leaves covered with epibiota to leaves without epibiota (Traer, 1979).

Much of the primary production (24 to 85%) is **exported** in the form of dead leaves (Fig. 28; Ott and Maurer, 1977; Francour, 1990; Boudouresque *et al.*, 1994b; Pergent *et al.*, 1994; Mateo-Minguez, 1995; Cebrian and Duarte, 2001). In other ecosystems, these dead leaves represent a sizeable food source: they may constitute up to 40% of the digestive contents of the sea urchin *Paracentrotus lividus* in a hard substratum community some hundreds of metres away from the nearest meadow (Verlaque and Nédélec, 1983; Cebrian and Duarte, 2001). They may also pile up temporarily on beaches, forming "**banquettes**": particularly big "banquettes", up to 2.5 m high, can be seen in Sardinia (Alghero), in Corsica (Cap Corse), in Sicily (Marsala) and in Libya (Fig. 27; Boudouresque and Meinesz, 1982; Bellan-Santini and Picard, 1984; Farghaly and Denizot, 1984).

Some of the dead leaves of *Posidonia oceanica* remain inside the meadow, where they form the **litter**. The litter is most abundant in summer and autumn (shallow depth) and in winter (great depth). Its mass increases with depth, and represents between 25 and 200% compared with the biomass of live leaves (Pergent-Martini *et al.*, 1992b; Romero *et al.*, 1992; Mateo-Minguez, 1995). Leaf litter decomposition (by micro-organisms and detritus feeders) is fairly slow: after one month, at 20 m depth, 11% (Ischia, Italy; Pergent *et al.*, 1994) to 35% (Marseille, France; Rico-Raimondino, 1995) only of its mass had disappeared. After 6 months (in Ischia, Italy) the percentage of degradation reached 64% (5 m) and 44% (20 m) (Pergent *et al.*, 1994). **Consumption by detritus feeders** is the main way primary production of *P. oceanica* leaves is transferred to higher trophic levels (Chessa *et al.*, 1983; Boudouresque *et al.*, 1994b).

At the basis of the detritus food web are detritus feeders, such as sea urchins *Psammechinus microtuberculatus* and *Spaerechinus granularis*, amphipod crustaceans *Atylus guttatus*, *Melita palmata* and *Gammarella fucicola*, the isopod *Zenobiana prismaticus* and the Brachyura *Sirpus zariquieyi*, which dilacerate the dead leaves (Wittmann *et al.*, 1981; Campos-Villaça, 1984; Paul *et al.*, 1984; Vadon, 1984; Mazzella *et al.*, 1986). Further down the food web are found the holothurian *Holothuria tubulosa* and the brittle stars *Ophiura texturata* and *Ophioderma longicauda* (Verlaque, 1981; Zupi and Fresi, 1984; Coulon and Jangoux, 1992). In reality, the effective degradation is carried out especially by bacteria and fungi[15], for example *Corollospora maritima*, the other organisms actually only have a role in fragmenting the leaf debris (Cuomo *et al.*, 1982; Mazzella *et al.*, 1995).

Many predators feed off small invertebrates, whether these live on the leaves, in the litter or within the "matte" (Fig. 28): the starfish *Echinaster sepositus* and *Asterina panceri*, the crustacean *Palaemon xiphias*, the molluscs *Chauvetia minima* and *Sepia officinalis* and the fishes *Coris julis*, *Diplodus annularis*, *Hippocampus guttulatus*, *Symphodus cinereus*, *S. doderleini*, *S. ocellatus*, *S. roissali* and *S. rostratus*, etc. (Galan *et al.*, 1982; Templado-Gonzalez, 1982; Chessa *et al.*, 1983; Ballesteros *et al.*, 1984; Fresi *et al.*, 1984; Lejeune, 1985; Harmelin-Vivien and Francour, 1992). The sea urchin *Paracentrotus lividus* is eaten by the starfish *Marthasterias glacialis*, the spider crab *Maja squinado* and the fishes *Coris julis*, *Diplodus vulgaris*, *D. sargus*, *Sparus aurata*, *Symphodus mediterraneus*, *S. roissali* and *S. tinca* (Dance and Savy, 1987; Savy, 1987; Boudouresque and Verlaque, 2001). The bivalve noble pen shell *Pinna nobilis* is eaten by the octopus *Octopus vulgaris* (De Gaulejac, 1989). Fish predators are the scorpion fish *Scorpaena notata*, *S. porcus*, *S. scrofa*[16], the combers *Serranus cabrilla* and *S. scriba* and the conger *Conger conger* (Harmelin-Vivien, 1984; Lejeune, 1985; Harmelin-Vivien *et al.*, 1989).

The **plankton-eating** fish, such as *Chromis chromis*, *Spicara smaris* and *S. maena*, by day exploit the water column, and at night sleep in the meadow (Harmelin-Vivien, 1984). There they are likely to be eaten by fish-eating predators, some of which are active by night, such as the congers and the scorpion fish (Harmelin-Vivien, 1982, 1984), this represents an **input** of organic carbon into the ecosystem (Fig. 28; Boudouresque *et al.*, 1994b).

Another energy **input** into the ecosystem is constituted by **filter** and **suspension feeders**, such as the leaf epibiota (hydroids, bryozoans) or of rhizomes (e.g. the polychaeta *Spirographis spallanzani*, the bivalve *Pinna nobilis* and the ascidian *Halocinthia papillosa* (Fig. 28; Mazzella *et al.*, 1986; Boudouresque *et al.*, 1994b).

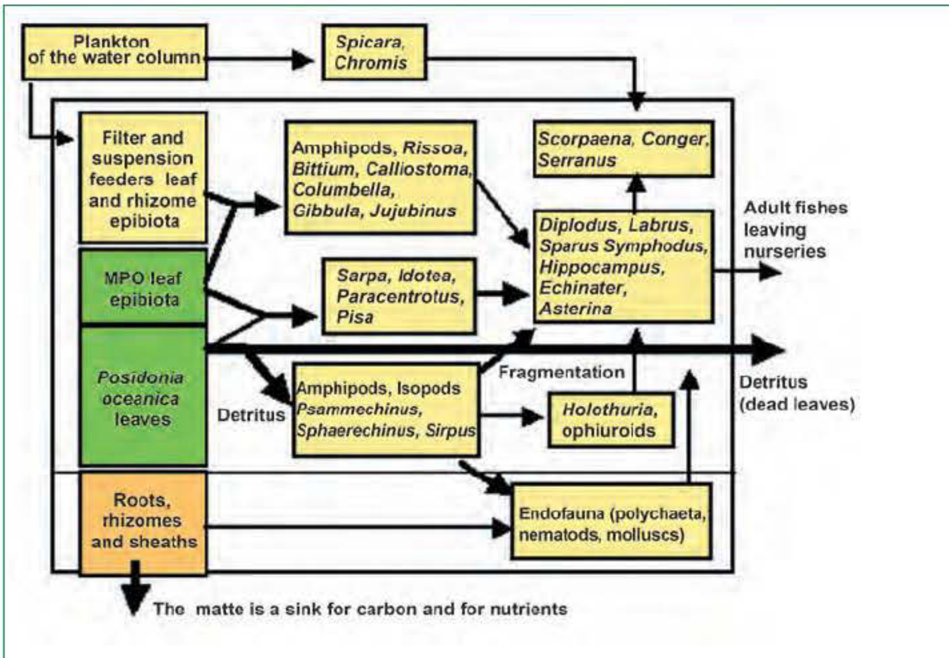


Fig. 28. Trophic relationships and functional compartments in the *Posidonia oceanica* ecosystem. From Boudouresque *et al.* (1994b), modified.

Some features of the *Posidonia oceanica* ecosystems are unusual in the marine environment, and resemble the **continental forest ecosystems** (Boudouresque, 1996): **(i)** the accumulation of

15 Fungi (=Eumycetes) are one of the groups that used to be called 'mushrooms'. In the popular sense of the term, 'mushrooms' are a polyphyletic, i.e. heterogeneous and artifical, group (Lecointre and Leguyader, 2001).

16 Of the 3 species of scorpion fish, *Scorpaena scrofa* is the greatest consumer of fish (Harmelin-Vivien *et al.*, 1989).

vegetal biomass over many decades, resulting in exceptionally high vegetal biomass. **(ii)** relatively modest animal biomass, concentrated in the "matte". **(iii)** low consumption of the primary production by herbivores, the main route for its transfer to upper trophic levels being the detritus fedders. However, the system is more open than the forest ecosystems, with organic carbon inputs (filter feeders, suspension feeders, plankton-eating fish), consistent organic carbon outputs (dead leaves, adult fish) and, especially, a poor retention of nutrients derived from organic matter recycling. Lastly, it is an original[17] system, considering the juxtaposition of two kinds of primary production (slow recycling and rapid recycling) and the presence of the "matte" that acts as a **sink**[18] (Fig. 28) for organic carbon and for nutrients (Pergent *et al.*, 1994; Boudouresque, 1996).

[17] This originality is shared with other marine Magnoliophyte ecosystems.

[18] A sink organic carbon and nutrients are buried too deeply in the "matte" to participate in recycling. They are sequestrated for a very long period of time. In certain conditions, and on a geological time scale, the organic carbon thus sequestrated can participate in the genesis of hydrocarbons (Burollet and Oudin, 1979).

3. THE ROLE OF *POSIDONIA OCEANICA* MEADOWS

3.1. GENERAL REMARKS

The role of *Posidonia oceanica* meadows in marine coastal environments is often correctly compared to that of the forest in terrestrial environments. These meadows constitute the basis of the richness of coastal waters in the Mediterranean, given the surface area they occupy (20-50% of the seabeds between 0 and 50 metres depth), and, in particular, given their essential biological role in maintaining the equilibrium of coastal waters and their concomitant economic activities.

3.2. ECOLOGICAL ROLE IN COASTAL SYSTEMS

Like most of the settlements of marine Magnoliophyte species, *Posidonia oceanica* meadows have a vital ecological role.

Darwin (1859) was the first to say that marine Magnoliophytes can constitute a food base for many species of macro-herbivores (marine turtles), but research done over the past few decades allows us today to better determine, and, especially, quantify, the true part these species play in the functioning of the coastal food web.

These Magnoliophytes produce enormous quantities of vegetal biomass that forms the basis of many food webs (McRoy and McMillan, 1977; Mazzella *et al.*, 1992; Pergent-Martini *et al.*, 1994; Romero, 2004b). This primary production is comparable to or greater than that of other high-production environments, whether terrestrial (temperate and tropical forests, cereal crops) or ocean (upwelling areas[19], mangroves, coral reefs and estuaries) (summary in Fergusson *et al.*, 1980). Marine Magnoliophyte meadows, which only occupy 0.15% of the world's ocean surface, produce **1%** of the ocean's net primary production, i.e. 6 Gt C/year (*in* Duarte and Chiscano, 1999: Templado, 2004). This is so for the *Posidonia oceanica* meadows, one of **the planet's most productive** ecosystems (see § 2.6).

However, as in most of the ecosystems based on marine Magnoliophytes, very little of the primary production is directly consumed by herbivores (Fig. 29). Most of this production is either **(i) stored** (in the "matte") or degraded (by detritus feeders) in the meadow's litter; or **(ii) exported** to other ecosystems as dead leaves (Pergent *et al.*, 1994). The exporting of big amounts of dead *Posidonia oceanica* leaves (Fig. 30) is a boon for the deeper areas (with little or no light) and the beaches that benefit from this allochthonous production (Wolff, 1976; Walker *et al.*, 2001).

Most of *Posidonia oceanica*'s production is thus assimilated by detritus feeders (micro-organisms, crustaceans, gastropods, echinoderms) which will then themselves be eaten and integrated within the food web. The few macro-herbivores that are present (the edible sea urchin *Paracentrotus lividus*, the isopod crustacean *Idotea baltica* and the fish *Sarpa salpa*) can nevertheless play a major part locally according to their numbers (Pergent *et al.*, 1993; Alcoverro *et al.*, 1997; Havelange *et al.*, 1997; Romero, 2004b).

[19] Upwelling rise of deep waters, generally rich in nutrient salts. Upwellings are sites of an important production of plant and animal plankton. It results a large abundance of fish, and therefore very active fisheries.

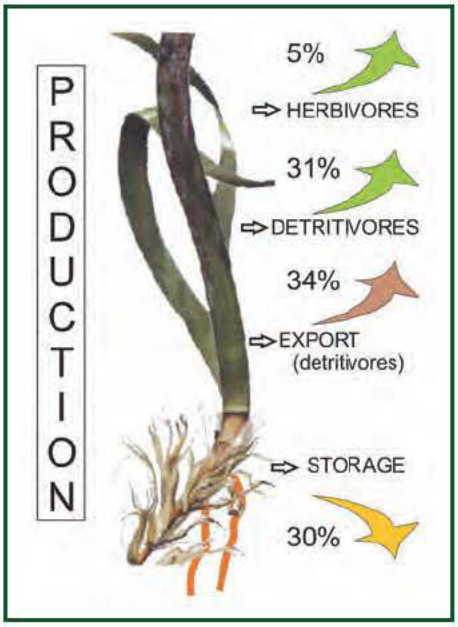


Fig. 29. Future of the primary production (in percentage of carbon) of *Posidonia oceanica*. The primary production of MPOs leaf epibiota is not considered here. After G. Pergent (unpublished).

It should also be noted that the Magnoliophytes offer support for many species of Multicellular Photosynthetic Organisms (MPOs) leaf epibiota that have large primary production, which is added to that of the Magnoliophyte itself (Modigh *et al.*, 1998), especially specific food for many animal species (Borowitzka and Lethbridge, 1989; Mazzella *et al.*, 1992; Havelange *et al.*, 1997). With *Posidonia oceanica*, the biomass of leaf epibiota varies between 6 and 34% of the above-ground biomass (Mazzella and Ott., 1984; Lepoint *et al.*, 1999). The bacteria present on the plant and in the substratum, as well as the high phytoplanktonic production measured at canopy make a significant contribution to this production (Velimirov and Walenta-Simon, 1992; Elkalay, 2002; Gobert, 2002).

One of the results of plant photosynthesis is also the **production of oxygen** (Fig. 30). Even if at death of the leaves part of this oxygen is consumed in their degradation (Mateo and Romero, 1996), the production of oxygen can be considerable as regards the shoots and the associated MPOs leaf epibiota, particularly at shallow depth (Alcoverro *et al.*, 1998). The quantities produced are greatly in excess of requirements, and the *Posidonia oceanica* meadows therefore constitute a major element for water oxygenation. For example, at a depth of 10 m, in Corsica, 1 m^2 of meadow produces up to 14 litres of oxygen per day (Bay, 1978).

Lastly, *Posidonia oceanica* meadows constitute a **spawning ground**[20], a **nursery** or a permanent habitat for very many species (Fig. 30); over 400 different plant species and several thousand animal species populate the *P. oceanica* meadows, making these underwater meadows a unique **biodiversity hotspot** (Boudouresque and Meinesz, 1982; Bell and Harmelin-Vivien, 1982; Bellan-Santini *et al.*, 1994; Francour, 1997; Boudouresque, 2004). As basis of the food web, the meadows are an essential factor in the organisation of animal communities and control the complexity of habitats, the diversity of species and the abundance of associated invertebrates (Heck and Wetstone, 1977; Stoner, 1980; Mazzella *et al.*, 1992). All these species live on the surface of leaves (attached or vagile[21]), the sediment, around the leaves and also within the "matte" that shelters a particularly rich and varied fauna (Bellan-Santini *et al.*, 1986; Francour, 1990; Somaschini *et al.*, 1994).

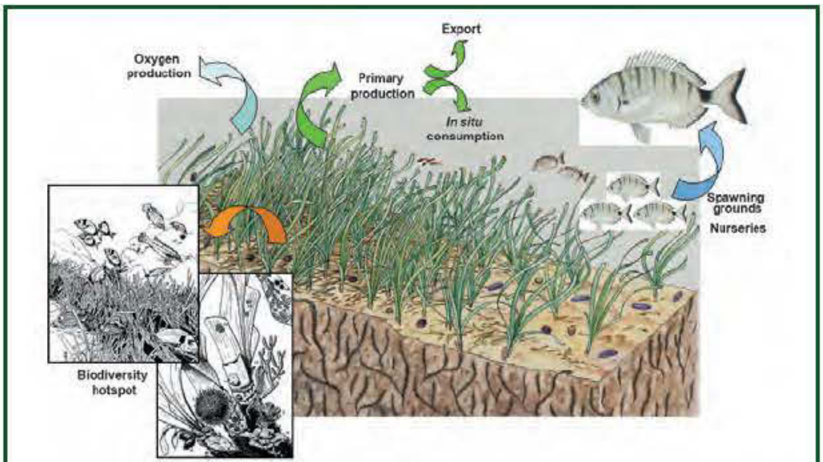


Fig. 30. Ecological role of *Posidonia oceanica*. From Harmelin (1993) and M.A. Mateo (unpublished).

20 Spawning ground= place of laying.

21 A vagile species is a mobile species, by opposition to fixed species.

3.3. PHYSICAL ROLE IN COASTAL SYSTEMS

On the coastal seabed, *Posidonia oceanica* meadows are real plant barriers that encourage the decantation and sedimentation of particles in suspension in the water column (trapping sediment) (Boudouresque and Meinesz, 1982; Boudouresque and Jeudy de Grissac, 1983; Jeudy de Grissac and Boudouresque, 1985; Gacia and Duarte, 2001; SDAGE, 2003; Romero, 2004b). This sediment is then retained under the canopy[22], between the rhizomes and the roots, thus forming a unique structure, the "matte", where it represents between 20 and 60% of the volume (Fig. 31, 32; Jeudy de Grissac, 1984a). This sediment of allochthonous origin, associated with the autochthonous sedimentation (debris of organisms that had lived on the leaves and at the base of the rhizomes), generates the vertical growth of rhizomes (and thus the "matte"), enabling it to fight against burial (Molinier and Picard, 1952).

This speed of growth is very variable according to the site and the time scale; the elongation of rhizomes, measured via lepidochronology, varies between 3.2 and 20.9 mm/year (7.4 mm/year on average in Pergent *et al.*, 1995); higher values have been observed (Boudouresque *et al.*, 1984). The vertical growth, measured over several decades, corresponds to the balance between the accretion and erosion phenomena (Blanc and Jeudy de Grissac, 1978; Mateo *et al.*, 1997); it can reach 1 m/century (Molinier and Picard, 1952). The meadow plays a similar role to European beachgrass and pine trees that stabilize the coastal sand dunes (trapping sediment, and **stabilization**). It should also be noticed that sediment settling (mainly fine particles) and trapping in the "matte" help increase the **transparency** of the coastal water (Boudouresque and Meinesz, 1982; Jeudy de Grissac and Boudouresque, 1985).

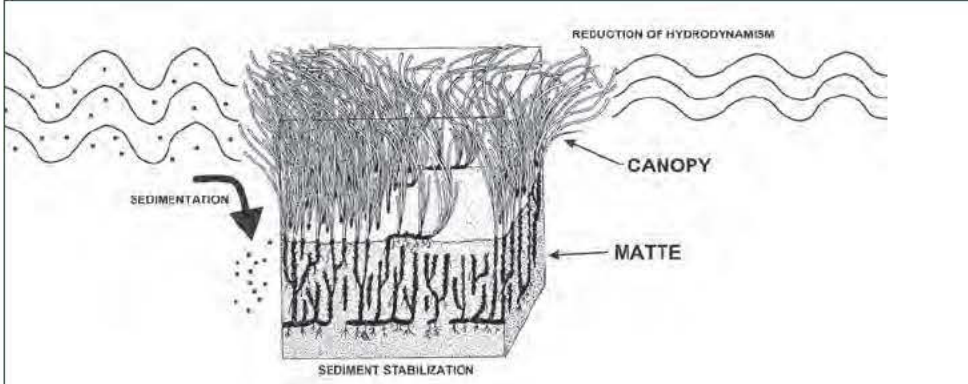


Fig. 31. Trapping sediment and reduction of hydrodynamism in a *Posidonia oceanica* meadow. From Boudouresque and Meinesz (1982, modified).

The *Posidonia oceanica* meadow's considerable vegetal biomass also acts as a kind of barrier which slows and **effectively absorbs hydrodynamism** (swell, currents) at the seabed (Fig. 31). This reduction in hydrodynamism was measured in the laboratory (ICI company, Delft laboratory, Holland; unpublished data) and *in situ* in extensive meadows (Jeudy de Grissac and Boudouresque, 1985; Gambi *et al.*, 1989; Gacia and Duarte, 2001; Duarte, 2004). Hydrodynamism was reduced by 10 to 75% under the cover of leaves (Jeudy de Grissac, 1984a; Gambi *et al.*, 1989; Gacia *et al.*, 1999), which reduces sediment re-suspension during storms (Gacia *et al.*, 1999; Terrados and Duarte, 2000; Gacia and Duarte, 2001; Duarte, 2004). Hydrodynamism was also reduced above the meadow. Several dozen centimetres above the canopy, the reduction in the speed of the current is 20% (Gacia and Duarte, 2001).

Fig. 32. A view of the thickness of the "matte" at an erosion scarp. Photo G. Pergent.

[22] The canopy is constituted by all the leaves.

Fig. 33. "Banquette" of *Posidonia oceanica* dead leaves. From Boudouresque and Meinesz (1982).

For other marine Magnoliophyte species of similar size and structure (for example, *Zostera marina* and *Amphibolis griffithsii*), hydrodynamism reduction values both above and beneath the leaves are of the same order (Fonseca *et al.*, 1982a; Gambi *et al.*, 1990; Komatsu, 1996; Van Keulen and Borowitzka, 2002).

This hydrodynamism reduction is particularly visible behind the *Posidonia oceanica* barrier reefs, where the presence of these plant barriers enables sheltered lagoons to be established (Molinier and Picard, 1952; Boudouresque and Meinesz, 1982; Bellan-Santini *et al.*, 1994; Boudouresque *et al.*, 1994b). More generally, the reduction in waves and currents is likely **to protect from coastal erosion** and helps stabilize the shoreline (Blanc and Jeudy de Grissac, 1978; Jeudy de Grissac and Boudouresque, 1985; Short *et al.*, 1989; Gacia and Duarte, 2001; Duarte, 2004). There are many instructive examples of coastal erosion after the regression of marine Magnoliophyte meadows (Larkum and West, 1990; Pergent and Kempf, 1993; Pasqualini *et al.*, 1999).

In the autumn, the increase in the mass of dead leaves (rate of leaf loss, size of leaves) plus the meteorological conditions (increased hydrodynamism, storms) drive large amounts of this dead matter towards the beaches (Boudouresque and Meinesz, 1982; Pergent *et al.*, 1997; Walker *et al.*, 2001). The leaves pile up on the shore as the currents take them, forming real banks (he eafte **banquettes**) likely **to protect the beaches** from erosion, particularly during the winter storms (Fig. 33; also see Chap. 2, Fig. 27) (Boudouresque and Meinesz, 1982; Jeudy de Grissac and Audoly, 1985; Chessa *et al.*, 2000; SDAGE, 2003). Despite the initially inhospitable[23] appearance of these banquettes, maintaining them on the beaches seems essential for the protection of the coast (see Chap. 6); in many communes (administrative districts), their removal (in the context of "cleaning up" the beaches) has often gone hand in hand with a significant regression of the shoreline (Pergent and Kempf, 1993; Pasqualini, 1997b).

3.4. ECONOMIC ROLE

Generally speaking, the economic role of *Posidonia oceanica* meadows is the result of its above-mentioned ecological and physical importance in coastal system.

(1) It obviously affects the management of **living resources** via its high biological production, the protection from predators it offers to young fish and young organisms (nurseries), and it also constitutes a much sought-after spawning ground for many species of commercial interest (crustaceans, cephalopods, fishes) (Jimenez *et al.*, 1996; Francour, 1997; Romero, 1999; Le Direach and Francour, 2001). This role is seen throughout the world: in Australia, for example, *Zostera* and *Posidonia*[24] species are the feeding grounds of a commercially exploited species of fish (Connolly *et al.*, 2005).

(2) It also affects the development of tourism and seaside activities, by helping maintain **water quality** (transparency), and especially by stabilizing the shoreline (beaches) that it defends by protecting it from erosion (reduction of water movement,

23 "Where to put the towel?" Wonders, legitimately, the bather.
24 It is *Posidonia australis* and *P. sinuosa*.

banquettes of dead leaves). Furthermore, even if the meadows are not always the "spots" sought by divers, they are at the origin of significant exported biological richness (in terms of species and food) to other more sought-after habitats (rocky bottoms) (see § 2.6).

On the other hand, the economic importance of *Posidonia oceanica* meadows is often highlighted by the negative results of its regression or disappearance.

Thus the Gulf of Gabès, in Tunisia, was in the second half of the 20th century the site of a dramatic **regression** of the meadows caused by the joint action of very destructive fishing practices ("gangave" trawl net[25]), large-scale industrial waste (chemical, phosphogypsum, cement and agro-alimentary industry), unprecedented demographic development and a general silting of the area (Burollet *et al.*, 1979; Darmoul *et al.*, 1980; Pergent and Kempf, 1993; Ben Mustapha *et al.*, 1999; anonymous, 2002a). The Gulf of Gabès, considered to be an extremely sought-after fishing area, stagnated over the 1980s and then experienced a significant decline (28 to 34%) in fish catch in the 1990s (Ben Mustapha, 1995), forcing the Tunisian Government to introduce a policy of redirecting the fishing fleet to less popular geographical areas (Pergent and Kempf, 1993). Furthermore, the Island of Jerba, lying to the east of the Gulf, whose economy is essentially dependent on seaside tourism (intake capacity 15 000 beds in 1990), witnessed the erosion of its shoreline, in some places up to several dozen metres, thus depriving several hotels of their beaches, even of part of their infrastructure, and requiring the construction of costly protection facilities whose medium-term efficacy has not been proven (Pergent and Kempf, 1993; anonymous, 2002a). This regression of the shore could be due to that of the *Posidonia oceanica* meadows in the Gulf of Gabès (see Chap. 4).

Table I. Average annual value of services provided by a few major types of terrestrial and marine ecosystems. Mha= million hectares. G$= billion US dollars. From Costanza *et al.* (1997).

ECOSYSTEMS	Surface area (in Mha)	Value/ha/year	Total value/year
TERRESTRIAL			
Temperate and boreal forests	2 955	$302	G$894
Tropical forests	1 900	$2 007	G$3 813
Meadows	3 898	$232	G$906
Wetlands	330	$14 785	G$4 879
Lakes and rivers	200	$8 498	G$1 700
Other (deserts, tundra, glaciers, etc.)	6 040	< $100	< G$130
Total	15 323	$804	G$12 319
MARINE			
Oceans (high seas)	33 200	$252	G$8 381
Oceans (coastal areas)	2 660	$1 610	G$4 283
Estuaries	180	$22 832	G$4 110
Macrophyte habitats (meadows, etc.)	200	$19 004	G$3 801
Coral reefs	62	$6 075	G$375
Total	36 302	$577	G$20 949

25 The gangave is a kind of trawl constituted by a beam, on which are arranged hooks and nets, that is towed in shallow depths, in particular in Tunisia, for harvesting sponges.

More generally, although the importance of the natural ecosystems is universally recognised, particularly as regards maintaining the natural equilibrium (ecological role), their overall economic value is harder to assess (Costanza *et al.*, 1997; Ami and Boudouresque, 2002). This economic assessment must take into account direct profits (for example, fishing and diving), indirect profits (ecosystem services, for example protecting the shore from erosion, water oxygenation), and optional values (for example, future uses). Beyond the figures advanced it is interesting to notice that marine meadows are, on a world scale, one of the ecosystems whose economic value (US$19 000 per hectare per year) is **the highest**: 10 times greater than the tropical forests and 3 times more than the coral reefs (Table I: Costanza *et al.*, 1997).

3.5. BIOINDICATOR ROLE

For several years now, the use of marine Magnoliophytes for environmental monitoring, to assess the evolution of impact, or more generally to manage coastal ecosystems has been envisaged (Brix *et al.*, 1983; Augier, 1985; Ward, 1987; Maserti *et al.*, 1988; Pergent, 1991b; Phillips, 1994; Abal and Dennison, 1996; Fourqurean *et al.*, 1997). The use of these species, known as "bioindicators", seems to be a quick and effective way of assessing the **quality of the environment** (Bellan, 1993). Their wide geographical distribution (Hartog, 1970), their longevity, their permanence over the seasons, the ease with which they can be sampled, their abundance, and their ability to concentrate a vast range of xenobiotics[26] (McRoy and Helferich, 1980; Ward, 1989), make marine Magnoliophytes potentially interesting organisms.

In the Mediterranean, *Posidonia oceanica* meadow constitutes a powerful integrator of overall marine water quality (Augier, 1985; Pergent, 1991b; Pergent *et al.*, 1995). Very widely distributed all along the coast, particularly sensitive to pollution (Augier *et al.*, 1984a; Bourcier, 1989) and other pressures linked to human activities (Ardizzone and Pelusi, 1984; Meinesz and Laurent, 1978; Boudouresque and Meinesz, 1982; see Chap. 4), with benthic characteristics, it demonstrates by its presence and its vitality (or its regression, betrayed by "dead mattes") the quality of the water above it. The footprint of water quality on the *P. oceanica* meadows is permanent: it does not therefore depend on wind or current direction at the time of observation. Many parameters are thus likely to be recorded by the meadow: **(i)** the average turbidity of the water (revealed by the position of the lower limit of the meadow and its shoot density); **(ii)** currents and hydrodynamism (revealed by the erosive structures that affect the "matte"); **(iii)** rate of sedimentation (revealed by the speed of growth of the rhizomes and, by their loss of hold where there is a deficit); **(iv)** stable pollutants (concentration and memorization of concentration over time); **(v)** desalination at the mouths of coastal rivers or underground water (revealed by the disappearance of the meadow); **(vi)** stress (revealed by the plant's level of phenolic acids and detoxication enzymes); and **(vii)** organic matter and nutrients (revealed by the leaf epibiota and the plant's chemical[27] composition). However, although several of these descriptors are today well understood (standardization of measuring, quality grids) and provide reliable information that can be reproduced, the decoding of other descriptors is still ongoing (Pergent *et al.*, 1995).

Among the validated information that has been routinely used for years we should mention the assessment of the water's average **turbidity**. Like all plants, *Posidonia oceanica* needs light to carry out photosynthesis; thus, its maximum bathymetric extension (lower limit) is a function of the amount of light received, and thus of the average transparency of the

26 Xénobiotics chemical elements introduced by man into the environment and having a negative impact on the organisms and/or the ecosystems.

27 Content of the various organs of the plant in carbon and nitrogen.

water (Meinesz and Laurent, 1978; Boudouresque and Meinesz, 1982). In sectors where water turbidity is important (discharges, mouths of coastal rivers), the light is absorbed much more quickly, and the position of the lower limit approaches the sea surface (Meinesz and Laurent, 1978; Pergent *et al.*, 1995). The position and condition of the lower limit of the *P. oceanica* meadow is mentioned in over 150 scientific publications. In areas where water transparency is greatest, authors mention limits that are usually located at over 35 metres' depth, and live shoots are present up to almost 50 metres down (Augier and Boudouresque, 1979; Colantoni *et al.*, 1982; Boudouresque and Bianconi, 1986; Borg and Schembri, 1995). But when the transparency of the water decreases, the lower limit rises and can settle at between 10 and 15 metres; this is the case near the mouths of coastal rivers or where urban or industrial waste is discharged at sea (Astier, 1984; Darmoul, 1988; Pergent-Martini and Pergent, 1993). But Mayot *et al.* (2005) suggest the hypothesis that the depth of the lower limit of *P. oceanica* meadows could also be affected by temperature.

Moreover, the **type of limit** observed is also able to inform us about temporal changes in water transparency (Meinesz and Laurent, 1978; Boudouresque and Meinesz, 1982): **(i)** progressive limits (Fig. 34), characterized by the presence of horizontal rhizomes growing parallel to the slope and that colonise substrata located further down, theoretically demonstrate an overall improvement in water transparency; **(ii)** sharp limits, characterized by the presence of partially vertical rhizomes without a deeper "dead matte", often indicate stable water transparency; and **(iii)** regressive limits, characterized by the presence of "dead matte" and a few deeper sample shoots, indicate a withdrawing meadow linked to an increase in the average turbidity of the water (Fig. 38).

Another descriptor that is particularly interesting to take into account, even if it is still being standardized, is stable **pollutant** concentration (Pergent-Martini and Pergent, 2000). Like many Magnoliophytes, *Posidonia oceanica* presents both **(i)** great power of "trace metal" concentration, proportional to the levels present in the environment (Augier, 1985; Capiomont *et al.*, 2000; Pergent-Martini and Pergent, 2000; Baroli *et al.*, 2001), and **(ii)** good resistance to metallic contamination (the species persists near major sources). Additionally, its ability to be kept in an aquarium for artificial contamination experiments (Ferrat *et al.*, 2002a), and especially its ability to memorize former levels within its tissues, allied to the possibilities of dating offered by lepidochronology, open up unique prospects for the temporal monitoring of pollution (Calmet *et al.*, 1988, 1991; Carlotti *et al.*, 1992; Pergent-Martini, 1998; Pergent and Pergent-Martini, 1999) and allow us to keep true biological archives that can inform us of the temporal development of a particular pollution (Fig. 35).

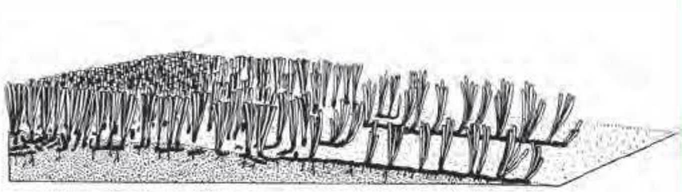


Fig. 34. A progressive lower limit of *Posidonia oceanica* meadow. From Meinesz and Laurent (1978), redrawn (Boudouresque).

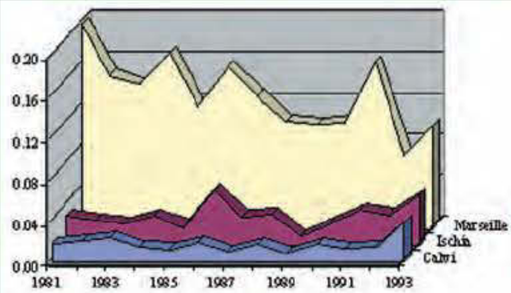


Fig. 35. Evolution over time of the mercury concentration (g.g-1) in the petioles of *Posidonia oceanica* in three localities of the Western Mediterranean. Dating by lepidochronology. From Pergent and Pergent-Martini (1999).

4. THE CAUSES OF *POSIDONIA OCEANICA* MEADOWS REGRESSION

During the 20th century, and certainly more especially since the 1950s, *Posidonia oceanica* meadows has considerably **regressed**, particularly around major urban centres and ports: Barcelona (Spain), Marseille, Toulon, Nice-Villefranche-sur-Mer (France), Genoa, Naples, Trieste (Italy), Athens (Greece), Alexandria (Egypt), Gabès (Tunisia) etc. (Pérès and Picard, 1975; Boudouresque and Meinesz, 1982; Pérès, 1984; Boudouresque, 1996, 2003; Romero, 2004b; Solis-Weiss *et al.*, 2004; Figs. 36 and 37). Meadow is regressing in deep areas (withdrawal of the lower limit because of the reduction in water transparency) (Fig. 38), at intermediate depths, and also at its upper limits. For Liguria (Italian region) as a whole, meadows have lost between **10** and **30%** of their surface area compared to the beginning of the 20th century (Bianchi and Peirano, 1995; Peirano and Bianchi, 1995). In Genoa, the *P. oceanica* meadow has become extremely scattered, and has even disappeared from many kilometres of the coast (Balduzzi *et al.*, 1984; Bianchi and Peirano, 1995). In Latium (Italian region), the regression is general, and *P. oceanica* has been replaced in some areas by another Magnoliophyte, *Cymodocea nodosa* (Diviacco *et al.*, 2001). In the Alicante region (Spain), Ramos-Esplà *et al.* (1984) believe that **52%** of the surface area of meadows has been destroyed. In Marseille, almost **90%** of the meadow mapped in the late 19th century by Marion (1883) has disappeared today (Boudouresque, 1996). In the Hérault (France), the meadow which used to stretch from Carnon to Agde over several dozen kilometres has mostly disappeared (Foulquié and Dupuy de la Granrive, 2003). This is so also in true in the Toulon Gulf (Var, France; Bourcier *et al.*, 1979), and in the Gulf of Gabès (Tunisia; CNT *in* Pergent and Kempf, 1993). But it should be noted that the decline is not generalised; in some regions, the limits of the *P. oceanica* meadows have remained stable. This is so around the island of Ischia (Gulf of Naples, Italy), where Colantoni *et al.* (1982) noted a fairly stable stretch between the late 1920s, the 1950s and the 1970s.

In their seminal work on *Posidonia oceanica* meadows, Molinier and Picard (1952) had already noticed this regressive trend. They put forward the hypothesis that it was at least partially due to a **lack of adaptation** of the plant to the Mediterranean's present hydrological and climate conditions, especially in the north-western coasts. Molinier and Picard's (1952) speculation was based on 2 things: **(1)** the rarity of the plant's flowering and fruit formation, especially in the western Mediterranean, and **(2)** the ageing of individual plants, deduced from the thickness of the "mattes", which seemed to imply a lifespan of several thousand years.

In fact, flowering and fruit formation are not as rare as had been supposed, except for the Gulf of Lion (see §2.2). Furthermore, successful reproduction of a plant with a very long life, a K[28] strategist (as defined by MacArthur and Wilson, 1967), does not require annual reproduction. Moreover, although the present warming of the Mediterranean (Béthoux and Gentili, 1998; Salat and Pascual, 2002) can disadvantage *Posidonia oceanica* in the eastern Mediterranean, this should rather encourage it[29] in the north-western Mediterranean, where the low winter temperatures are a limiting factor (see §2.3). In fact, if *P. oceanica* does have a fragility factor, this is rather its low genetic variability (Capiomont *et al.*, 1996; Raniello and Procaccini, 2002).

28 "K" strategists are species that invest most of their energy in their vegetative system and in (chemical or other) defence; for reproduction, they gamble on quality rather than quantity the chances of success of reproductive elements are maximized; these are often long-living species which reproduce discontinuously. Conversely, "r" strategists invest most of their energy in reproduction, preferring quantity to quality; these are often short-lived species which reproduce continuously.

29 Though Mayot *et al.* (2005) present data that do not confirm this hypothesis.

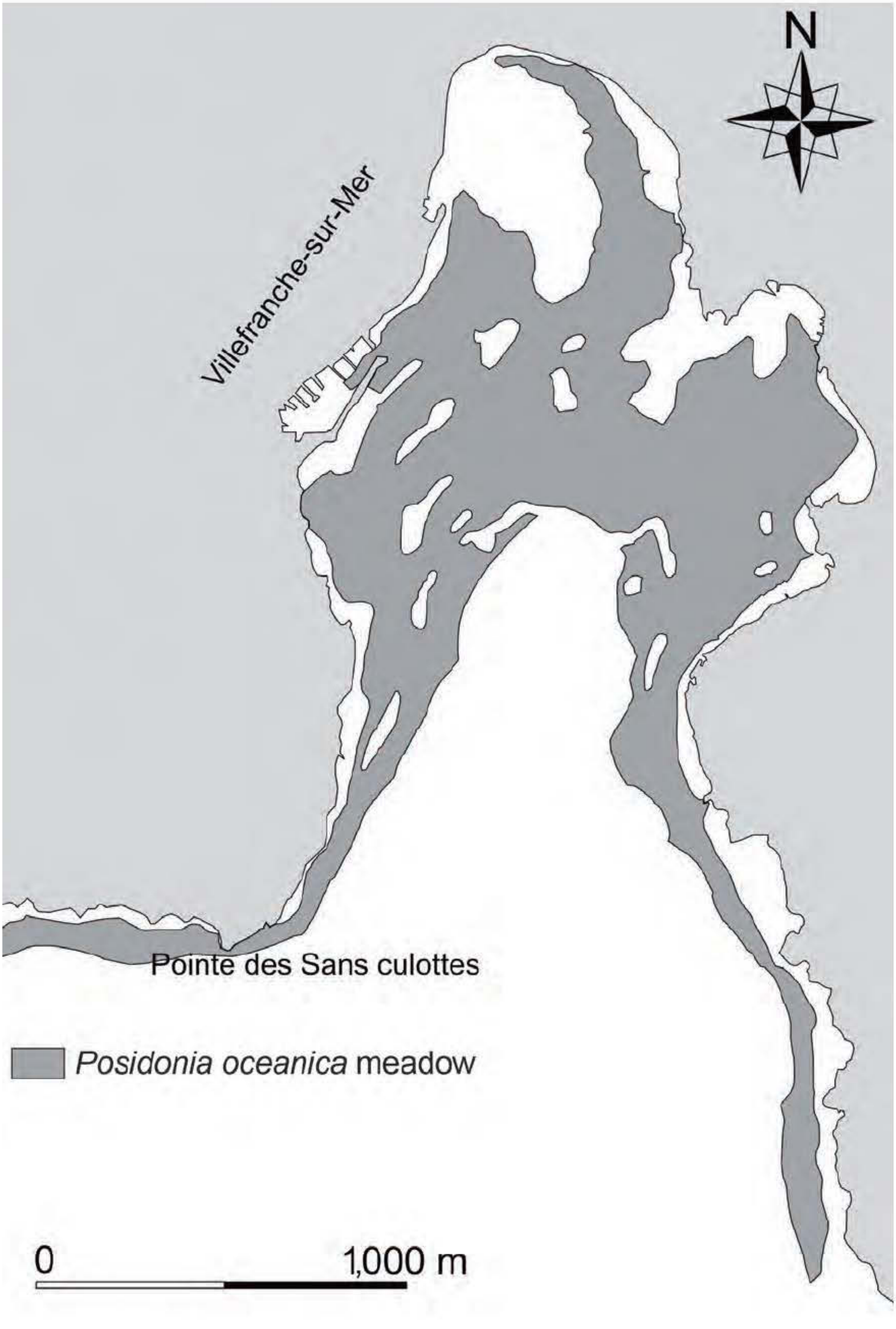


Fig. 36. Extent of the *Posidonia oceanica* meadow (dark grey) in Villefranche-sur-Mer Bay in 1957. From a map by Bourcart redrawn by A. Meinesz, L. Delahaye and F. Jaffrenou in Charbonnel *et al*. (1995a). Compare with Fig. 37.

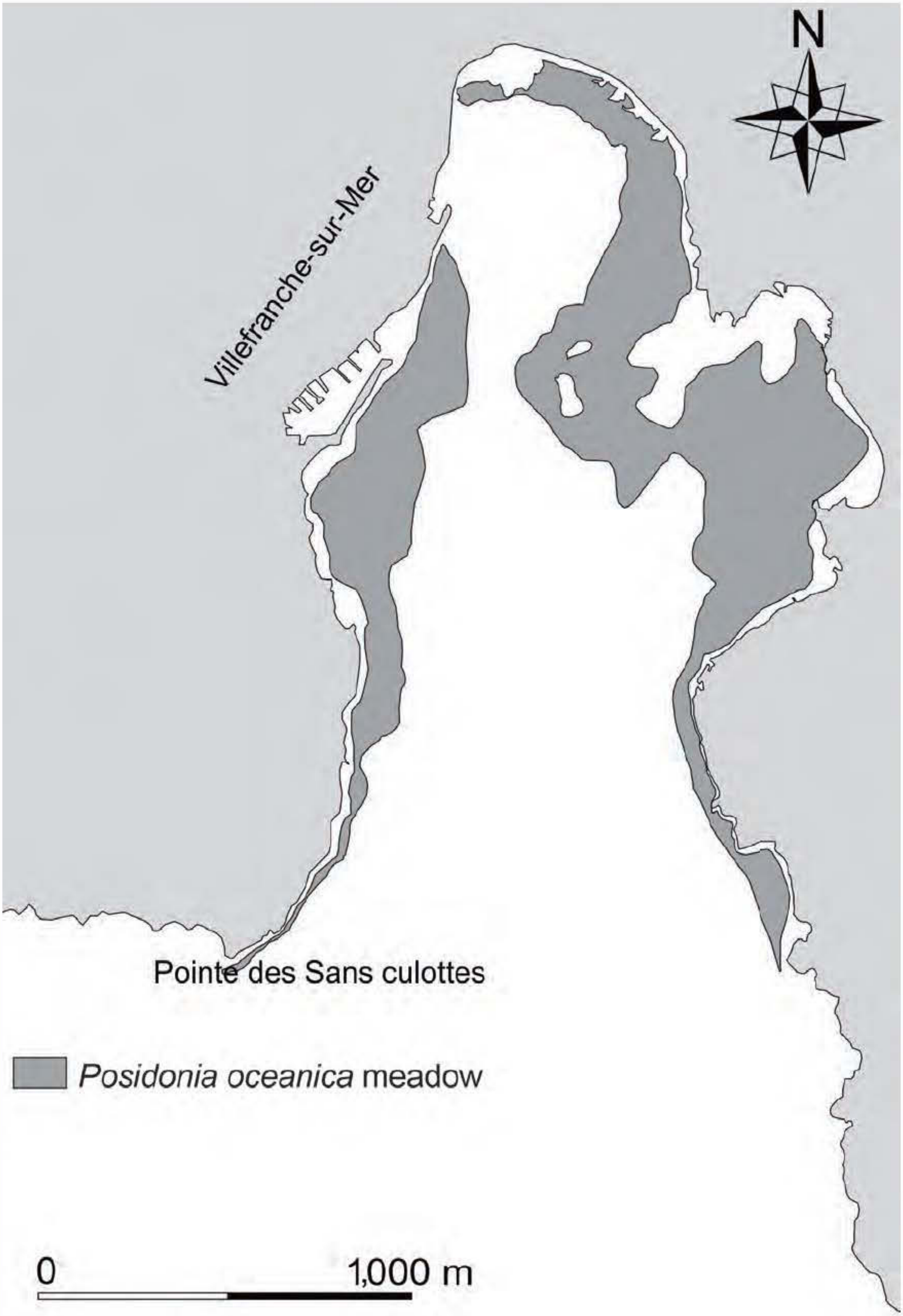


Fig. 37. Extent of the *Posidonia oceanica* meadow (dark grey) in Villefranche-sur-Mer Bay in 1990. From an Aérial ® photograph interpreted by A. Meinesz, L. Delahaye and F. Jaffrenou in Charbonnel *et al*. (1995a).

It should be said that in the area it occupies today, *P. oceanica* (and the species that preceded it) has for 100 million years successfully come through very severe geological and climatic events. In particular, it survived the Messinian crises[30] some 5.3 to 5.6 million years ago (Krigsman *et al.*, 1999; McKenzie, 1999; Taviani, 2002),then the ice ages (that occur every 100 000 years), and then the alternately cold and hot climate cycles of 1 500 years that characterize the Quaternary climate (Clark *et al.*, 1999; Bradley, 2000; DeMenocal *et al.*, 2000; McDermott *et al.*, 2001; Crowley, 2002; Esper *et al.*, 2002). The recent decline of *P. oceanica* throughout most of the Mediterranean can thus hardly be solely attribute to a recent "lack of adaptation" or to the warming of the water (Béthoux and Gentili, 1998; Salat and Pascual, 2002) which has been seen for about thirty years now.

It is clear that **human activities** are the main factor in the regression of the *Posidonia oceanica* meadows. Although the causes usually act in synergy (see §4.13), and it is not always easy to isolate them (Fig. 39), we shall first consider them separately.

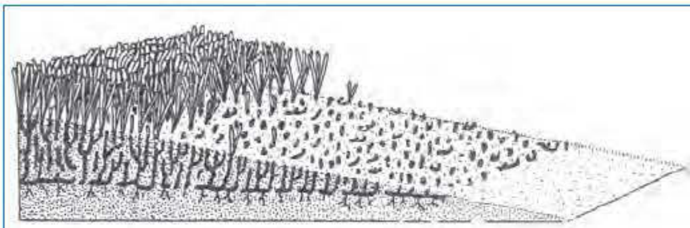


Fig. 38. The regression of the *Posidonia oceanica* meadow is often shown in the rising of its lower limit. This results in 'dead matte' downstream from the present limit. From Meinesz and Laurent (1978), redrawn by C.F. Boudouresque.

It is, however, important to notice that in a *Posidonia oceanica* meadow the presence of sandy **intermattes**, or "dead matte" intermattes, can be quite normal, resulting from the meadow's natural dynamics, with the alternate shoot death and recolonization (see §2.5; Boudouresque *et al.*, 1986a, 1986b; Meinesz *et al.*, 1988). Using the percentage of "dead matte" compared to living meadow as an index of the meadow's degradation (Moreno *et al.*, 2001) must thus be done with extreme caution. Similarly, some years, when the light is weak, the carbon budget (photosynthesis/loss) can show a loss, as happened in 1993 at 5 metres depth in the Mèdes Islands (Catalonia); then the plant draws on its reserves (stored in the rhizomes) and reduces shoot density (Alcoverro *et al.*, 2001). Man's impact is revealed in the multiplying of intermattes, which may come together, and in a regular decrease (over several years) of shoot density. In extreme cases, the meadow is completely replaced by vast stretches of "**dead matte**"; the very long persistence of the little putrescible rhizomes is a useful tool for determining the former extent of meadows and possibly for dating their disappearance[31] (Meinesz and Laurent, 1978; Boudouresque *et al.*, 1980c).

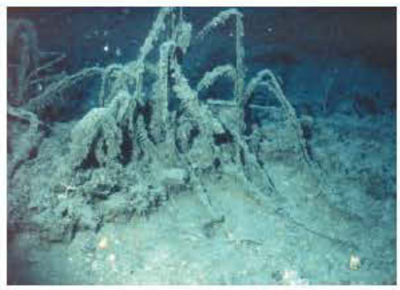


Fig. 39. A residual clump of *Posidonia oceanica*. The causes of its very poor condition are certainly multiple pollution, leaf epibiota overload, turbidity etc. Photo by GIS Posidonie.

The sensitivity of *Posidonia oceanica* meadows to human impacts makes this ecosystem the **biological indicator** *par excellence* of such impacts on the coastal environment (see §3.5; Pergent *et al.*, 1995; Boudouresque *et al.*, 2000; Guidetti, 2001; Charbonnel *et al.*, 2003). The effectiveness of choosing *P. oceanica* for impact studies is increased by the role the meadows play in the coastal equilibrium in the Mediterranean (see §3.2 and 3.3). Furthermore, the very wide distribution of *P. oceanica* around the Mediterranean (see §2.1) enables comparative studies to be performed on the most diverse scales, from one particular sector to the entire Mediterranean basin.

30 During the Messinian crises, the Strait of Gibraltar closed and most of the Mediterranean dried up. We do not know what allowed *Posidonia oceanica* to survive.

31 In the Prado Bay in Marseille, carbon 14 dating of "dead matte" located at depth (30 metres) has shown that the death of *Posidonia oceanica* probably happened in the 13th century, contrary to what one might have imagined, and thus cannot have been caused by recent human activity (Gravez *et al.*, 1992).

4.1. COVERING OR DIRECT INCLUSION IN COASTAL DEVELOPMENT AND MODIFICATION OF SEDIMENTARY FLOW

The building of facilities such as sea walls, platforms on land claimed from the sea and ports represents a major threat to coastal environments, especially to *Posidonia oceanica* meadows. In Liguria (Italy) there used also to be urban solid waste discharge at sea (Balduzzi *et al.*, 1984), a practice that fortunately no longer exists today. To such direct impacts must be added indirect impacts (pollution, turbidity, modification of sedimentary flow, etc.).

In the Provence-Alpes-Côte d'Azur region (France), the **direct** impact of coastal development on shallow depths, and thus on the potential habitat of *Posidonia oceanica*, affects 16% of the coastline and 15% of the surface area of the seabed at less than 10 metres depth (Table II page 29). In Liguria, these percentages are even higher (Regione Liguria, 2000). These shallow depths, where light is not a restricting factor, are among the most productive of the marine environment; moreover, it is there that we find the nurseries of many species of fish of commercial interest (Boudouresque, 1996).

As well as direct impacts, building coastal facilities changes swells and currents locally, and consequently the processes of coastal **sediment transport** that determine their distribution: erosion or accumulation (Astier, 1984). Such changes alter the balance between the rate of sedimentation and the vertical growth of the rhizomes which responds to this. Excessive accumulation of sediment determines the covering of the vegetative tips of *Posidonia oceanica*; if the rate of sedimentation is greater than 5-7 cm/year, the vegetative tips will die (Fig. 40; Boudouresque *et al.*, 1984); conversely, if this rate is zero or negative (the sediment is disappearing), the rhizomes are bared (Fig. 41); they are then extremely easily broken off (hydrodynamics, anchors, trawling, etc.) (Boudouresque and Jeudy de Grissac, 1983).

Fig. 40. A *Posidonia oceanica* shoot buried under 8-10 cm of sediment for less than a year. The leaves, which have been unable to pierce the sediment, have folded in accordion pleats. If the burial continues, the vegetative tip (and thus the shoot) dies. From Boudouresque *et al.*, 1984).

The building of any facility that projects out into the sea (port, seawall running straight out to sea) displaces the current out towards the open sea, with **hypersedimentation** upstream (sediment in transit deposited) and **erosion** (deficit of sediment) downstream (Blanc and Jeudy de Grissac, 1989). Seawalls running parallel to the shore also modify currents and deflect swells, which can have a similar effect. The larger is the facility, the greater is the effect. In Monterosso (Liguria, Italy), Gongora-Gonzales *et al.* (1996) observed the burying of an area of *Posidonia oceanica* meadow under fine sediment, linked with coastal development on land claimed from the sea. Similar observations concern southern Spain (Ruiz-Fernández, 2000).

As well as changes in current and sedimentary flow, ports and platforms can, when being built, generate **turbidity**. Hydrodynamic activity sweeps part of the terrigenous material deposited out at sea. This turbid cloud acts in 3 ways: it reduces water transparency (and thus photosynthesis); it is deposited on the meadow (hypersedimentation); and lastly, the finest particles of sediment are re-suspended during storms, reducing in the long term water

Table II. Percentage of surface area of infralittoral seabed and percentage of coastline occupied by coastal development in the Provence-Alpes-Côte d'Azur region (France) from Martigues to Menton. From Meinesz *et al.*, 1981a, 1982, 1990a, 1991b).

Sector	Seabed 0-10 metres	Seabed 0-20 metres	Coastline
East of Bouches-du-Rhône	27%	19%	21%
Var	11%	7%	12%
Alpes-Maritimes and Monaco	20%	12%	24%
The region, as a whole	15%	10%	16%

transparency (Charbonnel, 1993). In Le Mourillon (Toulon, Var, France), Astier (1984) has shown the direct destruction (covering up) of **22 hectares** of *Posidonia oceanica* meadow, followed by the indirect destruction of **10 hectares** and the silting up of **27 additional hectares**. Similarly, in the Prado Gulf (Marseille, France), the building of the Pointe Rouge port directly destroyed **11 hectares** and indirectly **68 hectares** (Gravez *et al.*, 1992; Charbonnel *et al.*, 1995d).

Lastly, the port basins are often very polluted sites because of anti-fouling paint and discharge of waste water from boats. This pollution then spreads to the area surrounding the ports.

Fig. 41. An exposed *Posidonia oceanica* meadow. At the bottom one can clearly see the rhizomes that are bared to over 10 cm. The sediment that would usually fill the interstices has been carried away. Such a meadow is extremely fragile (hydrodynamics, anchors, trawling, etc.). Photo by A. Meinesz.

4.2. CHANGES DUE TO RIVER INPUTS

Coastal rivers can have an impact on *Posidonia oceanica* meadows by **(i)** desalination (to which the plant is very sensitive; also see §2.3), **(ii)** nutrient inputs [32] (also see §4.4), and **(iii)** sediment input.

The flow of Mediterranean coastal rivers is subject to very strong seasonal (floods) and inter-annual variations (in particular as a result of the NAO[33]). These fluctuations are natural and it is possible to suppose that the meadows were never able to settle sustainably in an area influenced by a **plume of fresh water** during ten-year floods. Human correction of rivers has acted in 2 opposite ways: **(i)** channeling the course and reducing the surface area of the main bed (accessible to water during spates) accentuates peak outflow during floods. **(ii)** Building dams and reservoirs absorbs the outflow peaks during floods, at least in the initial phase. Furthermore, holding back water (reservoirs) and using it for farming increase water loss (evaporation, evapo-transpiration) and reduce the quantity of water that reaches the sea. In Spain, the course of the Ebro River (and its tributaries) is interrupted by over 100 dams (Prat, 1993). The case of the Nile, in the eastern Mediterranean, is particularly spectacular – its average flow at the mouth was 100 Mm^3/year in the 19th century; this dropped to 84-86 Mm^3/year after the dam downstream from Aswan was built in 1902, and then to 3 Mm^3/year after the high Aswan Dam (Nasser Dam) was built in 1964 (Abu-Zeid, 1991; Abu-Zeid and El Moatassem, 1993). Arguing from the hypothesis that desalination (as well as high temperature) is a major factor of the absence of *Posidonia oceanica* east of the Nile delta, it is possible that this species will settle there over the coming decades.

32 Nutrients (= nutritive salts, mineral salts) are salts of nitrogen (nitrates, nitrites, ammonium), of phosphorus (phosphates) and of silicum (silica). Nutrients are essential to photosynthetic organisms.

33 NAO=North Atlantic Oscillation. When the NAO is positive, the climate is dry in southern Europe and the Mediterranean basin; when it is negative, it is, on the contrary, damp (Hurrell *et al.*, 2001; Tourre, 2002).

The **nutrients** naturally brought by coastal rivers do not seem to play an important role in *Posidonia oceanica*; its distribution around the Mediterranean shows that it can have a high level of vitality in very oligotrophic water[34] as well as in mesotrophic water[35]. Man has caused a sometimes considerable increase in the nutrient input by rivers. This is particularly so for the Tiber (Italy; Izzo and Nicolai, 1993). The negative effect on *P. oceanica* is exerted by the proliferation of leaf epibiota and not by the eutrophication[36] as such (Pergent-Martini *et al.*, 1996; Pirc and Wollenweber, 1988; Ruiz-Fernández, 2000). In the Gulf of Fos (Bouches-du-Rhône, France) the almost total disappearance of *P. oceanica* (Pergent and Pergent, 1988) could be due to the nutrients and to other pollutants that were introduced by the Rhône and the Arc (via the Etang de Berre) during the second half of the 20th century, before waste water treatment reduced this form of pollution.

Building dams on watercourses leads to the **reduction of their sedimentary load** in the river mouths and the accumulation of sediment in the lakes of the dam. For example, the Rhône is interrupted by 19 dams between Geneva and the sea. Exploiting the sand and gravel (for the building industry) in the beds of watercourses has also helped reduce their sedimentary load. Today the Rhône carries 20% of the solid elements it carried in the late 19th century (Pont, 1993), and the Ebro 5% of the sediment it carried in the 1930s (Pearce, 1996). Almost all of the 124 Mt/year of sediment that the Nile used to carry is now trapped in the Aswan lake; in the Rosetta branch (one of the two branches of its delta), while the annual load of sediment in suspension used to be 68 Mt in 1958 this has now fallen to 0.5 Mt in 1990; as to the Damiette branch, while the annual load used to be 25 Mt/year it is now nothing at all, for the branch has dried up (Abu-Zeid, 1991; Abu-Zeid and El Moatassem, 1993; Stanley, 1993; Lamy, 1999). The result has been that the dam lakes have filled up. In Tunisia, the dam on the Mellègue river (a tributary of the Medjerda), built in the 1950s, has kept back 48 Mm^3 of sediment in 20 years and is now 1/5 full; the capacity loss of Tunisian dams is on average 1-2.5% per year. As for Lake Nasser, behind the Aswan Dam (Egypt), it should have filled up in 2 centuries' time (Pearce, 1996; Lamy, 1999). The low sediment input by the coastal rivers is partly responsible (see §4.1) for the *Posidonia oceanica* rhizome baring, that weakens them (hydrodynamism, anchors, trawling) (Boudouresque and Jeudy de Grissac, 1983; Jeudy de Grissac and Boudouresque, 1985). In Giens Gulf (Var, France), the very common baring of *P. oceanica* has been attributed to the deficit in sediment of the coastal rivers and to the change of a coastal river's mouth (Gravez *et al.*, 1988; Paillard *et al.*, 1993).

Correcting watercourses can also modify the **granulometric** features of the sediment carried down in favour of the finest particles. When hydrodynamism stirs up these fine sediment particles in suspension, this generates great turbidity in the water column (see §4.3) which restricts the photosynthetic action of *Posidonia oceanica* and also influences deeper assemblages (Tunesi *et al.*, 2001).

[34] Oligotrophic water poor in nutrients (=nutritive salts) especially nitrates and phosphates.

[35] Mesotrophic water fairly rich in nutrients (=nutritive salts).

[36] Eutrophic water richness in nutrients.

4.3. REDUCTION IN WATER TRANSPARENCY

Urban water and waters from other human activities can increase the coastal water load in suspended particles, nutrients and dissolved or solid organic matter. In their turn, nutrients and organic matter provoke the proliferation of planktonic organisms. All in all, water transparency is reduced.

When water transparency decreases this has a direct effect on *Posidonia oceanica* meadows. Compensation depth (the depth at which the losses due to respiration balance out with photosynthesis production) becomes shallower, and with it becomes shallower the lower limit of the meadow (Fig. 38). Ruiz and Romero (2001) have demonstrated experimentally, placing screens above a meadow at 8-10 metres depth, that a 30% reduction in light reduces by 30 days both growth rate, shoot biomass and storage of starch in the rhizomes; shoot density drops by 30% in 3 months; 1 year after normal light intensity has been re-established there is still no sign of recuperation. A 70% drop in light intensity provokes within 3 months the death of almost 90% of the shoots. Overall, the *P. oceanica* meadow's response to a lessening of light is first shown in a reduction of covering and shoot density, and then in the death of the meadow, which may be rapid – a few weeks (Fig. 42; Ruiz-Fernández, 2000; Ruiz and Romero, 2001, 2003).

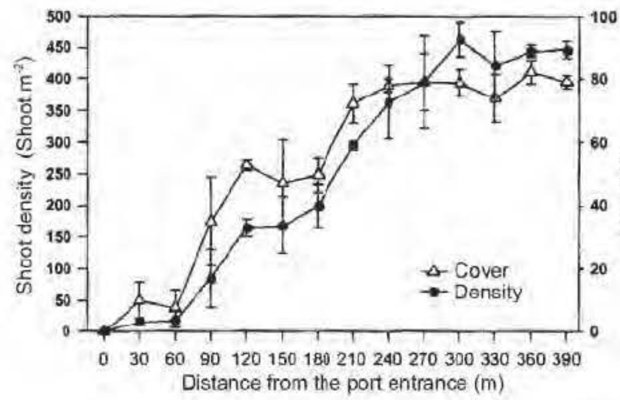


Fig. 42. *Posidonia oceanica* shoot density and cover as a function of the distance from Levante port (Murcia, Spain). The impact is due to the reduction in water transparency, but certainly also to the pollution from the port. The distances underlined correspond to not significantly different means (SNK test, $p > 0.05$). The vertical bars correspond to the mean standard error. From Ruiz and Romero (2003).

The **rising of the lower limit** of the *Posidonia oceanica* meadows is a general phenomenon in most of the areas around the big urban centres and ports. In much of the Alpes-Maritimes (France), for example, the limit rose from 35 to 25 metres depth between the 1950s and 1970s (Meinesz and Laurent, 1978, 1980). Similarly, in the Prado Gulf (Marseille, France), the lower limit rose from 35 metres in the 19th century[37] (Marion, 1883) to 30 metres depth in the early 1960s (Harmelin and True, 1964), and then to between 20 and 25 metres depth starting since the 1970s (Foucher, 1975; Niéri *et al.*, 1986; Gravez *et al.*, 1992). In Latium (Italian region), the lower limit rose from 35 metres to 25-30 metres depth (Diviacco *et al.*, 2001). Despite the improved quality of the coastal waters due to the opening of many waste water treatment plants between the 1970s and 1990s, the lower edge of the *P. oceanica* meadows is still rising in the Provence-Alpes-Côte d'Azur region (France) (Boudouresque *et al.*, 2000; Charbonnel *et al.*, 2003; Mayot *et al.*, 2005).

4.4. PRESENCE OF EXCESSIVE AMOUNTS OF NUTRIENTS AND CHEMICAL CONTAMINANTS

Anthropogenic waste, as well as greatly changing the sedimentary balance of the coastal water, also implies a wide range of contaminants, including detergents, hydrocarbons, pesticides, herbicides,

[37] However, turn to Note 31 at the bottom of Page 35 for a careful interpetation of this data.

"heavy metals" and elements of "anti-fouling" paint that affect the vitality of the *Posidonia oceanica* meadows (Pérès and Picard, 1975; Augier *et al.*, 1987). The effect of soluble substances is rapid, but insoluble substances can also have a very negative impact; being relatively stable, they can accumulate to reach concentrations that are toxic to flora and fauna. The presence of a high contaminant concentration can determine the alteration of the biosynthesis of photosynthetic pigments: along an increasing pollution gradient, the photosynthetic pigment content in *P. oceanica* leaves decreases (Augier and Maudinas, 1979).

Detergents (tensio-actives) accumulate in the sediment, contaminating the roots, rhizomes and leaves (Pérès and Picard, 1975). Augier *et al.* (1984b) have shown *in vitro* that dobane (an anionic tensio-active widely used in manufacturing commercial detergents) slightly encourages *Posidonia oceanica*'s photosynthesis at very low doses (50 ppb, parts per billion) but greatly lessens it between 100 and 500 ppb, concentrations which are found at the inputs of non-purified water discharges. As well as the decrease in photosynthesis, Augier *et al.* (1984b) describe morphological and histological alterations in the leaves of *P. oceanica*.

Mercury is absorbed by the root system, and laboratory studies confirm that the mercury content of *Posidonia oceanica* is correlated to its concentration in the sediment (Cristiani, 1980). An accumulation of mercury in the foliar tissue causes the plant severe physiological disorder that can lead to cellular necrosis and the stop of leaf growth.

Posidonia oceanica's ability to accumulate large amounts of "heavy metals", particularly in its rhizomes, and the possibility of dating rhizome segments by using lepidochronology, makes this species a useful bioindicator, able not only to integrate the average concentration but also to reconstitute its evolution over previous years (see §3.5) (Giaccone *et al.*, 1988; Catsiki *et al.*, 1987; Pergent-Martini *et al.*, 1998; Pergent and Pergent-Martini, 1999).

In the case of nutrients, these determine the proliferation of the *Posidonia oceanica* leaf epibiota, thus reducing leaf growth, and then reducing shoot density (Pergent and Pergent-Martini, 1995; Pergent-Martini *et al.*, 1996). In Australia, for *Posidonia australis*, the proliferation of leaf epibiota in a polluted site reduces by 65% the light that reaches the leaves (as against 15% in a non-polluted site); the resulting drop in primary production of the leaves is assessed as about 30% (Silberstein *et al.*, 1986). As to the plant itself, although *P. oceanica* in oligotrophic water is perhaps restricted by low-level nutrients, the experimental addition of nitrogen and phosphorus (N and P) does not increase its production (Romero *et al.*, 1998).

Studies intended to individualize the specific role of various pollutants in the context of short-term (*in situ*) or middle-term (in the laboratory) experiments do however usually conclude that the effects are only observed with doses that are rarely found *in situ*. For example, in the case of copper "anti-fouling" paint, reduced leaf growth is only observed for doses higher than those measured in the Mediterranean, including in port basins (Giglio, 1985). It is thus possible that in the past the direct role of pollution has been overestimated, by attributing to it those indirect effects (development of leaf epibiota or herbivores, for example), synergic inter-pollutant effects, or effects of other disturbance (e.g. turbidity) that are frequently associated with it (Balduzzi *et al.*, 1984).

4.5. ANCHORING

Posidonia oceanica meadows are particularly sensitive to human activites that cause direct impact by mechanical action. Among those mechanical impacts, the one most frequently mentioned as harming the meadows is the action of anchors (Fig. 43).

Fig. 43. Impact of an anchor of leisure boat on *Posidonia oceanica* meadow, with pulling out shoots of leaves and ploughing of the matte. Photo E. Charbonnel.

We can speak of anchoring (=mooring in the strict sense of the term) when a boat uses an anchor, and of organised mooring when boats moor alongside deadweight moorings that are placed legally (in France) in the context of a Temporary Occupation Permit (TOP) delivered by the Maritime Service of the *Direction Départementale de l'Equipement* (DDE). But we call it unauthorized mooring when boats moor alongside deadweight moorings that are placed illegally (without a TOP) (Ganteaume *et al.*, 2004, 2005).

The impact of anchors has become worrying because of the considerable increase in leisure boating over the past few decades. Not only during the touristic season but all year round at weekends, many sites, some of them of great ecological and landscape value, have become much frequented moorings. As well as the direct impact of the anchors (leaves and rhizomes torn out), it should be stressed that these mooring sites are places where there is significant pollution: "anti-fouling" paint, hydrocarbons, detergents, discharge of organic matter (see §4.4) and of macrowaste (Augier and Boudouresque, 1970a; Robert, 1983; Boudouresque *et al.*, 1995a; Francour *et al.*, 1997, 1998, 1999; Milazzo *et al.*, 2004).

An anchor can affect the *Posidonia oceanica* meadow in various ways: **(i)** at the moment of anchoring – breaking the rhizomes on which it drops or over which it drifts before catching hold; **(ii)** while it is on the seabed – the chain in front of the anchor slips on the seabed because of hydrodynamism and the current and tears out the leaves; **(iii)** when it is raised – the anchor breaks the rhizomes to which it has become attached; in some cases it can tear out a whole block of "matte". When a leisure boat anchors (the anchor is dropped, stays down and is raised) an average 16 to 34 shoots of *P. oceanica* are torn out[38]; this amount is made worse by the fact that the rhizomes are bared and the "matte" becomes less cohesive (Boudouresque *et al.*, 1995a; Poulain, 1996; Francour *et al.*, 1997, 1998, 1999). In the Elbu Cove (Scandola, Corsica), Boudouresque *et al.* (1995a) have estimated that 68 000 shoots of *P. oceanica* have been torn out in one year by anchors over a surface area of 1.4 hectares. In the Monasterio Cove (Riou, Marseille), for an identical surface area the estimated number was 88 000 shoots/year (Charbonnel, 1996). In Porquerolles (Var), Porcher (1984) observed the tearing out of whole sections of "matte" with all their shoots.

The direct action of anchors, by tearing out *Posidonia oceanica* shoots or sections of "matte", reduces the cover of the meadow, and encourages the forming of erosive "intermattes" that can later spread (because of hydrodynamism) and join together, thus fragmenting the meadow (Porcher, 1984; Francour *et al.*, 1997; Pasqualini *et al.*, 2000). The anchoring of big ships (cruise ships, warships) provokes particularly spectacular ploughing of the "matte" (Ganteaume *et al.*, 2005; see Fig. 77).
Recent studies have shown that the kind of anchor is likely to

[38] Values of under 10 shoots torn out on average per anchorage cycle were measured in Ustica, Italy (Milazzo *et al.*, 2004).

influence the size of the impact on the meadow. Anchors of the "Hall" kind are those which have the least impact (Milazzo *et al.*, 2002, 2004). Furthermore, incorrect ways of raising the anchor (i.e. when the boat is not directly above its anchor before starting to raise it) worsen the impact on the meadow.

4.6. TRAWLING

Fishing activities that use gear pulled on the seafloor[39], which scrape and plough the meadow, are prohibited between 0 and 50 metres depth and/or within 5 556 m (3 nautical miles) of the coast in almost all Mediterranean countries. However, this legislation is infrequently, or even never (in certain countries) respected (Ardizzone and Pelusi, 1984).

The damage caused by trawling (trawls) is linked to the features of the fishing gear (Kaiser, 1998). The trawl is dragged along by one boat (trawler) and the gear must be kept open both vertically and horizontally. The first function is achieved using floats (wood, or air-filled buoys) attached to the upper part of the net's opening, which lift it above the seabed, and by lead weights fixed to the lower part of the net's opening, which keep it in contact with the seabed. The second function (horizontal opening) is achieved using heavy metal or wooden "otter boards"[40] fixed to the net where the cables are inserted that allow it to be dragged by the trawler, in a way that widens the opening of the trawl due to the divergent pressure that the water pressure exerts on the "otter board".

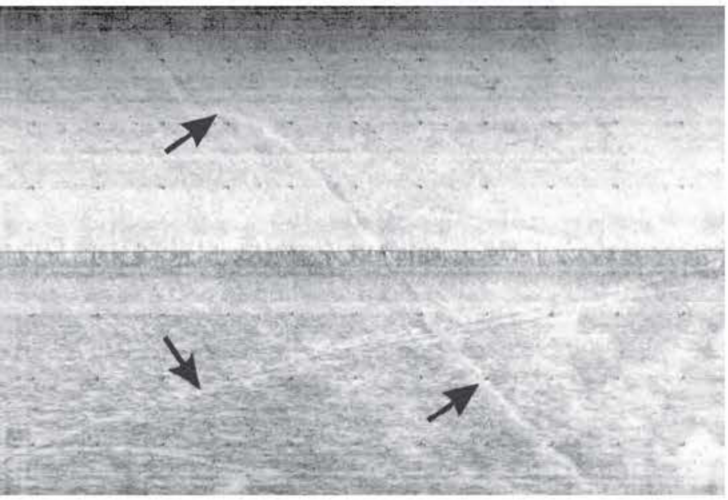


Fig. 44. Traces of a trawl (arrows) in a *Posidonia oceanica* meadow in Giens Gulf (Var, France). The furrows are dug by the "otter boards". Image obtained using side-scan sonar. From Paillard *et al.* (1993).

Because of its structural features, the trawl has a big effect on the *Posidonia oceanica* meadow. This is not only because of the lead line, which tears out the shoots (Ardizzone and Pelusi, 1984) but also because of its "otter board"., likely to dig deep furrows into the "matte" (Fig. 44; Paillard *et al.*, 1993; also see Fig. 77). These deep scars encourage the start of erosive phenomena, due to currents, and worsen by the sedimentary disbalance provoked by the re- suspension of sedimentary matter formerly trapped by the "matte".

Trawling **(i)** opens up corridors (intermattes) in the meadow; in a non-degraded meadow, the trawl's "otter board". are responsible for 94% of the torn out shoots; in southern Spain, a trawl probably tears out a total 100 000-360 000 shoots per hour, i.e. 240 to 1 100 kg DM/hour (Ramos-Esplá, 1984; Paillard *et al.*, 1993; Chessa and Fresi, 1994; Martin *et al.*, 1997; Pasqualini *et al.*, 1999, 2000); **(ii)** reduces the average cover of the meadow (nearly 40%; Ardizzone and Pelusi, 1984); **(iii)** brings up to the surface vast quantities of leaves and shoots (100 to 1 000 kg. per trawl done; Ardizzone and Pelusi, 1984); **(iv)** increases the mass of litter (over 80%); **(v)** allows fish and invertebrate species from the sandy or sandy-muddy bottoms to settle in the meadow and increases the abundance of filtering or detritus-feeders animals (Jiménez *et al.*, 1997; Ramos-Esplá *et al.*, 1997) and **(vi)** significantly reduces the biomass and the density of the ichthyofauna

39 Fishing gear pulled on the seafloor e.g. trawls and "ganguis".
40 The "otter boards" are often called "trawl doors".

(Ardizzone and Pelusi, 1984, but see Jiménez *et al.*, 1997; Anonymous, 2002b). However, trawling does not significantly change the shoot density in patches still occupied by the meadow (Sánchez-Jérez, 1994; but see Martin *et al.*, 1997; Anonymous, 2002b).

In south-eastern Spain, 40-50% of the surface area potentially occupied by *Posidonia oceanica* is illegally trawled (Sánchez-Lizaso *et al.*, 1990). Illegal trawling has caused marked regressions of *P. oceanica* meadows in Italy (Ardizzone and Migliuolo, 1982) and Spain (Martin *et al.*, 1997). In Corsica, the rate of deterioration of all the *P. oceanica* meadows together due to trawling is believed to be 12% (Pasqualini *et al.*, 2000); locally it can reach 23% (Pergent-Martini, 2000). In the Alicante region (Spain), trawling is responsible for almost half the meadow's regression, according to Ramos-Esplá *et al.* (1994), representing the destruction of almost 2 400 hectares of meadow. In Latium (Italy), trawling is probably the main cause of its regression at depth (Diviacco *et al.*, 2001). Bared meadows (frequent because of lack of sediment: see §4.2) are much more vulnerable than non-bared meadows (Boudouresque *et al.*, 1988; Paillard *et al.*, 1993).

4.7. EXPLOSIVES

Almost everywhere along the north-western Mediterranean coasts one can find circular spots of dead meadow that correspond to underwater explosions (Fig. 45): bombs that fell in the 1939-1945 war, mines exploding during or after the war, or fishing with dynamite (Paillard *et al.*, 1993; Pergent-Martini, 1994; Charbonnel, 1996; Harmelin *et al.*, 1996; Pasqualini *et al.*, 1999, 2000).

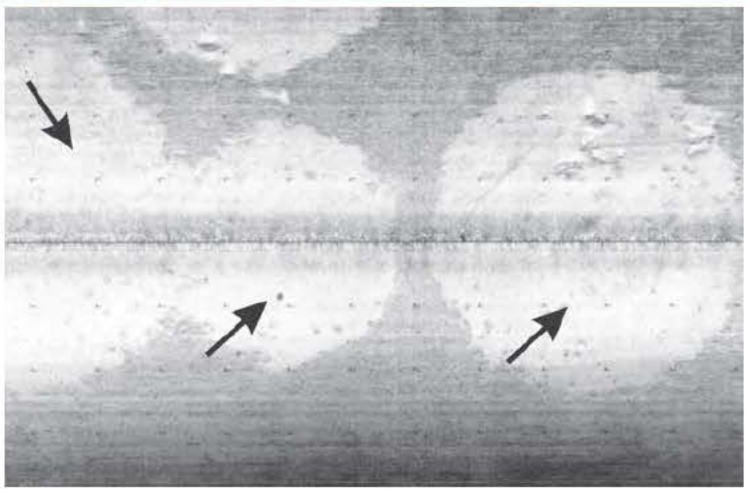


Fig. 45. Areas of dead matte (arrows) in a *Posidonia oceanica* meadow due to explosives in Giens Gulf (Var, France). Side scan sonar image. From Paillard *et al.*(1993).

Posidonia oceanica's **sensitivity** to explosives is certainly due to the presence of an aerarium inside its leaves: gas-filled channels (oxygen and/or carbon dioxide, according to the time of day). When there is an explosion, the aerarium bursts the leaves.

Recolonization of surface areas by *Posidonia oceanica* is an extremely slow process since sometimes 50 years after the event that caused its loss, there is still only partial recolonization (Fig. 46; Meinesz and Lefèvre, 1984; Pergent-Martini, 1994; Pergent-Martini and Pasqualini, 2000). Similarly, in south-eastern Australia, explosions set off during geological research (seismic shots) explain the existence of circular spots with no *Posidonia australis*: after 20 years they have practically not been recolonized (West *et al.*, 1989).

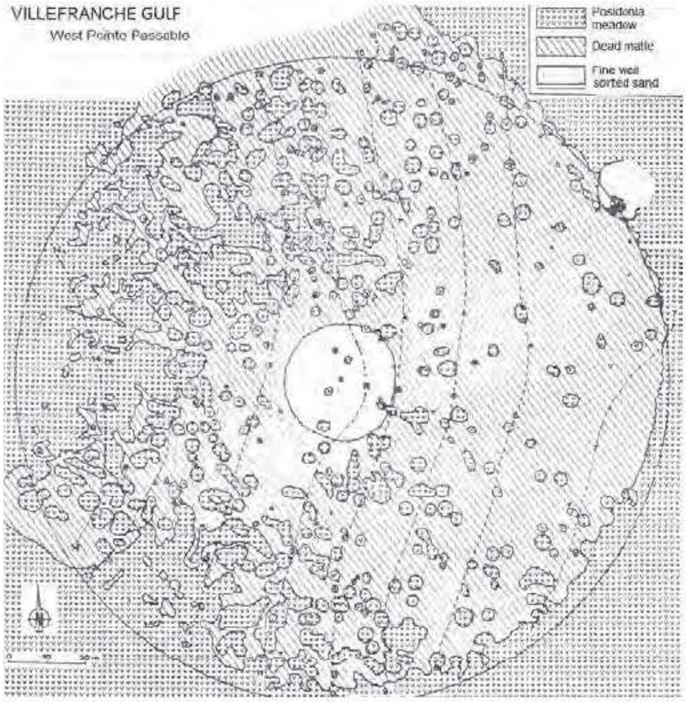


Fig. 46. Partial recolonization in 1983 of an area of "dead matte" created by the explosion of a bomb in 1943 between 6 and 15 m depth in Villefranche-sur-mer Gulf (Alpes-Maritimes, France). From Meinesz and Lefèvre (1984)

4.8. COASTAL AQUACULTURE

The introduction of fish farming in coastal water has accelerated over recent years. Studies show clearly that fish farms, when located near a *Posidonia oceanica* meadow, have a great effect on it: the sediment's organic matter and nitrogen content, and the sediment's interstitial water's phosphorus and total phosphorus content go up as one approaches the fish farming site, with as a consequence the decline in the meadow's vitality: reduced shoot density and drop in the plant's primary production (Cancemi *et al.*, 2000).

In El Hornillo Bay (Spain), mapping monitoring has shown that a fish farm led in 10 years to the destruction of 11 hectares of meadow and the degradation of another 10 hectares (Fig. 47; Ruiz-Fernández, 2000; Ruiz *et al.*, 2001).

IIt seems that the main cause of the impact of fish farming is the introduction of **organic matter**, the oxidation of which gives rise to anoxic conditions in the sediment lying under and near the farms (Delgado *et al.*, 1999), and the synthesis of reduced compounds that may be toxic to *Posidonia oceanica* (Hemminga, 1998). Moreover, nutrient enrichment of the water can cause the increase of leaf epiphytes, resulting in the reduction of *P. oceanica*'s photosynthesis (by restricting its access to light) and increasing the grazing of leaves by herbivores (Pergent *et al.*, 1999; Ruiz-Fernández, 2000). Lastly, the shade of the cages, also by restricting access to the light, significantly reduces the shoot density (Ruiz-Fernández, 2000; Ruiz and Romero, 2001)).

4.9. LAYING CABLES AND PIPES

Laying (water, gas, oil) pipes and underwater cables sometimes involves crossing a *Posidonia oceanica* meadow, when leaving or reaching the coast. For various reasons, not always relevant, even from a technical point of view (see Chapter 12), trenches have often been dug across the meadow.

These trenches, usually running straight out from the coast, can be a serious problem for the meadow: if sediment has been put down to close the trench, it is quickly borne off by hydrodynamism; hydrodynamics tend to widen the trench; and during the work, the meadow is usually harmed over a much greater width than the trench itself (see Chapter 12).

4.10. DUMPING

Dumping involves discharging into the sea dissolved or solid material, especially products of dredging. Its negative impact on a *Posidonia oceanica* meadow is direct (burial, silting) or indirect (fine particles re-suspension and increased turbidity; see §4.3). It has been highlighted particularly in Liguria (Italy; Peirano and Bianchi, 1995) and in Corsica, in the Gulf of Porti-Vechju (Pasqualini *et al.*, 1999).

Dumping permits usually clearly locate discharge sites far from the coast, thus not located over *Posidonia oceanica* meadows. But it has often been noticed that the public works enterprises responsible for such dumping, where there is no active monitoring by the authorities, **shorten**, sometimes considerably, the distance to the dumping site. Slabs of rock or products of dredging have thus been dumped directly onto *P. oceanica* meadows.

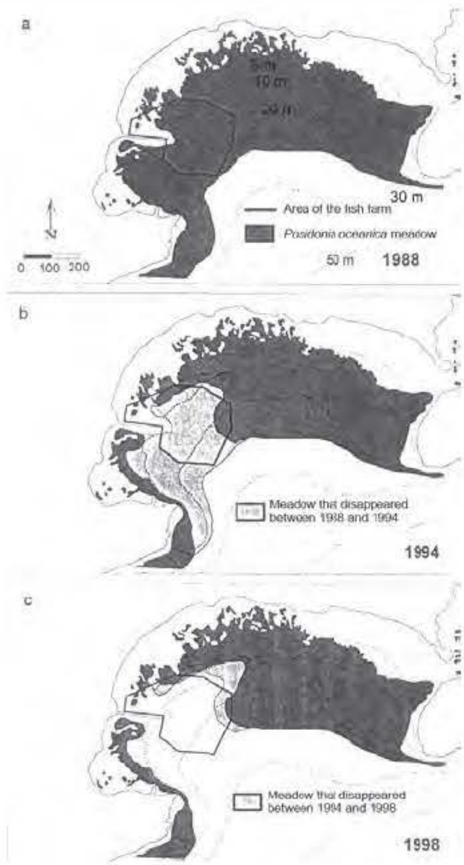


Fig. 47. Regression of the *Posidonia oceanica* meadow in El Hornillo Bay (south-eastern Spain) due to a fish farm (farming *Seriola dumerlii*, *Dicentrarchus labrax* and *Sparus aurata* fish) between 1988 (top) and 1998 (bottom). Scale in metres. From Ruiz-Fernández (2000).

4.11. COMPETITION WITH INTRODUCED SPECIES

The problem of competition between the *Posidonia oceanica* meadow and introduced species has become topical, with the introduction into the Mediterranean of 2 Chlorobionta (Plantae) – *Caulerpa taxifolia* and *C. racemosa* var. *cylindracea* – and 2 Rhodobionta, *Womersleyella setacea* and *Acrothamnion preissii*.

Caulerpa taxifolia (Fig. 48) is native of Australia and was accidentally introduced into the north-western Mediterranean in 1984 (Meinesz and Hesse, 1991). Its geographical expansion was relatively rapid and in late 2000 it was present in 103 stations distributed throughout 6 countries (Croatia, France, Italy, Monaco, Spain and Tunisia) and colonized a total 131 km^2([41]) (Meinesz *et al.*, 2001a). *Caulerpa taxifolia* is able to colonize almost all kinds of substrata, particularly *Posidonia oceanica* meadows and "dead matte" (Boudouresque *et al.*, 1995c). Even if *Caulerpa taxifolia*'s ability to wipe out a *P. oceanica* meadow in good condition has not been demonstrated in the short term, stressed and degraded meadows are an extremely favourable environment for this species, and it can speed their decline (Villèle and Verlaque, 1995; Torchia *et al.*, 2000). In the long term, *C. taxifolia*'s ability to replace non-degraded *P. oceanica* meadows, or some of them, remains an open question (Ceccherelli and Cinelli, 1997, 1998; Chisholm *et al.*, 1997; Molenaar, 2001). Anyway, the presence of *Caulerpa taxifolia* in a *P.oceanica* meadow profoundly changes the way the ecosystem functions (Ruitton and Boudouresque, 1994; Gélin *et al.*, 1998; Harmelin-Vivien *et al.*, 1999).

Caulerpa racemosa var. cylindracea is also a Chlorobionta, introduced by 1990 in the Mediterranean, from the southwest of Australia (Verlaque *et al.*, 2000, Durand *et al.* 2002; Verlaque *et al.*, 2003). Its expansion has been extraordinarily fast, since

[41] This surface corresponds to the "concerned surface", i.e. occupied either continuously or discontinuously (isolated spots) by the species. (Meinesz *et al.*, 2001).

Fig. 48. *Caulerpa taxifolia* (Chlorobionta, Plantae) general view of the tip of a rhizome on which some leaves are set. The longest leaf is about 15 cm. long. Photo A. Meinesz.

it is now present in most of the Mediterranean and even in the Canary Islands (Verlaque *et al.*, 2004, Piazzi *et al.*, 2005). When *C. racemosa* colonizes bottoms bordering *Posidonia oceanica* meadow, its growth in height is a function of the *P. oceanica* shoot density and the orientation of the meadow (Ceccherelli *et al.*, 2000).

As far as the Rhodobionta *Womersleyella setacea* and *Acrothamnion preissii* are concerned, they can form a very dense cover on *Posidonia oceanica* rhizomes. However, their possible impact on the *P. oceanica* meadow is not clearly known.

4.12. OVERGRAZING

Populations of the sea urchin *Paracentrotus lividus* are usually controlled by predators, the first of which are the Sparidae seabreams (*Diplodus* particularly). Overfishing the seabream is one of the reasons why the sea urchin population has exploded; another reason is urban pollution, which favours sea urchins (Harmelin *et al.*, 1981; Ruiz-Fernández (2000). Lastly, in nutrient-rich water, the nitrogen content of *Posidonia oceanica* leaves and that of its leaf epibiota rises significantly, attracting the macro-herbivores *Paracentrotus lividus* and *Sarpa salpa* (Ruiz-Fernández, 2000). The result is thus the overgrazing of benthic primary producers.

Nédélec and Verlaque (1984) assess at between 24 and 51 (according to the season) the number of individual *Paracentrotus lividus* sea urchins of 50 mm diameter starting from which the consumption is greater than the production of *Posidonia oceanica*, determining its overgrazing. For example, in Fontagne Cove (Riou, Marseille), Charbonnel (1996) observed great overgrazing of the *P. oceanica* meadow, and he partly attributed its regression to this. Around a fish farm in Spain (El Hornillo, Murcia), overgrazing by sea urchins, encouraged by pollution, is probably the direct cause of the meadow's regression or disappearance (Ruiz-Fernández, 2000).

4.13. SYNERGY OF DIFFERENT CAUSES OF REGRESSION

It is probable that none of the above-mentioned causes of regression is by itself able to degrade or destroy the *Posidonia oceanica* meadow over vast stretches, if one excepts local effects (cover by some kind of development, immediate proximity of an untreated waste water discharge, etc.) It is more probably the combination of various types of disturbance along certain sectors of the coast, and the synergy between them, that can explain the serious, spatially extensive existing damage: the total disappearance of the meadow or its decreased vitality (cover, shoot density) (see start of Chapter 4).

In general, the meadows that are now the most degraded are those located near the major urban centres and great ports. But to establish a true cause and effect relationship, it is necessary to set up specific monitoring systems, designed to take into account the natural spatio-temporal variability that is a characteristic of the *Posidonia oceanica* ecosystem.

Indeed, the ecological processes likely to influence *Posidonia oceanica* shoot density are numerous and are not all of human origin. Meadows exist which present a low shoot density (bearing in mind their depth), and/or low cover, and even vast stretches of "dead matte", while they are far from any known human impact. The reasons for this situation may be diverse and completely natural: exposure to hydrodynamism, the nature of the substratum, the rate of sedimentation, fresh water input etc. These natural causes, which are overlaid by the effects of human activity, make it sometimes hard to assess the health of a meadow in a given site and, especially, to make a local interpretation of the different causes of degradation. Furthermore, "dead mattes" may correspond to an old (natural or human) impact, possibly occured several centuries ago (Augier and Boudouresque, 1970a; Boudouresque *et al.*, 1980c; Gravez *et al.*, 1992).

The difficulty is made worse by the fact that a "natural" meadow (i.e. one in good health) does not present itself in a homogeneous way in different temporal and spatial scales, but presents a high degree of variability in shoot density and cover, even at a given depth. Indeed, a meadow can be seen as a mosaic where shoot density varies not only horizontally (from one point to the next) but in time, interrupted by spots without any living shoots (structural intermattes) and erosive structures whose position changes over time (see Chapter 2 and the start of Chapter 4). All these parameters must be carefully considered, in a site and on a given scale, before concluding that there is regression and setting up specific procedures.

One may legitimately wonder that after several decades of research on the *Posidonia oceanica* meadow, with hundreds of scientific publications, it is still so hard to decide between the different causes of regression. As well as the fact that *in situ* the causes can be difficult to isolate, this can be explained by *P. oceanica*'s morphology: one individual of this plant is made up of hundreds of shoots linked by rhizomes and stretching over several square metres; laboratory experiments on cut shoots (thus highly stressed), separated from the rest of the plant with which they usually exchange substances, cannot account for the *in situ* situation; in *in situ* experiments it is technically impossible to put under cloche any more than a few shoots, thus a very small part of the plant.

4.14. CONCLUSIONS

Since the early 1990s, in the north-western Mediterranean, the policy protecting *Posidonia oceanica* meadows (see Chapter 5) and to improve coastal water quality (setting up water treatment stations) have slowed the decline of the meadows and even, locally, led to a modest recovery (Gravez *et al.*, 1992; Charbonnel *et al.*, 1995d; Boudouresque *et al.*, 2000). This recovery must however be considered with caution: it is certainly very slow (a few centimetres per year), while the regression can be 10 to 100 times quicker. Moreover, if we exclude the north-western Mediterranean, in most of the Mediterranean the meadow's regression is continuing apace, and is probably going ahead in vast areas for which no data is available.

Furthermore, the fact that it is not always easy to distinguish between natural and human factors, or between the different kinds of human-induced factors, which almost always act simultaneously and certainly have synergic effects, should not hide a robust scientific certainty: **man really has been responsible** for most of the regressions observed in the second half of the 20th century.

5. POLICIES APPLYING TO *POSIDONIA OCEANICA* MEADOWS

Few policies directly aim at the protection of marine species other than turtles, birds and mammals, even if marked progress has been made – usually on the initiative of NGOs. Thus, in 1993 five marine invertebrate species were added to the list of species that are protected in France, and then in 1999 about twenty species of invertebrates and a dozen of macrophytes[42] (Boudouresque *et al.*, 1991; Boudouresque, 1996; Boudouresque *et al.*, 1996; Boudouresque, 2002c). Plant formations, in particular *Posidonia oceanica* meadows, have benefited from the new awareness, and a growing number of national provisions, Community directives (European Union) and international conventions refer to this. But we should differentiate between **direct** legal protection measures either concerning the species *P. oceanica* or the habitats it constitutes, and regulatory measures which, without directly aiming to protect the meadows, can **indirectly** encourage their conservation.

5.1. DIRECT PROTECTION MEASURES

5.1.1. International conventions and European Community texts

In policy terms, the ecosystem approach is a relatively recent one (e.g. the 1992 Rio de Janeiro Summit) and only international conventions signed after 1990, or those that were produced before this date but were updated, possibly take *Posidonia oceanica* meadows into account.

This is the case of the **Bern Convention** (Convention on the conservation of European wildlife and natural habitats), signed in 1979 under the auspices of the European Council by several Mediterranean countries (Table III). Indeed, while it did not initially mention any marine plant species, its Annexes were modified (in 1996) to add 3 of the 5 Magnoliophyte[43] species of the Mediterranean Sea (*Cymodocea nodosa*, *Posidonia oceanica*, *Zostera marina*). These species are mentioned as requiring protection (Boudouresque *et al.*, 1996; Platini, 2000). As well as protection of the species itself, the Convention provides (Chapter II, Article 4) that:

" 1 - Each Contracting Party shall take appropriate and necessary legislative and administrative measures to ensure the conserva¬tion of the habitats of the wild flora and fauna species, especially those specified in Appendices I and II, and the conservation of endangered natural habitats.

2 - The Contracting Parties in their planning and development policies shall have regard to the conservation requirements of the areas protected under the preceding paragraph, so as to avoid or minimize as far as possible any deterioration of such areas.

4 - The Contracting Parties undertake to co ordinate as appropriate their efforts for the protection of the natural habitats referred to in this article when these are situated in frontier areas. "

The same holds good for the **Barcelona Convention**, adopted in 1976, which was the key convention for the protection of areas and species in the Mediterranean. A legal tool of the Mediterranean Action Plan (MAP), launched by the UNEP[44] for the protection of regional seas, the Convention initially focused on the fight against

42 Macrophytes a polyphyletic (=artificial) set of usually photosynthetic pluricellular organisms, belonging to the Chlorobionta, Viridiplantae and Rhodobionta (Kingdom Plantae) and to the Chromobionta (Kingdom Stramenopiles).

43 Magnoliophytes = Phanerorogams (flowering plants). Magnoliophytes belong to the Viridiplantae.

44 UNEP United Nations Environment Programme

marine pollution (Tavoso, 1997). But from 1982 on, with the adopting of the Protocol on Mediterranean Specially Protected Areas, the 20 signatory countries (Albania, Algeria, Bosnia-Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Morocco, Slovenia, Spain, Syria, Tunisia and Turkey) and the European Community showed their interest in protecting marine habitats.

Table III. Mediterranean countries which had adopted (A) or ratified (R) international conventions by 3.4.2003. - missing data; * data updated according to RAC/SPA (2003).

COUNTRY	RAMSAR	BERN	BARCELONA
Albania	1995 A*	1998 R*	1990 A
Algeria	1984 A	-	1981 A
Bosnia-Herzegovina	2001 R*	-	1994 A
Croatia	1993 R*	2000 R	1993 A
Cyprus	2001 R*	1988 R	1979 R
Egypt	1988 R*	-	1978 R
European Union	-	-	1978 R
France	1986 A	1990 R	1978 R
Greece	1975 A	1983 R	1979 R
Israel	1997 R*	-	1978 R
Italy	1977 A	1982 R	1979 R
Lebanon	1999 R*	-	1977 A
Libya	2000 R*	-	1979 R
Malta	1988 A*	1993 A*	1977 R
Monaco	1997 A	1994 R	1977 R
Morocco	1980 R*	2001 R*	1980 R
Slovenia	1992 A*	1999 R*	1992 A*
Spain	1982 A	1986 R	1977 R
Syria	1998 R*	-	1978 A
Tunisia	1981 A	1996 R	1977 R
Turkey	1994 A	1999 R	1981 R
Yougoslavia[a]	1991 A	1999 R	-

[a]Today Serbia and Montenegro.

However, it was only in 1995, on the 20th anniversary of the MAP, that the Convention was amended and took the name of the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. A new MAP, the Action Plan for the protection of the marine environment and the sustainable development of the coastal areas of the Mediterranean (MAP Phase 2) was then adopted, and came into force in December 1999, accompanied by a new Protocol on Specially Protected Areas and Biological Diversity in the Mediterranean (Platini, 2000). This Protocol was accompanied by 3 Annexes, respectively concerning: **(i)** common criteria for the choice of protected marine and coastal areas that could be included in the SPAMI (Specially Protected Areas of Mediterranean Importance) list, **(ii)** a list of endangered or threatened species, and **(iii)** a list of species whose exploitation is regulated (Anonymous, 1998). It is in Annex II that the marine Magnoliophytes (*Posidonia oceanica*, *Zostera marina* and *Nanozostera noltii*[45]) are specifically mentioned. Also, as for the Bern Convention, the Contracting Parties to the Convention (Table III) are invited to draw up a list of SPAMIs; this list may include sites which: "*are of importance for conserving the components of biological diversity in the Mediterranean, contain ecosystems specific to the*

45 *Nanozostera noltii = Zostera noltii, Z. nana*

Mediterranean area or the habitats of endangered species, [or] *are of special interest at the scientific, aesthetic, cultural or educational levels".* This is expressed in *de facto* protection for *P. oceanica meadows* as a habitat. These provisions were enhanced when in October 1999 an Action Plan for the conservation of marine vegetation in the Mediterranean was adopted. Exclusively focusing on the protection of Mediterranean marine vegetation, this Action Plan identifies priority actions at national and regional level, such as **(i)** ensuring the conservation of species and plant formations by developing legal measures of protection and levels of knowledge about them; **(ii)** avoiding the loss and degradation of marine Magnoliophytes meadows and of other plant formations as habitats for marine species and maintaining them in a satisfactory state of conservation; and **(iii)** ensuring the conservation of formations that can be considered to be natural monuments, such as *P. oceanica* barrier reefs, bioconstructions (vermetid platforms) and belts of Chromobionta of the *Cystoseira* genus (Anonymous, 2000).

To these international conventions one should add the European Community Directives which first only concerned 4 Mediterranean states (France, Greece, Italy and Spain) but were then extended to countries like Cyprus, Malta and Slovenia as these entered the European Union.

Thus the Habitats Directive of 21 May 1992 (92/43 EEC/Natural Habitats) constituted the legal basis of conserving the natural habitats of wild fauna and flora and maintaining biodiversity throughout the European Union (Platini, 2000). The Directive has 6 Annexes; Annex 1 identifies types of natural habitat of Community interest whose conservation requires the designation of Special Conservation Zones (SCZs). In this Annex, in the context of coastal habitats and halophytic vegetation, appear the *Posidonia oceanica* meadows, which are, moreover, classified as a priority habitat (no. 1120). Similarly, through the Natura 2000 procedure, the states have identified meadow habitats as deserving to enjoy adapted conservation measures (Platini, 2000).

5.1.2. Policies in the countries of the RAMOGE areas

Regulations in France

In France, legal protection of the marine Magnoliophyte *Posidonia oceanica* comes under the Law of 10 July 1976 on nature protection, and its Implementing Decree of 25 November 1977 concerning the protection of the wild flora and fauna of the French natural heritage. This protection was made official by the Interministerial Order of 19 July 1988 (*Journal Officiel* of 9 August 1988, pp.10-128) on the list of protected marine plant species, which specifies: *"in order to prevent the disappearance of threatened plant species and to permit the conservation of the corresponding biotopes, the following are prohibited at all times and throughout Metropolitan France: the destruction, cutting, tearing out, mutilation, picking or removal, hawking, use, offering for sale, sale or purchase of all or part of the wild specimens of the species enumerated below (…) P. oceanica and Cymodocea nodosa" (in* Pergent, 1991a). The text adds: *"However, the ban on destruction does not apply to current exploitation operations of coastal farming establishments on plots of land that are usually cultivated"* (t ans ated f om the F ench).

The Decree of 7 July 1999 of the Ministry of Foreign Affairs (J.O. of 18 July 1999, pp. 10741-10758) publishing the amendments to the Annexes of the Convention on the conservation of European wildlife and natural habitats (Bern Convention) also mentions *Posidonia oceanica*.

As well as the *Posidonia oceanica* species itself, the meadows can enjoy protection under the terms of the Law of 3 January 1986, which states the principles relating to the development, protection and valorization of the coast. This Law, called in French *Loi littorale*, can enable the preservation of a meadow or part of a meadow that presents an ecological interest or that is deemed indispensable to the maintenance of the biological equilibrium (Platini, 2000). This is expressed by the Decree of 20 September 1989 (*Code de l'urbanisme* - Town Planning Code, provisions peculiar to the coast; Boudouresque *et al.*, 1995b) which stipulates that *"the following are protected, the moment that they constitute a site or landscape that is remarkable or characteristic of the coast's natural and cultural heritage, are necessary to the maintaining of biological equilibria or present an ecological interest: (...) environments sheltering natural concentrations of animal or plant species such as meadows (...)"* (t ans ated f om the F ench),

Lastly, some particular meadows, like the "reef" formations of *Posidonia oceanica* (e.g. the barrier reefs of Port-Cros and of Le Brusc in Provence, and the reef platform of Saint-Florent in Corsica), in the light of their remarkable landscape characteristics (Boudouresque *et al.*, 1991) are the subject of increased protection. Thus the barrier reef of Port-Cros, which is included in the Port-Cros National Park, and is specifically monitored (Augier and Boudouresque, 1975; Augier and Niéri, 1988) or the Saint-Florent platform (Boudouresque *et al.*, 1983), which has since 1999 been protected under a French Order called "*Arrêté préfectoral de protection de biotope*" (Anonymous, 2001b).

Regulations in the Principality of Monaco

In the Principality of Monaco, a bill is being prepared for those taxa which appear in the annexes to the international conventions that have been adopted to also benefit from specific protection under Monacan law (Platini, 2000).

Regulations in Italy

In Italy, the national competent authorities for protecting the biodiversity of the marine and coastal environment, protected marine species and the marine environment as a whole come under the Nature Protection Department of the *Ministero dell'Ambiente e della Difesa del Territorio e del Mare.*

Protecting marine biodiversity is a priority aspect of national strategies, and much energy has been devoted to selecting and setting up Marine Protected Areas, of which there are now 23.

MARINE PROTECTED AREAS CREATED IN ITALY

	Marine Protected Area	Decree creating it (year)	Present managing body	Surface area
1	**The island of Ustica**	1986	Palermo Port Authority (provisional management)	15 951 ha
2	**Gulf of Trieste Miramare**	1986	Italian Association for WWF for Nature - ONLUS	127 ha
3	**The Tremiti Islands**	1989	Ente Parco Nazionale del Gargano	1 466 ha
4	**Torre Guaceto**	1991	Management consortium of the districts of Brindisi, Carovigno and WWF Italy	2 227 ha
5	**Cyclops Islands**	1989	Management consortium of the district of Aci Castello and Catania University - Cutgana	902 ha
6	**Egadi Islands**	1991	District of Favignana	53 810 ha
7	**Capo Rizzuto**	1991	Province of Crotone	13 500 ha
8	**Ventotene and S. Stefano Islands**	1997	District of Ventotene	2 799 ha

able p 51 (ollowing)

9	**Punta Campanella**	1997	Management consortium of the districts of Massa Lubrense, Sorrente, S. Agnello, Piano di Sorrento, Vico Equense and Positano	1 128 ha
10	**Sinis Peninsula-Mal di Ventre Island**	1997	District of Cabras	30 000 ha
11	**Porto Cesareo**	1997	Management consortium of Lecce Province, the districts of Porto Cesareo and Nardò	17 156 ha
12	**Tavolara-Punta Coda Cavallo**	1997	Management consortium of the districts of Loiri Porto S. Paolo, S. Teodoro et Olbia	15 091 ha
13	**Cinque Terre**	1997	Ente Parco Nazionale delle Cinque Terre	2 784 ha
14	**Golfe de Portofino**	1998	Management consortium of the districts of Sta. Margherita Ligure, Portofino and Camogli, Genoa Province and University	372 ha
15	**Capo Carbonara**	1998	District of Villasimius	8 598 ha
16	**Tor Patemo shallows**	2000	Ente Roma Natura	1 387 ha
17	**Capo Gallo-Isola delle Femmine**	2002	Palermo Port Authority (provisional management)	2 173 ha
18	**Asinara Island**	2002	Ente Parco Nazionale dell'Asinara	10 732 ha
19	**Capo Caccia-Isola Piana**	2002	Alghero district (provisional management)	2 631 ha
20	**Pelagi Islands**	2002	Districts of Lampedusa and Linosa (provisional management)	4 136 ha
21	**Baia underwater park**	2002	Superintendency for archaeological property of the Provinces of Naples and Caserte (provisional management)	177 ha
22	**Gaiola underwater park**	2002	Superintendency for archaeological property of the Provinces of Naples and Caserte (provisional management)	41 ha
23	**Plemmirio**	2004	Management consortium of the Province of Syracuse and the District of Syracuse (provisional management)	2 429 ha

Italy adopted the Barcelona Convention's Protocol on Specially Protected Areas (SPAs) and on Mediterranean Biodiversity, which provides for the creating of Specially Protected Areas of Mediterranean Importance (SPAMIs) according to criteria that take into account the degree of biodiversity itself, the specificity of the habitats and the presence of rare, threatened or endemic species. Today, in addition to the Marine Mammal Sanctuary, the Marine Protected Areas of Portofino, Miramare, Plemmirio, Tavolara-Punta Coda Cavallo and Torre Guaceto are to be added to the list.

The activities currently carried out, coordinated by the *Ministerio dell'Ambiente e della Difesa del Territorio e del Mare*, involve implementing the Action Plans for cetaceans, marine turtles, *Posidonia oceanica* meadows and invasive non-native species.

The Nature Protection Department also organises, within a convention with 14 Coastal Regions, an activity for monitoring the marine and coastal environment which extends over about 6 000 km of coast.

The Ministry of the Environment and Territory pays special attention to *Posidonia oceanica*, devoting many projects to it over the past few years. Thus the distribution, and state of conservation, of *P. oceanica* meadows have been studied in many campaigns.

Furthermore, the Nature Protection Department of the Ministry of the Environment has set up a specific plan for mapping meadows on the Mediterranean coasts, in compliance with the "National Programme for locating and valorizing *Posidonia oceanica* and studying measures to protect it against phenomena likely to cause its degradation and destruction", provided for by Law no. 426/98.

In the 1990s, the first *Posidonia oceanica* meadow mapping programme in five Italian regions – Liguria, Tuscany, Latium, Basilicata and Apulia – was completed.

64 meadows were identified over a total surface area of 90 913 hectares. In Liguria, 25 meadows were identified, only 2 of which seem to be in a good state of conservation, and only representing 2.5% of the total surface area covered by the meadows along the Ligurian coast; the state of the other meadows was evaluated mediocre, weak or bad. In Tuscany there were 7 meadows, 3 of them in good health, representing 44% of the total surface area; the others show mediocre or low vitality. In Latium, there were 15 meadows, 4 of these in good health, corresponding to about 20% of the total surface area; the others are classified in mediocre, weak or bad vitality. For Puglia, 16 meadows were mentioned, 9 of which are in good health, corresponding to 65% of the total surface area; the other meadows' conservation levels are mediocre, weak or bad. The only meadow present in Basilicata stretches over 646 hectares and its state of conservation is mediocre.

The studies described above are associated with a number of monitoring and mapping measures carried out on different scales (Bianchi and Peirano, 1995; Bianchi *et al.*, 1995; Diviacco *et al.*, 2001).

The "BioItaly" project, launched in 1994 by the Ministry of the Environment, and aimed at identifying Sites of Community Importance (SCI, Habitats Directive), led to the selection of sites mainly composed of *Posidonia oceanica* meadows (Mariotti *et al.*, 2002). Thus, *P. oceanica* meadows are now protected within protected areas, whether these are Marine Protected Areas or Natura 2000 zones.

Posidonia oceanica

Programmes carr ed out thanks to the contr but on made by the M n ster o dell'Amb ente e della D fesa del Terr tor o e del Mare

- **1989 - 1991** Mapping meadows along the coast of Liguria, Tuscany and Elba Island, Latium and the Pontine Islands, Apuglia and the Tremiti Islands (Snamprogetti Project S.p.A. Ecologia – environmental studies)
- Since **1993** Research projects in every Marine Protected Area (a first study done on Multicellular Photosynthetic Organisms (MPOs) leaf epibiota, vagile fauna and mucilage in *P ocean ca* meadows in the Ustica Island Marine Protected Area)
- **1998-2002** National programme for locating and valorizing *P ocean ca* and study of measures to protect it against all phenomena likely to cause its degradation and destruction (Mare Vivo Association)
- **1999-2002** Mapping *P ocean ca* meadows along the coast of Sicily and the minor islands (CEOM Company)
- **1999-2002** Mapping meadows along the coast of Sardinia and the minor neighbouring islands (Nautilus Cooperative Society)
- **2001-2003** Checking the state of conservation of some *P ocean ca* meadows along the coasts mapped in the years 1989-1991 (Conisma)
- **2001-2003** Doing surveys on banquettes of washed up dead *P ocean ca* leaves as an additional element in monitoring and assessing the quality of *P ocean ca* meadows (Mare Vivo Association)
- **2002** Checklist/database of Italian vascular flora (Plant Biology Department, Rome University, "La Sapienza")
- **2003** As part of the "Furthering basic naturalist knowledge" project, basic description on a 1:250 000 scale of coastal marine biocenoses (Marine Biology and Animal Ecology Laboratory, Institute of Zoology, Genoa University)
- **2002-2004** Mapping *P ocean ca* meadows along the coast of Campania and Calabria (Fugro Oceansismica Company)

Since 1998, Italy has set up a legal procedure that aims to ensure the protection of *Posidonia oceanica* meadows. This is the "*Nuovi interventi in campo ambientale*" Law (no. 426 – 9/12/98) and, more recently, the Law on "*Disposizioni in campo ambientale*" (no. 93 – 23/3/2001; Procaccini *et al.*, 2003). These texts, although very general, devote specific paragraphs to the meadows, with financial provision for carrying out studies and programmes to protect and map *P. oceanica.*

In 2001 Liguria adopted regulations to assess the impact of development projects on sites of Community importance (Habitats Directive)[46], in which *P. oceanica* meadows were included (Deliberazione di Giunta Regionale no. 646 of 8 June 2001). Liguria also adopted a document identifying technical normative requirements for determining both the state of conservation of *P. oceanica* meadows (*Deliberazione della Giunta Regionale* no. 773 of 2003) and the impact of coastal facilities on the meadows (*Deliberazione della Giunta Regionale* no. 1533 of 2005). These normative requirements constitute an important instrument, both for developers (who must present projects that are compatible with the conservation of the habitat) and for administrations (who have to make an objective impact

46 "Valutazione di Incidenza sui Piani e Progetti che possono avere effetti sui Siti di Importanza Comunitaria (Habitats Directive)"

assessment on how the project affects the environment). Furthermore, in Liguria, the introduction of a Geographical Information System (GIS) for managing environmental knowledge of seabeds (Tunesi *et al.*., 2002) has permitted the detailed mapping of the main coastal biocenotic settlements (Coppo and Diviacco, in preparation). Using this instrument, the Ligurian Region has defined on a 1:10 000 scale all the marine SCIs (Sites of Communitary importance) (*Deliberazione della Giunta Regionale* no. 1561 of 2005).

5.1.3. Other policies in the Mediterranean

Outside the RAMOGE area, several countries now have specific laws about meadows or envisage such procedures, if only to make the provisions mentioned in the international conventions they have signed or ratified.

In Algeria, the Law on protecting and valorizing the coast (no. 02-02 of 22 Dhou El Kaada 1422 corresponding to 5 February 2002, which appeared in the *Journal Officiel* no. 10 of 12 February 2002) indicates that *"the occupation and use of coastal soil must protect those terrestrial and marine spaces that are remarkable or necessary to the maintaining of the natural equilibrium. The following are concerned by the present arrangement: rocky coasts of ecological interest, coastal dunes and moors, beaches and lidos, forests and coastal Woodland areas, coastal man-made lakes and land around these, islets and islands and all sites of ecological interest or scientific value on the coast, such as coral reefs, underwater meadows and underwater coastal formations."* (t ans ated f om F ench) The ministerial circular on implementing this Law, in the context of the coastal development plan (no. 380/SPM of 19 October 2002) states clearly that as regards underwater meadows and underwater coastal formations, no development work must be undertaken in these natural spaces, except, however, for light facilities intended for their management or valorization (Rachid Semroud, verbal comm.).

In Croatia, regulations are being introduced to protect the 4 species of marine Magnoliophytes – *Posidonia oceanica*, *Cymodocea nodosa*, *Zostera marina* and *Nanozostera noltii* (Platini, 2000).

In Spain, the autonomous governments of Catalonia (Catalunya) and the Comunitat Valenciana (out of the 5 which have authority over the Mediterranean coast) have effective protection for marine Magnoliophyte species. In Catalonia, the Order of 31 July 1991 enables the protection of *Posidonia oceanica*, *Cymodocea nodosa* and *Nanozostera noltii*. In the Comunitat Valenciana, the Order of 23 January 1992 forbids *"la destrucción de las praderas de Fanerógamas marinas, por ser zonas de interés pesquero"* (Boudouresque *et al.*, 1995b). As additional measures, in 1992 the *Direcció General de Pesca Marítima de la Generalitat di Catalunya* funded a detailed mapping of the meadows in the Catalan coasts and started a programme, "*Xarxa de vigilància de la qualitat biològica dels herbassars de Fanerógamas marinas*" that aimed at gathering data on how the marine Magnoliophyte meadows functioned in order to obtain information that could be useful for their protection and management (Javier Romero, verbal comm.).

In Libya, a law is being prepared to enable the protection of a large number of marine species. These species will be those adapted in the context of the Bern Convention and those identified by the Protocol on Specially Protected Areas (Platini, 2000).

In Malta, *Posidonia oceanica* is not legally protected, but since Malta is a signatory of the Bern Convention and the Barcelona Convention it must act to be in a position to put these Conventions into effect. Furthermore, Malta has joined the European Community and should, in the light of the Habitats Directive, consider *P. oceanica* meadows as priority habitats. Also, the Ministry of the Environment and of Development has set up a commission to discover the geographical distribution of the meadows and their state of health. The aim is to set up protection of the meadows that are in good health and/or the most sizeable meadows (Patrick Schembri, verbal comm.).

In Slovenia, *Posidonia oceanica* is included by a Ministerial Ruling, of 24 September 2002, in the red list of threatened flora and fauna, along with *Zostera marina* and *Nanozostera noltii*, which means that the state has to introduce conservation measures for these species. Currently, a Ministerial Decree is being prepared on the conservation of the natural heritage. It is anticipated that *P. oceanica* will be included in this Decree. Finally, Slovenia's *P. oceanica* meadows are classified as a Natura 2000 site and as such enjoy conservation measures (Robert Turk, verbal comm.).

In Turkey, strict protection steps are stated in the Ministry of Agriculture's Fishing Regulations for the marine Magnoliophytes *Posidonia oceanica* and *Nanozostera noltii*. *P. oceanica* is included in the Law on "aquatic products" (Ref. no. 1380) and its annual circular (Ebru Coskun, verbal comm.).

5.2. INDIRECT PROTECTION MEASURES

Indirect measures likely to help protect *Posidonia oceanica* meadows are extremely varied, since one can integrate them both within actions to conserve a given geographical territory (if it contains meadows) and also within all the approaches that aim at restricting, or compensating for, degradation of the coastal environment caused directly or indirectly by human beings. Many reasons have been advanced to explain the regression of the meadows (e.g. urban discharge, anchoring, use of trawls and explosives, coastal development and/or competition from introduced species; Boudouresque, 1996; see Chapter 4) and all the policy measures intended to reduce these can constitute a mode of protection. One can thus recall all the policy measures that aim at **(i)** restricting pollutant waste (e.g. the Protocols of the Barcelona Convention), **(ii)** ensuring the treatment of urban waste (e.g. European Directive 91/271/EEC), **(iii)** fighting against water eutrophication (e.g. European Directive 91/676/EEC), **(iv)** banning certain fishing techniques (e.g. European Community Regulation no. 1626/94 of the Council of 27 June 1994, modified, providing for certain technical measures to conserve fishing resources in the Mediterranean) and **(v)** fighting against the introduction of invasive species (e.g. European Directive 92/43/EEC). We are not aiming to offer an exhaustive inventory but to illustrate these approaches by giving some examples.

5.2.1. Protected areas

Setting up Marine Protected Areas (MPAs) can be a way of protecting *Posidonia oceanica* meadows, as Platini (2000) and Boudouresque *et al.* (2004) argue. Many Mediterranean MPAs include sizeable *P. oceanica* meadows (Augier and Boudouresque, 1970a; Ramos-Esplá and McNeill, 1994; Boudouresque, 1996; Platini, 2000; Francour *et al.*, 2001). Even if the conventions that aim at protecting and conserving spaces do not specifically refer to the *P. oceanica* meadows, or even to marine plants, they can *de facto* concern these and constitute effective protection measures.

This is the case for the **Ramsar Convention**, which came into force in 1975, and which aims at permitting wetlands as defined in Article 1.1, *"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."* to be conserved and managed; it is a good example of such measures. Indeed, meadows are concerned by this Convention, since it foresees the setting up of a network of protected areas, including the upper parts of *Posidonia oceanica* meadows. And this is what was done by the Principality of Monaco when it ratified the Protocol (Table III), by including among the Monacan wetlands of international importance

Table IV. Mediterranean Specially Protected Areas (SPAs) where Magnoliophyte meadows (*Posidonia oceanica*, *Cymodocea nodosa* and *Nanozostera noltii*) have been identified (from Platini, 2000, modified). - missing data. Yougoslavia = Serbia and Montenegro.

Country	Number	Name	Concerned species
Albania	0		
Algeria	1	El Kala National Park	*P oceanica*
Bosnia-Herzegovina	0		
Croatia	5	Lokrum Nature Reserve Malostonski Zaljev Nature Reserve Kornati Islands National Park Brijuni Islands National Park Mljet National Park	*C nodosa* *P oceanica* *P oceanica* *P oceanica* and *C nodosa* *P oceanica*
Cyprus	1	Lara-Toxeftra Nature Reserve	*P oceanica* and *C nodosa*
Egypt	0		
France	4	Cerbère-Banyuls Marine Nature Reserve Bouches de Bonifacio Nature Reserve Port-Cros National Park Scandola Marine and Coastal Nature Reserve	*P oceanica* *P oceanica*, *C nodosa* and *N noltii* *P oceanica* *P oceanica* and *N noltii*
Greece	1	Sporades National Marine Park	*P oceanica*
Israel	0		
Italy	11	Miramare Marine Reserve Tuscan Archipelago Nature Reserve Orbetello and Feniglia Nature Reserve Portoferraio Fishing Reserve Castellabate Fishing Reserve Ustica Marine Reserve Ciclopi Islands Marine Nature Reserve Egadi Islands Marine Nature Reserve Tremit Islands Marine Nature Reserve Torre Guaceto Marine Nature Reserve Capo Rizzuto Marine Nature Reserve	*C nodosa* *P oceanica*, *C nodosa* and *N noltii* *C nodosa* and *N noltii* *P oceanica* *P oceanica* *P oceanica* *P oceanica* and *C nodosa* *P oceanica* and *C nodosa* *P oceanica* *P oceanica* *P oceanica* and *C nodosa*
Lebanon	0		
Libya	1	Garabulli National Park	*P oceanica*
Malta	1	Fungus Rock Nature Reserve	*P oceanica*
Monaco	1	Larvotto Reserve	*P oceanica*
Morocco	0		
Slovenia	0		
Spain	9	Columbretes Islands Marine Reserve Medas Marine Reserve Punta N'Amer Nature Reserve Cabo de Palos Marine Reserve Cabrera National Park Salinas de San Pedro del Pinatar Marine Reserve Mar Menor Managed Zone Tabarca Marine Reserve Cabo de Gata Marine Reserve	C. nodosa *P oceanica* *P oceanica* *P oceanica* *P oceanica* *P oceanica* and *C nodosa* *P oceanica* and *C nodosa* *P oceanica* and *C nodosa* *P oceanica* and *C nodosa*
Syria	-		
Tunisia	2	Kneiss Islands Nature Reserve Zembra National Park	*P oceanica* and *C nodosa* *P oceanica*
Turkey	-		
Yougoslavia	-		

an area that shelters a *P. oceanica* meadow (Platini, 2000), the only one present in the water of the Principality of Monaco (Vaugelas and Trastour, 2002). However, apart from some areas with particular topographical features (e.g. the Gulf of Gabès, the lagoons on the Libyan coast), the Ramsar Convention is still not very much used for the marine environment (Platini, 2000).

Setting up networks of special areas for conservation (e.g. the Emerald network, implemented in the context of the Berne Convention; the Natura 2000 network, implemented by the member states of the European Union) may also help protect meadow habitats (Platini, 2000). A directory[47] of Mediterranean protected areas in which marine Magnoliophyte meadows have been identified has been established by RAC/SPA (Platini, 2000; Table IV).

5.2.2. Fishing gear

Restricting or banning certain fishing techniques that are particularly destructive to *Posidonia oceanica* meadows (Ramos-Esplá *et al.*, 1993) can offer them physical protection. This is so for the regulations concerning trawling in Spain and Italy (banned above the 50 metre isobath) and in Tunisia (banned in a 5.6-km wide zone or above a given isobath between 20, 30, or 50 metres according to sector and fishing type; Anonymous, 2002a). The same holds good for Cyprus, where the stationing of trawls in seabeds deeper than 55 metres (Fisheries Law (CAP 135) and Regulations, 1990 to 2002) results in effective protection to meadows as habitats (Myroula Hadjichristophorou, verbal comm.). In France, trawling is prohibited above the 100 metre isobath (except for some little ships of under 75 kW power which are permitted up to the 12 metre isobath).

5.2.3. Impact studies

Coastal development is one of the major causes of the regression of the *Posidonia oceanica* meadows as regards both the surface area concerned and the irreversible nature of the degradation. Also, the procedures that aim at assessing what impact a development will have before it is carried out, so as to determine whether the project should indeed be completed, constitute a tool for their conservation that could be more generally used in the Mediterranean. Indeed, although common to many States, the impact assessment procedure is still, for many Mediterranean countries, an innovative but essentially theoretical approach (Pergent-Martini, 2000). Although the idea of an impact assessment is known in all the Mediterranean countries, it does not appear systematically in national legislation, and meadows are never specifically mentioned in this (Pergent-Martini, 2000). On principle, according to the threats to meadows, any development being carried out in the maritime domain can justify an impact assessment procedure, and here one should mention the UNEP's approach, with its adopting of guidelines (Anonymous, 2001a).

As said above, in 2003 Liguria (Italy) adopted a technical standard as part of the environmental impact assessment in order to establish the state of conservation of *Posidonia oceanica* meadows, taking the following elements into consideration:

- Regional Law no. 38 of 1998 (*Valutazione di Impatto Ambientale*, VIA) provides that projects for new leisure ports should be subject to the VIA (environmental impact assessment) procedure, and removal of marine sediment, facilities built against coastal erosion, sea walls and any other facility that modifies the coastline should be subjected to the "verifica-screening" procedure.

47 This directory does not include all the Mediterranean Marine Protected Areas but only those that have requested and obtained SPA (Specially Protected Area) status.

- The surveys done in Liguria have revealed how inexact are the borders of the Sites of Community Importance (SCIs) concerning the real extent of *Posidonia oceanica* meadows.

It is necessary to consider the true situation of the habitats, and not their theoretical extent appearing in the Sites of Community Importance, in order to avoid a negative judgement on projected facilities according to their impact on habitats that are supposed to be in good condition, independently of possible compensations.

The technical standard, based on the available bibliographical data on the specificity of Liguria's meadows, considers 3 kinds of meadow. The first corresponds to meadows whose state of conservation is unsatisfactory, i.e. does not seem to present the characteristics required by the Habitats Directive for Sites of Community Importance (Table V).

Table V. Determining the state of conservation of *Posidonia oceanica* meadows according to shoot density and depth in Liguria (Italy). To use this Table, one should not look at the absolute density measured in the meadow areas, but the relative density, taking R cover (as a %) into account. From Regione Ligura (2003) in Diviacco and Coppo (2006).

Depth (m)	**Unsatisfactory**	**Intermediary**	**Satisfactory**
0-3	< 550	550-900	> 900
>3-5	< 420	420-700	> 700
>5-7	< 330	330-600	> 600
>7-10	< 240	240-500	> 500
>10-14	< 160	160-400	> 400
>14-18	< 90	90-350	> 350
>18-23	< 30	30-280	> 280
> 23	< 10	10-200	> 200

In the upper sectors (<10 metres depth) of the *Posidonia oceanica* meadow in Liguria (Italy), a corrective factor was introduced in relation to the values of Table V. This involved taking into account the fact that the meadows in this region have regressed greatly over the past few decades and thus today present low R cover:

$$R_{corrected} = R + R(100 - R)/100$$

The Ligurian technical standard also takes into account, when assessing *Posidonia oceanica* meadows and for impact assessment studies, meadows that reach (or almost reach) the surface of the sea and those that present a particular typology (see §2.4) as well as signs of flowering and fruit formation.

In France, too (Nathalie Quelin, personal comm.), prior to any request for permission for a project that could harm the environment, an assessment of its environmental consequences must be made (Art. L122-1 of the Environment Code). According to the size of the project, it is subject to an **impact assessment** or impact notice, and this document is an integral part of the dossier containing the request for a permit (since the request for a permit might come under various laws such as, for example, the Water Law). The contents are defined in Decree no. 77-1141 of 12/10/1977 modified to implement the Law of 10 July 1976 on nature protection, for projects for work and for development, and in Decree no. 77-1133 of 21/09/1977 for listed facilities, for protection of the environment. In its minimal form, as regards marine habitats, it includes:

- an analysis of the initial state of the site and of its environment,
- a study of the modifications the project would cause,
- measures envisaged to eliminate, reduce and where possible compensate for the harmful consequences on the environment.

Another indirect protection measure for *Posidonia oceanica* meadows in France (Nathalie Quelin, personal comm.) consists in submitting the dossier to a **public enquiry** under the Law of 12 July 1983. This is an indirect protection measure for meadows since this procedure aims at informing the public about development operations likely to affect the environment and collecting the public's remarks, suggestions and counter-proposals prior to certain decisions being made and certain operations set in train, in order to enable the competent authorities to have to hand all the elements needed to inform them. Many citizens have directly or through their representatives (users' associations, environmental protection associations, etc.) expressed their views to the investigating officer for these projects, in this context. Indeed, most of the dossiers on development and/or projects at sea are submitted to public inquiry.

It is interesting to notice that now, in France, a change is happening in awareness of the role of *Posidonia oceanica* banquettes in the beach concessions. Indeed, increasingly frequently there is a paragraph in the deed of concession specifically saying that *P. oceanica* debris washed up on beaches will not be cleared away except during the periods of summer visiting (Nathalie Quelin, personal comm.).

5.3. LEGAL ENFORCEMENT OF THESE POLICIES: EXAMPLES OF CASE LAW

In France, legal protection of *Posidonia oceanica* has led to the refusing of certain developments that risked harming the meadow or modifying others. Since the 1988 Protection Order was signed, no development involving the destruction of a *P. oceanica* meadow has gone ahead. The possible destruction of some isolated shoots or residual patches of *P. oceanica* that do not form a meadow has often been envisaged, for example during the Corbière, Marseille, beach developments (Crebassa, 1992). Confronted with the danger of opening a sort of Pandora's box[48], a loophole in which developers driven by very short-term interests[49] can take refuge, the only response must be the strict application of the law.

During the project to enlarge the port of Pointe-Rouge (Marseille, France), the town of Marseille first required precise mapping of the sector (Francour and Marchadour, 1989), by which means the areas occupied by *Posidonia oceanica* were effectively avoided. This was an exemplary case.

After building a private port on the island of Cavallo (Corsica) without a permit, its owner was sentenced by the Ajaccio Departmental Court. Among the offences he was charged with "*mutilating protected plants, and degrading species*" (Meinesz, 1989; Pergent, 1991a). The sentence (Ruling no. 90 of 2 February 1990) consisted of both a heavy fine and a request that the mooring post be destroyed and the coastline be reconstituted as it was originally (by closing an access channel at a depth

48 Indeed, how does one define the threshold at which isolated shoots or patches of *P. oceanica* do not constitute a meadow that deserves protection? The example of Prado Bay (Marseille, France), where isolated shoots and little patches of *P. oceanica* are rapidly expanding after a waste water treatment plant opened (Gravez *et al.*, 1999), illustrates the danger of such an interpretation.

49 By very short-term interests, the authors of this work mean the developers' interests, which may be very different from the short-, middle- or long-term interests of the people who live in the region.

of 2 metres) within 6 months (Pergent, 1991a). But it should be noted that by 1994 the channel was simply closed off by a chain and the coastline had still not been reconstituted (Boudouresque *et al.*, 1995b).

The existence of legal protection measures also allows us to envisage the implementation of environmental compensation measures for developments that harm a meadow. This is particularly so when work of collective interest such as the laying of underwater pipes or cables is carried out (Meinesz and Bellone, 1989). The replanting of *Posidonia oceanica* as cuttings or seeds has sometimes been envisaged as a compensatory step. However, as Boudouresque (2001) says, its effectiveness has not been fully demonstrated, and replanting must be considered with great caution; anyway, it should only be envisaged within an extremely precise and restrictive regulatory framework (see Chapter 13).

6. DEAD POSIDONIA OCEANICA LEAVES, BEACHES AND SAND REPLENISHMENT

6.1. THE PROBLEM

6.1.1. Dead Posidonia leaves

In the autumn, dead *Posidonia oceanica* leaves which have fallen off the rhizomes both accumulate in the meadow (litter: see §2.6) and are exported to areas of decantation, like sandy and intermatte areas. Then the autumn and winter storms drive them into other benthic ecosystems, from the infralittoral to the bathyal[50] stage, or onto the beaches (Fig. 49).

Fig. 49. Dead *Posidonia oceanica* leaves and aegagropiles on a Spanish beach. Isn't it lovely? Photo by J. Corbera in Romero (2004b).

On the beaches, the dead leaves, and sometimes the rhizomes, can pile up locally in considerable quantities until they are perhaps 1-2 metres thick. These piles of dead leaves are called "**banquettes**" in French (banchetti in Italian) (Fig. 27, Fig. 33) (Molinier and Picard, 1953; Picard, 1965a; Blanc, 1971). These banquettes are made up of *Posidonia oceanica* leaves and rhizomes in different stages of fragmentation and degradation (until they reach fibre stage), sediment and water. This ensemble forms a structure that is at the same time rigid and elastic.

The structure of the banquettes was studied in the Marseille (France) region by Jeudy de Grissac and Audoly (1985). They present a water content of between 30 and 90%, which increases from the upper part (exposed to the sun) down to the lower part of the banquette. The sand content varies from 0.5 to 85% according to the aspect of the site, the hydrodynamics, the texture of the beach matter (defined by granulometry) and the morphology of the beach. The plant matter is basically composed of leaves, fragments of leaves and fibres; the rhizomes are negligible in quantity. The plant debris which form the banquettes can be put into three categories:

- Type 1: Debris that have evolved very little, still green and still keep the 2 edges of the leaf. This represents under 1% of the banquettes.
- Type 2: Debris that presents much the same features as those of Type 1, but are brown. This represents 1-26% of the banquettes.
- Type 3: Debris that are very degraded, are brown, and present at most one of the 2 edges of the leaf. This represents 1-99% of the banquettes.

The beaches where *Posidonia oceanica* debris piles up, whether as a simple carpet (Fig. 49) or in banquettes, are usually disliked by bathers because of the smell they can give off, and especially because they interpret these piles as pollution. In reality, such banquettes are a **sign of good** water **quality** – they indicate the nearby presence of vast meadows.

50 The main marine stages are, from top to bottom, the Supralittoral (spray area), the Mediolittoral (area of waves and tidal sway), the Infralittoral (between the surface and 25-45 metres deph, a well-lit area), the Circalittoral (up to 70-150 metres depth, an ill-lit area), and the Bathyal (down to the great depths, where there is no light or insufficient light to ensure the presence of photosynthetic organisms).

Moreover, they are very **useful**. The base of the banquette is subjected to marine erosion and the leaf debris claimed by the water forms a dense suspension whose viscosity breaks the waves some metres ahead of the banquettes (Fig. 33) (Boudouresque and Meinesz, 1982). Thus the banquettes help **protect the beaches** from being eroded, especially during the winter storms.

Lastly, after the physico-chemical and biological processes of degradation of the dead leaves has finished, the banquettes constitute a source of carbon and nutrients that are used by various organisms along the **food chain**. Eliminating the banquettes should therefore not be done indiscriminately but carefully assessed, because of its negative consequences for the stabilisation of the beaches and the productivity of the coastal environment.

Elimination of banquettes is widely done by the territorial authorities on beaches of touristic interest. The dead leaves are carried off to (and possibly buried in) dumping sites, or piled up in areas near to the beaches, or pushed back into the sea. But on beaches of no resort interest, the banquettes are usually left alone.

Such practice means that in most of the western Mediterranean, where tourism is of great economic interest, the banquettes have become rare. Their scarcity can locally be due also to the regression of *Posidonia oceanica* meadows (see Chapter 4), and thus a decrease of the supply of dead leaves to the beaches.

6.1.2. Use of dead Posidonia leaves

Dead *Posidonia oceanica* leaves have been used by human beings since classical times (and even since prehistoric times) all around the Mediterranean (Boudouresque and Meinesz, 1982). Over 100,000 years ago, at about the end of the Riss ice age, men in the Lazaret cave (Alpes-Maritimes, France) certainly slept on litter composed of *P. oceanica* leaves (De Lumley *et al.*, 1969). Use of the leaves inside **mattresses**, or as bedding for animals, went on for a long time; indeed, "vermin" never entered the mass, certainly because of the phenolic acid contained in the leaves (Font-Quer, 1990). In ancient Egypt it appears that people made **shoes** with felted aegagropiles[51] (Täckholm and Drar, 1954); aegagropiles (*P. oceanica* balls) are fairly spherical agglomerates of fibre from dead *P. oceanica* leaves, formed by hydrodynamics in shallow waters and then thrown back onto the beaches (Weddel, 1877; Cannon, 1979, 1985).

Fig. 50. *Posidonia oceanica* aegagropiles on a beach. Photo by A. Meinesz. An aegagropile of record size (17x12 cm.) was observed in Mourillon (Toulon, France) by Jean-Marie Astier (personal comm.)

For centuries, when there was not yet any bubble wrap or expanded polystyrene, *Posidonia oceanica* leaves were used by the Venetians to wrap up and transport their famous, delicate glasswork, to the extent that these leaves were known as "Venetian straw"[52] (Boudouresque and Meinesz, 1982).

In North Africa (Egypt, Libya, Tunisia), in the early 20th century the coastal populations were still using dried *Posidonia oceanica* leaves to build roofs (Le Floch, 1983). In Corsica, under the roof of a classical sheep

52 This is why botanists prior to Linnaean nomenclature referred to *P. oceanica* as "*alga marina virtariorum*" (glaziers' marine "alga"). (Bauhin, 1623, *in* Grenier, 1860).

51 Aegagropile = "sea ball". The term aegagropile was first used to refer to balls of hair that formed in the stomachs of animals that lick themselves, such as cats, and were later regurgitated; by analogy, balls of *Posidonia oceanica* fibres are so called (Weddel, 1877).

barn, a coating of Posidonia leaves was discovered (Gérard Feracci, personal comm.), probably intended for **thermic insulation** (Boudouresque and Meinesz, 1982). Also for heat and sound insulation, conclusive tests using *P. oceanica* leaves were done in Sicily and Greece several decades ago (Sordina, 1951). In the early 1980s, the roof of the *Casa communa* in Pigna (Corsica) was heat insulated using dead leaves (Jean-Marcel Vuillamer, personal comm.).

Fig. 51. Late 19th century or early 20th century Corsican girl with a basket full of dead *Posidonia oceanica* leaves. The leaves were burned over the cropland to fertilize it. Reproduction by J.J. Allegrini, from an anonymous photo given by Mme. Conrad.

Dead *Posidonia oceanica* leaves were also used for a long time as **compost** by farmers on the Mediterranean coast. But it seems that they do not constitute a true compost but rather help maintain a certain rate of dampness in the surface soil or aerate over-compact soil if they are buried (Germain de Saint-Pierre, 1857; Sauvageau, 1892; Knoche, 1923; Braun-Blanquet *et al.*, 1952; Astier, 1972). In Corsica, dead leaves were burned over cropland to improve it (Conrad, 1982; Fig. 51). Today, these methods have gone out of favour, but tests have been done in Italy, Tunisia and Greece to produce a *P. oceanica* leaf-based compost, with interesting results (Sordina, 1951; Saidane *et al.*, 1979; Seri *et al.*, 2004). In Spain, the Denya town council (Comunitat Valenciana) with European funding (Life Environment project, 1996) and jointly with the University of Valencia, set up a composting facility capable of handling 15,000 cubic metres/year of plant waste. The compost obtained by mixing dead *P. oceanica* leaves with other plant detritus (in a ratio of about 1/3) has good agronomical features, is rich in oligo-elements and can be used for re-forestation and in other actions to restore the environment.

Freshly-picked dead *Posidonia oceanica* leaves have great nutritive value, like hay and alfalfa (Molinier and Pellegrini, 1966). By adding the powdered leaves to feed for hens in Italy the laying and the weight of the eggs was improved (Baldiserra-Nordio *et al.*, 1967, 1968; Gallarati-Scotti, 1968). In Tunisia, in the 1920s, attempts to feed cattle with the leaves mixed with fodder had a mixed success; donkeys and sheep refused to eat it, but 2 horses accepted it[53] (Pottier, 1929; Boudouresque and Meinesz, 1982). *P. oceanica* fruits washed up on the beach were eaten by cattle (Tunisia), pigs (Corsica) and even human beings in times of famine (Cuénod, 1954; Boudouresque and Meinesz, 1982; Roger Miniconi and Gérard Feracci, personal comm.).

Among other uses of *Posidonia oceanica* we can mention the production of paper at the end of the 19th century (Sauvageau, 1890; Lami, 1941). Lastly, the Egyptians attributed curative properties to it, especially for sore throats and skin problems, and an old botanics handbook (Cazzuola, 1880) mentions it as a product in the popular pharmacopeia.

All in all, although in the past dead *Posidonia oceanica* leaves were used by people living on the shore (Fig. 51), although this is usually anecdotal, modern tests have demonstrated the feasibility of its use but have usually run up against economic realities. Moreover, even if changing techniques should one day make use of the dead leaves profitable, this valorization would not solve the problems raised when the leaves are removed from the beaches (see §6.1.1 and 6.1.3): erosion of the beaches and impact on the food webs of the coastal

53 The Latin historian Hirtius told how in the African war horses and beasts of burden in Caesar's legions were saved by eating dead *P. oceanica* leaves (of course he did not call them this) since there was no other form of fodder (Pellissier, 1853; Brulard, 1885).

ecosystems. Also, it would, in the countries where the species is protected (see §5.1.2), run against the ban on its use in any way whatsoever.

6.1.3. Erosion of beaches

A beach is made up of deposits of detritic sediment carried by water currents or produced by marine erosion of the rocky coasts. The existence of a beach is the result of a delicate **balance** between the amount of sediment arriving and that washed away by coastal currents. When the balance is positive, the beach grows. When it is negative, the beach is eroded (Paskoff, 1993; RAMOGE, 2002; SDAGE, 2003).

Beach dynamics is a product of natural parameters such as hydrodynamics, swell, currents, wind and soil erosion, and it can be greatly modified by human activities such as (Boudouresque and Meinesz, 1982; Paskoff, 1993; Boudouresque, 1996; RAMOGE, 2002):

(1) Reduction of provision of solid matter from the watercourses that flow into the sea after they have been developed (dams, reservoirs) and/or material extracted from their beds.
(2) Coastal development, with the construction of coastal buildings or structures. Such construction prevents the sand from moving between the beach and the back of the beach (dune); during storms, therefore, it is driven out to sea (Paskoff, 1993).
(3) The building of port facilities that may constitute barriers to the carrying of sediment parallel to the coast. These bring about a sedimentary deficit for beaches located downstream of the facilities in relation to the dominant current (Cortemiglia, 1979).
(4) The creating of coastal defence facilities (groynes, breakwaters) that modify the coastal transport of sediment as in point 3.
(5) The degradation of *Posidonia oceanica* (or other marine Magnoliophytes) meadows. Such meadows stabilize the sediment and reduce hydrodynamism by dispersing the energy above them and on the coast where they grow (see §3.3). Their regression or disappearance thus leads to an increase in coastal hydrodynamism.
(6) As mentioned above (§6.1.1), uninformed bathers think that dead *Posidonia oceanica* leaves on a beach are a sign that the beach is badly looked after. To make beaches look clean, or because cleaning machines cannot tell a dead leaf from a plastic bottle, the coastal district authorities make sure everything is cleaned up. Banquettes of dead leaves reduce the available space on a beach and smell like "the sea". On the Atlantic beaches, people are used to this smell and actually like it – they associate the smell of kelp[54] with that of untamed nature. But people on Mediterranean beaches, whose ecological culture is often rather smaller, associate the smell with pollution. Now, dead leaves and banquettes help protect beaches, especially during winter storms (Boudouresque, 1996; SDAGE, 2003).
(7) Over-visiting of beaches. On some beaches there can be 500,000 visitors a day and per 100 linear km.
(8) Extraction of fresh water from underground reserves, which can cause subsidence as well as making the ground water irreversibly salty.

The frequent concomitance of these activities on the same stretch of coast, added to natural factors (Paskoff, 1993) brings about a very delicate situation: a considerable number of beaches are decreasing, sometimes dramatically so. To attempt to

54 "Varech" is the Breton word for "algae", especially seaweed on the beaches (foreshores).

compensate for this, very many coastal districts have started operations of **beach replenishment**. The amounts of sediment added can be considerable: in 1994 and 1995, 14,600 t of gravel and 3,800t of sand were spread over a single beach, Almanarre (Gulf of Giens, Var, France). Between Capo Noli and Capo Vado (Liguria, Italy), a 9km-long beach has since 1970 been totally covered every two years with sand (Relini, 1992; Boudouresque, 1996).

Adding sedimentary material to beaches in an attempt to give them a greater extent of sand can be a serious ecological problem for the benthic ecosystems because of the unsuitable nature of the material (silt, clay, "earthy" material generally) which changes the granulometry of the sediment. The nature of the soft substratum settlements is closely linked to the granulometry (Pérès and Picard, 1964). The use of unsuitable material also has negative effects on the *Posidonia oceanica* meadow (Relini, 1992). The worst aspects linked to the use of unsuitable material (for it contains fine sediment) are:

(1) The increase of water **turbidity**, which reduces the interval of depth compatible with photosynthesis of *Posidonia oceanica* and thus causes its lower limit to rise ("compensation depth") (see §4.3).
(2) The **silting** of the meadow, a phenomenon that means that fine sediment is deposited on the leaves (reducing their photosynthetic capacity) and an increased sedimentation rate. It should be remembered that the meadow traps sediment, that the growth of orthotropic (vertical) rhizomes usually compensates for the entry of sediment, but that if this entry is greater than a thickness of 5-7 cm. a year it is no longer compensated for by the growth of the rhizomes: the vegetative tips are then buried and *Posidonia oceanica* dies (Boudouresque and Jeudy de Grissac, 1983; Boudouresque *et al.*, 1984; Jeudy de Grissac and Boudouresque, 1985) (see §4.1).

6.2. CASE STUDIES

6.2.1. Managing banquettes in Malta

In Malta, a coastal vegetation management programme has been undertaken in collaboration with the university. There is a double aim: eliminating dead *Posidonia oceanica* leaves from the beaches for touristic purposes, and restoring the coastal terrestrial vegetation in sectors where it is degraded.

Dead *Posidonia oceanica* leaves taken from the beaches are heaped up, with other organic matter, in piles about 1.5 metres thick. After 2 years, plants such as *Atriplex halimus* are planted along the perimeter of the piles, and *Tamarix* sp. and Acacias are planted inside. After 15 years of this experiment, the results seem to be positive, in that green barriers of about 2 metres have been created, barriers which hinder access to the beach (particularly for motor vehicles) and encourage the recolonization of the back of the beach by pioneer growth.

We notice that although this experiment constitutes one of the rare examples of true valorization of dead *Posidonia oceanica* leaves (see §6.1.2), it fails to solve the problem of erosion of beaches and the impact on the marine ecosystems that removal of the banquettes causes. The praiseworthy reconstitution of vegetation at the back of the beaches can be achieved by other methods (see §6.2.3).

6.2.2. Port-Cros and Porquerolles beaches

In the islands of Port-Cros and Porquerolles (Hyères, Var, France), the Hyères district and the Port-Cros National Park have carried out an interesting experiment. According to the location and visiting of the beaches, 5 cleaning levels were defined (Table VI; Auby, 1998). Generally speaking, 3 principles were adopted: **(i)** non-natural or dangerous waste is removed as far as possible; **(ii)** removal and cleaning is done exclusively by hand; **(iii)** dead *Posidonia oceanica* leaves and banquettes (and these are fairly low) are left where they are.

Table VI. Cleaning levels on Port-Cros and Porquerolles beaches (Hyères, Var, France). + = removal, - = no removal. From Auby (1998)..

Level of intervention	Material removed (+) or not removed (-)				
	Artificial material[a]	Trunks (diameter >30cm)	Thick timber (diameter 5-30cm, length > 50cm)	Branches (diameter < 5cm, length < 50cm)	Dead *Posidonia oceanica* leaves
0	-	-	-	-	-
1	+	+	-	-	-
2	+	+	+	-	-
3	+	+	+	+	-
4	+	-	+	+	-

[a] Artificial material oil residue, plastics, rope, metal, glass and worked wood (=wood worked by humans).

For every beach and every season (touristic season, low season) a level of intervention has been defined (Table VII; Auby, 1998). Frequency of cleaning varies between daily and monthly according to the beach and the season (Patrick Auby, personal comm.).

Bathers are informed about this beach management strategy by explanatory boards (Fig. 52). They can read on the board: "*A natural beach. The presence on the beach of dried leaves is a sign of the good health of the nearby marine environment, where a true underwater meadow of flowering plants, Posidonia, is developing. Parts of their leaves drop off in the autumn and lie on the beach over the winter. This natural carpet is very clean and protects the beach sand against sea action.*"

Fig. 52. An information board on a Porquerolles beach. Photo by P. Robert.

It is interesting to state that this policy (the non-removal of dead Posidonia oceanica leaves) associated with information, has not stopped visitors: **(i)** number of visitors is no different for beaches with few dead leaves and those well covered with dead leaves; **(ii)** on beaches with a relatively high cover of dead leaves, the number of visitors did not decrease after the strategy of non-removal of dead leaves was introduced. Simply, the bathers who arrive first choose the places without dead leaves (Philippe Robert, personal comm.). This experiment of non-removal of dead leaves plus information on boards has been taken up by the districts of the Marine Observatory of the des Maures Coast (Cavalaire, Rayol-Canadel, La Croix-Valmer and Ramatuelle, Var, France.

Table VII. Examples of levels of intervention (see Table VI) for cleaning beaches, in the islands of Port-Cros and Porquerolles (Hyères, France) according to site and season. Touristic season from 1 May to 30 September. Low season from 1 October to 30 April. From Auby (1998).

Beach	Season	Level of intervention
South beach (Port-Cros)	Low season	1
	Touristic season	4
Port-Man bay (Port-Cros)	All year round	1
Port-Cros beach (Port-Cros)	Low season	1
	Touristic season	2
Brégançonnet (Porquerolles)	Low season	0
	Touristic season	2
Middle of Plage d'Argent (Porquerolles)	All year round	3
Plage de la Galère (Porquerolles)	All year round	0

6.2.3. Almanarre beach, Hyères

Almanarre beach lies at the base of the western Giens tombolo (Hyères, Var, France). It is a much-visited beach, 5 km. long. On several occasions, the most recent being 1992 and 1994, the spit of the western tombolo has been broken by storms of exceptional force (Frédérique Lantéri-Gimon, personal comm.). There are certainly many reasons for this breaking; the main one is probably the sedimentary deficit of the Giens harbour, into which (today) no major watercourse, likely to facilitate sediment input, flows. More generally speaking, in Provence, the 20th century has been marked by a drop in farming, reconstitution of the forest cover, reconstitution of the soil and thus reduction of terrigenous sedimentary inputs into the sea (Gravez et al., 1988). However, the destruction of the dunes behind the beach, the building of a road too near to the sea, and the rip-rap intended to fight against erosion of the beaches – but whose effect has been to accentuate this erosion – have also played a negative part. In any case, the breaking of the western tombolo in 1992 and 1994 was the spark that led managers to question a certain number of practices and to set up integrated management of the area as a whole (Daniel Barbaroux and Frédérique Lantéri-Gimon, personal comm.).

Almanarre beach (Fig. 53) is managed today by the Environmental Service of the Hyères town council, with technical advice from the Port-Cros National Park and the Botanical Conservatory of Porquerolles. Its **management measures** are as follows (R. Barety, personal comm.): **(i)** non-removal of dead *Posidonia oceanica* leaves and banquettes over a 1 km stretch (since 1996) and then over the southern 3 km (since 2001); on the rest of the beach, these dead leaves are relatively rare; **(ii)** artificial macrowaste (plastics, glass, worked wood etc.) is removed by hand every day during the touristic season (15 June to 15 September); the natural wood (trunks, branches) is left where it is; **(iii)** since 1996, the dunes at the back of the beach have been protected by wooden barriers (ganivelles); people can only cross the dunes where there are signposted crossings (about one passage every 100 metres). Some of the crossings are wide enough to allow windsurfers to pass. This protection has enabled some degraded dunes to increase in height by 2-5 cm a year; **(iv)** in some sectors where the dunes had been completely destroyed by trampling they have been artificially reconstituted, and replanted with the sea

Fig. 53. The northern part of Almanarre beach in May 1997. The dead *Posidonia oceanica* leaves are visible on the beach. Photo by R. Barety and F. Lantéri-Gimon.

daffodil *Pancratium maritimum*, the maritime daisy *Anthemis maritima*, the cotton weed *Otanthus maritimus*, and the sea-holly *Eryngium maritimum*; all these plants are species that are characteristic of the dunes at the back of the beaches in the region; this operation was supervised by the Botanical Conservatory of Porquerolles, given the decrease of the northern part (over 2 km) of Almanarre beach, and in 2 points beach **replenishment** operations are continuing. At first, this involved gravel (15-20 mm in diameter) from the Durance. Then finer, marine origin, sand was chosen from a quarry in Signes (diameter <5 mm); and sand dredged from the access channels to certain Var ports was added. The total amount is 10,000 cubic metres a year. Rip-rap, thought to protect the beach but unfortunately eroding it instead, was removed (R. Barety and Frédérique Lantéri-Gimon, personal comm.).

Informing the **public** about why these management measures are being taken is done verbally by a dozen seasonal agents, through the local press, and, to a lesser extent, by a leaflet produced by the Hyères town council and by posters distributed to shopkeepers (Frédérique Lantéri-Gimon, personal comm.). Visitors to the beach did not decrease after these management measures were put into effect. They have remained stable from year to year; the restrictive factor is the number of parking spaces. Generally speaking, the public's reaction to these management measures has been extremely favourable; people are respecting the obligation to only cross the dunes behind the beach using the signposted crossings (R. Barety, personal comm.).

6.3. RECOMMENDATIONS

Beach replenishment aims at countering a situation (erosion of the beach, deficit of sediment) which has usually arisen because of an alteration in the former balance. To really solve a problem of this kind sustainably, and thus often more economically, the **cause** should be addressed, i.e. the factor leading to the disbalance should be corrected.

(1) Avoiding the reduction of beaches, means first of all permitting the free movement of sand between the beach and the back of the beach (dune): **(i)** protecting the dune against trampling by means of obstacles to crossing. Users must be informed why it is wished that they only cross the dune at certain duly signposted crossings. When the dune has been degraded by trampling, introducing protection allows it to reconstitute itself naturally[55]; **(ii)** banning all construction (roads, buildings) on the beach and at the back of the beach – it must only start beyond the dune; **(iii)** keeping dead *Posidonia oceanica* leaves and banquettes of dead leaves on the beach. Users should be told why they have not been removed: to protect the beach from erosion and to maintain underwater life; moreover, the public should be made aware that leaves washed up on the beach indicate the presence of Posidonia meadows nearby and thus the good overall quality of the water. Use of phrases like "**ecological beach**" or "bio beach" is recommended[56]; **(iv)** if a choice is made to remove (or reduce the amount of) banquettes of dead leaves, this should be done as late as possible before the touristic season to allow them to act as protection during the greater part of the year; **(v)** when the state of an artificial groyne (or any other facility intended to "protect" the beach) deteriorates, before it is repaired or rebuilt a study should be done on a correct scale (the hydro-sedimentary unit which it is part of) to make sure that such repair or rebuilding is really appropriate.

55 As well as the examples mentioned above (particularly Hyères, Var, France), the management of Pampelonne beach (Var, France), with the reconstitution of the dune environment, deserves to be highlighted.

56 Non-removal of dead *Posidonia oceanica* leaves is a practice that is becoming more widespread. As well as the examples described above (§6.2.2 and 6.2.3) one can mention Gigaro beach (Croix-Valmer, Var, France) and an Antibes beach (Alpes-Maritimes, France) (Corine Lochet, personal comm.).

(2) When there really is no alternative to **beach replenishment**, the following rules should be borne in mind: **(i)** the material used should be composed of sediment whose granulometry is sufficiently coarse to effectively absorb the force of the waves. And gravel gives the shore a more sloping profile and thus increases the surface area of the beach more than sandy material would do (RAMOGE, 2002); **(ii)** no sedimentary material must be discharged directly over *Posidonia oceanica* meadows; **(iii)** if *P. oceanica* meadows are present within 300 metres of any part of the beach (including parts of the beach where the material is not directly discharged; drifting currents disperse it fairly quickly over the entire beach), the materials that can be used for this spreading of sand should have certain specific features. In Liguria (Italy), the *Normativa regionale della Liguria* (L.R. no. 13/1999)[57] concerning sand spreading projects indicates, as well as respect for a number of conditions, the granulometric nature of the material to be used, provided according to Wentworth's scale, indicating the main granulometric fractions (as a percentage of the weight: gravel, sand, silt and clay); a prior study is needed when the addition is over 10 cubic metres per linear metre of beach. In particular, the *Normativa regionale della Liguria* provides that the material to be used on the coasts of Marine Protected Areas, Natura 2000 sites (Habitats Directive) and areas that host hard substratum settlements of great heritage value, must satisfy the 2 following conditions: a maximal quantity of pelite[58] (2%), and a maximal quantity of pelite per linear metre of beach (and per period of five years) (0.8 cubic metres). The *Normativa regionale della Liguria* could be used as a model in other Mediterranean regions.

(3) So far, **valorization** of dead *Posidonia oceanica* leaves taken from the beaches has remained, despite many attempts, more an issue of traditional ethno-sociology than of economic future. Even if in future the leaves could really be made good use of, their removal should be ruled out because of the role they play in protecting the beaches against erosion and in the food webs of the coastal ecosystems. In France, where *P. oceanica* is a protected species, removal is in fact **illegal** (see §5.1.2 and protection text) and the valorization of these dead leaves is also illegal. It is only in the Mediterranean regions where the species is not protected and where it is not threatened (regions so far unidentified) that use of the dead leaves of *P. oceanica* could legally be envisaged, although we strongly advise against it.

57 http //www.comuneloano.it/comune/documenti/110lr13_99%20lr01-02.pdf

58 Pelite sediment whose grain diameter is under 0.063 mm.

7. THE *POSIDONIA OCEANICA* MEADOW AND MANAGEMENT OF FACILITIES ON THE MARITIME PUBLIC DOMAIN

7.1. THE PROBLEM

The Maritime Public Domain is the space between the low water line and the high tide line or the limit to where the waves reach the greatest known temporary range. It includes the beaches and areas of loose material such as sand, gravel or pebbles, land reclaimed from the sea and ports.

Coastal development mainly involves building on the shore (like marinas), building ports, breakwaters (sea walls running parallel to the coast) or groynes (sea walls running straight out from the coast), creating artificial beaches and pushing the shoreline further out to sea using sea walls (reclamation[59]). One could add seaside urbanization (especially along the beaches). "**Balearization**" means that such developments pretty much run into each other along the beach in the context of touristic activity: the word is taken from "Balearic Islands", which were among the first Mediterranean regions (starting from the 1950s) to undergo such massive, chaotic development (Ros, 1994).

In the Mediterranean, **the continental shelf is usually narrow**, so that seabeds of less than 50 metres only represent about 5% of the surface area. With a few rare exceptions, all coastal development is concentrated on seabeds of less than 20 metres; now, most of the **primary** production[60], of the plant biomass, and thus of the animal biomass, as well as a great deal of the **biodiversity** (species diversity and ecosystem diversity) is concentrated in these depths (Meinesz *et al.*, 1985; Boudouresque, 1996). Moreover, habitats defined as priority[61] are found on seabeds of less than 50 m (*Posidonia oceanica* meadows, coralligenous bioconstructions). And fish **nurseries** are often located in very shallow water (less than 10 m depth) (Vigliola, 1998; Vigliola *et al.*, 1998).

The percentage of the surface area of infralittoral[62] seabeds occupied (and whose settlements are irreversibly destroyed) by coastal development is already considerable in some Mediterranean regions, like the PACA Region (Provence-Alpes-Côte d'Azur, France; Table VIII; Fig. 54) and Liguria (Italy). The development of Le Mourillon artificial beaches in Toulon, where 22 hectares have been covered by direct discharge into the sea of earth, rubble and waste, is particularly representative (Astier *et al.*, 1980).

Table VIII. Percentage of the surface area of the infralittoral seabed and percentage of the shoreline occupied by coastal development in the Provence-Alpes-Côte d'Azur Region (France) from Martigues to Menton (656 km of coastline). From Meinesz and Lefèvre (1976a, 1976b, 1978), Meinesz *et al.* (1981a, 1982, 1985, 1990c, 1991b).

Sector	Seabed 0-10 m	Seabed 0-20 m	Shoreline
Eastern Bouches-du-Rhône	27%	19%	21%
Var	11%	7%	12%
Alpes-Maritimes and Monaco	20%	12%	24%
Region as a whole	15%	10%	16%

59 "Reclamation" means claiming areas from the sea and using these for coastal development (generally urbanization).

60 Primary production production of living matter from carbon dioxide and nutrients by using light (photosynthesis) or chemical (chemosynthesis) energy.

61 Habitats of Community interest in the context of the "Habitats Directive" of the European Community and the network of Natura 2000 sites.

62 The infralittoral stage (=sublittoral stage) corresponds to the bathymetric area occupied by *Posidonia oceanica* meadows. It starts a few centimetres below average sea level and extends (according to the transparency of the water) down to 23-40 metres depth (Pérès and Picard, 1964).

In all, in the PACA Region (from Martigues to the Italian border, including Monaco), 3 059 hectares of shallow depths are covered by development, i.e. 15% of shallow depths located between 0 and –10 metres, and **10% of seabeds** between 0 and –20 metres (Table VIII; Meinesz *et al.*, 1985, 1991b). Out of 656 km of coast, **106 km** is now man-made, i.e. 16% of the coastline. There are **134 ports** and shelters (i.e. on average one port or shelter every 5 km); in the Alpes-Maritimes alone there are 38 ports (or shelters) for 119 km of coast (i.e. one port every 3.1 km). In the Camargue, 145 rocky groynes (about 200 metres long) have been built along the sandy coast, so that half the coastline is now man-made (Eric Coulet, personal comm.). In the Languedoc-Roussillon Region (France), there are 32 ports for 214 km of coast, i.e. on average one port every 6.7 km (Boudouresque, 1996). Liguria in Italy, the Balearic Islands (Mallorca, Ibiza), part of Sardinia, and southern Cyprus are also badly affected regions. In Genoa province (Liguria, Italy), 33% of the coastline is man-made (Giuliano Fierro[63]). In Corsica[64], however, less than 1% of the seabeds between 0 to -10 metres are built areas (Meinesz *et al.*, 1990c).

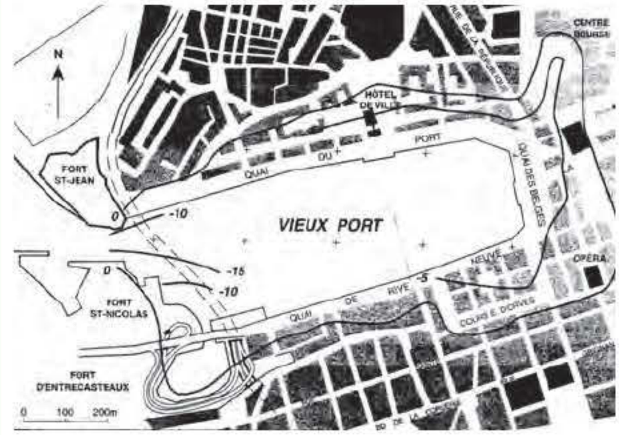


Fig. 54. Extent of the Lacydon (the Greek name for the bay) of Marseille (France) (outer contour) and isobaths (inner contours) in about 600BC, compared with the "Vieux port" and urbanization today. From Millet *et al.* (2000).

The impact of coastal development is a major cause of the reduction of the *Posidonia oceanica* meadows. This impact can be **direct**, by covering up – this is the case, for example, of the port of Beaulieu-sur-Mer (Alpes-Maritimes) (Fig. 55; Meinesz and Lefèvre, 1978) and the port of Bandol, where a car-park area was reclaimed from the sea over one of the last *P. oceanica* barrier reefs in the north-western Mediterranean (Fig. 56; Pérès and Picard, 1963; Boudouresque and Meinesz, 1982). It can also be **indirect**. A port is often a major source of pollution that escapes from waste water treatment: "anti-fouling" paint [65] of ships' hulls, waste water discharged from boats[66] when the boats and/or ports are not fitted with waste water recuperation systems. Such discharges

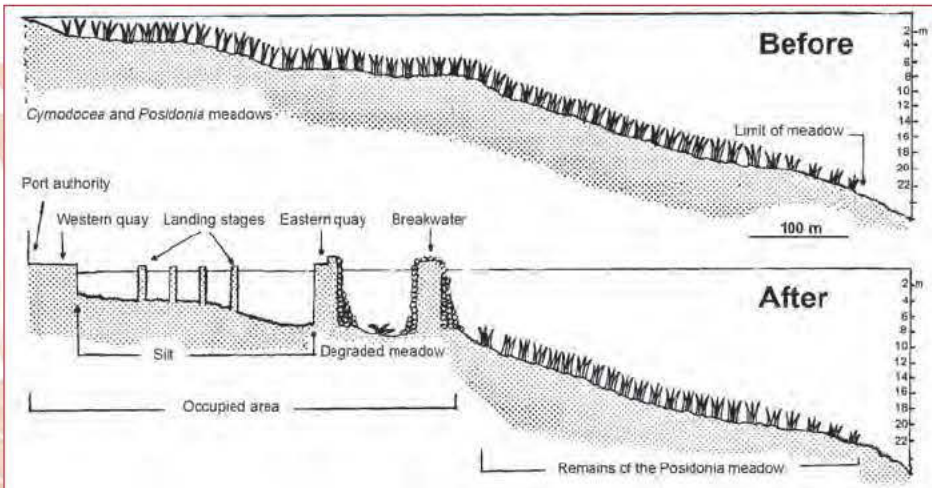


Fig. 55. An example of the disappearance of a *Cymodocea nodosa* meadow and the reduction of a *Posidonia oceanica* meadow as a result of the building of a port cross section at the western quay of the port of Beaulieu-sur-Mer (Alpes-Maritimes). From Meinesz and Lefèvre (1978).

63 Professor of Marine Geology at Genoa University, Italy. Verbal communication at the Hydrotop Scientific Colloquium, Marseille, April 1996.

64 The coastline of Corsica, measured on 1 25 000 maps, is 941 km long (Meinesz *et al.*, 1990a).

65 "Anti-fouling" paint is intended to prevent living organisms (=fouling) from developing on ships' hulls. National and European laws have led since the 1980s to a reduction in the toxicity of the biocides used

66 The discharging of waste water by boats is usually forbidden within the port, at least in countries in the RAMOGE area, although this does still happen there.

Fig. 56. The port of Bandol (Var, France). The two areas that surround the harbour (above and below) were reclaimed from the sea. The bottom one covered one of the last *Posidonia oceanica* barrier reefs in the north-western Mediterranean. Anonymous photo.

are frequent when leisure boats are used as secondary residences, as is often the case in the Mediterranean (Meinesz *et al.*, 1985; Boudouresque, 1996). *P. oceanica* is known to be sensitive to pollution (Boudouresque and Meinesz, 1982; Augier *et al.*, 1984b; Pergent *et al.*, 1995; Boudouresque, 1996; Argyrou *et al.*, 1999; Delgado *et al.*, 1999; Pergent *et al.*, 1999). Furthermore, as a photosynthetic organism, *P. oceanica* is very sensitive to even short-termed water turbidity, for example turbidity generated during coastal development work (Meinesz and Laurent, 1978; Boudouresque, 1996; Ruiz-Fernández, 2000; Ruiz and Romero, 2001).

Rocky groynes running straight out to sea have often been built in an attempt to fight erosion of beaches (see Chapter 6). These groynes hinder the drift of currents and sediment along the coast. Ports and reclamations have a similar effect. The result is that upstream of the groyne sediment accumulates, and downstream there is a deficit of sediment. If the entry of sediment is over 6-7 cm/year, the orthotropic rhizomes of *Posidonia oceanica* are unable to compensate by their vertical growth for being buried (Boudouresque and Jeudy de Grissac, 1983; Boudouresque *et al.*, 1984; Jeudy de Grissac and Boudouresque, 1985; Romero, 2004b). The vegetative tips are then buried and die; the meadow is destroyed. Conversely, downstream from the development, the departure of sediment causes baring of the rhizomes (see Fig. 41). The bared meadow is then extremely vulnerable to hydrodynamism (swell, storms), trawling (at depth) and the anchoring of boats; in the long term it is also destroyed (Boudouresque, 1996).

7.2. CASE STUDIES

7.2.1. Developing Le Mourillon beaches in Toulon

The Vignette Bay (Le Mourillon, Toulon, Var, France) was until the 1960s occupied by a set of small beaches much visited by the people of Toulon, and by a *Posidonia oceanica* barrier reef which extended out to sea in a vast plain meadow.

Fig. 57. The artificial beaches of Mourillon (Toulon, Var, France) were built over a *Posidonia oceanica* meadow, in particular a barrier reef. The most recent development (a nautical club), on the right, does not appear in this photograph. From Astier *et al.* (1980).

This was, moreover, a site much used by artisanal fishermen (Astier *et al.*, 1980; Astier, 1984). Between 1964 and 1979, reclamation took place (artificial beaches and a nautical club) in this site (Fig. 57). No precautions were taken (for example, prior rip-rap) before replenishing the area: companies and individuals discharged clayey earth, rubble and miscellaneous material into the sea. When the east wind blew strongly, the finer materials were carried off by hydrodynamism (Fig. 58 and 59; Astier, 1984). Overall, **22 hectares** (lagoon, barrier reef and *Posidonia oceanica* plain meadow) were directly covered. Moreover, hypersedimentation and the increased turbidity of the water resulted in the destruction of **10 hectares** of meadow (rise of the lower limit) in front of the facilities built. Lastly, **37 hectares** of meadow were seriously degraded by silting (Nodot *et al.*, 1978; Astier *et al.*, 1980). Without a map of the meadows before the start of the development, the figures are probably much higher[67]. At the exit to the most eastern cove of Le Mourillon, a bit of a *P. oceanica* barrier reef has escaped being covered (Charbonnel *et al.*, 1996). Almost two decades later, the situation of the meadow seems to have stabilized in front of the development as regards both its upper limit, where it reaches the foot of the rip-rap, and its lower limit; 78 hectares of meadow remain, the lower limit of which is between 10 and 14 metres depth; beyond this, the seabed is made up of nearly 200 hectares of fairly silted up "dead matte"; as hydrodynamism stirs this sediment up into suspension, great turbidity results, which seems to slow down seriously any recolonization by *P. oceanica* (Charbonnel *et al.*, 1996; Bernard *et al.*, 2001).

If the economic and social benefits (increased visiting of the beaches, several years of activity for maritime industries) and the ecological and economic costs, which will increase in the long term, i.e. for centuries, are weighed in the balance, the final outcome will be strongly negative. Today, such an error in coastal development would probably finish in legal proceedings, but in fact would perhaps not even have occurred.

Fig. 58. Developing Le Mourillon's artificial beaches (Toulon, Var, France). A lorry discharging earth directly into the sea.

Fig. 59. Developing Le Mourillon's artificial beaches (Toulon, Var, France). Fine sediment is carried off by hydrodynamism. From Astier *et al.* (1980).

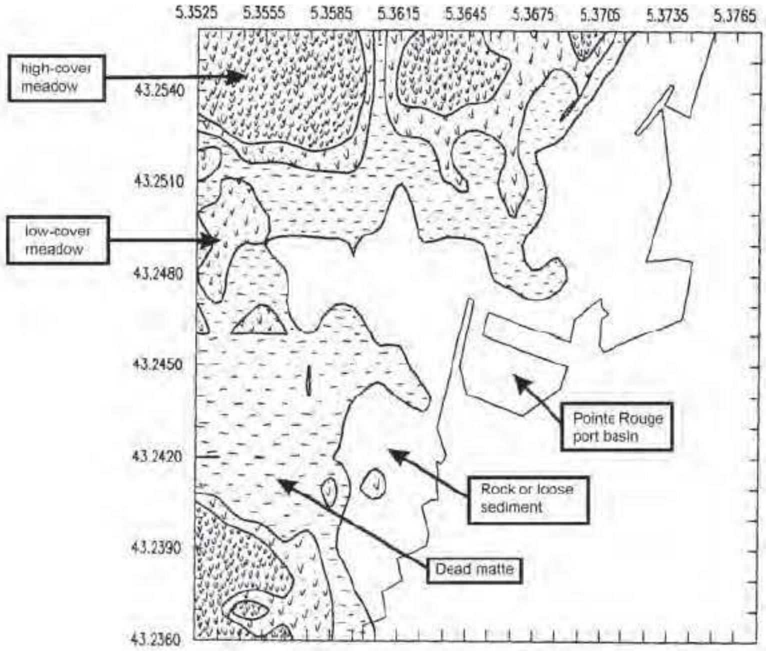
7.2.2. Building Pointe-Rouge port in Marseille

Until the end of the 19th century, Prado Gulf (Marseille, France) was occupied by a vast *Posidonia oceanica* meadow (Marion, 1883). In the 1960s, the meadow was still well represented there, although its lower limit was only 24-29 metres deep (Massé, 1962; Harmelin and True, 1964). Vast stretches of "dead matte" extended further in depth, down to about 32 metres, but it is possible that these were old (several centuries old; Gravez *et al.*, 1992) and their presence not due to contemporary human activity. Later, the Prado Gulf meadow regressed seriously; not only did its lower limit rise (to 22-24 metres depth) but there were splits between its upper limit (located at about 9-10 metres depth) and its lower limit; it was interrupted by stretches of "dead matte", some of which were enormous, or reduced to isolated patches scattered over the "dead matte" (Gravez *et al.*, 1995, 1997).

There were many reasons for this regression. **(i)** Pollution and turbidity introduced by the inputs of a coastal river, the Huveaune (before it was diverted towards the Cortiou sewage discharge in 1977); **(ii)** pollution due to the town of Marseille's waste water discharges into the sea (equal to 1.5 million population equivalents) into

67 Vast stretches of "dead matte" located beyond the lower limit of the meadow, which occupies almost 200 hectares, could be at least partly linked to development.

Fig. 60. Map of types of seabed and of *the Posidonia oceanica* meadow around Pointe-Rouge port (Marseille, France). Only part of the maps made appears here. From Francour and Marchadour (1989).



the Cortiou calanque, waste water brought by the dominant east-west current into the Prado Gulf (before a treatment plant started operating in 1987) (Bellan-Santini, 1966; Bellan *et al.*, 1999); **(iii)** turbidity brought about by the construction of the Prado artificial beaches and, especially, by the building of Pointe-Rouge port in 1968, which directly covered 11 hectares of *Posidonia oceanica* meadow and indirectly destroyed 68 other hectares, i.e. six times the surface area of the development itself (see §4.1) (Gravez *et al.*, 1992). From the moment the town of Marseille's waste water treatment plant started operating (1987) the trend was reversed: monitoring of permanent quadrats and permanent transects has demonstrated the progression of clumps of *P. oceanica* (Gravez *et al.*, 1995, 1997); this progression is of course very slow, given the plant's biological characteristics (see §4.7), and it will certainly take several centuries to get back to the situation of the late 19th century. In these conditions it became vital to manage coastal development (former or future) so that no impact, direct or indirect, could undermine the natural reconstitution of the Prado Gulf *P. oceanica* meadow.

In the late 1980s, the town of Marseille envisaged enlarging Pointe-Rouge port. So as not to repeat past errors and to take into account the legal protection of *Posidonia oceanica* and its ecological and economic importance, an exemplary procedure was followed. Unlike what was usually done – first making development plans and then doing an impact study, whose conclusions might run awkwardly counter to projects that were already far advanced – the town of Marseille undertook a preliminary study of the seabed (in particular the *P. oceanica meadows*; Fig. 60); this study was not restricted to the immediate surroundings of the port but took in a relatively vast area (Francour and Marchadour, 1989; Francour and Gravez, 1990). Only after this did the town of Marseille ask promoters to come up with projects for enlarging the port; all the ecological information, in particular the map of *P. oceanica*'s distribution, was by then available (Fig. 60). Naturally, this procedure does not exempt it from making a later impact study, which is compulsory.

7.2.3. Banyuls-sur-Mer port

The port of Banyuls-sur-Mer (Pyrénées-Orientales, France) is a little recreational port (350 boats in all) that also has some fishing boats. Between 2 and 5 metres depth, near the entrance to the port, there is a *Posidonia oceanica* meadow. It occupies about 10% of the port area and presents signs of fairly good vitality: shoot density (350-500/m^2), presence of many plagiotropic shoots[68], length of leaves and leaf area index[69] as high as,

68 Plagiotropic rhizomes are shoots situated at the tip of creeping rhizomes that tend to colonize free areas and thus extend the surface area of the meadow.

69 Leaf Area Index (LAI) the total surface area of the leaves per m of soil surface. Only one side of the leaf is counted when calculating the LAI.

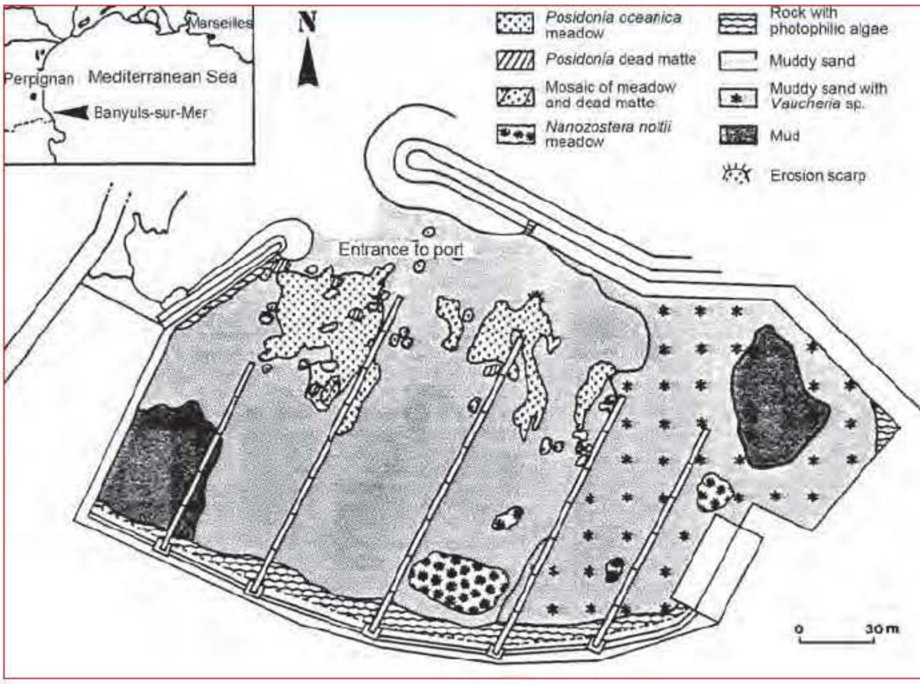


Fig. 61. Map of the seabed in Banyuls-sur-Mer port (Pyrénées-Orientales, France). From Pergent *et al*. (1991).

or higher than, in the open sea in the region, scarcity of "dead matte" (Fig. 61; Pergent *et al*., 1991). This meadow was present before the port was built (Pruvot, 1894) and nothing allows us to argue that it has regressed after the building, except at the entrance to the port, where it was destroyed by the dredging of an access channel (Pergent *et al*., 1991).

The persistence of a *Posidonia oceanica* meadow in a port basin is atypical; in almost all the ports built over a meadow, the meadow has disappeared. It is therefore interesting to try to understand the reasons for this situation (Pergent *et al*., 1991). **(i)** This is a little port; **(ii)** the port's rate of occupancy outside the touristic season is fairly modest – under 60%; **(iii)** no waste water is discharged, and there is no boat maintenance companies, in the port. Furthermore, leisure boats are not used as floating campers in the summer, which restricts the discharge of pollutants; **(iv)** there is no storm overspill in the port. Thus the salinity remains permanently high there. And *P. oceanica* is very sensitive to desalination (Ben Alaya, 1972); **(v)** the port is exposed to hydrodynamism in a region with a great deal of wind and probably rapid renewal of water; also, it is near the entrance to the port that the *P. oceanica* meadow is located (Fig. 61); **(vi)** the landing stages for the boats are all built on stilts, which facilitates the movement of water in the port.

7.2.4. Ospedaletti

The coast in front of Ospedaletti (Liguria, Imperia province, Italy) is characterized by the presence of a vast *Posidonia oceanica* meadow. Between the railway line and the sea, sizeable discharges, dating from about thirty years ago, have changed both the landscape above the sea and the seabed (Fig. 63 and 64). The *P. oceanica* meadow (Fig. 62) that used probably to be continuous along this coast, today shows signs of regression there, with in particular areas of "dead matte" that break it up and reduced width. Its length is 2.5 km and its surface area about 45 hectares.

This part of the coast was the subject of a project for a recreational port accompanied by various coastal facilities. Something may be said about this project and its implications for the marine environment.

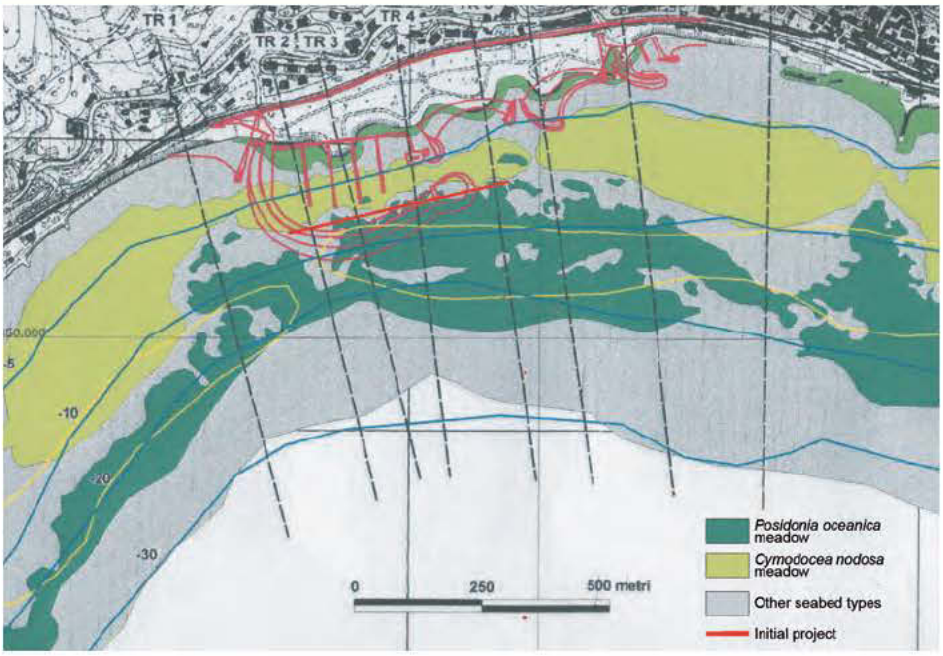


Fig. 62. Map of Ospedaletti's types of seabed and marine biocenoses (Imperia province, Liguria, Italy). In red, the initial project for the port facilities.

On one hand, a **priority habitat** (the *Posidonia oceanica* meadow) is present, a habitat for which a Site of Community Interest (SCI) has been defined. Thus any intervention that could have consequences for this site must be subjected to an impact assessment.

On the other hand, there is **local demand** for a port to be built, which would correct the area's lack of mooring places (berths) and provide jobs. Furthermore, the project would solve the problem of the big waste dump that over the past decades has had a very negative impact on the natural environment both above and below the sea surface.

Analysis of the available information enables the following considerations to be formulated. **(i)** There is in the area a *Posidonia oceanica* meadow whose vitality is good or acceptable; part of this meadow is included in the SCI. In front of this meadow, but rather at more shallow depth, the meadow is much more damaged and has partially disappeared. Finally, there is an area with practically no *P. oceanica* but which is occupied by *Cymodocea nodosa* (another Magnoliophyte), "dead matte" and sand. **(ii)** As required by the European Union's Habitats Directive, the area of the meadow in good or acceptable health should be protected as a priority habitat. For the more degraded parts, like those located at the upper limit, one can envisage carrying out recuperation work, after first making the dump safe and then building the port facilities.

Fig. 63. Cervo (Imperia province) facility for defence against erosion of the coast and the railway line (Settore Ecosistema Costiero archives – Liguria region).

The company which established the project has studied and mapped in detail the marine biocenoses and its conclusions agree with the map drawn by the Liguria region (Diviacco, 2000; Fig. 64). According to the regional regulations and indications (see §5.2.3), the original project – which would have caused the certain destruction of a fairly sizeable part of the meadow – has been modified to only affect the most superficial, fragmented parts of the meadow that are already degraded.

Also, as well as what was provided for by the VIA (*Valutazione di Impatto Ambiantale*: impact assessment) regulation, the Liguria Region considers that it is necessary, if the project is accepted, to comply with a certain number of prescriptions intended to minimize the possible damage these coastal facilities could have on the marine environment, for example: **(i)** using materials that reduce to the utmost the re-suspension of fine particles that is likely to make the surrounding water turbid, **(ii)** using building techniques that restrict re-suspension of fine particles (turbidity), **(iii)** paying special attention to how materials are moved about on the seabed, **(iv)** monitoring the health of the surrounding meadows both during and after the work, and **(v)** undertaking restoration work, payable by the Project Manager, by replanting *Posidonia oceanica* in the surrounding areas (including areas where the plant was already scattered for other reasons than the building work).

Fig. 64. Cervo (Imperia province) building a coastal defence facility (Settore Ecosistema Costiero archives – Liguria region).

7.2.5. Spotorno

The coast at the limit of the Noli and Spotorno districts (Savona province, Liguria, Italy) was also selected for a project to build a recreational port although the area is occupied by a *Posidonia oceanica* meadow. As in Ospidaletti (see §7.2.4), the project anticipates rehabilitating the whole coastal area, now characterized by rip-rap defence work for the national highway and 2 big waste dumps, which profoundly modified the area both above and below sea level before the publication of the European Union's Habitats Directive (Fig. 65, 66 and 67). As a result, the *P. oceanica* meadow suffered marked damage and regressed over the past decades. The damage was all the worse in that the meadow used to reach the coast, where it constituted fringing reef formations (see §2.4) (Fig. 68) (Bianchi and Peirano, 1995).
The requirements of the European Union's Habitats Directive and the targeting of a SCI for the *Posidonia oceanica* meadow in question make an assessment of this habitat necessary, in order to see whether the project is compatible or needs to be modified to protect the meadow.

Fig. 65. Borghetto Santo Spirito (Savona province) Building a coastal defence facility (Settore Ecosistema Costiero archives – Liguria region).

Fig. 66. Laigueglia (Savona province) A facility to defend the coast against erosion (Settore Ecosistema Costiero archives – Liguria region).

Fig. 67. Varazze (Savona province) Enlarging the recreational port (Settore Opere Marittime ed Ecosistema Costiero archives).

Fig. 68. 1973 aerial photo of the coast between Noli and Spotorno (Liguria, Italy). In yellow, the coastline in 1954, in red the coastline in 1973. From the aero-photogrammetric archives of the Liguria region. Crafted on Mapinfo Professional®. From Maggioncalda (2002).

The company that carried out the project made a study of the marine biocenoses that tallies fairly well with the data from the Liguria Region services (Fig. 69; Diviacco, 2000). The building would cause the destruction of 4 hectares of meadow, part of which is regressing and about 0.5 hectares in an acceptable state of vitality. According to the criteria adopted by the Liguria Region (see §5.2.3), the authors of the project modified it to minimize the surface area of *Posidonia oceanica* destroyed and planned a replanting operation under strict scientific control (see §14.4) as a compensatory step.

7.3. RECOMMENDATIONS

7.3.1. Can a meadow remain in good health in a port?

Generally speaking, the *Posidonia oceanica* meadow cannot be found in ports, either because it has been destroyed, or because it has never existed there. But there are some ports where the meadow has survived: Banyuls, Le Brusc and Porquerolles. These are relatively recent ports (less than 50 years old) and nothing guarantees that the meadow's persistence will continue in the longer term. Moreover, these ports have some unusual features: wide openings onto the sea, strong hydrodynamism, and little visiting by leisure boat/campers[70]. The movement of the water is not, however, a guarantee of the meadow's survival. In the bay of Port-Cros (Var, France), which is very widely open to hydrodynamism, since there is no outside sea wall, and where the port has functioned for several centuries, the *P. oceanica* meadow has disappeared from the area where there are landing stages for boats to moor (Augier and Boudouresque, 1970a; Belsher *et al.*, 2005).

As regards the few ports where the meadow has survived, we lack the data on the rate of renewal of the water or on average turbidity that would allow us to define the hydrological conditions that are compatible with the meadow's survival.

70 Leisure boat/campers Leisure boaters who live on their boats and thus use the port as a floating camping site.

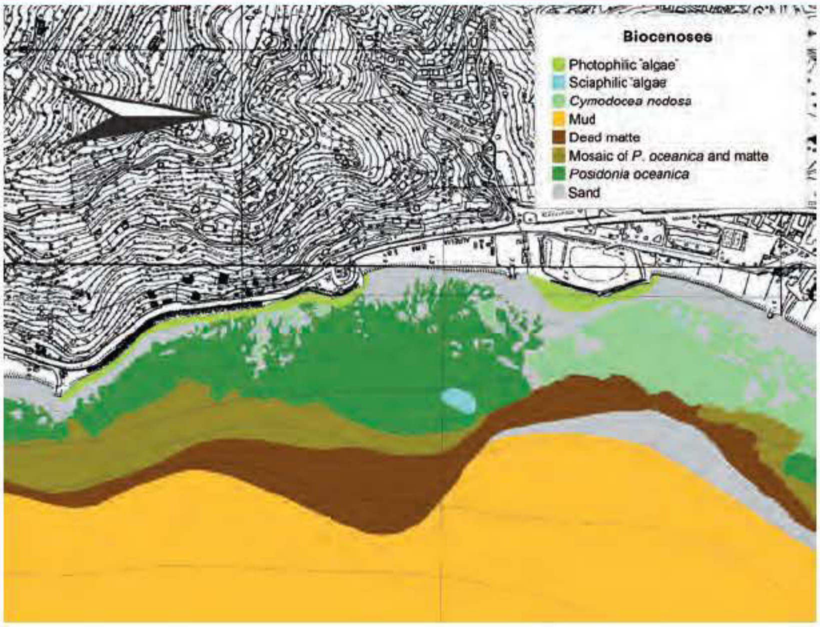


Fig. 69. Map of types of seabed and of marine settlements between Noli and Spotorno (Liguria, Italy). From Diviacco (2000).

In the present state of knowledge, the meadow's survival in some ports must not, therefore, hide the general trend: a meadow included in a port is very probably **doomed to disappear** in the short, medium or long term. Thus it is vital to avoid including *Posidonia oceanica* meadows in a port basin. Moreover, building a port sometimes brings about the disappearance of the meadow, replaced by the port, with the meadow sometimes being cut in two on either side of the port (**fragmentation** of the habitat), as can be seen in Pointe-Rouge (Marseille, France) and Saint-Tropez (Var, France).

7.3.2. Minimum distance between artificial rip-rap and the meadow

There are a certain number of examples of artificial rip-rap (ports, breakwaters, areas reclaimed from the sea) which are in direct contact with the *Posidonia oceanica* meadow. This is so for example in Galeria (Corsica), around the Sporting d'été in Monaco, in front of the nautical club of Le Mourillon (Toulon, France) (Fig. 70), in La Madrague de Giens and Le Brusc (Six-Fours, Var, France) (Charbonnel *et al.*, 1996; Verlaque and Bernard, 1997; Bernard *et al.*, 2002; Charbonnel *et al.*, 2002).

However, in most cases there is a "dead matte" area between the rip-rap and the first living *Posidonia oceanica*. This is so, for example, off the port of Saint-Tropez, Aygade port in Hyères (Var, France), and in Pointe-Rouge port (Marseille, Bouches-du-Rhône, France) (Francour *et al.*, 1995; Francour and Marchadour, 1989; Charbonnel *et al.*, 1997b). The absence of data on the meadow's original state, before and immediately after the building of this rip-rap, makes it impossible to determine with certainty the possible responsibility of this rip-rap.

We think it improbable that rip-rap is the **direct** cause of the presence of a strip of "dead matte", several dozen metres to over 100 metres wide, between its base and the living meadow. The existence of meadows in good health directly in contact with rip-rap, as is the case in La Madrague de Giens (Charbonnel *et al.*, 2002), rather argues to the contrary. It is, however, probable that when rip-rap is exposed to intense hydrodynamism this can erode the meadow.

[71] Dumping discharge of solid matter into the sea.

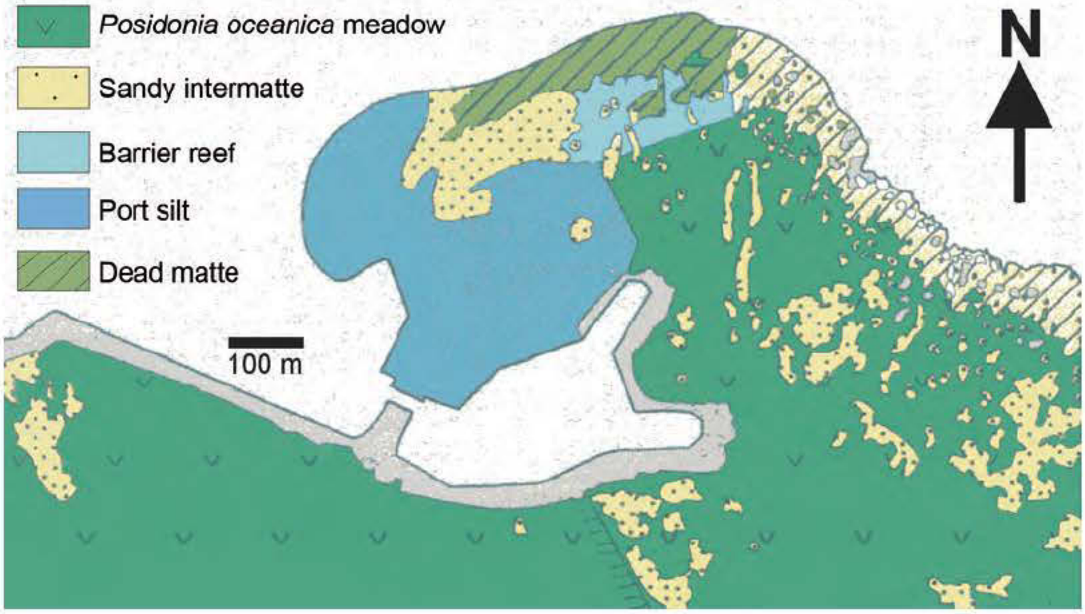


Fig. 70. Map of types of seabed and of the *Posidonia oceanica* meadow in Le Mourillon nautical club (4th port cove in Toulon, Var, France). Rip-rap appears in grey. From Charbonnel *et al.* (1996).

In fact, the link between rip-rap and the meadow's regression is often **indirect**. Among the more probable indirect causes are: **(i)** pollution and suspended matter (turbidity) which spread around a port; **(ii)** discharge of mud from dredging the port basin at the exit to the port, or too near the exit; dumping[71] areas, defined by the competent authorities, are in fact almost never respected by the companies that have obtained the contract, sometimes thanks to an unrealistic minimizing of costs that should have alerted people to the *de facto* non-respecting of dumping constraints; it is, unfortunately, rare that non-respect for dumping areas is denounced and even more rare that it is punished; **(iii)** the turbidity generated when the facility is built, when fine materials have been dumped in the sea. This was the case for Le Mourillon (Toulon) and Pointe-Rouge (Marseille, France) (Astier *et al.*, 1980; Gravez *et al.*, 1992, 1995, 1997); **(iv)** the action of site equipment (barges) when building the facility (see §7.3.3); and **(v)** the modification of the hydrodynamism, in particular coastal currents, brought about by the facility.

Given everything that has been said above, the difficulty of predicting the impact of rip-rap on the meadow, and the precautionary principle, we recommend a minimum distance of **10 metres** between the new rip-rap and the nearest living Posidonia.

7.3.3. Necessary precautions for a building site

A significant part of the impact affecting the *Posidonia oceanica* meadow after coastal development is linked to construction techniques. To minimize this impact, companies that have been the beneficiaries of a tender should be subjected to a certain number of constraints, and a company should not be systematically chosen because it is the **lowest bidder** but because it is the **best bidder** (the company that is most credible as regards respect for the quality and environment protection regulations, even if it is more expensive, precisely for this reason).

When reclaiming land from the sea, dumping fine material (diameter less than 1mm), or blocks mixed with fine material, at sea must be absolutely ruled out. When laying down rip-rap, the blocks of rock should be rinsed beforehand. Despite these precautions, washing the blocks and re-suspending the sediment that is there generates **turbidity**. Protective **geotextile** screens

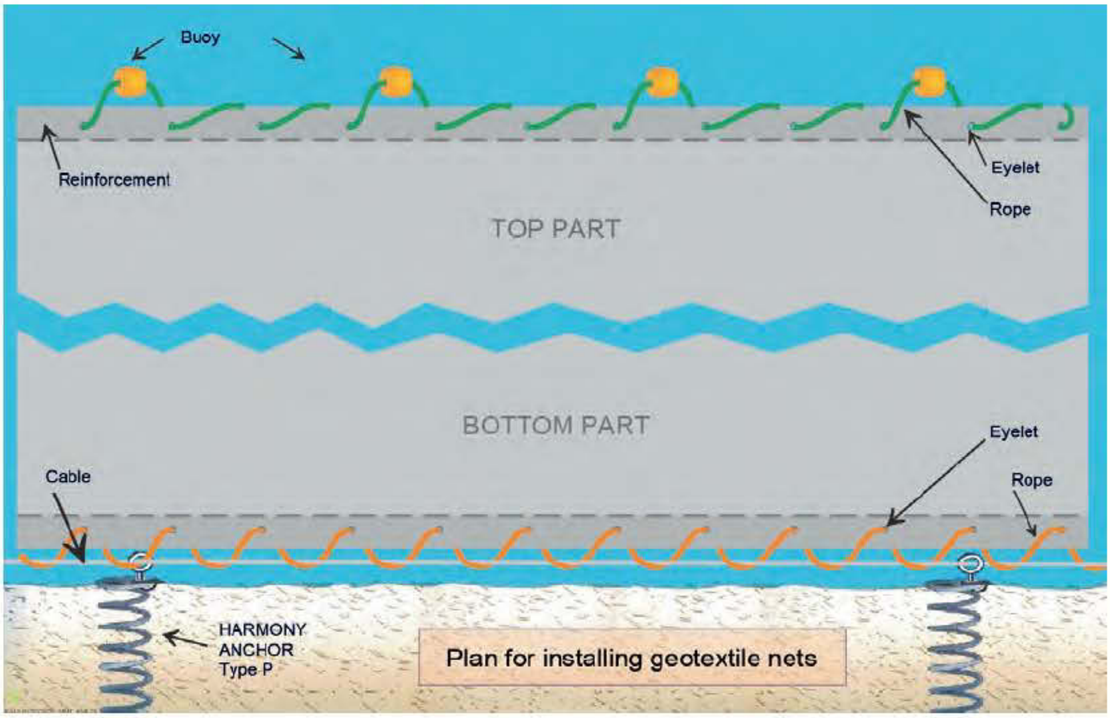


Fig. 71. A geotextile screen designed to restrict the spreading of turbidity from an underwater building site. It is fixed to the seabed in a non-destructive manner, Harmony® –type, anchors.

(Porcher, 1987) must be set up around the building site to minimize the turbidity caused (Fig. 71). The same holds good when rocks have to be cleared away (Fig. 72). Exemplary precautions were taken to this end by the French Navy in the Canier building site (Saint-Mandrier peninsula near Toulon, France) (Fig. 73) (Bonhomme *et al.*, 2001; Bonhomme *et al.*, 2003c; Spina, 2003).


Fig. 72. . A barge and rock-clearing equipment during the digging of an access channel to a port in the Var (France). The turbidity of the water caused by the work is obvious. Photo by P. Bonhomme.

The site equipment is usually fixed to the seabed for reasons of stability, directly and/or with anchors, which has a very negative effect on the seabed – making holes (base of equipment) or furrows (chains of anchors) in the *Posidonia oceanica* meadow (Fig. 74 and 75). Use of equipment must therefore be avoided as far as possible, and **use of equipment located on dry land** must be encouraged, especially for laying down rip-rap.

Finally, the season when the work is carried out must take *Posidonia oceanica*'s biology into account. **The summer**, a time when the plant is reconstituting its reserves (stored in the rhizomes) for the following year (Alcoverro *et al.*, 2001) must absolutely be avoided.

Fig. 73. A geotextile screen (left) protecting a *Posidonia oceanica* meadow (right) during underwater work on the Canier site (Var, France). Photo by E. Charbonnel.


Fig. 74. Print left by the support structure of a platform for underwater work on a dead *Posidonia oceanica* "matte". Photo by E. Charbonnel.

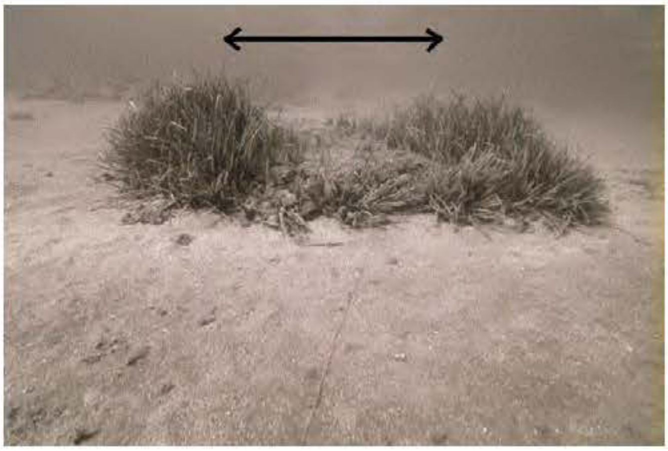


Fig. 75. Central part (arrow) of a *Posidonia oceanica* clump eroded by the anchor chain of an underwater work barge. Photo by E. Charbonnel.

These constraints should systematically appear in the contract specifications. Moreover, the Contracting Authorities should carry out efficient on-site checks to make sure they are effectively implemented.

7.3.4. Less "harmful" solutions

There are technical solutions that in certain cases mitigate the impact of coastal development. Sea walls and piers must be as "open" as possible, i.e. must close off the man-made lake as little as possible. Piers **built on stilts** should be given preference over rip-rap walls, which have a strong grip on the seabed and hinder the movement of the water.

Furthermore, for any development accompanying steps should be taken: preventing mooring (anchoring and unauthorized mooring; see §4.5 for definitions) around the work, monitoring the evolution of *Posidonia oceanica* meadows (see Chapter 15), eliminating macrowaste, etc.

8. THE *POSIDONIA OCEANICA* MEADOW AND MOORING

8.1. THE PROBLEM

Posidonia oceanica meadows are threatened by the mechanical action of anchors of leisure boats (Fig. 76) and bigger ships (warships, cargo boats or cruise ships) when they moor outside ports (Fig. 77). Even though *P. oceanica* can recolonize patches that have been degraded by anchors (at least, small patches) thanks to growth and the natural ramification of the rhizomes, their rate of growth is very slow, at most some centimetres per year. Beyond a certain density and frequency of mooring, rhizome growth can no longer recolonize the openings and strips made in the "matte", and the meadow gradually deteriorates: shoot density drops, as does cover[72] (Boudouresque and Meinesz, 1982; Francour *et al.*, 1997, 1999).

Fig. 76. Mooring between the Lérins Islands (Sainte-Marguerite and Saint-Honorat Islands, Alpes-Maritimes, France). In this photo, taken on 19 August 1996, one can count 415 boats in all. Anonymous photo.

The most beautiful and famous shores of the Mediterranean are particularly attractive to leisure boaters. It is the very great concentration of mooring[73] in sheltered, aesthetic sites, that is a problem for some kinds of seabed, like the *Posidonia oceanica* meadow. Now this meadow constitutes a kind of seabed much sought after for mooring – not only is the anchor held strongly by the network of rhizomes, but there is no danger of its catching on rocks and it is thus easy to raise. When a boat is mooring, its anchor slips over the meadow, possibly furrowing it, and then catches hold between the rhizomes (see Fig. 43). During the mooring, the anchor's chain crushes the leaves. The chain moves with the wind and current (sliding over the seabed) and can draw a circle whose radius is the chain's length, crushing and pulling out a large number of leaves.

Finally, when the anchor is raised, the rhizomes to which it was attached are broken off (Boudouresque *et al.*, 1995a; Milazzo *et al.*, 2002). In some cases, when there are erosion scarps[74], whole blocks of "matte" with a number of living shoots, living and dead rhizomes and interstitial sediment are pulled out (see §4.5).

Of course, the damage varies according to the size of the anchor and of the chain (see below), the weather conditions (greater when there is a strong wind than when the sea is calm), and how the anchor is weighed (greater when the boat pulls on its anchor than when it is positioned above it and weighs it vertically). The extent of the damage caused to a *Posidonia oceanica*

72 In a meadow, the density is the average number of shoots per square metre; cover is the percentage of surface area of seabed covered by living meadow (of whatever density) and not by "dead matte" or intermatte.

73 Under the term "mooring" we include anchoring (mooring strictly speaking, using an anchor), organised mooring (when boats moor to deadweights mooring that are legally provided within the context of a Temporary Occupation Permit) and unauthorized mooring (when boats moor at illegally placed deadweights mooring (see §4.5).

74 Erosion scarp a mini-cliff inside or on the limit of a meadow.

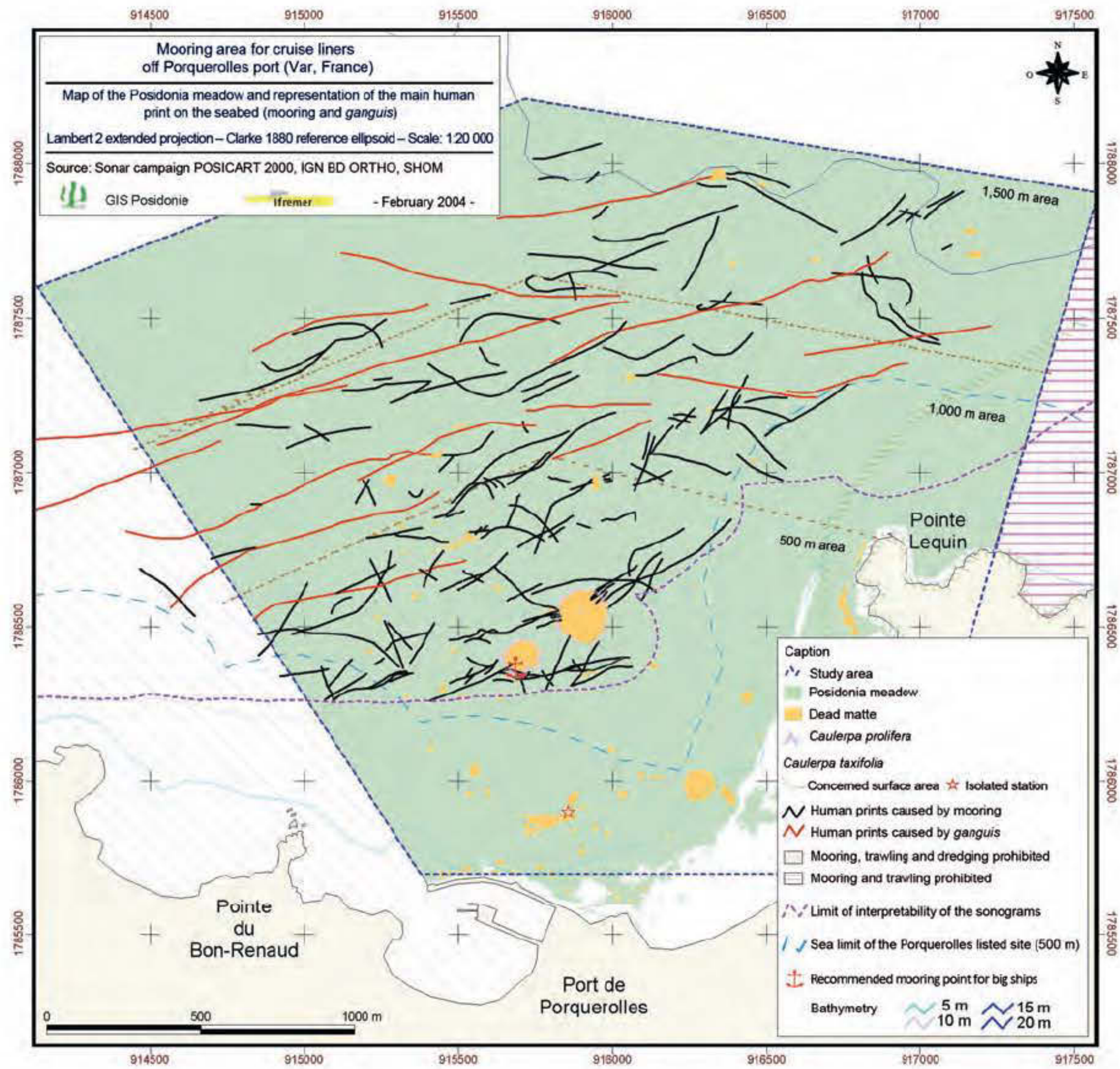


Fig. 77. Marks in the *Posidonia oceanica* meadow in front of Porquerolles port (Var, France) caused by the anchoring of cruise ships (black lines). Tracks of *ganguis* (small trawls) can also be seen (red lines). From Ganteaume *et al.* (2004).

meadow by anchors also depends on the frequency of anchoring, the size of the ship, the type of anchor and the nature of the "matte" (compact or loose) (Francour *et al.*, 1997, 1999; Milazzo *et al.*, 2004; Ganteaume *et al.*, 2005).

The mechanical damage done to the *Posidonia oceanica* meadow by leisure boat mooring has been the subject of some studies done in France (Porcher and Jeudy de Grissac, 1985; Boudouresque *et al.*, 1995a; Francour *et al.*, 1997, 1999; Ganteaume *et al.*, 2005) and in Italy (Milazzo *et al.*, 2002, 2004) and constitutes a major worry as to its protection (Doumenge, 1992). One should add to this the anchoring or mooring of big ships, particularly cruise liners and warships (Fig. 77; Roy *et al.*, 1999; Ganteaume *et al.*, 2004, 2005).

In many touristic sites, especially in Marine Protected Areas, to avoid the disadvantages of leisure boats' anchoring, fixed moorings constituted by deadweight moorings and surface mooring buoys (organised mooring) have been provided. But indeed the effects of this kind of mooring on the *Posidonia oceanica* meadow may be even worse than those of anchors (Robert, 1983). Concrete deadweight moorings, though heavy, can move around, eating into the "matte" and eroding it. The chains that link the deadweight moorings to each other and to the surface buoys dig furrows into the "matte" and destroy the *P. oceanica* growing around the deadweight mooring (Fig. 78).

Fig. 78. Furrow dug in a Posidonia meadow by the chain of an organised mooring. Anonymous photo.

For bigger ships, for example ships of the French Navy in Hyères Gulf (Var), moorings made of a sea surface steel buoy linked to chains (on the seabed) terminating in fixed anchors each weighing several tons have been put down. The impact of such mooring systems on the *Posidonia oceanica* meadow is considerable (Roy *et al.*, 1999).

A particular problem is leisure boats' permanently mooring in sheltered places and laying "personal deadweight mooring" without a TOP (Temporary Occupation Permit delivered, in France, by the *Direction Départementale de l'Equipement*) and thus completely illegally (unauthorized mooring). The impact may be direct, if the deadweight mooring is located over a *Posidonia oceanica* meadow, or indirect, when they have to cross a *P. oceanica* barrier reef (eroding it on the way) to reach their mooring. This last case is illustrated by the many (about a hundred) boats that come into the Brusc lagoon (Six-Fours, Var, France).

Finally, we should not forget that a boat at anchor can constitute a source of pollution: discharge of waste water and solid waste. In Elbu Cove (Scandola, Corsica), over a surface area of 1.3 hectares used by leisure boats for anchoring in July and August, the mass of macrowaste has been assessed at 54 kg (mainly glass), while being almost zero in a neighbouring cove, Petraghja, very little visited by boats (Bianconi *et al.*, 1990).

8.2. CASE STUDIES

The areas most concerned by the problem of mooring, in the RAMOGE area, are, in Italy (Liguria), the Portofino Peninsula, the island of Bergeggi, the island of Gallinara and Capo Mortola and, for France (PACA region), the Villefranche Bay, the Lérins Islands (Alpes-Maritimes), Port-Cros Island and Porquerolles Island (Var) and the Calanques massif (between Marseille and Cassis, Bouches-du-Rhône). Many much visited moorings lie outside the RAMOGE area, for example the Gulf of Ghjirulata (Corsica).

8.2.1. The Italian coast under the RAMOGE Agreement

The seabed of the **Portofino** Marine Protected Area, whose historical and ecological importance is extremely great, is a "must" for divers from all over Italy and various European countries. *Posidonia oceanica* is present there in 2 large, densely covered areas, surrounded by sparser, smaller meadows. The 2 main meadows lie west (between Camogli and Punta Chiappa) and east (between Paraggi and Santa Margherita) of the Portofino Peninsula, and are the 2 sectors most used by leisure boaters for mooring. In the 2 sectors, respectively about 1 000 and 500 metres long and about 100 metres wide, hundreds of boats of every size, from 3 metres to over 20 metres long, moor, especially in summer and at weekends. Since the Marine Protected Area was set up in 1998, there are rules for activities that provide for the defining of anchoring areas and regulated mooring areas. But for the time being, anchoring is permitted in the sectors that contain *P. oceanica* meadows.

A similar situation is found around the **Bergeggi** (not far from Savona) and **Gallinara** (off Albenga) islets. The seabed facing the land (north/north-west) there is still occupied by *Posidonia oceanica* meadows, although over the past few decades these meadows have regressed, particularly because of trawling, anchoring, coastal development and land reclamation. In the summer they are invaded by boats trying to find mooring sites, which can be over the *P. oceanica* meadows. Anchoring, added to other causes of regression, worsens their effects.

Regarding Gallinara Island, Balduzzi *et al.* (1994) have calculated that within a radius of 56 km around the islet there are about 4 000 places in the ports, and that it is one of the leisure boaters' favourite spots. When we consider that the seabed concerned by mooring is no greater than 10 000 m^2, and that the same boats visit and revisit the site, we can imagine their impact on the seabed, especially on the *Posidonia oceanica* meadow. Late summer diving has enabled the harm done to the benthic habitats to be verified and the many abandoned anchors observed.

8.2.2. The French coast under the RAMOGE Agreement

From the early 1970s, the *Posidonia oceanica* meadows' regression has been remarked in Port-Cros Bay (Var, France) and attributed to **(i)** the anchoring of leisure boats and **(ii)** the movement of boats over very shallow meadows, on which they not infrequently run aground, ploughing furrows in the meadow (Fig. 79; Augier and Boudouresque, 1970a; Boudouresque *et al.*, 1975, 1980a). The passage of boats has therefore been prohibited in the shallow areas of the bay (especially the barrier reef area), using a rope and a line of buoys. Furthermore, mooring was organised by sinking deadweight moorings linked by a parent chain; secondary chains, on which the mooring buoys were fixed, branched off from the parent chain (Robert, 1983). When the mooring buoys were all occupied, anchoring remained possible.

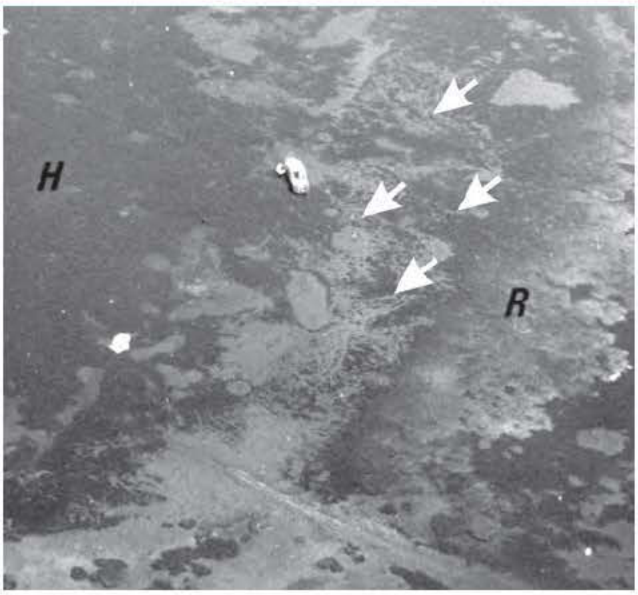


Fig. 79. Aerial photo of the bay of Port-Cros (Var, France). The deep *Posidonia oceanica* meadow (H) appears in dark grey and the barrier reef in grey (R). Between the deep meadow and the barrier reef, the light grey areas represent dead matte. The lines (arrows) show the erosion of the superficial meadow by boats that have run aground there. Anonymous photo.

During the summer of 1982, observation of the *Posidonia oceanica* meadow lying in the organised mooring area revealed that, added to the action of the anchors, the deadweight moorings and chains were a new cause of the meadow's degradation, and that this was more serious than the original deterioration (Robert, 1983). The parent chains would move sideways, pulled by the secondary chains, under pressure from the boats driven by wind and currents. The result was the digging of a channel whose width varied between 1 metre (near the deadweight moorings) and 6 metres (where the secondary chains joined the parent chain); it was estimated that 1 000 m^2 of meadow (1% of the bay's surface area) had been thus destroyed by chains sunk for mooring (Fig. 80; Robert, 1983).

Given that the deadweight moorings and the chains were sunk precisely to protect the *Posidonia oceanica* meadow, the cure seemed worse than the disease. And directly attaching the secondary chains to the deadweight moorings would not have solved the problem: as well as reducing the elasticity of the mooring, the first part of the chains would have remained in contact with the seabed, destroying the meadow around the deadweight moorings. Among possible solutions, Robert (1983) suggested **(i)** for deep areas (>6 m), fixing the secondary chain to the deadweight mooring and placing an intermediate buoy on the secondary chain so that it would not be in contact with the seabed; and **(ii)** for shallower areas, providing floating pontoons in a daisy shape linked to a single big deadweight mooring submerged in an area of "dead matte".

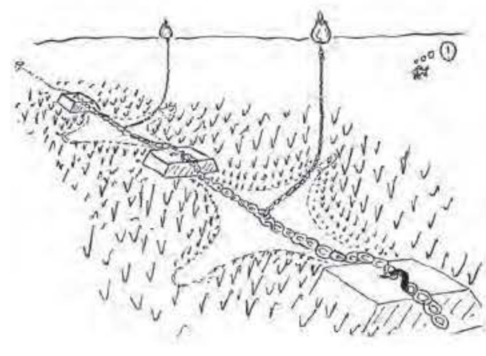


Fig. 80. Impact on the *P. oceanica* meadow of the organised mooring system used in Port-Cros Bay (Var, France) deadweight moorings, parent chains and secondary chains terminating in mooring buoys. From Robert (1983).

Then a technical solution to the problem of mooring in *Posidonia oceanica* meadows, Harmony® mooring, was developed by a French company (SMAT Neptune Environnement) and experimented in collaboration with the Port-Cros National Park (Fig. 81). After conclusive trials, the deadweight moorings and chains were removed from Port-Cros Bay and replaced by a set of Harmony-type moorings, that would not harm the meadow.

The Harmony® system has the following characteristics (Smat Neptune Environnement, 2000):

- simple, resistant and reliable anchoring
- negligible environmental impact
- no contact of the mooring line with the seabed
- anchoring point is almost level with the soil and is not an obstacle for fishing gear
- adapts to all kinds of seabed, including *Posidonia oceanica* meadows
- easy to install and remove

The Harmony system consists of a steel helical spring that screws into the "matte" without harming the surrounding meadow, particularly the rhizomes (Fig. 71). Outside the "matte" only the tip of the helicoid, bearing the fastening ring for mooring, less than 10 cm in diameter (Fig. 81), protrudes. The mooring cable that rises from the fastening ring is kept at a certain distance above the seabed by a small intermediate buoy, itself linked to the mooring buoy on the sea surface (Fig. 82).

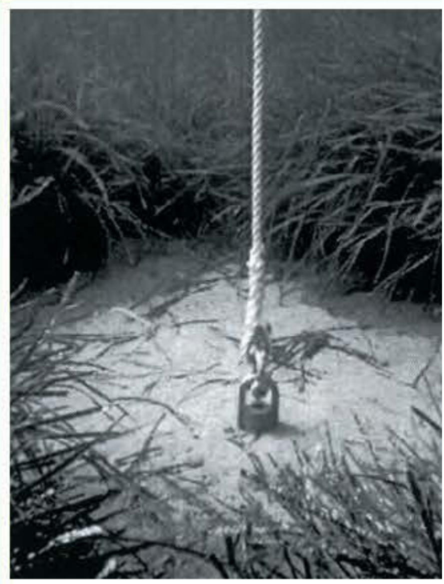


Fig. 81. The fastening ring of a Harmony-type mooring, with the first part of the mooring cable, in a *Posidonia oceanica* meadow. From Smat Neptune Environnement (2000).

The length of the mooring cable is determined so that a traction angle of 45° is obtained, allowing the boat to move on the surface in a radius equal to the depth, whereas in traditional mooring using deep buoys the mooring cables are three times as long as the depth. This method of mooring thus not only permits the *Posidonia oceanica* meadow to be kept from harm but also enables more boats to be accepted for an equal surface area.

The helicoids are designed to bear all the traction forces produced by leisure boats, even large ones. Calculations done by the company which produces Harmony® mooring take winds of 120 km/hour into account. Resistance tests have shown that a mooring of this kind in a *Posidonia oceanica* meadow

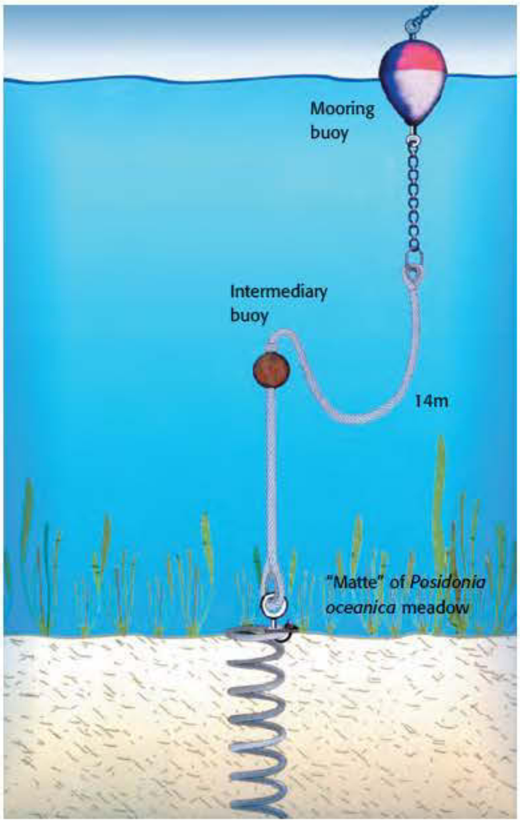


Fig. 82. A Harmony-type mooring system, in a *Posidonia oceanica* meadow, 10 metres depth. The boats have 10 metres surface radius room to swing. From Smat Neptune Environnement (2000) redrawn.

can bear a force of 21kN, i.e. 2.14t, equal to that borne by a concrete deadweight mooring weighing 4 t and with 1.9 metre sides. To give an example, a 16 metre long 4.5 metre-wide yacht, with a headwind of 120 km/hour, generates a horizontal force of 14 kN, or 1.43 t.

The Harmony® system, and those of the same type developed by other enterprises, do not require a large staff or particularly sophisticated equipment to be installed or removed: 2 underwater divers and hydraulic equipment are sufficient.

In Port-Cros Bay, as well as organised moorings, anchoring is permitted; the density of boats at anchor can reach 7.5/hectare at the height of the touristic season (Ganteaume *et al.*, 2005). Outside Port-Cros Bay, anchoring in the water of the Port-Cros National Park is permitted, except on the northern coast of Port-Cros Island and in a sector of the south-eastern coast of Bagaud Island (Fig. 84). A comparison between this sector, where anchoring has been prohibited since 1993, and a neighbouring sector where anchoring is permitted, though moderate (density of boats: 2.5/hectare at most) does not reveal significant differences in the state of the *Posidonia oceanica* meadow (shoot density, cover, % of plagiotropic shoots) (Ganteaume *et al.*, 2005). This confirms that the meadow can tolerate the anchoring of little leisure boats when this is very moderate.

8.2.3. Areas outside the RAMOGE Agreement

Milazzo *et al.* (2002, 2004) have studied the impact of leisure boating on the *Posidonia oceanica* meadow in the island of Ustica (north of Sicily, Italy). They did an experimental comparison of the effect of mooring with various kinds of anchor. A preliminary survey in Ustica port showed that the anchors most used by small boats (<5.5 metres) are anchors of the Hall, Danforth and Ombrello (=Folding Grapnel) kind (Fig. 83; also see Fig. 41), weighing about 4 kg. The experiments thus dealt with these 3 models.

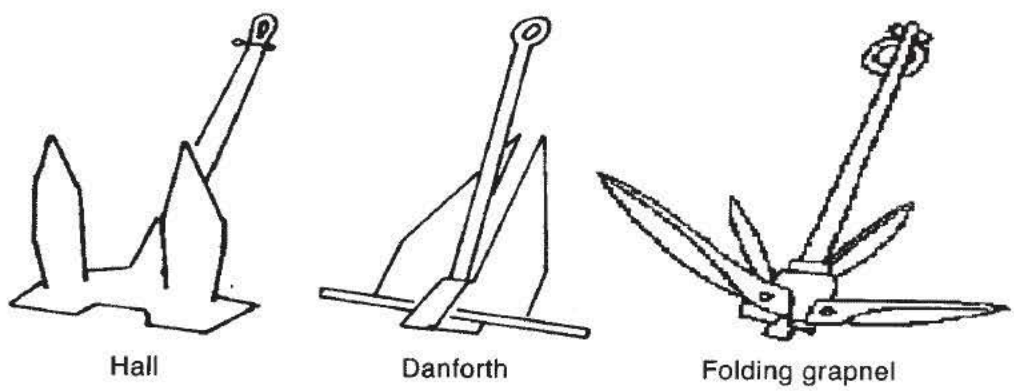


Fig. 83. Hall, Danforth and Ombrello (=Folding Grapnel) type anchors. From Milazzo *et al.* (2004).

The anchors were dropped from a 4.5-metre-long rubber dinghy and raised after staying 10 minutes at the bottom on a meadow between at 8 and 12 metres depth (shoot density: 500-530 shoots/m^2). The impact on the seabed was observed by divers who counted the broken shoots after the anchoring phase and that of raising the anchor (Milazzo *et al.*, 2002, 2004).

The average number of shoots broken during the anchoring phase (dropping the anchor) was between 0.47 (Danforth anchor) and 0.93 (Hall anchor). During the mooring phase (stay) the only anchor that caused harm (and this was modest) was the Ombrello (0.07 broken shoots). During the anchor raising phase, the values were between 0.67 (Hall) and 4.87 (Ombrello) ([75]). The presence or absence of a chain did not significantly change the impact. The impact for the 3 phases of mooring was compared for each kind of anchor (Milazzo *et al.*, 2002, 2004):

Hall:	anchoring =raising >stay
Danforth:	raising >anchoring >stay
Ombrello:	raising >anchoring >stay

Similarly, the impact of the 3 kinds of anchor was compared for each phase of the mooring:

Anchoring:	Hall >Danforth =Ombrello
Raising:	Ombrello >Danforth >Hall
Stay:	Ombrello >Danforth =Hall[76]

In all, Danforth and Ombrello anchors cause greater damage than Hall anchors. Milazzo *et al.* (2002) therefore suggest that, as a possible tool for protecting *Posidonia oceanica*, only boats with low-impact anchors be permitted to moor over a *P. oceanica* meadow.

These reports show that the anchor model can be improved to mitigate the harm done to the meadow. Among the initiatives taken to this end, we can mention the development of an anchor with a pivot system that functions during raise and thus limits the tearing of the meadow (Fig. 84).

8.3. RECOMMENDATIONS

Tourism and leisure boating have a major social and economic role in the Mediterranean. Even if anchoring harms the *Posidonia oceanica* meadow, the impact is certainly not significant for most of the meadows: the density and frequency of leisure boat moorings there is outdone by their regeneration capacity (ramification of rhizomes replacing broken rhizomes; Molenaar, 2000). There is thus no question of forbidding mooring there, which would anyway be unrealistic. However, practices that mitigate the impact should be recommended to leisure boaters: **(i)** avoid, whenever the choice is possible, anchoring over a *P. oceanica meadow*; **(ii)** do not raise the anchor by hauling on it but first position the boat vertically above the anchor and then raise it.

75 In Elbu Cove (Corsica), Boudouresque *et al.* (1995) measured a much higher total number of shoots torn out per mooring cycle (anchoring + stay + raise of anchor) 17 on average.

76 The authors believe that for the mooring stay the values were negligible and the differences not significant. But we do note that the duration of the stay considered was only 10 minutes, which is tiny compared to the real duration of a stay over a mooring – usually 10 to 100 times longer.

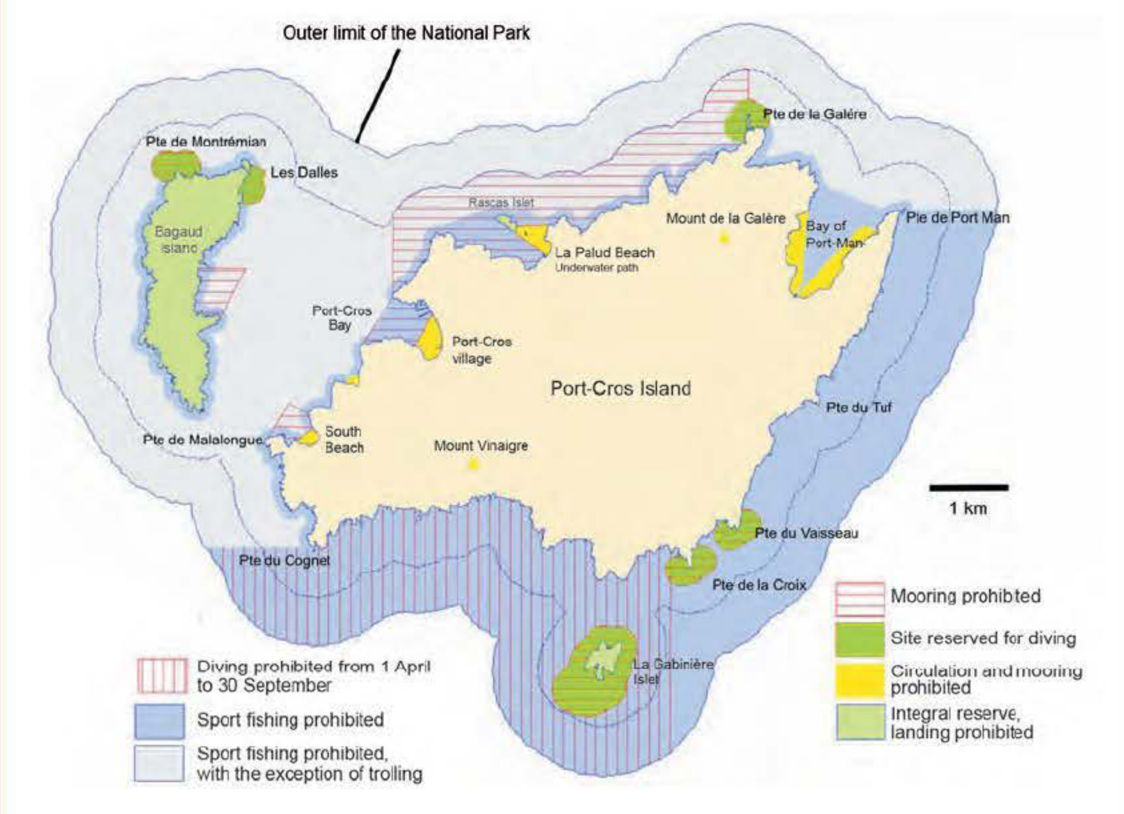


Fig. 84. Regulating activities (especially mooring) in the Port-Cros National Park (Var, France). From the Port-Cros National Park.

The problem arises at the level of certain areas, often of limited extent, that are particularly appreciated by leisure boaters because of their beauty (landscape) and the shelter they provide. When the density and frequency of anchoring is considerable, during much of the year, management measures become necessary. When the amount of leisure boat mooring is more on average than 2 anchorings/hectare/day (annual average) or more than 10 boats/hectare (at peak period) we recommend that organised mooring be established. However, organised mooring should never be done over deadweight moorings (whose negative impact is much greater than that of anchors) but should call for a non-destructive system[77].

Unauthorized mooring (installation of deadweight moorings without permits) has as negative an impact as mooring organised over deadweight moorings. It is shocking that this illegal practice should sometimes be tolerated by the authorities concerned.

In Marine Protected Areas, as in all areas where the *Posidonia oceanica* meadow presents good vitality and great heritage value (e.g. in Natura 2000 sites and ZNIEFFs[78]), we recommend regulating mooring. This can be achieved through a fallow period system (alternately banning and permitting over 5-year periods) in some sectors, through a permanent ban in other sectors, and lastly through organised mooring based on a non-destructive system, as is the case in Port-Cros (Var, France; Fig. 84) (Boudouresque *et al.*, 2004). Such regulation of mooring should be done as part of a management plan on a consistent scale, for example that of a bay or a coastal massif.

In sectors where there are *Posidonia oceanica* **barrier reefs**, mooring should be prohibited over the reef itself and in the lagoon lying behind the reef, at the same time as the passage of boats. For this ban to be respected, it is vital that in front of the reef

77 Several kinds of non-destructive mooring already exist in France (e.g. Harmony®, Ancrest®). Others will probably exist in the future.

78 ZNIEFF =natural areas of ecological, floristic and faunistic Interest

and the lagoon a line of buoys is placed, if possible joined to each other by a rope, as is the case in Port-Cros Bay (Port-Cros National Park, Var, France).

Finally, regarding the **mooring of big ships**, this should be restricted to areas with no *Posidonia oceanica* (loose sediment or "dead matte") and that are large (at least 100-200 metres in diameter). When a mooring buoy is provided on the surface, linked to a system of chains (3 or 4 branches each terminating in an anchor) all linked centrally by a metal plaque ("forking"), in addition to the above we recommend: **(i)** reducing to the minimum the impact of the pendant and the "forking"; for this, calculate the minimum length of the pendant that is needed for the buoy's elasticity; install a booster buoy at intermediate depth to prevent the pendant and "forking" from eroding the "matte"; **(ii)** reducing maintenance work (taking up the chains and anchors) and replacing these structures as exactly as possible where they were (Roy *et al.*, 1999).

9. THE *POSIDONIA OCEANICA* MEADOW AND THE MARKING OF THE 300 m STRIP

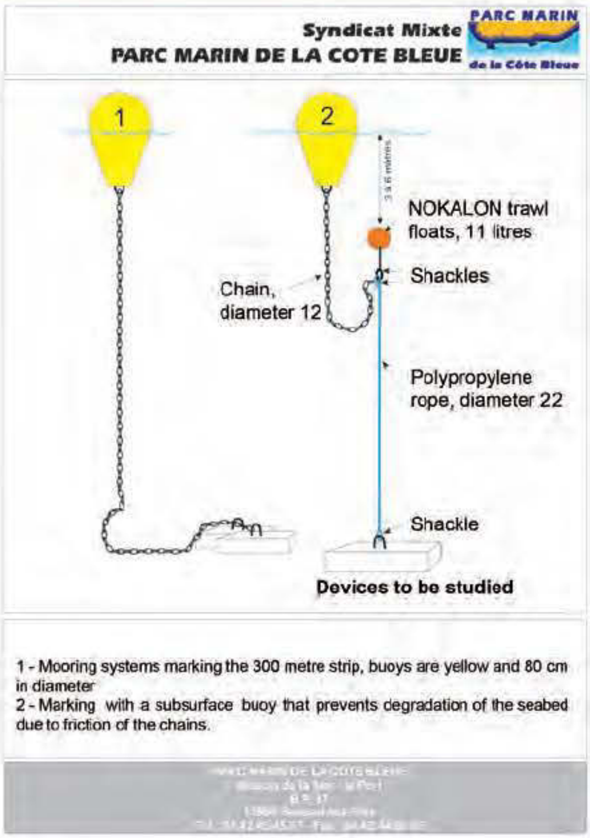


Fig. 85. Outline of principle of the traditional marker device for the 300 metre strip and the alternative device used by the Blue Coast Marine Park (Bouches-du-Rhône, France).

9.1. THE PROBLEM

Increasingly intensive use of the coast for tourism-related activities has in recent years brought about a sharp increase in the number of marker buoys delimiting summer bathing areas. These yellow buoys, placed in coves or along beaches, have a marked visual impact on the landscape and also a severe impact on the seabed, particularly on the *Posidonia oceanica* meadows.

In France, it is the local authority ("*commune*") that is responsible for placing buoys to delimit the bathing areas. Since the Order of 27 March 1991, the law makes the mayor responsible for managing certain nautical activities (bathing, the use of non-registered and non-motorized craft) within the 300 metre strip. The local authority is responsible for acting and informing the public about this. Installing marker buoys often represents a heavy cost for the local authority, and the systems adopted vary widely from one local authority to another.

To mark the 300 metre strip, the system generally used involves linking a yellow hemispherical buoy to a deadweight mooring block (Fig. 85 and 86) via a chain whose movement is cushioned on the seabed around the deadweight mooring block. It is the motion of this chain around the deadweight mooring block that causes most of the damage (Fig. 86) (also see §8.2.2).

Fig. 86. Example of the degradation of the *Posidonia oceanica* meadow caused by avoidance of the chain of a deadweight mooring used to mark the 300 metre strip. Photo by F. Bachet.

9.2. CASE STUDY: THE CÔTE BLEUE MARINE PARK

As a marine environmental management organisation, the Côte Bleue Marine Park has for several years taken an interest in the impact marking the 300 metre strip has on the seabed, in particular on the *Posidonia oceanica* meadow. Inspections carried out at the start and end of the summer season have shown that the motion of the chain around the deadweight mooring causes the degradation and **destruction of 5 to 10 m² of meadow** every season (for each deadweight mooring).

Once the deadweight moorings have been withdrawn, at the end of the season, all that remains is a facies of very damaged "matte" covered with sediment on the most affected zones and very bared *Posidonia oceanica* rhizomes on the limit. The problem is worsened by the fact that the following year the deadweight moorings **are not put in exactly the same places**, and thus a new hole is dug in the meadow. Once these holes have been opened up, various erosion phenomena can provoke or accentuate the splitting up of the meadow, particularly erosion by currents.

As a result of these first observations, the Marine Park wished to take on responsibility for installing the 300 metre buoys in the Carry-le-Rouet Reserve (a no-take area within the Côte Bleue Marine Park). The degradation noticed was indeed incompatible with the objectives of managing an integrally protected marine area. The Park decided to use an alternative mooring line consisting of a rope, a chain and a **submerged subsurface buoy** that would prevent the seabed from being degraded by dredging and the motion of the chain (Fig. 85 and 87). This system had already been successfully applied to the permanent buoys in the Carry-le-Rouet Reserve. The Park thus tested for 2 years the installing and removal of these buoys in the Reserve.

In early 2003, the Park decided to widen its approach to the scale of the Côte Bleue. Legal research showed that there is no obligation to mark the 300 metre strip when one is in a zone coming under a single set of general regulations as regards navigation. But for some sectors where there is a great deal of nautical and bathing activity, the local authorities find it hard to avoid marking this zone, given that the mayor is responsible for bathing and safety.

Fig. 87. The system of mooring of buoys marking the 300 metre strip used by the Côte Bleue Marine Park (Bouches-du-Rhône, France) the subsurface buoy which prevents erosion of the *Posidonia oceanica* meadow due to the motion of the chain. Photo by F. Bachet – Côte Bleue Marine Park.

In this context, a technical file concerning the use of the alternative mooring system, tested on the Carry-le-Rouet Reserve, was proposed to the local authorities (*communes*) of the Côte Bleue as a whole. All the *communes* proved very receptive to this problem, and ready to act. In summer 2003, the system advocated by the Marine Park was installed in front of each *commune*.

9.3. RECOMMENDATIONS

When the 300 metre zone marker buoys are positioned over a *Posidonia oceanica* meadow, it is recommended to use at least the alternative system, with subsurface buoy, perfected by the Côte Bleue Marine Park. This system is easy to implement, does not require specialist staff, and its cost is very close (+ 20%) to that of the traditional device (without subsurface buoy).

Other even more efficient systems can be envisaged, but the additional cost is greater. It is, for example, possible to use a sliding buoy on slack adjuster system, as in fish farming, and also fixed deadweight moorings (not removed at the end of each summer season), or to replace the deadweight moorings with screw anchorage (non-destructive Harmony® type anchorage, or similar systems). These systems, which require professional divers to install them, could be implemented in the Marine Protected Areas (MPAs) and in other sites of great heritage value.

In any case, in the medium term it is vital to **stop removing the deadweight moorings** at the end of the summer season; the present precision of the GPS systems, and anyway the incomparable precision of positioning by seamarks, enable deadweight mooring to be found again when the buoy has been removed.

10. THE *POSIDONIA OCEANICA* MEADOW AND TRAWLING

10.1. THE PROBLEM

Fishing with towed gear is very harmful to the seabed, especially for *Posidonia oceanica* meadows (see §4.6). In France, in theory, benthic and pelagic trawling is prohibited within the ca. 5 600 m (3 nautical miles) coastal strip and at less than 100 metres depth. In Spain and Italy, it is prohibited at less than 50 metres depth. In practice, however, it is widely practiced over shallow depths, which has negative consequences for the meadow (regression) and its ecological and economic functions.

Indeed, trawling causes (also see §4.6): **(i)** a disbalance in halieutic resources, for this non-selective fishing catches immature juveniles and harms the stocks of many non-target species; **(ii)** the degradation of habitats, spawning grounds and nurseries, particularly of exploited species. Trawling is thus the main cause of the regression of the *Posidonia oceanica* meadows in Spain, in the Alicante region (Guillén *et al.*, 1994; Bombace, 1995; Ramos-Esplá *et al.*, 2000). Moreover, the degradation of the topography of the seabed and the associated habitats leads to a reduction of spatial heterogeneity, an essential element of biodiversity (Kaiser, 1998).

Furthermore, there is a **user conflict** between trawlers, when they approach the coast and destroy spawning grounds and nurseries, and artisanal fishermen, who depend on the sustainable use of these spawning grounds, these nurseries and thus the resource.

Insofar as the authorities of the countries that border the Mediterranean have not the means, or the will, to make sure the law is respected, which goes against the interests of the artisanal fishermen, but also of the trawlers (although they are not always aware of this), the most realistic solution consists of placing physical obstacles in the way of trawling: **anti-trawl reefs** (Tocci, 1996). These reefs protect the *Posidonia oceanica* meadow (and its ecological and economic functions) and thus permit sustainable management of the halieutic stock through artisanal fishing (Ramos Esplá *et al.*, 2000).

10.2. HISTORY OF ANTI-TRAWL REEFS

Anti-trawl reefs in the Mediterranean were first sunk in the 1970s in the Languedoc-Roussillon region (France), when 3-metre-high concrete stakes were put down in the sediment in Palavas and in Gruissan (Collart and Charbonnel, 1998). This attempt ran into trouble, however.

In 1986, the Côte Bleue Marine Park (near Marseille, France) experimented with the submersion of 83 big slabs of rock (10 to 12 t) arranged in a line and spaced every 40 to 60 metres, particularly intended to **protect the *Posidonia oceanica* meadows**. The Côte Bleue meadow is in fact the biggest one in the Bouches-du-Rhône (over 1 000 hectares; Cristiani, 1980; Bonhomme *et al.*, 2003a), and is the last continuous meadow between Provence and the Spanish border. Since then, Côte Bleue Marine Park has diversified its anti-trawl reefs: 5 different types of anti-trawl reef are found there – slabs of rock, sea-rocks, "Fakir", Negri and tripods (Fig. 88 and 89). In all, along the 25 km of Côte Bleue coast, 326 anti-trawl obstacles (i.e. 2 200 m^3) have been sunk by the Marine Park, forming 17.5 km of anti-trawl lines, intended to protect the coastal strip from the trawlers' illegal incursions (Bachet, 1992; Daniel and Bachet, 2003; Charbonnel *et al.*, 2001b; Fig. 88).

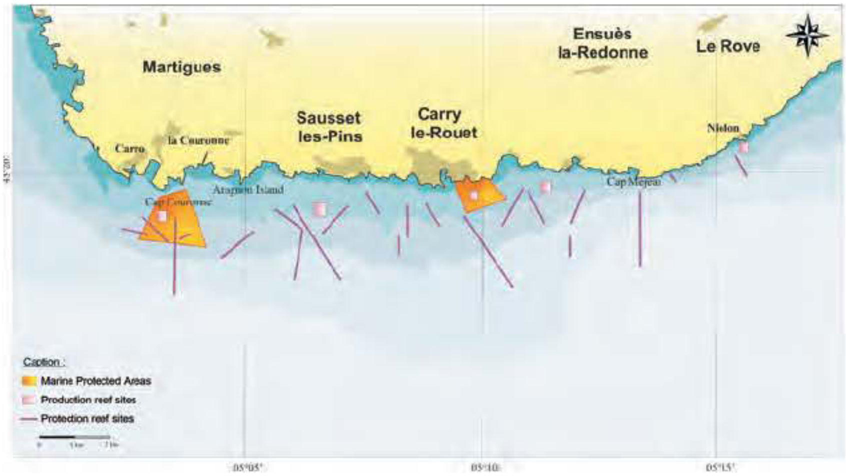


Fig. 88. Map showing the location of anti-trawl protection reefs (purple lines) placed along the coast of the Côte Bleue Marine Park (Bouches-du-Rhône, France). The orange polygons indicate the Reserves of Carry-le-Rouet and Cap-Couronne. From Daniel and Bachet (2003).

In Languedoc-Roussillon (France), many sinking operations have taken place since 1992, with one 8.15 t model of concrete double pipe for 7.1 m³ (Collart and Charbonnel, 1998; Fig. 91): Marseillan (105 pipes in 1992 and 1996), Agde (200 pipes in 1996), Aigues-Mortes (109 pipes in 1999); other projects are under way, anticipated in 2004 and 2005 in Leucate, Valras, Agde and Argelès (Béatrice Pary, personal comm.). Despite the almost complete absence of *Posidonia oceanica* meadows in this region (Boudouresque and Meinesz, 1982), anti-trawl reefs enable user conflicts between fishing craft to be managed, by **sharing the space** and the halieutic resource between fixed net fishermen (small-scale fishery) and trawlers. It should be stressed that it is often the artisanal fishermen themselves who spark off the putting down of artificial reefs. The seabed protection role that anti-trawl reefs can have is today giving rise to growing demand from fishermen in the Mediterranean.

Fig. 89. "Fakir" type anti-trawl protection modules based on reconditioned EDF (Electricité de France) electricity poles. 91 modules of this kind were sunk in 1997 inside and outside the Reserve of Cap-Couronne in the Côte Bleue Marine Park. Photo by E. Charbonnel.

In Liguria (Italy), the first artificial anti-trawl reefs were sunk in the Gulf of Tigullio (Genoa province) in December 1980; these reefs were made of wrecks, concrete blocks and tubes, and blocks of stone for a total volume of 16 185 m³ (Relini *et al.*, 1986). After this first experiment, a second reef was sunk in Loano (Savona province) in 1986, under the scientific control of Genoa University and with funding from the European Union (Relini *et al.*, 1995; Relini, 2000). The facility, which also has a repopulating function, lies at between 18 and 23 metres depth, near the lower limit of a regressing *Posidonia oceanica* meadow. It has a central (200 m x 100 m) core of 30 pyramids each made up of 5 2-metre-sided cubes of cement (4 at the first level, + 1 at the second level) with an opening and a cavity (Fig. 92). Around this central core, a vast area (350 hectares), between 5 and 45 metres in depth, constitutes the protection area; 200 blocks of cement with 1.2 metre sides were sunk there (anti-trawl blocks). During the 16 months following their sinking, many anti-trawl blocks were pushed aside by trawls. To enhance protection, 150 new cement blocks, rather bigger (2 metre sides), were sunk.

In 1989, another experiment was carried out in Spotorno (Savona province, Liguria, Italy) under the scientific control of GIS Posidonie and Genoa University with funding from the European Union.

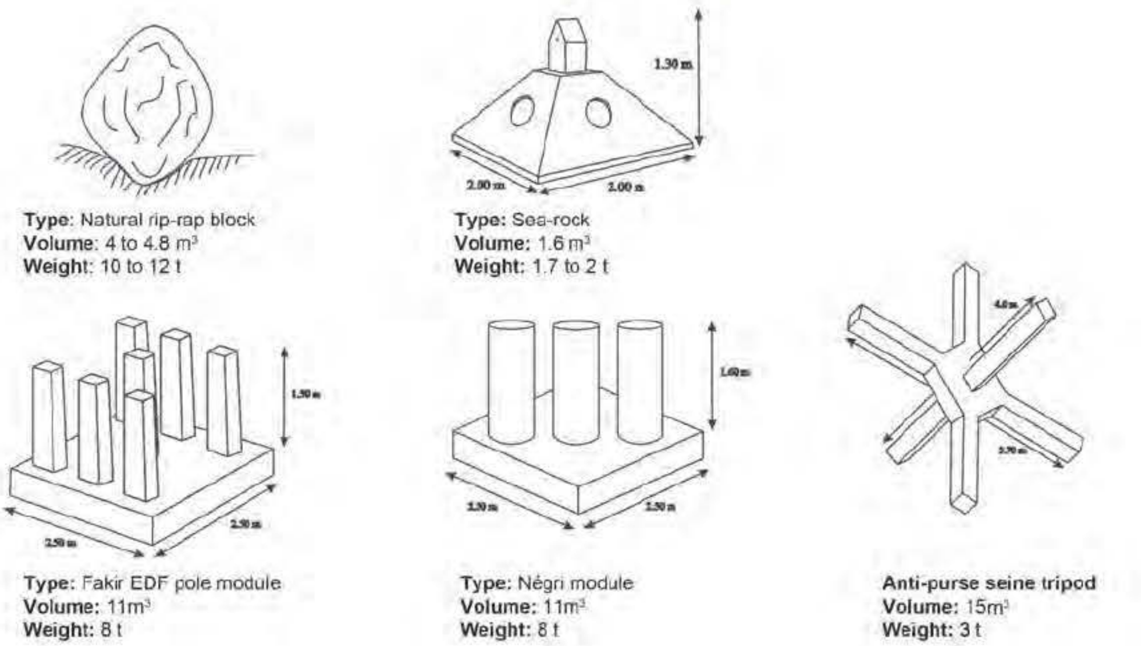


Fig. 90. Diagrams of 5 types of artificial anti-trawl protection reef used by the Côte Bleue Marine Park (Bouches-du-Rhône, France) between 1986 and 2000. From Daniel and Bachet (2003).

Fig. 91. Diagram of an artificial anti-trawl protection reef used in the Languedoc-Roussillon region (France). From Collart and Charbonnel (1998).

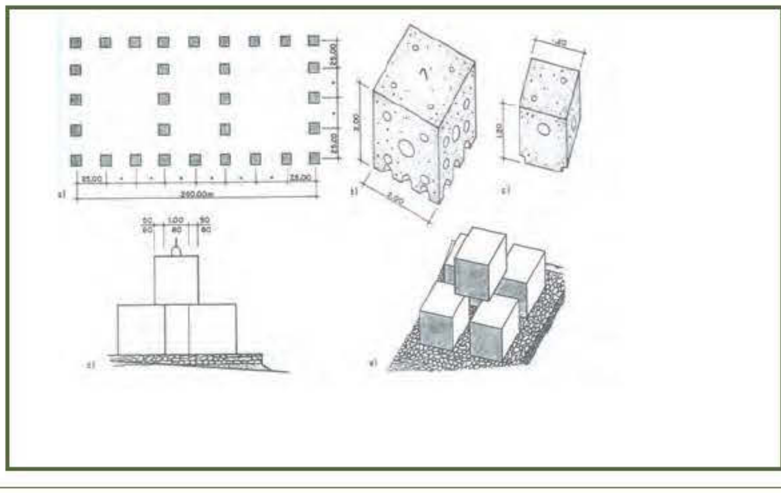


Fig. 92. . Artificial reefs (with a repopulating and anti-trawl function) sunk in Loano (Liguria, Italy). Above left map of the central core. Above right cement cubes. Below left cross-section of a pyramid in the central core. Below right bird's eye view of a pyramid. From Relini *et al*. (1995).

As in the above example, an area of repopulating reefs was provided for as well as an area of anti-trawl reefs intended to protect a *Posidonia oceanica* meadow that was regressing because of trawling. However, the project was never completed, and only a few big cement modules, of Bonna® type, were sunk (Fig. 93).

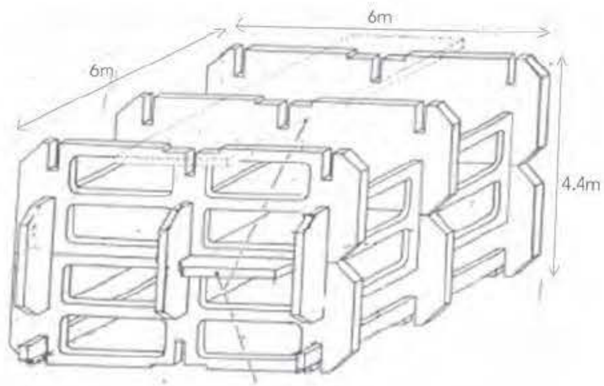


Fig. 93. Diagram of a Bonna® type module sunk in Spotorno (Liguria, Italy) as part of an unfinished project for coupling repopulating reefs and anti-trawl reefs.

Between 1997 and 1998, under the scientific control of Genoa University, artificial reefs were sunk in Alassio (Savona province, Liguria, Italy) near the lower limit of a *Posidonia oceanica* meadow. The facility has on its extreme right and left areas 2 "repopulation oases" made up of 3 groups of 8 pyramids each formed of 5 cement cubes with 2 metre sides, at a depth of between 8 and 25 metres. Between the 2 oases, at 20-24 metres depth, many smaller cement cubes (1 metre sides), alternating with tetrapods, were sunk in order to protect the meadow from trawling (Fig. 94).

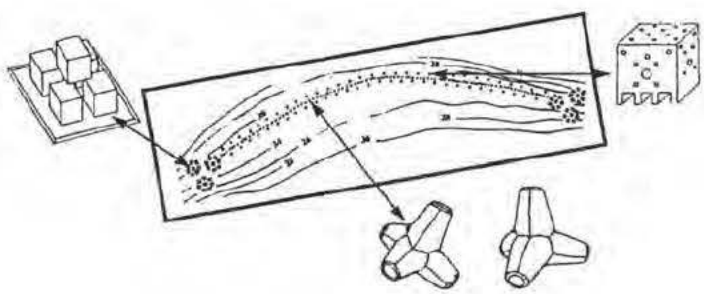


Fig. 94. Diagram of artificial repopulating reefs (pyramids of cubes) and anti-trawl reefs (cubes and tetrapods) sunk in Alassio (Liguria, Italy).

Anti-trawl reefs have also been sunk in El Campillo and Nueva Tabarca (Alicante province, Spain) and Catalonia (Spain) (Ramos, 1990; Alluè-Puyelo and Olivella-Prats, 1994; Guillén *et al.*, 1994; Ramos-Esplá *et al.*, 1994). These are often (El Campillo in particular) cement cubes with 1-1.5 metre sides, weighing 7-9 t, criss-crossed by bits of railway track (Ramos-Esplá *et al.*, 1994).

10.3. RECOMMENDATIONS

The key to the success of any anti-trawl protection reef is its **design** – both the architecture of its modules (material, shape, height, length, volume) and how they are arranged on the seabed. This design plays a preponderant part in whether the facility is effective and lasting. Protection reefs must constitute an obstacle that is sufficiently dissuasive to stop trawlers entering the area – they would risk damaging their equipment.

(i) The modules of anti-trawl reefs must be sufficiently heavy (at least 8 t) to constitute an effective physical obstacle and not be pulled away by the trawl or harmed by the trawls' side panels. **(ii)** The modules must offer a sufficient load-bearing surface against the sediment not to sink right into it. Sea-rocks (Fig. 90) are particularly effective on mud bottoms and also are not well detected by trawlers' sounders (Francour *et al.*, 1991). **(iii)** It is also important that the shape of the anti-trawl module should not risk damaging the nets of artisanal fishermen (small-scale fishery) who must be able to work in the protected areas and benefit from anti-trawl reefs. **(iv)** The anti-trawl modules must be sunk one by one to leave spaces between them (50 to 200 metres). **(v)** The ensembles of anti-trawl reefs must occupy the maximum space possible to really be dissuasive to trawlers.

If the topography and size of the site to be protected allow this, the modules must be arranged in lines running straight out from the coast (most of the trawls are in fact dragged parallel to the coast), thus forming a series of barriers as in the Côte Bleue (Fig. 88). They can also be arranged at regular intervals on the seabed. In Spain, the modules are arranged in a 300-500 metre sided square, or a 400 m x 200 m rectangle, with a module on each side and one in the middle. The area thus protected varies between 1.6 and 5 hectares per module (Ramos-Esplá *et al.*, 2000), according to the distance left between each module (50 to 100 metres).

In addition to their role of physical obstacle on the seabed, certain anti-trawl reef modules are designed with crevices in order to offer a shelter zone for fishes, and thus have a **production** role.

Fig. 95. 2 *Pinna nobilis* noble pen shells (molluscs) in a *Posidonia oceanica* meadow. This threatened species, protected by law (France) and by the Barcelona Convention (all the countries bordering on the Mediterranean), is very vulnerable to trawling, which breaks its shell. Photo by E. Charbonnel.

Artificial anti-trawl reefs are one of the most effective tools for **integrated management** of the coastal resources, after the creation of Marine Protected Areas. This management can concern both uses (sharing the space and the halieutic resource between artisanal fishermen and trawlers) and the ecological aspect (protecting vulnerable or protected species and habitats, restoring degraded environments, diversifying naturally poor substrata).

All in all, artificial protection reefs are a very effective tool against the illegal practice of trawling, for managing user conflicts (sharing space) between artisanal fishermen and trawlers, for the sustainable protection of the resource, for protecting *Posidonia oceanica* meadows and for protecting those species that are dependent on them, such as the noble pen shell *Pinna nobilis* (Fig. 95).

As part of the overall improvement of the coastal zone, the European Union can fund the installing of anti-trawl reefs through the intervention of structural funds such as the FIFG[79] (Financial Instrument for Fisheries Guidance ; in French IFOP) to the tune of 50% of the investment. The gain in terms of protecting the resource and priority natural habitats is thus recognised, in comparison with the lack of performance of checking systems, respect for rules and regulations, and maritime surveillance.

79 IFOP http //www.info-europe.fr/document.dir/fich.dir/QR001094.htm.

11. THE *POSIDONIA OCEANICA* MEADOW MEADOW AND FISH FARMS

11.1. THE PROBLEM

The term aquaculture covers all the activities that aim to produce and market aquatic species, whether these are **(i)** plants or animals, **(ii)** freshwater, brackish or salt water, **(iii)** during part or all of the reproduction cycle (Barnabé, 1989). Aquaculture is a very old tradition, already being carried on 4 000 years ago by the Chinese, that involves using natural or artificial aquatic environments to achieve the production of species useful to man.

In 1990, Mediterranean fish farming was producing 130 000 t of fish, molluscs[80] and crustaceans, i.e. 1.6% of world marine aquaculture production (De la Pomélie, 1991). Since then, it has been essentially the marine farming of fish (pisciculture) that has developed strongly, both in the north-western and in the eastern Mediterranean, thanks to the post 1975 mastery of the reproduction of the European sea bass (*Dicentrarchus labrax*) and the gilthead sea bream (*Sparus aurata*) (Dosdat *et al.*, 1994). This production grew by nearly 29% per year in the 1990s (12 500 t) to reach a value of 124 000 t in 1999, i.e. ten times greater than in 1990 (Belias and Dassenakis, 2002). Since the late 1980s, there has been mass production of sea bass and gilthead sea bream in Greece, Spain, Italy, Turkey and France[81], and today this constitutes the bulk of aquaculture production of fish (92%; Belias and Dassenakis, 2002). In 1998, this fish farming production represented over 654 million dollars, and aquaculture development attracts a growing number of Mediterranean countries (e.g. the appearance of 3 new producer countries in 1999; Belias and Dassenakis, 2002).

But the development of fish farming seems likely in some cases to threaten the quality of the coastal environment (Videau and Merceron, 1992) and thus some of its uses (see Chapter 1; Teinturier, 1993; RAC/PAP, 1996; UNEP, 1999). Because of **(i)** their specific geographical situation, often sheltered bays where there is little water movement, **(ii)** the size of the waste (uneaten foodstuff, excretions), **(iii)** the frequent recourse to "health" substances (antibiotics, trace elements[82]), aquaculture facilities can actually have a negative impact on the natural environment (Handy and Poxton, 1993; Hevia *et al.*, 1996; Karakassis, 1998; Miner and Kempf, 1999; Boyra *et al.*, 2004; but see Aubert, 1993 and Machias *et al.*, 2004 for a more nuanced, or contrary, opinion), particularly the *Posidonia oceanica* meadow. Whereas the impact of intensive marine pisciculture (cages) has been the subject of many studies in northern Europe (e.g. the developing of salmon farming; Gowen and Bradbury, 1987; Videau and Merceron, 1992; Munday *et al.*, 1994; Wu, 1995; Merceron and Kempf, 1995) there is fairly little data on its impact in the Mediterranean, where this activity is more recent (e.g. Aubert, 1993; Verneau *et al.*, 1995; Mendez *et al.*, 1997; Delgado *et al.*, 1999; Karakassis *et al.*, 1999; Pergent *et al.*, 1999; Cancemi *et al.*, 2000; Dimech *et al.*, 2000a, 2000b; Mazzola *et al.*, 2000; Karakassis *et al.*, 2000; Ruiz-Fernández, 2000; Ruiz *et al.*, 2001; Karakassis *et al.*, 2002; Cancemi *et al.*, 2003; Machias *et al.*, 2004, 2005).

80 In 1990, *Mytilus galloprovincialis* mussels were the main species (in tonnage, about 90%) produced by Mediterranean aquaculture.

81 In the Provence-Alpes-Côte d'Azur region (PACA) (France), the production of sea bass and gilthead sea bream was in 1999 estimated to be about 1 200 t per year (Source Guide de la production aquacole française, 2001 edition), i.e. about 1% of the Mediterranean basin's production for these species (FAO, 2001). In 2003, the production dropped to 990 t (60 t in the Bouches-du-Rhône, 150 t in the Var and 780 t in the Alpes-Maritimes) (Source French *Département des Affaires Maritimes*).

82 The Nutreco® feed presents, for example, a copper content of about 4 mg/kg and the Gouessant® feed a content of about 3 mg/kg (E. Roque and D. Coves, personal comm.).

11.2. CASE STUDIES

Some studies have been done, starting from the 1990s. They concern fish farms that carry on intensive pisciculture, in cages, of the sea bass *Dicentrarchus labrax* (Corsica - Verneau *et al.*, 1995; Pergent *et al.*, 1999; Cancemi *et al.*, 2000, 2003; Sardinia – Pergent *et al.*, 1999), of the gilthead sea bream *Sparus aurata* (Balearic Islands – Delgado *et al.*, 1997, 1999; Malta – Dimech *et al.*, 2000a, 2000b), of the amberjack *Seriola dumerilii* (Spain – Ruiz-Fernández, 2000) or of several of these species (Ruiz-Fernández, 2000; Ruiz *et al.*, 2001). The production of these fish farms varies from some tonnes (Gulf of Sant'Amanza, Corsica, 15 t/year; Figari Bay, Corsica, 18 t/year) to several hundred tonnes (Gulf of Aranci, Sardinia, 200 t/year; Bay of El Hornillo, Spain, 700-800 t/year). The disturbance caused by these farms is measured through abiotic[83] (light, sediment, interstitial water) and biotic (density of the *Posidonia oceanica* meadow, leaf biometry, lepidochronology (see §2.2), primary production, leaf epibiota, reserve carbohydrates in the rhizomes) parameters, according to the growing distance from the cages and in geographically close reference sites.

The increased turbidity registered near the cages gives rise to a significant reduction in luminous intensity. This reduction is estimated to be over 30%, on average, under the cages in Figari Bay (Corsica; -10 m; Pergent *et al.*, 1999) and 23% at 40 metres from the cages at El Hornillo (Spain; -8 m; Ruiz *et al.*, 2001). When the cages are placed in shallow areas the lighting at the seabed remains far superior to what it is at the lower limit of the *Posidonia oceanica* meadow. But this factor must be taken into consideration for fish farming facilities located over deeper meadows (Verneau *et al.*, 1995). Furthermore, the shade shed by the cages (independently of turbidity) significantly reduces the density of the *P. oceanica* shoots (Ruiz-Fernández, 2000; Ruiz and

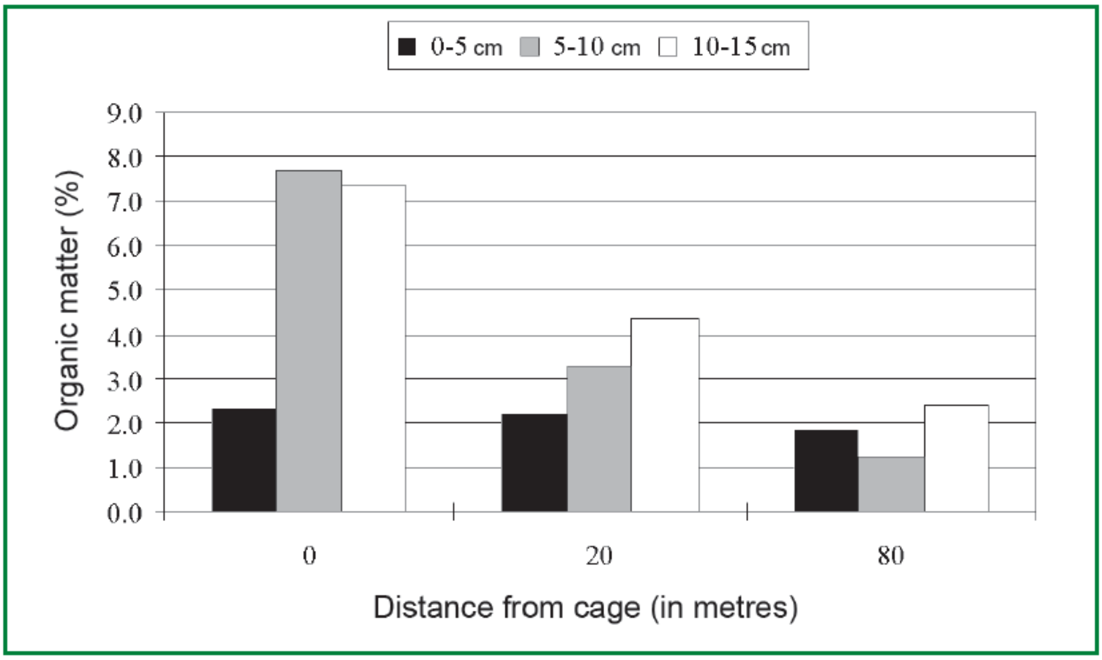


Fig. 96. Changes in organic matter content in sediment, according to distance from the fish farming cages and sediment layer (0-5, 5-10 or 10-15 cm deep) taken into account, in Sant'Amanza (Corsica) in April 1994 (Pergent *et al.*, 1995).

Romero, 2001; see §4.8).

[83] Abiotic parameters non-biological (=non biotic), i.e. physicochemical.

Similarly, an increase in the organic matter and silt content can be seen the nearer one gets to the cages (Delgado *et al.*, 1999; Pergent *et al.*, 1999; Dimech *et al.*, 2000a; Karakassis *et al.*, 2000; Ruiz *et al.*, 2001). This enrichment in organic matter can best be seen in the deepest sediment layer (Fig. 96; 10-15 cm layer). In the most serious cases, the sediment presents a black, anoxic[84] superficial layer, with escape of methane CH_4 and hydrogen sulphide H_2S (Karakassis *et al.*, 2002). Near the cages, the fauna is dominated by the polychaeta *Capitella* (cf *capitata*), a species that indicates extremely high pollution (Bellan *et al.*, 1975, 1999; Karakassis *et al.*, 2000).

Other parameters, such as nutrient salts concentration (Table IX), and chlorophyll a and pheopigments[85] content, are also greatly influenced by the presence of fish farm cages (Aubert, 1993; Pergent *et al.*, 1999).

However, the main changes are observed at the level of the *Posidonia oceanica* meadow. Thus the density (number of shoots per m²) shows a significant drop when nearing the cages, with very often the **disappearance of the meadow under the cages** (Table X). Even at **a distance of 300 m**, it was seen that the average density, measured in the Figari (Corsica) and St. Paul (Malta) sites, is lower than the density values considered "normal" for that depth (Pergent-Martini *et al.*, 1999). In El Hornillo Bay (Spain), the impact on *P. oceanica* is also visible up to several hundreds of metres from the cages; 11 hectares of meadow have been destroyed and 10 hectares significantly degraded, representing in all 53% of the meadow's original surface area in the bay; the surface area of destroyed or degraded meadow is 7 times as much as the area occupied by the cages (Ruiz-Fernández, 2000; Ruiz *et al.*, 2001; see Fig. 47). Unlike what was observed for other benthic habitats, for which some authors note an impact that goes no further than 25-30 metres from the cages (Karakassis *et al.*, 2000, 2002; see references in Machias *et al.*, 2004), the impact on the *P. oceanica* meadow is thus perceptible over a great distance. As for demersal fish, in the oligotrophic water of the Genoa coast, the impact (increase in abundance and in biomass) can be seen over a still greater distance – several kilometres (Machias *et al.*, 2005).

Table IX. Nutrient content in the interstitial water of the sediment (in µM; mean values and 95% confidence interval in brackets) in 3 stations in Figari Bay (Corsica) according to the distance from the fish farm, and in the Moines Islands reference site; the Moines Islands lie 5 km out to sea, about 15 km from the fish farm. From Cancemi *et al.* (2003).

	0m	20m	100m	Moines Islands
Total phosphorus (mg/kg)	2,206 (± 429)	786 (± 229)	568 (± 33)	-
NO_3^- (nitrates)	2.5 (± 0.7)	3.7 (± 0.8)	2.3 (± 0.9)	3.1 (± 0.8)
NH_4^+ (ammonium)	19.5 (± 8.7)	12.4 (± 2.3)	8.4 (± 1.6)	1.8 (± 1.1)
PO_4^{3-} (phosphates)	5.2 (± 0.6)	1.8 (± 0.6)	1.3 (± 0.6)	1.7 (± 0.6)

Table X. Density of the *Posidonia oceanica* meadow (number of shoots per m). Mean values ± confidence interval (95%). *Pergent *et al.*, 1999; **Dimech *et al.*, 2000b.

Sites	Distance from cages				
	Under cage	1m	20m	80m	300m
Figari (-10m) – Corsica*	0	63 ± 11	108 ± 16	250 ± 28	313 ± 41
St Paul (-12m) – Malta **	0	-	-	225 ± 20	310 ± 30
Golfo Aranci (-23m) – Sardinia*	0	110 ± 16	-	175 ± 29	200 ± 32

84 The black (anoxic) sediment lying under the cages is termed by Holmer (1991; *in* Karakassis *et al.*, 2002) *"farm sediment"*.

85 Pheopigments are the products of the degradation of certain chlorophylls.

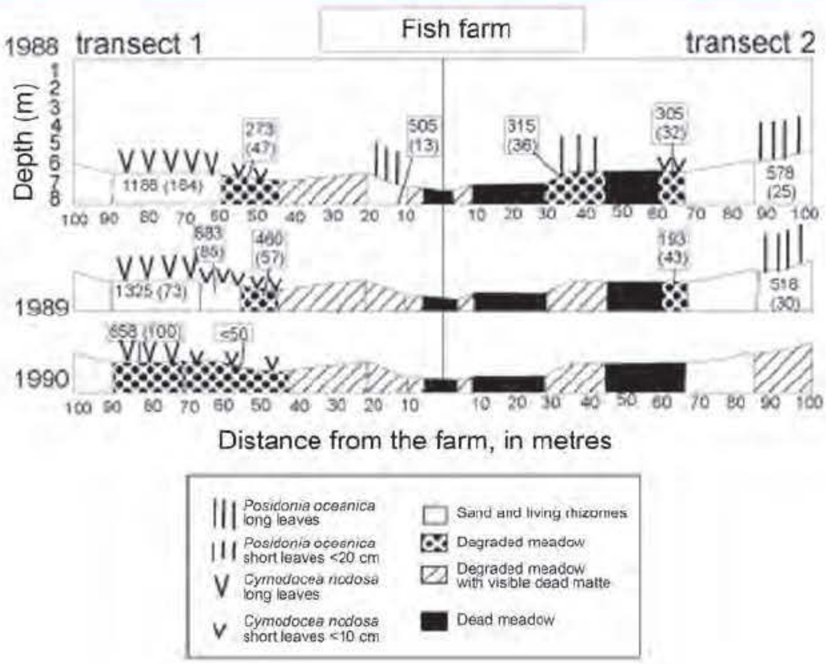
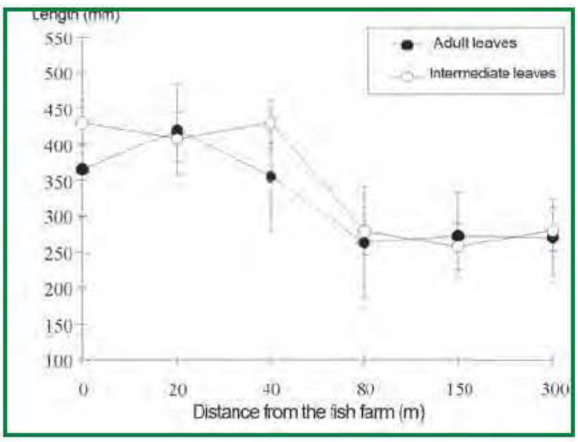


Fig. 97. Changes in *Posidonia oceanica* and *Cymodocea nodosa* meadows, from 1988 to 1990, in the Balearic Islands, after fish farms were set up (Delgado *et al.*, 1997, modified). The figures correspond to the mean and to the standard deviation (between brackets) of the shoot density.

Also in the Balearic Islands, temporal monitoring of *Posidonia oceanica* and *Cymodocea nodosa* meadows shows a significant regression of these formations after fish farm facilities were set up (Delgado *et al.*, 1997). This regression is expressed in a reduced density of these meadows, and even their disappearance (Fig. 97). Worse still, Delgado *et al.* (1999) show that 3 years after the farms stopped operating, the regressive dynamics of the meadows is continuing.

Fig. 98. Changes in adult and intermediate leaf length according to site (distance from cages) in Figari Bay (Corsica) in May 1994. The confidence interval (95%) is shown. From Pergent *et al.* (1999).



Although the average number of leaves per *Posidonia oceanica* shoot seems not be influenced by the presence of a fish farming facility[86], the average length of adult and intermediate leaves does significantly increase in spring the nearer they are to the fish farm (Fig. 98); the same holds good for the leaves' surface area (Leaf Area Index) and the foliar biomass (expressed per m^2; Pergent *et al.*, 1999). However, in the summer the average length of these leaves decreases near the cages (Delgado *et al.*, 1999; Dimech *et al.*, 2000b); this phenomenon could express a higher **grazing pressure** at a time of year when foliar growth is reduced, and during which the development of MPOs (Multicellular Photosynthetic Organisms) leaf epibiota can induce a phenomenon of competition with *P. oceanica*. This hypothesis is corroborated **(i)** by a rise in coefficient A (definition: Table XII), which expresses the impact of hydrodynamism and herbivores near the cages (Pergent *et al.*, 1999) and **(ii)** by the values obtained during the yearly cycle (Cancemi *et al.*, 2003). In El Hornillo Bay (Spain), Ruiz-Fernández (2000) and Ruiz *et al.* (2001) attribute most of the direct and indirect regression of the *P. oceanica* meadow to the increase in herbivore grazing; the original cause of this is probably that the leaves are richer in nitrogen the

86 In El Hornillo (Spain), however, the average number of leaves per shoot drops when nearing the cages (Ruiz *et al.*, 2001).

nearer they are to the cages, and that the herbivores choose their grazing sites according to the richness in nitrogen of the plants they graze (Ruiz-Fernández, 2000); this overgrazing reduces *P. oceanica*'s photosynthetic potential and as a result the storing of reserve carbohydrates in the rhizomes; now, the plant's yearly growth cycle, whose carbon balance shows a deficit most of the year, depends on these reserves (Alcoverro *et al.*, 2001).

The biomass of the *Posidonia oceanica* **leaf epibiota** increases greatly near the fish farming facilities (Fig. 99; but see Ruiz *et al.*, 2001); it varies on average during the year between 93.5±45.8 mg/shoot (Figari, Corsica, 20m), 51.5±55.3 mg/shoot (Figari, 100 m), and 37.8±35.0 mg/shoot (the Moines Islands reference site; Cancemi *et al.*, 2003). However, the maximal values are not found at the station that is nearest to the fish farm cages (where the nutrient content is, however, the highest) but at a distance of 20-40 m (Pergent *et al.*, 1999; Dimech *et al.*, 2000a). Additions of copper, added in the fish feed (estimated to be between 450 and 500 g/year for the Figari farm; Pergent *et al.*, 1999) could act as an algicide in the immediate proximity of the cages and explain this result.

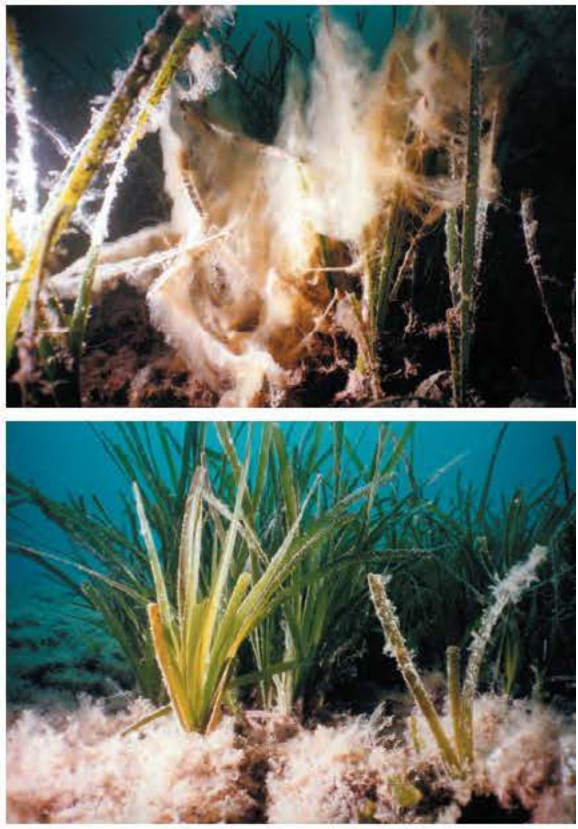


Fig. 99. Appearance of the *Posidonia oceanica* meadow, 80 m (above) and 300 m (below) from the fish farming cages in Figari (Corsica) (April 1994). Anonymous photo.

The number of leaves produced every year, as well as the speed of growth of the rhizomes, do not seem to be affected either by the operations of the fish farms or by the distance from the cages. However, near the fish farm facilities, *Posidonia oceanica* presents a particularly well developed root system that seems to be the result of an adaptation to silting (Pergent *et al.*, 1999).

Primary production, measured during a yearly cycle by lepidochronology (see §2.2), shows very high values for the reference station (the Moines Islands) compared to those recorded near the fish farm cages in Figari (Corsica; Table X) (Cancemi *et al.*, 2003).

Table XI. Primary production of *Posidonia oceanica* in different stations in Figari Bay (Corsica) according to the distance from the cages of a fish farm. DM = dry mass. The Moines Islands lie 5 km out to sea, about 15 km from the fish farm. From Cancemi *et al.* (2003).

	20m	100m	Moines Islands
Foliar production (gDM/m^2)	82.9	123.0	1,022.5
Rhizome production ((DM)g. m^{-2})	5.0	6.2	48.1

Higher **copper** (Cu) and **zinc** (Zn) contents are recorded in the *Posidonia oceanica* rhizomes the nearer one is to the cages, in Figari (Corsica; Fig. 100). Additionally, the Zn content particularly seems to increase, starting from when the fish farm started operating (Fig. 101). Similar phenomena have been revealed in sediment impacted by the faeces[87] of salmonids (Uotila, 1991; Merceron and Kempf, 1995). It seems that the origin of this enrichment is linked to the supplementing of feed by these 2 trace elements. The content measured is respectively 9.9 µg/g of Cu and 118 µg/g of Zn in the feed used[88] (Mendez *et al.*, 1997). But one should

[87] Faeces (or feces) solid excrement.

[88] The manufacturer of the feed (Super.aquasard®) indicates a content of 5 µg/g of Cu, and fails to mention the presence of zinc.

note that, according to present scientific data, a negative effect (with this content) on *P. oceanica* is very improbable (see §4.3).

The benthic **macrofauna** of the *Posidonia oceanica* "matte" shows a higher species diversity in a reference meadow compared to a meadow located near fish farm facilities. Preliminary measurements over 0.01 m³, done in October 2002 in Calvi Bay (Corsica), show that the number of species goes on average from 45.3±4.4 to 31.3±5.3. In Malta, the highest specific richness and abundance are recorded for a distance of 50-170 m from the cages (Dimech *et al.*, 2000b). Additionally, studying the distribution of several species of this macrofauna (echinoderms, decapods and molluscs) reveals zoning according to the distance from the cages (Dimech *et al.*, 2000b). This zoning is like that revealed in Scotland for a salmonid farm located in a fjord (Brown *et al.*, 1987):

- an azoic area (no macroscopic fauna) under the cages
- a highly enriched area
- a transitional area
- a "clean" area (similar to the reference zone).

This distribution is reminiscent of that observed near the sea outlet of a waste water discharge near Marseille (Bellan, 1985).

Fig. 100. Average copper and zinc content (µg/gDM) in *Posidonia oceanica* rhizomes according to the distance (in m) from the fish farm cages in Figari (Corsica). DM = dry mass. From Pergent *et al.* (1999).

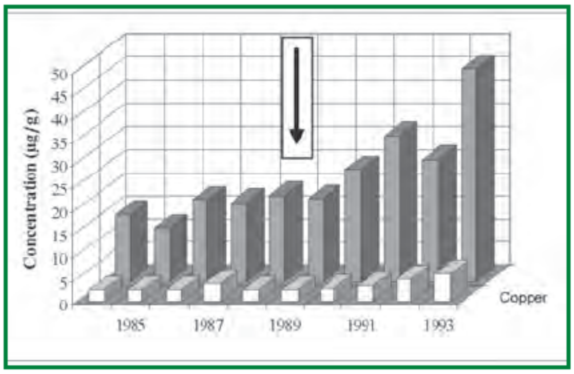


Fig. 101. Average copper and zinc content (µg/gDM) in *Posidonia oceanica* rhizomes according to time, in Sant'Amanza (Corsica). The arrow indicates the year the fish farm started operating. DM = dry mass. From Pergent *et al.* (1999).

The results set out above are of course relative to the sites studied, whose characteristics differ, and anyway these results cannot be transposed to all Mediterranean fish farming sites, nor general conclusions drawn, insofar as they depend on **multiple factors** that are hard to separate, such as hydrodynamism, height of the water column under the cages, density of farming, feed used, rate of feeding and how it is distributed throughout the day (Karakassis *et al.*, 2000). Furthermore, many of these parameters (e.g. density of farming, rate of feeding, feed used) are not clearly stated in studies on the impact of fish farms on benthic settlements, making it even more difficult to try to generalize. Lastly, it is rarely possible to completely separate, in the fish farming sites studied by the authors, the impact of fish farms from the other possible impacts (discharge of waste water from the coast, anchoring, etc.).

Regarding the impact of fish farms on *Posidonia oceanica* meadows, it is important to stress the fact that this impact is **irreversible** on the human scale (when the meadow has been destroyed).

Works that emphasize the relatively rapid reversibility of the impact (after the operation of a fish farm is stopped) do not concern the *P. oceanica* meadows (Mazzola *et al.*, 2000). On the contrary, in the case of the *P. oceanica* meadow, the impact can even go on becoming worse after the operation stops (Delgado *et al.*, 1999).

11.3. SUMMARY AND RECOMMENDATIONS

Studies on the impact fish farms have on *Posidonia oceanica* meadows are still recent and sparse. However, the results are fairly homogeneous and show **significant degradation** of these plant formations in all the sectors studied. Generally speaking, when the fish farm cages have been set above a *P. oceanica* meadow, the meadow has been greatly degraded or has disappeared, according to the age of the farm. Although many descriptors already seem to be pertinent, others still deserve to be refined (Table XII).

Table XII. Main descriptors enabling characterization of the impact of fish farms on the coastal environment. N no significant difference; O↓ significant drop; O↑ significant increase. ( ) high seasonal variability.

Compartment	Descriptor	Measurements taken	Impact
Water column	Turbidity	Light	O↓
	Nutrients	NO_3 (nitrates)	N
		NH_4 (ammonium)	N
		PO_4 (phosphates)	N
Sediment	Organic matter	Organic matter content	O↑
	Nutrients (interstitial water)	NO_3 (nitrates)	N
		NH_4 (ammonium)	O↑
		PO_4 (phosphates)	O↑
		Total phosphorus	O↑
	"Trace metals"	Zinc and copper	N
	Benthic "micro-algae"	Chlorophyll *a*	O↑
		Pheopigments	O↑
Posidonia oceanica	Phenology	Density of meadow	O↓
		Leaf length	O↑ (¹)
		Epiphytic cover	O↑
		Coefficient A[89]	O↑
		Leaf Area Index[90]	O↓
		Foliar biomass (per m^2)	O↓
		Primary production (per m^2)	O↓
	Lepidochronology	Rhizome growth	N
		Number of leaves produced	N
		"Trace metals" (Zn, Cu) rhizomes	O↑
	Associated macrofauna	Biodiversity	O↓

89 Coefficient A percentage of broken (by hydrodynamism) or grazed (mainly fishes and sea urchins) leaves.

90 Leaf Area Index=foliar surface area in m of leaves per m of seabed surface area.

In view of their effect on the environment, especially on *Posidonia oceanica* meadows (in many countries a protected species; see §5.1.2), setting up of new fish farms must take into account:

- the characteristics of the site where the farm is to be installed (physicochemical factors, e.g. currents, biological factors and user conflicts).
- the operating practices envisaged (species farmed, type of feed, mode of distribution, management of the daily ration[91], waste control, health products, etc.).
- the production (tonnage) envisaged in relation to the site's characteristics (carrying capacity).
- the regulatory constraints (see Chapter 5), in particular the presence of the *P. oceanica* meadow.

Only by implementing an **overall policy** can these requirements be satisfied. From this point of view, the approach initiated by the *collectivité territoriale* of **Corsica** (in particular the *Agence de Développement Economique de la Corse*), the *Direction Régionale de l'Environnement de Corse*, the *Direction Régionale des Affaires Maritimes* de Corse, and people in the fish farming business, working in collaboration with scientists, is exemplary. From this perspective, a Methodological Guide for the development of files to request permission for "*Installations Classées pour la Protection de l'Environnement*" (ICPE)[92] and an atlas for ecological awareness of the coastal environment regarding fish farming, were published in 2003. Among the criteria selected were: **(i)** the presence of strong currents (preferentially directed seawards), **(ii)** the absence of "sensitive" habitats (in particular *Posidonia oceanica* meadows), **(iii)** remoteness from other potential sources of disturbance (waste water discharge, coastal rivers) and **(iv)** significant depth underneath the fish farm facilities.

The **Liguria** Region (Italy), for example, has a document (adopted on 28 March 2001) that, as part of an environmental impact assessment (*Valutazione di Impatto Ambientale*, VIA), lays down a set of technical norms for fish farm projects. The criteria for positioning fish farm facilities in exposed sites (*Criteri di Posizionamento di Impianti di Maricoltura in Siti esposti*), accompanied by a fish farming map, constitute a useful tool for authors of projects in that they provide useful indications for the identification of favourable sites and for the impact study. The things that must be taken into account when positioning a fish farm are:

- **Sites of Community Importance** (SCI – Habitats Directive). A safety distance is suggested according to the characteristics of the environment (currents, type of seabed, etc.) and those of the fish farm (number of cages, quantity of fish, etc.)
- **Marine Protected Areas** (existing or foreseen). A safety distance must be respected according to the characteristics of the environment and of the fish farm
- **Terrestrial Protected Areas**. The fish farms must not have a negative visual impact from the land (distance, visual angles, size, etc.) for landscape reasons
- ***Posidonia oceanica*** and ***Cymodocea nodosa***. A safety distance must be respected from the meadows which these species form, according to the characteristics of the environment and of the fish farm
- **Bathymetry**. A depth of at least 30 m is required, which usually distances the fish farm from the most sensitive habitats and ensures better dilution of effluent from the farm
- **Distance from the coast:** At least 1 000 metres
- **Mouths of rivers.** Attention to these outflows is required for several reasons: entry of fresh water, interaction with currents, entry of pollutants, etc.

[91] Rigorous management of the daily ration, which allows the amount of uneaten feed introduced into the surrounding environment to be minimized, is anyway interesting for fish farmers, for whom uneaten feed constitutes an unproductive load.

[92] Guide méthodologique pour l'élaboration des dossiers de demande d'autorisation d'Installation Classée pour la Protection de l'Environnement (ICPE) en matière de pisciculture marine pour la Région Corse, 2003. Rapport Ifremer DEL/PAC/03-04 pour la collectivité territoriale Corse.

- **waste water discharge.** A sufficient distance must be kept to avoid contamination of fish in the fish farm
- **Zone under regulations of the port authorities.** (Anchoring merchant ships, etc.)
- **Undersea lines.** A safety distance must be kept from underwater water pipelines, telephone cables and electricity cables
- **Archaeological sites** (for example, wrecks). A safe distance must be kept.

The Liguria Region's impact assessment procedure also provides for setting up a **monitoring** programme to evaluate over time the environmental situation of the area in which the fish farm is established.

In **France**, the law regulates the permission to use the MPD (Maritime Public Domain) for fish farming via the "**permission to exploit marine crops**"[93] procedure, prepared by the *Affaires Maritimes* as a public and administrative enquiry which requires that producers provide a file presenting the projected installation and how it integrates with the other uses of the area. If need be, permission is granted for a limited period, usually 5 or 10 years. Since 1993, marine fish farming facilities producing over 5 t/year have, in France, been subject to restrictive general regulations concerning all the kinds of installation that could present dangers or disadvantages, particularly for environment protection[94]. Facilities with less than 5 t/year are the subject of a simple declaration, with deposit of a complete file; for those with 20 t/year or more (new installation or extension) a request for permission is required. This is prepared by the Veterinary Services and is the subject of an administrative and public inquiry among the potentially concerned stakeholders, with an investigating commissioner, on the basis of a file presented by the producer. This very complete file must contain a detailed **impact assessment**, whose contents are indicated by legislative decree[95]. This study, usually carried out by a research department and paid for by the producer, has several parts, including an analysis of the original state of the site, an analysis of the direct and indirect effects on the environment, landscapes, surroundings etc., the reasons why the site was chosen, and the steps envisaged for eliminating, minimizing or compensating for the disadvantages of the installation. In the French Mediterranean, the most delicate item is usually **the potential impact on the *Posidonia oceanica* meadow**, a protected species, as the remarks made during public enquiries and litigation show. Permission, in the shape of a bylaw, is granted for a limited period and is accompanied by prescriptions which usually contain a demand for regular monitoring of the potential effects of the installation on the environment and, if need be, on the *P. oceanica* meadows located nearby, with a report made to the administration[96].

In the absence of a predictive[97] model that enables the impact on the *Posidonia oceanica* meadow of a fish farm project to be precisely anticipated, according to where it is (depth, distance from the coast, movement of water, etc.) and its characteristics (species produced, anticipated tonnage, anticipated load in the cages in kilos of fish/cubic metre, farming techniques, kind of feed used, etc.), and given the **irreversible** nature of the harm possibly done to the *P. oceanica* meadow, our recommendations are clearly based on the precautionary principle[98].

93 This procedure is governed by Decree no. 83-228 of 22 March 1983, modified on 14 September 1987.

94 Law no. 76-663 of 19 July 1976 on *Installations Classées pour la Protection de l'Environnement*.

95 Decree of 25 February 1993.

96 French fish farmers are of the opinion that this set of regulations constitutes a very major restraint on the development of marine fish farming in the French Mediterranean, which has stagnated since the 1990s.

97 European research programmes are under way to attempt to anticipate the consequences for the environment of discharge from fish farms MERAMED, Development of monitoring guidelines and modelling tools for environmental effects from Mediterranean aquaculture (www.meramed.com) and MEDVEG, Effects of nutriment release from Mediterranean fish farms on benthic vegetation in coastal ecosystems.

98 An impact assessment, according to the model on which it is based, can propose optimistic predictions, i.e. the probable absence of impact. But if it proves to have an

Regarding the sectors where *Posidonia oceanica* meadows are present, the following recommendations are thus suggested:

- **(1)** No fish farm structure must be directly established over a *P. oceanica* **meadow.**
- **(2)** If there is a meadow nearby, a **minimum distance** of 100 m from the cages must be respected. This distance must be raised to 200 m near the lower limit of a meadow (more sensitive to turbidity than the superficial meadows) and adjusted according to the currents and the size of the farm.
- **(3)** Generally speaking, an installation on a 45-50 m seabed must be given priority[99] whenever possible.
- **(4)** An **impact assessment** should accompany any request for setting up a fish farm[100].
- **(5)** Permission to set up a fish farm should be reviewed every 4 years for possible extension, according to the demonstration that the *P. oceanica* meadows located nearby have not regressed (spatial extent and vitality; parameters in Table XII). This constraint, that implies setting up **monitoring of meadows** (see Chapter 16) should lead fish farmers to distance themselves as much as possible from the meadows.

Table XIII. A grid that shows the eligibility of fish farming sites according to the distance from the nearest *Posidonia oceanica* meadow, the depth and movement of water (openness of site). In green the combinations of ineligible factors. The eligible values shown correspond to the maximum annual production (in tonnes of fish produced per year). Open sites or not open sites located outside a bay or within a bay. For seabeds deeper than 40 m, the extrapolations suggested should be validated by case studies. Furthermore, no minimum distance has been suggested regarding farms producing more than 1 000 t, in the absence of concrete cases, and, thus, scientific data on the Mediterranean and *P. oceanica* meadows.

Depth	**Openness**	**Distance of the nearest *Posidonia oceanica* meadow**				
		< 100 m	100-200 m	200-300 m	300-400 m	> 400 m
< 5 m	Open				< 100 t	< 500 t
	Not open					< 100 t
5-10 m	Open			< 100 t	< 500t	< 1 000 t
	Not open				< 100 t	< 500 t
10-20 m	Open		< 100 t	< 500 t	< 1 000 t	< 2 000 t
	Not open			< 100 t	< 500 t	< 1 000 t
20-40 m	Open			< 100 t	< 500 t	< 1 000 t
	Not open				< 100 t	< 500 t
> 40 m	Open		< 500 t	< 1 000 t	< 2 000 t	< 5 000 t
	Not open		< 100 t	< 500 t	< 1 000 t	< 2 000 t

In order to help applicants for a fish farm project optimize their choice of site, as a rough guide we are suggesting an eligibility grid for fish farming sites (Table XIII). This grid is empirical, in the absence of sufficiently precise scientific data (see §11.2). It cannot therefore replace a precise study of the site for the envisaged fish farm (currents, water movement, modelling of the diffusion of the mineral or organic substances produced) and cannot take into account the characteristics that are peculiar to a project (types of feed used, economics of their distribution, presence or not of antibiotics, mass of fish per cubic metre, etc.).

99 *Posidonia oceanica* meadow is indeed absent at this depth (see §2.3).

100 The impact assessment is mandatory in some countries or regions (see above).

The main element of the decision-making process that we are suggesting lies in the fact that permission to occupy the Maritime Public Domain for fish farming purposes should be restricted in time (as is anyway the case in some countries), and especially that their possible prolongation should depend on a demonstration (by the applicant or not) of an **absence of impact** on the *Posidonia oceanica* meadows. This constraint should lead applicants, in accordance with the precautionary principle, to interpret in the broadest sense the recommendations made in Table XIII.

12. THE *POSIDONIA OCEANICA* MEADOW AND DISCHARGE OF EFFLUENTS

12.1. THE PROBLEM

Among the many causes of the *Posidonia oceanica* meadows' regression, the discharge of effluents, whether urban, industrial or from leisure boats, bears a heavy responsibility (see Chapter 4). Domestic effluent represents 1% of the annual renewal of the water of the Mediterranean (UNEP, 1996). In the Mediterranean, 33.3% of these effluents has not been treated at all, 13.5% has been pretreated, 12.1% has undergone primary treatment, and 41.1% secondary treatment (UNEP, 1996).

Generally speaking, the discharge of effluents mainly acts at 3 levels on coastal marine habitas: **(i)** reducing water transparency, **(ii)** increasing the nutrient concentration, **(iii)** adding chemical contaminants. It can also bring about local drops in salinity that can harm *Posidonia oceanica* in that the species is stenohaline[101] (Ben Alaya, 1972). For *P. oceanica*, a photophilous species[102] that is sensitive to pollution, this discharge is thus a major factor of disturbance, on top of the other factors of regression (see Chapter 4).

Urban discharge presents a high nutrient and organic matter content. It directly (through turbidity) or indirectly (by encouraging plankton to develop) reduces water **transparency**. This has a negative impact on the *Posidonia oceanica* meadows, especially at depth: reduced shoot density, breaking up of the meadow and rise of the lower limit (Fig. 38).

The input of nutrients encourages the development of the *Posidonia oceanica* **leaf epibiota**[103] that intercept the light and thus harm their host's photosynthesis. Moreover, both directly (via the increase in the leaves' nutritive value) and indirectly (via the leaf epibiota) nutrients encourage grazing of *P. oceanica* by herbivores (see Chapter 4).

Urban and industrial discharge also acts on *Posidonia oceanica* meadows through the presence of **xenobiotics** (detergents, hydrocarbons, pesticides etc.): direct effects on *P. oceanica*, indirect effects on the flora and fauna of the ecosystem. Pollutants act on different levels according to their chemical characteristics: roots, rhizomes and/or leaves (Pérès and Picard, 1975).

The presence of pollutants causes a fairly marked change in the physiological activity of *Posidonia oceanica*: histological damage, impact on photosynthetic pigments, reduction in the growth rate of the leaves (Augier *et al.*, 1984b). Pollutants also have an impact on the other species of the ecosystem, giving rise to a drop in specific diversity, more marked for fauna (proportionally favoured) than for flora (Eugène, 1979).

12.2. CASE STUDIES

12.2.1. Meadows in the Genoa Region

Balduzzi *et al.* (1984) studied the situation of some *Posidonia oceanica* meadows in the Ligurian Sea (Genoa

101 A stenohaline species is one whose tolerance of variations in salinity is little.

102 A photophilous species (etymologically "light-loving") is one that lives in well-lit habitats.

103 Leaf epibiota (= epiphytes) are organisms that attach themselves to a plant (in this case, *P. oceanica* leaves) which only constitutes a substratum for them. Thus they are not parasites.

Region, Italy) subject to several kinds of pollution and compared it with Issel's description (1912, 1918b) in the early 20th century. The massive pollution from the central parts of Genoa and its port caused the disappearance of *P. oceanica* from the most directly affected areas, whereas, further east, along the Ligurian coast, the mainly domestic pollution and earthy discharge provoked a regression of the meadow's upper limit without having any visible impact on the meadow's interior, except in certain particular cases.

Along the Genoa coast, for example, the *Posidonia oceanica* meadow is in a state of irreversible degradation in Foce, i.e. at the mouth of the Bisagno torrent and near the entrance to the port, whereas moving eastwards, thus away from the town centre, in Sturla, some isolated clumps can be found, only at 10 metres depth. Moving eastwards, the state of the meadow seems to resemble that formerly described by Issel (1912, 1918b), although at that time the upper limit was much nearer the shore. In some cases, the concentration of discharge in the big sewage outfalls opening out in front of the meadow has caused degradation there: a sizeable reduction in shoot density, a drop in the specific diversity of the epifauna, etc. In Nervi, i.e. 10 km from the town centre, the state of the meadow is much better, and the withdrawal of the upper limit seems more due to local human pressure than to pollution from the town of Genoa.

12.2.2. The Marseille sewage outfall

The waste water discharge of the town of Marseille (France) has from 1886 opened out east of the town, some kilometres from Cap-Croisette, in the Cortiou *calanque* (Fig. 102).

At the time (19th century) this was a considerable advance, since it was one of the first complete waste water collection and discharge networks in France. In 1959, the water of the Huveaune, a very polluted little coastal river that ran into the Prado Bay (Marseille), was partially diverted to the discharge (in summer) and then, completely, from 1977 on (Belsher, 1977; Bellan, 1994; Bellan *et al.*, 1999; Arfi *et al.*, 2000a). Usually the current pulls this waste water westward, i.e. towards Cap Croisette (Fig. 102). Since a physicochemical treatment plant started operating (October 1987), over 80% of suspended matter, 50% of organic matter, 15% of nitrogen, 40% of phosphates, 55% of hydrocarbons and 60-80% of heavy metals have been withdrawn from the effluent (Bellan, 1994; Bellan *et al.*, 1999). However, in all, the depollution rate only reaches an average 47%.

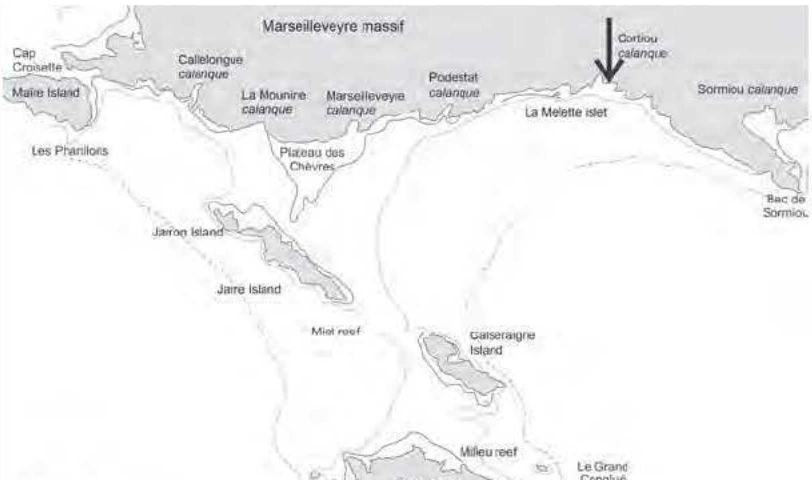


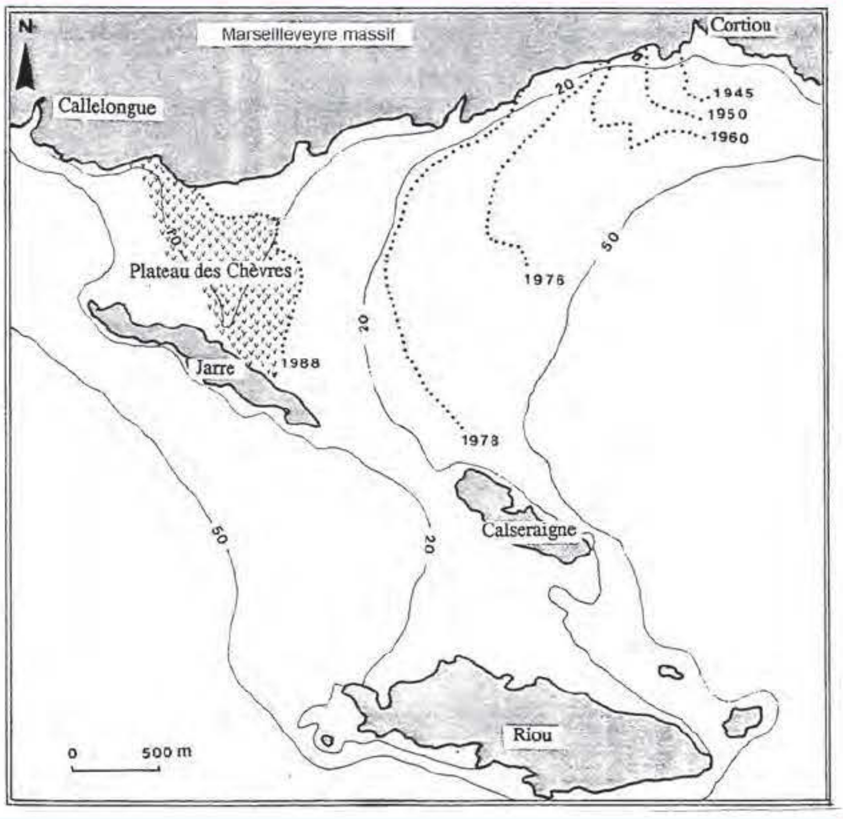
Fig. 102. Geographical location of the sector where the town of Marseille's urban discharge releases its water. The arrow shows where the sewage outfall is.

However, the imposed norms for discharge (e.g. reduction at source of pollutant additions, discharge of suspended matter limited to 50 mg/l with a maximum flow of 4.1 m^3/s, Bertrandy, 1990) have brought about a clear drop in turbidity and more generally in pollution in this sector. The regression of the *Posidonia oceanica* meadow has been spectacular, mainly between Cortiou and Cap Croisette (Fig. 102 and 103). This regression, as is obvious from the assessments of Blanc and Jeudy de Grissac (1978) resumed by Pergent-Martini and Pergent (1990) (Fig. 103), does seem to have been exaggerated; for example, it does not appear that the meadow ever existed near Cortiou, and also no "dead matte" is observed there (Pergent-Martini, 1994). An attempt to reconstitute the historical data allows us to estimate at **471 hectares** the surface area occupied by the meadow in the early 20th century, and at **263 hectares** in 1994, i.e. a regression of nearly 46% (Pergent-Martini and Pergent, 1996; Arfi *et al.*, 2000b).

Since the treatment plant started operating, this regression seems to have stabilized. Signs of recuperation, naturally very slow, have even been seen at the level of a characteristic structure (aureole produced by a bomb; Fig. 104) as well as recolonization by the meadow as regards its lower limit (Pergent *et al.*, 1988; Pergent-Martini and Pergent, 1990; Pergent-Martini *et al.*, 2002).

The case of the Cortiou sewage outfall is particularly interesting in that the pipe was laid down in a sector where the other causes of the *Posidonia oceanica* meadow's regression do not, or did not, at the time when it regressed, have a major role. Indeed, **(i)** there are no ports in the sector; **(ii)** trawling cannot (in theory) be blamed when the seabed is too superficial[104]; **(iii)** the development of leisure boating, and thus anchoring, postdates most of the regression and **(iv)** there are no fish farms in the sector. Thus, unlike in other Mediterranean regions where many causes of regression act in synergy and are thus hard to separate (see §4.13), the regression of the *P. oceanica* meadow in the Cortiou sector can clearly be related to the discharge of waste water by an urban sewage outfall.

Fig. 103. Changes in the position of the lower limit of the *Posidonia oceanica* meadow (dotted line) between Cortiou *calanque* (where the waste water of the town of Marseille is released) and Callelongue calanque (east of Cap Croisette, Marseille) since 1945 (according to Blanc and Jeudy de Grissac, 1978). The present extent of the meadow in the sector is shown by the letters "v". Continuous lines show the isobaths. The meadow is present further south, between Calseraigne and Riou Islands, but has not been shown on this map. Since 1987, waste water from the town of Marseille has been treated by a physicochemical treatment plant. According to Pergent-Martini (1994), this map exaggerates the regression of *P. oceanica*; the meadow was certainly never present near Cortiou.



104 In fact, this point should be considered with caution illegal trawling has indeed been regularly seen in this sector over a seabed of only 8 metres.

12.3. RECOMMENDATIONS

No waste water discharge should open out into a *Posidonia oceanica* meadow. This is valid whatever the level of water treatment; indeed, this is fresh water that would usually rise to the surface, but the base of whose dilution cone can have a certain grip on the seabed, according to currents and during storms; now, *P. oceanica* is very sensitive to the low salinity (see §2.3). Additionally, even if phenomena of natural recolonization can be seen, they should not blind us to the fact that the species' biology means that the reconquest of a single hectare can take almost a century (Pergent-Martini, 1994).

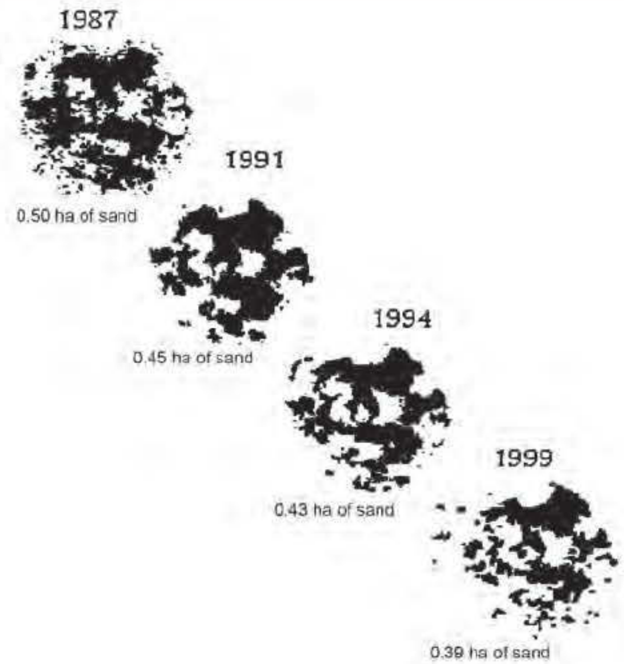


Fig. 104. Regression of areas of sand (in black) in favour of recolonization by the *Posidonia oceanica* meadow (in white) between 1987 and 1999, where a bomb dating back to World War Two had fallen, on the Plateau des Chèvres (Marseille, France), after the town of Marseille's treatment station started operating. From Pergent-Martini *et al.* (2002).

Whether the pipes are old or new, there should be **monitoring** of the nearest *Posidonia oceanica* meadows, using markers and permanent quadrats (see §16.2), to check that the level of treatment is sufficient.

In the case of **old sewage outlets**, as is the case of that of Hyères-Carqueiranne[105], in Giens Gulf (Var, France) (Boudouresque *et al.*, 1988), a "dead matte" area already surrounds the point of release. Its evolution should be monitored using markers and permanent quadrats (see §16.2). If the situation has stabilized, especially if the meadow has begun to recuperate, as is the case in Giens Gulf (Charbonnel *et al.*, 1997a), after a treatment plant has started operating, or there is an improvement in its rate of treatment of waste water, it is usually not necessary to undertake expensive work to move the pipe or extend it beyond the limits of the meadow.

In the case of new sewage outlets, a **minimum distance** should be planned between the point of release and the nearest meadows (Table XIV). This grid is obviously very simplistic; in fact, the most important thing for a *Posidonia oceanica* meadow is firstly a big reduction in SM (suspended matter) and secondly a reduction in the discharge of nutrients and detergents, aims that should be attained without difficulty with the application of the European Directive on Urban Waste Water Treatment (EUR of 30 May 1991). The effectiveness of the reduction also depends on the kind of treatment used (Table XV), so that it would be a good idea to increase the distances by 50% in the case of treatment of the physicochemical type alone.

Regarding the waste water **pipe**, when a new pipe is laid, crossing a *Posidonia oceanica* meadow should be avoided, or the length of meadow crossed minimized (see Chapter 14). When the pipe crosses a meadow, it must not be buried (see Chapter 14). Furthermore, for various reasons (ageing of materials, collision with fishing gear, etc.), it is not unusual that these pipes present leaks. There must therefore be regular inspections (every year).

105 District Association of Hyères-Carqueiranne for cleaning up Giens Gulf.

Table XIV. Minimum distance recommended between the point of release of a sewage outlet and the nearest *Posidonia oceanica* meadow, according to the size of the discharge and the rate of treatment.

Rate of treatment	Wastewater load (population equivalent)				
	<1 000	1 000 - 10 000	10 000 - 100 000	100 000 - 1 million	>1 million
<10%	100 m	200 m	300 m	500 m	800 m
10-50%	50 m	100 m	200 m	300 m	400 m
>50%	20 m	50 m	100 m	150 m	200 m

Table XV. Effectiveness of reduction of various elements in domestic effluent, according to type of treatment installed after mechanical pretreatment. * low effectiveness; ** medium effectiveness; *** good effectiveness; SM = Suspended Matter

	SM	Organic C	N	P	Metals	Detergents	Bacteria
Physicochemical	***	**	**	*	**	*	*
Biological	**	**	**	**	**	**	**
Lagooning	**	***	**	***	***	***	***

13. THE *POSIDONIA OCEANICA* MEADOW AND SOLID WASTE

13.1. THE PROBLEM

Once built, ports have a tendency to silt up, at variable speeds. Regular dredging is necessary, and the problem then is that of the release of **dredged mud** and its impact. This mud is rarely stored on land; in fact, to cut costs, it is often released in the sea in dumping sites intended for this purpose, as long as its pollutant content is moderate (Mauvais, 1990). In Italy, between 1988 and 1997, 4.8 million cubic metres per year on average were dumped at sea, 0.7 million cubic metres per year of this in Liguria (Barbera, 2000).

The vertical growth of orthotropic *Posidonia oceanica* rhizomes does not allow the meadow to resist sedimentary entry of more than 5-7 cm/year (see §4.1). Dumping fairly dissolved materials from the dredging of ports or canals on the *P. oceanica* meadow thus has an extremely negative impact (see §4.10).

This impact on the *Posidonia oceanica* meadow is **direct** – it is **buried** at the site of waste release. The death of the meadow is quick, even if, over later months or years, the sediment can be re-suspended by hydrodynamism. It is also **indirect**: re-suspending the sediment, which settles further away, gives rise to the silting of the surrounding areas of meadow. Moreover, re-suspending fine particles increases the water's **turbidity**[106] (see §4.3); now, *P. oceanica*, a photosynthetic organism, needs light. The negative impact of dumping on the meadow has been demonstrated particularly in Liguria (Italy; Peirano and Bianchi, 1995), in Corsica in the Gulf of Porti-Vechju (Pasqualini *et al.*, 1999), and in Portmán (Murcia, Spain), where mining waste rich in mercury, lead, cadmium, zinc and manganese (2.5Mt/year) is released out at sea, including over *P. oceanica* meadows (Ros, 2003).

When the discharge is made up of **rock slabs** from coastal work, especially the removal of rocks, the direct impact is of course due to the (irreversible) covering of the *Posidonia oceanica* meadow. An indirect impact is also possible, because of hydrodynamism, through erosion around the blocks if they are big and movement of them if they are small. This impact is partly comparable to that of the deadweight moorings sunk in organised or unauthorized mooring (see §8.2.2).

Lastly, we should mention **macrowaste** discharge of human origin (bottles, batteries, tyres, engines, etc.) that as well as causing possible pollution and the aesthetic deterioration of underwater landscapes, whatever the ecosystem concerned, has the same effect on the *Posidonia oceanica* meadow as slabs of rock (see below) (e.g. Relini, 1972; Clark, 1986; Bianconi *et al.*, 1990; Guéna and Thomas, 1997a, 1997b; Thomas, 1997; Meinesz *et al.*, 2001b).

13.2. CASE STUDIES

In spring 1989, Saint-Jean port (La Ciotat, Bouches-du-Rhône, France) was dredged. 1 013 m^3 of dredged mud was dumped over the *Posidonia oceanica* meadow (between 27 and 35 metres depth) in the bay of La Ciotat. The site indicated by the authorities lays much

106 The negative effect of turbidity increase not only concerns the discharge of mud from dredging over the *Posidonia oceanica* meadow but also discharge that is outside the meadow, but too close to it.

further out to sea. This mud formed a number of heaps (each certainly equal to the discharge from a barge) from 80 to 100 cm high and with a surface area of about 30 m² (Fig. 105). The mud piles slowly spread out over the seabed; 6 months later, their height had been reduced by half (40 cm) and their diameter had doubled (Fig. 105). Under these heaps, the *P. oceanica* meadow died (Rivoire and Ceruti, 1989). Diving explorations in the bay of La Ciotat enabled many circular patches of dead meadow to be discovered, which could correspond to older dumping of dredged mud (Rivoire and Ceruti, 1989). It should be pointed out that it was not the authorities who discovered that the company responsible for the work was not respecting the contract specifications, but the residents of La Ciotat and local NGOs.

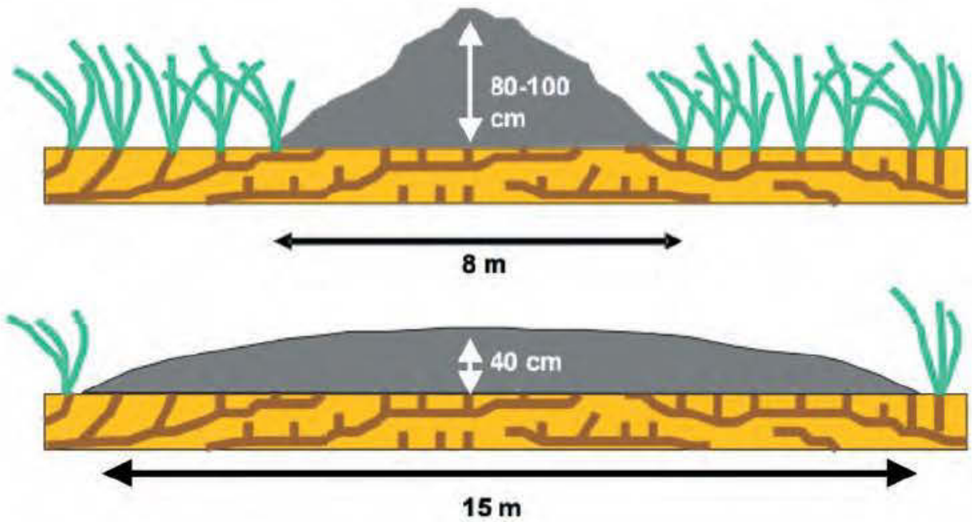


Fig. 105. Dumping of dredged mud (in grey) from Saint-Jean port (La Ciotat, France) over the *Posidonia oceanica* meadow. Above 2 days after the dumping. Below 6 months after the dumping. From Rivoire and Ceruti (1990), redrawn (C.F. Boudouresque).

In Cassis (Bouches-du-Rhône, France), as part of the improvement of Saint-Pierre quay, the sinking of **materials from rock removal** (about 600 m³) was permitted on the outer embankment of the port's southern protective sea wall, in the late 1990s. Furthermore, only the rocky materials, with the exception of silt and other products from the demolition, could be dumped out at sea. But, contrary to what had been provided for, the company responsible for the work dumped the discharge, or part of the discharge, directly over the *Posidonia oceanica* meadow located between 50 and 100 metres from the port's sea wall. Blocks of rock up to 1 metre in diameter, gravel and fine materials caused major degradation of this meadow (Fig. 106). Later on, the company responsible for the work was asked to remove blocks of sufficient size that the withdrawal operation would not cause additional degradation to the *P. oceanica* meadow (Bonhomme and Palluy, 1998). As in La Ciotat, it was not the authorities who discovered that the company responsible for the work was not respecting the contract specifications, but a local NGO.

In 1995, a public works company, acting in the Madrague district (Saint-Cyr-sur-Mer, Var, France), under the control of the town council and the Regional Equipment Department (the DDE), chose to dump rubble from a sea building site over a *Posidonia oceanica* meadow, and not in a dumping site, as was provided for. Given the protection that *P. oceanica* enjoys in France (see §5.1.2), the case was referred to the court and investigations were ruled for "*degradation of non-cultivated* *and protected plant species*". In 1989, in Cavallo (southern Corsica), the sponsor and the 3 entrepreneurs who had started to build a private port were sentenced by the Tribunal Correctionnel (court trying fairly serious criminal cases) of Ajaccio (Corsica); the ruling concerned 5 offences, including "*execution of building work without a building permit in a 100 m coastal strip*", and "*mutilation of protected plants*"; indeed, the slabs of rock had been placed over a *P. oceanica* meadow (Pergent, 1991a).

We do not go into here the cases, fortunately the most frequent, of discharge of dredged mud that has indeed been done in sites permitted by the administration that has competence in the matter, defined on scientific (ecological, toxicological) and economic grounds very far away from *Posidonia oceanica* meadows (e.g. Cocito *et al.*, 1994; Salen-Picard *et al.*, 1997; Ausili and Gabellini, 2000; Matteucci, 2000; Pellegrini, 2000; Virno-Lamberti, 2000) or the possible impact on other ecosystems than the meadow.

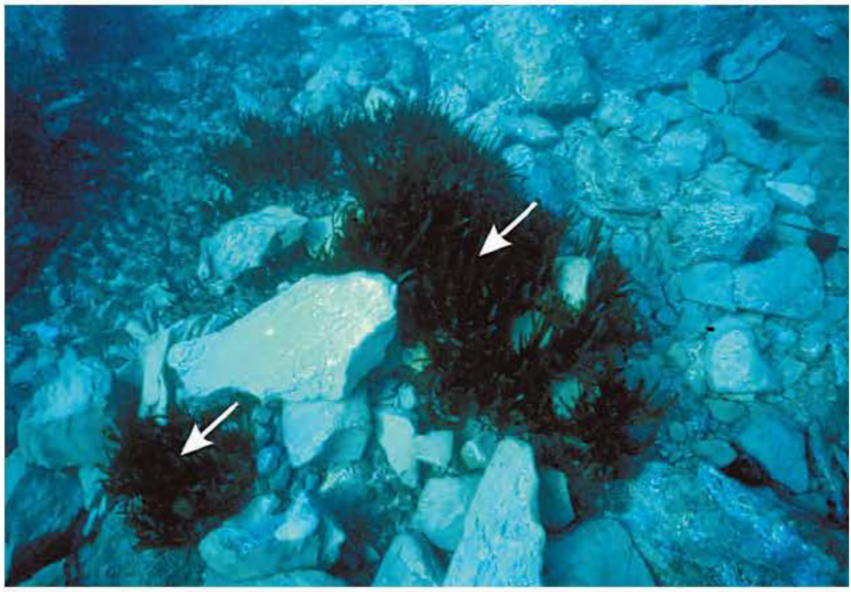


Fig. 106. Dumping of slabs of rock from rock removal onto the *Posidonia oceanica* meadow off the port of Cassis (Bouches-du-Rhône, France). A few clumps of *P. oceanica* (arrows) have escaped being buried. Photo by J. Laborel.

There are also some cases of steps that have been taken to protect the surrounding *Posidonia oceanica* meadows from any impact, direct or indirect, during dredging and rock removal operations. The port development of the Pointe du Canier (Saint-Mandrier, Var, France) is exemplary from this angle. From the start it was given scientific assistance. The meadows near the development area were marked at the surface during the whole period of the work; this marking defined the area of the building works which the various site equipment in operation should never cross. Protective geotextile screens (see §7.3.3) were placed in front of the main areas of meadow in order to restrict the diffusion of fine particles. Lastly, regular inspections of the seabed to assess the state of the meadow's vitality were made during the entire period of the building work. When situations that were critical for the meadow were observed, the frequency and intensity of the dredging operations were reduced, as is (moreover) stipulated by the legislation in force (see §13.3). Monitoring the meadow confirmed that the meadow had in all only been very locally affected by the building works (Bonhomme *et al.*, 2001, 2003b, 2003c, 2004).

13.3. THE LEGISLATIVE FRAMEWORK

Internationally, discharge at sea comes under the London Convention[107], signed by most of the Mediterranean countries, including those within the RAMOGE Agreement. Discharge of any substance or material not appearing on the reverse list is forbidden[108] (Barbera, 2000).

In Italy, the discharge of dredged mud at sea is controlled by the Ministerial Decree of 24 January 1996, which complies with

107 The London Convention (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter) was signed in 1972. Its additional Protocol dates back to 1996.

108 This *reverse list* was introduced by the 1996 Protocol. It replaces the list of permitted substances and materials, and is thus much more restrictive (Pellegrini, 2000).

the provisions of the London Convention (Barbera, 2000). In Leghorn (Italy), a series of discharge sites was defined more than 30 km out to sea, very far away from the nearest *Posidonia oceanica* meadows (Secche della Meloria), with the site changing from one discharge operation to the next (Barbera, 2000).

In France, dredging and discharge are subject to declaration, in accordance with Law no. 92-3 of 3 January 1992 on water and the Interdepartmental Order of 23 February 2001([109]). Permission is delivered by the *département* (the chief administrative division in France) prefect, after preparation of the file by the Maritime Department (Coastal Water Quality Unit, Facilities Board of the *département*).

13.4. RECOMMENDATIONS

No discharge of products of dredging or slabs of rock should be permitted over the *Posidonia oceanica* meadow, as, besides, over any ecosystem with great ecological or economic value (GESAMP, 1975, 1982).

In the European Union countries (and thus in the RAMOGE area), dumping permits usually specify sites for release that are far away from the coast, and are thus not located over *Posidonia oceanica* meadows. However, it has often been noticed that public works companies responsible for this discharge, in the absence of active monitoring by the authorities, **shorten**, sometimes considerably, the distance of the discharge. Slabs of rock or products from dredging have thus been dumped directly over the *P. oceanica* meadow.

The **choice of the company responsible for the work** is thus very important. The *collectivités territoriales* (regional authorities) which, within the context of a call for tender, very logically choose the *lowest bidder* (the cheapest) must be aware of the fact that an exaggeratedly low cost can imply *ipso facto* that the **contract specifications will not be respected**, and therefore the discharge will be much nearer the dredging site than provided for (possibly over the *Posidonia oceanica* meadow).

Moreover, it is very shocking that it is often private individuals and **NGOs** who **alert** the authorities to the dumping of products from dredging and slabs of rock over a *Posidonia oceanica* meadow, thus non-respect of the contract specifications. This absence of vigilance could in fact be interpreted as condonation.

109 Also see the *Journal Officiel* (JO, government publication) of 30 March 1993.

14. *POSIDONIA OCEANICA* MEADOWS AND THE LAYING OF CABLES AND PIPES ON THE SEABED

14.1. THE PROBLEM

It is often necessary, to provide an island with electricity or water, that a cable or "sea-line" pipe be installed on the seabed. The questions asked are: **(i)** Do these installations have an impact on the natural environment, first and foremost on the *Posidonia oceanica* meadow? **(ii)** Are some of the techniques for laying these less harmful than others? **(iii)** What overall strategy must be implemented to mitigate the impact?

Today we possess many impact assessments that were done before cables or pipes were laid and which, according to the local features (topography, biocenoses crossed, potential risks linked to uses – anchorage, trawling), make recommendations as to the technique to be implemented and the route to be taken (Meinesz and Bellone, 1989; Avon *et al.*, 1992; Francour *et al.*, 1992; Pergent-Martini *et al.*, 1992a; Pasqualini and Pergent, 1993; Charbonnel and Francour, 1994; Charbonnel *et al.*, 1994b, 1995c, 1995e; Bellone and Meinesz, 1995; Ruitton and Chiaverini, 1997; Charbonnel *et al.*, 1998, 1999; Bonhomme *et al.*, 1999; Charbonnel *et al.*, 2000a; Pergent *et al.*, 2002b; Bernard *et al.*, 2003; Pergent *et al.*, 2003). This experience allows a decision-making process to be formalized. Unfortunately, little data exists on the actual evolution of the settlements over the years which follow the work of laying down, that would enable the choices that were made to be validated (or not) (Pasqualini and Pergent, 1993; Molenaar, 1994; Charbonnel *et al.*, 2000a; Pergent *et al.*, 2002b).

Furthermore, in almost every case, the Contracting Authority has decided beforehand on the sites of departure and arrival on land ("landing" or "grounding") of the pipe or cable, according to 3 imperatives: **(i)** the shortest possible sea route (supposedly a straight line); **(ii)** the cost of land work and of burying to reach these sites of departure and arrival; **(iii)** safety of the placing in relation to the risks of being moved and degradation linked to uses (anchorage, fishing with towed gear). This practice is incompatible with a correct strategy for minimizing the environmental impact.

14.2. CASE STUDIES

14.2.1. Drinking water pipe between Hyères and the island of Porquerolles

To improve the provision of drinking water to the island of Porquerolles (Var, France), the town of Hyères planned to lay a 15-16 cm diameter pipeline with a flow of about 100 cubic metres a day. According to technical imperatives, the route originally proposed was from Tour Fondue to Bon-Renaud cape (Fig. 107). A major constraint was that the route had to enter an area that was forbidden to mooring and trawling because of the lines of cables already laid down (Francour *et al.*, 1992; Bernard *et al.*, 2003).

Benthic habitats, especially the *Posidonia oceanica* meadow, have been mapped with precision (7 km²) using aerial photography, field verifications and transects observed by divers (Francour *et al.*, 1992). Such mapping has shown that the map then available for the sector (Blanc, 1975) was very inexact. Moreover, a quality bathymetric profile of possible routes was established.

It is important to know whether there are unevennesses such as erosion scarps or rocky cliffs; indeed, the pipe cannot adjust exactly to a very uneven seabed, and as a result is exposed and precariously balanced (Fig. 108) and thus vulnerable to hydrodynamism, trawling and anchors.

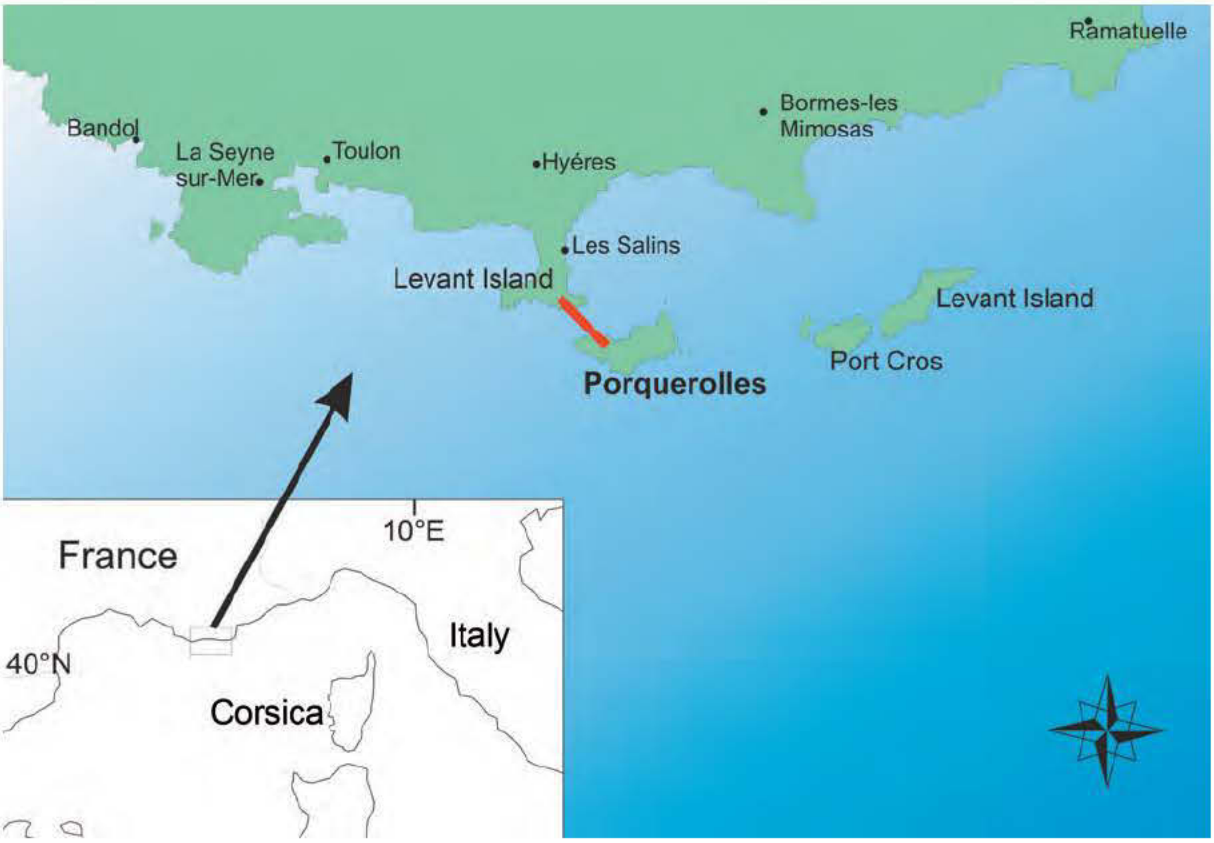


Fig. 107. Route originally traced for the pipeline between Tour Fondue (Giens Peninsula, Hyères, Var, France) and Bon-Renaud Cape (Porquerolles Island).

Fig. 108. An underwater cable, exposed and precariously balanced, in Marseille (Prado Bay). The erosion scarp in the *Posidonia oceanica* meadow is visible on the right. From Charbonnel *et al.*, 1999). Photo by E. Charbonnel.

On the basis of this new map, it appeared that 100% of the **original route** (the route originally traced) lay on the meadow. The **optimal route** for the pipe, that kept the crossing of the *Posidonia oceanica* meadow to a minimum (about 65% of its route) would have been the following: Tour Fondue–islet of Petit-Langoustier–Sainte-Anne cape (Fig. 109). However, this route presented many disadvantages (from economic and technical criteria) : **(i)** it became too deep (almost 40 metres over one-third of the route); **(ii)** the land route, on Porquerolles Island, was much longer; **(iii)** one part of the sea-line was outside the area where mooring and trawling are prohibited. A first compromise line (**compromise route 1**) was suggested: 80% of it still ran over the meadow, and 55% over dense meadow, and it ended in the Rousset cape (Fig. 109; Francour *et al.*, 1992). After much more precise mapping (aerial photography, side-scan sonar[110] and field verifications), a new compromise route (**compromise route 2**) was suggested (Fig. 109; Bernard *et al.*, 2003).

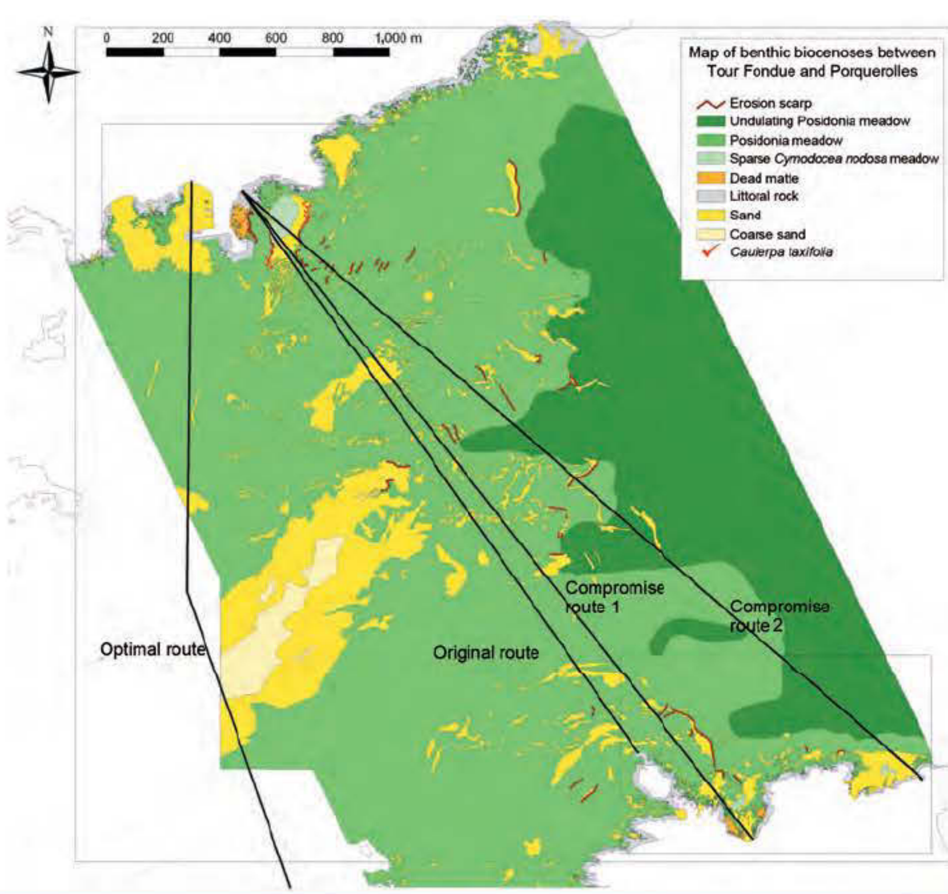


Fig. 109. Map of the seabed between the Giens Peninsula (top) and the island of Porquerolles (bottom) (Var, France). Original route (suggested by the Hyères town council), optimal route (minimizing the impact on the *Posidonia oceanica* meadow) and compromise routes 1 and 2. From Bernard *et al.* (2003).

The route selected by the Contracting Authority (compromise route 2) crosses, near Tour Fondue, a meadow that is highly uneven and has erosion scarps (shifting intermattes in particular; see §2.5). To avoid parts of the pipe being exposed and precariously balanced, it seemed necessary to **bury it in a trench**[111], despite the negative consequences for the meadow: **(i)** direct, by destruction of the meadow; **(ii)** indirect, through the trench being widened by hydrodynamism and erosion; **(iii)** indirect re-suspending sediment and increasing turbidity (Francour *et al.*, 1992). It should be noticed that in cases where the pipe is not buried, when the meadow presents great unevenness and the depth is less than 20 metres, hydrodynamism alone can dig out a trench around the pipe (Bernard *et al.*, 2003). The surface area of the meadow directly destroyed by laying the pipeline was estimated to be between 0.6 and 2.1 hectares (Table XVI; Francour *et al.*, 1992; Bernard *et al.*, 2003).

110 Side scan sonar data was acquired in 2000 as part of the "Posicart" campaign funded by the PACA Regional Council, the Rhône-Mediterranean-Corsica Water Board, and DIREN PACA.

111 Burial digging a trench at the bottom of which the pipe or cable is laid, then covering it up again with sediment.

Table XVI. Estimate of the surface areas of the *Posidonia oceanica* meadow destroyed by the laying of a pipeline between Hyères (Tour Fondue) and the island of Porquerolles (Var, France). Compromise route 1. From Francour *et al.*, 1992.

Type of meadow			Trenching and rock removal	Length (m)	Direct impacts (m²)	Indirect impacts (m²)	Total impacts (m²)
Sand		absent	No	400	0	0	0
Posidonia oceanica meadow	North	Strong relief, high cover	Yes	500	500	2 500-7 500	3 000-8 000
	Centre	Low cover	No	820	160	1 600	1 760
	South	High cover	No/Yes	500	100-500	500-7 500	600-8 000
	South on rock	High Cover	No/Yes	180	40-200	180-2 700	220-2 900
			TOTAL	2 400	800-1 360	4 780-19 300	5 580-20 660

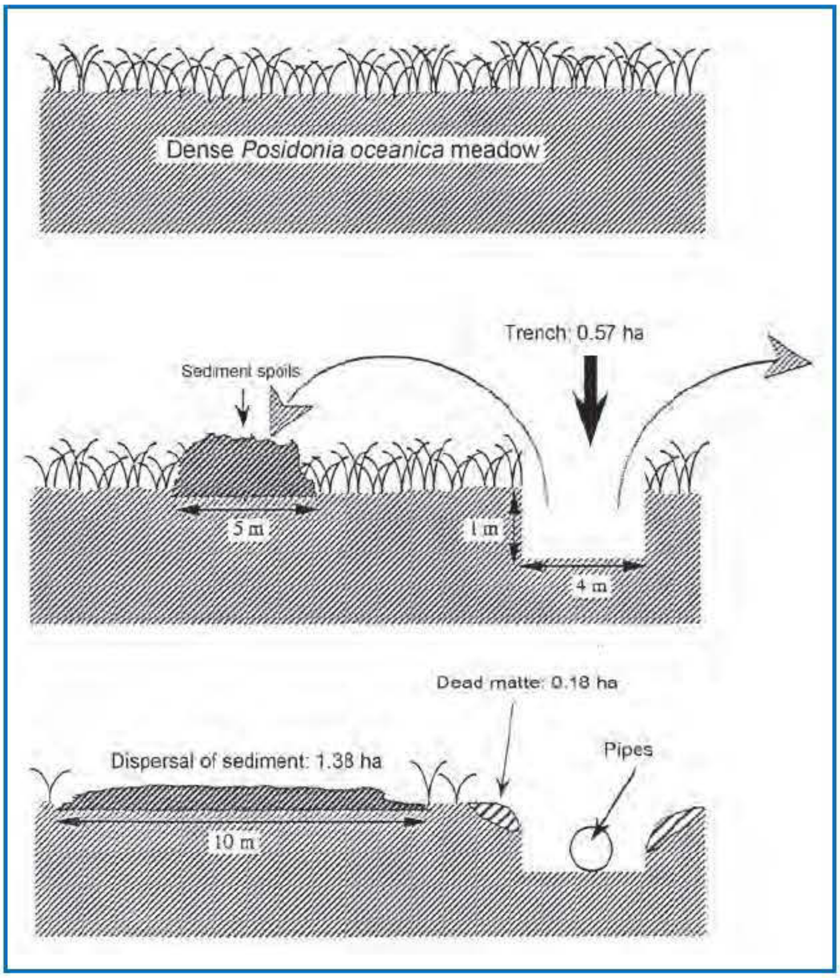


Fig. 110. Diagram of the direct and indirect impacts caused by the digging of a trench in the *Posidonia oceanica* meadow to hold a pipe carrying fresh water from Cannes to Sainte-Marguerite Island (Lérins Islands, Alpes-Maritimes, France). From Molenaar (1994).

14.2.2. Water pipes between Cannes and Sainte-Marguerite Island

2 water pipes were laid in 1992 between Cannes and Sainte-Marguerite Island (Alpes-Maritimes, France). Digging the trench for them, over a length of 1 500 metres (1 200 metres of this in the meadow), caused directly or indirectly the destruction of 2.13 hectares of meadow: the trench itself (0.57 hectares), the widening of the trench by hydrodynamism (0.18 hectares) and the burial of the meadow under sediment from the trench (1.38 hectares) (Fig. 110; Molenaar, 1994). The indirect destruction of the meadow thus almost tripled the surface area that had been directly destroyed.

112 EDF Electricité de France.

It should be added that subsequently, after 1994, the regression continued, worsened by local hydrodynamic conditions (shallow areas and presence of currents from the east speeded up in the channel by the Venturi effect).

In 1992, in the same sector, between the Lérins Islands (Sainte-Marguerite and Saint-Honorat), the digging of a trench using a mechanical digger on a barge to protect an EDF[112] electric cable had a very great effect on the *Posidonia oceanica* meadow (Fig. 111; Ruitton and Chiaverini, 1997). Indeed, over a 760 metre underwater route, 2.65 hectares of meadow were destroyed, and a 30-65 metre wide channel of "dead matte" appeared around the trench.

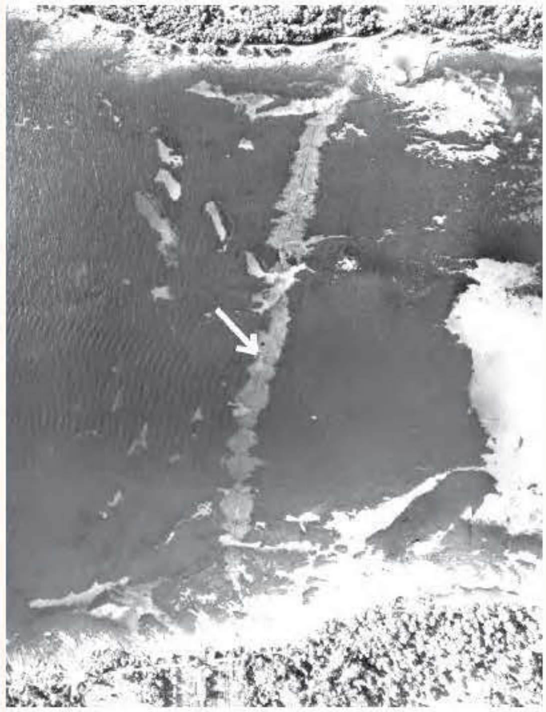


Fig. 111. Trench opened in the *Posidonia oceanica* meadow to house an electric cable (arrow). Lérins Islands (Alpes-Maritimes, France). Aerial® photo.

14.2.3. Telephone cable between the continent and the island of Port-Cros

To improve the telephone link between the continent and the Hyères Islands (Var, France), France Télécom decided to lay down a new optic fibre underwater cable to replace the existing network. Nearly 50 km of cable was to link Tour Fondue (Giens peninsula, the continent) with the islands of Porquerolles, Port-Cros and Le Levant, and thence to Bormes-Le Lavandou on the continent (Charbonnel *et al.*, 1995f). Much of the route was over the Hyères Gulf *Posidonia oceanica* meadow, the biggest on the French continental coast (Boudouresque and Meinesz, 1982; Astier and Tailliez, 1984).

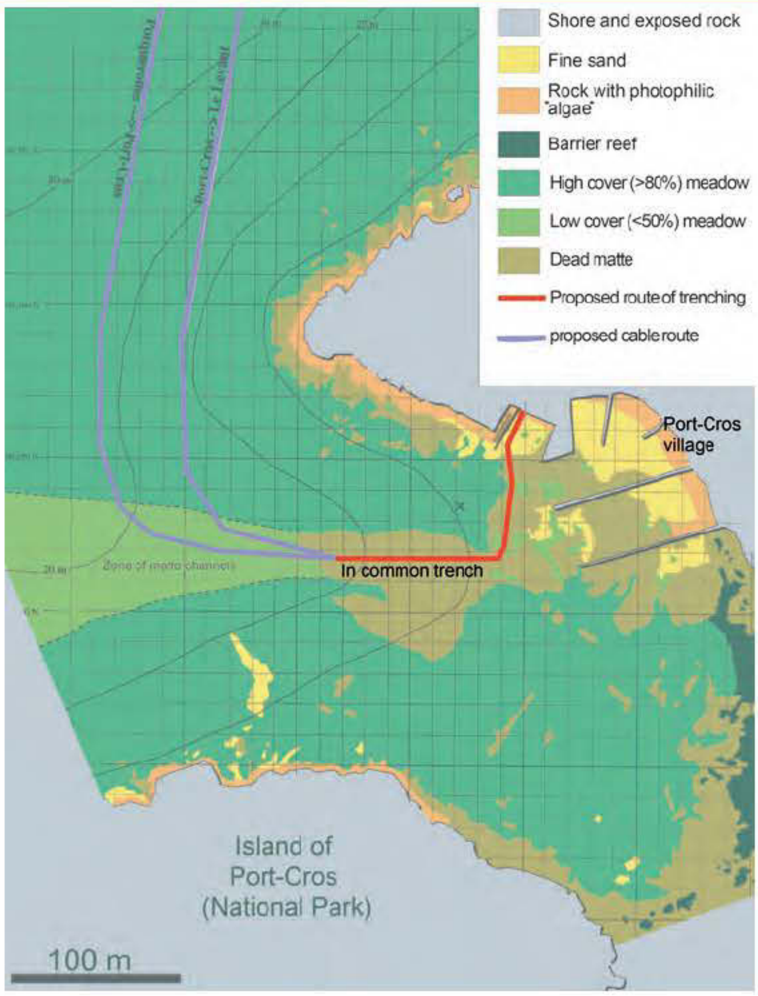


Fig. 112. Suggested route (in red and mauve) for the France Télécom cable between the continent and the Hyères Islands (Var, France) coming up to land at Port-Cros. From E. Charbonnel *et al.*, 1995f.

The impact assessment, with its mapping of the benthic habitats in the areas where the cable comes up to the land, showed that housing the cable in a trench (near these areas) is possible in Tour Fondue (over 280 m distance), in Port-Cros (over 210 m) and in Bormes (over 800 m) without causing any particular ecological impact: the seabed is in fact occupied by "dead matte" or sand. The technique of trenching is generally preferred by the Contracting Authority, since it guarantees maximum safety from the risks of use-linked deterioration and displacement. In Le Levant, it also seems possible to remove the rocks over a length of 30 metres without harming the *Posidonia oceanica* meadow. Lastly, the depth increases quickly and it is no longer necessary to protect the cable by housing it in a trench; it can just be laid on the seabed (Charbonnel *et al.*, 1995f).

In Port-Cros, in the water of the National Park, where the cable comes up to the land, the impact study led to the suggestion that the original route should be moved 70 metres southward, allowing the live meadow to be avoided and the cable to be housed in a trench, since the seabed was made up of "dead matte". Moreover, the presence of a historic wreck (sunk in 1710; Guérout, 1981) also made it necessary to shift the originally traced route (Fig. 112; Charbonnel *et al.*, 1995f).

14.2.4. Electric cable between Corsica and Sardinia

There is an electricity link between Italy and Sardinia, via Corsica. The Corsica-Sardinia cable ("SACOI cable") was laid in 1967 by EDF. It starts from Cala di Sciumara (Bouches de Bonifacio, southern Corsica) and crosses various settlements and types of bed, including a *Posidonia oceanica* meadow (down to 33 m depth) (Fig. 116). The interest of the cable lies in its being one of the rare cases for which we have a study of its impact, 35 years after it was laid (Pergent *et al.*, 2002b, 2003).

Fig. 113. The electric cable between Corsica and Sardinia, simply laid over the meadow near Cala di Sciumara (Corsica). 35 years after it was laid (in 1967) there is no negative impact on the meadow. From Pergent *et al.* (2002b).

When the cable crosses areas of sand it seems to bury itself naturally under its own weight, gaining a good protection. When the cable was laid over a *Posidonia oceanica* meadow, without either being buried in a trench or material added, the natural growth of the rhizomes has partially covered it again, especially at depth (Fig. 113). When the cable was buried under imported material (little blocks of cement) the meadow has been destroyed over a width of 1 metre; given the slowness of *P. oceanica*'s growth, the recolonization has only been partial: 42% of the surface area recovered (Fig. 114 and 115). In any case, it does not seem that the cable has moved significantly under the effect of hydrodynamism; there are thus no secondary effects (Pergent *et al.*, 2002b).

Fig. 114. The electric cable between Corsica and Sardinia, near Cala di Sciumara (Corsica) was laid in 1967. It was fixed over the superficial meadows (10-15 metres) by covering it with little slabs of rock. 35 years later, the impact of this covering has not evolved. The line crossing it is a measuring tape unrolled over the bed during observations. From Pergent *et al.* (2002b).

Fig. 115. The electric cable between Corsica and Sardinia, near Cala di Sciumara (Corsica) was laid in 1967. Its hold on the meadows has been reduced by a start of recolonization of the slabs of rock by *Posidonia oceanica*. From Pergent *et al.* (2002b).

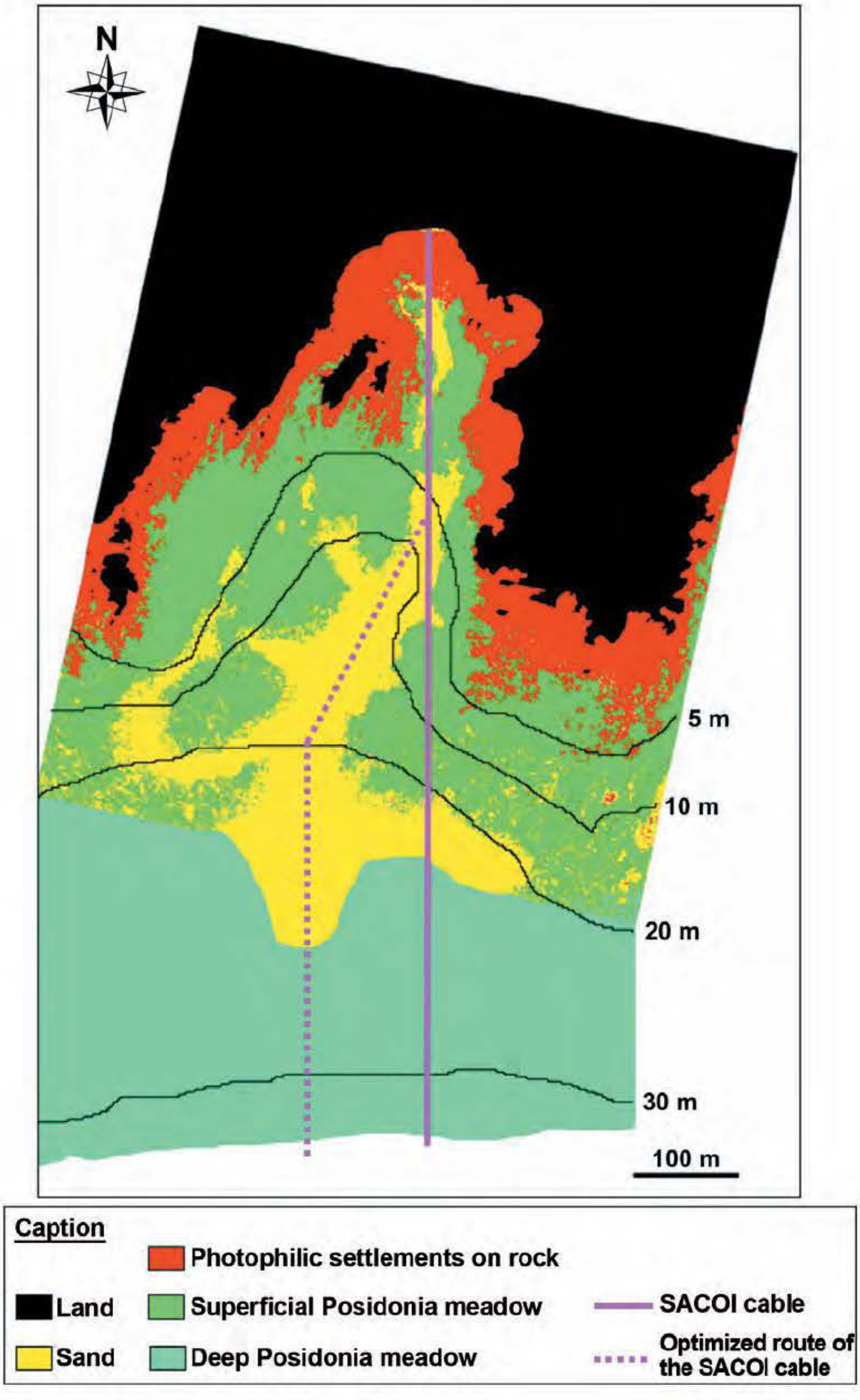


Fig. 116. Mapping the main habitats and seabed types present in Cala di Sciumara (Bouches de Bonifacio, southern Corsica). The route of the SACOI electric cable, laid in 1967 by EDF, and the optimized route that could have been selected if mapping had been done then, are shown. From Pergent *et al*. (2002b).

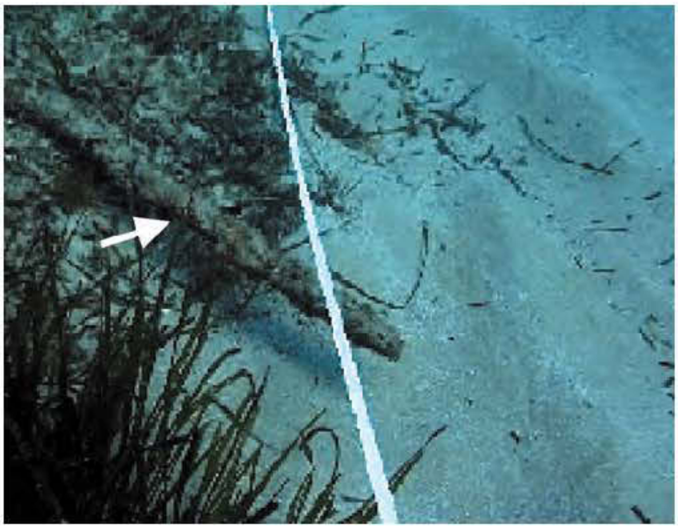


Fig. 117. An unused length of cable (arrow) left when the EDF cable was laid between Corsica and Sardinia lying in a *Posidonia oceanica* meadow, Cala di Sciumara. The line crossing the photo is a measuring tape unrolled over the seabed during observations. From Pergent *et al.* (2003).

The map of habitats and seabed types made by Pergent *et al.* (2002b) shows that the route taken by the cable could easily have been bettered, mostly avoiding the *Posidonia oceanica* meadow (Fig. 116). When the cable was being laid, unused lengths of the cable were left lying about, which constitutes visual pollution, especially regrettable in that the sector is today in the Bouches de Bonifacio Nature Reserve (Fig. 117; Pergent *et al.*, 2003).

14.3. RECOMMENDATIONS

(1) The Contracting Authority must propose a minimum 3 sites of departure and/or arrival at land. It can put these variants into its preferred order, explaining the reasons: additional cost due to the length of the underwater route, additional cost linked to the work on land or at sea (removal of rocks), etc.

(2) It is necessary to have a precise map (between the 1:1 000 and the 1:5 000) of the nature of the seabed (rock, sand, mud, etc.) and its settlements, particularly of the extent of the *Posidonia oceanica* meadow and its cover and types of meadow present, and also of other habitats of heritage value (coralligenous bioconstructions, *Cystoseira* forests, *Cymodocea nodosa* prairies, etc.) (Table XVII; Pergent *et al.*, 2002b). The rate of baring of the *P. oceanica* rhizomes must also be assessed (measuring procedure: Boudouresque *et al.*, 1980a; Charbonnel *et al.*, 2000b; see Chapter 16). In most cases, the preexisting maps are unsuited to the problem (Charbonnel and Francour, 1994) and a precise map must thus be drawn before any choice of route is made (Bonhomme *et al.*, 2003a; Denis *et al.*, 2003).

Table XVII. Ecological sensitivity of various habitats and seabed types. From Pergent *et al.* (2002b), modified.

Ecological sensitivity	Settlement and seabed type
Very high 6	*Posidonia oceanica* meadow on "matte" (striped, atolls) and on rock (staircase)
Very high 5	*Posidonia oceanica* meadow on "matte" (hill, sugar-loaf)
Very high 4	*Posidonia oceanica* meadow on rock (other), bioconstructions
High 3	*Posidonia oceanica* meadow on "matte" (plain meadow)
High 2	*Cystoseira* forest (on rock)
Low 1	*Cymodocea nodosa* meadow
Low 0	Other habitats and seabed types (sand, other "algae" on rock, etc.)

(3) Along the various routes envisaged or proposed (scenarios) it is necessary to establish very precise **bathymetric profiles** (vertical precision: 10 cm; horizontal: 1 metre), at least in sectors where there is great unevenness (Francour *et al.*, 1992; Charbonnel *et al.*, 1998; Bonhomme *et al.*, 1999). The presence of this unevenness (erosion scarp, erosive intermatte, etc.) may in fact make burial in a trench necessary. Also, the **hydrodynamism** must be assessed from indicators that can be observed on the seabed: erosive structures, baring of the rhizomes, undulating meadow, ripple marks etc. (Charbonnel and Francour, 1994; Bonhomme *et al.*, 1999).

(4) Digging a trench in the *Posidonia oceanica* meadow to house the pipe or cable (**burial in a trench**) is a technical choice to be avoided as far as possible (Table XVIII; Charbonnel *et al.*, 1995c, 1995f; Bernard *et al.*, 2003). In fact, the trench rarely keeps the sediment that covers the pipe (=filling in sediment) and hydrodynamism tend to widen the trench. The baring of the rhizomes, expressing strong hydrodynamim and/or a sedimentary deficit, is an indicator of this risk (Charbonnel and Francour, 1994). The fact that the filling sediment has gone has been verified between Cannes and Sainte Marguerite Island (Alpes-Maritimes, France; Molenaar, 1994) and in the Giens Gulf (Var, France); in the last case, the original (1 metre wide) trench has been widened to 35 metres (Gravez *et al.*, 1988). On the other hand, burial is well suited to crossing soft bottoms. **Just laying** the pipe on the seabed is possible when there is not much hydrodynamim, especially from 10 metres depth (Avon *et al.*, 1992). Apart from the low destruction of the meadow by direct burial, the indirect impacts on the meadow are very limited (Fig. 113; Table XVIII; Avon *et al.*, 1992; Pergent-Martini *et al.*, 1992a; Charbonnel *et al.*, 1995f, 2000a). In the case of meadows in good health, the impact can even be zero: in fact, the meadow tends to cover the cable and incorporate it in the matte, as has been seen for the cables that were laid down in former days between Tour Fondue and Porquerolles: a cable laid in 1948 is now covered by 35 cm of "matte" (Fig. 118; Charbonnel *et al.*, 1995c, 1995f). An intermediate solution consists of covering the cable under slabs of rock or cement to secure it (at shallow depth); this is particularly suited to rocky beds (Pergent *et al.*, 2003); in Cala di Sciumara (southern Corsica), where this technique was used over the meadow, the immediate impact was significant, but appears to be relatively modest after 35 years (Fig. 114 and 115; Pergent *et al.*, 2002b).

Fig. 118. A cable laid in 1948 between Tour Fondue and Porquerolles (Var, France) is today cover in "matte". The photo was taken on a segment where the *Posidonia oceanica* meadow is bared, revealing the cable. From Charbonnel *et al.*, 1995e). Photo by E. Charbonnel.

(5) When the pipe or cable is simply laid down on the seabed, it may be necessary to **secure** it, especially where there is strong hydrodynamism; the movement of the structure under the effects of the hydrodynamism can harm the bed, as well as the risk of the structure's deteriorating (Charbonnel *et al.*, 1995c; Bonhomme *et al.*, 1999; Pergent *et al.*, 2002b, 2003). In a meadow on "matte", concrete deadweight moorings are effective, but have a big grip on the bed (1-1.5 metres) and may give rise to secondary effects on the meadow when the hydrodynamism is strong; this solution was adopted, for example, between the Ratonneau Islands and Château d'If Island (Marseille, France) (Fig. 119; Charbonnel *et al.*, 1998, 2000a). The best thing would be to lay cast iron half-clamps or staples around the pipe or cable (Table XVIII; Charbonnel and Francour, 1994; Bernard *et al.*, 2003), or non-destructive clamps of the Harmony® or similar kind about every 10 metres (Fig. 120; Charbonnel *et al.*, 1995c; Francour and Soltan, 2000; Pergent *et al.*, 2002b, 2003). When the meadow is on rock, the best securing system is pegging, using a securing gun for underwater work of the Spit® Rock HD 200 kind, or one like it (Augier, 1969; Pergent *et al.*, 2003). Usually there is no danger of a pipe or cable being damaged by **trawls** since trawling (towed gear) is prohibited within 3 miles of the coast (France, Italy, Tunisia), and above the 50 m (Spain, Italy, Algeria, Gulf of Tunis), or 20 m (rest of Tunisia) isobath (Boudouresque, 1996). This law is, however, not respected in any country. It is thus necessary to study local fishing practices and envisage, with the maritime authorities (in France, the Maritime Affairs Department), an order

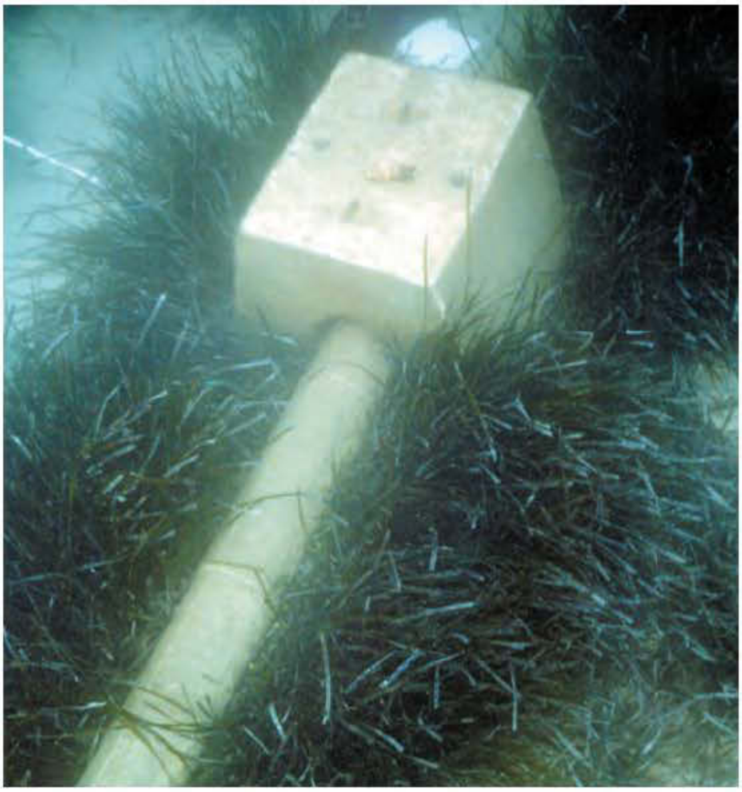


Fig. 119. Clamping a drinking water pipe crossing a *Posidonia oceanica* meadow by using deadweight moorings. Underwater pipe between the Ratonneau and If Islands (Marseille Gulf, Bouches-du-Rhône, France). From Charbonnel *et al.* (1998). Photo by E. Charbonnel.

Fig. 120. A Harmony®-type screw to hold a cable or pipe in a *P. oceanica* meadow on matte. From Francour and Soltan (2000) and Pergent *et al.* (2003).

Table XVIII. Direct and indirect impacts of laying a pipe over a *Posidonia oceanica* meadow, according to technique used. (-) negligible, (+) low, (++) great, (+++) very great. From Charbonnel *et al.* (1995b).

Technique	Direct impact	Indirect impact	Potential recolonization by meadow	Cost of implementation	Protecting the pipe
Ballast	+++	+++	-	+++	++
Staplers	-	-	+++	+	+
Half-shells	+	-	+	+	+
Weights at intervals	-	-	++	-	+
Small trench opened by jet of water under pressure (jetting)	++	++	+	++	+++
Big trench + filling	+++	+++	+	+++	+++
Anchorage on the seabed + resistant piping	+	-	+++	++	+++

forbidding mooring in the sector plus strict respect for the ban on trawling. If this is not enough, one solution is to lay down anti-trawl reefs (see Chapter 10). For example, in Cap Couronne (Bouches-du-Rhône, France) 13 t modules have been laid down to protect the telecommunications cables between France and Africa (Charbonnel *et al.*, 2001b; Frédéric Bachet, personal comm.; see Chapter 10).

(6) The presence of heritage elements other than *Posidonia oceanica* and the settlements mentioned in (2) (protected species such as the noble pen shell *Pinna nobilis*, wrecks of archaeological interest, etc.) must also be taken into account (Charbonnel *et al.*, 1995c, 1995f, 1999).

Table XIX. Grid for assessing the various scenarios for laying an underwater pipe or cable, from 0 (the worst scenario) to 100 (the best). An example of the calculation is given below.

Criteria		Method of calculation	Maximum number of points
Ecological criteria	C1. Length of the *Posidonia oceanica* meadow and other intercepted habitats	Percentage (P) of habitat intercepted (compared to the shortest route) and contribution (C) per habitat: *Posidonia oceanica* meadow (p): $C_p = P_p \times 0$ Bioconstructions (b): $C_b = P_b \times 0.1$ *Cystoseira* forest on rock (f): $C_f = P_f \times 0.2$ *Cymodocea nodosa* meadow (c): $C_c = P_c \times 0.3$ Other habitats (a): $C_a = P_a \times 0.4$	40
	C2. Types of *P. oceanica* meadow intercepted [a]	From 8 (no meadow or only plain meadow), to 6 (undulating meadow present), to 4 (hill meadow or sugar-loaf meadow present), to 2 (staircase meadow present) to 0 (striped meadow, atolls, barrier reef)	8
	C3. Other heritage elements	Protected species, wrecks of archaeological value: from 4 (absent) to 0 (many, abundant)	4
	C4. Trench *versus* laying flat	Percentage (P) of habitat intercepted (compared to the shortest route) and contribution (C) per type of seabed (T) and method of laying (M). C = P x T x M. Type of seabed: *P. oceanica* and bioconstruction: = 0.1, *Cystoseira* on rock = 0.2, *Cymodocea nodosa* and other habitats = 0.3. Method of laying: trench = 0.1, covered by slabs = 0.2, just laying it on the seabed = 0.3.	9
Technical and economic criteria	C5. Length of sea route	From 25 (shortest route) to 0 (route 100% longer or more)	25
	C6. Additional cost, land route	From 9 (cheapest route) to 0 (most expensive route)	9
	C7. Hydrodynamism in landing areas	From 5 (very weak) to 0 (very strong)	5

[a] For the definition of these types of meadow, see §2.5.

(7) We suggest above (Table XIX), as a rough guide, an assessment grid of the scenarios for laying a pipe or cable that will enable the best choice of scenario to be made, according to ecological, technical and economic criteria. This grid uses the elements of an environmental awareness scale proposed by Pergent *et al.* (2002b).

(8) When **laying** a cable or pipe, it is vital that the cable-carrying ship does not anchor in the *Posidonia oceanica* meadow: it must anchor outside the meadow's lower limit. Work done near the coast should be done using a small service boat (Pergent *et al.*, 2003). If burial work is done inside the meadow, geotextile screens (Porcher, 1987) (see §7.3.3) should be placed all around so that fine particles do not settle on the meadow (Charbonnel *et al.*, 1995f; Pergent *et al.*, 2003). Lastly, it is vital that the cable-carrying ship does not leave unused segments of cable or pipe lying about, likely to constitute visual pollution (Fig. 117; Pergent *et al.*, 2003).

Example of how to apply an assessment grid for a route scenario

C1. The length of the route to be assessed is 1 300 metres; the shortest route is 1,000 m. The route to be assessed crosses 500 m of *Posidonia oceanica* meadow, i.e. 50% (of the 1 000 m shortest route) (C_p = 50 x 0 = 0), 10 m of coralligenous bioconstruction (C_b = 1 x 0.1 = 0.1), 100 m of *Cymodocea nodosa* meadow (C_c = 10 x 0.3 = 3), and 690 m of other settlements, of which only 390 m will be taken into account, to refer to the shortest route (C_a = 39 x 0.4 = 15.6). C1 is thus gets 0 + 0.1 + 3 + 15.6 = 18.7/40.

C2. Over part of the route, the cable crosses a hill meadow, and over another part a staircase meadow. The length of the crossing is not taken into account in the figure: types of meadow of great heritage value must be avoided. If many types of meadow of heritage value are crossed, that which is of the highest value (here, a staircase meadow) is taken into account. C2 thus gets a mark of 2/8.

C3. Only one species of heritage value (as well as *Posidonia oceanica* and *Cymodocea nodosa*, already taken into account in C1) has been found: the noble pen shell *Pinna nobilis*. Its density (0.5 individuals/hectare) is modest. So C3 gets the mark 3/4. Generally speaking, heritage species are those that appear in the Annexes to the Habitats Directive and the Berne and Barcelona Conventions (Boudouresque *et al.*, 1996).

C4. In crossing various types of seabed, a trench will be necessary over 100 m of *Posidonia oceanica* meadow (C = 10 x 0.1 x 0.1 = 0.1) and 100 m of *C. nodosa* meadow (C = 10 x 0.3 x 0.1 = 0.3), the cable will be covered by slabs over 100 m of meadow (C = 10 x 0.1 x 0.2 = 0.2) and will just be laid on the bed over the rest of its route in the meadow (C = 30 x 0.1 x 0.3 = 0.9), over bioconstructions (C = 1 x 0.1 x 0.3 = 0.03), and other settlements (C = 39 x 0.3 x 0.3 = 3.51). C4 thus gets a mark of 4.94/9.

C5. The route is 300 m longer than the shortest route (1 000 m), i.e. a 30% increase in length. C5 thus gets 25 – 25/100 x 30 = 17.5.

C6. The additional cost of the land route, compared to the less expensive route, is 40%. C6 thus gets a mark of 9 – 9/100 x 40 = 5.4/9.

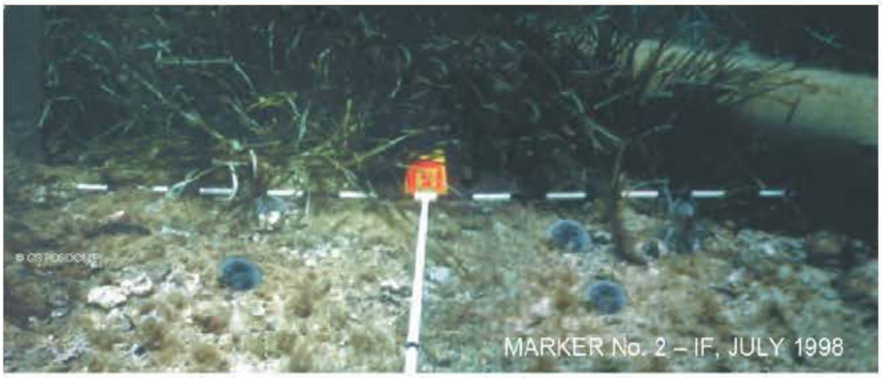
C7. There is little hydrodynamism in the departure site; it is strong in the arrival site. The mark is thus 2.5/5.

The total mark (C1 + C2 + C3 + C4 + C5 + C6 + C7) is 53.9/100.

(9) In any case, **impact monitoring** of the pipe or cable should be provided for (Charbonnel *et al.*, 1998, 2000b; Pergent *et al.*, 2003), after it has been laid, and after 2 years, 5 years and 10 years, to validate (or not) the selected choice of scenario and to allow management of this kind of development to be improved, as is suggested in the present work. This monitoring can be done by setting up markers (at least ten or so) just after the pipe or cable has been laid (Fig. 121) and monitoring these (initial reference state, and later monitoring) using the techniques of the Posidonia Monitoring Network (RSP; Boudouresque *et al.*, 2000; Charbonnel *et al.*, 2000b).

14.4. CONCLUSIONS

All in all, laying a pipe or cable over the *Posidonia oceanica* meadow constitutes a development that today we know how to best manage. As long as the decision-making strategy (see §14.3) is respected, the impact on the meadow can be extremely modest, especially when the meadow's health (shoot density, cover) is good. If it is accompanied by a real ban on trawling and anchorage (intended to protect the pipe or cable), this development can even be **positive** in an overall way: restoring the seabed and its habitats. But on the other hand, when the *P. oceanica* meadow is already degraded, laying cables or pipes can be an aggravating factor that is likely to speed up its local regression.



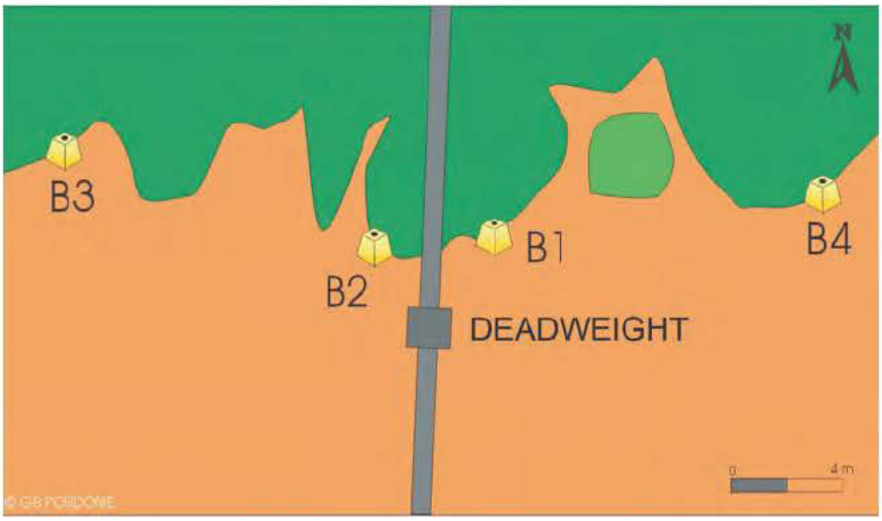


Fig. 121. Monitoring the impact of laying a drinking water pipe over the *Posidonia oceanica* meadow, between the Ratonneau and If Islands (Marseille, France).

Photographic monitoring (reference) of marker B2 using the RSP technique. A 1 metre long measuring rod can be seen plus another rod that gives the distance of the photo setting.

Locating the markers (B1 to B4), the meadow (green), the "dead matte" covered in sediment (orange) and the pipe (grey).

From Charbonnel *et al.* (1998, 2000a). Photo by E. Charbonnel.

15. CAN DEAD MEADOWS BE RESTORED?

15.1. THE PROBLEM

Posidonia oceanica meadows play a central part in **how the Mediterranean coastal environments function** (see Chapter 3): strong primary production and exporting part of this production to the many coastal ecosystems, controlling sedimentary flows, mitigating the hydrodynamism and protecting the beaches from erosion, recruiting species of fish and shrimps of commercial interest, protecting threatened species like the noble pen shell *Pinna nobilis* (Fig. 95) (Boudouresque and Jeudy de Grissac, 1983; Gambi *et al.*, 1989; Boudouresque *et al.*, 1994b; Pergent *et al.*, 1994; Jiménez *et al.*, 1996; Pergent *et al.*, 1997; Orth, 2000). The meadows also constitute a habitat with a particularly high specific diversity (biodiversity) (Boudouresque, 1996). Their protection is therefore a must, not only for reasons of ecological balance and heritage protection, but also for economic reasons (see Chapter 5) (Boudouresque and Meinesz, 1982).

Posidonia oceanica meadows are very vulnerable to anthropogenic pressures (see Chapter 4). Their **regression** has been considerable, especially near the great urban, industrial and port centres (Bourcier *et al.*, 1979; Boudouresque and Meinesz, 1982; Meinesz and Lefèvre, 1984; Pérès, 1984; Ramos-Esplá, 1984; Blanc and Jeudy de Grissac, 1989; Shepherd *et al.*, 1989; Meinesz *et al.*, 1991b; Boudouresque *et al.*, 1995a; Peirano and Bianchi, 1995; Pasqualini *et al.*, 1999; Orth, 2000; Pergent-Martini and Pasqualini, 2000).

Natural recolonization of marine Magnoliophyte ecosystems, **when the causes of their regression have ceased to operate**, is slow to extremely slow. In Australia, the horizontal progression of the rhizomes of *Posidonia australis* and *P. sinuosa* is 8-26 and 8-15 cm a year respectively (West *et al.*, 1989; Cambridge *et al.*, 2000). The average horizontal progression of a *Posidonia oceanica* meadow's front is no more than 3-4 cm a year (Meinesz and Lefèvre, 1984). Near Marseille, an area of 1.13 hectares destroyed by a bomb in 1942 was still not completely recolonized by 1999, i.e. 57 years later; 0.39 hectares of sand remain without any *P. oceanica* (see Fig. 104; Pergent-Martini, 1994; Pergent-Martini and Pasqualini, 2000). Furthermore, the ceasing of a pressure does not imply that recolonization will start immediately. In Menorca (Balearic Islands), 3 years after a fish farm stopped its operations, *P. oceanica* continues to regress. This persistence could be linked to the storing of organic matter in the sediment of the "matte" (Delgado *et al.*, 1999). In the Provence-Alpes-Côte d'Azur region (French Mediterranean), the Posidonia Monitoring Network (RSP) has reported an increase in the number of progressive meadow limits since practically all the waste water has started going through a treatment plants, but many meadows continue to regress (Boudouresque *et al.*, 2000; Charbonnel *et al.*, 2003).

It is the size of the regression of marine Magnoliophyte meadows, joined to the slowness of the natural recolonization, that has led to the idea that it could be necessary to start **restoring** the meadows, via transplanting or seeding (Meinesz *et al.*, 1990b, 1991a; Cinelli, 1991; Molenaar and Meinesz, 1992c, 1992d; Calumpong and Fonseca, 2001). The first attempts at transplanting marine Magnoliophytes dates back to 1947. These were done on the eastern coast of the USA and concerned *Zostera marina* (Addy, 1947a, 1947b). Later, on the eastern and south-eastern coasts of the USA there was an attempt to transplant in shallow (less than 6 metres) areas a whole set of species, mainly *Thalassia testudinum*, *Halodule wrightii*, *Syringodium filiforme* and *Zostera marina* (Thorhaug, 1979; Fonseca *et al.*, 1982b, 1982c; Meinesz *et al.*, 1990b;

Sheridan *et al.*, 1998). In Florida (USA), *Thalassia testudinum* has been successfully planted from seeds in a site where the species had been destroyed by heat pollution; 4 years after sowing, the reconstituted meadow was seen flowering and fruiting (Thorhaug, 1979). In Japan, many attempts have been made to reconstitute *Zostera marina* meadows from seeds germinated in an aquarium (Kawasaki *et al.*, 1988) or cuttings.

We call it **re-introduction** when a species is reintroduced into a region where it has existed in the past and where human action has caused it to disappear. We call it **re-stocking** when we release or replant individuals of a threatened species into a region from which it has not disappeared but where its numbers are thought to be too low. The restoring of seagrass meadows we mention here in fact always involves re-stocking (via transplanting or seeding).

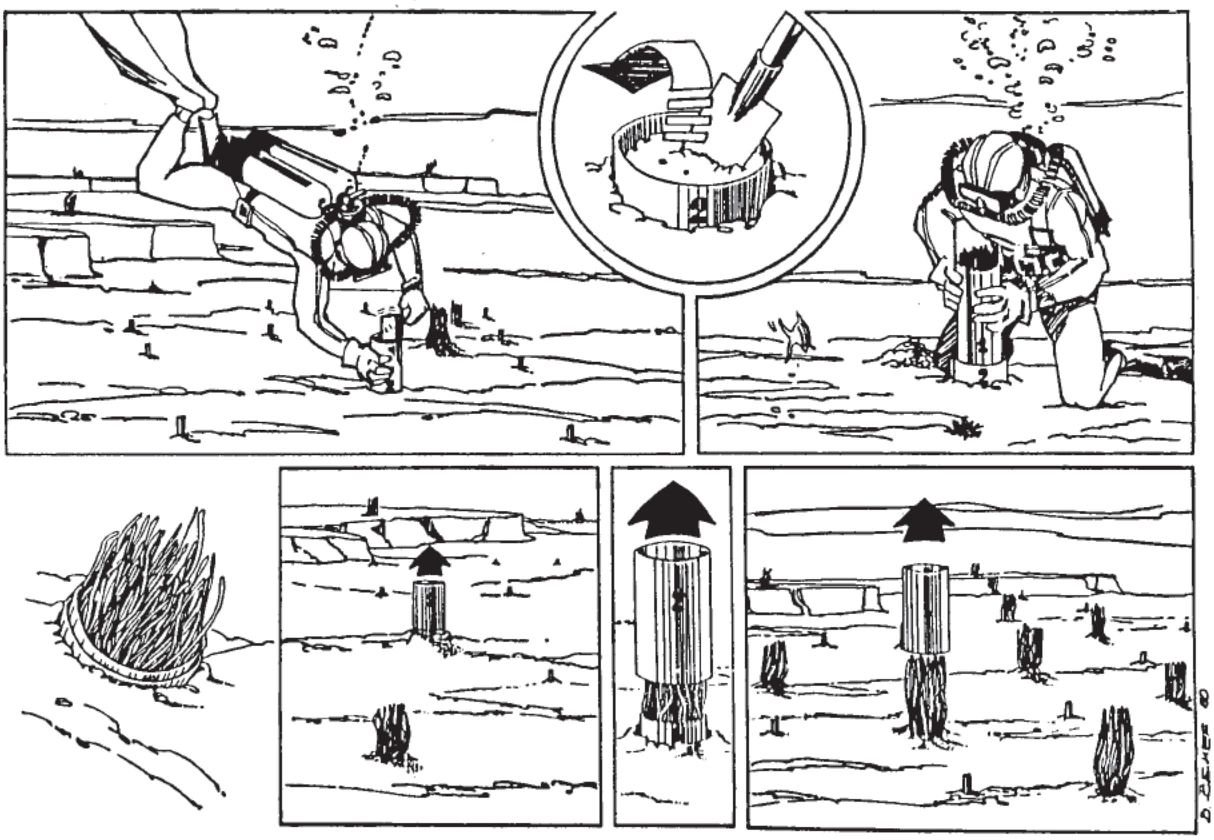


Fig. 122. The different stages of transplanting *Nanozostera noltii* using clumps (plant, roots and sediment) placed in two PVC tubes that fit into each other, and are later removed. From Jeudy de Grissac (1984b).

15.2. RESTORING TECHNIQUES

In the Mediterranean, attempts to restore *Cymodocea nodosa* and *Nanozostera noltii* meadows by transplanting **clumps** (plant, roots and sediment) have been made in the Bouches-du-Rhône, Var and Alpes-Maritimes (France) (Fig. 122; Meinesz, 1976, 1978; Meinesz and Verlaque, 1979; Jeudy de Grissac, 1984b). In the Venice lagoon (Italy), experiments with transplanting *Zostera marina*, *Nanozostera noltii* and *Cymodocea nodosa* have given interesting first results (Curiel *et al.*, 1994; Rismondo *et al.*, 1995; Faccioli, 1996). It is, however, *Posidonia oceanica* that has given rise to the greatest amount of work (Meinesz *et al.*, 1990b).

There are many techniques[113] perfected for transplanting marine Magnoliophytes (e.g. Phillips, 1980b; Lewis, 1987; Meinesz *et al.*, 1990b; Cinelli, 1991; Piazzi and Cinelli, 1995; Calumpong and Fonseca, 2001) and involve **(i)** laying **cement slabs** with holes in them, in which the cuttings are placed (Maggi, 1973); **(ii)** laying **cement frames** at the centre of which are placed a large number of cuttings held by wire mesh (Fig. 123; Cooper, 1976; Giaccone and Calvo, 1980; Cooper, 1982; Chessa and Fresi, 1994); **(iii) plastic** or metal **mesh** laid flat on the bed, onto which cuttings are fixed (Larkum, 1976; Molenaar and Meinesz, 1992a, 1992b; Molenaar *et al.*, 1993; Piazzi and Cinelli, 1995; Piazzi *et al.*, 1998, 2000); **(iv)** systems for fixing the cuttings directly onto the bed by **pegs** ("support stakes") or **hooks** (Fig. 124; Fonseca *et al.*, 1982c; Molenaar, 1992; Charbonnel *et al.*, 1995f; Rismondo *et al.*, 1995; Davis and Short, 1997); **(v)** digging holes in which blocks of matte (**clumps**) are placed (Fig. 122; Addy, 1947a; Phillips, 1980a; Noten, 1983; Jeudy de Grissac, 1984b; Dennison and Alberte, 1986; Chessa and Fresi, 1994; Rismondo *et al.*, 1995; Faccioli, 1996); in Australia, an amphibious machine weighing 3 t (ECOSUB1) was perfected for removing rootballs and then planting them (Paling *et al.*, 2001a, 2001b; Calumpong and Fonseca, 2001; Paling *et al.*, 2003); **(vi)** biodegradable **nets** (Fonseca *et al.*, 1979; Kenworthy *et al.*,1980); and finally **(vii)** planting out young individuals (**plantlets**) that have germinated in the laboratory (Addy, 1947a; Cooper, 1976; Thorhaug, 1979; Lewis and Phillips, 1980; Kawasaki *et al.*, 1988; Piazzi and Cinelli, 1995; Balestri *et al.*, 1998; Piazzi *et al.*, 2000).

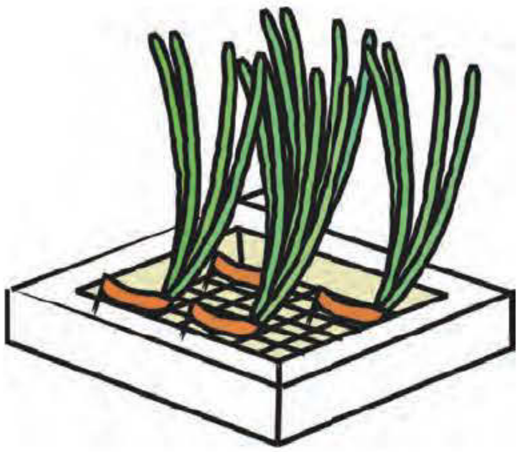


Fig. 123. A Cooper® type cement frame, with *Posidonia oceanica* cuttings. Drawing from Boudouresque (2001).

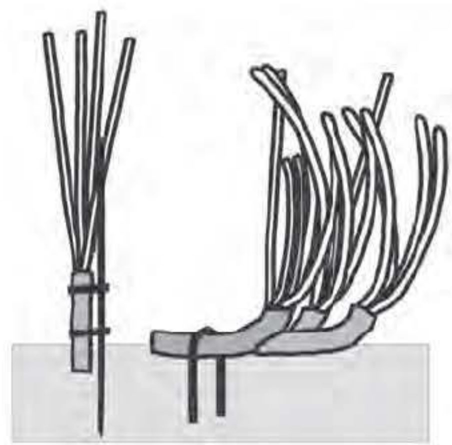


Fig. 124. Orthotropic (left, fixed to a support stake) and plagiotropic (right, 3 shoots fixed by a hook) cutting of *Posidonia oceanica*. University of Nice-Sophia Antipolis® technique. Drawing from Boudouresque (2001).

Techniques that do not involve laying cement structures are preferable in that if the attempt fails there is no impact on the environment (Jeudy de Grissac, 1984b).

The **cuttings** are either wrecked rhizomes (Cooper, 1976, 1982; Sougy, 1996) or rhizomes removed from living meadows. Cuttings from wrecked rhizomes have the advantage of being available in tens of thousands, naturally produced by hydrodynamism, while their chances of being naturally replanted are very remote (Meinesz and Lefèvre, 1984). As to the removal of cuttings in living meadows, the advantage is that we know exactly where they come from (depth), we can decide on the number of shoots per cutting and the type of rhizome (plagiotropic or orthotropic), and thus optimize the restoring conditions (see below). In countries where *Posidonia oceanica* is a protected species, the

113 Some of these techniques have been patented. Thus use of them does not come under the Public Domain.

removal of cuttings, wrecked or not, is prohibited and is therefore subject to specific permission being granted.

The best **season** for transplanting *Posidonia oceanica*, for the cuttings to survive and develop, is spring for plagiotropic cuttings (creeping rhizomes; Fig. 124), with an average survival rate of 92% (after 3 years), and autumn for originally orthotropic cuttings (erect rhizomes), with a survival rate of 45% (Molenaar, 1992; Meinesz *et al.*, 1992). **Plagiotropic** cuttings give better results (74-76% survival on average) than orthotropic cuttings (30-60% survival), and their growth is quicker (Meinesz *et al.*, 1992; Molenaar *et al.*, 1993; Piazzi and Cinelli, 1995; Piazzi *et al.*, 1998, 2000). For orthotropic cuttings, the optimal **length** of the rhizome is 10-15 cm (Meinesz *et al.*, 1992). Cuttings from **deep meadows** give better results than those from superficial meadows (Molenaar and Meinesz, 1992a; Chessa and Fresi, 1994; Génot *et al.*, 1994). Furthermore, it is a good idea to put the cuttings **near to each other** (5-10 cm apart) (Molenaar and Meinesz, 1993, 1995). The survival rate depends on the **substratum**: in the case of plantlets grown from seeds, after 3 years it is 68% on "dead matte" as against 0% on a pebble seabed (Balestri *et al.*, 1998). However, for *Thalassia testudinum*, replanting from seeds has given poor results (Thorhaug, 1974).

With certain species (e.g. *Zostera marina*) cuttings taken from **distant sites** have not given good results. The reason could be that they present small genetic differences that make them less suited to the replanting site than the indigenous stock (Hartof, 2000). But for *Posidonia oceanica* transplanting cuttings from very distant sites has given very good results (Meinesz *et al.*, 1993).

If one bears in mind, when transplanting, all the above-mentioned elements, the survival rate of *Posidonia oceanica* cuttings can be very good: for example, 84% after 4 years in the Prado Bay in Marseille (Niéri *et al.*, 1991; Charbonnel *et al.*, 1994a, 1995e). But recolonization is always **slow**: on the same Prado site, the total number of shoots (about 1 240) did not differ significantly between 1991 and 1993; their growth on the surviving cuttings merely compensated for the drop in the number of cuttings (Table XX). It is only from the third or fourth year that growth compared to the number of shoots originally replanted becomes significant (Table XX and Fig. 125; Charbonnel *et al.*, 1995e).

Posidonia oceanica transplants, usually experimental, involving over 150 000 cuttings, have especially been done in Marseille, Toulon, Hyères, Port-Cros, Cannes, Golfe-Juan, Nice, Villefranche-sur-mer, Galeria and the Lavezzi Islands (France) (Maggi, 1973; Cooper, 1976; Loques *et al.*, 1989; Molenaar *et al.*, 1989; Molenaar and Meinesz, 1991; Niéri *et al.*, 1991; Molenaar and Meinesz, 1992b, 1992c, 1992d, 1993; Meinesz *et al.*, 1993; Molenaar *et al.*, 1993; Génot *et al.*, 1994; Molenaar and Meinesz, 1995), in Monaco (Sougy, 1996), in Tuscany (Piazzi *et al.*, 1998), north of Civitavecchia (Piazzi and Cinelli, 1995), in Naples (Cinelli, 1980; Chessa and Fresi, 1994), in Sardinia (Chessa and Fresi, 1994), and in Sicily (Italy) (Giaccone and Calvo, 1980). These transplants are however of very limited size if compared to those of *Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme* done in the south-east of the USA. Lewis (1987) mentions 13 major operations there, the largest of which concerns a surface area of 49 hectares. In Japan, many large-scale *Zostera marina* transplanting campaigns have also taken place (Kawasaki *et al.*, 1988).

Campbell (2000) considers that transplanting is successful if the survival rate of the transplants is at least 50% and if the rate of advance of the rhizomes is at least 50%. Out of all the operations done, the success rate was less than 50% in the USA and less than 22% in Australia (Fonseca *et al.*, 1996; Campbell, 2000). In the Mediterranean, it is hard to assess the success rate with any precision.

Table XX. Experimental transplanting of *Posidonia oceanica* in the Prado Bay (France), using the method patented by the University of Nice-Sophia Antipolis. Changes in the number of cuttings and the total number of shoots (one cutting contains several of these) between 1991, date when the transplant was done, and 1995. dm=missing data. From Charbonnel *et al.* (1994b, 1995e) modified, in Boudouresque (2001).

Station	Original number of cuttings (1991)	Survival rate of cuttings (1993)	Survival rate of cuttings (1995)	Average number of shoots per cutting (1991)	Average number of shoots per cutting (1993)	Average number of shoots per cutting (1995)	Total number of shoots (1991)	Total number of shoots (1993)	Total number of shoots (1995)
1	132	84%	dm	2.9	2.7	dm	383	299	dm
2	100	85%	dm	2.9	3.4	dm	290	289	dm
3	139	89%	84%	2.8	3.1	6.4	389	384	747
4	100	87%	84%	2.8	3.1	5.2	280	270	437

In fact, most of the operations mentioned in the literature on the subject have been experimental tests, and in some cases the transplanted cuttings have been pulled up at the end of the experiment to analyse the features of their growth. Furthermore, most of the transplantings have not yet been assessed, several years after they were done. We empirically assess it as about 30-40% (Boudouresque, 2001).

15.3. RESTORING THE MEADOWS

We use the word **mitigation** (or compensatory measures, or even accompanying measures) to describe the measures intended to mitigate the effects of human impact on the environment, to compensate for such effects, or to get back to a former situation. Creating Marine Protected Areas (MPAs), putting down artificial reefs, optimizing artificial ripraps and jetties, enhancing the population of a species (transplanting marine Magnoliophytes, for example) can also be mitigating steps (Boudouresque, 2001). The notion of mitigation must, however, be used with the greatest caution: the risk does exist of mitigation being used as an excuse to enable destructive development to continue, deceiving the public and leaving the elected representatives with a clear conscience. It must in fact be clearly understood that no real compensation can be made for a development; **the destruction of a *Posidonia oceanica* meadow** when it has been covered under a facility is **irreversible**, for it is the biotope that has been definitively destroyed. Mitigation must therefore be seen only as an attempt at restoring approximately what was destroyed in the past, not as a justification for future destruction based on a hypothetical compensation (Boudouresque, 2001). Furthermore, any compensation measures announced at the time when a development decision is made do not legally commit the developing company, which usually has not the (legal and financial) authority to put them into effect. Oliver (1993) cites the very instructive case of the development of the Languedoc-Roussillon coast; in 1978, the Interdepartmental Team for developing the Languedoc-Roussillon coast (France) had accepted the principle of creating some fifteen or so "Biological Protection Zones" or "Nature Reserves" to compensate for the foreseen development; the CNPN (National Nature Protection Council, Ministry of the Environment, France) had approved these mitigation measures. But what really happened was that the creation of Nature Reserves necessarily had to comply with the normal procedure, in which the *collectivités territoriales* (regional authorities) have a decisive role; further, the Interdepartmental Team disappeared once the development had been completed; 20 years later, only 3 sites (out of the fifteen originally foreseen) are protected.

Improving marine Magnoliophytes transplanting techniques, and then actually implementing them, seems urgent. The natural regeneration of the meadows is in fact very slow and it can prove necessary, in sectors where the regression has been considerable, to speed up natural regeneration by transplanting activity. But it should first be ascertained that the causes of the regression have ceased to operate (Fig. 126). The constraints specific to the marine environment do make such transplantation fairly expensive: for example, 250 to 500 man-hours, i.e. $30 000-45 000 ([114]), are necessary to replant one hectare of *Zostera marina* (Thorhaug and Austin, 1976; Fonseca *et al.*, 1979, 1982a, 1982b, 1998; Chessa and Fresi, 1994). It would not therefore be very consistent to try to regenerate 1 or 2 hectares of meadow (at the end of 50-100 years, perhaps more, in the case of *Posidonia oceanica*) in a sector where many hectares of meadow continue to disappear every year because of human activity. In all, transplanting must be integrated within an overall meadow management strategy on the scale of a bay or a region (Campbell, 2000; Hartog, 2000; Orth, 2000). This strategy must take into account the following elements (Fig. 126; Boudouresque *et al.*, 1994a, 2000): **(i)** the total surface area of the existing meadows; **(ii)** the area lost every year due to regression and the causes of this regression; **(iii)** the area reclaimed every year through natural regeneration (if this exists); **(iv)** the area that one can hope to reclaim through transplanting, with a 10, 20 or 50 year schedule; **(v)** the cost of transplanting, and a comparison with the effects of an identical alternative investment in mastering the causes of the regression (water treatment, laying anti-trawl reefs, providing organised moorings for leisure boats, creating Marine Protected Areas, etc.). Also, one should make sure that the marine Magnoliophyte population used in the transplanting is as close as possible to the population that has disappeared[115], geographically, ecologically and genetically (Lambinon, 1994; Hartog, 2000); **(vi)** lastly, in any case, it is necessary that a trial be done on a small control plot, and monitored over at least 3 years. Only a favourable result can justify a large-scale operation (Boudouresque, 2001).

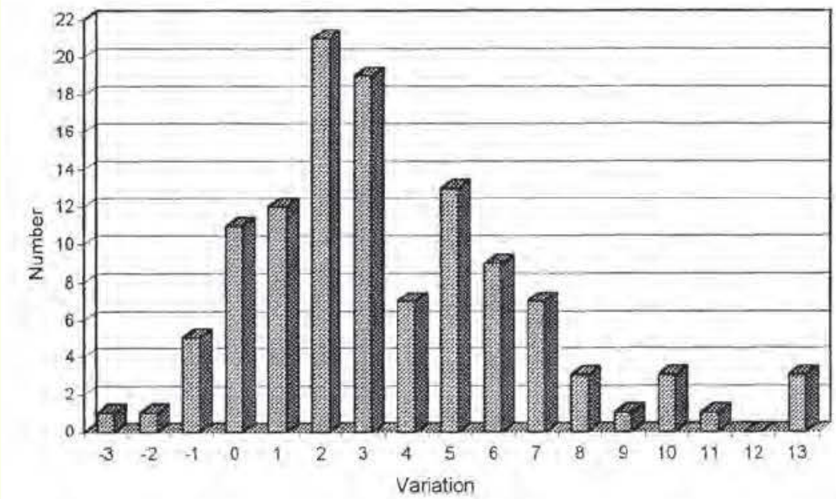


Fig. 125. Experimental transplanting of *Posidonia oceanica* in Prado bay (Marseille, France) changing number of shoots per cutting (-3 to +13) compared with the original number of shoots per cutting, between 1991 (date of transplanting) and 1995, for the 117 surviving cuttings (139 planted). From Charbonnel *et al.* (1995e).

Unfortunately, there is a serious risk that the technical possibility of transplanting is misused to **serve as an excuse for further destruction** (Fonseca *et al.*, 1979, 1987). Transplanting *Posidonia oceanica* in the Mediterranean does indeed offer many examples of "planting for planting's sake" with no overall strategy, at the whim of local representatives' appeals (Boudouresque *et al.*, 1994a, 2000). **(i)** Planting has been done where *P. oceanica* does not exist naturally and seems never to have existed: what justification can there be for trying to replace an infralittoral sandy bed (certainly not a biological desert, but the public does not always know this) with a few clumps of *P. oceanica*? **(ii)** Planting has been done where the meadow is rapidly regressing. **(iii)** In Cannes (Alpes-Maritimes) some transplanting has been done in a *Cymodocea nodosa* meadow, another marine Magnoliophyte which, like *P.*

114 Dollars the late 1970s value, not corrected to reflect the dollar's present value.
115 This point does not perhaps concern the special case of *Posidonia oceanica* (Meinesz *et al.*, 1993).

oceanica, is protected by law in France (Order of 19 July 1988); destroying one protected species to replace it with another protected species is a rather inconsistent strategy. **(iv)** More seriously, transplanting *P. oceanica* has been suggested as a compensatory measure in the context of projects to build or enlarge marinas/ports. This is the case, for example, of the project to enlarge the port of Sanary-sur-Mer: to compensate for the (certain) destruction of a large area of meadow, it was planned to plant several thousand cuttings in an area where nothing suggested that meadows had ever existed in the past, or that *P. oceanica* would be able to survive there. Be that as it may, in France, because of the legal protection *P. oceanica* enjoys, transplanting operations that involve collecting and transporting cuttings are not permitted by the Ministry of the Environment; the only dispensations that have been granted concern scientific research (Boudouresque *et al.*, 1994a, 2001).

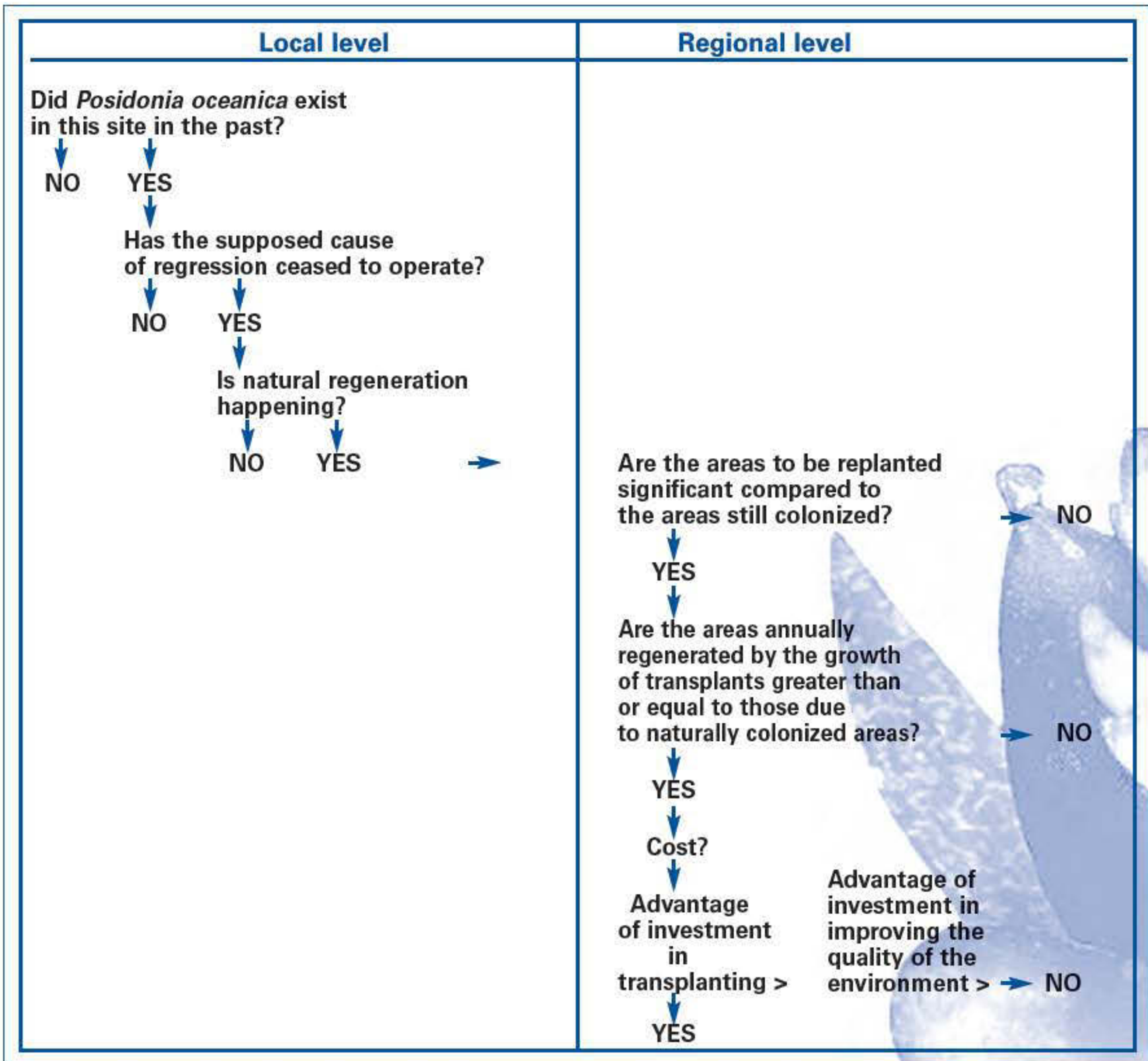


Fig. 126. Decision-making strategy for transplanting *Posidonia oceanica* and other marine Magnoliophytes. The question-answer sequence first looks at the local level (the site of the anticipated transplanting) and then the regional level (a homogeneous area, such as a bay). "No" answers should lead to the project's being abandoned. From Boudouresque (2001), modified.

15.4. A CODE OF GOOD CONDUCT

To avoid techniques of transplanting *Posidonia oceanica* being used as an excuse for going ahead with the destruction of existing meadows, a code of good conduct has been proposed, at the request of the French Ministry of the Environment (Boudouresque *et al.*, 1994a, 2001). Its principles appear below:

(1) The exact site and the biotope where the transplanting will be done must have been occupied by *Posidonia oceanica* before[116].

(2) The causes of the disappearance of *Posidonia oceanica* (pollution, trawling, anchorage, etc.) from the site where the transplanting will be done must have ceased to operate. Thus, before any transplanting is done, one must demonstrate that the meadows or isolated clumps of *P. oceanica* that are nearest to the transplanting site have started a process of natural recolonization.

(3) Transplanting must not be done near very extensive meadows. It is useless to add several dozen or hundred square metres (0.001 to 0.01 hectare) to a meadow consisting of several hundred or thousand hectares[117].

(4) Transplanting cannot be done to compensate for the destruction of a meadow. To avoid this abuse, no transplanting must be done within a distance of 10 km from a deliberate destruction (as part of coastal development) for a 10-year period.

(5) Transplanting on the exact site of a temporary destruction should however be possible, at least in the countries where the legal protection of *Posidonia oceanica* is not opposed to this. This is the case when an open trench for an archaeological dig is closed, or a pipe (or cable) crossing a meadow is buried.

(6) With the exception of the special case above (point 5), any transplanting of *Posidonia oceanica* must come after an experimental transplanting of several hundred cuttings; scientific monitoring for at least 3 years must show that the experiment has been a success before a larger operation can be envisaged.

(7) The removal of cuttings for transplanting must not endanger existing meadows. It must therefore be spread over a large area of meadow (less than 2 cuttings/m^2). The use of cuttings detached naturally, although giving less good results, or plantlets from seeds, can also be envisaged.

(8) Lastly, transplanting must be done within an overall strategy of *Posidonia oceanica* meadow management of the concerned region (see §15.3).

116 But the special case of a coast profoundly changed by heavy development that has modified the pre-existing habitats (changes in sediment transfer, river diversion, etc.) should be considered. In this case, the new habitat can be tested, for it is likely to be naturally colonized by *Posidonia oceanica* over several centuries without human help. This is the case of the beaches of Nice (Alpes-Maritimes, France), where environmental conditions were shattered when 250 hectares of platform were laid down to build an airport, with the lasting diversion of the main coastal river in the Alpes-Maritimes, the Var, and the rapid erosion of the beaches. Similarly, other marine Magnoliophytes have been successfully transplanted in sites that have been profoundly changed by coastal development. This is the case of the artificial beach of Beaulieu (Alpes-Maritimes), and the area where the Martigues-Ponteau thermic effluent is released (Bouches-du-Rhône, France) (Meinesz, 1976, 1978; Meinesz and Verlaque, 1979).

117 But one can consider the special case of sites of great heritage value (Marine Protected Areas) or educational value (underwater trails), where transplanting would allow the natural recolonization to be speeded up.

Similar procedural guides for decision-making, suited to local problems and species, have been crafted in the US (Fonseca *et al.*, 1996, 1998) and in Australia (Campbell, 2000; Calumpong and Fonseca, 2001).

15.5. CONCLUSIONS

Despite a considerable research effort on a global scale, the tangible results of transplanting marine Magnoliophytes remain uneven. The result has been that the restoring of marine Magnoliophyte meadows cannot yet be compared to reafforestation, as practiced in the continental domain. The least disappointing results come from the US and, especially, Japan, where transplanting has been done on a wider scale than in the Mediterranean. This is explained by the much faster growth of the concerned species, *Zostera marina*, *Thalassia testudinum* and, especially, *Halodule wrightii* and *Syringodium filiforme* compared to *Posidonia oceanica*. True meadows, that is, areas of several hectares occupied almost continuously by marine Magnoliophytes that have grown from transplanted plants, have been reconstituted.

As for *Posidonia oceanica*, one of the slowest-growing marine Magnoliophytes in the world, the operational applications of the results obtained, from the experimental transplanting that has been done, are not very encouraging. More than 25 years after the first transplanting was done, there is still no true meadow reconstituted from transplants.

The cost remains very high[118], even if one could imagine that this could fall for large-scale operations. Moreover, the cost/result ratio of transplanting does not seem to be competitive compared to other operations of protecting the quality of the environment or restoring coastal ecosystems.

All in all, transplanting *Posidonia oceanica* does not constitute a pertinent tool for managing Mediterranean coastal environments, at least in the present state of knowledge and considering the state of the environment of most of the Mediterranean coast. This conclusion does not rule out the possibility that in some particular cases transplanting can be envisaged; it should in these cases be very solidly governed by the **code of good conduct** mentioned above (see §15.4) and by an overall reflection on the integrated management of coastal environments on a wider regional scale.

118 The fact that transplanting must be done by professional divers explains, in particular, the high cost.

16. METHODS OF MONITORING *POSIDONIA OCEANICA* MEADOWS

16.1. INTRODUCTION

The aim of monitoring *Posidonia oceanica* meadows is threefold: **(i)** Monitoring an ecosystem that is of great heritage value but is vulnerable (see Chap. 3 and 4) in order to notice any new degradation rapidly. **(ii)** Using this ecosystem as a biological indicator of the overall quality of coastal environments (see Chap. 17). **(iii)** Measuring the effectiveness of a local or regional coastal environment policy, the set up of waste water treatment plants, the improvement of water quality, the reduction of domestic and industrial pollutant levels in the rivers flowing towards the Mediterranean, the set up of Marine Protected Areas (MPAs) and the freezing of coastal development at the expense of the sea (ports, reclaimed land, etc.) (Boudouresque *et al.*, 1990b, 1994a; Charbonnel *et al.*, 1993; Pergent *et al.*, 1995; Boudouresque *et al.*, 2000; Sandulli, 2004).

16.2. MONITORING TOOLS

Tools for monitoring *Posidonia oceanica* meadows concern 3 spatial scales: **(i)** ecosystem scale: mapping, use of aerial photographs other than for mapping, measuring cover, permanent transects; **(ii)** local scale: placing markers at the upper and/or lower limits of the meadow, permanent quadrats; **(iii)** microscale – shoots or groups of shoots: shoot density, plagiotropic to orthotropic rhizome ratio, degree to which rhizomes are bared, sediment granulometry, lepidochronology, leaf biometry (leaf length, number of leaves per shoot, etc.), cover and biomass of leaf epibiota. These tools have been gradually diversified and perfected since the 1980s, according to the experience drawn from their implementation and the progress made in scientific and technological research (Charbonnel *et al.*, 1993; Niéri *et al.*, 1993a; Boudouresque *et al.*, 2000; Pergent-Martini *et al.*, 2005).

Methods of mapping marine Magnoliophyte meadows and managing the cartographical data in Geographical Information Systems (GISs) were addressed by many authors (e.g. Augier and Boudouresque, 1970a, 1970b; Meinesz *et al.*, 1981b; Calloz and Collet, 1997; Lehmann and Lachavanne, 1997; Ward *et al.*, 1997; Dahdouh-Guebas *et al.*, 1999; McRea *et al.*, 1999; Stanbury and Starr, 1999; Bernard *et al.*, 2001; Denis *et al.*, 2001; McKenzie *et al.*, 2001; Pasqualini *et al.*, 2001; Kendrick *et al.*, 2002; Bianchi *et al.*, 2003; Bonhomme *et al.*, 2003a; Denis *et al.*, 2003; Bianchi *et al.*, 2004; Leriche *et al.*, 2004) and do not form the subject of the present work.

16.2.1. Cement markers

A dozen or so permanent cement markers are laid down at the lower limit of the meadow (one marker about every 5 metres) or its upper limit (one marker every 5-15 metres) (Harmelin, 1976, 1977; Meinesz, 1977; Buia *et al.*, 2004). A buoy is placed above each marker to make it easier to locate it when diving (Fig. 127). A "photo-stake" of 0.5 m height is placed at 1.5 m from each marker, facing the limit of the meadow.

The markers are placed in 4 stages (Fig. 127). **(i)** the limit is defined using a rope. When the limit is not clear cut, with isolated clumps of *Posidonia oceanica*, the choice of where to place the marker can be difficult (Fig. 128). It is better to leave aside spots that are completely isolated

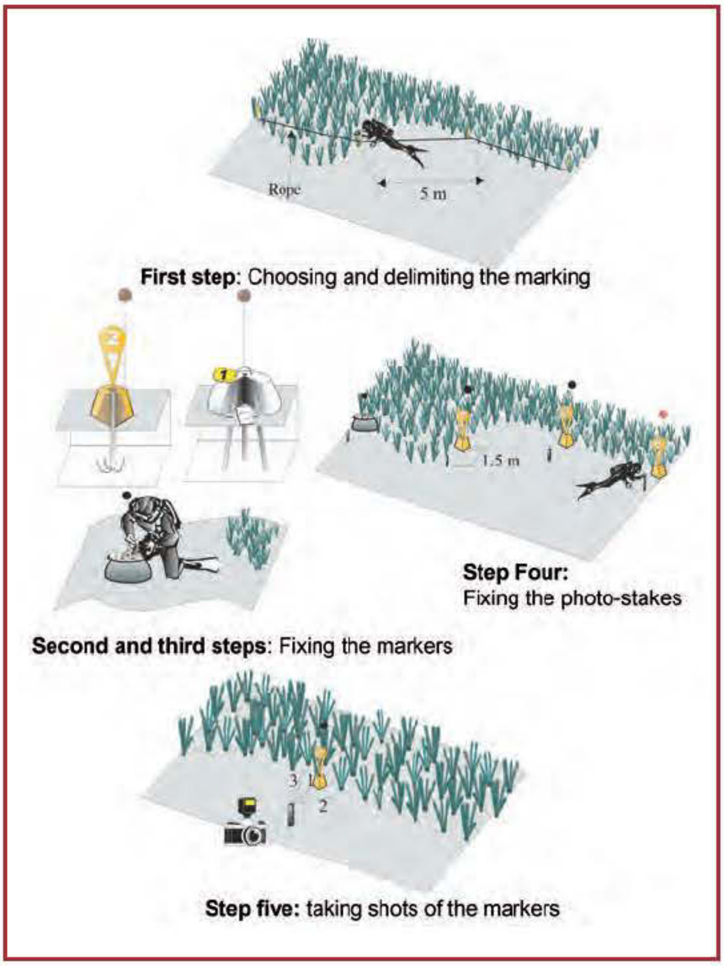


Fig. 127. The 4 stages of the marking up the limit of a Posidonia oceanica meadow and of the first photographic monitoring of a marker (see text). From Charbonnel *et al.* (2000b), modified.

from a sharp limit. If there is no clear cut limit, but just spots of meadow fairly distant from each other, the marker is placed from spot to spot, leaving out the most offshore spots (Fig. 128). However, the importance of these placing problems should not be exaggerated: the aim is to highlight the stability or changes in the overall meadow's limit, not of specific spots. Moreover, often a meadow progresses with respect to some markers and regresses at others; this is why about a dozen markers are used. **(ii)** positioning and fixing of markers (Fig. 127); Fixing them should enable them to resist hydrodynamism and, especially, trawling. However, sites that are too often trawled should be avoided. **(iii)** Placing "photo-stakes" in front of each marker. A number is fixed on each marker, and a plaque with the marker's number is also slid underneath it[119]. **(iv)** Finally, the first photographic monitoring is done (starting point) (Fig. 127).

During the first photographic monitoring and the following photomonitorings, 3 photos (one off-centre to the left, one full-front, and one off-centre to the right) are taken of each marker and the surrounding meadow, in addition a measuring scale set in front of the marker (Fig. 129); photos are taken from the tip of the "photo-stake" using a camera with a 15 or 35 mm lens (Charbonnel *et al.*, 2000b).

The monitoring of markings is aimed at highlighting the stability, progression or regression of the meadow at the level of each marker (Fig. 130). Changes are measured (to the nearest centimetre). When groups of shoots (clumps) stand out well immediately around the markers, the shoots are counted in these clumps.

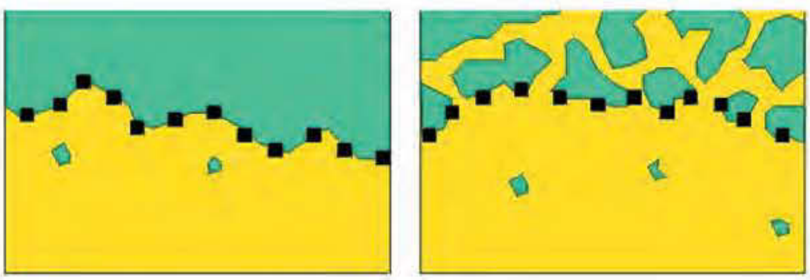


Fig. 128. Choice of where to place the marking, when the limit is sharp (on the left) or not clear cut (on the right). In green the meadow, in yellow a soft bottom or a "dead matte". The black squares correspond to markers (their size is exaggerated). After C. F. Boudouresque (unpublished).

119 This plaque allows to identify more easily the marquer below which it is slid in case its number was torn away by the hydrodynamism or by recreational divers.

The regression of a meadow's limit can be relatively quick, so that the marker can be found several metres from the new limit. The photos become difficult to interpret, and the precision of the *in situ* measuring of the distance between the meadow and the marker lessens. In this case, a new marker must be placed where the limit now is (Fig. 131).

The traditional technique of horizontal photographic shots can be supplemented by a mosaic of vertical shots of the lower limit of the meadow between the markers (Fig. 132). This technique was developed in Corsica for the Posidonia Monitoring Network.

16.2.2. Acoustic positioning

Acoustic positioning is an interesting alternative to placing markers (see § 16.2.1.) (Descamp *et al.*, 2005). An **acoustic marker** is placed in the neighbourhood of the *Posidonia oceanica* meadow's limit that is to be monitored (less than 100 metres off) (Fig. 142; Aquamètre D100®[120]). Its position must be very exactly noted so that later return visits are possible, for example by a cement deadweight that remains in place when the acoustic marker is removed. The acoustic marker consists of 4 hydrophones that detect signals from a **pointer**. The pointer is used by divers, who direct it towards points at the limit of the *P. oceanica* meadow whose position they wish to record. The precision of the positioning is between 2 and 20 cm. This precision is academic, for it does not take into account errors of positioning on a later return visit due (particularly) to the acoustic marker's new positioning on the deadweight (Descamp *et al.*, 2005). Anyway, this method enables the limit of a meadow to be traced with very many points, not just from a dozen markers (see § 16.2.1.). For the time being, despite its great interest, this method is experimental (but see § 16.3.3.).

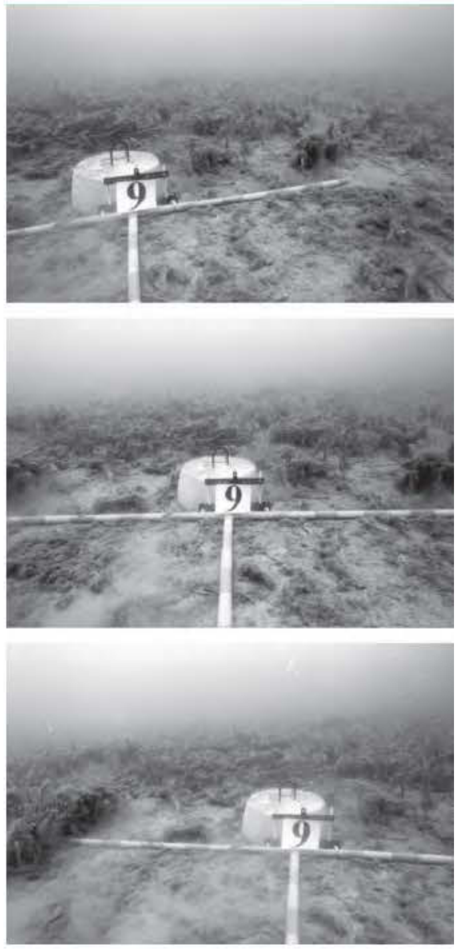


Fig. 129. Marker No. 9, at the lower limit of *Posidonia oceanica* meadow, in Golfe-Juan (Alpes-Maritimes, France), 31m deep. 3 photos (offset to the left, centered, offset to the right) are taken during monitoring dives. Photos A. Meinesz.

Fig. 130. Marker No. 4, at the lower limit of the *Posidonia oceanica* meadow, in Niolon (Bouches-du-Rhône, France), 26 m deep, in 1987 (on the left) and in 1996 (on the right). Photos CQEL 13.

Marker No. 6, at the upper limit of the *Posidonia oceanica* meadow, in Cassis (Bouches-du-Rhône, France), 10 m deep, in 1994 (on the left) and in 1999 (on the right). Photos E. Charbonnel. In the 2 cases, the meadow is in progression.

120 PLSM, Paris, France.

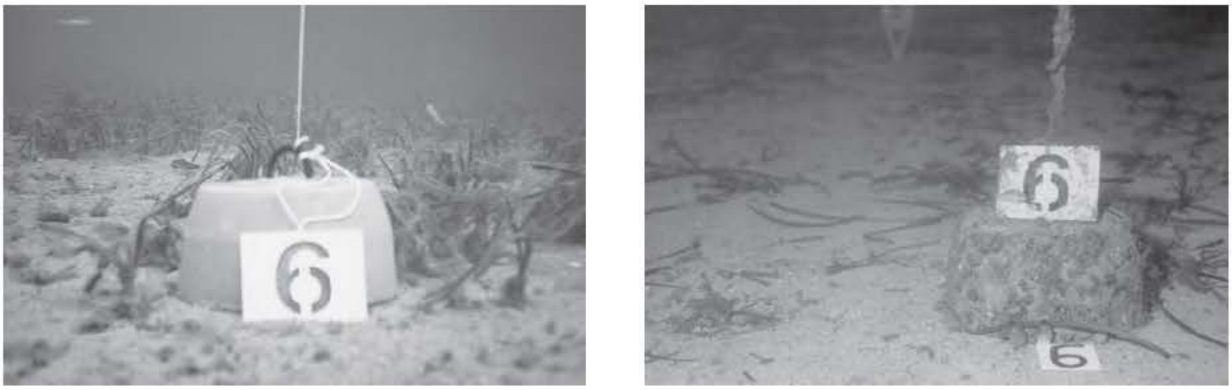


Fig. 131. Marker No. 6, at the lower limit of the *Posidonia oceanica* meadow, in Saint-Tropez (Var, France), 36 m deep. In 2000 (left), the regression of the meadow is already clear, but shoots of *Posidonia* are still present around the marker. In 2002 (right), the regression continued, isolated shoots around the marker (in the foreground) disappeared. A new marker has been put in place (in the background). Photos E. Charbonnel (GIS Posidonie).

Fig. 132. Mosaic of vertical shots, between two markers, in the lower limit of the medow of Lavezzi (-31 m). Photos G. Pergent.

16.2.3. Measuring meadow cover and shoot density

Cover is the average percentage of substratum covered (in vertical projection) by the *Posidonia oceanica* meadow (whatever the shoot density within the meadow or the clumps of *P. oceanica*) compared to the total surface area of the sector considered (sand, mud, "algal" settlements on the hard substratum, "dead matte" and living meadow). In fairly shallow, healthy meadows, cover can be high (80-100%). But at the lower limit of the healthy meadow and in meadows subject to great human pressures, cover is usually low (between 5 and 40%) (Pergent *et al.*, 1995; Charbonnel *et al.*, 2000b); however, there may be exceptions (see below).

Cover is measured using a 30 cm x 30 cm see-through plastic slide divided into nine 100 cm^2 squares. The diver swims 3 metres above the seabed, holding the plaque at arm's length, and counts the number of squares that are (more or less completely) occupied by *Posidonia oceanica* (Fig. 133). He takes 30 measurements at fairly regular intervals (for example, every so many flipper strokes). Reproducibility is good[121].

The Conservation Index proportion of "dead matte" compared to live *Posidonia oceanica* meadow in a given sector was suggested to act as an indicator of anthropogenic disturbance. CI = L/(L+D), where L is the surface area of the live meadow and D that of the "dead matte"

4 classes of CI are considered (Moreno *et al.*, 2001):

(1) CI < (x – 1/2 s)
(2) CI between (x – 1/2 s) and x
(3) CI between x and (x + 1/2 s)
(4) CI > (x + 1/2 s),

where x is the average of CI in the sector under consideration and s is the standard deviation.

121 A Kruskal-Wallis non-parametric ANOVA test did not detect significant differences between divers (Gravez *et al.*, 1995).

This index is however to be used with the greatest prudence; indeed, the presence of "dead matte" in a *Posidonia oceanica* meadow may be **of natural origin** (see § 2.5.) (Leriche, 2004). In some types of meadow, for example in the striped meadow, with very great heritage value, the surface area of "dead matte" may be much greater than that of the live meadow. It is in reality the evolution of the CI over time in a given sector that expresses anthropogenic disturbances, and not its absolute or relative value.

Shoot density is the number of live *Posidonia oceanica* shoots per unit of surface area (Giraud, 1977a, 1977b; Romero, 1986; Duarte and Kirkman, 2001; Buia *et al.*, 2004). Only those areas that are effectively covered by the meadow (thus excluding the intermatte) are taken into consideration when measuring density (Giraud, 1977a, 1977b). The measuring is done by counting, when diving, within 20 cm x 20 cm quadrats randomly set with at least 30 replicates per site (Pergent-Martini and Pergent, 1996; Charbonnel *et al.*, 2000b). Larger quadrats (30 cm x 30 cm or 40 cm x 40 cm, for example) are sometimes used, but they increase the potential measuring error; for the same sampling effort (time spent diving), it is better to use small quadrats, which allow the number of replicates to be increased[122]. It is important to note that depth explains 54% of the **variability** of shoot density: it decreases naturally with depth (Table XXI; Pergent *et al.*, 1995). Furthermore, the variability of shoot density is considerable, at short or mid distance, within the meadow, thus interpreting this parameter is very tricky and requires the greatest prudence (Panayotidis *et al.*, 1981; Balestri *et al.*, 2003; Leriche, 2004). To avoid simplistic mistakes, we suggest that it should not be routinely used by administrations responsible for the coastal environment.

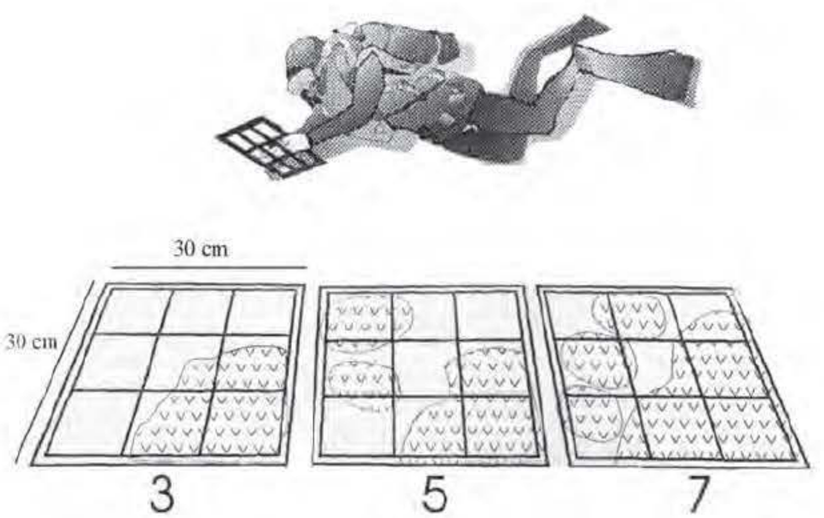


Fig. 133. measuring of the cover of *Posidonia oceanica* meadow by a diver swimming 3 m above the bottom and holding a see-through plastic at arm's lengh (above). Three examples of counting of the number of squares (more or less completely) occupied by the meadow (below). From Gravez *et al.* (1995).

122 It is important that the number of replicas is as high as possible, for the comparison of the average density as a function of time and the use of statistical tests (but see Romero, 1986).

Table XXI. Abnormal, close to normal and normal average density of *Posidonia oceanica* shoots of leaves, according to the depth, in Western Mediterranean sea. From Pergent *et al.* (1995), modified.

Depth (m)	Abnormal density	Close to normal density	Normal density
1	< 822	822-934	> 934
5	< 413	413-525	> 525
10	< 237	237-573	> 573
15	< 134	134-246	> 246
20	< 61	61-173	> 173
25	< 4	4-116	> 116
30	-	< 70	> 70
35	-	< 31	> 31
40	-	-	> 1

16.2.4. Permanent transects

Permanent transects are set perpendicularly to the limits of the *Posidonia oceanica* meadow, or perpendicularly to the isobaths. They are a few tenths to several hundred metres long. On the seabed, they consist of permanent markers of the same type as those used for marking the meadow limits (see § 16.2.1.), placed every 50-100 metres. At the start and end of the transect there is usually a group of 3 markers, so that the loss (e.g. by being buried under the sand) or removal of one or two of them does not compromise the later localizing of the permanent transect.

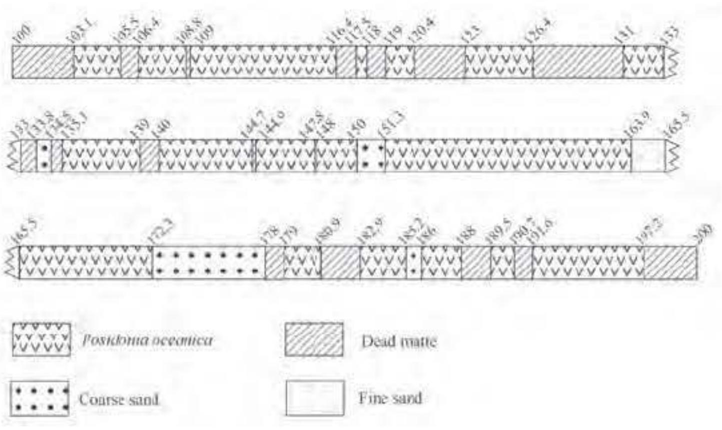


Fig. 134. Example of habitats and bottom types intercepted along a pemanent transect, in Prado Bay (Marseille, France), between metres 100 and 200 of the transect. The values indicated along the transect correspond to the distance (in m) since its origin. From Gravez *et al.* (1992).

When monitoring the transect while diving, a measuring tape is held between the markers. The habitats and types of seabed intercepted by the measuring tape over a width of 2 m (1 m each side of the tape) are noted: sand, mud, "algal" settlements on hard substratum, "dead matte" and live meadow (Fig. 134). Limits between habitats and types of seabed are noted to within 20 cm, but actual accuracy does not exceed 50 cm, due to imprecision in the tape positioning (Gravez *et al.*, 1992).

Permanent transects are placed in Port-Cros (Var, France) (Boudouresque *et al.*, 1980a; Nédélec *et al.*, 1981), in the Giens Gulf (Var) (Charbonnel *et al.*, 1995d, 1997a; Bernard *et al.*, 2000) and in the Prado Bay (Marseille, Bouches-du-Rhône, France) (Gravez *et al.*, 1992, 1995, 1997, 1999).

16.2.5. Permanent Quadrats

Permanent quadrats are made up of 8 markers (placed at the angles and in the middle of the sides). They are usually measure 6 m x 6 m (Fig. 135; Gravez *et al.*, 1992). Bigger permanent quadrats (10 m x 10 m) have also been placed (Boudouresque *et al.*, 1981, 1986b); but these take too long to map. During cartographical monitoring when diving, the permanent quadrat is divided by ropes into 1 m² squares; the ropes are removed after mapping. In each of the squares the habitats and types of seabed (the same as for permanent transects) are mapped to within 20 cm; naturally, the real actual accuracy, bearing in mind any possible error on the positioning of the ropes stretched out at each cartographical monitoring, is no more than 40 cm (Fig. 136; Boudouresque *et al.*, 1986b; Gravez *et al.*, 1992; Bernard *et al.*, 2000).

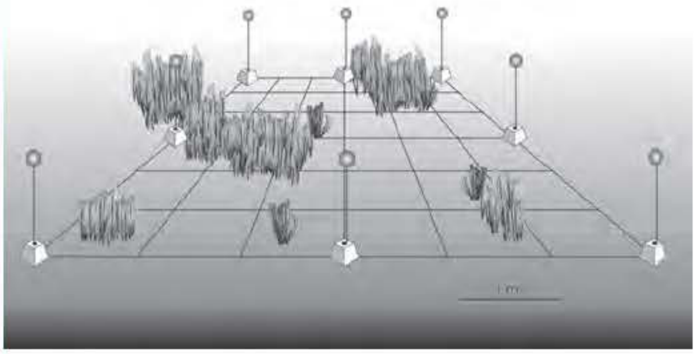


Fig. 135. Schematic drawing of a permanent quadrat of 6 m side, in degraded *Posidonia oceanica* meadow. The grid in small squares of 1 m, with ropes, intended for the mapping, is in place. These ropes will be removed after the mapping. After S. Ruitton (unpublished).

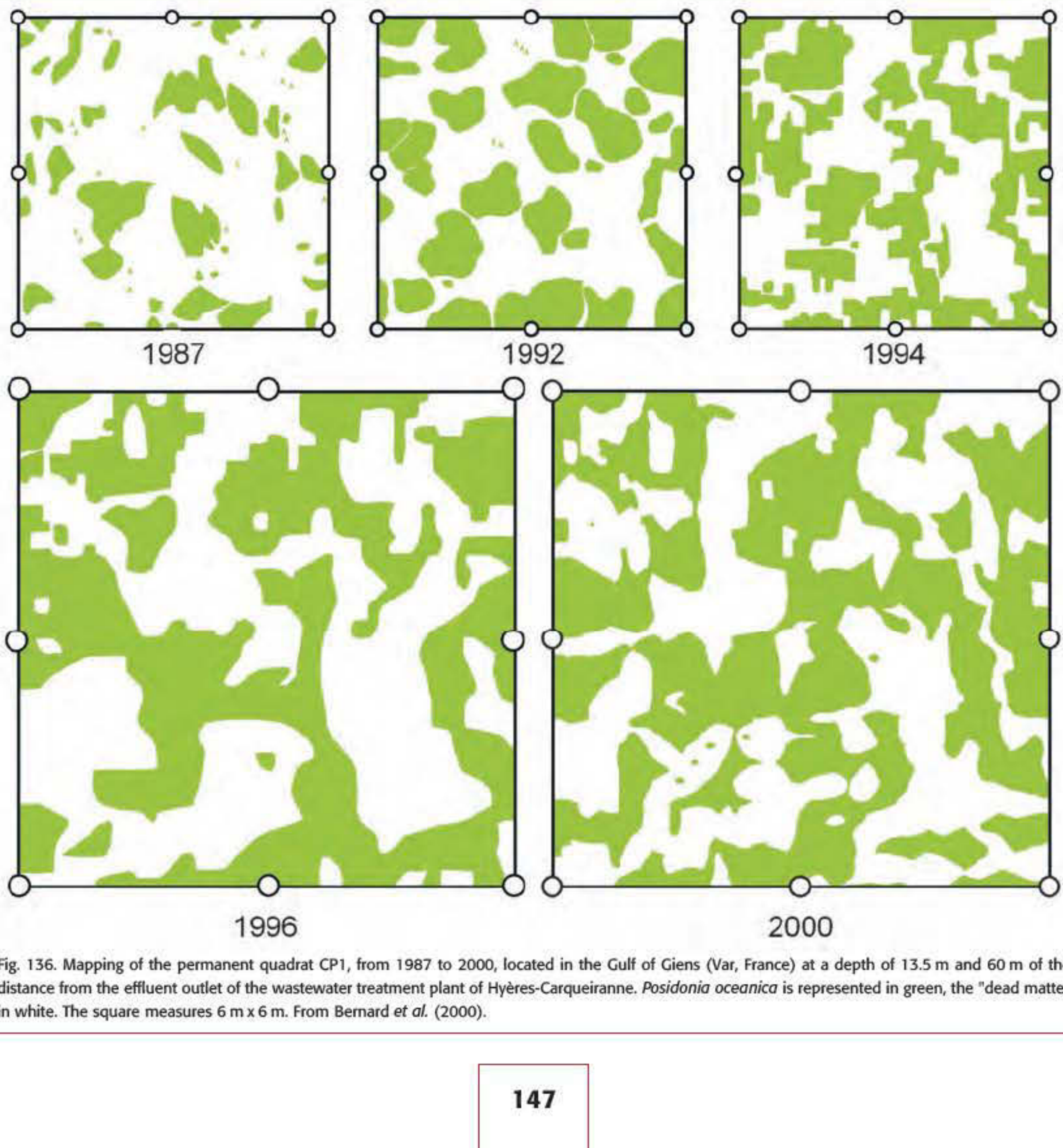


Fig. 136. Mapping of the permanent quadrat CP1, from 1987 to 2000, located in the Gulf of Giens (Var, France) at a depth of 13.5 m and 60 m of the distance from the effluent outlet of the wastewater treatment plant of Hyères-Carqueiranne. *Posidonia oceanica* is represented in green, the "dead matte" in white. The square measures 6 m x 6 m. From Bernard *et al.* (2000).

16.2.6. Aerial photographs

Shallow sites (< 10-15 m) can be monitored by means of aerial photographs. The aim is not to map the meadow itself (even if a map is made) but to closely monitor the possible changes in its limits, or in some easily recognizable structures (e.g. intermattes). The photos are taken according to a standardized protocol: altitude, lens, angle of shot, hour of day, definition and contrast of the film, etc. (Lefèvre *et al.*, 1984). The photos (monochrome, scale 1/4 500) are digitized and computer processed to get a 1/1 000 scale orthophoto map. The processing technique involves geometrical corrections on the basis of accurately located landmarks (Leriche-Guichard, 2001; Leriche *et al.*, 2004).

On these orthophoto maps, the borders between benthic structures are traced and an initial interpretation made. A light area usually corresponds to a spot of sand, whereas a dark area can reveal either the presence of *Posidonia oceanica* meadow or accumulations of dead *P. oceanica* leaves on the sea floor. The intermediate grey area usually corresponds to "dead matte" or settlements of photophilous "algae" on the rock. Afterwards, these borders (or a certain number of them selected for subsequent monitoring) are validated *in situ* by divers ("ground truth") (Fig. 137; Lefèvre *et al.*, 1984; Niéri *et al.*, 1993b; Pergent-Martini *et al.*, 1995a; Charbonnel *et al.*, 2000b). This validation is extremely important as many errors can result from photointerpretation not supported by this check; there are many examples of maps made without a "ground truth", or where the "ground truth" has been hastily done, and which contain basic errors – sometimes over vast stretches.

16.2.7. Microscale tools

A first microscale monitoring tool, **shoot density**, has for logical reasons been dealt with in the section on meadow cover and shoot density (see § 16.2.3.).

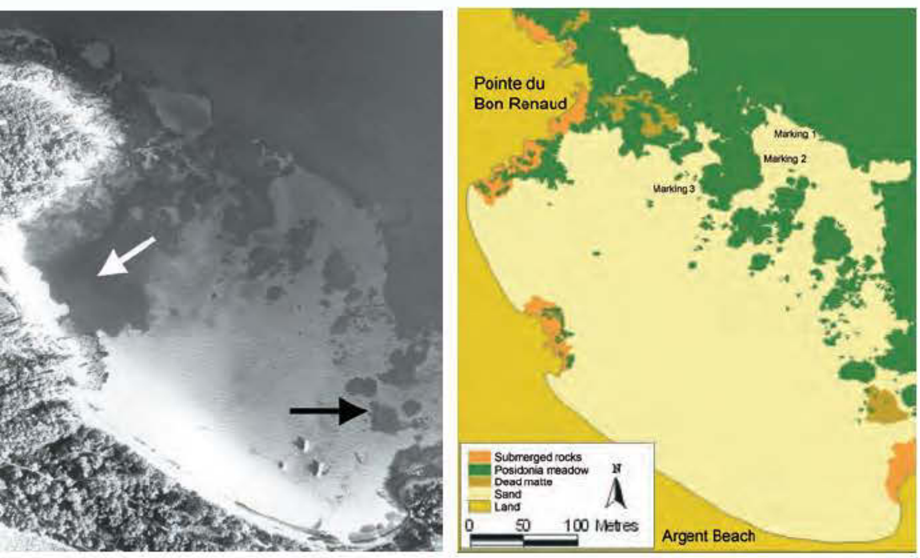


Fig. 137. Orthophoto map (on the left) and map of the habitats and bottom types (on the right) of Plage d'Argent (Porquerolles, Var, France). To the left of the photograph (white arrow), a vast dark zone corresponds to dead leaves of *Posidonia oceanica* which recover a sand bottom. To the right of the photograph, a dark spot corresponding to a "dead matte" (black arrow) appears with the same nuance of grey as a spot of a nearby alive *P. oceanica*. Data of the Posidonia Monitoring Network (RSP). From Charbonnel *et al.* (2003).

At the limit of a meadow, or of a *Posidonia oceanica* spot, the presence of **plagiotropic** shoots (horizontally growing rhizomes) is a sign of good health, since it expresses the meadow's tendency to colonize (or recolonize) neighbouring areas (Table XXII and Fig. 138; Charbonnel *et al.*, 2000b). But within a meadow the importance of plagiotropic rhizomes can also express the meadow's (positive) reaction to stress, for example mooring pressure (Francour *et al.*, 1999).

Rhizome **baring** is the result of a sedimentary deficit in the meadow (see § 4.2.): the amount of sediment trapped by the canopy (all the leaves together)

Table XXII. Measure of *Posidonia oceanica* vitality to the limit of the meadow pourcentage of plagiotropic shoots compared to the whole of the shoots, plagiotropic (creeping) ant orthotropic (erect). From Charbonnel *et al.* (2000b).

Pourcentage of plagiotropic shoots	Interpretation
< 30%	Stable meadow
30 à 70%	Slight trend to progress
> 70%	Net trend to progress

and the biogenic sediment produced *in situ* (remains of calcified organisms that had lived in the meadow: mollusc shells, sea urchin tests and spines, calcareous "alga", etc.) is less than the amount of sediment that has left the meadow, for example during storms (see Fig. 41). Conventionally, the degree of regression is measured as follows (Boudouresque *et al.*, 1980a): **(i)** (creeping) plagiotropic rhizomes: the distance between the level of the sediment (soil) and the lower part of the rhizomes; **(ii)** (erect) orthotropic rhizomes: the distance between the sediment and the base of the outermost leaf, minus 2 cm (Fig. 139).

Fig. 138. Plagiotropic shoots (rhizomes growing horizontally) in the lower limit of a *Posidonia oceanica* meadow. Photo C.F. Boudouresque.

Granulometry (size of sediment grains, and distribution by size class) is indicative of hydrodynamism. Sediment traps (Gardner, 1980) provide information about the sedimentary balance and about silting. The sedimentary balance may account for the decrease of certain *Posidonia oceanica* meadows. When the yearly balance is more than 6-7 cm, the growth of orthotropic rhizomes' vegetative tips is not enough to compensate for sedimentation, and the vegetative tips die (see Fig. 40; Boudouresque *et al.*, 1984).

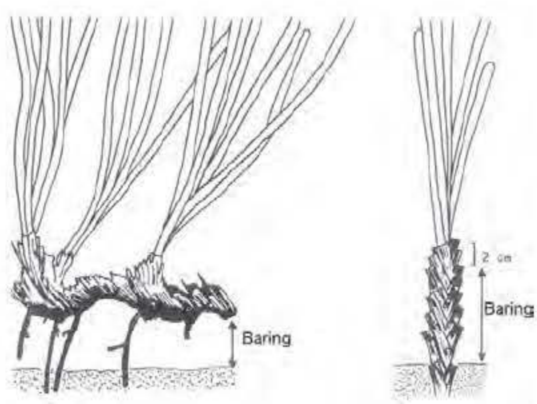


Fig. 139. Conventions for the measurement of the baring of plagiotropic (on the left) and orthotropic (on the right) rhizomes. See the text. From Boudouresque *et al.* (1980a).

Big ripple marks and, especially **sand inundation**[123], can also bury the vegetative tips of shoots for a sufficiently long period (weeks or months) to kill them. In the context of the Posidonia Monitoring Network (PMN; RSP in French, see § 16.3.1.), banks of driven sand that temporarily hid the markers were observed. Such movements of sediment must be taken into account to avoid blaming on human pressure local regressions of *Posidonia oceanica* whose origin is in fact natural (Fig. 141).

When *Posidonia oceanica* leaves die, only the limb falls off. The base of the leaf (sheath) remains attached to the rhizome. The thickness of the sheaths and their anatomical structure present cyclical

123 Sand inundation are natural movements (but irregular) of the sediment, which can bury settlements (meadows, hard substrate), then withdraw, under the effect of the hydrodynamism. The thickness of sediment can reach several dozen centimetres and even exceed the metre.

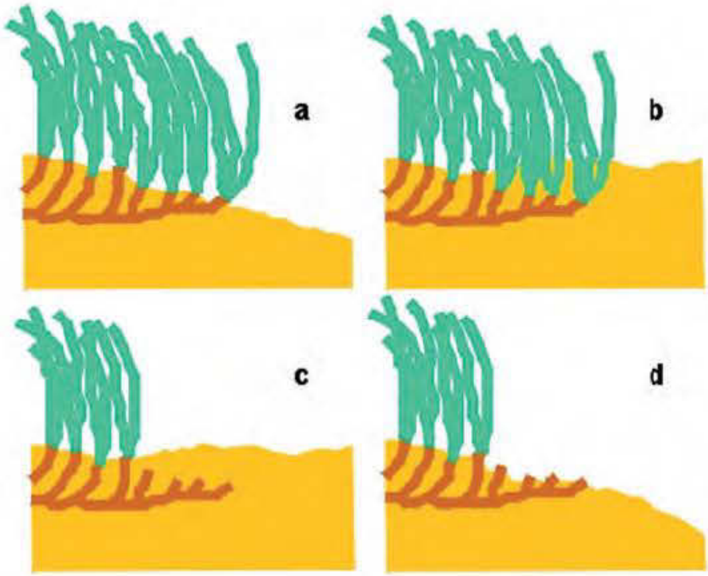
Fig. 140.

Effect of a sand inundations on a limit (**a**) of *Posidonia oceanica* meadow.

b the sediment submerges the margin of the meadow during an hydrodynamic event.

c the shoots of leaves die.

d The sediment withdraws following a new hydrodynamic event; a zone of "dead matte" appears (C.F. Boudouresque, unpublished).



variations according to their order of insertion along the rhizome, and thus to the period of the year when the leaves were born, lived and died. These cyclical variations have chronological significance: each cycle corresponds to a 1 year period (Fig. 3). This is like the variations in the thickness of growth rings in tree trunks (dendrochronology). By analogy, the analysis of the thickness cycles of *P. oceanica* sheaths has been called "lepidochronology" (Crouzet, 1981; Boudouresque *et al.*, 1983; Crouzet *et al.*, 1983; Pergent *et al.*, 1989b; Pergent, 1990a). As well as the chronological signal (years) *P. oceanica* sheaths enable a whole set of other parameters to be memorized: speed of growth of the rhizomes, number of leaves produced each year, primary production, and how these change from one year to the next, according to sedimentation rate, water quality and climate parameters. Lepidochronology is thus a powerful tool for backdating events that happened before the date of monitoring (Calmet *et al.*, 1986, 1988, 1991; Pergent *et al.*, 1992; Pergent-Martini and Pergent, 1994; Roméo *et al.*, 1995; Pergent-Martini, 1998).

Posidonia oceanica leaves constitute a substratum for **leaf epibiota**[124]: Phaeophyceae (mainly Ectocarpales), Rhodobionta (mainly Acrochaetiales and Corallinales), Bryozoa, Hydroids, etc. Their biomass presents a seasonal cycle with a maximum from March to September (Thélin and Bedhomme, 1983). This biomass is particularly high in sites where there is a high input of nutrients and/or organic matter (Jupp, 1977; Pergent-Martini *et al.*, 1995b, 1999). The biomass of the epibiota is thus a water quality indicator and allows the impact of the waste water discharges, fish farms and recreational ports, to be measured. However, because of the seasonal and bathymetric variations of the epibiota biomass, comparisons must be drawn from the same season and the same depth (Romero, 1986; Pergent-Martini *et al.*, 1999). In addition, grazing is likely to reduce the epibiota biomass; indeed, epibiota are particularly palatable to herbivores (Kitting *et al.*, 1984; Ott and Maurer, 1977; Traer, 1979; Tomàs-Nash, 2004); consequently, interpretation of data on epibiota biomass is an extremely complex matter.

The **biometry of the leaves** includes several descriptors. **(i)** Number of leaves per shoot. **(ii)** Length of adult leaves (leaves whose growth is over). **(iii)** Foliar surface area per shoot (in cm^2). **(iv)** Leaf area index[125] (LAI, in m^2/m^2). **(v)** Coefficient A (percentage of leaves which have lost their apex).

124 Leaf epibiota organisms that grow on a plant that they use as a substrate.

Parameters **(i)** to **(iv)** provide information on *Posidonia oceanica*'s vegetative development, whereas coefficient A gives information either on herbivore pressure (characteristic grazing marks) or on hydrodynamism (breakage of leaves) (Drew and Jupp, 1976; Giraud, 1977a, 1979; Giraud *et al.*, 1979; Panayotidis and Giraud, 1981; Boudouresque and Meinesz, 1982; Pergent-Martini *et al.*, 1999). As for leaf epibiota biomass, natural seasonal variations mean that comparisons should only be drawn for the same season.

16.3. THE MAIN MONITORING SYSTEMS

The tools described above (§16.2) interact differently to constitute monitoring systems on a local or regional scale.

16.3.1. RSP (the Posidonia Monitoring Network)

The *Réseau de Surveillance Posidonies* (RSP; the Posidonia Monitoring Network) is the main system for monitoring *Posidonia oceanica* meadows in the Provence-Alpes-Côte d'Azur region (PACA, France). It was set up in 1984 by the PACA Regional Council, the *services maritimes* of the concerned *départements* (chief administrative divisions in France), the Alpes-Maritime *Conseil Général* (the council who administer the *département*) a scientific NGO, GIS Posidonie (Boudouresque *et al.*, 1990b; Charbonnel *et al.*, 1993; Niéri *et al.*, 1993; Charbonnel *et al.*, 1994a, 1995a, 1995b; Boudouresque *et al.*, 2000; Charbonnel *et al.*, 2000b, 2000c, 2003; Cadiou *et al.*, 2004). It continued until 2004 (anonymous, 2005a, 2005b, 2005c).

In 1984, 24 monitoring sites were selected along the 650 km of PACA region coast. 9 new sites were added in 1994, bringing the number of sites up to 33 (Fig. 141). These sites were located **(i)** in sites where human pressures are important (and where one can expect regression of *Posidonia oceanica* meadows), **(ii)** in reference areas where *P. oceanica* is not a priori exposed to human pressures and where one might think that the meadows are stable or progressing, and **(iii)** in sites with intermediate characteristics (Boudouresque *et al.*, 2000; Charbonnel *et al.*, 2000b, 2003). The RSP sites were located at the 2 extremes of *P. oceanica*'s bathymetric area: the upper limit (15 sites) and the lower limit (18 sites). Indeed, it is at these two levels that the meadow is most sensitive to environmental change. The tools used are mainly: aerial photographs (validated by "ground truth") at the upper limit, monitoring markers at both the lower limit and the upper limit of the meadow, measuring meadow cover and shoot density, measuring rhizome baring, assessing the proportion of plagiotropic rhizomes, measuring lepidochronology and leaf biometry characteristics of shoots.

Given the slow growth of *Posidonia oceanica*, each site is monitored every 3 years. The RSP's chronology was thus the following: the period 1984-87 (selecting the sites, setting up markers and description of the initial state against which future measurements are compared), the period 1988-90 (first return to the sites), the period 1991-1993 (second return), the period 1994-96 (third return), the period 1997-1999 (fourth return) and the period 2000-2002 (fifth return) (Boudouresque *et al.*, 1990b; Charbonnel *et al.*, 1993; Niéri *et al.*, 1993a; Charbonnel *et al.*, 1994a, 1995a, 1995b; Boudouresque *et al.*, 2000; Charbonnel *et al.*, 2000c, 2001a; Ruitton *et al.*, 2001b; Charbonnel *et al.*, 2003; Cadiou *et al.*, 2004).

[125] Leaf Area Index (LAI) = total leaf surface per unit ground surface area.

During the 15 years of monitoring, along the coast of Provence and the French Côte d'Azur, the *Posidonia oceanica* meadows presented 2 opposite trends (Table XXIII). At the upper limit, the number of **regressing** sites dropped. But conversely, at the lower limit the regression continued or even worsened. All in all, between 1988-90 and 1997-99, the percentage of regressing or stable limits dropped (from 79% to 59%) whereas that of the progressing limits increased (Table XXIII; from 21% to 42%). For each site and each period, a dynamic score was calculated as follows: 0=very marked regression; 1=marked regression; 2=slight regression; 3=stability; 4=slight progression; 5=relatively great progression[126]. The "no change" between 1988-90 and 1997-99 hypothesis was rejected for the upper limits [127] (Table XXIV). More detailed analysis of the data highlighted marked differences between sectors, for example between the east (Côte d'Azur) and the west (Provence) of the region. Furthermore, for a given site change often took place irregularly over time, with alternating phases of regression and progression (Boudouresque *et al.*, 2000).

16.3.2. The Prado Bay monitoring system

Prado Bay (Marseille, France) was in the past occupied by a vast *Posidonia oceanica* meadow (Marion, 1883; Picard, 1965b). Then this meadow was subject to heavy human pressures: artificial beaches reclaimed from the sea, 2 marinas/ports, turbidity caused by the construction of one of these ports, industrial pollution brought by the coastal river (the Huveaune), domestic and industrial

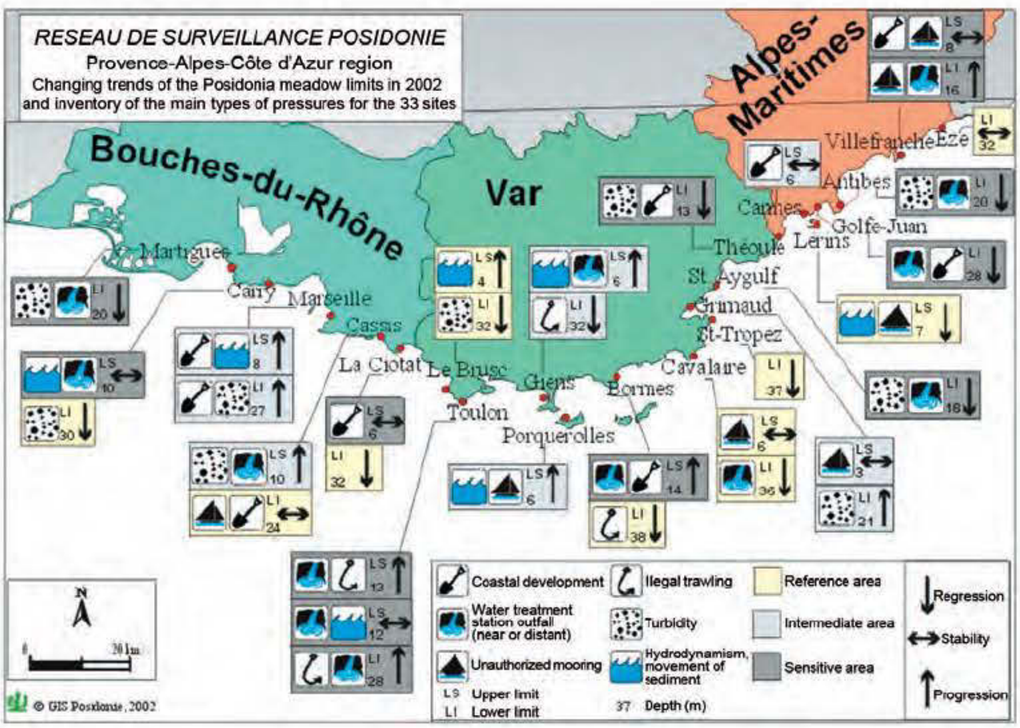


Fig. 141. The 33 RSP (Posidonia Monitoring Network) sites in Provence and the Côte d'Azur (France). From Charbonnel *et al.* (2003).

126 The regression can be considerable (the limits of the meadow can retreat several metres). On the other hand, the progression can only be slow a few dozen centimetres is seen as a relatively sizeable advance.

127 McNemar test for the significance of changes and binomial test; Siegel, 1956.

Table XXIII. Changing limits of *Posidonia oceanica* meadows (regression, stability or progression) as a percentage of the 24 sites set up in 1984-1986 by the RSP (Posidonia Monitoring Network) in the Provence-Alpes-Côte d'Azur region (France) over 5 monitoring periods. From Boudouresque *et al.* (2000), updated data.

		1988-1990	1991-1993	1994-1996	1997-1999	2000-2002
Regression	Upper limit	42	25	17	17	8
	Lower limit	50	45	67	67	67
	All sites	**46**	**35**	**42**	**42**	**37**
Stability	Upper limit	50	42	58	33	50
	Lower limit	17	36	8	0	0
	All sites	**33**	**39**	**33**	**17**	**25**
Progression	Upper limit	8	33	25	50	42
	Lower limit	33	18	25	33	33
	All sites	**21**	**26**	**25**	**42**	**38**

Table XXIV. Changing average dynamic score (see text) of the sites monitored by the RSP, at the upper and lower limits of the *Posidonia oceanica* meadows (Provence-Alpes-Côte d'Azur region, France). Data *in* Charbonnel *et al.* (2001a). NS=Not significant. Binomial test between 1988-90 and 1997-99. The period 2000-2002 is incomplete.

	Number of sites	1988-1990	1991-1993	1994-1996	1997-1999	2000-2002	Binomial test
Upper limite	12	2.5	3.1	3.1	3.6	3.5	p = 0.002
Lower limite	12	2.4	2.4	1.9	2.2	2.3	NS

pollution from an untreated sewage outfall (until 1987) located 10 km upstream of the dominant current (Harmelin and True, 1964; Niéri *et al.*, 1986; Pergent and Pergent, 1988). Between 1970 and 1980, the water of the coastal river was diverted towards the Cortiou seawage outfall (see §12.2.2). Lastly, in 1987, a (primary) water treatment plant started operating. The result was a significant drop in the pollution level (Bellan *et al.*, 1999; Soltan *et al.*, 2001).

The Prado Bay monitoring system was set up in 1986 at the request of the town of Marseille[128]. The monitoring tools used were the following: 2 permanent transects, 4 permanent quadrats, marking the meadow's lower limit, measuring meadow cover, quantitative mapping of part of the meadow (based on cover; kriging method) and laying sediment traps (Niéri *et al.*, 1986, 1993b; Gravez *et al.*, 1992, 1995). From 1988 on, i.e. 1 year after the town of Marseille's sewage treatment plant started operating, *Posidonia oceanica* not only stopped regressing but actually progressed significantly in certain sectors (Gravez *et al.*, 1995, 1997, 1999).

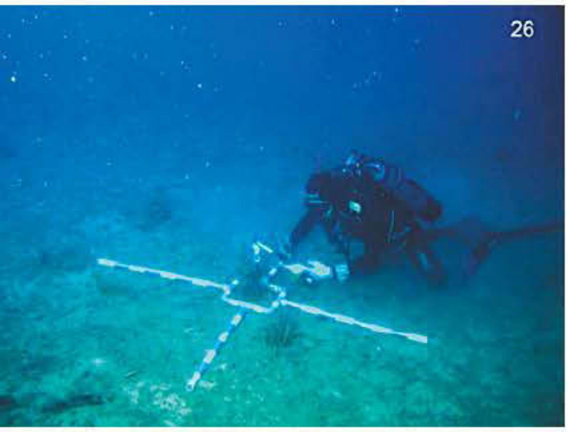
16.3.3. The Monaco monitoring system

The Larvotto Underwater Reserve (Principality of Monaco) occupies 50 hectares. It was set up in 1976. The *Posidonia oceanica* meadow constitutes the most important habitat in this Reserve. This meadow is the sole representative of this habitat in Monaco. Preserving it is thus a priority, both because of its heritage importance and because of its exemplary value in the Principality of Monaco's environmental policy.

Monitoring this *Posidonia oceanica* meadow started in 1977 with the placing of cement markers on a portion some 100 metres long of its lower limit (Alexandre Meinesz, unpublished data), which makes it one of the longest long-term set-ups concerning *P. oceanica* in the Mediterranean. To study

128 The town of Marseille decided in 1999 to abandon the site. It is not for us to judge the political and financial reasons for this decision. From the scientific point of view, abandoning a "long-term monitoring site" is always regrettable in that its interest grows exponentially with time.

Fig. 142. Positioning the limit of a *Posidonia oceanica* meadow using the Aquamètre® acoustic positioning system. Photos by J. de Vaugelas and A. Meinesz.



Locating the acoustic marker.

Divers handling the pointer.

The acoustic marker.

the long-term evolution of this meadow, it was mapped in 2001 (Jean de Vaugelas, unpublished data). The position of the lower limit was established using an Aquamètre D100® (Fig. 142, and see §16.2.2). This position was compared to that established by Alexandre Meinesz in 1977. More than 25 years later, it appears that the lower limit has remained stable.

In 2004, using the Aquamètre D100®, the *Posidonia oceanica* meadow's lower edge was positioned over a distance of about 1.5 km. (Fig. 142). This positioning will enable an extremely exact monitoring to be done later.

16.3.4. The Liguria Region (Italy) monitoring system

The Ligurian monitoring network of *Posidonia oceanica* meadows was set up in 2002 by the Liguria Region, in cooperation with the Italian Ministry of the Environment. It is based upon two procedures.

In 3 sites (Imperia, Cogoleto, Punta Mesco) the **marking** technique is being used: this consists in monitoring the meadows' lower limit using the cement markers, according to the specifications suggested by the Ministry of the Environment (drawing their inspiration from the French model); this procedure involves placing 10 markers at about 5-metre intervals to check every year how this limit is changing, documented by measurements and photographs; for each site, over a strip 10 metres behind the markers, the following data is also noted:

- type of limit (sharp, progressive, erosive, regressive)
- estimate of meadow cover
- estimate of shoot density
- type of rhizome growth (% of plagiotropic rhizomes)
- estimate of the percentage of bared meadow
- shoot collection for phenological and lepidochronological analyses.

In 6 other sites (Sanremo, Arma di Taggia, Borghetto S. Spirito, Genoa Quarto, Camogli, Riva Trigoso) the **"transect"** procedure is used: this biennially checks the state of conservation of the meadows along a transect that runs straight out from the coast, where 3 stations were identified, the first near the upper limit, the second at intermediate level and the third near the lower limit of the meadow; in correspondence to these 3 stations, the following data is noted:

- type of limit (sharp, progressive, erosive, regressive)
- estimate of meadow cover
- estimate of shoot density
- type of rhizome growth (% of plagiotropic rhizomes)
- estimate of the percentage of bared meadow
- shoot collection for phenological and lepidochronological analyses.

16.3.5. Other monitoring systems

Many *Posidonia oceanica* meadow monitoring systems have been set up along the Provence and Côte d'Azur coast (France) in response to local needs: the Riou Archipelago, near Marseille (Pergent-Martini, 1994; Pergent-Martini *et al.*, 1995a; Pergent-Martini and Pergent, 1996; Pergent-*al.*, 1995d, 1997a; Bernard *et al.*, 2000); the Maures coast, between Cavalaire and Saint-Tropez (Var; Bonhomme *et al.*, 2000); and Cap-Martin, between Monaco and Nice (Alpes-Maritimes), in a site colonized by the introduced Chlorobionta *Caulerpa taxifolia* (Ruitton *et al.*, 2001a).

In Spain, *Posidonia oceanica* meadow monitoring systems have been set up in Catalonia[129] (33 sites), in the Comunitat Valenciana[130] (15 sites), in the Balearic Islands[131] (13 sites) and in the Murcia region (Alvárez and Marbà, 2001). A monitoring system very similar to that of the RSP in the PACA region (France) was set up in Algeria in the Algiers region (Semroud *et al.*, 1998; Boumaza and Semroud, 2000).

16.4. CONCLUSIONS

The great heritage, ecological and economic value of the *Posidonia oceanica* meadows, as well as the need to assess how effective the measures for protecting and managing coastal areas that have been implemented are, make the monitoring of meadows necessary. Today a wide range of monitoring tools is available.

These tools can be combined in various ways to constitute monitoring systems according to local objectives and situations, and are today widely used, particularly in the Provence-Alpes-Côte d'Azur region (France). There, the largest of these systems is the RSP (Posidonia Monitoring Network), which covers the entire coast of the region. Similar systems have been, or are now on the point of being, set up in other Mediterranean regions (Corsica, Spain, Algeria) (Semroud *et al.*, 1998; Boumaza and Semroud, 2000; Alvárez and Marbà, 2001).

Above and beyond the original aim of these monitoring systems, *Posidonia oceanica* is used as a biological indicator of the overall quality of the coastal environment (Pergent-Martini *et al.*, 1993; Pergent *et al.*, 1995; Pergent-Martini *et al.*, 1999; Boudouresque *et al.*, 2000) (see Chapter 17).

All in all, the *Posidonia oceanica*-based monitoring systems can provide policy-makers, local authorities and all coastal area managers with **effective**, relatively **cheap**, user-friendly tools to measure both the health of the meadows and at the same time of the coastal environment.

129 Contact www.cram.es.

130 Contact ecologic@dip-alicante.es and www.dip-alicante.es/IEL.

131 Contact ealvarez@dgpesca.caib.es.

17. *POSIDONIA OCEANICA* MEADOW AND THE WATER FRAMEWORK DIRECTIVE

17.1. SOME KEY ELEMENTS OF THE WATER FRAMEWORK DIRECTIVE

Adopted on 23 October 2000, and published in the European Communities' Official Journal of 22 December 2000, the Water Framework Directive (WFD) was transcribed into French law by the Law of 21 April 2004. A major text, which will structure water policy in each European Member State, this Directive commits the countries of the European Union to improving the state of water quality and aquatic environments. It is ambitious: aquatic environments (rivers, man-made lakes, lakes, groundwater, coastal water and transitional water) must reach good ecological status by 2015, except when technical or financial reasons explain why this aim cannot be achieved. To carry out this work successfully, the WFD advocates working on the scale of the hydrographic basins called "hydrographic districts", in this case the Rhône district and the Mediterranean as regards the Provence-Alpes-Côte d'Azur region and Corsica (France). It gives as the main deadlines the drafting of an assessment (late 2004) and of a management plan (by 2009). The management plan will state the objectives to be achieved by 2015. In France, the management plan will consist of a modified SDAGE (*Schéma Directeur d'Aménagement et de Gestion des Eaux* = Regional Planning Programme for Water Development and Management) plus a programme of measures to be defined by 2009.

The WFD confirms and enhances principles of water management that have been verified and tested: management by drainage basin (catchment area), balanced management of the water resource, and participation by stakeholders. But it goes further, introducing 3 major innovations: setting out environmental targets, taking socio-economic factors into account, and public participation.

17.1.1. A major innovation of the WFD: targets for all aquatic environments

It is no longer a question of "doing better" but of acting to achieve good ecological status by 2015, or else explaining why this objective of "good ecological status" cannot be achieved. From this simple objective a certain number of logical consequences derive, such as: the need to take coastal planning and economic data into account when setting out relevant objectives, affirming the principle of non-deterioration of water resources, defining specific strategies that tackle, for example, the fight against chemical pollution or the protection of groundwater.

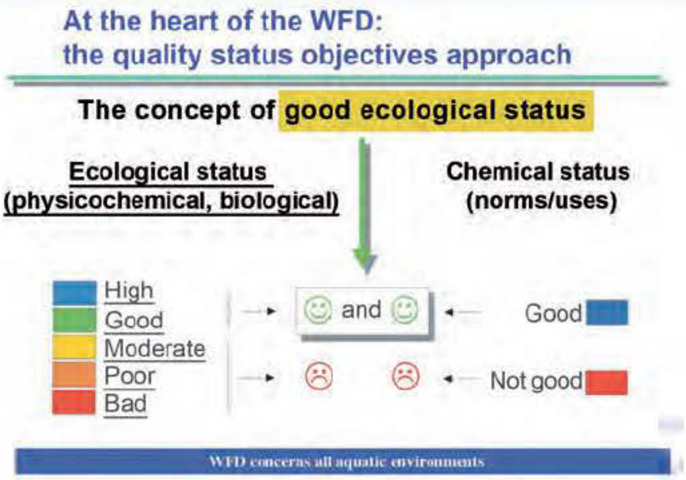


Fig. 143. Defining good ecological status according to the WFD.

For surface water, "good ecological status" consists of (Fig. 143):

- "good chemical status" of the water, this being assessed using other active Directive (bathing, shellfish, drinking water directives etc.),
- "good (or high) ecological status", assessed on the basis of biological quality elements.

Today, systems to assess water quality and to formulate objectives to be achieved vary greatly from one country to the next within the European Union. The Directive thus requires the development of a common framework for the assessment of water quality, in order to have an objective view of the assessments and strategies in the various member states. This European reference framework has been developed over the years 2003 to 2006.
Exceptions will however be possible, to objectives that are less ambitious than that of "good ecological status by 2015", whether in terms of the final date (postponing the objectives to 2021, 2027) or in terms of level of objectives. Such exceptions must be justified by:
- financial reasons (estimation of disproportionate cost)
- natural conditions (e.g., time taken for pollutants to migrate)
- specific technical reasons (e.g. very big discharge into a little river with low dilution ability), to take into account existing uses that cannot be challenged and whose impact is such that the good ecological status of the environmental objective is technically unattainable. This takes up the idea of "highly modified water bodies" for which the objective will be adapted (the idea of "potentially good") owing to heavy physical development, linked, for example, to navigation, to certain hydroelectric facilities, or to the crossing of certain urban areas, to bear in mind the origin of the environment itself, with the idea of "artificial water bodies" for which the objective will also be adapted by defining the "potentially good".

17.1.2. The WFD's analysis unit: the waterbody

The unit for analyzing whether or not the WFD's objectives have been achieved is the waterbody. A waterbody is a stretch of a water course, or a lake, a pond, a section of coastal water, all or part of one or several aquifers of sufficient size bearing in mind the homogeneous biological and physicochemical features.

From both the qualitative and the quantitative point of view, waterbodies can thus be the subject of a **well-determined management objective**. Thus, when one is on a mountain torrent, a water course on the plain, a Mediterranean river, a lake, or the coast, the condition of the environment will not be characterized by the same (particularly biological) indicators. The waterbodies consequently correspond to a type of environment on a scale for which a homogeneous objective may be set and monitored according to a given indicator: "objective good ecological status 2015", "potentially good 2015" or "good ecological status 2021".

17.1.3. Good ecological status and coastal waterbodies

To assess the good status of waterbodies, the WFD requires that **monitoring programmes** are implemented for the ensemble of aquatic environments concerned. This monitoring must be based on "biological quality elements" (BQE). For coastal water, the BQE recommended in the Mediterranean by the WFD are: phytoplankton, "macroalgae", magnoliophyta (of which the *Posidonia oceanica* meadow), and benthic invertebrates. For each of these elements, work is in progress to assess their relevance in the WFD's future monitoring programme.

17.2. THE POSIDONIA MEADOW AS A "BIOLOGICAL QUALITY ELEMENT"

Given the importance of the Posidonia meadows in the Mediterranean (see Chapter 3) and the many studies that have been done on them, it is quite natural that they have been selected as one of the biological quality elements, able to give information on the ecological status of coastal waterbodies, and more particularly on the soft bottoms. However, using the meadow as a biological quality element requires perfecting a **Comprehensive Posidonia Index** able to characterize the general condition of the ecosystem. Although it is not yet possible to present this index, **applicable by all** the EU countries of the Mediterranean, since the approach is currently ongoing, several elements may already be acknowledged:

(1) The index will necessarily be based on several parameters. The available parameters are numerous, and many are already being used to assess meadow health (Fig. 144; Buia *et al.*, 2004; Romero *et al.*, 2005; Pergent-Martini *et al.*, 2005). Thus, the parameters most widely used at present are:

- shoot density, which expresses the number of shoots per unit of surface area (see §16.2.3)
- depth of the lower limit, which gives information on the general transparency of the water and its evolution over time

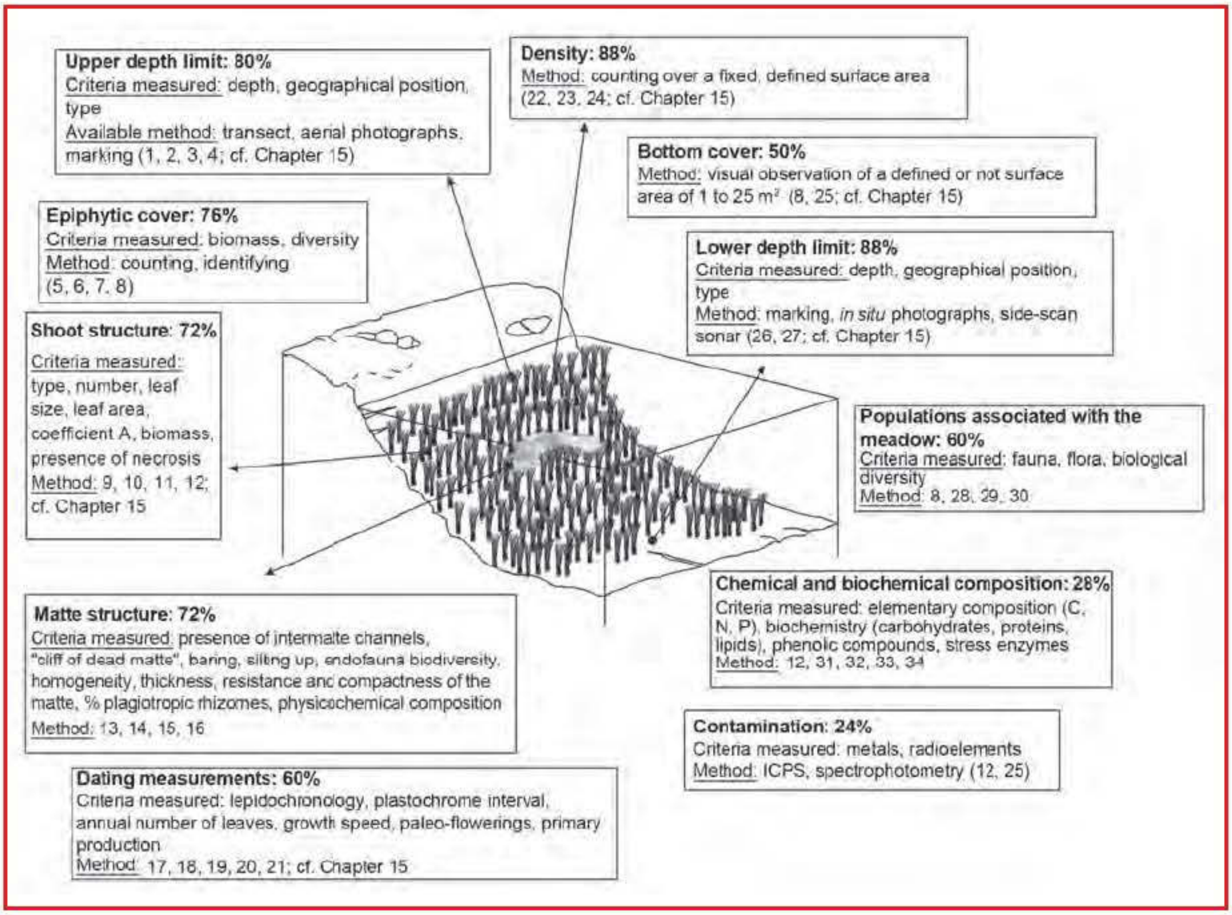


Fig. 144. Parameters used to assess the health of a *Posidonia oceanica* meadow and percentage of use (answers from 25 research institutes), criteria measured and methods of acquisition **1)** Lefèvre *et al.*, 1984 ; **2)** Pasqualini *et al.*, 1997a ; **3)** Mc Kenzie *et al.*, 2001 ; **4)** Pasqualini *et al.*, 2005 ; **5)** Balduzzi *et al.*, 1981 ; **6)** Cinelli *et al.*, 1984 ; **7)** Morri, 1991 ; **8)** Buia *et al.*, 2003 ; **9)** Giraud, 1977b ; **10)** Giraud, 1979 ; **11)** Drew and Jupp, 1976 ; **12)** Romero *et al.*, 2005 ; **13)** Blanc, 1956 ; **14)** Clairefond and Jeudy De Grissac, 1979 ; **15)** Willsie, 1987 ; **16)** Pergent *et al.*, 1995 ; **17)** Pergent, 1990a ; **18)** Duarte, 1991 ; **19)** Cebrian *et al.*, 1994 ; **20)** Mateo *et al.*, 1997 ; **21)** Pergent *et al.*, 1989a ; **22)** Panayotidis *et al.*, 1981 ; **23)** Romero, 1986 ; **24)** Duarte and Kirkman, 2003 ; **25)** Pergent-Martini *et al.*, 1999 ; **26)** Ramos-Martos and Ramos-Espla, 1989 ; **27)** Pasqualini *et al.*, 2000 ; **28)** Blanc-Vernet, 1984 ; **29)** Russo and Vinci, 1991 ; **30)** Harmelin-Vivien and Francour, 1992 ; **31)** Hamoutene *et al.*, 1995 ; **32)** Ferrat *et al.*, 2002b ; **33)** Mateo and Sabaté, 1993 ; **34)** Gobert *et al.*, 1995.

- the upper limit, which expresses more specifically the impact of human activity on the coast (coastal development; also see Chapters 4 and 7)
- epiphytic cover, which gives information on nutrients richness
- foliar biometry and/or the structure of the "matte", which gives overall information on the environment.

(2) Parameters whose **response times are relatively low** (Table XXV) should be integrated, enabling their use to be envisaged for the WFD's surveillance monitoring programmes. Correctly interpreted, they enable a meadow's response to be identified after a change of environmental conditions. Generally speaking, descriptors corresponding to individuals react more quickly than descriptors that correspond to populations.

(3) The parameters selected may **differ from one member state to the next** insofar as the Comprehensive Posidonia Index provides, in a given situation, a comparable assessment of the ecological status of the environment. It is, nevertheless, desirable for a small number of common parameters to be identified. Three parameters were chosen to this effect at the Ispra meeting (WFD, MED-GIG, February 2005):

- shoot density
- percentage of plagiotropic rhizomes, i.e. percentage of rhizomes which grow horizontally. At the limit of the meadow, this parameter gives information on the ability to colonize new substrata; on the other hand, in a meadow, it expresses the presence of a degradation within it and attempts at recolonization
- shoot foliar surface , which integrates all the phenological variables (number and size of leaves).

(4) The parameters selected may differ according to the **type of monitoring** required by the Water Framework Directive: surveillance monitoring (medium field) or operational monitoring (close field). Thus, in the context of an operational monitoring, parameters will be selected to reflect the nature of the disturbance (e.g. nutrient enrichment /eutrophication, moorings; Table XXV), whereas in a surveillance monitoring, parameters giving information on the condition of the population should be included (Table XXV), while permitting comparisons between sites (at regional and national level) and overcoming bathymetric constraints (e.g. a parameter independent of depth or assessed at a previously set homogeneous depth, of for example 15 metres).

Experience acquired over many years as to the evolution over time of *Posidonia oceanica* meadows (see Chapter 16) shows that regression is always quicker than recolonization (Boudouresque, 2001). In this respect, the *P. oceanica* monitoring networks set up in several Mediterranean countries (Boudouresque *et al.*, 2000; Buia *et al.*, 2004; Romero *et al.*, 2005; Pergent *et al.*, in press) constitute an element of appraisal that can validate the most pertinent descriptors.

The WFD monitoring programmes must become operational in the year 2006. So must the Comprehensive Posidonia Index. As regards France, it will come under the general strategy of the acquisition of data on coastal water (Fig. 145). The years 2005 and 2006 will from now on be devoted to putting the final touches to this index, and also to the work of intercalibration with the countries bordering the Mediterranean, which will in the end enable comparisons to be made on the health of *Posidonia oceanica* meadows throughout the Mediterranean basin (the text, written in 2005, has not been updated).

Table XXV. Main parameters of the *Posidonia oceanica* meadow, main anthropogenic pressures able to modify them and average response time to an improvement or deterioration in environmental conditions.

Parameter	Information level	Main impact	Response time	
			Deterioration	Improvement
Upper limit Bathymetric position	Population	Coastal developments	Yearly	X–ten-year
Lower limit Bathymetric position	Population	Turbidity	X-monthly	X-yearly
Type of limit			Yearly	X–ten-year
Density	Population	Turbidity Eutrophication	Yearly	Yearly
Cover	Population	Trawling & dredging Mooring	X-monthly	X-yearly
"Matte" structure	Population	Coastal		
% of plagiotropic rhizomes		developments	X-yearly	X-yearly
Compactness		Dredging discharge	X-yearly	X–ten-year
Burial/baring	Mooring		Yearly	X-yearly
Endofauna biodiversity			X-monthly	X-yearly
Associated species Ichthyological populations	Population	Overfishing Invasive species	X-monthly	X-yearly
Epiphytic cover	Individual	Eutrophication	Monthly	X-monthly
Leaf biometry	Individual	Eutrophication		
Leaf surface area		Overfishing	Yearly	Yearly
% of necrosis			X-monthly	Yearly
Coefficient A				Yearly
Dating measurements	Individual	Eutrophication		
Number of leaves produced/year		Coastal	Yearly	Yearly
Rate of rhizome growth/year		developments Dredging discharge	Yearly	Yearly
Contaminants	Individual	Urban sewage outfall Industrial waste	Monthly	X-monthly
Chemical and biochemical composition	Individual	Eutrophication Urban sewage outfalls		
Carbohydrates and CNP content		Industrial waste	X-monthly	X-monthly
Phenols and stress enzymes		Invasive species	Monthly	Monthly

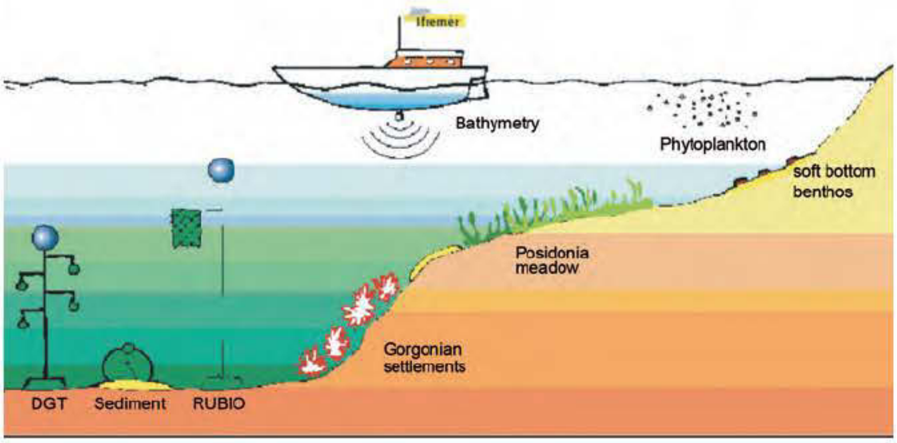


Fig. 145. Tools for monitoring the quality of the coastal water envisaged by the French *Agence de l'eau Rhône-Mediterranée-Corse* in the context of the WFD.

18. THE *POSIDONIA OCEANICA* MEADOW. A SUMMARY

This chapter addresses **non-specialist** managers and decision-makers as well as policy makers. It offers them a quick read free from scientific references or explanations. The recommendations appearing in this chapter are "**robust**", i.e. it is extremely unlikely that current research will lead to them being modified. The manager or representative who wishes to make a decision, one that is obviously in compliance with the regulatory texts in force but is also the best possible one for the underwater heritage and for the economy, and thus falls within a **sustainable development** approach, will be taking no risks in following the recommendations that we propose.

Sustainable development – don't let its meaning be abused!

Sustainable development involves 3 inseparable elements – **protection** of the environment, **economic development** and **social justice**. There can be no sustainable economic development without protection of the environment, no protection of the environment without economic development and social justice, and no social justice without economic development and protection of the environment. There is thus **symbiosis** between these three aspects.

It is regrettable that the idea of sustainable development is very often **misinterpreted** by ecologists, sociologists and policy makers. **(i)** Ecologists, for whom nature takes precedence over man; **(ii)** sociologists, who do not accept that animals can be protected while human beings are threatened, and **(iii)** certain politicians who only tolerate protection of nature if this does not interfere with their naïve, archaic and very (very) short-term idea of economic development.

In order to make it easier for readers to refer back to the specialist chapters that make up this work, the **paragraphs** in this chapter **bear the same number** as the chapters where the information is laid out in detailed form: the information corresponding to paragraph 18.1 is found in chapter 1, the information in paragraph 18.2 is in chapiter 2, and so on and so forth (even if the titles of the chapters differ slightly).

Each time it was not necessary to change the text to make the meaning clearer, we have used the same words, and sometimes the same phrases, as in the corresponding chapter. **Repetitions** are thus deliberate. When we were unable to avoid using a technical term, we gave its definition again, even if this had already appeared in the specialist chapters

Beyond the regions in the RAMOGE area (Provence-Alpes-Côte d'Azur Region, Liguria, Monaco), our recommendations are addressed to the whole of the **Mediterranean**. Readers from a country or region in the RAMOGE area should therefore not be surprised at recommendations that can already be part of the national law of their country or region.

These recommendations are the fruit of the collective experience of the authors and of the existing **literature** (more than a thousand references) on Posidonia. Although it was necessary to take them into account, with the aim of protecting and conserving the Posidonia meadows, they do not commit the RAMOGE Agreement. Furthermore, they are not a substitute for the regulatory texts which may exist in Mediterranean countries or regions.

18.1. INTRODUCTION: WHY BE INTERESTED IN POSIDONIA ?

The seagrass *Posidonia oceanica* and the meadows it constitutes have over the past decades become a major focus for protecting and **managing** the marine environment throughout the Mediterranean.

Indeed, the Posidonia meadows are an element that is fundamental for the **quality of the** coastal **environments** on which artisanal fishing and tourism development depend. Because of its socio- economic importance and the contribution it makes to maintaining the balance of trade, tourism is a key element that no Mediterranean country can do without (about 10% of GDP (Gross Domestic Product) of the Mediterranean states). artisanal fishing, whose economic importance is more modest, has a major social and cultural dimension, with positive repercussions on tourism.

The protection and conservation of the Posidonia meadows is thus justified not only by their very great heritage value but also for social and **economic** reasons. It thus illustrates the idea of sustainable development (see insert).

18.2. POSIDONIA AND THE MEADOWS

475 million years ago, life (until then restricted to the marine environment) started to conquer the continents. Evolution then speeded up, giving first of all mosses and then ferns and lastly the plants with flowers and roots that we know. A little over **100 million years** ago, terrestrial flowering plants that were like today's rushes returned to the marine environment, while retaining the "technology" (and thus superiority) they had acquired on the continents: flowers, roots etc. These were Posidonia's ancestors.

A few dozen million years later, terrestrial **mammals** took the same route; they became dolphins and whales. They also retained the "technology" they had acquired on the continents: lungs, warm blood, etc. There is as much difference between a Caulerpa and a Posidonia as between a fish and a dolphin.

Posidonia is present in almost the whole Mediterranean, from east to west and from north to south, and is **only** present in the Mediterranean. Posidonia can thus be seen as emblematic of this sea, in the same way the olive tree is of its shores (Fig. 146 and 147).

Like the oak and the olive tree, Posidonia can live a very long time: more (and even a lot more) than a thousand years. As with the oak and the olive, growth is very slow. Its **superiority** to other species is therefore not manifest in the short term (the time-scale of a human life) but on a scale of centuries. But Posidonia's special biological characteristics, which guaranteed its success for millions of years, explain its **vulnerability**, its fragility, when faced by the very rapid change and disturbances that are a feature of the present decades.

Posidonia grows between the surface and **20-40 metres** depth. As a photosynthetic[132] plant, the maximum depth at which it can develop depends on the transparency of the water. It dislikes lack of salt (and therefore does not live

132 Photosynthetic it manufactures organic matter out of carbon dioxide and mineral salts, using the energy of light.

near river mouths). The density of its leaves allows it to trap sediment. It resists being buried under sediment by the vertical growth of its rhizomes[133]. Thus a matte is built up, consisting of rhizomes, roots and the sediment that fills the interstices (Fig. 148).

Fig. 146. Olive tree. Photo by S. Ruitton.

Over the centuries, the "matte" thickens and the meadow then grows closer to the surface of the sea. At the back of sheltered bays, it may reach the surface. Thus are formed what are called barrier reefs. The most typical Mediterranean **barrier reefs** are those found in Port-Cros and the Brusc (Var, France). Almost 10 000 years were needed to build them up. Their destruction would therefore be irreversible on a human scale.

The Posidonia meadow is not present as a uniform facies in a given region, and of course on the Mediterranean scale. As well as barrier reefs there are plain meadows, hill meadows, striped meadows, staircase meadows, etc. As with the barrier reefs, it took thousands of years to build them up, and their destruction is **irreversible.**

Fig. 147. Posidonia. Photo by A. Meinesz.

The Posionia meadow presents a **biomass**[134] that is exceptionally high for the marine environment. Its primary production[135] is one of the highest in the world (terrestrial and marine environments taken together). A large part of this primary production is **exported** in the form of dead leaves to other types of seabed (for example, beds at several hundred metres depth), where it constitutes a vital alimentary resource. Furthermore, the meadow is host to 25% of species present in the Mediterranean (**biodiversity**). The importance of the Posidonia meadows is thus far greater than the surface areas (modest, on a Mediterranean scale) they occupy.

18.3. THE ROLE OF THE POSIDONIA MEADOWS

In the Mediterranean, the Posidonia meadow has a role that is often compared to that of the **forest** in a land environment, but that actually goes far beyond this.

(1) The meadow acts as a refuge for a quarter of the (flora and fauna) species that live in the Mediterranean, which is impressive when we consider that it covers less than 1% of Mediterranean seabed . Like coral reefs and the Amazonian forest, it therefore constitutes a **biodiversity hot spot**.

(2) The meadow produces enormous quantities of vegetal matter. This vegetal matter feeds the rich fauna it shelters (Fig. 149). Furthermore, a great deal (about **40%**) of this matter is **exported** as dead leaves to other types of seabed. This entry of organic matter is a boon to

133 Rhizome=underground stem.

134 Biomass the mass of living matter per square metre.

135 Primary production production of living matter by photosynthetic plants from carbon dioxide and mineral salts, using the energy of light.

the organisms that live at depths of more than 50-100 metres. Indeed, at such depths there is little (or no) light, and thus little (or no) photosynthesis. So the organisms that live there depend on organic matter that comes from elsewhere, particularly dead Posidonia leaves. The **fish** that are caught on the seabed out at sea are thus in a certain way the product of Posidonia. **By protecting Posidonia, we are defending the fishermen.**

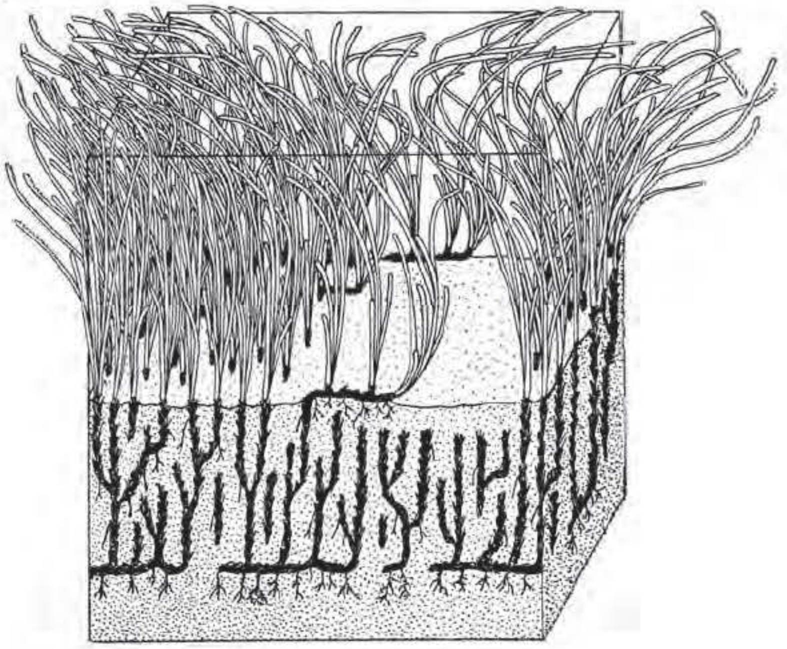


Fig. 148. A Posidonia meadow. Rhizomes (underground stems), shoots and "matte" (made up of rhizomes, roots and sediment that fills in the interstices) can be seen. From Boudouresque and Meinesz (1982).

(3) The meadow constitutes a **spawning ground** (egg-laying) area or a **nursery** (place where juveniles grow up) for many species of fish and crustaceans of economic interest. This role is easily understood when we notice that the thousands of long Posidonia leaves (Fig. 150) per square metre on the seabed constitute an inviolable refuge from predators. All fishermen know that without spawning areas and nurseries there can be no adult fishes.

(4) By means of photosynthesis, the Posidonia meadow produces **oxygen** and is thus an important factor in oxygenating the water. At 10 metres depth, 1 m² of meadow releases up to 14 litres of oxygen per day.

(5) The Posidonia meadow traps and stabilizes **sediment**, as Marram grass (European Beachgrass) does on the sand dunes of the Atlantic coast. It thus stops it moving around during storms. By preventing sediment from re-suspended, it helps to keep the water **transparent**.

Fig. 149. The Posidonia meadow part the leaves a little and you will discover an oasis of living things. Photo by G. Pergent.

(6) The Posidonia meadow with its maze of leaves reduces **hydrodynamism** (swell, current) not only under the blanket of leaves, which is easily understood, but also in the water column. This is how it cushions the force of the waves on the coast and protects the **beaches** from erosion. By protecting the meadow, we protect the beaches.

(7) Before reaching deep seabeds, the dead Posidonia leaves often pile up on beaches in **banquettes** (see Fig. 27 and 33). These banquettes also protect the beaches from erosion during the autumn and winter storm.

(8) By its presence, state of health, or absence, the Posidonia meadow indicates the average quality of the water in which it is bathed all year round. It is thus an **efficient tool for monitoring** the overall quality of the coastal water and the coastal environments.

All in all, the **economic value** of the meadows is considerable. Readers will perhaps be amazed to learn that, according to internationally recognized economists, this is 3 times greater than that of the coral reefs, 10 times greater than that of the tropical forests and 100 times greater than that of a terrestrial meadow.

18.4. REGRESSION OF THE POSIDONIA MEADOWS

Fig. 150. The damselfish *Chromis chromis* above a *Posidonia oceanica* meadow. Port-Cros National Park. Photo by S. Ruitton.

During the 20th century, especially since the 1950s, the Posidonia meadow has regressed considerably, especially around the great industrial-port centres: Barcelona, Marseille, Toulon, Nice, Genoa, Naples, etc. This regression may be up to 90% in the case of the Prado Bay in Marseille. **Human activity** is clearly the cause of this regression.

The regression concerns the lower limit, which very logically rises because of the drop in water transparency, and also the upper limit and intermediate depths. First of all this is expressed in a reduced shoot density and the formation (or extension) of intermattes[136]. The meadows' regression is due to many factors, especially when they act together:

(1) Being covered under coastal development (land reclaimed from the sea=reclamation).

(2) Modification of the **sedimentary flow**. Developments on river catchment areas reduce the entry of sediment into the marine environment. Coastal facilities (ports, rocky groynes) hamper the lateral transfer of sediment along the beaches. The result is that the meadow can either be bared because of a sedimentary deficit (the rhizomes lie above the sediment) or buried under a layer of sediment that the shoots are unable to pierce. In the first case, the meadow is very vulnerable (anchorage, trawling, storms) and in the second it is destroyed.

(3) A reduction in water **transparency**. This may be due to sedimentary particles brought by rivers, to waste water, and to the sediment being re-suspended by hydrodynamism. It can also be due to the development of plankton in water rich in nutrients (nitrogen, phosphorus).

(4) Anchoring. Obviously in areas where there is very frequent anchoring, an impact is perceptible.

(5) Trawling. More or less forbidden according to depth, distance from the coast, type of towed gear and country, but everywhere tolerated by the authorities. Trawling is one of the main causes of the meadows' regression, especially at important depth.

(6) Pollution. Whether this is due to urban discharge, leisure boats or fish farms, pollution has a direct or indirect negative impact on Posidonia.

136 Intermatte a patch of sand or of "dead matte" (Posidonia rhizomes that have lost their leaves) inside the meadow.

(7) Competition with **invasive species** is a problem whose importance is currently growing. It will take some decades to know the outcome of the competition between Posidonia and various Caulerpa species and other introduced Macrophytes[137]. The precautionary principle must thus be applied here.

(8) Overgrazing by sea urchins or herbivorous fish. This may be due to the fact that fishing has eliminated the fish that used to be predators of sea urchins. It may also be due to pollution, which encourages sea urchins. Moreover, nitrogen pollution increases the nitrogen content of the Posidonia leaves and makes them more attractive to herbivores.

In most cases, the regression of the Posidonia meadow has no single cause but is the result of the accumulation (**synergy**) of several causes. And it is important to stress the fact that unlike other disturbances, which are reversible on a human scale[138], the disappearance of a Posidonia meadow is **irreversible**: natural recolonization takes centuries.

18.5. THE REGULATORY TEXTS THAT APPLY TO THE MEADOWS

The importance of the Posidonia meadows from both the **ecological** (protection of biodiversity) and the **economic** (fishing, tourism, etc.) points of view has led the national, European and/or international authorities to protect them. There are direct and indirect protection measures.

Posidonia (and the meadows it forms) is **directly** protected by international conventions ratified by most of the Mediterranean countries, in particular the countries of the RAMOGE area: the **Bern** Convention (on the conservation of European wildlife and natural habitats), the **Barcelona** Convention (on the protection of the marine environment and the coastal region of the Mediterranean) and the European Union's (1992) **Habitats Directive**. It is also protected at national or regional level in France, Liguria (Italy), Catalonia, the Comunitat Valenciana (Spain) and Slovenia. It is important to note that in France, protecting Posidonia involves banning the destruction, removal and transporting of Posidonia, or of parts of Posidonia, both living and dead. That means that the widely practiced removal of dead leaves from the beaches is **illegal**.

Many **indirect** measures also protect the Posidonia meadows: Marine Protected Areas, measures intended to curb pollutant discharge and to restrict certain fishing techniques such as towed gear, and the obligation to carry out an **impact assessment** before making any request for a permit for a project that could harm the environment.

18.6. DEAD POSIDONIA LEAVES, BEACHES AND BEACH NOURISHMENT

Dead Posidonia leaves are driven by storms and currents either out to the great depths or onto the beaches. There they form **banquettes** that can be 2 metres thick (in exceptional cases). These

137 Macrophytes=multicellular plant, i.e. big ones.

138 This is the case for most types of pollution, including oil spills, which are (rightly) very much subject of mediatisation but are reversible in a few years.

banquettes **protect the beaches from erosion**. But ill-informed tourists do not appreciate this, so much so that many regional authorities (administrative districts, *collectivités territoriales*) see these dead leaves as waste and get rid of them, in the same way that they would plastic bottles and cigarette butts.

The **reduction of beaches** is a complex phenomenon, with many causes. The regression of the meadows (which cushion the force of the waves and swell) and the elimination of dead Posidonia leaves on the beaches are part of the cause. Adding more sand on the beaches to counterbalance the fact that they are decreasing may accentuate the regression of the meadows and constitute a kind of "vicious circle". The decreasing beach problem is an example of the economic superiority of **integrated management** of a problem (decreasing beaches, dead leaves on beaches, beach nourishment and protection of meadows) compared to a case-by-case approach (the beach is decreasing so it is necessary to add more sand).

As well as the necessary protection (or reconstitution) of the **dunes** behind the beach, which does not specifically concern Posidonia, and the checking of the causes of the meadows' regression, the most sustainable solution is **not to remove the dead Posidonia leaves from the beaches**. Contrary to what one might think, bathers accept this perfectly well as long as it is explained to them. The success of "**ecological beaches**", whose number is rapidly growing, is there to prove this.

As for **beach nourishment**, if this is really necessary and if it is part of overall management of the decreasing beach problem, it must be done with the appropriate sediment (see §6.3) and at a distance of at least **300 metres** from the nearest meadows.

18.7. COASTAL DEVELOPMENT IN THE MARITIME PUBLIC DOMAIN

Shallow seabeds have a major role in the Mediterranean: since light is not a restrictive factor there, plant production is maximal. Moreover, **nurseries** for many species of fish of economic interest are located there. Their destruction by covering by coastal development (land reclamation -land gained from the sea-, ports, etc.) is **irreversible** on a human scale. As well as meadows possibly being buried under a reclamation or included inside a port, these facilities have often led to the **indirect** destruction of areas of meadow that are much larger than that of the facility itself.

No coastal development must be carried out over a meadow. Meadows included in a **port** have very little chance of survival in the long term, and the few examples of patches of Posidonia surviving in ports should not hide what is generally the case. Facilities (rocky groynes, ports, land reclamation) have a great impact on the meadows, even if they are not located directly above them: they can in fact modify sedimentary flow either by a sedimentary deficit or by an excess of sedimentation. In any case, **10 metres** is the minimum distance that must be respected between rip-rap and the nearest living Posidonia.

The indirect destruction of the meadows by coastal development is partly linked to the **construction techniques**. In order to minimize this impact, companies that are the beneficiaries of tenders should be subjected to a number of constraints. The choice of company must not be made systematically to favour the lowest bidder (the cheapest) but the **best bidder** (the most credible enterprise as regards respect for environment protection regulations). When the development work is being done, there should be checks that the contract specifications in this matter[139] are being respected.

Dumping **fine material** (diameter less than 1 mm), or slabs mixed with fine material, at sea is to be totally ruled out. **Geotextile** protection screens must be set up around the building site, to minimize the turbidity caused. Site equipment must work **from the land**, not from the sea; if it is essential to use equipment at sea, it must not anchor over or be supported by Posidonia meadows. Finally, **summer** is the season to be avoided because of Posidonia's biological characteristics.

18.8. MOORING

Here we draw a distinction between moorings using anchors (anchoring), organized mooring (using deadweight moorings or some other system of fixed mooring legally provided) and unauthorized mooring (using deadweight moorings without permission).

Organized mooring using **deadweight moorings** causes the Posidonia meadows much more harm that anchors (Fig. 151). Therefore it must systematically be avoided. When providing organized mooring, meadow areas should be avoided. If this is not possible, it is indispensable that "**ecological**" mooring systems be used (see § 8.2.2) that have no impact on the meadow, with an intermediate buoy that prevents the mooring cable making contact with the seabed.

Fig. 151. The negative impact of a deadweight mooring and its chain on the Posidonia meadow off Aygade port, the Levant Island (Var, France). Here the deadweight mooring is not linked to a mooring buoy but to a buoy that marks the entrance to the port. The entire centre of the photo shows a vast area of "dead matte" that has been opened up in the meadow by the movement of the chain. Photo by E. Charbonnel.

The impact anchors have on the meadow depends on the **type** of anchor used (Hall-type anchors are less harmful), the **size** of the boat (cruisers have a greater impact than little leisure boats), and the **practice** of removing the anchor (it is preferable that the boat first be stationed above the anchor, which is then lifted vertically).

Be that as it may, and subject to optimizing anchoring techniques, the anchoring of little leisure boats certainly represents a lesser threat to the meadow than trawling, pollution, and of course coastal development. When it is less than 2 boats/day/hectare (on average) or 10 boats/hectare (at peak periods), it is not necessary to provide organized mooring, except in Marine Protected Areas or sectors of heritage importance.

139 It is shocking that it is often individuals or NGOs (non-governmental organisations) who warn the public departments or the regional authorites (administrative districts, *collectivités territoriales*) that a building site is not respecting environmental clauses.

18.9. MARKING THE 300-METRE ZONE

During the touristic season, markers are set up 300 metres from the shore to protect **bathing** areas. Yellow buoys are linked to a deadweight mooring; as in mooring, when the deadweight mooring is located in a meadow both it and the chain that links it to the buoy **erode** the meadow (Fig. 151). Moreover, at the end of the touristic season the deadweight mooring is removed, and the following year it is not sunk in exactly the same place, so that there are increasingly more patches where the meadow is degraded.

We recommend **(i)** not removing deadweight moorings at the end of the touristic season; the precision of the (GPS or seamark) locating systems is such that they can easily be found the following year; **(ii)** using an intermediate buoy that prevents the chain eroding the meadow; **(iii)** if possible, replacing the deadweight mooring by an "ecological" mooring system.

18.10. TRAWLING

Fishing with towed gear is one of the main causes of the Posidonia meadows' regression at depth. Also, it harms the meadow's role of nursery for many species of fish of commercial interest. Lastly, it gives rise to **user conflicts**, between artisanal fishermen (small-scale fishery) and trawlers. Indeed, the trawlers do not usually respect the national laws (minimum depth, minimum distance from the coast) that normally ban trawling over meadows.

Laying down **anti-trawl reefs** is a solution to this problem: they dissuade the trawlers, which run the risk of damaging their equipment. We make some recommendations: **(i)** anti-trawl reef units must be sufficiently heavy (at least 8 t) to constitute an effective physical obstacle and not be dragged off by the trawl or harmed by the trawl's side panels; **(ii)** they must offer a sufficient carrying surface to grip the sediment and not sink into it; **(iii)** it is also important that their shape should not harm the nets of artisanal fishermen, who must be able to work in the improved areas and benefit from the anti-trawl reefs; **(iv)** anti-trawl units must be sunk separately so that they are spaced out (50 to 200 metres between units); **(v)** anti-trawl reef ensembles must occupy the maximum space possible to be really dissuasive to trawlers; **(vi)** if the topography and surface area of the site to be protected permit this, the units should be placed in straight lines running out from the coast (most trawlers tow their gear parallel to the coast), thus forming a series of barriers.

18.11. FISH FARMS

The impact of fish farms (cages) is due to possibly uneaten **food**, fish' **excrement**, possibly the **antibiotics** and trace elements (copper, zinc) used, and lastly the **shade** shed by cages onto the seabed. The result is usually the entry into the environment of organic matter and nutrients and diminished lighting on the seabed. The impact of fish farms obviously depends on many factors, such as the type of food used, management of the food ration (minimizing or not minimizing losses), the density of fish, the size of the farm (tonnage annually produced) and obviously the local currents.

Fig. 152. "Dead matte", with some surviving *Posidonia oceanica* shoots, under a fish farm in Corsica. Photo by G. Pergent.

When fish farms have been set up above a Posidonia meadow, the meadow located under and near the cages is either greatly **degraded** or has actually disappeared, according to how long the farm has been operating (Fig. 152).

We therefore make the following recommendations: **(i)** no fish farming structure must be set up directly above a *Posidonia oceanica* **meadow**; **(ii)** if there is a meadow nearby, a **minimum distance** of 100 metres from the cages must be respected. This distance must possibly be increased, according to depth, currents and the size of the farm; **(iii)** generally speaking, a facility over seabeds **45-50 metres** deep must be preferred whenever possible; **(iv)** an **impact assessment** should accompany any request to set up a fish farm; **(v)** every four years, the permit to set up a fish farm should be reviewed for possible continuation, depending on the demonstration that the *P. oceanica* meadows nearby have not regressed. This constraint, which involves a **monitoring of the meadows**, should lead fish farmers to move as far away from the meadows as possible.

18.12. DISCHARGE OF EFFLUENTS

Generally speaking, the discharge of effluents acts mainly at 3 levels on marine coastal settlements: **(i)** lessening the transparency of the water; **(ii)** increasing the nutrient content; **(iii)** input of chemical contaminants. It can also give rise to a local reduction in salinity that can be harmful to Posidonia, in that the species does not like low salinity water.

When considering the impact of effluent on the meadows, it is not easy to separate the **direct** effects, such as toxicity and low salinity, from the **indirect** effects, due to the input of nutrients, such as the developing of leaf epibiota[140] on the leaves and the increase of grazing by herbivores. In any case, throughout the Mediterranean the meadow has disappeared, sometimes at great distances, around sewage outfalls.

We therefore make the following recommendations: **(i)** no new sewage outfall should open out into a meadow. This holds good whatever the level of treatment of the water; **(ii)** a minimum distance must be kept between the point of release and the nearest meadow. This distance varies according to the volume of water released and the level of treatment; **(iii)** the underwater pipe that carries the waste water should not cross the meadows, or should reduce to a minimum the length of meadow crossed; **(iv)** the nearest meadows must be monitored (by marking, permanent quadrats) both for new sewage outfalls and for older ones, in order to check that the level of treatment of the water is sufficient; **(v)** in the case of old sewage outfalls, if monitoring the meadow shows that the situation has stabilized, and especially if there has been a beginning of recuperation by the meadow (due to improved treatment of the waste water), we do not recommend moving the pipe or extending it beyond the limits of the meadow.

140 Leaf epibiota are organisms that develop on the leaves. They intercept the light and therefore harm Posidonia, which needs light for photosynthesis.

18.13. SOLID WASTE

Discharging silt (from the dredging of a port or canal) or slabs of rock (from the removal of rocks) onto a Posidonia meadow destroys it, at the place where it happens, irreversibly. **All dumping over the meadow should therefore be prohibited**.

The problem is that companies that have won tenders do not always respect the contract specifications when these provide for discharge outside the meadow (also see § 18.7). It is indeed economically advantageous for these companies to dump solid waste as near as possible to the site where the dredging or removal of rocks is being done.

It is shocking that it is often individuals or NGOs who warn the public departments or the district authorities (*collectivités territoriales*) that the contract clauses are not being respected. We recommend that the latter show greater vigilance.

18.14. LAYING CABLES AND PIPES ON THE SEABED

To provide an island with electricity or water, it may be necessary to lay a cable or pipe on the seabed. The impact on the Posidonia meadow is modest or even nil when the cables or pipes are merely laid over the meadow. But when they are **buried** (digging a trench), the impact is very great.

The ideal would be to avoid the cables and pipes crossing the meadows, but this is neither realistic from an economic point of view nor possible in many cases. We therefore recommend: **(i)** that the Contracting Authority suggest a minimum 3 points of **departure** from and/or **arrival** on land; **(ii)** that a precise **map** be made of the nature of the seabed (rock, sand, mud, meadows); **(iii)** that the selected route be the best possible compromise between the total **length** of the route (as short as possible from the economic point of view) and the length of meadow crossed (as short as possible from an ecological point of view). An assessment grid of the various scenarios is proposed (see §14.3); **(iv)** that there be no trench burial but that the cable or pipe be simply **laid** on the seabed, with clamping when necessary; **(v)** that impact **monitoring** be provided for (after 2, 5 and 10 years) in order to validate (or not) the selected scenario and to improve the future management of cables and pipes.

18.15. CAN WE RESTORE MEADOWS THAT HAVE BEEN DESTROYED?

Natural recolonization by Posidonia meadows, when the causes of their destruction have ceased to operate, is very slow, so it is tempting to try to speed up this recolonization by **transplanting**, as is done in the continental environment (reafforestation).

A certain number of **techniques** have been perfected using cuttings or seeds: cement frames in the centre of which are placed cuttings held in by wire mesh, stakes or hooks that fix cuttings directly onto the bed, "matte" clumps, etc. Optimum methods of transplanting (season, origin and length of cuttings, etc.) have also been defined. However, transplanting Posidonia suffers from the same handicap as natural recolonization: the plant's extremely slow growth. It takes decades to truly judge the possible success of the transplanting experiments that have been carried out in the Mediterranean. Significant successes have been obtained in Japan and the US, but these concern another species, the quickly-growing eelgrass *Zostera marina*.

There is a serious risk that the technical possibility of transplanting and seeding Posidonia will be misappropriated **to serve as an excuse for new destruction**. This destruction is immediate and irreversible, whereas the possible success of the "compensatory" transplanting can only be judged very long after it has been done. Moreover, there are several examples of "planting for planting's sake", with no overall strategy, done at the whim of requests by locally elected politicians. **(i)** Posidonia has been planted in sectors where it does not exist naturally and seems never to have existed. What could justify trying to replace a sandy bed (which is in no way a biological desert, though the public is often unaware of this) by a few clumps of Posidonia? **(ii)** It has been planted in areas where the regression of the bed is ongoing. **(iii)** It has been planted in a Cymodocea meadow (a protected species, like Posidonia). Trying to replace one protected species by another protected species is hardly a very consistent strategy.

Despite the very high **cost** of the transplanting, it can be envisaged. It must in this case be set within the framework of a comprehensive reflection on the integrated management of coastal environments, of a significantly wide regional scale with, particularly, a comparison between the cost/result ratio of transplanting and that of other operations to preserve or restore the quality of the coastal environments. To help in decision-making, we suggest a **decision-making strategy** (Fig. 126) and a **code of good conduct**, the main points of which are: **(i)** the exact site where the transplanting is done must have been formerly occupied by Posidonia; **(ii)** the causes resulting in Posidonia's disappearance must have ceased to operate; **(iii)** transplanting must not be done near very extensive meadows; **(iv)** transplanting cannot be done to compensate for the destruction of a meadow; **(v)** before any transplanting is done there must be experimental transplanting, with at least a 3-year monitoring, to verify its feasibility.

Fig. 153 . Laying a cement marker on the limit of a *Posidonia oceanica* meadow. The progression, stability or regression of the meadow compared to the cement marker position are then measured. Photo by E. Charbonnel.

18.16. MONITORING THE POSIDONIA MEADOWS

The aim of monitoring Posidonia meadows is threefold: **(i)** monitoring a settlement that has great **heritage value** but is vulnerable, to rapidly notice any new regression; **(ii)** using the meadow as a **biological indicator**[141] of the overall quality of the coastal water; **(iii)** measuring the effectiveness of regional coastal environmental policies, for example starting waste water treatment plants, improving the level of water treatment, reducing the input of the domestic and industrial pollutants brought by rivers, and setting up Marine Protected Areas.

Tools for monitoring the meadows work on 3 spatial levels: the scale of the entire meadow, the local scale within a meadow, and the microscale, for example that of a shoot.

Tools that act on **the scale of the meadow** as a whole are mapping, the use of aerial photographs for some use other than mapping, measuring cover (percentage of surface area of the

141 A biological indicator is a living organism that informs us indirectly (by its presence, health or absence) about the quality of the environment. The advantage of biological indicators is that they integrate over the long term complex physicochemical parameters that act in synergy (e.g., pollutants) and that can fluctuate enormously from day to day.

seabed covered by the living meadow) and permanent transects. These are tracks in the meadow that are exactly located so that they can be revisited later to detect possible changes there.

Tools that act **on a local scale** are laying cement markers (Fig. 153) at the upper and/or lower limit of the meadow and permanent quadrats. Markers enable changes in the meadow's limit to be observed (by comparing with photos, counting shoots etc.) even if these changes are rather minor, and thus detect them early on. Permanent quadrats are little areas (a few dozen square metres) that are precisely located and mapped, and which can be revisited later to detect possible changes there.

Tools that act on a **microscale** (that of a shoot or group of shoots) are measuring shoot density, the percentage of creeping and erect shoots, baring of the rhizomes (which expresses a sedimentary deficit), granulometry of the sediment (mud, fine sand, coarse sand, etc.), lepidochronology (recording any series of events, like that of the growth rings in trees), leaf length, etc.

Combining these tools (or some of them) has enabled meadow **monitoring systems** to be set up, the oldest and best known of which is the Posidonia Monitoring Network (RSP in French) in the Provence-Alpes-Côte d'Azur region (France). These Posidonia-based monitoring systems can provide policy-makers, local authorities and all managers of coastal areas with effective tools that are relatively cheap and user-friendly to measure the state of health of the meadows as well as that of the coastal environment.

18.17. POSIDONIA AND THE WATER FRAMEWORK DIRECTIVE

The Water Framework Directive (WFD), adopted in 2000, is a major text that structures water policy in the member states of the European Union. Its aim is to **improve and recover the quality of water** and aquatic environments (rivers, lakes, groundwater, coastal water, etc.). The WFD sets out as main deadlines the development of an assessment (late 2004) and a management plan (by 2009). The aquatic environments must be "in good ecological status" by 2015. Dispensations, if they are justified, will however be possible, with less ambitious objectives than that of "good ecological status by 2015", whether this concerns deadlines (postponing objectives to 2021, 2027) or level of objectives.

The WFD confirms and enhances verified and tested principles of water management: management by drainage basin (catchment area), balanced management of the water resource, and participation by stakeholders. But it goes further, introducing 3 major innovations: setting out the **objectives of environmental results**, taking **socio-economic** considerations into account, and **public participation**.

"Good status" consists of **(i)** "good **chemical** condition" of the water, this being assessed in the light of active Directives (bathing, shellfish, drinking water, etc.), and **(ii)** "good (or high) **ecological** status", assessed according to biological criteria.

To assess the good ecological status of waterbodies, the WFD makes the implementation of **monitoring programmes** compulsory. This monitoring must be based on descriptors or "biological quality elements". For coastal waters, the descriptors recommended in the Mediterranean by the

WFD are: phytoplankton, "macroalgae", Posidonia meadows, benthos[142] of soft bottom and benthos of hard bottom. For each of these elements work is being done to assess their relevance in the WFD's future monitoring system.

As for the Posidonia meadow, its use as a biological quality element requires the perfecting (now under way) of a **Comprehensive Posidonia Index**. This index will be developed using several parameters (see §18.16 and Chapter 16). The selected parameters can differ from one member state to the next, although it is desirable that some of them are held in common. The selected parameters can also differ according to the **type of monitoring** required by the Water Framework Directive: surveillance monitoring (average field) or operational monitoring (near field). Thus, in the context of an operational monitoring, recourse to a parameter will reflect the nature of the disturbance (e.g. enrichment in nutrient, mooring, etc.) while in the surveillance monitoring it will be necessary to include parameters that give information about the state of the population, while permitting comparisons to be made between sites (on a regional and national scale).

142 The benthos is made up of all the organisms that live on the seabed, in contrast to those that live in the body of water.

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