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Contribution to the study of *Posidonia oceanica* through the West algerian coasts : localisation, characterisation and use for coastal water status assessment.

Cognome / Surname **BENTAALLAH** Nome / Name **Mohammed El Amine**

Matricola / Registration number **788697**

Tutore / Tutor: **Prof. Cesare CORSELLI**

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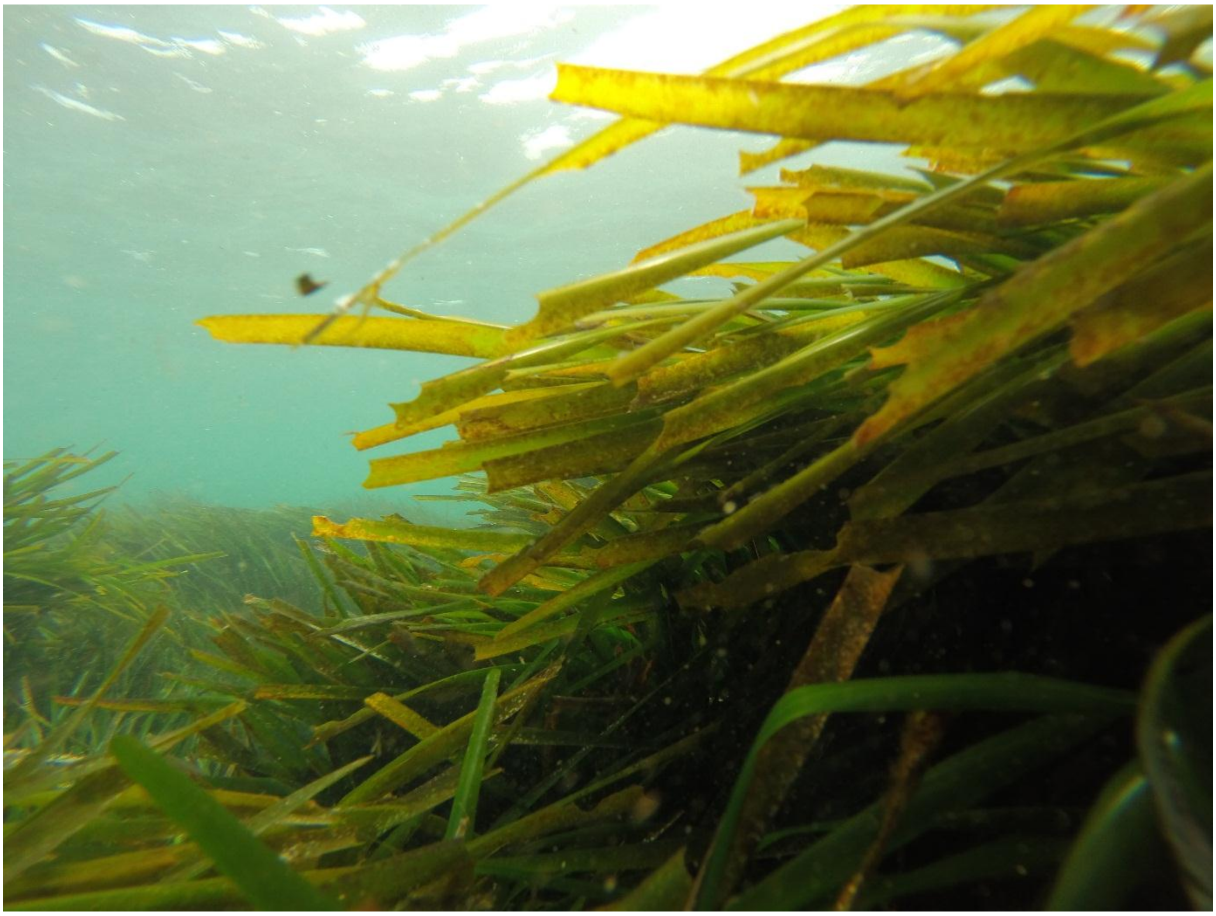
Contribution to the study of *Posidonia oceanica* through the West algerian coasts : localisation, caracterisation and use for coastal water status assessement.

BENTAALLAH Mohammed El Amine

Directed by
Prof. Cesare CORSELLI



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Abstract

Posidonia oceanica is a Mediterranean endemic species that forms dense and extensive meadows, providing important ecological functions and services and supporting a rich and diversified community, including species of economic interest.

Despite its important, the seagrass *Posidonia oceanica* meadows distribution and characterisation were poorly documented and scarcely studied in the southern part of the Mediterranean basin, through the Algerian coasts. However, in the last few years, there has been a little growing interest to the study of the *P. oceanica* through the Algerian coast, primarily centred in Algiers region.

According to our literature investigations, from 2000 to date, only few documents described some aspects of the *P. oceanica* in Western Algeria, mainly grey literature written in French. The detailed distribution remains largely unknown. Furthermore, some maps and point data helped document the distribution of beds along the west Algerian coasts. Our investigations on 12 zones in four Wilaya (districts), from the western Algeria (Chlef, Mostaganem, Oran and Ain Temouchent) combined to literature data from different sources, provides that the *P. oceanica* is more represented in western Algeria with a discontinuity through the coasts.

A study of the phenology of *Posidonia oceanica* meadows was conducted on five zones on the west Algerian costs (Zimba, Arzew, Stidia, Capo russo, Cap carbon) providing new data on density, leaf number, leaf length, leaf surface and the state of the apexes as determined by the "coefficient A". The outcomes showed information about the health status of the *P. oceanica* meadow through these zones. According to (Pergent *et al.* 1995) classification meadows have abnormal density, these can be due to the sampling depth that do not exceed 3m. On the other hand, mean densities in Arzew and Zimba sites, were lower, which would appear to indicate a more general source of perturbation.

Elsewhere, for the assessment of coastal waters status, many indices (classification systems) based on the *Posidonia oceanica* (a Biological Quality Element according to the EU Water Framework Directive) have been developed and applied in the North part of Western Mediterranean, and only few of them have been applied and tested in the south Mediterranean basin. In order to fill the gap, we made use of an ecological index (BiPo) based of four *P. oceanica* descriptors to assess the ecological status of coastal water in two localities from west

Algerian coasts: Stidia in Mostaganem and Cap Blanc in Oran. Results show that on a scale ranges from 'Bad' to 'High', the Ecological Quality Ratio EQR values using BiPo ranged Cap Carbon area waters body in 'Good' according to BiPo scale, Stidia water quality has been classified as 'High'. Using this index and PREI index Boumaza (Boumaza *et al.* 2015) recommended the use of PREI for more suitable for assessing the ecological status of Algiers coastal waters.

Data presented in this thesis work have been collected on a limited *P. oceanica* meadow distribution sites. A study covering a relatively large amount of sites and descriptors is necessary to carefully fill the gap on the *P. oceanica* situation trough the Algerian coasts.

Key words

Posidonia oceanica, distribution, health status, BiPo, Algeria, Mediterranean Sea.

Riassunto

Posidonia oceanica è una specie endemica mediterranea che forma prati denso ad ampio, che fornisce importanti funzioni e servizi ecologici e supporta una comunità ricca e diversificata, comprese le specie di interesse economico.

Nonostante la sua importanza, la distribuzione e la caratterizzazione dei prati di seagrass Posidonia oceanica sono stati scarsamente documentati e poco studiati nella parte meridionale del bacino del Mediterraneo, attraverso le coste algerine. Tuttavia, negli ultimi anni, vi è stato un interesse crescente per lo studio della *P. oceanica* attraverso la costa algerina, principalmente concentrata nella regione di Algeri.

Secondo le nostre indagini sulla letteratura, dal 2000 fino ad oggi, solo pochi documenti descrivono alcuni aspetti della *P. oceanica* nell'Algeria occidentale, soprattutto letteratura grigia scritta in francese. La distribuzione dettagliata rimane in gran parte sconosciuta. Inoltre, alcune mappe e dati di punta hanno contribuito a documentare la distribuzione dei letti lungo le coste algarie occidentali. Le nostre indagini su 12 zone in quattro Wilaya (distretti), dall'Algeria occidentale (Chlef, Mostaganem, Orano e Ain Temouchent) combinate con dati di letteratura provenienti da diverse fonti, prevedono che la *P. oceanica* sia più rappresentata nell'Algeria occidentale con una discontinuità attraverso le coste.

Uno studio sulla fenologia dei prati di Posidonia oceanica è stato condotto su cinque zone sui costi algerini occidentali (Zimba, Arzew, Stidia, Capo russo, Cap carbon) che forniscono nuovi dati sulla densità, il numero di foglie, la lunghezza del foglio, la superficie del foglio e lo stato degli apici determinate dal "coefficiente A". I risultati hanno mostrato informazioni sullo stato di salute del prato di *P. oceanica* attraverso queste zone. Secondo (Pergent *et al.* 1995), classificazione dei prati del 1995 hanno una densità anormale, questi possono essere dovuti alla profondità di campionamento che non supera 3m. D'altra parte, le densità media nei siti di Arzew e Zimba erano inferiori, che sembrano indicare una fonte di perturbazioni più generale.

Altrove, per la valutazione dello stato delle acque costiere, sono stati sviluppati e applicati molti indici (sistemi di classificazione) basati sulla Posidonia oceanica (un elemento biologico di qualità secondo la direttiva quadro UE sull'acqua) nella parte nord del Mediterraneo occidentale e solo pochi di loro sono state applicate e testate nel bacino sud del Mediterraneo. Al fine di colmare il divario, abbiamo utilizzato un indice ecologico (BiPo) basato su quattro descrittori di P. oceanica per valutare lo stato ecologico delle acque costiere in due località della costa

algerina occidentale: Stidia a Mostaganem e Cap Blanc ad Oran. I risultati mostrano che su una scala varia da "Cattivo" a "Alto", i valori dei rapporti di qualità ecologica (Ecological Quality Ratio: EQR) utilizzando la BiPo Le zone di acque di carbonio di Cap Carbon circondato in 'Buono' secondo la scala BiPo, la qualità dell'acqua di Stidia è stata classificata come 'Alto'. La qualità dell'acqua di Stidia è stata classificata come 'High'. Utilizzando questo indice e l'indice PREI di Boumaza (Boumaza *et al.* 2015) ha raccomandato l'utilizzo di PREI per una più adatta per valutare lo stato ecologico delle acque costiere di Algeri.

I dati presentati in questo lavoro di tesi sono stati raccolti su un sito limitato di distribuzione dei prati *P. oceanica*. Uno studio che copre una quantità relativamente elevata di siti e descrittori è necessario per colmare attentamente il divario sulla situazione di *P. oceanica* attraverso le coste algerine.

Parole chiave

Posidonia oceanica, distribuzione, stato di salute, BiPo, Algeria, Mediterraneo.

List of Abbreviations

ANOVA	Analysis of variance
BiPo	Biotic Index based on *Posidonia oceanica*
BQE	Biological Quality Element
EQR	Ecological Quality Ratio
POMI	*Posidonia oceanica* Multivariate Index
PREI	*Posidonia* Rapid Evaluation Index
WFD	Water Framework Directive

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GENERAL INTRODUCTION

The seagrass *Posidonia oceanica* (L.) Delile is an endemic species of the Mediterranean Sea, whose meadows constitute an engineering ecosystem playing a major ecological, geological and economic role in coastal zones (Boudouresque and Meinesz 1982, Pergent-Martini *et al.* 1994, Boudouresque 2004). Therefore, the study of the *Posidonia oceanica* from different field became essential due to its ecological and even economic importance described by several studies.

For this, we focused our study especially on providing an updated data for the localization and characterization of *P. oceanica* meadows through a part of the Algerian coasts, to fill the gap of the information availability for the scientific community.

- Chapter I represent state of the art on the Mediterranean seagrass *Posidonia oceanica*, of some essential characteristics and studies. Including Eco-biology, meadows geographic repartition, the use of this species as a bio-indicator and its concerned legislation.
- A literature review of studies treating mapping, characterisation and health status assessment of *P. oceanica* from different sources, mainly, a non-published thesis written in French are presented in Chapter II.
- Later in Chapter III *P. oceanica* localisation map was updated by adding to literature data our field data from 5 zones from Western Algeria. Health status is, also, assessed according to usually used descriptors.
- Finally, in chapter IV, we tested the feasibility of the assessment of the coastal waters by the adoption of a biotic index developed by (y Royo *et al.* 2010) BiPo that was drawn up according to the requirements of the Water Framework Directive. This index has been implemented on two coastal sites from the western Algeria. In Stidia belonging to Mostaganem department and Cap Blanc belonging to Oran department.

CHAPTER I

State of the art on the seagrass *Posidonia oceanica*

Posidonia oceanica (L.) Delile (common name: Neptune grass) is an endemic seagrass species of the Mediterranean Sea (Den Hartog 1970). This species belongs to the subphylum *Angiospermae*, class Monocot, order *Potamogetonales*, family *Posidoniaceae*.

The scientific name, *Posidonia oceanica*, seems strange as this plant only grows in the Mediterranean Sea. However, Seagrass thrived and spread in the warm Tethyan seas of the Eocene. The present global distribution is likely to be far more limited than in the past due to continental drift, temperature changes and the impact of enormous variations in sea levels since the Pleistocene (Long *et al.* 1999).

Posidonia oceanica (L.) Delile is the most important seagrass in the Mediterranean coast, with an estimated extend of 2.5 to 4.5 million hectares (Pergent *et al.* 1995). This represents 1 to 2% of the Mediterranean bottom and 20% of the Mediterranean basin shallower than 50 m (Pasqualini *et al.* 1998). It forms extensive meadows ranging from surface to depths up to 25-40m (Pérès and Picard 1964, Ribera and Boudouresque 1995) when sufficient light is available (Den Hartog 1970) and is commonly found on sandy and rocky substrata with the exception of estuaries where the input of freshwater and fine sediments is high (Green and Short 2003).

Posidonia oceanica is a large, slow-growing rhizomatous plant possessing both horizontal (plagiotropic) and vertical (orthotropic) rhizomes. Rhizomes are arranged as a sequence of segments (internodes) separated by nodes Figure 1. Horizontal and vertical internodes are short (3.5–1 mm on average, respectively) and thick (up to 1 cm) revealing the slow growth of this species. Roots (up to 4 mm thick, and up to 40 cm long) are typically produced at the nodes of both kinds of rhizomes. Long (75 cm, on average) and wide (10 mm, on average) leaves (blade plus sheath) arranged in bundles on shoots (up to 8–10 leaves) arise from the nodes of the orthotropic rhizomes (Pérez-Lloréns *et al.* 2014).

Figure 1 Detailed view of *Posidonia oceanica* shoots and orthotropic rhizomes fully covered by the fibrous rests of old leaf sheaths. The outermost leaves of the shoots (the oldest leaves) are covered by calcareous epiphytes (Photographs: Juanma Ruiz) (Pérez-Lloréns *et al.* 2014)

Reproduction

Posidonia oceanica is characterized by long persistence, slow vegetative growth, sporadic sexual reproduction and low genetic variability (Buia and Mazzella 1991, Buia *et al.* 1992, Procaccini and Mazzella 1998). This species presents both a vegetative and a sexual reproductive strategy. The former is accomplished by clonal growth while the latter entails the production of hermaphrodite inflorescences and the formations of fruits and seeds (Mazzella *et al.* 1983). Sexual reproduction generally occurs at the end of the fall with fruit formation about six months later (March-April) (Mazzella *et al.* 1983).

Geographic repartition:

Posidonia oceanica occur in 16 Mediterranean countries (Giakoumi *et al.* 2013). The total known area of *P. oceanica* meadows in the Mediterranean Sea was found to be 1,224,707 ha (12,247 km^2) (Telesca *et al.* 2015).

To the west, it disappears a little before the Straits of Gibraltar due to the influence of Atlantic water that is colder and less salty than the Mediterranean (Pérez-Lloréns *et al.* 2014). The most westerly remnants are recorded 20 km east from the Gibraltar Strait on the Spanish coast (Estepona Bay), and 280 km towards Morocco coasts, near Sebkha-bou-Areg, and Chaffarine islands (Meinesz *et al.* 2009, Giakoumi *et al.* 2013).

In the east, it is absent from the coasts of Egypt (east of the Nile delta), Lebanon and colonised Palestine. Thus, its absence on a relatively narrow strip of the eastern Levant Sea (Lebanon coasts) has been associated to temperatures above the maximum range (Celebi *et al.* 2007).

Finally, it is rare or absent in the extreme north of the Adriatic (Gamulin-Brida 1974) and along the Languedoc coast (southern France), between the Camargue and Port-la-Nouvelle (Boudouresque and Meinesz 1982, Boudouresque *et al.* 2012). Figure 2.

Posidoania ocenica presence next to the mouth of large rivers (e.g., Rhône, Pô or Nile) is limited by sediment and freshwater inputs.

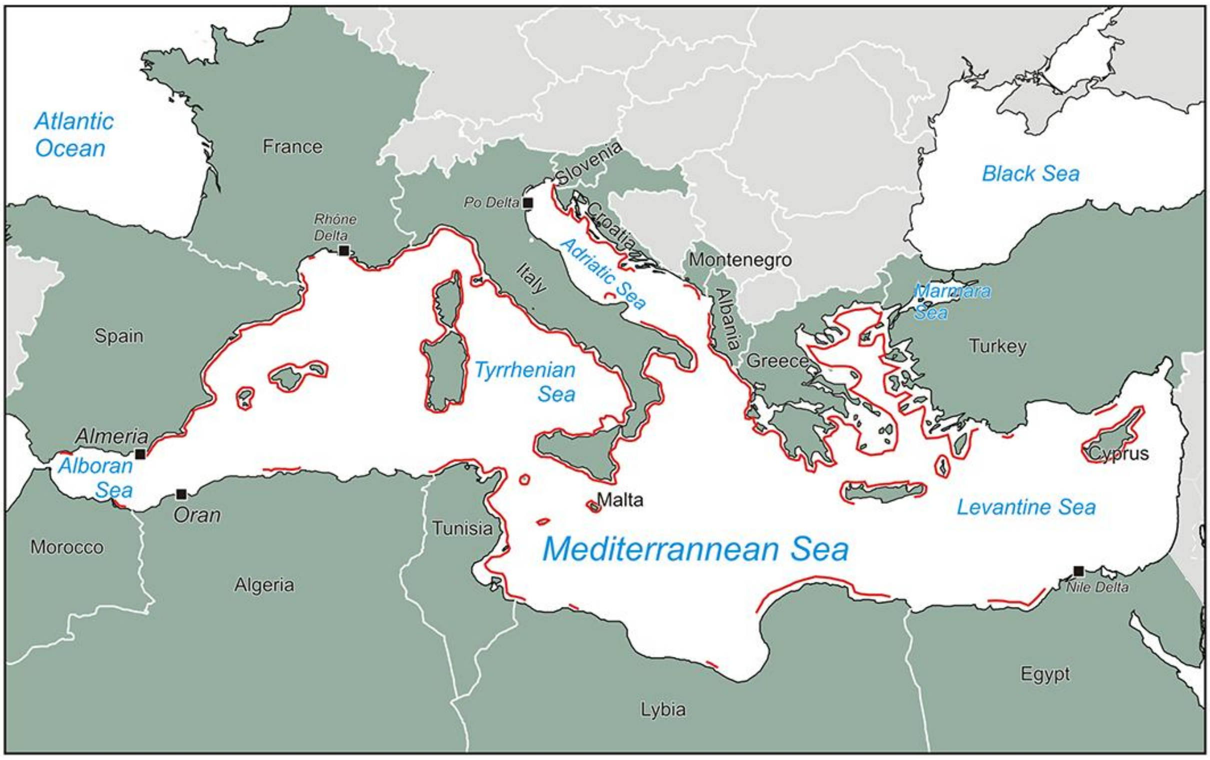

Figure 2 Distribution of *Posidonia oceanica* (red line) along the coast of the Mediterranean Sea. in *(Vacchi et al. 2016)*

P. oceanica is considered supporting salinity values between 36.5 (e.g., Alborán Sea) and 39.7 (e.g., Cilician Sea), although it also occurs at lower salinities (e.g., from 21.5 to 28 in the Dardanelles Strait and in the Marmara Sea) or in hypersaline coastal lagoons (e.g., 39–44 in Farwa Lagoon on Libyan coast) (Pérez-Lloréns *et al.* 2014).

The presence of the *P. oceanica* in the north-western Mediterranean is widely recorded, whereas in the south-western and eastern Mediterranean is scarcer (Green and Short 2003).

There are slight morphological and genetic differences between P. oceanica meadows from different regions. In particular, there is a genetic cleavage between the Eastern and Western Mediterranean meadows, which suggests that these meadows were temporally isolated from each other during last glaciations (Arnaud-Haond *et al.* 2007). Nevertheless, there are no clear geographical differences in meadow structure and function between the two basins, and the morph type differences disappear after some years of acclimatization when transplanted to another site (Meinesz *et al.* 1993).

Importance

P. oceanica meadows play a major ecological, sedimentary and economic role (Bell and Harmelin-Vivien 1983, Jeudy de Grissac and Boudouresque 1985, Gambi *et al.* 1989, Romero *et al.* 1992, Duarte and Chiscano 1999, Duarte 2002).

The *Posidonia oceanica* meadows represent one of the bases of the richness of the coastal waters (Boudouresque and Meinesz 1982) and the most important ecosystem of the Mediterranean coastline for biodiversity, comprising 20 to 25% of Mediterranean plant and animal species (Boudouresque *et al.* 2006). In addition, *P. oceanica* meadows form a key ecosystem component in the shallow waters of the basin and are an important resource for the fishery (Mazzella *et al.* 1983). Thus, their role is comparable to that of other plants in temperate and tropical seas supporting high biodiversity (Larkum *et al.* 1989).

From a functional point of view, *Posidonia oceanica* meadows constitute both a nutrition zone by their enormous primary production which makes it a major source of food for the trophic network inside the meadow and in other ecosystems by dead leaves exporting to the medialittoral, infralittoral, circalittoral and bathyal (Pergent *et al.* 2008, Boudouresque 2013), spawning grounds and a nursery, But also a shelter for many species, some of which are of high commercial value. The meadow also absorbs the hydrodynamic effects of swell and their structure promotes trapping of particles, which results in stabilization of the sandy coastal strands (Stephane and Colombe 2012, Boudouresque 2013). Finally, seagrass beds play a major role in carbon sequestration (carbon sinks) and contribute significantly to mitigating the effects of carbon emissions (Duarte *et al.* 2005).

Today, because of its sensitivity to water quality (transparency and nutrient concentrations), *P. oceanica* is used as biological sentinels or "shore canaries" (Pergent-Martini and Pergent 2000, Orth *et al.* 2006), for example as biological indicators in the European Water Framework Directive (2000/60/CE) and Marine Strategy Framework Directive (2008/56/CE).

The value of the *P. oceanica* indicator works at three levels (Montefalcone 2009): the 'individual' level, where plant phenology (in particular leaf biometry) provides information on its status and growth conditions (Leoni *et al.* 2003, Buia *et al.* 2004, Marbà *et al.* 2006).

The "population" level, where the structure (e.g. density and / or cover) and meadow morphology (such as the presence of regressive structures: dead matte) represent characteristic of environmental conditions (Pergent *et al.* 1995, Montefalcone *et al.* 2008).

The community level, where the associated flora and fauna (especially epiphytes) are equally sensitive to environmental changes (Ruiz *et al.* 2001, Cancemi *et al.* 2003, Balata *et al.* 2007).

P. oceanica **as a bio-indicator**

Moreover, seagrasses, mainly, the *P. oceanica* can be considered as biological sentinels or ''coastal canaries'' since any changes in its distribution, such as a reduction in the maximum depth limit or widespread seagrass loss signal changes in the environment (Orth *et al.* 2006).

Posidonia oceanica seems to be a reliable bioindicator (Augier 1985, Pergent 1991, Pergent-Martini and Pergent 2000), according to:

- Their sensitivity to disturbances, as demonstrated by a number of reports of meadow regression due to various causes (Delgado *et al.* 1999, Ruiz *et al.* 2001, Ruiz and Romero 2003). And to assault related to human activities (Meinesz and Laurent 1978, Boudouresque *et al.* 2006).
- Its wide distribution along the Mediterranean coast (Pasqualini *et al.* 1998)*Vacchi et al. 2016*).
- The good knowledge about the specific response of the plant and of its associated ecosystem to specific impact. Furthermore, this species is able to inform about the present and past level of trace-metals in the environment (Pergent-Martini 1998). By its presence and vitality (or its regression materialized by dead mattes), it gives an assessment of the water body status.

Moreover, like many marine Magnoliophyta, *Posidonia oceanica* has a high concentration of trace elements, proportional to the concentrations present in the environment (Augier 1985, Capiomont *et al.* 2000, Pergent-Martini and Pergent 2000), and good resistance to metal contamination (the species persists in the vicinity of important sources). In addition, its capacity to be maintained in aquariums for short-lived artificial contamination experiments (Ferrat *et al.* 2002) and, above all, its capacity to memorize the old contents within its tissues, combined with the dating possibilities offered by Lepidochronology, open up unique perspectives in the follow-up over time of pollution and allow to have at their disposal a real biological archive able to inform about the temporal evolution of a pollution (Calmet *et al.* 1988, Pergent *et al.* 1995, Pergent-Martini 1998).

In other hand, some species indicate seagrass perturbation: the overgrowth of epiphytic algae and especially the episodic formation of dense mucous layers of filamentous algae (*Ectocarpales* and *Crysophyceae*) on the meadow canopy is associated with water eutrophication and reduced hydrodynamics (Lorenti *et al.* 2005). The green algae *Caulerpa* spp. invades declining sparse meadows, especially when the sediment is enriched with organic matter (Terrados and Marbà 2006). When nutrient inputs to the bed are too intense, sea urchins *Paracentrotus lividus* (normal densities 0-5 urchins m-2) become over abundant (may attain 30 urchins m-2) on meadows that grow near rocky substrates and consequently overgraze *P. oceanica* leaves (Ruiz and Romero 2003). Their excess is therefore indicative of habitat eutrophication. Fire worms (e.g. *Hermodice carunculata*) also appear in degraded meadows with an excess of labile organic matter.

Problems

P. oceanica, like any seagrass, is vulnerable to changes in coastal environments and can be easily destroyed or damaged. If the degradation is faster than its adaptation rate, then the result would be a reduction in the plant's distribution area.

Because of its bathymetric range, the Posidonia is directly exposed to natural and anthropogenic pressures, therefore it has become evident that it is regressing at several sites in the Mediterranean (Duarte 2002, Spalding *et al.* 2003, Jordà *et al.* 2012), mainly near industrial and port facilities. This regression has been attributed to various causes, including: coastal restructuring (Meinesz *et al.* 1991, Ruiz and Romero 2003, Boudouresque *et al.* 2012), fisheries and aquaculture (Delgado *et al.* 1999, Pasqualini *et al.* 2000, González-Correa *et al.* 2007, Kiparissis *et al.* 2011), solid and liquid waste (Pergent-Martini *et al.* 1995, Boudouresque *et al.*

2012), the development of recreational boats and tourist cruises (Montefalcone *et al.* 2007, Boudouresque *et al.* 2012) Exotic species introduction (Boudouresque *et al.* 2012) and pollution (Dimech *et al.* 2000).

Legislation *in* (Telesca *et al.* 2015)

In the last twenty years, *P. oceanica* has become one of the main targets of the protection and management of the Mediterranean marine environment. The European Union's Habitat Directive (92/43/ CEE) includes P. oceanica beds among priority habitats (Habitat Type 1120: *P. oceanica* beds - *Posidonion oceanicae*). Seagrass meadows also have a dedicated Action Plan within the framework of the Barcelona Convention, under the "Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean". More recently, the Marine Strategy Framework Directive (MFSD) (2008/56/EC) has established a framework according to which each Member States shall take the necessary measures to achieve or maintain "Good Environmental Status" in the marine environment. Angiosperms have been listed as a biological feature in Table 1 of Annex III "Indicative list of characteristics, pressures and impacts" and *P. oceanica* has been selected as representative species of the angiosperm quality elements for the Mediterranean marine environment. Parallel to this, each EU Member State has defined its own method to evaluate the health status of *P. oceanica* meadows according to the Water Framework Directive (2000/60/EC).

In Algeria, Posidonia is a protected species by Article 3 of Executive Decree No 12-03 of 4 January 2012 establishing the list of protected non-crop plant species. (Official Gazette No. 3 of 18 January 2012 - Annex, page 17).

CHAPTER II

Posidonia oceanica through the West Algerian coasts

The main objective of this Task is the revision of historical and current data on the locations, characterisation and health status of *Posidonia oceanica* over the West Algerian coast.

Data collection

At a first time, searches were conducted using ISI Web of Knowledge, ScienceDirect, SpringerLink and Google Scholar for relevant keywords, including "*Posidonia* mapping", "*Posidonia* cartography" and "*Posidonia* Algeria". In addition to data base searches, we also hand checked the reference lists of all studies retrieved to identify all relevant primary research published in other peer reviewed journals, books, and proceedings of international conferences. We also made searches on PNST[1] (National Theses Reporting Portal). In a second time, we checked Ph.D. thesis and Magister/Master in different West Algerian universities, which do not provide access via the internet, for studies directly treating with *Posidonia*. Or indirectly, ex: benthic biodiversity, sea cucumber and urchins, which can provide data about presence or absence of *Posidonia* in the study area. We, also, contacted some authors wishing to get some unpublished data for the status of the *P. oceanica*.

To find more about the localization of the *P. oceanica*, we made a questionnaire for sea divers in some diving clubs[2] and for underwater hunt practitioner. In another side, more than 20 free diving activities were made, on 12 different zones in west Algeria, to assess presence / absence and status of the Posidonia meadow (see Chapter III).

***Posidonia oceanica* localisation (map)**

In the southern part of the Mediterranean basin, trough the Algerian coasts, the seagrass *Posidonia oceanica* meadows are scarcely studied. it was reported that currently surveyed coastline in Algeria is about 16% for a total current area of 4,072 ha (Telesca *et al.* 2015) Figure 3.

[1] https://www.pnst.cerist.dz/
[2] Trident Club

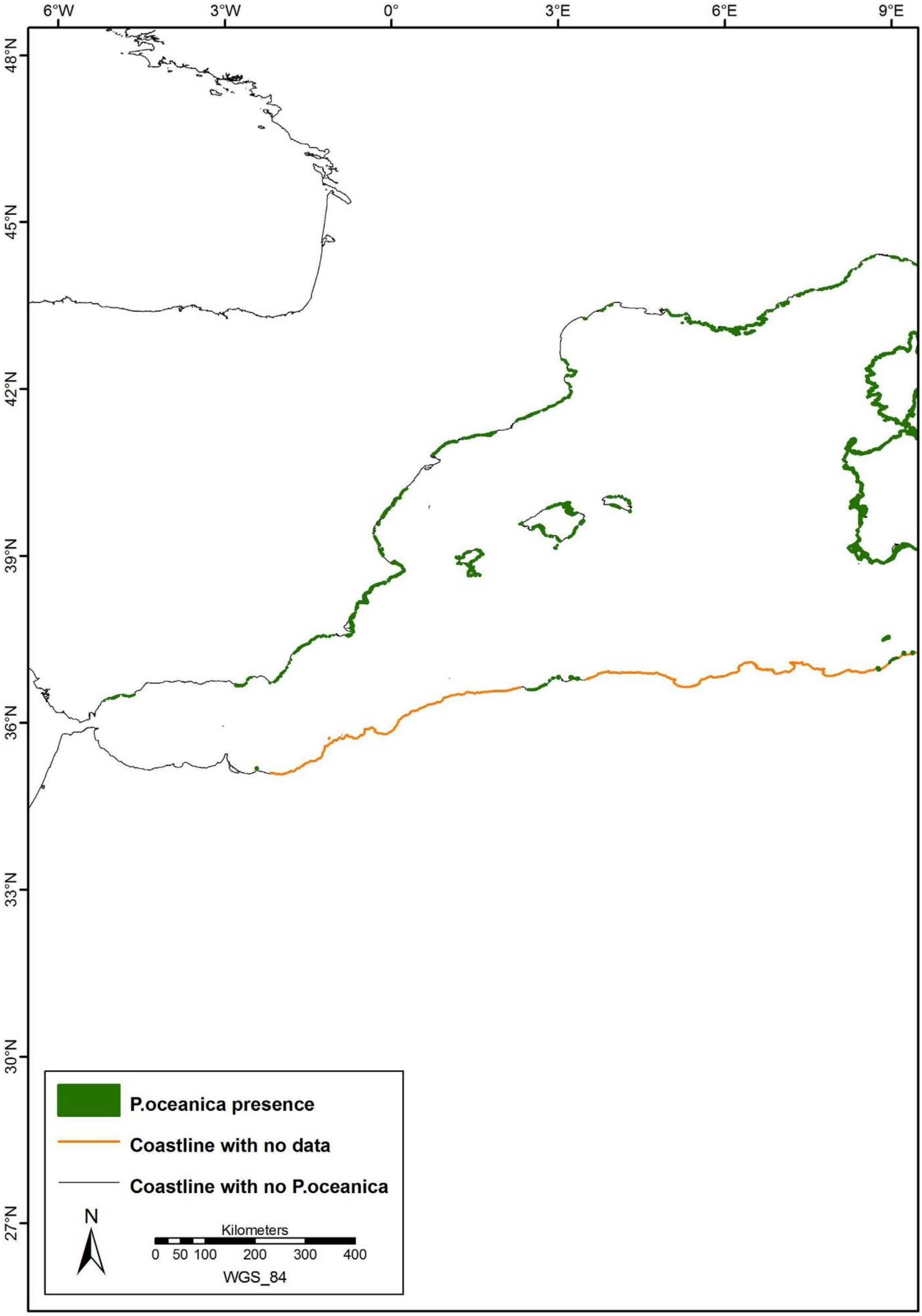

Figure 3 : Detail of the current distribution of *Posidonia oceanica* meadows in the Western Mediterranean Sea (Telesca *et al.* 2015)

According to our literature investigations, from 2000 to date, we found that only few documents described some aspects of the *P. oceanica* in West Algeria, mainly grey literature (Magister and doctoral thesis) written in French. Studies results were limited to Oran and Mostaganem, Oran coasts were the most represented (Table 1).

Table 1: *P. oceanica* localisations from literature investigations.

Wilaya (District/Province)	Locality	GPS	Referece
Oran	Ain franin	35° 46’ 49,78 N 0° 31’ 01,51 W	(Cahrour 2013, Boudjella 2015)
	Cap carbon	35° 54’ 6.36 N 0° 20’ 20,22 W	
	Cap blanc	35° 41' 3" N 1° 2' 35" E	(Khodja 2013)
	Madagh	35° 37’ 53’’ N 1° 04 ‘ 01’’ W	(Dermeche *et al.* 2009, Husein Kais 2015)
	Arzew	35° 52’ N 0° 19’ W	(Husein Kais 2015)
	Ain el turc	Not cited	
	Cap falcon	Not cited	
	Pain sucre	Not cited	
Mostaganem	stidia	35° 49’ N 0° 01' W	(Belbachir 2012)
	Hadjaj	36° 08' N 1° 80' E	
	Sidi Lakhdar	36° 12’ 40.63 N 0° 23’ 20.78 E	(Boudjella 2015)

Summary of *P. oceanica* locations in western Algeria

The questionnaire made for the diving club gave us with zones of *P. oceanica* presence that has currently been reported by literature. Our investigations result to 12 zones from four Wilaya, from the western Algeria (Chlef, Mostaganem, Oran and Ain Temouchent), provides that the *P. oceanica* is more represented in western Algeria with a discontinuity through the coasts. It’s than absent in 6 areas (Table 2)

- Damous, Beni Haoua belonging to Wilaya (district) of Chlef.
- Oureah in Mostaganem
- Canastel in Oran
- and in Sidi Boucif and the zone of Madrid beach belonging to Wilaya of Ain Temouchent

Table 2: *P. oceanica* points localisations from our investigations.

Wilaya (District/Province)	Locality	Presence/absence	Year
Chlef	Damous	-	2016
	Beni haoua	-	
Mostaganem	Oureah	-	
	stidia	+	2017
Oran	Marsa elhadjaj	+	2016
	Arzew	+	
	Canastel	-	
	Cab blanc	+	
	Cap Carbon	+	2017
Ain Temouchent	Zimba	+	
	Madrid	-	2016
	Sidi Boucif	-	

Data from literature research (Table 1) and our investigations (Table 2) have been combined to provide current distribution map of *Posidonia oceanica* meadows through the west Algerians coasts, in the Western Mediterranean Sea, the result represents a new detailed map of the presence of *P. oceanica* trough the west Algerian coasts (Figure 4).

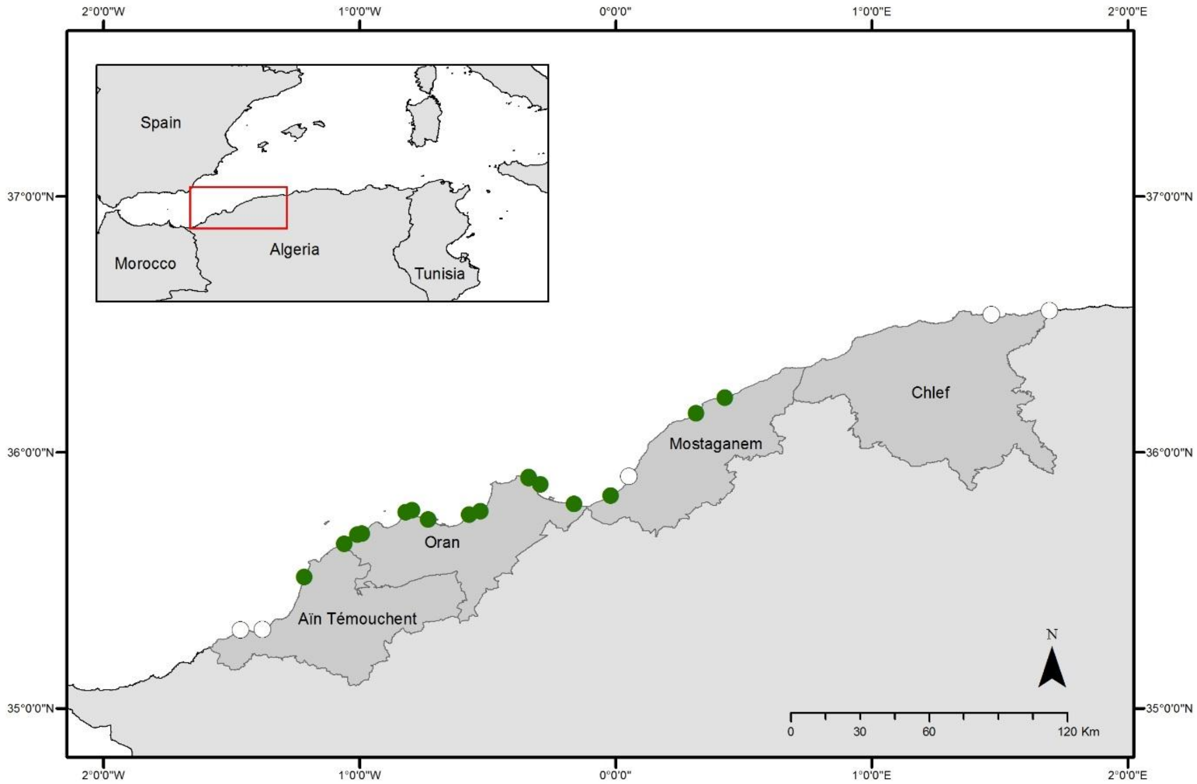

Figure 4: *Posidonia oceanica* trough the west Algerian coasts. Green points: *P. oceanica* localisations. White points: absence of the *P. oceanica*.

Characterisation and Health status

Through the Oran coasts, the *Posidonia oceanica* occupied area remains modest, due to the narrowness of the continental shelf. The surface of the beds is important in Cap Carbon, Arzew, Ain El Türck, Pain Sucre and Madagh.

The upper limit of the Cap Carbon Posidonia meadow is 0.6m and the lower limit is 27m, at Arzew it is (Sup Lim: 1m and Inf Lim: 30m), Ain Turk (Lim Sup: 12 / 14 m and Lim Inf: 30 m, the maximum limit of a few spots is 40 m), Andaluse bay (Sup Lim: 3 to 4m and Inf Lim: 30m), Pain Sucre And 5 m, becomes dense at 6 and 8 m and Lim. Inf: 25 m) and Madagh, has a dense meadow with an upper limit of 0.1 to 0.3 m depth. When the sea is calm, apex of the leaves emerge and the lower limit of the Posidonia bed is around 27 m. The second category of the stations is that which contains less dense meadows than the first one, namely Cape Falcon: the herbarium is in the form of several spots on soft substrate with an upper limit located at 7m of isobaths. At Plane Island there is a total absence of Posidonia around the island, but at the N / W of the island between 8 and 12 m deep there is a spot covering an area of 30 m² (Husein Kais 2015). Meadow density is of type I "very dense" with respective coverage rates of 75% in Ain Franin, 80% in Cap Carbon (Boudjella 2015). According to the classification of (Giraud 1977) and (Pergent *et al.* 1995), *P. oceanica* meadows in Ain Franine and Cap Carbon are in good condition (Boudjella 2015).

According to the classification of (Giraud, 1977), *P. oceanica* meadow at Cap Carbon is of type III which is described as « Sparse » In Ain Franine, it's of type II described as « dense ». According to the latest classification (Pergent et al., 2005), meadows in both Ain Franine and Cap Carbon are considered as being in « poor condition » (Chahrour *et al.* 2013) Table 3.

From Mostaganem, meadow density is of type I "very dense" with coverage 83.33% in Sidi Lakhdar. According to the classification of (Giraud 1977) and (Pergent *et al.* 1995), *P. oceanica* meadows are in good condition (Boudjella 2015). Thus, the *Posidonia oceanica* meadow of Hadjadj area has a better vitality compared to the one of Stidia; though both meadows of the studied areas show a light sign of disturbance dues to their weak shoot densities (Mezali and Belbachir 2012) Table 3.

Table 3: Posidonia meadows classification of Oran and Mostaganem sites

Wilaya (District / Province)	Locality	Depth (meter)	Sampling year	Density (Shoots.m^{-2})	Reference	Giraud (1977)	Pergent et al 1995
Oran	Cap Carbon	10	2009	350	(Cahrour 2013, Chahrour *et al.* 2013)	III	
	Ain Franine	10		403		II	
	Cap Blanc	10	2012	468.2 ±68,29	(Khodja 2013)	II	Densité normale
	Cap Blanc	5		807 ±50,89		I	densité sub-normale supérieure
	Cap Carbon	1-2	2014	956.64 ±122,79	(Boudjella 2015)	I	
	Ain Franine	2-3		827.7 ±81, 09		I	
Mostaganem	Sidi Lakhdar	1-2		1054.83 ±116,75		I	
	Hadjaj	1.5	2011	505.6 ± 316.98)	(Belbachir 2012)	II	Anormale
		3		193.6 ± 59.13		IV	Anormale
		3		379.2 ± 157.50		III	Anormale
	Stidia	0.7		181.4 ± 75.40		IV	Anormale
		1.5		350.8 ± 188.57		III	Anormale

The Posidonia beds are deeply degraded near towns coasts and industrial infrastructures. Coastal development leads to a reduction in the coastal strip, which has led to the disappearance of beds habitats (Semroud 1993). This phenomenon is widespread in large urban centers such as the Oran coast, where the meadow has regressed significantly during the last 50 years, its upper limit has clearly decreased following the development of the city of Oran (Husein Kais 2015).

The temperature associated with the discharge of heated water causes a change in the temperature of the sea water. This has been observed at the Arzew thermal power station, where the herbarium has completely disappeared and has been replaced by the green alga *Caulerpa prolifera* (OULD AHMED 1994). However, since chlorine is also released, it is difficult to know which of these two agents resulted in the disappearance of *Posidonia oceanica* (Husein Kais 2015).

Conclusion

A limited volume of scientific literature has been devoted to the study of the *Posidonia oceanica* through the west Algerian coast compared to other area in North Mediterranean. This literature, usually written in French, is dispersed in a few university libraries and sometimes local scientific journals, and thus remains less accessible to the international scientific community.

After all, in the last few years, there has been a little growing interest to the study of the *P. oceanica* through the Algerian coast, primarily centered in Algiers region. However, no mapping programs have been conducted to assess the seagrass distribution in exception of the CNDRB (National Centre for the Development of Biological Resources) *Posidonia* cartography project that started in 2008 (no result published till now).

According to limited information available along the western Algeria coasts, assembled from various type of document, the detailed distribution remains largely unknown. Furthermore, some maps and point data helped document the distribution of beds along the west Algerian coasts.

Therefore, these data on current distribution are scarcely informative of the situation of the *P. oceanica* meadows which have been assessed only through a limited amount of information. This represents a strong limitation in providing a baseline *Posidonia* health status assessment.

CHAPITRE III

Characterisation of *Posidonia oceanica* through the west Algerian coasts

Objective: *Posidonia oceanica* meadow characterisation through different descriptors used to assess the ecological health status of the meadow.

Posidonia oceanica is considered as a reliable bioindicator (Augier 1985, Pergent 1991, Pergent-Martini and Pergent 2000), according to:

- their sensitivity to disturbances, as demonstrated by a number of reports of meadow regression due to various causes (Delgado *et al.* 1999, Ruiz *et al.* 2001, Ruiz and Romero 2003).
- its wide distribution along the Mediterranean coast (Pasqualini *et al.* 1998, Procaccini *et al.* 2003)
- the good knowledge about specific response of the plant and of its associated ecosystem to specific impact (Romero *et al.* 2005)

Furthermore, *Posidonia oceanica* is able to inform about present and past level of trace-metals in the environment (Pergent-Martini 1998).

(Pergent-Martini *et al.* 2005) gave a review of the most used *Posidonia oceanica* descriptors, in order to better define the advantages of each of them in the assessment of the status of the *Posidonia oceanica* meadow and good ecological status of coastal zones. These parameters are used at a different level:

- The individual level (the plant) and most of the analyses at the community level (the associate organisms of leaves and rhizomes) require the collection of shoots, thus being defined as destructive techniques. The mean number of sampled and measured *P. oceanica* shoots ranges from about 10 to 20 shoots (Pergent-Martini *et al.* 2005).
- On the contrary, analyses at the population level (the meadow) and some of the analyses at the community level, i.e. the mobile fauna associated to the meadow, require simply underwater surveys for collecting data, thus being defined as not destructive techniques.

In Figure 5 the main descriptors of *P. oceanica* and for each descriptor, the different parameters used and their methods.

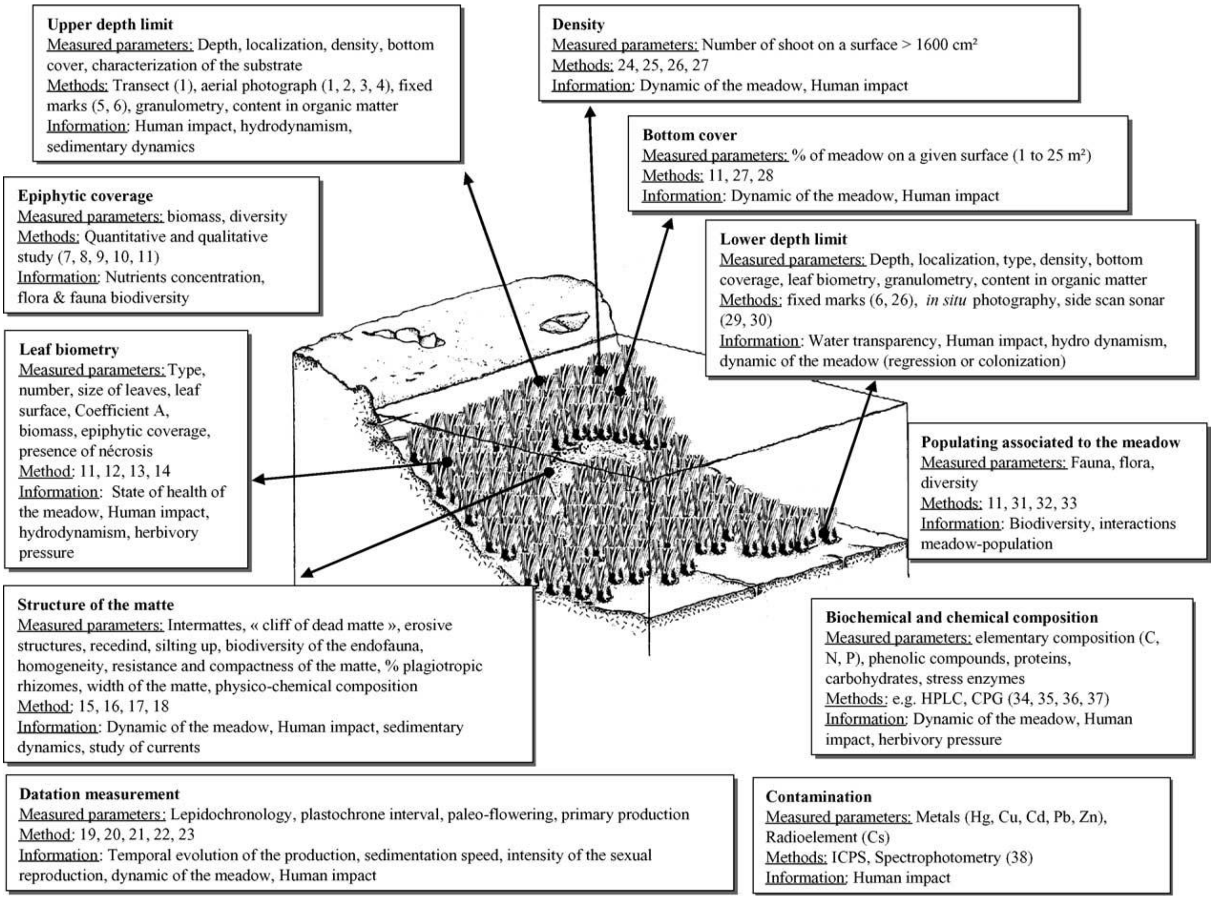

Figure 5: Recapitulative plan of the main descriptors of *Posidonia oceanica*, with the measured parameters and the methods of investigation (Pergent-Martini *et al.* 2005).

Considered descriptors measured *in situ*

Shoot density is widely measured parameters, and has been used in many in-depth studies (Giraud 1977, Pergent *et al.* 1995, Pergent-Martini *et al.* 2005, González-Correa *et al.* 2007, Romero *et al.* 2007, Fernández-Torquemada *et al.* 2008).

Density represents the number of shoots per surface unit (usually per sq. m.). The measuring can be determined by in situ counting inside a quadrate of 400 cm² Figure 6. High density is thought to characterize a healthy *Posidonia oceanica* meadow, whereas low density is seen as a consequence of human impact (PIAZZI *et al.* 2000).

Meadows status assessment has been made using shoot density classification according to (Giraud 1977) (see Table below), (Pergent *et al.* 1995) and (PNUE-PAM-CAR/ASP 2011) (see Annex I).

Shoot number per square meter	Meadow type
Plus de 700 faisceaux/m²	Type I, Very dense meadow
400 à 700 shoot/m²	Type II, dense meadow
300 à 400 shoot/m²	Type III, Sparse meadow
150 à 300 shoot/m²	Type VI, Very sparse meadow
De 50 à 150 shoot/m²	Type V, semi-meadow
Moins de 50 shoot/m²	Isolated Shoots 'Faisceaux isolés'

Descriptors measured in laboratory

Ex-situ we measured for metrics that are Shoot length, Leaf number per shoot and Leaf area. Leaf surface per shoot corresponds to the leaf area expressed in cm² per shoot (Drew and Jupp 1976). Only one side is taken into account. The latter is calculated for each category of leaves as defined by (Giraud 1979).

Leaf Area Index (LAI): Knowing the density, the Leaf Area Index is calculated by multiplying the leaf area by the density: it is then expressed in m² / m².

Figure 6: 400 cm² quadrate used for this study

Sampling and methodology

Ten quadrats were placed randomly along a 50 m transect parallel to the shore. At each quadrat the number of shoots was counted in a determined depth. The percentage of cover by *P. oceanica* was visually assessed using a square meter quadrat. Ten shoots were sampled from shallow water to 3 m depth, by free diving. Since *Posidonia oceanica* is a clonal plant, samples were taken at about 1-2 m distance from each other in order to obtain independent replicates.

Samples were kept in 10% formoled sea water until processing.

Later, the leaves were separated into three categories depending on their maturity, these are classified according to categories as defined by (Giraud 1979)

- Adult leaves, with a sheath (sheath greater than or equal to 2 mm) and measuring more than 50 mm long.
- Intermediate leaves with no sheath and measuring more than 50 mm long.
- Juvenile leaves with no sheath and measuring less than 50 mm long.

For each leaf, total length and width were measured as well as a sheath. The percentage of leaves that had lost their apex was also recorded as “A coefficient”.

Those measurements allowed calculation of the following descriptors:

- Mean number of leaves (Adult, Intermediate, and juvenile) per shoot;
- Mean leaves length and width.
- Mean leaf surface for Adult and Intermediate leaves.
- Mean leaf area index (LAI) for Adult and Intermediate leaves.

Study sites

The study was conducted through different sites from the west Algerian coasts (Figure 7).

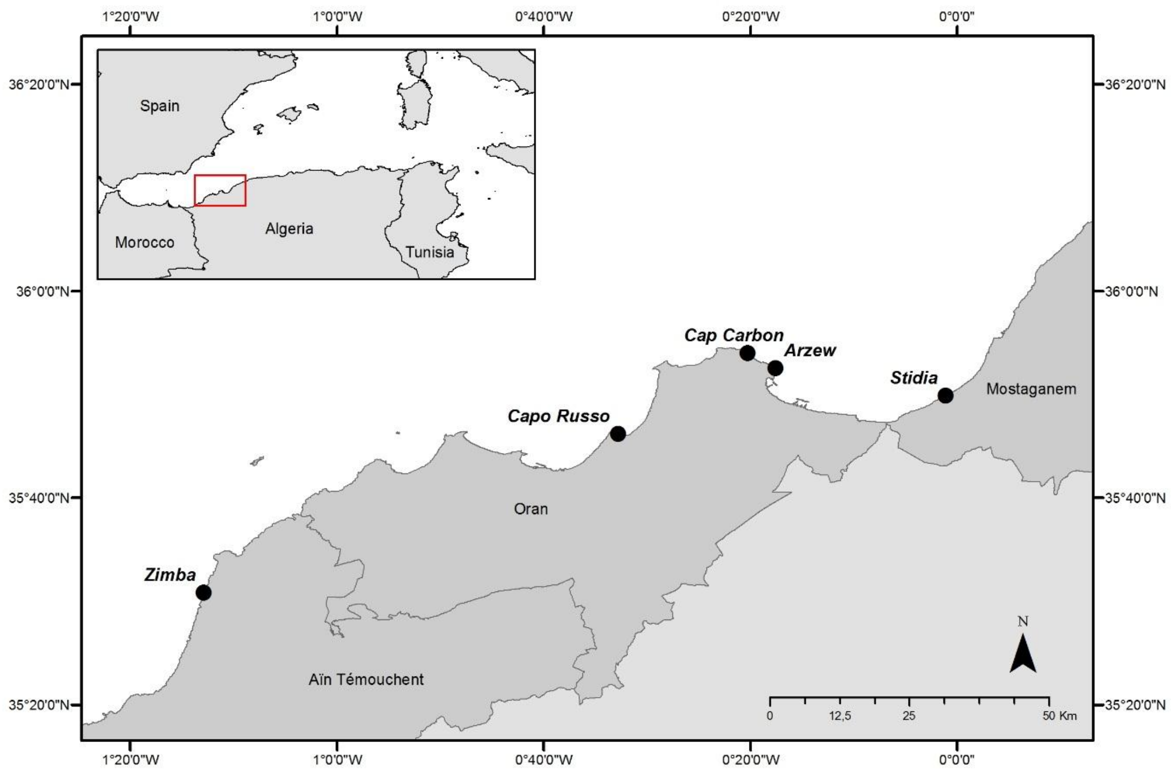

Figure 7: locations of sampling sites

Stidia (Mostaganem)

Located at a distance of about 20 km south-west of Mostaganem, the site of Stidia (Figure 8) presents a rocky area interrupted by a few coves, sometimes sandy, open towards the northwest but its geomorphology (it is not Sheltered enough) leaves it still exposed to the prevailing wind (northeast). This site is located at the foot of a mountain and the few sandy beaches that exist there have a coastal linear rather small and a width that does not exceed fifteen meters. Overall, the underwater aspect of the Stidia site consists mainly of an alternation of rock substrate, scree and sandy substrates (Belbachir 2012).

Figure 8: Stidia studied sites (Photos by BENTAALLAH M.E.A.)

Cap Carbon (Oran)

This zone is situated extremity west of the Arzew Gulf. The bottom is characterized by the presence of large rocks and some sandy spaces (Kais Boumediene 2015). Localized at the coordinates 35°54'7.62''N ; 0°20'22.31''W.

Figure 9: Cap Carbon studied site (Photos by BENTAALLAH M.E.A.)

Capo russo (Oran)

Zone with difficult access, A few fishermen settled and built shelters for their small boats (Figure 10). Studied site is located at the coordinates 35°46'17.75''N ; 0°32'59.82''W.

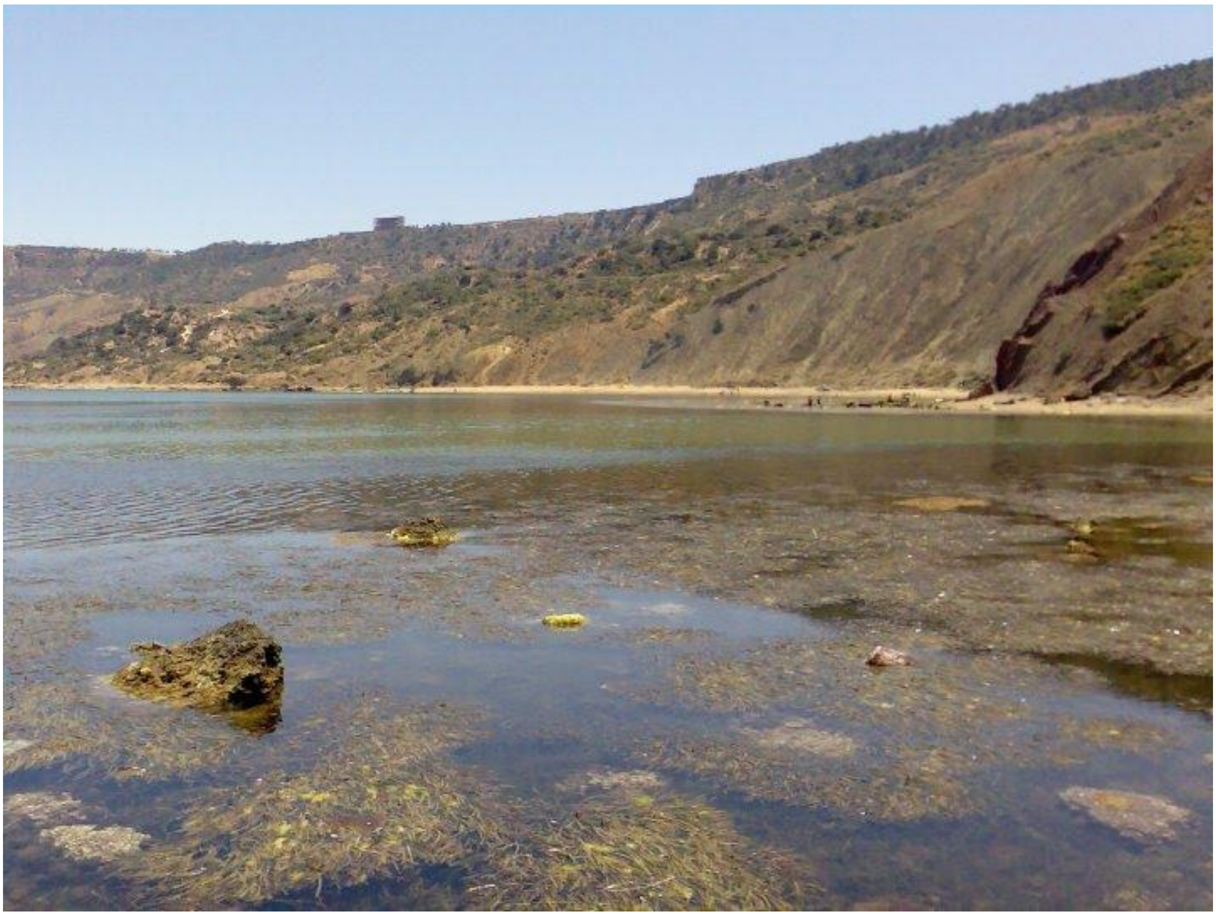

Figure 10: Capo russo studied site

Arzew (Oran)

The zone of Arzew is an urban-industrial zone located to the East of the wilaya of Oran. Arzew extends on a coastal linear of 22 Km. Arzew gulf is suggested to the influence of a significant industrial releases from petrochemical industrial units and complex (Kouadri Mostfeai 2014). The city of Arzew is a pole of the petrochemical industry and as such is considered to be one of the main sources of oil (Hydrocarbons) pollution with the city of Bethioua (GRIMES 2010). This station is localized at coordinates 35°53'24.47"N ; 0°19'31.17"W.

Figure 11: Arzew studied site (Photos by BENTAALLAH M.E.A)

Zimba (Ain Temouchent)

Zimba is an isolated zone not frequented at all because of its difficult access (Figure 12). It’s located at the coordinates 35°30'34.22"N ; 1°12'59.08"W.

Figure 12: Zimba studied site (Photos by BENTAALLAH M.E.A.)

Results and discussion

Density

Mean density values range from 350 in Zimba to 462.5 Cappo russo (Figure 13). This density, represented by the number of shoots of *Posidonia oceanica* per square meter, shows a significant difference, when using One way ANOVA (p = 0,03) (see Annex II) between the different studied sites, even if the sampling depth range is not large (1 to 2.5m depth).

According to the densities of the meadows in different studied sites, it seems that *Posidonia oceanica* is in reduced vitality status which is a warning signal for the disturbances that can be caused by effluent.

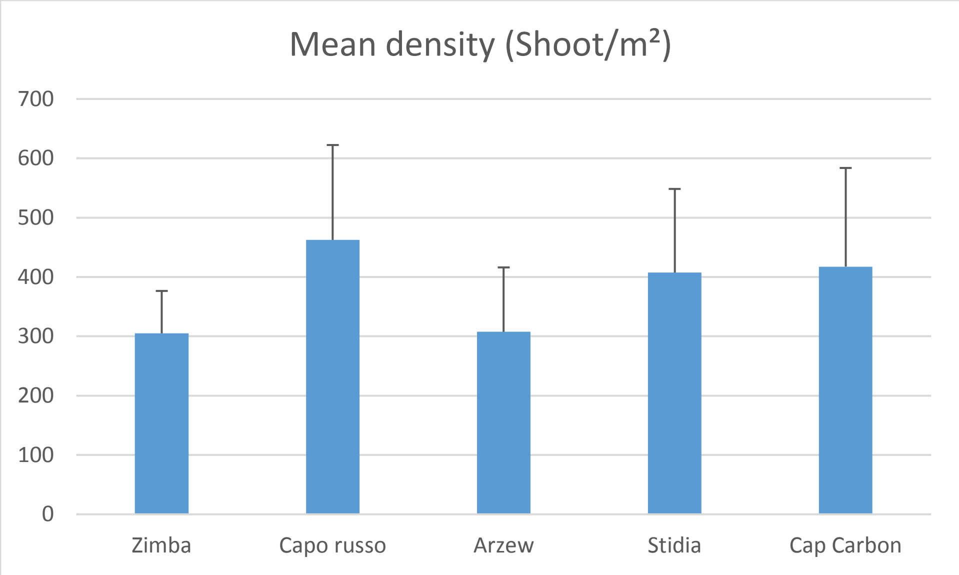

Figure 13: Mean density of *Posidonia oceanica*

Classification of these meadows status, according to the grid proposed by (PNUE-PAM-CAR/ASP 2011) (see Annex II), indicates that meadows correspond to "bad density" (densité mauvaise) at the indicated depth ranged from -1m to -2.5m, and according to (Pergent *et al.* 1995) classifications, it indicates that the meadows status correspond to "Abnormal density" ("densité anormale") (Table 4).

While according to (Giraud 1977), Zimba and Arzew meadows constitute a Type III meadows which correspond to "Sparse meadow" ("Herbier clairsemé"). Then, Capo russo, Cap Carbon and Stidia constitute a type II meadow which corresponds to "dense meadow" ("Herbier dense") (Table 4).

Table 4: Classifications of *P. oceanica* meadows from different studied sites

Location	Mean density	SD	Meadow classification				
			(Giraud 1977)		(Pergent *et al.* 1995)	(PNUE-PAM-CAR/ASP 2011)	Depth
			Classification	Description			
Zimba	305	71,49	Type III	Sparse meadow	Abnormal density	Bad density (Densité Mauvaise)	2.5
Capo russo	462,5	159,96	Type II	Dense meadow			1
Arzew	307,5	108,68	Type III	Sparse meadow			1.5
Stidia	407,5	140,95	Type II	Dense meadow			2
Cap Carbon	417,5	166,27	Type II				2

Moreover, this classification, which expresses the variability of density based on depth, does not take into account the other factors that can affect this parameter, such as substrate nature, morphology and topography and/or nutrient content (Balestri *et al.* 2003, Zupo *et al.* 2006, Giovannetti *et al.* 2010).

Mean leaves number per shoot

For the five studies sites, mean number of adult leaves per shoot is always superior to intermediate leaves, and juvenile leaves number is the lowest. According to mean leaves number per shoot chart represented in Figure 14 it seems that no difference is present between the studied sites. One way ANOVA results that there was no statically difference between adult leaves per shoot for the different studies sites (p = 0.435) (see Annex II). Mean leaves number per shoot for adult leaves is 3.4, 3.2, 3.6, 3.6, 3.3 respectively for Cap carbon, Stidia, Arzew, Capo russo and Zimba.

One way ANOVA results that mean number of intermediate leaves per shoot do not present a statistically difference at the studied sites (p = 0.4099) (see Annex II). Mean intermediate leaves number per shoot is 1.8, 1.9, 1.6, 1.9, 1.6 respectively for Cap carbon, Stidia, Arzew, Capo russo and Zimba (Figure 14).

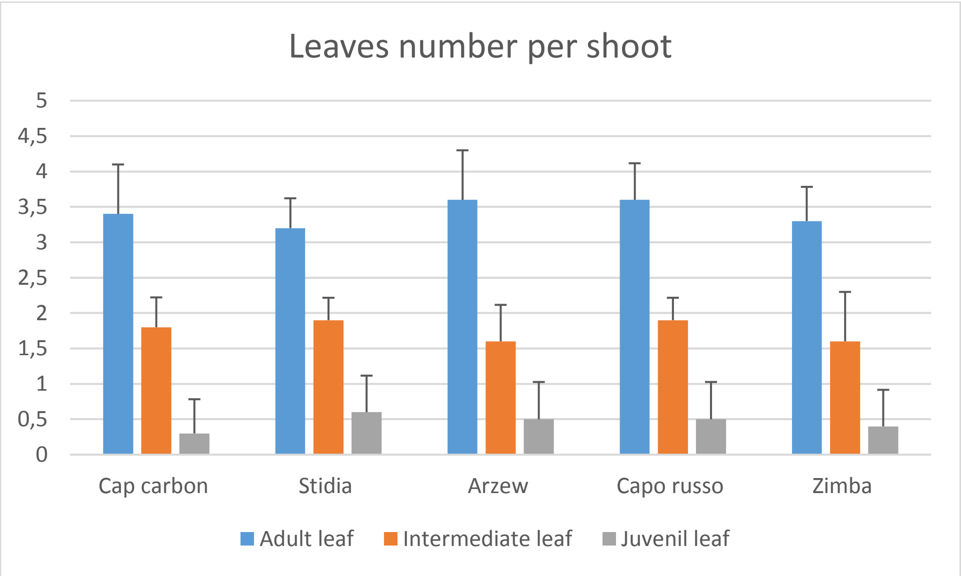

Figure 14: Mean leaves number per shoot

Despite the absence of statistically difference between leaves number per shoot for the different studied sites, even if these sites are very different in case of human pressure and disturbance, we consider that the sampling period can effectively affect proportions of the different types of leaves constituting the shoot (in our case study: adult and intermediate leaves), as it was noted by several authors (Semroud 1996, Gobert 2002, Belgacem *et al.* 2007). These fluctuations in the leaves number could be a considerable parameter making that difference non-significant.

Mean leaves length

Leaves length (Figure 15) is visibly lowest at Zimba studied site with 40.377 cm for adult leaves. Tallest adult leaves have been recorded for Stidia (mean = 68.6775 cm ± 35.3). However, there is no statistically difference between sites for adult leaves length ($p = 0.149$). One way Anova sorted that a significant difference exists for intermediate leaves ($p = 0.00489$). Means for intermediate leaves length are 30.565 ± 10.04, 28.135 ± 11.46, 17.631 ± 7.24, 25.4755 ± 6.9, 17.22 ± 9.94 respectively for Sidia, Cap carbon, Arzew, Cappo russo and Zimba.

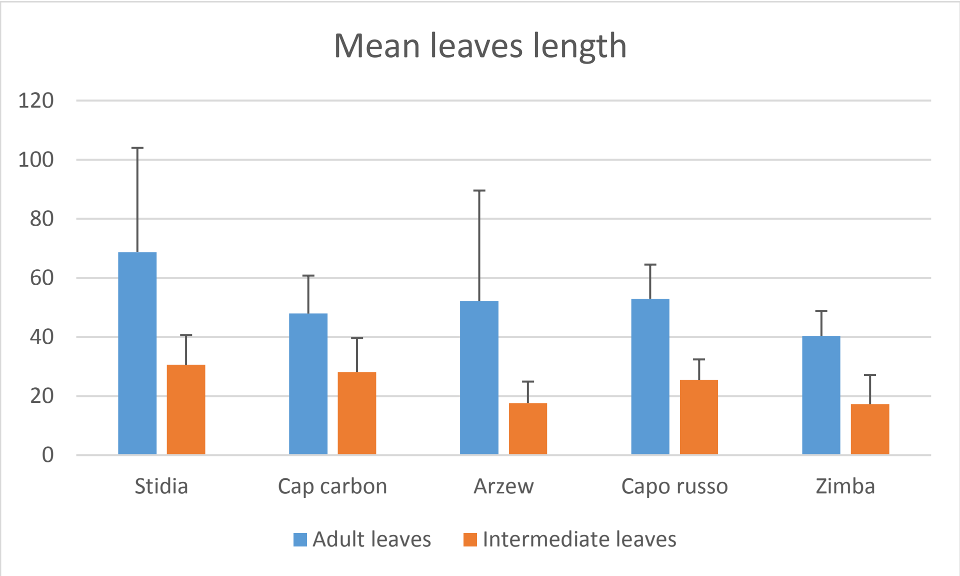

Figure 15: Mean Adult and Intermediate leaves length (cm)

Mean leaf surface for Adult and Intermediate leaves

Mean leaf surface per shoot (Figure 16) is minimum in cap carbon comparing to other studied sites. One way ANOVA result shows a non-significant difference between the studied site for both adult (p = 0,816) and intermediate (0,304) leaves surface per shoot.

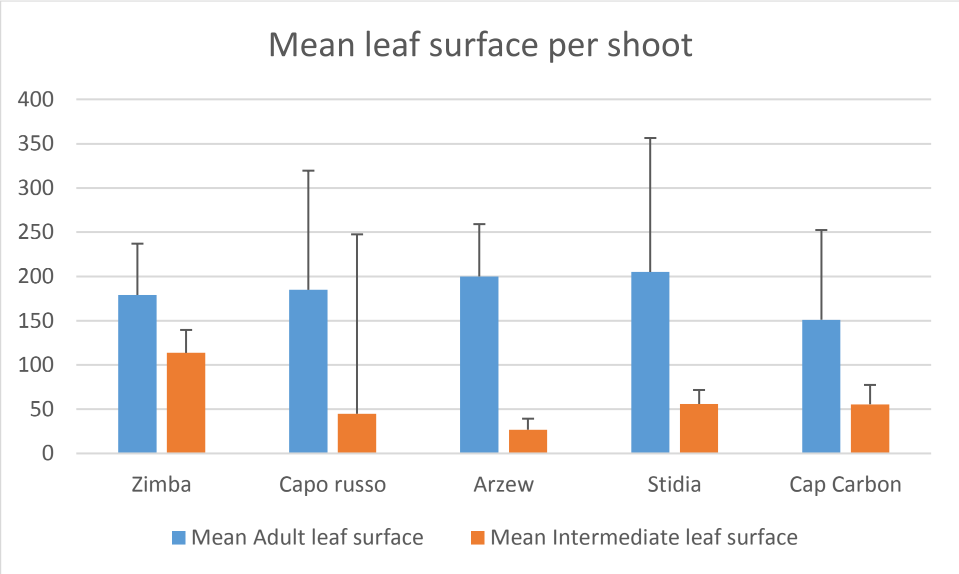

Figure 16: Mean leaf surface per shoot for Adult and Intermediate leaves (cm² per shoot)

The differences for intermediate leaf length, and consequently in leaf area (surface), between studied sites confirm the sensitivity of the *P. oceanica* parameters to various kinds of anthropogenic activities, such as urban discharge outfalls (Balestri *et al.* 2004)and similar pressure such as that arising from fish farms (Cancemi *et al.* 2003, Ruiz and Romero 2003, Rountos *et al.* 2012) which is the case of Zimba site. These activities induced a decrease of water clarity and nutrient enrichment affecting the primary production of *P. oceanica* (Pergent *et al.* 1995, Leoni *et al.* 2006).

Coefficient A

The state of the *Posidonia oceanica* leaves apex provides information for a given site on the rate of grazing (Velimirov 1984, Zupi and Fresi 1984) or the action of hydrodynamism (Wittmann *et al.* 1981).

The state of the apexes is determined by the "coefficient A" of GIRAUD (GRAUD 1977), which is expressed by the percentage of leaves that have lost their apex (broken or grazed leaves).

In the five studies sites, we observe that *P. oceanica* leaves apexes is almost always broken (or grazed). The coefficient "A" of the intermediate leaves is distinctly lower than that of the adult leaves (Figure 17); The latter, in fact, are smaller and better protected from the action of the grazers because of their position inside the shoot (GRAUD 1977, Rico and Pergent 1990).

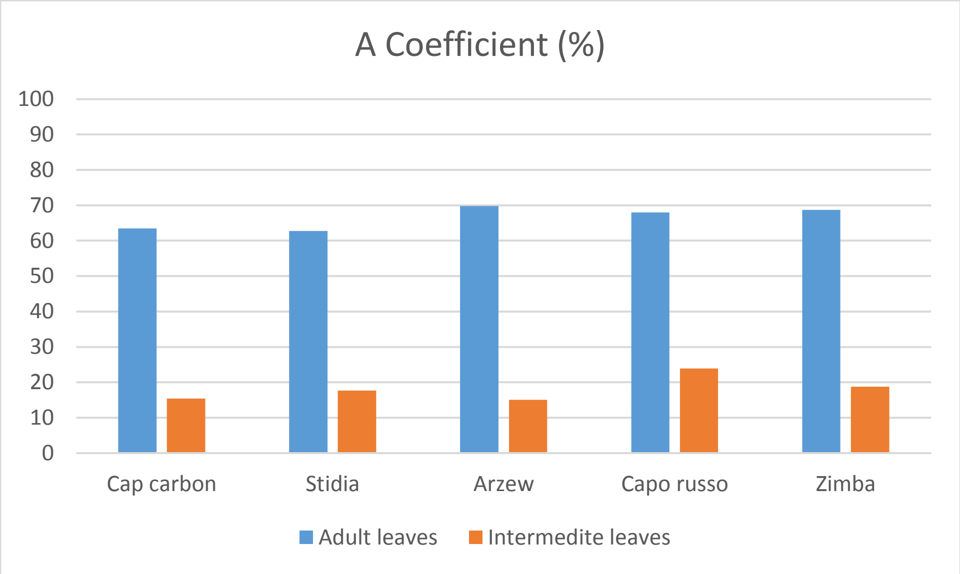

Figure 17: A Coefficient for Adult and intermediate leaves (%)

The mean value of the A coefficient for the different sampled meadows for both Adult and Intermediate leaves in Capo russo is higher than those observed in other sites (Figure 18). Global coefficient data from different sites were tested using one way analysis of variance (1 way ANOVA). The results reported a non-significant difference ($p = 0.113$) (see Annex II).

The decrease in the ‘Coefficient A’ seems to be linked to by pressures from herbivores (e.g. sea urchin *Paracentrotus lividus*) in these zones (Kouadri Mostfeai 2014).

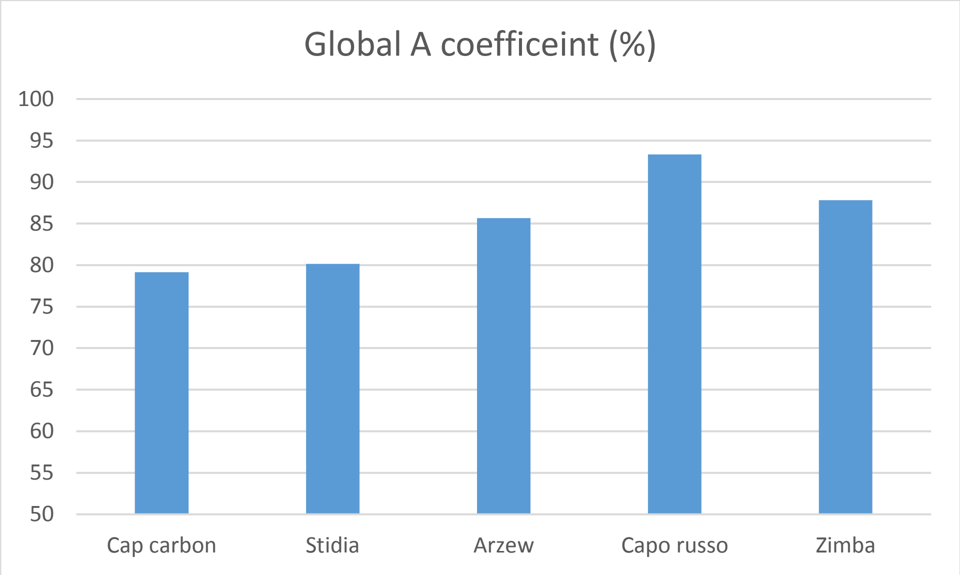

Figure 18: A coefficient for Adult + Intermediate leaves (%)

Conclusion

The parameters related to the spatial structure of the meadow - density and coverage - measured in studied sites are largely influenced by local factors in each zone, the nature of the substrate and the hydrodynamism. Moreover, (Martínez-Crego *et al.* 2008) consider that these parameters are only relevant indicators when measured at deep stations.

In addition, if the density of the *Posidonia oceanica* meadow showed statistically significant differences when comparing inter-sites. Its decrease marked at the level of the station of Arzew is probably due to the proximity of these stations to points of various forms of pollution; Industrial, agricultural and even urban domestic discharges.

Biometric parameters showed some variability between the study sites. However, no statistically significant differences were observed in the inter-site comparisons for the descriptors: number of leaves per shoot, mean leaf length and mean leaf surface.

CHAPTER IV

Assessment of the ecological status of coastal water using *Posidonia Oceanica*

Objective: Implementation of the BiPo index for the ecological quality assessment of water bodies using meadows of *Posidonia oceanica*.

For more than 40 years, *P. oceanica* has been used as bio-indicator in the Mediterranean Sea. Several studies, approaches, and methodologies (e.g. WFD, trace metals, nutrients, stable isotopes, lepidochronology), provide evidences that *P. oceanica* can be considered as a useful, relatively inexpensive and easy indicator to assess the quality of the marine environment (Gobert 2012).

It was permitted by the Water Framework Directive that each member state can define its own method to evaluate the state of the *Posidonia oceanica* meadow.

Many indexes have been developed to assess coastal water status using *Posidonia oceanica*:

- POMI (multivariate index based on the seagrass *Posidonia oceanica*) (Romero *et al.* 2007).
- Valencian CS (Fernández-Torquemada *et al.* 2008)
- BiPo (Biotic index using *P.oceanica*) (y Royo *et al.* 2010), have been developed to evaluate the status of coastal waters based on the *P. oceanica*.
- PREI (*Posidonia oceanica* Rapid Easy Index) developed and tested on French coasts (Gobert *et al.* 2009)

Application of BiPo to the west Algerian coast

The BiPo (Biotic index using *P.oceanica*) index is based on four descriptors (selected metrics): shoot density, Leaf length/shoot leaf surface, depth of lower limit, and type of the lower limit (y Royo *et al.* 2010).

Sampling and data collection

Sampling sites

According to previous information on the presence locations of *Posidonia oceanica* (see Chapter II and Chapter III) two sampling sites were chosen according to the location of the *Posidonia oceanica* meadow (Figure 19) and to the feasibility in relation to access, depth and technical requirements.

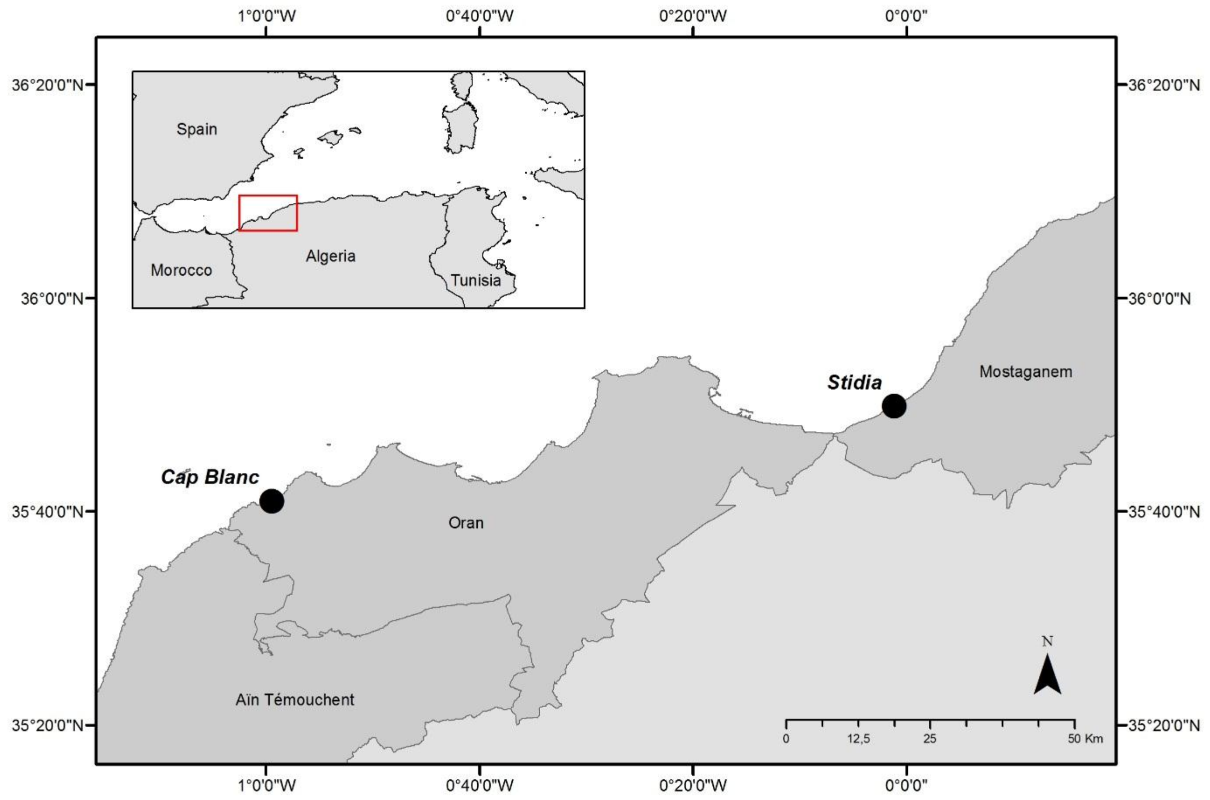

Figure 19: Locations of sampling sites for BiPo index descriptors evaluation

Stidia (Mostaganem)

See description on Chapter III.

Cap Blanc (Oran)

Cap Blanc studied station is located at 40 km west of the Oran city, at the geographical coordinates 35°40'42.68"N ; 1° 0'53.33"W (Figure 20). Cap Blanc beach area, localised east of the sampling zone, is less frequented because it’s quite far from the urbanised zones (Khodja 2013).

Figure 20: Cap Blanc studied site (Photos by BENTAALLAH M.E.A.)

Methodology

In each *Posidonia* meadow, two sampling stations were investigated by scuba divers at the fixed depth of 10 m and in correspondence of the lower bathymetric distribution limit (27m for Stidia and 23 for Cap Blanc). For stations at 10 m depth, 5 shoots density measurement at 40x40 cm square quadrat (shoot m^{-2}) and 10 shoots sampling were carried out. Shoot leaf surface was carried out according to the methodology described in Chapter III.

Ecological Quality Ratio for each metric (EQR') is calculated according to (Table 5) from (y Royo *et al.* 2010)

Table 5: EQR' calculation of the BiPo index.

Class		High	Good	Moderate	Poor	Bad
Lower limit depth	Values	>31	31-25	25-19	<19	n/a
	EQR'	((X-31)(7)x0.225)+0.775	((X-25)(6)x0.225)+0.55	((X-19)(6)x0.225)+0.325	((X-19)x0.225)+0.1	0.05
Lower limit type	Values	Progressive and erosive limits	Sharp limits	Sparse limits	Regressive limits	n/a
	Supporting parameters	>70% cover or >70% plagio	<70% cover and <70% plagio	<15% cover, % plagio n/a	Recent dead matte	n/a
	EQR'	0.89	0.66	0.44	0.21	0.05
Shoot density	Values (shoot m^{-2})	>399	339-239	239-172	<172	n/a
	EQR'	((X-339)/260)x0.225)+0.775	((X-239)/100)x0.225)+0.55	((X-172)/67)x0.225)+0.325	((X/172)x0.225)+0.1	0.05
Shoot leaf surface	Values (cm $shoot^{-1}$)	>200	200-152	152-119	<119	n/a
	EQR'	((X-200)/133)x0.225)+0.775	((X-152)/48)x0.225)+0.55	((X-119)/33)x0.225)+0.325	((X/119)x0.225)+0.1	0.05

Then BiPo is calculated according to the next equation

$$BiPo = EQR = (EQR'_{\text{Lower limit depth}} + EQR'_{\text{Lower limit type}} + EQR'_{\text{Density}} + EQR'_{\text{shoot leaf surface}})/4$$

Classification of *P. oceanica* ecological status is obtained using EQR results on the EQR scale defined in Table 6

Table 6: Boundaries for the different levels of ecological status

EQR	Ecological status
1 - 0.755	High
0.754 – 0.55	Good
0.549 – 0.325	Moderate
0.324 – 0.1	Poor
< 0.1 - 0	Bad

Results and discussion

Based on (Pergent *et al.* 1995), the meadow densities measured for both Stidia and Cap Blanc locations at 10 m depth are indicative of normal meadow density. One way Anova sorted that there is no significant difference between Stidia and Cap Blanc sites for the density descriptor (Table 7)

Table 7: Mean shoot density for Stidia and Cap Blanc, and ANOVA 1 p-value.

Site	Mean shoot density m^2	*P-value*
Stidia	405 ± 50,99	0,713
Cap Blanc	420 ± 60	

Mean values for measured phenological parameters (leaves number per shoot, leaves length and leaves surfaces) are represented in Figure 21, Figure 22 and Figure 23 respectively.

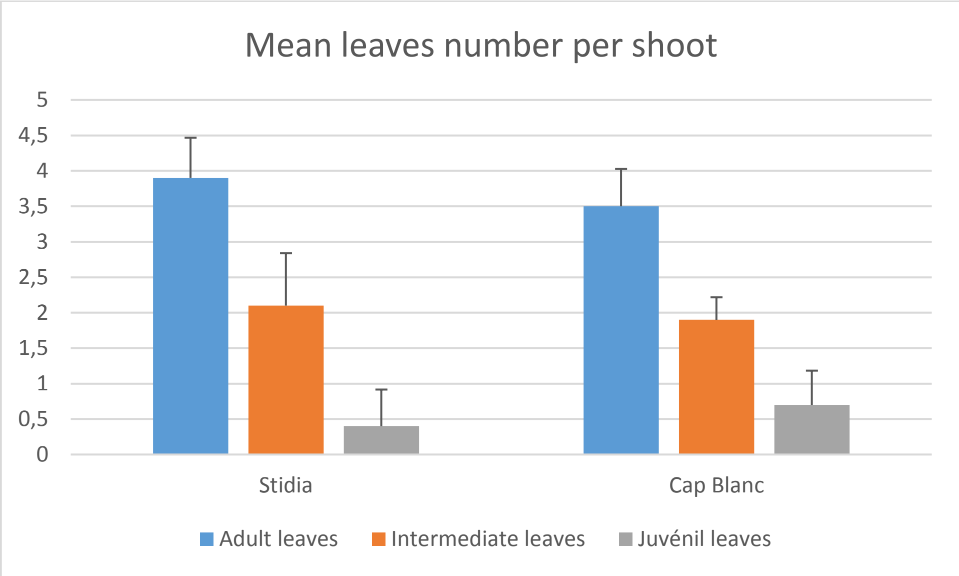

Figure 21: Mean leaves number per shoot

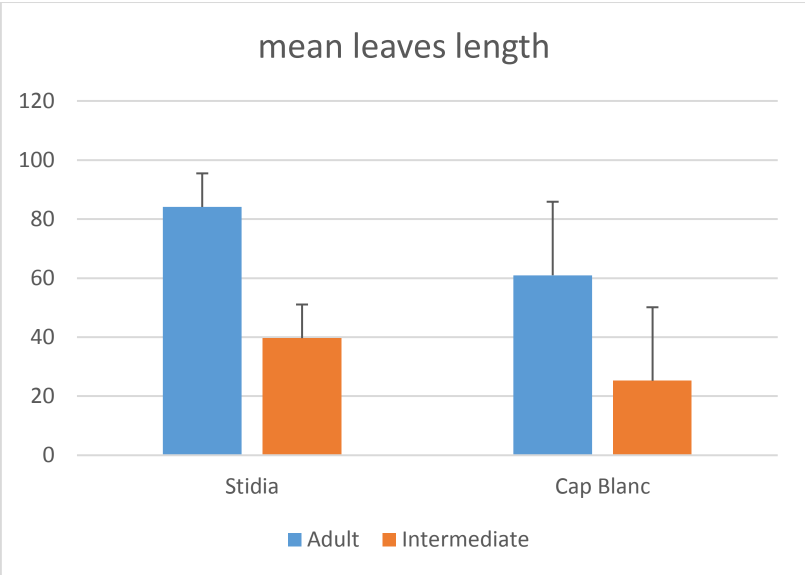

Figure 22: Mean leaves length per shoot

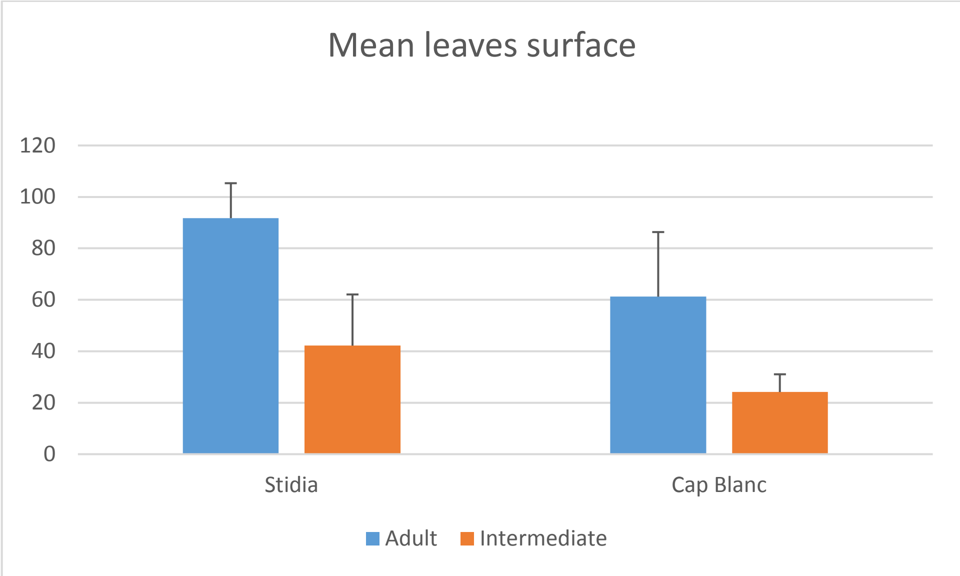

Figure 23: Mean leaves surface cm²/shoot

For all descriptors: number, length and surface of leaves Cab Blanc seem to be less important than Stidia for the same sampling depth 10m.

BiPo index calculation

Descriptors values from Stidia and Cap Blanc sites.

BiPo metrics	Stidia	Cap Blanc
Shoot density (shoot m^2)	405	420
Shoot leaf surface (cm^2 per shoot)	438,3	263,7
Type of this limit (regressive, progressive, stable)	Sharp	Sparse
Lower depth limit (m)	27	23

Showing results of BiPo metrics it's evident that shoot leaf surface is largely different in the two studied sites, it's lower in Cap Blanc. This metric will automatically influence the EQR' of the shoot leaf surface metric and consequently the EQR value for this site.

Table 8: BiPo Metrics values and EQR evaluation for Stidia site

	Class	Metric value	EQR'
Lower limit depth	Good	27	0,625
Lower limit type	Good		0,66
Shoot density	High	405	0,832115
Shoot leaf surface	High	438,3	1,178139
EQR			0,823814
Ecological status			High

Table 9: BiPo Metrics values and EQR evaluation for Cap Blanc site

	Class	Metric value	EQR'
Lower limit depth	Good	23	0,475
Lower limit type	Moderate		0,44
Shoot density	High	420	0,845096
Shoot leaf surface	High	263,7	0,882763
EQR			0,660715
Ecological status			Good

The EQR values for both sites (0.82 for Stidia and 0.66 for Cap Blanc) range on a scale condition ‘High’ for Stidia and ‘Good’ for Cap Blanc. This gives a reference for the actual conditions of these two sites.

Even if the region of Cap Blanc is subject to various types of pollution sources, artisanal fisheries, and discharge of domestic waters directly to the sea (Khodja 2013), The EQR value using BiPo ranged this area waters body in ‘Good’ according to BiPo scale. This result seems contradictory to the situation of this zone as described by (Khodja 2013). In this case results, it’s possible that the pollution sources had no effect on depth waters Posidonia.

In other hand, visual assessment of pressure using satellite images (Google Earth images) according to the methodology of (y Royo *et al.* 2009) seems to reflect correctly the ecological status of coastal water evaluated by the BiPo. According to the methodology of (y Royo *et al.* 2009) Stidia Studied sites has no significant pressure (land use: 90% natural, No river, No industry, No artificial structures).

(Boumaza *et al.* 2015) that experienced the application of both PREI and BiPo indexes in Algiers region results that the PREI seems to best reflect the expected ecological status, while it is not the case for the BiPo index which loses its correlation with human pressures. It was concluded that the use of the PREI is more suitable for assessing the ecological status of Algiers coastal waters (Boumaza *et al.* 2015).

The present chapter work was entirely based on *P. oceanica* data that we made available from a two sites sampling. And, even if several studies on the morphometry of *P. oceanica* have been carried out in the west Algerian coasts (see Chapter II), and that provides -relatively- useful data that could significantly improve a comparative analysis, few qualified for use in the present study since the metrics had to fit the criteria of BiPo index for a specific water depth.

Conclusion

The development of integrated approach proposed by indices based on the seagrass *Posidonia oceanica* (e.g POMI (Romero *et al.* 2007), BiPo (y Royo *et al.* 2010), PREI (Gobert *et al.* 2009)) by combining different descriptors of health status of *P. oceanica* meadows to assess water quality, fulfil the Water Framework Directive requirements for environmental quality assessment of coastal waters, providing essential tools for the application of the WFD and highlighting the role of seagrasses as Biological Quality Element.

The application of these indices will allow easy, rapid and coast effective estimation of the status of coastal environments. And, even if Algeria is not involved for WFD legislation it’s necessary to admit that it’s concerned because of its boundaries to the Mediterranean Sea. As all the Mediterranean countries that are required to protect *P. oceanica* meadows because of their importance for coastal ecosystems.

The application of BiPo index (y Royo *et al.* 2010) in this study chapter, covered two sites with *Posidonia oceanica* meadows in “Cap Blanc” and “Stidia” from the west Algerian coasts. Results provide instant new data on the water quality assessment.

Old monitoring programs are, costly, time-consuming, especially in terms of laboratory work and sample management, and destructive (Montefalcone *et al.* 2008). In comparison, use of ecological indices may represent a convenient protocol that provides immediate information about the ecosystem health and that may be adopted by the Algerian authorities in specific monitoring plans.

GENERAL CONCLUSION

General conclusion

Research activities have been done specifically through western Algeria coasts. It was, first, about the localisation and characterisation of the marine seagrass *Posidonia oceanica* meadows.

The *P. oceanica* repartition map was updated according to field research and a literature review of documents from different sources. This part study provides 15 new data point of the presence of the *P. oceanica* beds on the Algerian coasts. Even with this, and despite the seagrass *Posidonia oceanica* importance, it seems that its distribution and characterisation was scarcely studied in the southern part of the Mediterranean basin through the Algerian coasts, comparing to North Mediterranean.

Adding to this we have, also, updated, data about the health status of the *P. oceanica* meadows. For 5 coastal sites, this later has been assessed by specifics descriptors (Shoot density, Leaves number per shoot, Leaves surface, leaf area and A coefficient).

Finally, using some Posidonia specifics metrics, and following the methodology of the BiPo index evaluation, we were able to assess the ecological status of coastal water on two zones from different localities in the western Algeria. It seems that the Biotic index based on *Posidonia oceanica* (BiPo) results correspond to the expected ecological status reflected by human pressure assessment.

Future work should focus on the mapping of the *P. oceanica* meadows through the whole coasts using remote sensing technics for large area and/or sonars for relatively small area. This would provide the necessary knowledge then expertise to facilitate additional future studies on the importance of *P. oceanica* beds and, later, its legislative protection.

In addition, an index based on *Posidonia oceanica* metrics (and other bio-indicator species for an ecosystem approach) could be developed, standardised and used through different Algerian’s costal area. This will fill the gap in this study area and provide scientific data that could have implications for successful management of the coastal area.

Annex I

Figure 24: (Pergent *et al.* 1995) *P. oceanica* classification scale based on shoot density and depth.

Prof.	DA	DSI	DN	DS	Prof.	DA	DSI	DN	DSS
1	← 822	↔	934 ↔ 1158	→	21	← 48	↔	160 ↔ 384	→
2	← 646	↔	758 ↔ 982	→	22	← 37	↔	149 ↔ 373	→
3	← 543	↔	655 ↔ 879	→	23	← 25	↔	137 ↔ 361	→
4	← 470	↔	582 ↔ 806	→	24	← 14	↔	126 ↔ 350	→
5	← 413	↔	525 ↔ 749	→	25	← 4	↔	116 ↔ 340	→
6	← 367	↔	479 ↔ 703	→	26			106 ↔ 330	→
7	← 327	↔	439 ↔ 663	→	27			96 ↔ 320	→
8	← 294	↔	406 ↔ 630	→	28			87 ↔ 311	→
9	← 264	↔	376 ↔ 600	→	29			78 ↔ 302	→
10	← 237	↔	349 ↔ 573	→	30			70 ↔ 294	→
11	← 213	↔	325 ↔ 549	→	31			61 ↔ 285	→
12	← 191	↔	303 ↔ 527	→	32			53 ↔ 277	→
13	← 170	↔	282 ↔ 506	→	33			46 ↔ 270	→
14	← 151	↔	263 ↔ 487	→	34			38 ↔ 262	→
15	← 134	↔	246 ↔ 470	→	35			31 ↔ 255	→
16	← 117	↔	229 ↔ 453	→	36			23 ↔ 247	→
17	← 102	↔	214 ↔ 438	→	37			16 ↔ 240	→
18	← 88	↔	200 ↔ 424	→	38			10 ↔ 234	→
19	← 74	↔	186 ↔ 410	→	39			3 ↔ 227	→
20	← 61	↔	173 ↔ 397	→	40			↔ 221	→

Figure 25: *P. oceanica* classification grid according to PNUE (PNUE-PAM-CAR/ASP 2011)

Profondeur (en m)	Très Bonne		Bonne			Moyenne			Médiocre			Mauvaise	
1	>	1133	1133	à	930	930	à	727	727	à	524	<	524
2	>	1067	1067	à	863	863	à	659	659	à	456	<	456
3	>	1005	1005	à	808	808	à	612	612	à	415	<	415
4	>	947	947	à	757	757	à	567	567	à	377	<	377
5	>	892	892	à	709	709	à	526	526	à	343	<	343
6	>	841	841	à	665	665	à	489	489	à	312	<	312
7	>	792	792	à	623	623	à	454	454	à	284	<	284
8	>	746	746	à	584	584	à	421	421	à	259	<	259
9	>	703	703	à	547	547	à	391	391	à	235	<	235
10	>	662	662	à	513	513	à	364	364	à	214	<	214
11	>	624	624	à	481	481	à	338	338	à	195	<	195
12	>	588	588	à	451	451	à	314	314	à	177	<	177
13	>	554	554	à	423	423	à	292	292	à	161	<	161
14	>	522	522	à	397	397	à	272	272	à	147	<	147
15	>	492	492	à	372	372	à	253	253	à	134	<	134
16	>	463	463	à	349	349	à	236	236	à	122	<	122
17	>	436	436	à	328	328	à	219	219	à	111	<	111
18	>	411	411	à	308	308	à	204	204	à	101	<	101
19	>	387	387	à	289	289	à	190	190	à	92	<	92
20	>	365	365	à	271	271	à	177	177	à	83	<	83
21	>	344	344	à	255	255	à	165	165	à	76	<	76
22	>	324	324	à	239	239	à	154	154	à	69	<	69
23	>	305	305	à	224	224	à	144	144	à	63	<	63
24	>	288	288	à	211	211	à	134	134	à	57	<	57
25	>	271	271	à	198	198	à	125	125	à	52	<	52
26	>	255	255	à	186	186	à	117	117	à	47	<	47
27	>	240	240	à	175	175	à	109	109	à	43	<	43
28	>	227	227	à	164	164	à	102	102	à	39	<	39
29	>	213	213	à	154	154	à	95	95	à	36	<	36
30	>	201	201	à	145	145	à	89	89	à	32	<	32
31	>	189	189	à	136	136	à	83	83	à	30	<	30
32	>	179	179	à	128	128	à	77	77	à	27	<	27
33	>	168	168	à	120	120	à	72	72	à	24	<	24
34	>	158	158	à	113	113	à	68	68	à	22	<	22
35	>	149	149	à	106	106	à	63	<	63			
36	>	141	141	à	100	100	à	59	<	59			
37	>	133	133	à	94	94	à	55	<	55			
38	>	125	125	à	88	88	à	52	<	52			
39	>	118	118	à	83	83	à	48	<	48			
40	>	111	111	à	78	78	à	45	<	45			

Annex II

Table 10: One way ANOVA of "shoot density" on different studied sites

SUMMARY

Groups	Count	Sum	Average	Variance
Zimba	10	3050	305	5111,111
Capo russo	10	4625	462,5	25590,28
Arzew	10	3075	307,5	11812,5
Stidia	10	4075	407,5	19868,06
Cap Carbon	10	4175	417,5	27645,83

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	198500	4	49625	2,756094	0,03921	2,578739
Within Groups	810250	45	18005,56			
Total	1008750	49				

Table 11: One way ANOVA for adult leaves number per shoot.

SUMMARY

Groups	Count	Sum	Average	Variance
Cap carbon	10	34	3,4	0,488889
Stidia	10	32	3,2	0,177778
Arzew	10	36	3,6	0,488889
Capo russo	10	36	3,6	0,266667
Zimba	10	33	3,3	0,233333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1,28	4	0,32	0,966443	0,435227	2,578739
Within Groups	14,9	45	0,331111			
Total	16,18	49				

Table 12: One way ANOVA for intermediate leaves number per shoot.

SUMMARY

Groups	Count	Sum	Average	Variance

Cap carbon	10	18	1,8	0,177778
Stidia	10	19	1,9	0,1
Arzew	10	16	1,6	0,266667
Capo russo	10	19	1,9	0,1
Zimba	10	16	1,6	0,488889

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0,92	4	0,23	1,014706	0,40996	2,578739
Within Groups	10,2	45	0,226667			
Total	11,12	49				

Table 13: One way ANOVA for adult leaves length.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Stidia	10	686,775	68,6775	1246,377
Cap carbon	10	478,8983	47,88983	165,5639
Arzew	10	521,1475	52,11475	1401,228
Capo russo	10	529,2583	52,92583	133,5235
Zimba	10	403,77	40,377	71,61764

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4302,09	4	1075,522	1,781664	0,149171	2,578739
Within Groups	27164,79	45	603,6619			
Total	31466,87	49				

Table 14: One way ANOVA for intermediate leaves length

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Stidia	10	305,65	30,565	100,8217
Cap carbon	10	281,35	28,135	131,4773
Arzew	10	176,31	17,631	52,49305
Capo russo	10	254,755	25,4755	47,62206
Zimba	10	172,2	17,22	98,919

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1487,176	4	371,7939	4,309824	0,004899	2,578739
Within Groups	3881,998	45	86,26661			
Total	5369,173	49				

Table 15: One way ANOVA for adult leaves surface per shoot

SUMMARY

Groups	Count	Sum	Average	Variance
Cap carbon	10	1511,967	151,1967	3340,904
Zimba	10	1792,632	179,2632	18096,08
Capo russo	10	1850,076	185,0076	3476,471
Arzew	10	1999,253	199,9253	22893,84
Stidia	10	2052,054	205,2054	10266,87

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18027,2	4	4506,8	0,388021	0,816077	2,578739
Within Groups	522667,4	45	11614,83			
Total	540694,6	49				

Table 16: One way ANOVA for intermediate leaves surface per shoot

SUMMARY

Groups	Count	Sum	Average	Variance
Cap carbon	10	554,7177	55,47177	668,8037
Zimba	10	1137,721	113,7721	40987,89
Capo russo	10	449,7184	44,97184	153,8828
Arzew	10	269,4957	26,94957	250,8209
Stidia	10	556,7296	55,67296	478,0469

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	42468,42	4	10617,1	1,247913	0,304452	2,578739
Within Groups	382855	45	8507,888			

Total	425323,4	49

Table 17: One way ANOVA of global "A coefficient"

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Cap carbon	10	791,4286	79,14286	7,346939
Stidia	10	801,6667	80,16667	5,216049
Arzew	10	856,6667	85,66667	121,1111
Capo russo	10	933,3333	93,33333	607,4074
Zimba	10	878,3333	87,83333	113,6111

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1353,227	4	338,3067	1,979113	0,113915	2,578739
Within Groups	7692,234	45	170,9385			
Total	9045,46	49				

Table 18: One Way ANOVA for shoot density on Stidia and Cap Blanc (10 m depth sample)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Stidia	5	2025	405	3250
Cap Blanc	5	2100	420	4500

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	562,5	1	562,5	0,145161	0,713122	5,317655
Within Groups	31000	8	3875			
Total	31562,5	9				

Table 19: One way ANOVA for leaves number per shoot on Stidia and Cap Blanc (10 m depth)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Stidia	10	60	6	0,888889

Cap Blanc	10	54	5,4	0,266667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1,8	1	1,8	3,115385	0,094516	4,413873
Within Groups	10,4	18	0,577778			
Total	12,2	19				

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