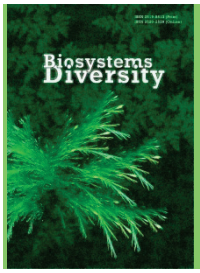

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Distribution and status of *Posidonia oceanica* meadows on the North-Western coast of Algeria

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Posidonia oceanica is an endemic species of the Mediterranean Sea that in pristine coastal waters forms extensive meadows, which are, actually, exposed to natural and anthropogenic pressures, causing their regression throughout the basin. The aim of our study is to summarise and evaluate current knowledge about the characterisation of *Posidonia oceanica* along the Western Algerian coast, in order to provide new evidence about the distribution and health status this species. To realize our objectives, we combined extracted data from published articles, theses, results of project reports, *in situ* observations and laboratory analysis. The results show the presence of the meadows in fifteen coastal zones of Western Algeria, mainly located in shallow surface waters from 0.5 to 18 metres depth.The mean leaf length across all sites ranged from 153 to 667 mm. The mean number of leaves/shoot ranged between 4.7 ± 0.9 and 6.0 ± 0.5 leaves/shoot. Leaf length showed a highly significant difference between the cold and hot season. The data analysis shows that the leaf biometric values and the shoot densities of the *P. oceanica* are greater than those of Mediterranean samples although these measures tend to decrease deeply. The analyses carried out on structural features of *P. oceanica* show that the Western Algerian meadows are, globally, in good health status according to standardised scale. The available data on *P. oceanica* summarised in this article represent an important starting point to build effective plans for understanding levels of environmental threats and for supporting conservation strategies for these important ecosystems. Conversely, the limited information available on this seagrass along the Western Algerian costs only allows the description of some structural features, and permits us to draw overall conclusions on its general health status.

Keywords: *Posidonia oceanica*; distribution; status; characterisation; Algeria; Mediterranean Sea.

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 & Meinesz, 1982; Pergent-Martini et al., 1994; Boudouresque, 2004). *Posidonia oceanica* is the dominant seagrass species in the basin (Den Hartog, 1970), where it occurs 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).

Because of its sensitivity to water quality as transparency and nutrient concentrations, *P. oceanica* is used as a biological sentinel or "shore canary" (Pergent-Martini & Pergent, 2000; Orth et al., 2006). Just for instance, it is considered one of the most important biological indicators in the European Water Framework Directive (2000/60/CE) and in the Marine Strategy Framework Directive (2008/56/CE).

Because of their bathymetric range, the *P. oceanica* meadows are directly exposed to natural and anthropogenic pressures. Therefore, it has become evident that they are regressing in several sites within the Mediterranean Sea (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 & 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), introduction of exotic species (Boudouresque et al., 2012) and marine pollution (Dimech et al., 2000).

Data about the presence of *P. oceanica* in the north-western Mediterranean are widely recorded, whereas in the south-western and eastern Mediterranean data are scarcer (Green & Short, 2003; Telesca et al., 2015) especially from the Algerian coasts. The latest detailed map of the distribution of *P. oceanica* meadows in the Western Mediterranean Sea (Telesca et al., 2015) shows the western Algerian coast as a coastline with no data. The few studies dealing with the characterisation of the species have been concentrated in the central part of the Algerian coasts (Semroud, 1996; Boumaza & Semroud, 2000; Boumaza et al., 2014).

Here, we summarise the data available from multiple and diverse information sources about the presence and status of *P. oceanica*. However, the knowledge of marine seagrasses along the Western Algerian coasts is prevalently confined to grey literature. To fill this gap, we have investigated different zones of the region to collect new data, combined with bibliographical ones, so to characterise the distribution of *P. oceanica* meadows along the Western Algerian coasts.

Such information about the characterisation of *P. oceanica* meadows along the western coasts of Algeria, will guide a better understanding of their health status and an effective risk assessment of *Posidonia* seagrasses in a regional context, supporting seagrass conservation actions.

Materials and methods

Study area and data collection. This study was conducted along the Western Algerian coast in four administrative regional districts distinguished from east to west as: Chlef, Mostaganem, Oran and Ain Temouchent.

Initially, bibliographic research was conducted using ISI Web of Knowledge, Science Direct, Springer Link and Google Scholar for relevant keywords, including "*Posidonia* mapping", "*Posidonia* cartography" and "*Posidonia* Algeria". In addition to this data base, we hand checked

the reference lists of all studies retrieved to identify all relevant primary researches published in other peer reviewed journals, books, reports and proceedings of international conferences. Bibliographic research was also conducted on the digital platform PNST (National Thesis Reporting Portal / Algeria website). We also checked Ph. D. and Master's theses in different West Algerian universities, which are not accessible via the internet, for studies directly concerning *P. oceanica*. Finally, we searched other items such as: benthic biodiversity, sea cucumber and urchins, which can provide data about the presence or the absence of *P. oceanica* in the Western Algerian coast.

To find more about the localization of the *P. oceanica*, meadows more than 20 free diving activities were made in 12 different zones in Western Algeria (Fig. 1), to assess the presence or the absence of *Posidonia* meadows.

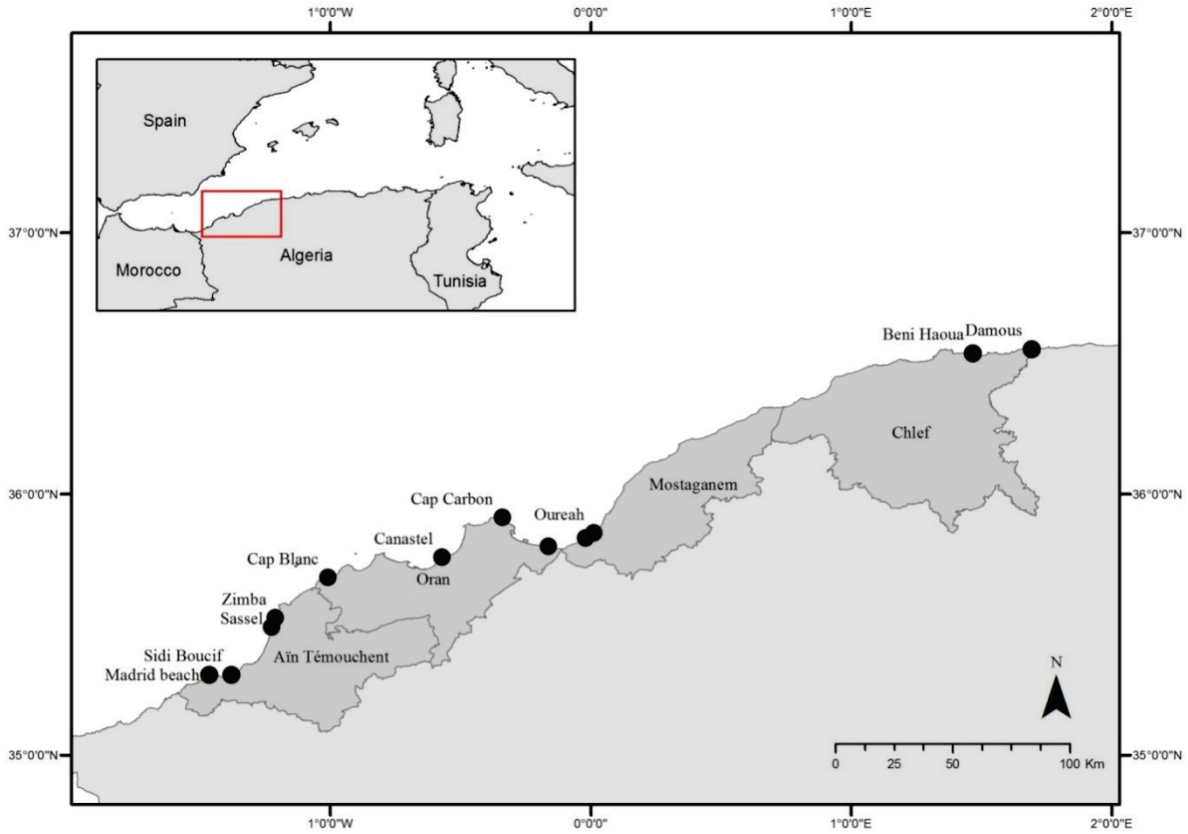

Fig. 1. Research areas for *P. oceanica* meadows *in situ* identification

Then, to assess the health status of *P. oceanica* meadows *in situ*, ten quadrats were placed randomly along a 50 m transect parallel to the shore. At each quadrat, the number of shoots was counted at a determined depth. The cover percentages of *P. oceanica* were visually assessed using a ¼ square meter quadrat. Ten shoots were sampled from shallow water to 3 m depth, by free diving. Samples were kept in 10% formaldehyde sea water until processing. The health status of *Posidonia* meadows was assessed by morphometric descriptors, as: shoot density, shoot length and leaf number per shoot. Finally, the health status *P. oceanica* meadows were assessed according to Pergent et al. (1995).

Statistical analysis. Leaf biometry was calculated as mm/leaf and was expressed as mean ± standard deviation (SD). A one-way analysis of variance (ANOVA) test was applied for leaf length considering $P < 0.05$ as statistically significant.

Results

Posidonia oceanica distribution. The *in situ* investigations from 12 zones in four districts of Western Algeria (Chlef, Mostaganem, Oran and Ain Temouchent) show that the *P. oceanica* is more represented in Western Algeria with some discontinuity along its coast. In fact, the species is absent in several areas, namely: Damous and Beni Haoua belonging to Chlef district, Sidi Boucif and Madrid beaches belonging to Ain Temouchent district.

Data from literature research and present investigations have been combined to provide a current distribution map of *P. oceanica* meadows along the Western Algerian coasts, in the Western Mediterranean Sea. These results represent a new detailed map concerning the presence of *P. oceanica* meadows along the Western Algerian coasts (Fig. 2).

Leaf biometry. In the current study, leaf biometry values, including leaf length and number of leaves per shoot, were collected in the framework of several data, including the *in situ* investigations, ranging from 2009 to 2017 (Table 1). To avoid confounding effects of seasonality, leaf biometry data has been structured for two fixed periods of the year: the cold season (from December to February) and the hot season (from May to August) (Fig. 3). Altogether, 35 *P. oceanica* mean leaf length data were examined.

Table 1
Mean number of leaves/shoot of *P. oceanica* along the Western Algerian coast

District	Site	Depth, m	Mean leaves/shoot	Reference
Oran	Cap Carbon	1–2	5.61	Iman (2015)
	Ain Franine	2–3	5.58	
	Cap Carbon	10	5.66	Cahrour (2013)
	Ain Franine	10	5.55	
	Cap Blanc	10	5.13	Khodja (2013)
	Cap Blanc	5	4.91	
	Cap Carbon	2	5.20	Main Study
	Capo russo	1	5.50	
	Arzew	1.5	5.20	
Mostaganem	Stidia	2	5.10	
	Sidi Lakhdar	1–2	5.80	Iman (2015)
Ain Temouchent	Rachgoun island	0.5	6.00	UNEP-MAP/RAC-SPA (2016)
	Rachgoun island	18	5.20	
	Rachgoun island	2–3	4.70	Tektek et al. (2017)
	Zimba	3	4.90	Main Study

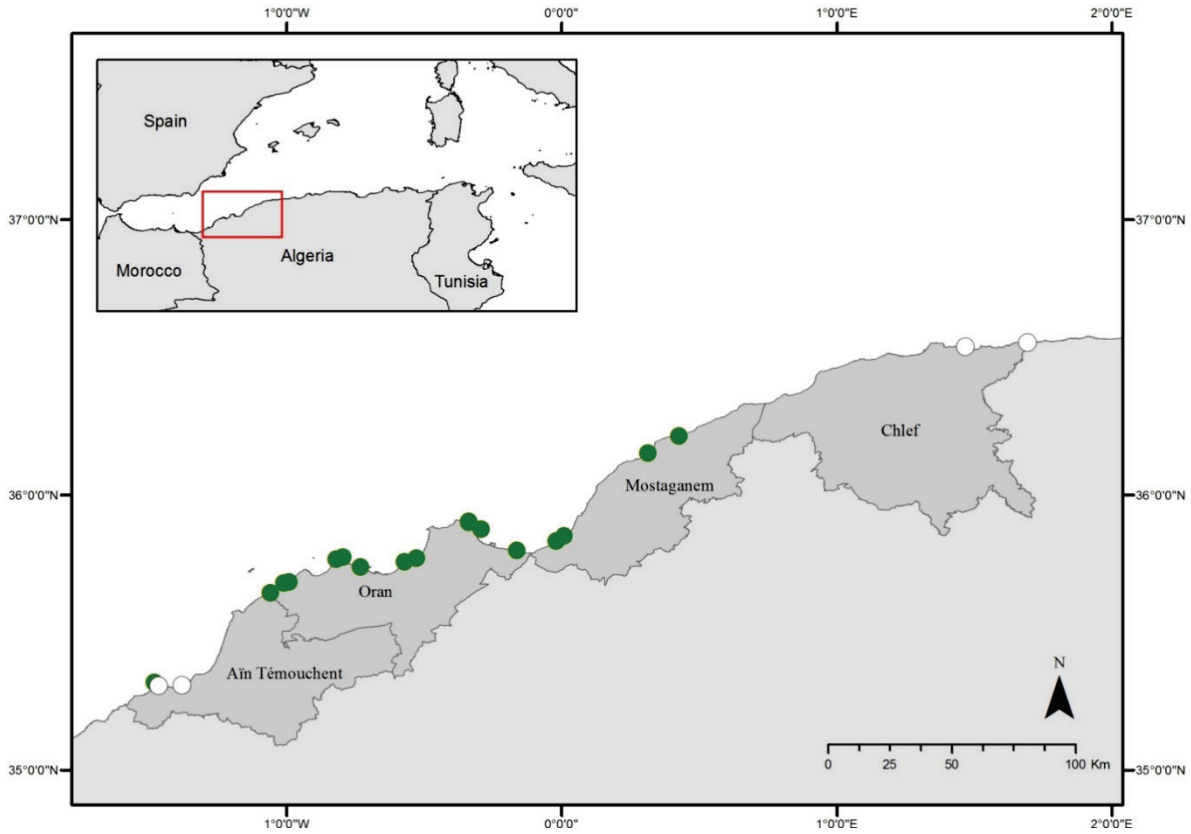

Fig. 2. Map of *P. oceanica* meadows along the West Algerian coasts: green points – presence of *P. oceanica*, white points – absence of *P. oceanica*

The mean number of leaves/shoot (adult and intermediate leaves) across all sites along the Western Algerian coast (Table 1) ranged between 4.7 ± 0.9 and 6.0 ± 0.5 leaves/shoot. Mean number of leaves/shoot was 5.34 ± 0.37.

The mean leaf length across all sites along the Western Algerian coasts ranged from 153 ± 77 to 667 mm. Overall mean leaf length was 234 ± 72 mm for the cold season and 439 ± 103 mm for the hot season. According to one-way ANOVA analysis ($P < 0.0001$) leaf length showed a highly significant difference between the two seasons.

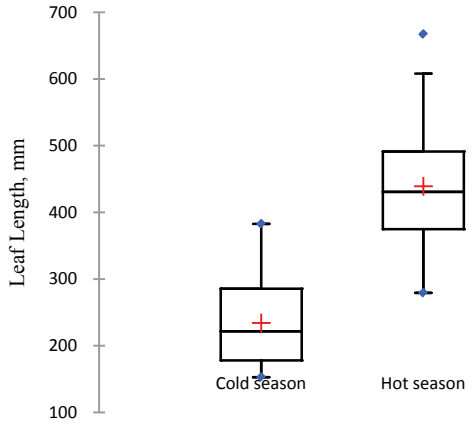

Fig. 3. Box plot of leaf length of *P. oceanica*: red plus represents the mean, blue points are minimum and maximum, the box represents lower quartile Q_1, median Q_2 and upper quartile Q_3

Shoot density and meadow status. Altogether, the mean densities of *P. oceanica*, from 0.5 to 18 m depth of 22 sites data along the Western Algerian coast, were treated. Mean density values ranged from 102 ± 7 to 1,055 ± 117 shoots/m². These data on minimum and maximum shoot densities were collected at 18 m depth from Rachgoun Island (Ain Temouchent) in June and at 2 m depth from Sidi Lakhdar (Mostaganem) in last May, respectively. There was no significant difference ($P > 0.05$) in the shoot density between the three districts (Mostaganem, Oran and Ain Temouchent).

Discussion

According to the Pergent et al. (1995) standardised scale for *P. oceanica* density classification, about one third of the West Algerian *P. oceanica* meadows, belongs to the best classes 'Normal density' and 'Higher Sub normal density' respectively as 23% and 9% of the whole. The main represented class was 'Abnormal density' representing 68% of all cases. The average shoot density of the 'Abnormal' class was 344 ± 34 shoots/m² when the average of the classes 'Normal' and 'Higher Sub normal' were respectively 601 ± 122 and 931 ± 124 shoots/m² (Fig. 4).

'Normal density' class of *P. oceanica* meadows were detected from Cap Carbon, Ain Franine and Cap Blanc (Oran district) indicating meadows in equilibrium. These zones are mainly situated far from man-induced disturbance sources such as harbours, urban and industrial sewage. Otherwise, meadows classified as 'Abnormal density' were mainly located along Rachgoun Island, Zimba (Ain Temouchent district), Hadjaj and Stidia (Mostaganem districts) stations mainly close to man-induced disturbance sources as the industrial harbour of Arzew, the fishing and pleasure harbour of Mostaganem and urban/industrial sewage.

Posidonia oceanica distribution. A total of 12 documents describing aspects of *P. oceanica* in North-Western Algeria were used to assess the presence and the health status of *P. oceanica* meadows. As these data were quite brief in literature review, combining them with *in situ* observations and laboratory analysis, helped to improve data availability.

In the southern part of the Mediterranean basin, along the Algerian coast, *P. oceanica* meadows have scarcely been studied. The only large-scale mapping of *P. oceanica* meadows available for the Algerian coast was established by Vaissiere and Fredj in 1963 (Husein Kais, 2015). This study showed that the seagrass beds were well developed across the entire seafloor. Indeed, it was reported that the latest surveyed coastline in Algeria for *P. oceanica* is about 16%, with the total current area occupied by seagrass being 4,072 ha (Telesca et al., 2015), mainly concentrated along the central Algerian coasts, but there are no details concerning the distribution of *P. oceanica* meadows in Western Algeria.

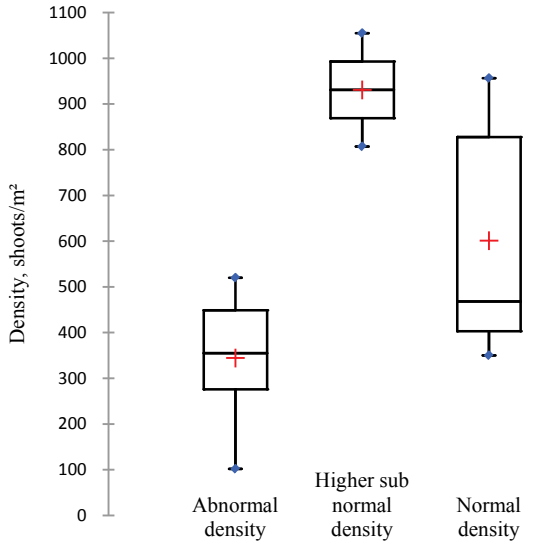

Fig. 4. Boxplot of Western Algerian coasts concerning the *P. oceanica* meadow classification according to Pergent et al. (1995) scale

Along the Algerian coasts, coastal development has led to the reduction of coastal zones, leading to the loss of seagrass habitat (Semroud, 1996). Along the Oran coasts, the *P. oceanica* meadows occupied a small area while the surface area of the beds was significant in Cap Carbon, Arzew, Ain El Türck, Pain Sucre and Madagh. In Cape Falcon, the meadow was formed by several spots on soft substrate with an upper limit located at 7 m depth (Husein Kais, 2015). At Plane Island, there is a total absence of *Posidonia* beds around the island, but along its NW coastline, between 8 and 12 m deep, there is a spot covering an area of 30 m² (Husein Kais, 2015).

Above all, *P. oceanica* of the Western Algerian coasts does not colonise bottoms deeper than 30 m, especially on the Oran (Cahrour, 2013; Chahrour et al., 2013; Husein Kais, 2015) and Mostagenm coasts (Noureddine, 2012). Finally, along the Ain Temouchent coasts the presence of the species does not exceed 18 m depth near Rachgoun Island (PNUE/PAM-CAR/ASP, 2016).

Leaf biometry. Shoot morphological analysis is commonly used to characterise *P. oceanica* meadows (Pergent-Martini et al., 2005). The results presented here emphasize varying leaf biometry values through the seasons and the sites. The low leaf length in cold seasons could be due to low temperatures that causes cessation of meristematic activity (Caye & Rossignol, 1983) and leaf elongation. Above all, *P. oceanica* leaf length varies with season and the causes for the detected differences could mainly related to the cyclic vegetative growth of the plant during the cold/hot seasons (Buia et al., 1992; Vasapollo & Gambi, 2012).

A comparison between our data and those available from the Mediterranean basin at comparable depth (0 to 10 m) and sampling seasons indicates that the average values of Western Algerian coast for leaf length are generally greater than in the rest of the basin (Table 2).

The number of leaves per shoot values were comparable among different sectors from the Mediterranean Sea (Table 2) except for the Tunisian coast of El Kantaoui (Sghaier et al., 2006) and the French coast of Revellata Bay in Corsica (Leoni et al., 2006), where our study values of leaf number per shoot were ~10% higher than in the other sectors. Nevertheless, leaf biometry changes with seasons, whereas in good ecological environments shoot density does not change temporally within a year (Mutlu et al., 2023), but decreases with increasing depth (Gobert et al., 2003).

Shoot density and meadow status. In the present study, average shoot density estimated on meadows along the Western Algerian coast was greater than the estimated shoot density of *P. oceanica* meadows from Bousmail Bay (Central Algerian coast) and the Turkish Mediterranean coast (Mutlu et al., 2023), but also compared with meadows growing on rocky substrata in northern Sicily (Italy) (Di Maida et al., 2013). Previous studies on the Mediterranean coast have shown variable densities. For example, Sghaier et al. (2006) reported mean density values from 298 to 637 shoot/m² along the Tunisian coast. Similarly, *P. oceanica* shoot densities reported from coast of Greece (Table 2) ranged from 339 to 674 shoot/m² (Tsirika et al., 2007).

Table 2
Mean values of *P. oceanica* leaf biometry variables observed in the literature (grand mean for each variable was calculated by using all mean values recorded per station)

Country	Locality	Depth, m	Leaf length, mm	N° leaves per shoot	Shoot density	Ref.
Algeria	Kouali	5	437	–	302 ± 79	Boumaza et al. (2014)
	Kouali	10	298	–	252 ± 77	
	Bou Ismaïl	5	310	–	318 ± 95	
	Bou Ismaïl	10	231	–	223 ± 36	
Tunisia	El Kantaoui	2–10	139	3.56	298	Sghaier et al. (2006)
	Monastir	2–10	190	5.33	360	
	Hergla	2–10	243	4.93	465	
	Mahdia	2–10	406	5.46	637	
Turkey	Turkish Mediterranean coast	5–30	267	4.80	334	Mutlu et al. (2023)
Greece	Laganas Bay (Zakynthos)	5	–	6.50	674	Tsirika et al. (2007)
	Laganas Bay (Zakynthos)	10	–	–	509	
	Laganas Bay (Zakynthos)	15	–	–	339	
France	Revellata Bay (Calvi, Corsica)	6–13	353–417	3.0–3.1	–	Leoni et al. (2006)
	Cerbère-Banyuls	8	304	4.8	–	Ferrari et al. (2008)

The density of *P. oceanica* meadows depends on depth, in particular, density gradually decreases from shallower to deeper waters. This is consistent with the results of other studies conducted in the Mediterranean region (Pergent et al., 1995) and with the data resulting from the current investigation (Fig. 5).

Posidonia oceanica shoot density is a widely measured parameter that has been used in many in-depth studies (Pergent-Martini et al., 1995, 2005; González-Correa et al., 2007; Fernández-Torquemada et al., 2008). Also, shoot density has widely been considered as an important descriptor of the status of meadows (Pergent-Martini et al., 2005; Lopez y Royo et al., 2010; Vasapollo & Gambi, 2012).

Finally, it is observed that *P. oceanica* meadows could favour more transparent water columns (Effrosynidis et al., 2018). According to present data, mostly (77.8%) of the shallow *P. oceanica* meadows (0 to 5 m depth) are classified as 'Abnormal density' class, whereas 'Normal density' was found in deeper waters (10 m depth, Fig. 6).

Conclusion

This study is an overview of the characterisation of the seagrass *P. oceanica* (L.) Delile on the Western Algerian coast. The *P. oceanica* repartition map was updated according to field research and a literature review of documents from different sources. This research provides sixteen data points concerning the presence of *P. oceanica* beds in Mostagenm, Oran and Ain Temouchent districts along the Algerian coast with an absence of the meadows in the Chlef district. Even with this and despite

the importance of the seagrass *P. oceanica*, it seems that its distribution and characterisation had been scarcely studied in the southern part of the Mediterranean basin along the Algerian coast, compared to the Northern Mediterranean Sea.

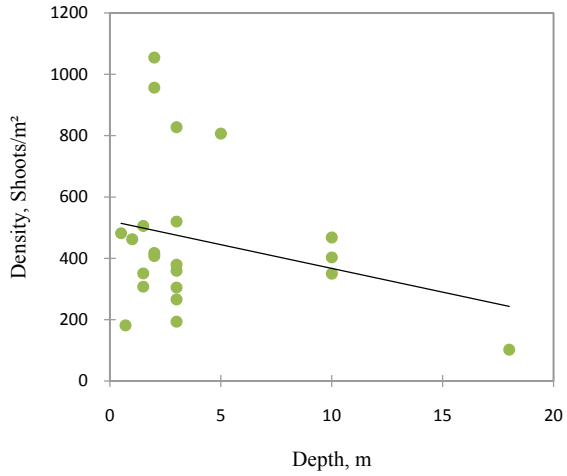

Fig. 5. *P. oceanica* shoot density variations by sampling depth

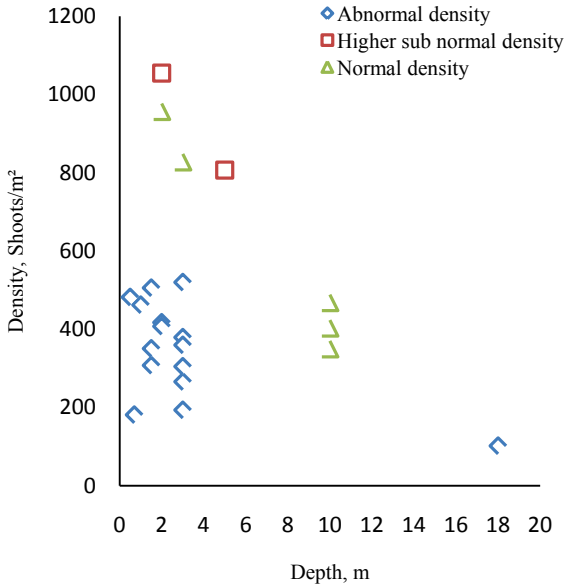

Fig. 6. Relationship between density (shoots/m²) and depth (m) superimposed by Pergent et al. (1995) classification

The leaf metrics of *P. oceanica* meadows changed with different seasons and depth variables through the Western Algerian coastal sites. Leaf descriptors, especially, leaf length variability were important factors against hot and cold seasons. The leaf morphometrical variables, such as shoot densities, tended to decrease with bottom depths. These morphological factors influenced the health status of the meadows, which similarly show better density classes of *P. oceanica* for shallower waters (< 5 m depth). Future work should focus on the mapping of the *P. oceanica* meadows along the entire Algerian coast using remote sensing technology for large areas and/or sonar for relatively small areas. This would provide the necessary knowledge and expertise to facilitate additional future studies aimed at strengthening the importance of *P. oceanica* beds and, later, improving their legislative protection.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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