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Seabed Status, Mapping and Assessing *Posidonia oceanica* in the Edough Mountains MPA, Annaba (Northeastern Algeria): A Baseline for Spatio-Temporal Monitoring

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ABSTRACT

In the Mediterranean region, the number of Marine Protected Areas (MPAs) has been steadily increasing, though their distribution remains uneven between the northern and southern coastlines. Algeria has shown a growing commitment to protecting its coastal ecosystems. Despite *Posidonia oceanica* being the most significant and extensively studied seagrass species in the Mediterranean, efforts to compile and analyze comprehensive spatial data on its distribution across the basin are still limited. This study aimed to map the current distribution of *P. oceanica* meadows in the newly established MPA of the Edough Mountains in Annaba, located in northeastern Algeria. In 2023, the surface water quality in the area was found to be satisfactory, with an average temperature of 22°C, a pH of 8.09, salinity of 37, a dissolved oxygen concentration of 6.9 mg/l, and a total suspended solids concentration of 0.21 mg/l. The upper limits of *P. oceanica* meadows, along with surrounding soft and rocky habitats, were surveyed using GPS over a 37km stretch, from Cap de Garde to Roche Axine, covering half of the MPA. The survey, which included 278 stations, identified 97 seagrass beds in good conservation status, with minimal epiphyte presence, at depths ranging from -1.5 to -24 meters. These initial findings will serve as a reference for future spatio-temporal monitoring of the growth and health of these meadows.

INTRODUCTION

Posidonia oceanica (L.) Delile, 1813 is a key endemic seagrass species in the Mediterranean Sea, capable of forming extensive meadows or beds that range from the surface down to depths of 40–45 meters **(Boudouresque *et al.*, 2006; Telesca *et al.*, 2015)**. It contributes to 1% of net primary production, serving as a crucial foundation for many food chains and providing a habitat for numerous animal and plant species **(Templado, 2004)**.

Seagrass meadows provide a range of essential ecosystem services, including key regulatory functions, such as carbon sequestration and storage, oxygen production, water purification, nutrient and contaminant capture, seabed stabilization, and protection against coastal erosion **(Campagne *et al.*, 2015; Boudouresque *et al.*, 2016)**. Additionally, the high structural complexity and productivity of *P. oceanica* meadows make them crucial habitats for various life stages of many species. These meadows serve as spawning grounds, settlement areas, nurseries, and feeding zones for organisms across different trophic levels, from primary producers residing on *P. oceanica* leaves to top predators foraging within the canopy **(Appolloni *et al*., 2023; Capasso *et al*., 2024)**.

These meadows enjoy international protection status, thanks in particular to the Bern Convention (1979), the Barcelona Convention of 1976 (Amended in 1995 and 1999) and the new Mediterranean Action Plan (IMAP-MPA Project "2019-2023").

Algeria has demonstrated its interest in the protection and sustainable use of marine biodiversity, notably through Law 02-02 (2002). Our study is part of the Algerian-German Cooperation Program for Environmental Governance and Biodiversity in Algeria (GENBI), implemented by the German Agency for International Cooperation (GIZ). It contributes to the implementation of the National Strategy for Integrated Coastal Zone Management and the Strategy for the Protection of the Environment and Biodiversity of the Algerian Coast (PEBLA) **(MEER, 2022)**. For the first time, *P. oceanica* meadows were mapped, soft and rocky bottoms were identified, and the main physico-chemical parameters of the surface waters were measured along half the length of the Edough Mountains MPA in Annaba (2023). Our results indicate that *P. oceanica* is in good conservation status, and the water quality is satisfactory. Once these observations are completed along the entire linear stretch, they will provide a baseline for spatio-temporal monitoring of the meadow and its conservation, supporting the sustainable management of the MPA.

MATERIALS AND METHODS

1. Study area

The district (wilaya) of Annaba is located on the south-western coast of the Mediterranean Sea, in the eastern part of Algeria. It covers an area of 1412km² with a population of approximately 6.10^5 inhabitants **(ANIREF, 2012)**. The MPA-of Edough mountains is located to the west of the city. It stretches for 66km between Cap de Garde and Sidi Akkacha and is divided into an eastern and a western section. The MPA covers an area of 4880ha, with 3 types of zones: core, buffer and transition (Fig. 1).

2. Methodology

Our research concentrated on the eastern portion of the Edough Mountains Marine Protected Area (MPA), encompassing over half of the protected coastline, specifically extending 37km. This area was systematically divided into two distinct sectors. Sector 1

(S1) extends from Cap de Garde (longitude 7° 47' E) to Pain de Sucre and encompasses the outflow of the Oued Bagrat. Conversely, Sector 2 (S2) spans from Pain de Sucre to Ain Barbar (longitude 7° 30' E), which includes the mouths of the Oueds Semhoute and El Gueb (Fig. 2).

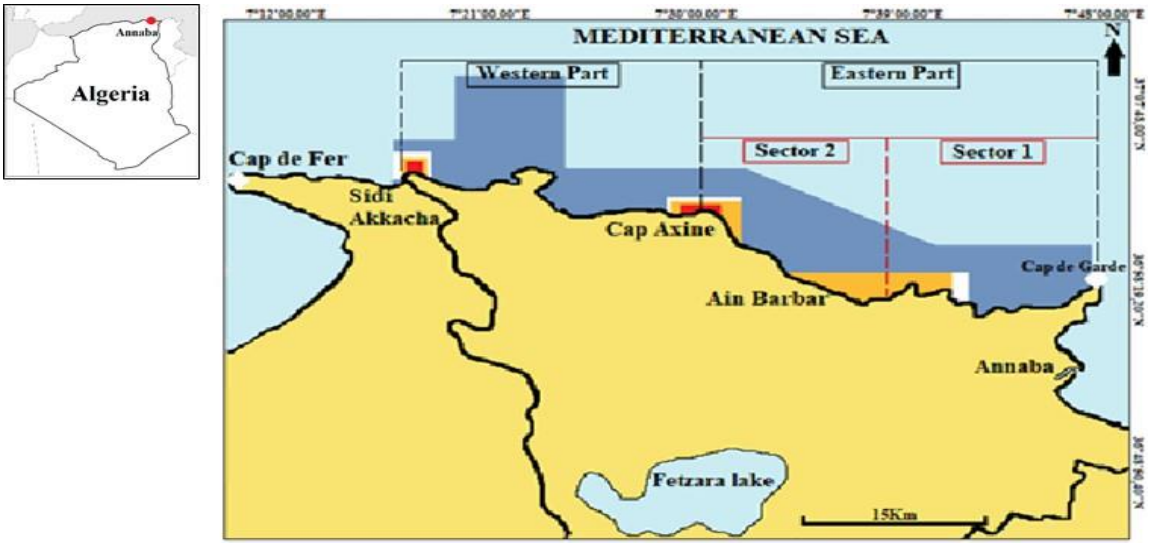


Fig. 1. Map showing the administrative division of the Edough mountains MPA in Annaba: blue in the zone of interest, red is the central zone, yellow is the buffer zone and white is the zone of transition (Decision N°. 2261) **(DEA, 2023)**

Each sector was further stratified into four zones, resulting in a total of 278 sampling stations (St.), as depicted in Fig. (2). Comprehensive measurements of critical physico-chemical parameters, including temperature, pH, dissolved oxygen, salinity, and total suspended solids (TSS) in surface waters, were conducted between June 2023 and May 2024 utilizing a field multiparameter instrument HI 9829. Monthly mapping of the *P. oceanica* meadows was performed, wherein we assessed the seabed composition (rocky, soft, or *Posidonia oceanica*) through the use of a bathyscope. Georeferencing of sampling points was accomplished with a Garmin GPS device, and depths were accurately measured using an electronic depth gauge.

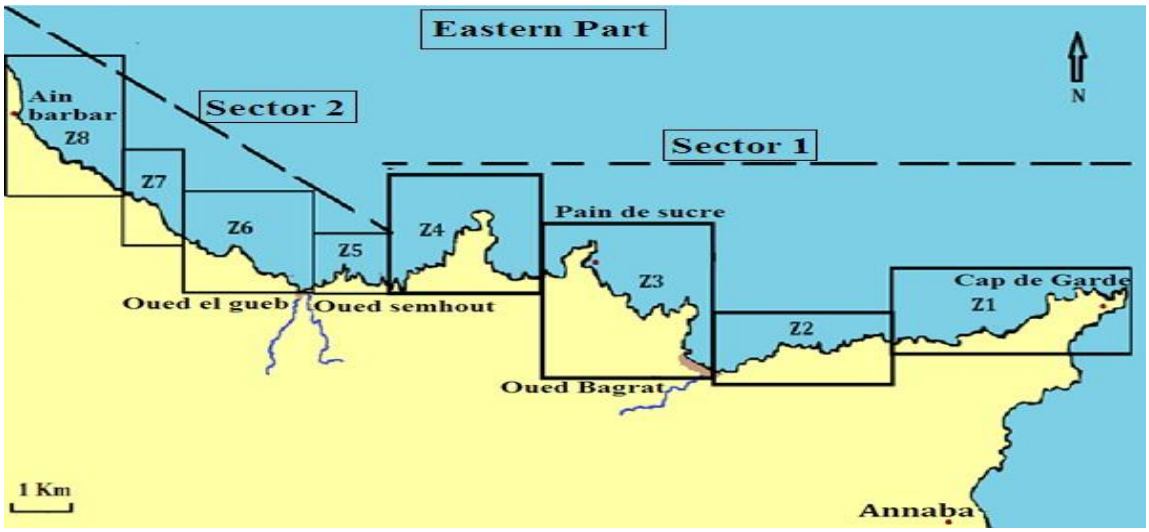


Fig. 2. Map showing the subdivision of the eastern part of the Edough mountains MPA in Annaba (Z: zone)

RESULTS

1. Physico-chemistry of surface water

In Sector 1 (S1), winter temperatures range from 12.5 to 16°C with salinity levels between 38 and 41g/ L, while in summer, temperatures increase to 21-28°C with salinity levels slightly lower, ranging from 38.2 to 40.4g/ L. Annually, pH values fluctuate from 7.67 to 8.75, dissolved oxygen concentrations from 5.6 to 9.49mg/ L, and total suspended solids (TSS) from 0.12 to 0.25mg/ L.

In Sector 2 (S2), winter temperatures were recorded at 15.1°C, rising to 28.9°C in summer, with mean salinities of 36.61g/ L in winter and 37.5g/ L in summer. The pH levels vary between 7.70 and 8.80, dissolved oxygen levels between 5.87 and 9.05mg/ L, and TSS values from 0.10 to 0.21mg/ L throughout the year (Table 1).

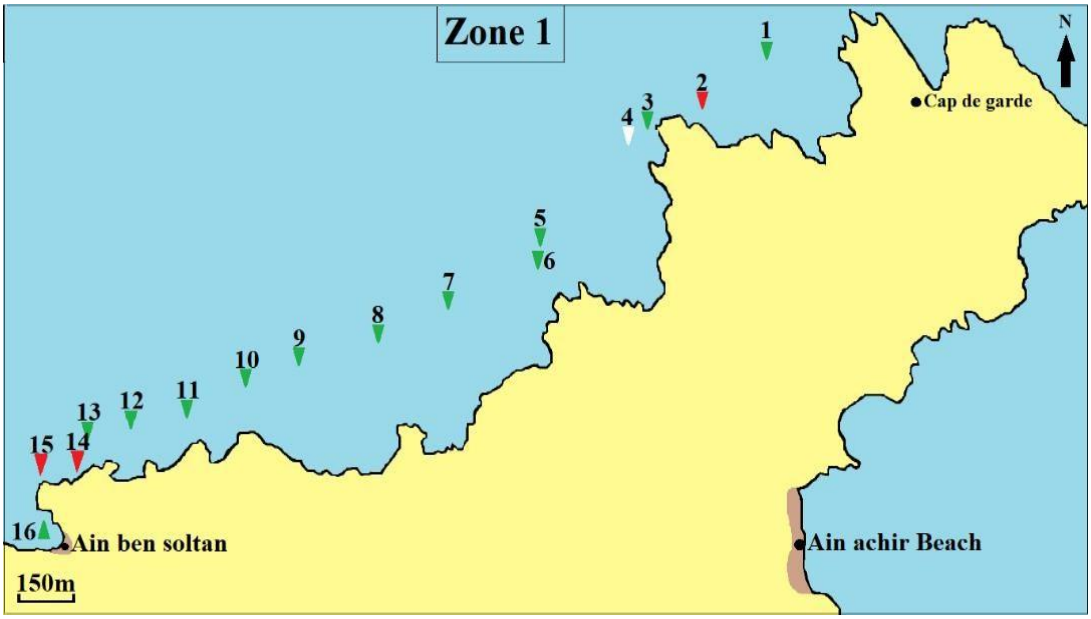
Table 1. Average values of surface water physico-chemical parameters measured between June 2022 and May 2023 in the eastern part of the Edough mountains MPA in Annaba (S: Sector)

Parameters	S1	S2
T °C	19.45	21.44
Salinity (g/l)	39.7	37
pH	8.15	8.08
O_2 (mg/l)	6.89	7.68
TSS (mg/l)	0.21	0.22

2. Location and characterization of the P. oceanica bottom type in Sector 1

Zone 1 (Z1), designated as the focus area within the MPA, spans from Cap de Garde in the east to Ain Ben Soltan in the west. This area includes 16 monitoring stations positioned approximately 180 meters apart along a total length of 2.55km. Observations were limited to a depth of -18m due to visibility constraints, which precluded data collection from Station 4. *P. oceanica* seabeds were detected at 12 stations (Sts. 1, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 16), located between -8 and -16m depths. On the other hand, its absence was confirmed at three stations (Sts. 2, 14, and 15), which ranged from - 4 to -14m in depth and featured a rocky substrate (Fig. 3a) (Table 2).

The second zone of interest (Z2) extends from Ain Ben Soltan in the east to Oued Bouqrat in the west, covering a length of 4.62 km. It is represented by 27 survey points, spaced approximately 176 meters apart, at depths ranging from -6 to -20 meters (Table 2). Of the seabed, 66.6% is rocky, and 18.5% is loose, with two focal points of *P. oceanica* meadows located at Stations 18 and 19 (Fig. 3b).



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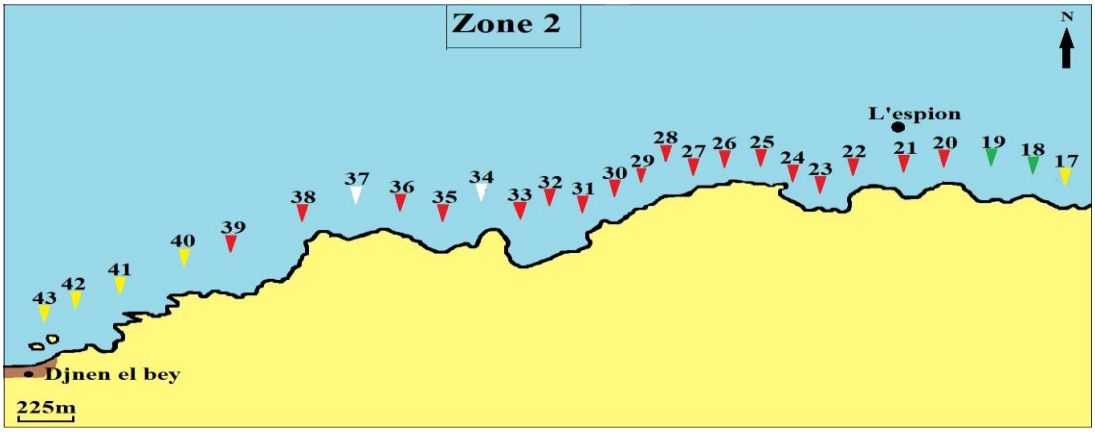

Fig. 3. Location and characterization of *P. oceanica* seabed types in Z1 and Z2 in Sector1 (Green: *P. oceanica*, Red: rocky bottom, Yellow: soft bottom, White: no visibility)

Table 2. Geolocation (GPS) and depth (m) of *P. oceanica* meadows in the Z1 and Z2 of S1 of the Edough mountains MPA (Z: Zone)

Z1			Z2		
N°	**GPS**	**Depth**	**N°**	**GPS**	**Depth**
1	36°58.109’/ 07°46.756’	16	17	36°57.479’/ 07°45.328’	12
2	36°58.038’/ 07°46.640’	14	18	36°57.514’/ 07°45.239’	16
3	36°58.008’/ 07°46.539’	10	19	36°57.539’/ 07°45.129’	13
4	36°57.988’/ 07°46.498’	18	20	36°57.538’/ 07°45.995’	10
5	36°57.818’/ 07°46.333	17	21	36°57.520’/ 07°44.884’	18
6	36°57.809’/ 07°46.333’	12	22	36°57.508’/ 07°44.745’	10
7	36°57.750’/ 07°46.171’	17	23	36°57.488’/ 07°44.654’	21
8	36°57.701’/ 07°46.042’	15	24	36°57.492’/ 07°44.579’	12
9	36°57.669’/ 07°45.896’	16	25	36°57.538’/ 07°44.492’	20
10	36°57.638’/ 07°45.795’	16	26	36°57.532’/ 07°44.352’	17
11	36°57.596’/ 07°45.690’	12	27	36°57.521’/ 07°44.274’	19
12	36°57.580’/ 07°45.588’	11	28	36°57.510’/ 07°44.301’	09
13	36°57.564’/ 07°45.510’	10	29	36°57.491’/ 07°44.253’	11
14	36°57.550’/ 07°45.495’	04	30	36°57.448’/ 07°44.155’	12
15	36°57.517’/ 07°45.425’	08	31	36°57.429’/ 07°44.080’	16
16	36°57.454’/ 07°45.432’	08	32	36°57.416’/ 07°44.016’	15
			33	36°57.361’/ 07°43.900’	16
			43	36°57.404’/ 07°43.870’	17
			35	36°57.400’/ 07°43.714’	16
			36	36°57.368’/ 07°43.583’	16
			37	36°57.412’/ 07°43.475’	18
			38	36°57.412’/ 07°43.366’	19
			39	36°57.300’/ 07°43.083’	16
			40	36°57.233’/ 07°42.912’	19
			41	36°57.146’/ 07°42.735’	13
			42	36°57.105’/ 07°42.620’	09
			43	36°57.065’/ 07°42.536’	06

Zone 3, designated as the transition zone within the MPA, stretches from Oued Bouqrat in the east to Pain de Sucre in the west, covering approximately 7km. This zone comprises 36 monitoring stations, each separated by an average distance of 193 meters, with depths ranging between -3 and -24 meters (Table 3). *P. oceanica* meadows were documented at seven stations (Sts. 48, 49, 50, 51, 54, 68, and 80), accounting for 13.91% of the seabed area. The remaining seabed was characterized as either soft sediment (13.88%), rocky substrate (19.44%), or unobservable due to bathyscopic limitations (52.77%) (Fig. 4a).

Zone 4, situated in the buffer region between Pain de Sucre and Oued el Gueb, spans a length of 7.3km. This area is represented by 71 stations, each spaced approximately 88 meters apart, with depths ranging from -1 to -24 meters (Table 3). Within this zone, rocky seabeds accounted for 25.35% of stations, while soft seabeds comprised 28.16%. Observations identified 31 stations supporting *P. oceanica* meadows (Sts. 83, 85, 86, 88, 89, 90, 92, 94, 96, 106, 108, 117, 120, 122, 123, 125, 127, 135, 137, 139, 140, 141, 142, 145, 146, 147, 148, 149, 150, 151, and 152) (Fig. 4b).

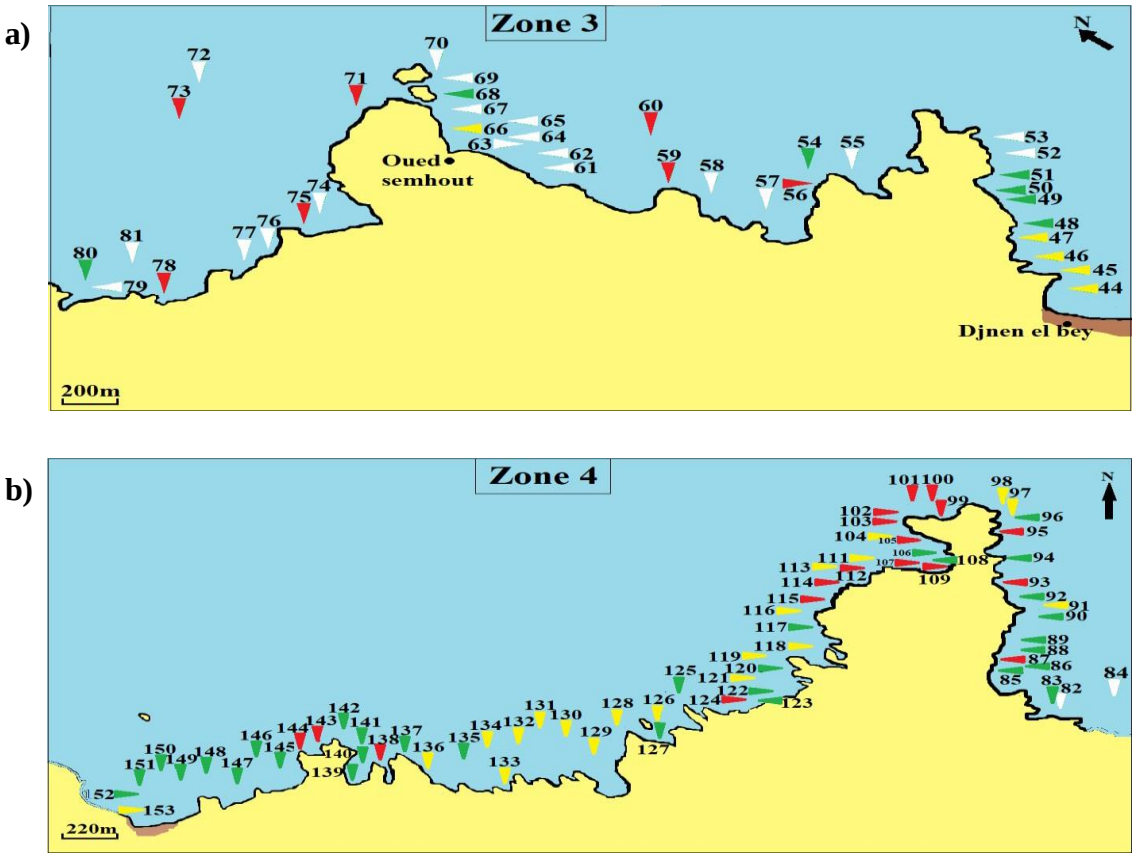

Fig. 4. Location and characterization of *P. oceanica* seabed types in Z3 and Z4 in Sector1 (Green: *P. oceanica*; Red: rocky bottom; Yellow: soft bottom; White: no visibility)

Table 3. Geolocation (GPS) and depth (m) of *P. oceanica* meadows in the Z3 and Z4 of S1 of the Edough mountains MPA (Z: Zone)

Z3			Z4					
N°	GPS	Depth	N°	GPS	Depth	N°	GPS	Depth
44	36°57.166’/ 07°42.156’	03	82	36°58.071’/ 07°39.735’	16	120	36°58.148’/ 07°39.003’	13
45	36°57.222’/ 07°42.173’	06	83	36°58.103’/ 07°39.726’	17	121	36°58.155’/ 07°38.976’	14
46	36°57.291’/ 07°42.135’	07	84	36°58.105’/ 07°39.726’	10	122	36°58.124’/ 07°38.969’	11
47	36°57.360’/ 07°42.124’	08	85	36°58.196’/ 07°39.577’	06	123	36°58.098’/ 07°38.932’	10
48	36°57.396’/ 07°42.146’	08	86	36°58.206’/ 07°39.646’	18	124	36°58.098’/ 07°38.897’	15
49	36°57.449’/ 07°42.155’	09	87	36°58.224’/ 07°39.578’	06	125	36°58.096’/ 07°38.717’	10
50	36°57.511’/ 07°42.164’	13	88	36°58.255’/ 07°39.634’	16	126	36°58.028’/ 07°38.660’	11
51	36°57.555’/ 07°42.188’	16	89	36°58.290’/ 07°39.632’	13	127	36°57.974’/ 07°38.667’	07
52	36°57.613’/ 07°42.247’	12	90	36°58.364’/ 07°39.679’	16	128	36°58.013’/ 07°38.552’	13
53	36°57.672’/ 07°42.254’	10	91	36°58.404’/ 07°39.698’	19	129	36°57.995’/ 07°38.478’	12
54	36°57.750’/ 07°42.018’	09	92	36°58.430’/ 07°39.629’	11	130	36°57.981’/ 07°38.413’	10
55	36°57.713’/ 07°41.834’	10	93	36°58.475’/ 07°39.580’	13	131	36°58.008’/ 07°38.345’	13
56	36°57.704’/ 07°41.702’	12	94	36°58.552’/ 07°39.592’	10	132	36°57.825’/ 07°38.253’	12
57	36°57.770’/ 07°41.436’	14	95	36°58.639’/ 07°39.571’	07	133	36°57.900’/ 07°38.231’	10
58	36°57.674’/ 07°41.543’	16	96	36°58.674’/ 07°39.614’	17	134	36°57.860’/ 07°37.108’	08
59	36°57.844’/ 07°41.344’	17	97	36°58.686’/ 07°39.608’	24	135	36°57.845’/ 07°37.075’	06
60	36°58.031’/ 07°41.069’	12	98	36°58.723’/ 07°39.582’	20	136	36°57.833’/ 07°37.044’	10
61	36°58.031’/ 07°41.069’	10	99	36°58.729’/ 07°39.395’	12	137	36°57.930’/ 07°37.985’	14
62	36°58.097’/ 07°41.047’	13	100	36°58.730’/ 07°39.340’	11	138	36°57.903’/ 07°37.916’	08
63	36°58.133’/ 07°41.018’	15	101	36°58.684’/ 07°39.411’	11	139	36°57.834’/ 07°37.844’	01
64	36°58.187’/ 07°40.987’	10	102	36°58.696’/ 07°39.306’	13	140	36°57.954’/ 07°37.866’	08
65	36°58.210’/ 07°40.960’	12	103	36°58.673’/ 07°39.309’	13	141	36°57.982’/ 07°37.825’	08
66	36°58.212’/ 07°40.885’	16	104	36°58.609’/ 07°39.310’	24	142	36°57.963’/ 07°37.748’	07
67	36°58.260’/ 07°40.911’	20	105	36°58.608’/ 07°39.367’	12	143	36°57.939’/ 07°37.721’	12
68	36°58.320’/ 07°40.922’	21	106	36°58.565’/ 07°39.407’	17	144	36°57.893’/ 07°37.662’	12
69	36°58.346’/ 07°40.929’	19	107	36°58.521’/ 07°39.428’	14	145	36°57.855’/ 07°37.625’	09
70	36°58.405’/ 07°40.951’	20	108	36°58.523’/ 07°39.390’	12	146	36°57.842’/ 07°37.534’	14
71	36°58.371’/ 07°40.683’	24	109	36°58.535’/ 07°39.304’	17	147	36°57.861’/ 07°37.452’	16
72	36°58.595’/ 07°40.320’	20	110	36°58.530’/ 07°39.358’	17	148	36°57.851’/ 07°37.366’	08
73	36°58.503’/ 07°40.214’	17	111	36°58.545’/ 07°39.237’	18	149	36°57.828’/ 07°37.325’	07
74	36°58.077’/ 07°40.414’	18	112	36°58.516’/ 07°39.213’	14	150	36°57.814’/ 07°37.291’	08
75	36°58.061’/ 07°40.358’	21	113	36°58.520’/ 07°39.172’	16	151	36°57.784’/ 07°37.288’	08
76	36°58.022’/ 07°40.224’	20	114	36°58.476’/ 07°39.146’	17	152	36°57.742’/ 07°37.286’	03
77	36°58.020’/ 07°40.186’	20	115	36°58.419’/ 07°39.108’	11	153	36°57.974’/ 07°38.667’	07
78	36°57.984’/ 07°39.903’	17	116	36°58.382’/ 07°39.046’	25			
79	36°58.071’/ 07°39.735’	17	117	36°58.250’/ 07°39.079’	07			
80	36°58.103’/ 07°39.726’	17	118	36°58.302’/ 07°39.026’	24			
81	36°58.105’/ 07°39.726’	18	119	36°58.240’/ 07°38.963’	22			

3. Location and characterization of the P. oceanica bottom type in sector 2

Zone 5 (Z5), positioned within the buffer zone, spans 3.26km and comprises 41 stations, each spaced approximately 84 meters apart, with depths ranging from -3 to -16 meters (Table 4). Of these stations, 41.46% are situated on rocky seabeds and 12.19% on soft bottoms. In this area, we identified 19 *P. oceanica* beds, corresponding to stations 154, 155, 156, 157, 159, 161, 163, 164, 165, 166, 167, 168, 171, 180, 181, 182, 183, 190, and 194 (Fig. 5a).

Zone 6, also designated as a buffer zone, extends between Oued el Gueb and Ain Barbar over a distance of 3.55 km. It is represented by 29 stations, spaced 101 meters apart, with depths ranging from -4 to -14 meters (Table 4). Within this zone, 37.93% of stations are located on rocky bottoms, while 17.24% are on soft bottoms. Observations recorded 13 *P. oceanica* meadow stations at Sts: 197, 202, 203, 204, 205, 206, 207, 208, 210, 211, 212, 213, and 214 (Fig. 5b).

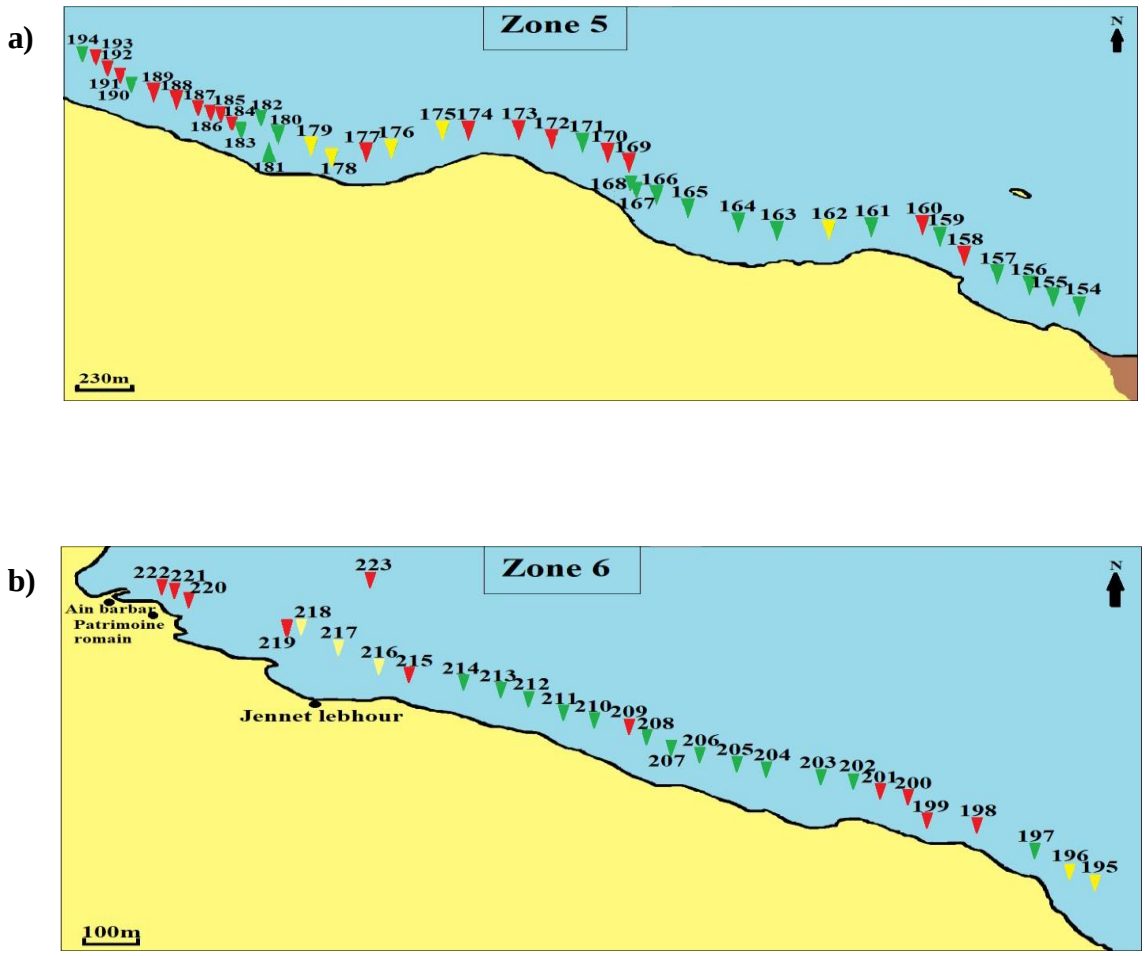

Fig. 5. Location and characterization of *P. oceanica* seabed types in Z5 and Z6 in Sector 2 (Green: *P. oceanica*; Red: rocky bottom; Yellow: soft bottom; White: no visibility)

Table 4. Geolocation (GPS) and depth (m) of *P. oceanica* meadows in the Z5 and Z6 of S2 of the Edough mountains MPA (Z: Zone)

Z5			Z6		
N°	**GPS**	**Depth**	**N°**	**GPS**	**Depth**
153	36°57.742’/ 07°37.286’	03	195	36°58.504’/ 07°35.532’	14
154	36°57.764’/ 07°37.240’	04	196	36°58.530’/ 07°35.500’	11
155	36°57.775’/ 07°37.227’	06	197	36°58.578’/ 07°35.458’	08
156	36°57.801’/ 07°37.200’	08	198	36°58.647’/ 07°35.382’	07
157	36°57.821’/ 07°37.168’	07	199	36°58.658’/ 07°35.292’	04
158	36°57.890’/ 07°37.124’	05	200	36°58.720’/ 07°35.279’	07
159	36°57.901’/ 07°37.113’	09	201	36°58.739’/ 07°35.231’	07
160	36°57.925’/ 07°37.109’	13	202	36°58.767’/ 07°35.187	07
161	36°57.926’/ 07°37.018’	07	203	36°58.782’/ 07°35.129’	11
162	36°57.918’/ 07°36.952’	07	204	36°58.808’/ 07°35.028’	11
163	36°57.913’/ 07°36.873’	09	205	36°58.826’/ 07°34.974’	11
164	36°57.933’/ 07°36.818’	07	206	36°58.855’/ 07°34.905’	09
165	36°57.969’/ 07°36.744’	11	207	36°58.885’/ 07°34.851’	11
166	36°58.003’/ 07°36.697’	08	208	36°58.914’/ 07°34.806’	11
167	36°58.024’/ 07°36.667’	06	209	36°58.954’/ 07°34.769’	11
168	36°58.045’/ 07°36.658’	07	210	36°58.968’/ 07°34.702’	11
169	36°58.092’/ 07°36.656’	08	211	36°58.997’/ 07°34.641’	08
170	36°58.123’/ 07°36.620’	10	212	36°59.044’/ 07°34.567’	12
171	36°58.158’/ 07°36.576’	12	213	36°59.083’/ 07°34.508’	12
172	36°58.166’/ 07°36.538’	11	214	36°59.105’/ 07°34.427’	13
173	36°58.186’/ 07°36.471’	10	215	36°59.141’/ 07°34.306’	11
174	36°58.190’/ 07°36.374’	10	216	36°59.170’/ 07°34.237’	12
175	36°58.193’/ 07°36.326’	12	217	36°59.248’/ 07°34.137’	14
176	36°58.136’/ 07°36.248’	10	218	36°59.332’/ 07°34.039’	16
177	36°58.122’/ 07°36.208’	05	219	36°59.333’/ 07°34.038’	12
178	36°58.105’/ 07°36.153’	05	220	36°59.452’/ 07°33.749’	10
179	36°58.138’/ 07°36.108’	07	221	36°59.502’/ 07°33.700’	08
180	36°58.176’/ 07°36.038’	09	222	36°59.522’/ 07°33.662’	08
181	36°58.186’/ 07°36.004’	08			
182	36°58.202’/ 07°35.964’	06			
183	36°58.215’/ 07°35.955’	08			
184	36°58.216’/ 07°35.944’	05			
185	36°58.248’/ 07°35.912’	09			
186	36°58.257’/ 07°35.890’	07			
187	36°58.273’/ 07°35.861’	12			
188	36°58.294’/ 07°35.811’	13			
189	36°58.324’/ 07°35.754’	13			
190	36°58.361’/ 07°35.696’	08			
191	36°58.395’/ 07°35.657’	15			
192	36°58.426’/ 07°35.617	15			
193	36°58.478’/ 07°35.567’	15			
194	36°58.490’/ 07°35.534	16			

Zone 7, recognized as a zone of interest, stretches from Ain Barbar to Ain Errihane over a distance of 4.66km, and includes 33 stations spaced 136 meters apart, with depths

ranging from -4 to -11 meters (Table 5). Rocky seabeds represent 34.37% of the substrate here, with soft seabeds accounting for 18.75%. Observations indicated the presence of 15 seagrass beds at Sts: 226, 227, 228, 229, 231, 239, 240, 241, 243, 244, 245, 246, 253, 254, and 255 (Fig. 6a).

Finally, Zone 8 (Z8) encompasses both the buffer and central zones of the MPA, extending from Ain Errihane to Roche Axine over a length of 3km. It comprises 23 stations approximately 137 meters apart, at depths ranging from -5 to -16 meters (Table 5). Rocky bottoms were observed at Sts: 259, 273, and 278, while the remaining 20 stations, including Sts: 256, 257, 258, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 274, 275, 276, and 277, contained *P. oceanica* meadows (Fig. 6b).

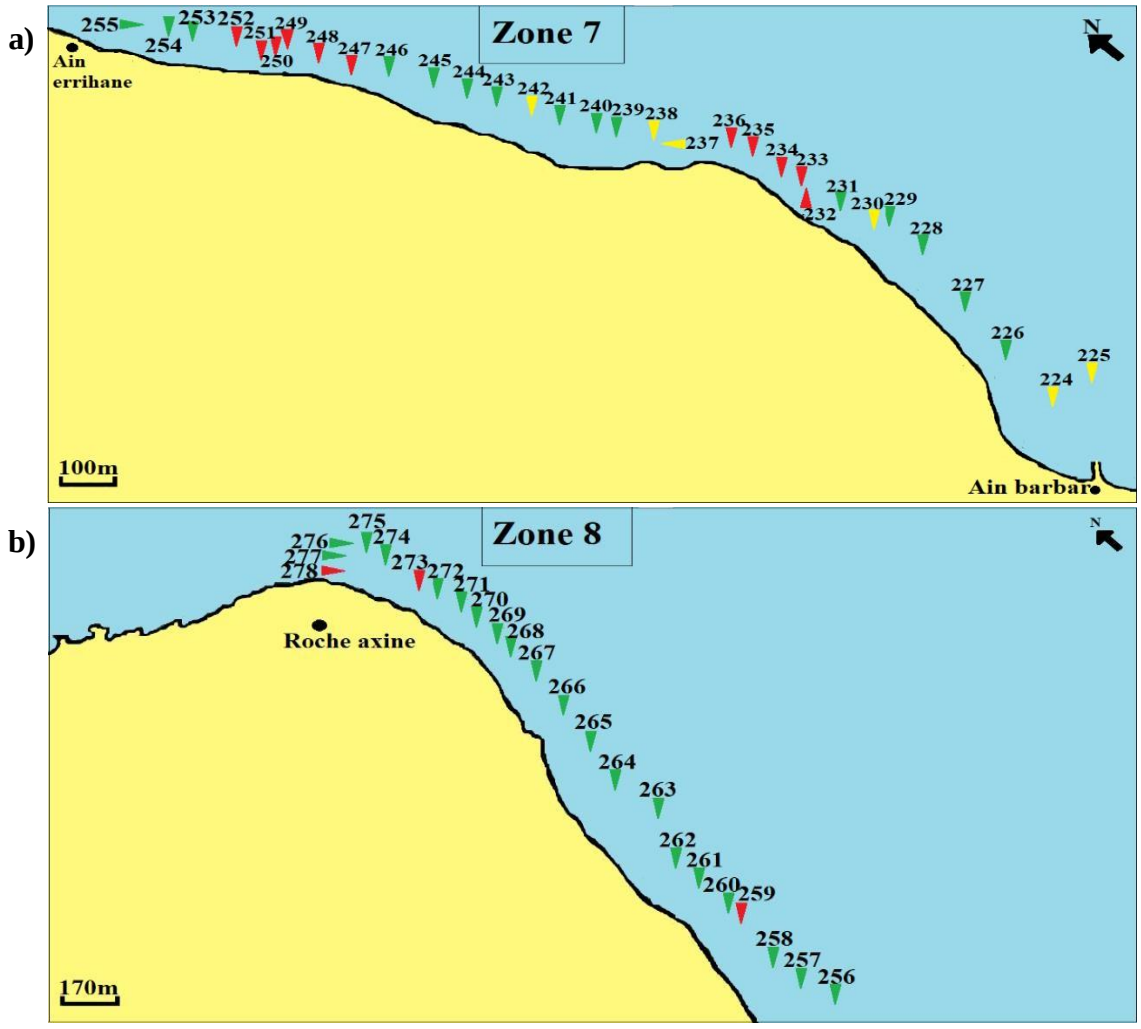

Fig. 6. Location and characterization of *P. oceanica* seabed types in Z7 and Z8 in Sector 2 (Green: *P. oceanica*; Red: rocky bottom; Yellow: soft bottom; White: no visibility)

Table 5. Geolocation (GPS) and depth (m) of *P. oceanica* meadows in the Z7 and Z8 of S2 of the Edough mountains MPA (Z: Zone)

Z7			Z8		
N°	**GPS**	**Depth**	**N°**	**GPS**	**Depth**
223	36°59.534’/ 07°33.606’	08	256	37°01.265’/ 07°31.660’	16
224	36°59.658’/ 07°33.543’	07	257	37°01.318’/ 07°31.593’	09
225	36°59.659’/ 07°33.541’	11	258	37°01.376’/ 07°31.544’	09
226	36°59.757’/ 07°33.518’	10	259	37°01.489’/ 07°31.508’	08
227	36°59.871’/ 07°33.504’	06	260	37°01.521’/ 07°31.487’	08
228	37°00.017’/ 07°33.498’	06	261	37°01.587’/ 07°31.436’	10
229	37°00.102’/ 07°33.469’	11	262	37°01.645’/ 07°31.396’	11
230	37°00.098’/ 07°33.432’	09	263	37°01.831’/ 07°31.423	16
231	37°00.166’/ 07°33.391	08	264	37°01.931’/ 07°31.325’	15
232	37°00.240’/ 07°33.337’	10	265	37°02.027’/ 07°31.260’	13
233	37°00.243’/ 07°33.334’	13	266	37°02.096’/ 07°31.239’	11
234	37°00.283’/ 07°33.303’	07	267	37°02.154’/ 07°31.210’	07
235	37°00.352’/ 07°33.263	09	268	37°02.234’/ 07°31.166’	06
236	37°00.393’/ 07°33.227’	09	269	37°02.272’/ 07°31.141’	07
237	37°00.439’/ 07°33.065’	08	270	37°02.326’/ 07°31.102’	07
238	37°00.450’/ 07°33.054’	08	271	37°02.370’/ 07°31.078’	07
239	37°00.473’/ 07°32.969	09	272	37°02.423’/ 07°31.029’	05
240	37°00.494’/ 07°32.925’	11	273	37°02.450’/ 07°30.987’	06
241	37°00.543’/ 07°32.844’	12	274	37°02.539’/ 07°30.920’	08
242	37°00.583’/ 07°32.782’	12	275	37°02.585’/ 07°30.880’	09
243	37°00.637’/ 07°32.706’	10	276	37°02.605’/ 07°30.854	08
244	37°00.677’/ 07°32.638’	08	277	37°02.583’/ 07°30.838’	07
245	37°00.733’/ 07°32.557’	09	278	37°02.553’/ 07°30.816’	05
246	37°00.795’/ 07°32.449’	07			
247	37°00.815’/ 07°32.350’	04			
248	37°00.886’/ 07°32.269’	08			
249	37°00.951’/ 07°32.149’	10			
250	37°00.946’/ 07°32.141’	09			
251	37°00.915’/ 07°32.116’	07			
252	37°00.990’/ 07°32.049’	10			
253	37°01.040’/ 07°31.927’	10			
254	37°01.070’/ 07°31.861’	10			
255	37°01.144’/ 07°31.789’	11			

DISCUSSION

The Mediterranean region comprises 1,087 officially designated marine protected areas (MPAs), 257 of which hold national status, encompassing 8.33% of the Mediterranean's surface area. In Algeria, only 225.76km², representing a mere 0.17% of the national territory, is under protection. The country hosts two specially protected areas

of Mediterranean importance (SPAMIs) – Banc des Kabyles and Îles Habibas – along with two nature reserves at Cap Lindles and Îles Planes, and four national parks, namely: El Kala, Gouraya, Taza, and the Edough Mountains **(MEER, 2022; Boubekri *et al.*, 2023)**.

The presence of *P. oceanica* at shallow depths, coupled with the high quality of the surrounding water and the lack of human activity, supports the classification of the Edough Mountains MPA in Annaba. This seagrass meadow plays a vital role in regulating water quality and serves as a significant factor in mitigating the impacts of climate change within the region **(Briac, 2020)**. To meet this challenge, financial support is needed from the Global Environment Facility (GEF) through the MedFund as part of the "Building back a blue and stronger Mediterranean" project. The need for conservation and sustainable management is clear.

In the Mediterranean, surface water temperatures exhibit considerable variation between the southern and northern coasts, influenced by several factors including regional climate, topography, duration of sunshine, hydrodynamics, and water depth **(McNeely *et al.*, 1990)**. Within the Edough Mountain MPA, the average temperature is approximately 21.44°C, with increases noted toward the western region near the Strait of Gibraltar, where temperatures can reach up to 23.5°C **(Rouane, 2013)**. In contrast, lower temperatures of around 16.5°C are recorded in the Gulf of Lyon (southern Mediterranean) and Lebanon (eastern Mediterranean) **(Halwani *et al.*, 2001; Zouari, 2021)**.

These temperature conditions are conducive to the growth of *P. oceanica*, which thrives within a temperature range of 10 to 28°C, as documented by **Boudouresque and Meinesz (1982)**. Our findings align with this literature, indicating that the prevailing thermal regime in the Edough MPA supports the sustainability of this critical seagrass habitat, which plays a vital role in maintaining marine biodiversity and ecosystem health. Understanding these temperature dynamics is essential for effective conservation strategies in response to ongoing climate change.

The correlation between temperature and the distribution of *P. oceanica* highlights the need for continued research and monitoring to assess the impacts of fluctuating environmental conditions on marine habitats in the Mediterranean region

The salinity of marine waters is affected by several factors, including the influx of freshwater from rivers and wadis, evaporation rates, and exchanges with the open ocean **(Zouari, 2021)**. Our findings align with previous studies conducted along the Algerian coast **(Ounissi & Frehi, 1999)** and throughout the Mediterranean **(Zweng *et al.*, 2019)**, revealing salinity levels that range from 35 to 39g/ l.

These salinity values are conducive to the healthy growth of *P. oceanica*, which demonstrates resilience to elevated salinity levels, with a tolerance threshold reaching approximately 41g/ l. However, it is important to note that *P. oceanica* is sensitive to

desalination processes; growth may significantly decline if salinity drops below 33g/ l, as highlighted by **Ben Alaya (1972)**.

The optimal salinity conditions in the Edough Mountain MPA not only support the vitality of *P. oceanica* meadows but also play a crucial role in maintaining the overall health of the marine ecosystem. Continuous monitoring of salinity fluctuations, particularly in context of climate change and human impact, is essential for the effective conservation of these vital habitats. Understanding the intricate relationships between salinity, water quality, and seagrass health will inform future management strategies aimed at preserving the biodiversity and ecological functions of the Mediterranean marine environment.

The pH levels of coastal waters in the Mediterranean region are influenced by various natural processes, including phytoplankton growth, which sequesters CO_2, the decomposition of organic matter that releases CO_2, the influx of freshwater, and the introduction of continental organic material, as well as the effects of urban and industrial pollution **(Aminot & Keroual, 2004)**. Typically, pH values in the Mediterranean range from 7.9 to 8.3 **(Barnabé, 1991)**, which is consistent with the alkaline characteristics observed in the waters of the Edough Mountains MPA, where pH levels fluctuate between 7.6 and 8.8.

Dissolved oxygen (O_2) concentrations in marine environments are subject to numerous biotic and abiotic influences, primarily the interplay between photosynthesis and respiration, as well as external factors such as wind and temperature variations **(Kattabi, 2002)**. In Annaba, seasonal fluctuations in O_2 levels are evident, with concentrations ranging from 5.6mg/ l during the summer to 9.49mg/ l in winter. These findings align with observations made along the coast of Mostaganem in Western Algeria, where O_2 levels varied from 7.2 to 10.6mg/ l. Thus, it can be concluded that the physicochemical conditions present in the surface waters of the Edough Mountains MPA are conducive to the growth and sustainability of *P. oceanica*.

A total of 97 *P. oceanica* meadows were identified along 37km of coastline within the Edough Mountains MPA, with extensions into offshore depths exceeding 400m. These meadows are situated at varying depths ranging from -4 to -24m, which is consistent with findings reported from the Kerkennah Islands in Tunisia **(Ben Mustapha & Hattour, 1992)**, and comparable to the depths of -26m recorded in Egypt **(Mansour & Mostafa, 2000)**.

The seabed of the Mediterranean is characterized by three distinct substrate types: rocky, soft, and *Posidonia* meadows. In our study area, *P. oceanica* meadows comprise at least 34.89% of the surveyed region, with 34.65% characterized by rocky substrates and 25.28% by soft bottoms. These proportions, however, exhibit considerable variability across different locations; for instance, in Mallorca (Balearic Islands), *P. oceanica* covers approximately 89% of the seabed, while rocky substrates account for 10% and soft substrates for merely 1% **(Fornes *et al.*, 2006)**. Such variability underscores the

importance of local ecological conditions in shaping seagrass distributions across the Mediterranean basin.

Our study demonstrates that the *P. oceanica* meadow is both extensive and in a healthy state along the eastern coastline of the Edough Mountains MPA. This initial mapping effort establishes a vital baseline reference that can be utilized for ongoing monitoring of the meadow's health, as well as its spatial and temporal dynamics. Regular assessments and comparisons against this baseline will enhance our understanding of the factors influencing the meadow's condition, such as climate change and anthropogenic impacts, thereby supporting effective management and conservation strategies **(Romero *et al*., 2006; Boudouresque *et al*., 2014)**.

Furthermore, such baseline data are critical for assessing potential changes over time, allowing for proactive measures to be implemented in response to observed declines in seagrass health or distribution **(Short *et al*., 2011)**. Thus, the mapping of *P. oceanica* meadows not only contributes to our ecological knowledge but also plays an essential role in the sustainable management of marine resources within the Mediterranean region.

CONCLUSION

Our research significantly contributes to the implementation of the National Strategy for Integrated Coastal Zone Management and the PEBLA initiative within the Annaba marine protected area (MPA), recognized as a critical ecosystem in the Mediterranean basin. Notably, despite its proximity to urban areas, the MPA is characterized by high water quality and minimal human interference, rendering it an ecologically and economically valuable asset for local communities. The primary physico-chemical characteristics of the surface waters within the MPA create favorable conditions for the growth of *P. oceanica* meadows, which play a crucial role in enhancing biodiversity and stabilizing the marine ecosystem. However, it is essential to highlight that the Edough Mountains MPA constitutes merely a small fraction of the marine protected areas in Algeria, and even less within the broader Mediterranean context. The expansion and effective management of these protected areas are vital for conserving marine life and supporting coastal ecosystems. To ensure consistency in monitoring the ecological, geographical, and temporal changes of the Posidonia meadow, it is imperative to expedite the completion of mapping efforts across the remaining sections of the MPA. Such initiatives will serve as a benchmark for ongoing conservation efforts and enhance our understanding of this vital habitat.

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