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Biodiversity of marine macroalgae in Oran coast (Algerian west coast – Mediterranean Sea)

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ABSTRACT

This work aims to establish the current state of knowledge of the macroalgae on the Oran coast. This research used a survey method using three stations (Marsa El Hadjaj, Kristel and Ain Franine). Sampling was taken out in the intertidal zone of the coastal area. The study was conducted from April to May 2022. Floristic studies have been mainly focused on identifying the algae growing on rocky substrate. The results showed that there were 22 species of macroalgae grouped into 12 orders, 13 families, and 3 divisions: 5 Phaeophyceae, 8 Ulvophyceae and 9 Florideophyceae. The Ain Franine site is the most diverse, followed by Marsa El Hadjaj and Kristel with (21, 16 and 10 species) respectively. With a Global Average Cover of 47.80%, the Florideophyceae dominate the site of Marsa El Hadjaj, and the Chlorophyceae dominate at the sites of Ain Franine and Kristel with (52.53%; 48.35% and 48.35%) respectively.

Keywords: Macroalgae, Phaeophyceae, Ulvophyceae, Florideophyceae, Coastal ecosystems, Algerian west coast

Introduction

Macroalgae have long been used as biological indicators of marine ecosystem health worldwide due to their ecological importance and sensitivity to environmental stress (Su Jin et *al.,* 2023). Benthic macroalgae form a rather heterogeneous group of primary producers, including three major divisions based on the nature of their pigments and other fundamental characteristics: Phaeophyceae (brown algae), Ulvophyceae (green algae) and Florideophyceae (red algae), (Kokabi and Yousefzadi, 2015). Macroalgae play a key role in maintaining the ecological balance of the aquatic environment and are an indicator of the state of the marine environment. Macroalgae populations are influenced by various factors that define their spatial and temporal distribution in different habitats and regions (Hernández-Casas et *al.,* 2024). The diversity of algae in aquatic environments can help assess the health of ecosystems, provide information on invasions of new species and inform us about changes in species diversity based on environmental conditions (Birje, et *al.,* 1996; Ramdani et *al*., 2020). Macroalgae provides a habitat for several marine organisms, such as crustaceans, molluscs, echinoderms, small fish, and other small algae. The distribution of macroalgae in waters is influenced by various environmental factors such as human and anthropogenic factors (Mushlihah *et al.,* 2021). It is in this context that the study aims to determine the diversity and structure of macroalgae at 3 sensitive sites (Marsa El Hadjaj, Kristel and Ain Franine), in the Oran Coast (Algerian west coast). The ecological characterisation of communities is a fundamental part of using and exploiting resources, including seaweed.

Materials and Methods

Study Area

Our study area located on the coast of Oran, has 3 sites (stations) of ecological interest prospected over the period April - May (2022). Our study area located on the coast of Oran, has 3 sites (stations) of ecological interest prospected, in order to better understand the algal components and monitor the overall cover rate and by species (Fig. 1). The first Site (S1: Marsa El Hadjaj: 35°'49'928'; 0°9 35'756), characterized by siliceous clay sludge covering the area of a large mudflats (Kerfouf and Bouceta, 2022). It is an anthropogenic zone due to its proximity to a large petrochemical complex in Arzew and a large port in Bethioua (Dilem and *al.,* 2015). The second site (S2: Kristel: 35°50'40 N; 0°2 35'56 W), is more or less remote from pollution sources, with a bedrock with significant biodiversity (Hassani et *al*., 2015; Kies et *al.,* 2020). The third site (S 3: Ain Franine: 35°48'44.46 N; 0°35’ 01), is considered not impacted due to its remoteness from the urban fabric and all industrial activities, and its difficult access. The bedrock of the resort, which is rocky and sandy, is bathed in radioactive water, rich in sulfur from the nearby thermal spring (Belhadj Tahar et *al.,* 2021).

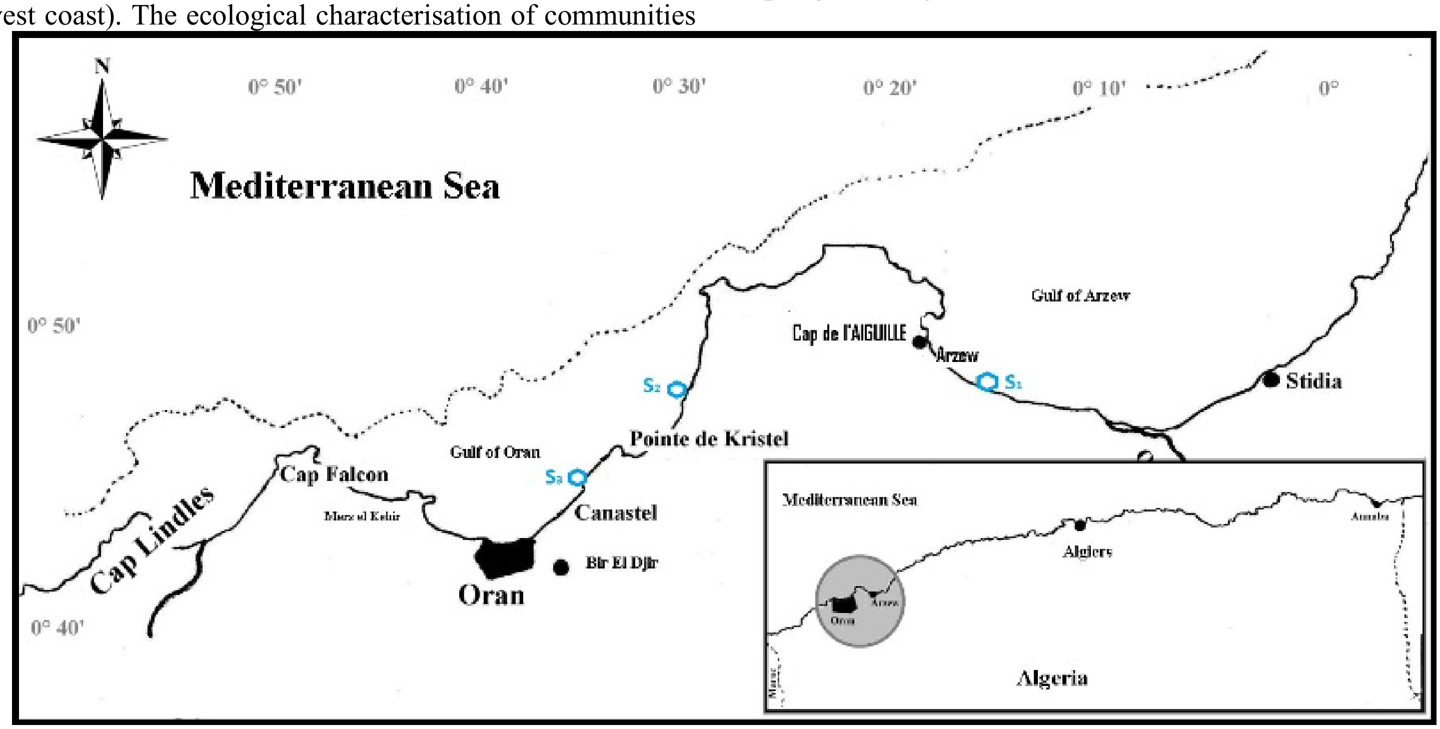

Figure 1. Geographical location of the study area

Sampling

The method used for the inventory of macroalgae flora is that of the minimum recommended area for phytosociological samples. Two major factors are taken into consideration when choosing the sampling period (season and pollution). Climatic conditions are favourable during the warm season for most floristic species (from May to August), and an increase in anthropogenic pressure (human use, flow of urban effluent discharges) is a determining factor in the proliferation or disappearance of sensitive species. The samples are taken on an elementary surface constituting a survey using a quadra with a surface of 50x50 cm^2, which corresponds to the minimum area adopted for the study of the macroalgae community (Boudouresque, 1971). Also, the complete scraping of the sampled surface is essential to continue its study in the laboratory. To establish an exhaustive floristic list of the studied stations, we conducted a random sampling of five surveys per station. The quadra is fixed on the surface to take samples between the upper mesolittoral and the upper infralittoral at depths between 1m and 3m. The collected material is sorted on the spot, in order to separate the thalli of the different species and then are kept separately in seawater (Ramdani et *al*., 2020) in bags kept cool in a cooler, for transport to the laboratory. In the laboratory, the species are separated and cleaned and dried as quickly as possible for quality samples. Macroalgae often lose their colour after drying. An identification number that appears on the outside of each folder of the paper, as well as data on the colour of the species and its habitat and recorded in a field notepad. The code of the macroalgae, the date and the place of harvest are indicated on a sheet. Several species identification keys are used, including the AlgaeBase database and Word Register of Marine Species (WORMS). Macroscopic characters such as colour, shape, size and also location facilitate the determination of species.

Data Analysis

Several classical and synthetic methods were used to evaluate the distribution and structure of macroalgae such as abundance, and species richness, as well as the Shannon and Weaver diversity index (H') and the index equity (J), (Shannon and Weaver, 1963), and the frequency of species. All statistical analyses were performed with R 3.5.2 (R Development Core Team 2019) provided with the FactoMineR package.

The cover rate for all individuals of a given species is calculated and estimated visually on a scale ranging from 5 to + (5: species covering more than ¾ (75%) of the surface; 4: from ½ to ¾ (50%-75%); 3: ½ to ¼ (50%-25%) ; 2: abundant species but covering less than ¼ (5%-25%); 1: species well represented but covering less than 5%; +: (species present but negligible).

The Ri cover rate is the first of the two main coefficients assigned to each species (Boudouresque, 1971). This is the approximate percentage of the substrate area projected by species i. Total survey cover over the total number of surveys: Ri n R=1 /Nr (n is the number of survey species, Nr: the number of surveys).

At each step (class) of the cover coefficient Ri assigned to the n species i of a survey corresponds a conventional mean value (class center) named average cover: Absence = 0; + = 0.1%; 1 = 2.5%; 2 = 15.0%; 3 = 37.5%; 4 = 62.5%; 5 = 87.5%. The GAC (Global Average Cover) for species i in a set of N records is, therefore, the average of its successive average cover:

GAC= Ri n p =1 / N

In a survey divided into qu adra, the frequency Fi of species I expressed as a percentage. It is the ratio of the number of quadra where it is present to the total number of quadra:

F (%) = ni/Nx100.

F is characterized by five classes: 0< F <20%: Class I: Very rare species; 20% <40%: Class II: Rare species; 40%< F < 60%: F Frequent species; 60%< F < 80%: Abundant species; 80%<F<100%.

Results and Discussion

Specific Diversity

Prospecting our study area has identified 22 species: 5 Phaeophyceae, 8 Ulvophyceae and 9 Florideophyceae (Table 1).

The largest number of algae was recorded at the stations of Ain Franine (18 species) followed by Marsa El Hadjaj (16 species). The lowest species richness is recorded at Kristel station (13 species) (Figure 2).

For the Marsa El Hadjaj station, 16 species of benthic macrophytes: 3 Phaeophyceae, 6 Ulvophyceae and 7 Florideophyceae were observed. Thus, the surveys show a dominance of Florideophyceae (red algae) (43.75%), followed by Ulvophyceae (green algae) (37.5%) and Pheophyceae (brown algae) (18.75%). Species with a coefficient of 5 and 4 are defined as very abundant: *Colpomenia sinuosa* (Phaeophyceae); *Ulva compressa*, *Ulva intestinaloides*, *Ulva lactuca* (Ulvophyceae); *Hypnea musciformis*, *Osmundea pinnatifida* (Florideophyceae). Most species are assigned an index of 2 and 1 where the cover rate is 25% to minus 5%, and are well represented by: *Dictyota dichotoma, Padina pavonica*

(Phaeophyceae); *Caulerpa prolifera, Caulerpa racemosa*, *Cladophoropsis membranacea* (Ulvophyceae); *Asparagopsis armata Harvey*, *Ellisolandia elongata*, *Gelidium sp*, *Gracilariopsis longissima* (Florideophyceae). Those indicated by the + sign are species present, but not quantified, it is *Peyssonnelia squamaria*. (Florideophyceae). The total absence of species marked by the sign - is represented by *Ericaria amentacea*, *Sargassum muticum* (Pheophyceus); *Codium decorticatum*, *Codium fragile* (Ulvophyceae), *Gelidium crinale*, *Palisa da perforata* (Florideophyceae).

Table 1. Floristic list according to the WORMS (World Register of Marine Species) database.

Class	Phylum (Division)	Order	Family	Genus	Species
Phaeophyceae	Ochrophyta	Dictyotales	Dictyotaceae	Padina	*Padina pavonica* (Linnaeus) Thivy*, 1960*
				Dictyota	*Dictyota dichotoma (*Hudson) J.V.Lamouroux, 1809
		Ectocarpales	Scytosiphonaceae	Colpomenia	*Colpomenia sinuosa* (Mertens ex Roth) Derbès & Solier, 1851
				Sargassum	*Sargassum muticum* (Yendo) Fensholt, 1955
				Ericaria	*Ericaria amentacea* (C.Agardh) Molinari & Guiry, 2020
Ulvophyceae	Chlorophyta	Bryopsidales	Codiaceae	Codium	*Codium decorticatum* (Woodward) M.A. Howe, 1911
					Codium fragile (Suringar) Hariot, 1889
			Caulerpaceae	Caulerpa	*Caulerpa racemosa* (Forsskål) J.Agardh, 1873
					Caulerpa prolifera (Forsskål) J.V.Lamouroux, 1809
		Cladophorales	Boodleaceae	Cladophoropsis	*Cladophoropsis membranacea* Bang ex C.Agardh) Børgesen, 1905
		Ulvales	Ulvaceae	Ulva	*Ulva compressa* Linnaeus, 1753
					Ulva intestinaloides (Koeman & Hoek) H.S. Hayden, Blomster, Maggs, P.C. Silva, Stanhope & Waaland, 2003
					Ulva lactuca (Linnaeus) 1753
Florideophyceae	Rhodophyta	Bonnemaisoniales	Bonnemaisoniaceae	Asparagopsis	*Asparagopsis armata* Harvey, 1855
		Gelidiales	Gelidiaceae	Gelidium	*Gelidium crinale* (Hare ex Turner) Gaillon, 1828
					Gelidium sp
		Gracilariales	Gracilariaceae	Gracilariopsis	*Gracilariopsis longissima* (S.G. Gmelin) Steentoft, L.M. Irvine & Farnham, 1995
		Gigartinales	Cystocloniaceae	Hypnea	*Hypnea musciformis* (Wulfen) J.V.Lamouroux, 1813
				Osmundea	*Osmundea pinnatifida* (Hudson) Stackhouse, 1809
		Peyssonneliales	Peyssonneliaceae	Peyssonnelia	*Peyssonnelia squamaria* (SGGmelin) Decaisne ex J. Agardh ،1842
		Corallinales	Corallinaceae	Ellisolandia	*Ellisolandia elongata* (J.Ellis & Solander) K.R.Hind & G.W.Saunders, 2013
		Ceramiales	Rhodomelaceae	Palisada	*Palisada perforata* (Bory) K.W.Nam, 2007

At the Kristel station, 13 listed species are divided into three groups (3 Phaeophyceae, 3 Ulvophyceae and 7 Florideophyceae), with a dominance of Florideophyceae compared to other groups. Red algae dominate (53.86%) more than double the two other groups, as well as a homogeneous distribution of brown algae (23.076%) and green algae (23.076%). The Pheophyceus *Ericaria amentacea* occupies the largest area in all the station's surveys, as well as the Florideophyceae, *Hypnea musciformis*, with a coefficient 4. These two species are defined as very abundant with a cover of more than 50%, followed by two o Florideophyceae with a coefficient 3 (*Ellisolandia elongata* and *Palisada perforata*), as well as Ulvophyceae, *Ulva lactuca* considered a frequent species. Most species are abundant or well represented and assigned an index of 2 and 1 where the cover rate is from 25% maximum to 5%. They are represented by two Phaeophyceae *Dictyota dichotoma*, *Padina pavonica*; one Ulvophyceae, *Codium fragile*, and four Florideophyceae, *Asparagopsis armata Harvey*, *Ellisolandia elongata*, *Gelidium sp*, and *Gracilariopsis longissima*. We note the total absence of species marked by the sign -, especially the Ulvophyceae, with five species *Caulerpa prolifera, Caulerpa racemosa*, *Cladophoropsis membranacea, Codium decorticatum, Ulva compressa*. The two Phaeophyceae *Colpomenia sinuosa* and *Sargassum muticum*, and the two Florideophyceae *Gracilariopsis longissima*, *Peyssonnelia squamaria* are absent.

22 species are harvested in all stations surveyed.

For the station of Ain Franine, 18 species of benthic macrophytes were collected including 4 Phaeophyceae, 7 Ulvophyceae and 7 Florideophyceae, with a dominance of Florideophyceae (red algae) and Ulvophyceae (green algae) with the same percentage of (38.9%), followed by Phaeophyceae (brown algae), with a percentage of (22.2%). Some species are considered very dominant by attributing to them the coefficient 5 or 4: *Cladophoropsis membranacea* and *Ulva compressa* (Ulvophyceae), and others with the coefficient 3, considered abundant species: *Padina pavonica*, (Pheophyceus) and *Ulva lactuca*, (Ulvophyceae), *Asparagopsis armata Harvey*, *Ellisolandia elongata*, *Hypnea musciformis*, *Palisada perforata*, (Florideophyceae). Many species are well represented, with an index of dominance coefficient 2 or 1, whose cover rate is 25% to less 5%. These are *Ericaria amentacea*, *Dictyota dichotoma* (Phaeophyceae) *Caulerpa racemosa*, *Codium decorticatum*, *Codium fragile*, *Ulva intestinaloides* (Ulvophyceae), *Gelidium sp.*, *Gracilariopsis longissima*, *Osmundea pinnatifida* (Florideophyceae). The least represented are denoted by the index +, and present but not quantified: Sargassum *muticum* (Pheophyceus). The total absence of species is marked by the sign -, case of *Colpomenia sinuosa* (Pheophyceae), *Caulerpa prolifera*, (Ulvophyceae), *Gelidium crinale* and *Peyssonnelia squamaria* (Florideophyceae).

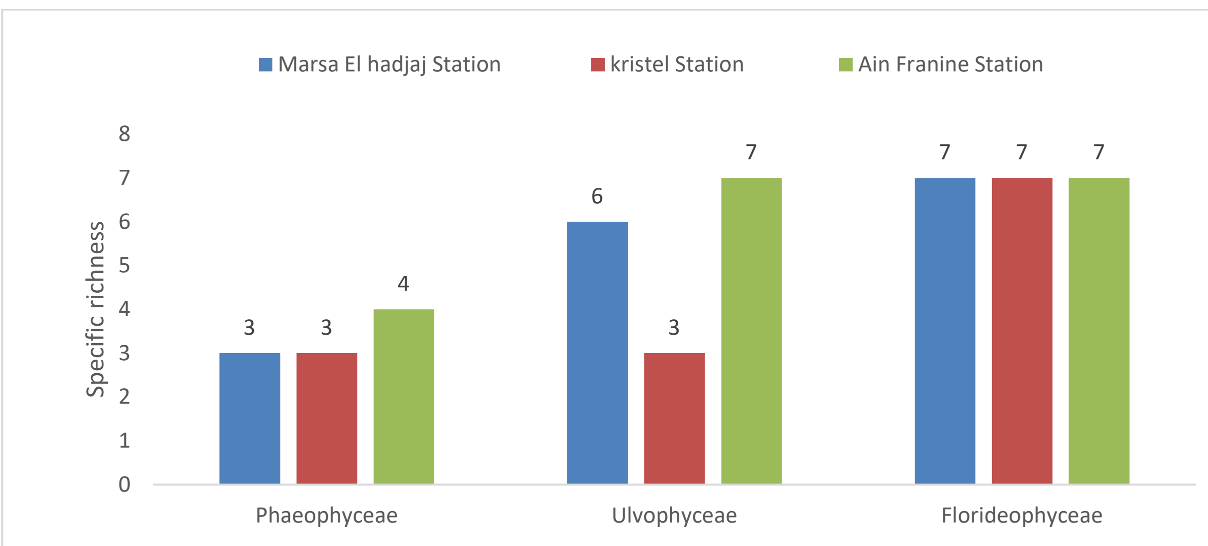

Figure 2. Specific richness of the three stations**.**

The Shannon index (H'), presents moderate to high diversity at the Ain Franin station and Mars el Hadjaj station, with an index of 2.84 and 2.72 respectively. The Kristel station with the lowest diversity with an index of 2.52, presents the highest equitability among the three stations, followed by Mars El Hadjaj and Ain Franin. The differences between (J) are very slight, suggesting a relatively balanced distribution of individuals between species at each station. These results indicate that the habitats of the three stations can support a similar diversity of species with comparable distributions (Figure 3).

Frequency of Species

The most frequent macroalgae at the Marsa el Hadjaj station are brown algae (Pheophyceae), including *Colpomenia sinuosa* and *Dictyota dichotoma* with a frequency of 100% each; they are therefore considered very constant species. Abundant species such as *Caulerpa prolifera*, *Caulerpa racemosa*, *Ulva compressa*, *Ulva intestinaloides, Ulva lactuca,* (Ulvophyceae), have a frequency of 80%, as well as *Gelidium sp*. *Gracilariopsis longissima* and *Osmundea pinnatifida* (Florideophyceae), with a frequency of 80%. The presence and development of the Ulve and Caulerpe threaten the ecological balance of the marine ecosystem. Other frequent species are found in this station, such as *Padina pavonica* (Pheophyceae), *Asparagopsis armata harvey*, *Ellisolandia elongata* (Florideophyceae). This last indicator of disturbed environment (Gramulin-Brida et *al*., 1967) and *Hypenea musciformis* (Florideophyceae) have a frequency of 60%, followed by other algae with a low frequency (40%) *Cladophoropsis membranacea* (Ulvophyceae) and *Peyssonnelia squamaria* (Florideophyceae) considered a very rare species with a frequency of 20%. However, the results of the analytical parameters reveal the presence of indicator species of pollution and eutrophication due to a remarkable proliferation of Ulvophyceae, as well as the total absence of algae indicative of the good state of the environment in particular, the Cyctoseira. From this observation, we can consider the station of Marsa El Hadjaj as a disturbed area, subject to a serious anthropism. A sampling at the Kristel stations shows the massive presence of green algae (Ulvophyceae) such as *Ulva lactuca*, *Eneromorpha intestinalis* and *Codium fargile*. For this purpose, literature mentions the dominance of green algae in highly disturbed environments such as *Ulvales* (Golubic, 1970; Rodriguez-Prieto & Polo, 1996), or Enteromorpha (Ballesteros et *al*., 1984). Their presence is mainly due to coastal discharges of wastewater. According to previous work, the Kristel station is considered to be in relatively good condition and spared important sources of contaminants), with a high abundance (17.80%) of *Ericaria amentacea* in this station. The latter is very present. It was noted that the high percentage of *Ericaria amentacea* recorded in areas characterized by high hydrodynamic, a non-vertical substrate and good lighting emphasizes a good general environmental situation (Figure 4).

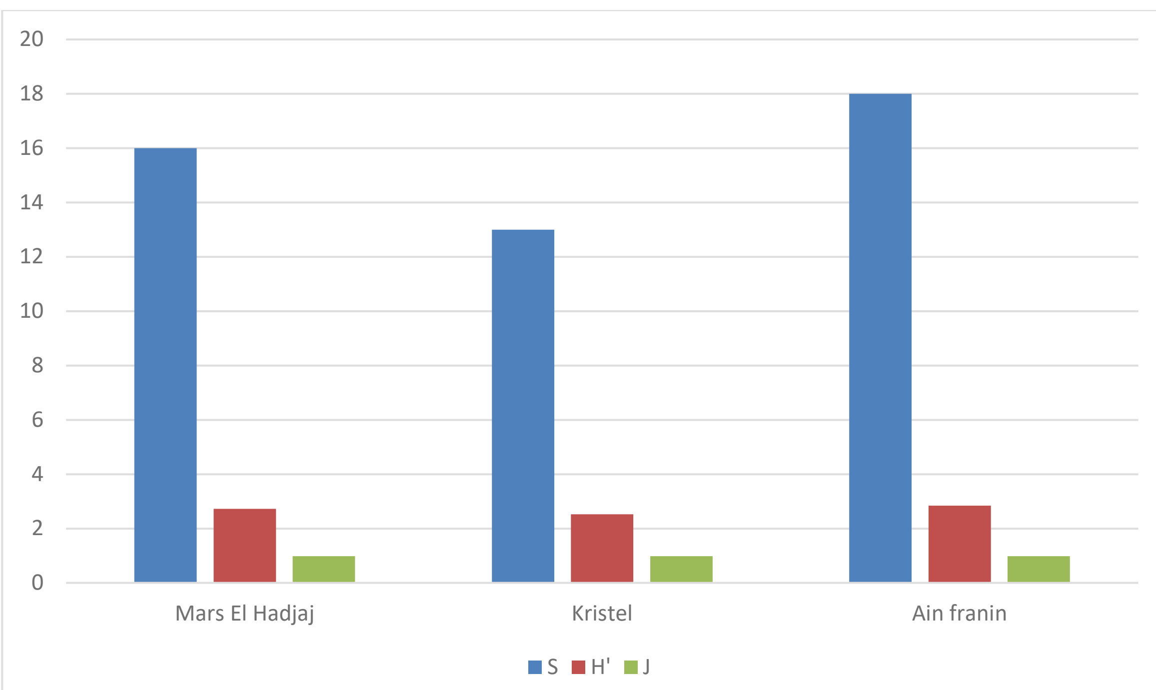

Figure 3. Diversity index and specific richness of sampled stations in the coast of Oran

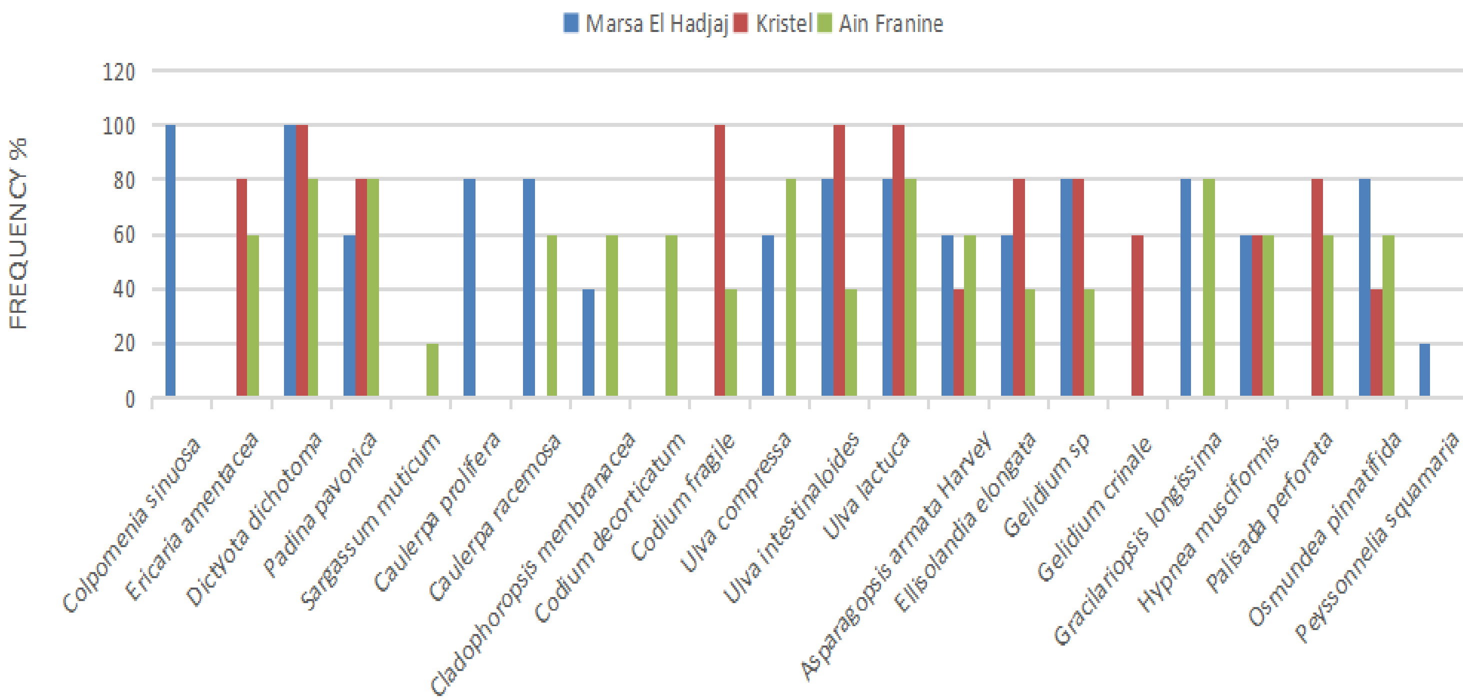

Figure 4. The frequency of algae at the three stations

Cover Rate

The rate of cover of each species at the three stations indicates a macroalgal diversity at the Marsa El Hadjedj station between a maximum cover rate per species of 30% and 0.04%, marked by the dominance of the red algae *Hypnea musciformis* (30%) then the green algae *Ulva lactuca* (23.8%), the red algae *Osmundea pinnatifida* (21.4%) and then *Padina pavonica* (alga bunes) (17%). Only one cover rate is minimum for the red alga *Peyssonnelia squamaria*. (0.04%). *Caulerpa racemosa* represents a cover rate of 12.8% (Fig. 5A). The diversity of machrophytes at the Kristel station shows that the majority species are *Ericaria amentacea*, (Phaeophyceae), *Ellisolandia elongata* (Florideophyceae), *Hypnea musciformis* (Florideophyceae), with a percentage of 17.8%, 20.4% and 23.2% respectively. *Caulerpa prolifera* and *Caulerpa racemosa*, are absent at this station, but present the station of Mars El Hadjadj with a cover rate respectively of 7.8% and 12.8%. The peculiarity of this station is the abundance of *Ulva lactuca* representing a sign of eutrophication and disruption of the environment (Borsali et *al*., 2020), like Caulerps with a 25% overlap rate, similar to station 1 which occupies a rate of 24%, which corresponds to similar results for this species (Bachir Bouiadjra et *al.,* 2021) (Figure 5). As with the Aïn Franine station, it is important to note the dominance of green algae according to their cover rates: *Ulva lactuca* (27%), (26.4%) and *Cladophoropsis membranacea* (22.8%) at the level of the various surveys, and a significant decrease in the overall average cover rate of brown algae indicating a good ecological state of the environment: *Ericaria amentacea* (3%). In this station, we can also notice the presence of invasive algae *Caulerpa racemosa* with a percentage of (3%). The brown alga *sargassum mitucum* (0.12%) absent in the other two stations, has a low overall mean overlap (Figure 5).

The Global Average Cover values of the three groups of algae are higher in Florideophyceae for Marsa el Hadjaj (47.8%) compared to Ulvophyceae (33.06%) and Phaeophyceae (19.14%) (Figure 6). Concerning the stations of Ain Franine, and of Kristel, the overall average cover rate is high respectively in the Ulvophyceae (52, 53%; 48.35%) compared to the Florideophyceae (33, 27%; 32.35%) and Phaeophyceae (14, 2%; 19.3%).

Noting that statistical analysis reveals a significant difference ($p < 0.05$) between all groups. F test (1.5468) is less than the critical value (1.8009) for a threshold of 0.05.

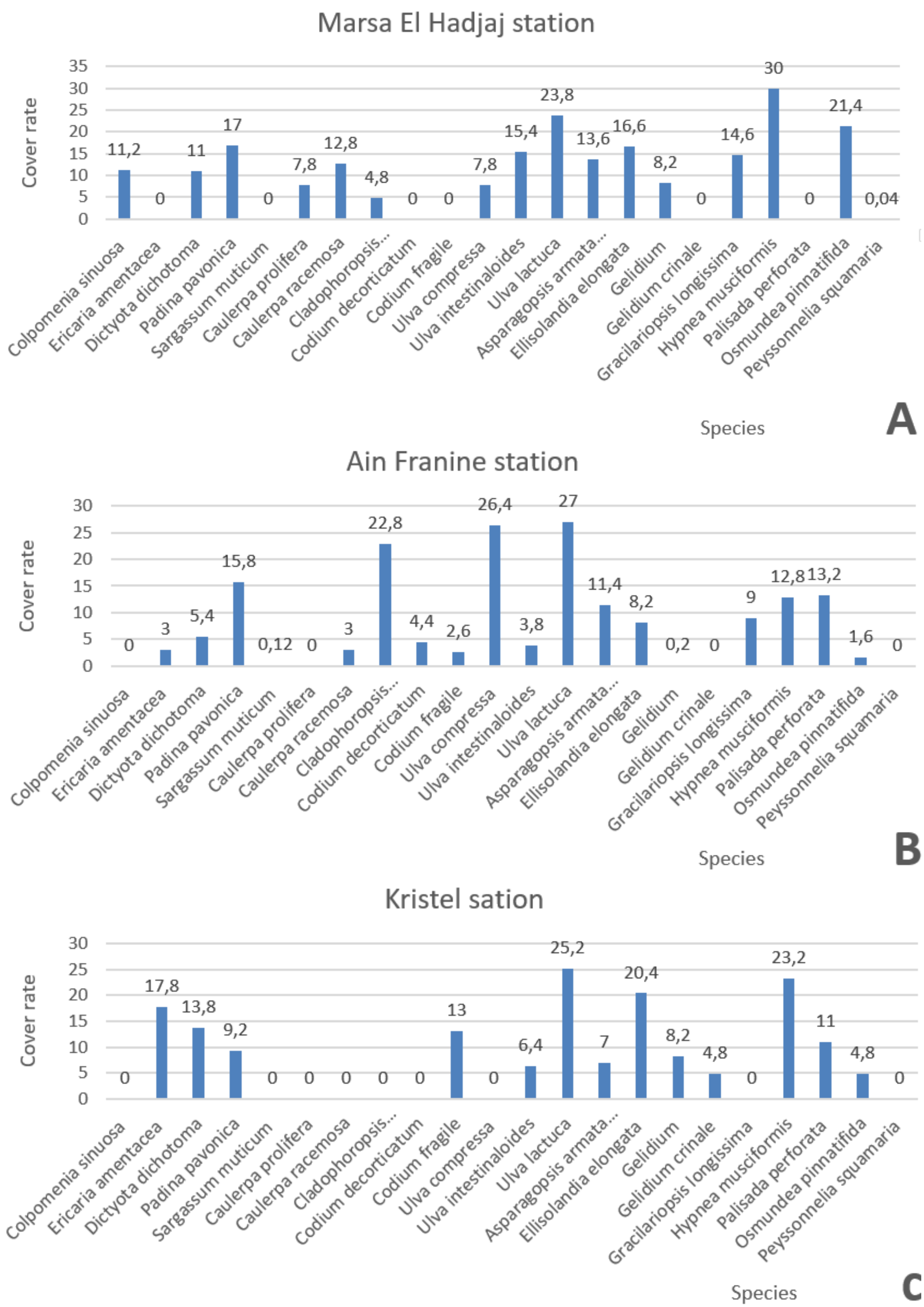

Figure 5. Cover rate of macroalgae in the three stations

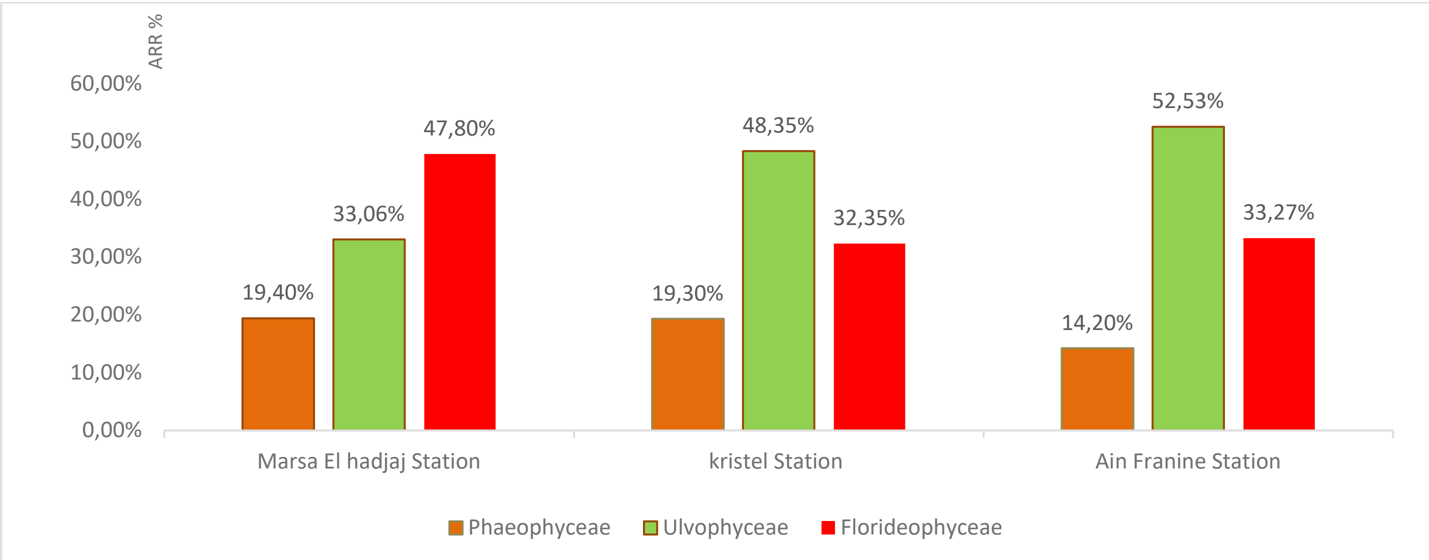

Figure 6. Global Average Cover of the three stations

The macroalgae encountered, called abundant, at the station of Ain Franine with a frequency of 80% are: *Dictyota dichotoma, Padina pavonica* (Pheophyceae) *Ulva compressa*, *Ulva lactuca* (Ulvophyceae) and *Gracilariopsis longissima* (Florideophyceae), and frequent species with a frequency of 80% such as *Ericaria amentacea* (Pheophyceae), *Caulerpa racemosa* , *Caudium decorticatum*, *Cladophoropsis membranacea* (Ulvophyceae) *Asparagopsis armata harvey*, *Palisada perforata* , *osmundea pinnatifida* (Florideophyceae). The presence of the invasive species *Caulerpa racemosa*, which appeared following climate change and the harmful effects of pollution in the Mediterranean basin (Boudouresque & Verlaque, 2002) at this site tends to colonize disturbed ecosystems, and decreases native algal biomass (Klein, 2007; Klein et *al*., 2008). Other rare species have a low frequency of 40%: *Codium fragile*, *e* (Ulvophyceae), *Gelidium sp*, *Osmundea pinnatifida* and finally *Sargassum muticum* with a low frequency of 20% said very rare. Previous work carried out on this station considers Ain Franine as a clean zone without impact (Djad *et al.,* 2015), due not only to the regression of the average overall cover rate of *Ericaria amentacea* but also to the evolution of Ulvophyceae, in particular, the overall average cover rate of Ulves and *Ulva compressa* which has progressed from the proliferation of *Caulerpa racemosa* which is constantly invading this relatively healthy coastal station. Finally, according to the results of the analytical parameters and the presence of pollution indicator species and a low presence of algae indicating the good state of the environment (*Ericaria amentacea*), we can consider that the Ain Franine Station is slightly impacted. The species identified were previously observed on the Algerian west coast (Hellal et *al.,* 2021; Mansouri et *al.,* 2021, Mehiaoui et *al.,* 2022), and macroalgae are excellent indicators of degradation in the Algerian coast (Khadidja et *al.,* 2018; Belhouari and Bezzina, 2019). The algae observed, are of economic interest, in particular *Ulva* used in pharmacy, animal feed and as fertilizer; as well as *Ericaria amentacea* used in the chemical industry and as fertilizer. However, the algae that we observed can also be used in the assessment of the ecological status index of coastal waters (Arevalo & Pinedo, 2007; Cavallo et *al*., 2016).

Macroalgae have long been used as biological indicators of marine ecosystem health worldwide due to their ecological importance and sensitivity to environmental stress (Su Jin et *al.,* 2023). Community composition and distribution are influenced by coastal morphology, turbidity, hydrodynamics, nutrient inputs and climatic conditions (Traiche et *al*, 2018). The presence of the invasive species *Caulerpa racemosa* var. cylindracea, which tends to colonize disturbed ecosystems, could explain the reduction in native algal flora (Piazzi and Ceccherelli, 2006; Klein and Verlaque, 2008; Klein 2007).

Conclusion

This study aims to assess the diversity of macroalgae on the intertidal area zone of the Algerian west coast. A total of 22 taxa (5 Phaeophyceae, 8 Ulvophyceae and 9 Florideophyceae) are listed in this study. The classification of species according to their frequency makes it possible to better situate the degree of attachment of species to environmental conditions, in particular to environmental disturbance conditions. Our results showed that the cover rate of each of the 22 species varies from one station to another. The Aïn-Franine, and Kristel stations have a more or less good to acceptable quality environment, without neglecting continuous biomonitoring. The station of Mars El Hadjaj deserves more attention by first making sure to reduce anthropogenic pressure and discharges of domestic and industrial wastewater.

Compliance with Ethical Standards

Conflict of interest: The author(s) declare no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: Ethics committee approval is not required for this study.

Data availability: Data will be made available on request from the author(s).

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Disclosure: -

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