Spatial and temporal variation of diversity seaweed (rhodophyceae, chlorophyceae and Phaeophyceae) in the Marchica lagoon (North-East Morocco)

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Abstract

The present work is mainly devoted to determine the distribution spatio-temporel seaweeds inventory of the Marchica lagoon. Several sampling campaigns, carried out at the Marchica lagoon (October 2014, January, April, July 2015, and July 2017), had the following objectives: To study the diversity Seaweeds (macroalgal) in different zones of the Marchica lagoon (north-eastern of Morocco), and studies the spatio-temporal variation of the Marchica algae. The results obtained provided the identification of about 59 algae species inventories, with the dominance of rhodophyceae Ceramieae C. Agardh is a highly diverse group in terms of number of taxa followed by chlorophyceae and fucophyceae. Chlorophyceae make up the majority of the stand during the spring period, but during the summer period the stand experiences a decrease in chlorophyceae and an increase in rhodophyceae. Rhodophyceae (*Gracilaria*) are the most abundant seaweeds species at the continental edge, near Oued Tirkâa, at the southeast and south of the lagoon. However, chlorophyceae and rhodophyceae (*Gracilaria*) are located in large quantities near the new pass. While for the fucophyceae, we noticed the new species of *C. barbata*, which is not found by González and Conde (1991).

Introduction

Algae are of paramount ecological importance in the water body as it represents the food source for the higher trophic levels, and they are the most productive photosynthetic organisms in the world (Kasting et al. 2002). However, sometimes this food, stimulated by nutrient inputs (agricultural or domestic discharges also rich in chemical, organic or mineral contaminants), constitutes a major problem (ecological and sanitary) both for the population, which uses the water resources, and for the fauna and flora for which water represents the living environment (Viessman et al. 2009). For this reason, regular monitoring, aimed at surveillance and control of the development of this seaweed, is necessary.

Algae are chlorophyllous organisms capable of occupying all types of environments, although they are abundant in fresh and marine waters, on damp ground and even on snow. They also exist in all humid environments and tropical regions, and can be found even on the walls of buildings. They can be endophytes of certain protozoa or metazoa. Some algae associate with fungi and form lichens. They are divided into 6 large phylums according to the nature of the pigments and cell reserves; these are Cyanophytes, Chlorophytes, Euglenophytes, Chrysophytes, Rhodophytes and Pyrrhophytes (Iltis 1980). In this work we are interested in Seaweed. It is limited to tidal, photic and benthic areas and contributes to 10% of total marine productivity (Seckbach 2010). Algae are the main habitat generators. Changes in global temperature and ocean chemistry have been associated with increased concentrations of greenhouse gases, which have had an effect on biological systems, causing large-scale changes. In addition, these algal ecosystems contribute to the development of global socio-economic activities through their use in food, agriculture and industry. Algae are a bioindicators of ecosystem health and integrity because they form the basis of most food chains in aquatic environments, and of the properties of their components. They are used in many sectors: Agriculture and horticulture, the exploitation of algae in agriculture is also a way of adding value to algae. At present, we are moving towards the use of

extracts that not only act as fertilizers, but also accelerate growth and protect crops, limiting the antifungal activity (Nafis et al. 2021). Farmers use algae to strengthen plants natural defences, instead of using, for example, pesticides. These new products, commonly known as SDN (Natural Defense Stimulator), could eventually replace certain phytosanitary treatments (Jaulneuet et al. 2010). In the medicinal and pharmaceutical field, through their anti-amyloidogenic role (Vasarri et al. 2020), antibacterial, antiviral, antimyco-bacterial, antiplasmodial, antiprotozoal, antifungal and strongly anti-inflammatory properties (Allmendinger et al. 2010; Oumaskour et al. 2013; Spavieri et al. 2013; khelil-Radji et al. 2017; Nafis et al. 2021), having antitumor and antioxidant potential on human colorectal adenocarcinoma cells (Zbakh et al. 2014). Indeed, green algae contain a family of sulphated polysaccharides called ulvanes, which are the subject of several studies aimed at highlighting their beneficial activities in protecting plants against pathogens (Misurcova et al. 2012). Seaweeds are also used in the pharmaceutical industry (Trono, 1973; Febles et al. 1995; Lima-Filho et al. 2002; Ely et al. 2004; Inci et al. 2006). In cosmetics, Algae are an excellent source of minerals with a high affinity for skin cells. Seaweeds as source of dyes, of aromas and of fragrances (Couteau and Coiffard 2016). Algae extracts are used as active ingredients for hydrating and anti-ageing products (Couteau and Coiffard, 2016), thanks to the wealth in complete supply of active elements nourishes, stimulates epidermal cells and promotes skin renewal. For example, minerals contribute to the good balance and vitality of the cells, notably by participating in the activity of numerous enzymes (Nahas et al. 200; Cardozo et al. 2008; Li et al. 2009). Renewable energy, its special interest was devoted to micro- and macro-algae for biofuel production (Chisti 2007; Hankamer et al. 2007). At present, an industry is developing to produce biofuels from lignocellulose, so-called second and especially third generation biofuels (Didderen et al. 2008). According to El Asri et al (2017a and b), the *Caulerpa prolifera*, *Gracilaria bursa-pastoris*, *Colpomenia sinuosa* and *Alsidium corallinum* species in the Marchica lagoon present an exploitable energy reserve. The alginates salts extracted from algae are of great interest in the textile industry, they play an essential role in fixing colours in a fabric (Pereira and Cotas 2020). This alginate allows better penetration of the colour into the textile fibres but does not prevent the sun's rays from progressively reducing contrasts. Whereas in environment, algae play an important role for biodiversity, nutriment cyclique and ecosystems services in nearly all environment (Preirna and Neto 2014) and in maintaining the balance of aquatic environments, as primary producers and an important source of oxygen for the links in the ecosystem's food chain. As pollution indicator organisms, some red algae (*Alsidium sp.*, *Sargassum fluitans*) (Figueira et al. 1997; Matoir et al. 2015), green algae (*Ulva rigida*, *Chaetomorpha linum*, *Caulerpa prolifera*, *Enteromorpha intestinalis*, *Chaetomorpha linum*, *Ulva lactuca*) (Kaimoussi et al. 2004; Chouba et al. 2010; Rahmouni et al. 2016) and brown algae (*Ascophyllum nodosum*, *Fucus vesiculosus* (Kuyucak et Volesky 1988; Holan et Volesky 1994; Fourest et Volesky 1997) are used to examine and assess the state of contamination by certain heavy metals. Because of their ability to bio-accumulate pollutants, these algae often considered as bioindicators of pollution and could be used in phytoremediation, mainly the species of *Chaetomorpha aerea* (Aknaf et al. 2018) for chlorophyceae, while for rhodophyceae : *Alsidium corallinum* and *Gracilaria gracilis* which have a higher level of protection against climate changes (Aknaf et al. 2020). This work was carried out in parallel with other parameters, namely sedimentological, biological and chemical (Aknaf et al. 2015, 2018 (a, b), 2017(a, b), 2021).

The purpose of this research was to evaluate the spatial and temporel distributions of the algae inventory of the Marchica lagoon, as well as their in relation to environmental variations and the dominant species distribution of Seaweeds in lagoon after opening the new pass in 2011.

Materials And Methods

Marchica lagoon (35° 05' and 35° 14'; 2° 44' and 2° 56'W) is located on the northeast coast of Morocco. It's the largest Moroccan lagoon and the second largest in North-Africa and represents a parallel system (Ruiz et al. 2006; Zerrouqui et al. 2013). Marchica lagoon is part of the Moroccan Mediterranean wetland complex with an area of 115 km², its maximum depth is about 7.5 meters in the middle and decreases towards the shore. It is separated from the sea by a 25 km long dune barrier that runs parallel to the coast in a north I west/south-east direction. In 2011, the lagoon is connected with Mediterranean Sea by the new pass opening of 300 m wide and 6 m deep, which water exchanges takes place, and is manifested by a decrease in eutrophication (Aknaf et al. 2015).

The samples were collected in October 2014, January, May, July 2015 and July 2017 along the Marchica lagoon at eleven sampling stations established to cover the different areas of the Marchica lagoon (Fig. 1). In the laboratory, the sample was stored in 5% formulated seawater for the floristic study. Anatomical section was mode by hand with à razol blande. The identification of the species, we used a binocular magnifying glass and the optical microscope. Based on systematic works and specialised literature, notably those of Cabioc'h et al. 2006; Lauret et al. 2011 and AlgaeBase (Guiry and Guiry 2015).

Results

The inventory of Seaweeds and epiphytes collected in the Marchica lagoon during the period October 2014 to July 2015 and July 2017 is presented in the table below (Table 1). It also indicates the geographical distribution of each species in the lagoon. The total number of taxa identified includes 59 species, of which 26 species of chlorophyceae, 29 species of rhodophyceae and 4 fucophyceae, in addition to two species of flowering plants: *Cymodocea nodosa* and *Zostera noltei*.

Table 1
Taxons of Seaweeds identified in the Marchica lagoon during the study period

	Stations									
Species	1	2	3	5	6	7	8	9	10	
Cholophyceae										
Ulvales										
<i>Blidingia marginata</i> (J. Agardh)	x	x	x		x	x	x		x	
<i>Enteromorpha compressa</i> (Linnaeus)			x	x	x			x		
<i>Enteromorpha flexuosa</i> (Wulfen) J	x	x	x	x	x		x		x	
<i>Enteromorpha intestinalis</i> (Linnaeus)		x	x				x			
<i>Enteromorpha linza</i> (Linnaeus)		x	x	x	x	x	x	x	x	
<i>Enteromorpha multiramosa</i> Bliding.			x	x	x	x	x	x		
<i>Enteromorpha prolifera</i> (O. F. Müller) J. Agardh	x		x		x			x		
<i>Enteromorpha torta</i> (Mertens) Reinbold	x	x	x	x	x	x	x	x	x	
<i>Ulva intestinalis</i> (Linnaeus), 1753		x	x				x		x	
<i>Ulva fasciata</i> (Delili)		x				x		x		
<i>Ulva rigida</i> C. Agardh1823	x						x	x	x	
Cladophorales- Cladophoraceae										
<i>Chaetomorpha aerea</i> (Dillwyn) Kützing, 1849	x				x					
<i>Chaetomorpha linum</i> (O. F. Müller) Kützing		x	x	x	x			x	x	
<i>Cladophora coelothrix</i> Kützing		x	x	x	x		x		x	
<i>Cladophora dalmatica</i> Kützing		x	x	x	x		x		x	
<i>Cladophora vagabunda</i> (Linnaeus) Van den hoek, 1963			x							
<i>Cladophora echinus</i> (Biasoletto) Kützing	x	x	x				x			
<i>Cladophora prolifera</i> (Roth) Kützing		x	x		x		x		x	
<i>Cladophora rupestris</i> (Linnaeus)										
<i>Cladophora vadorum</i> (Areschoug)			x		x	x	x	x	x	
<i>Rhizoclonium tortuosum</i> (Dillwyn) Kützing16		x	x		x	x	x	x		

x : presence

	Stations						
<i>Cladophora globulina</i> (Ktitzing) Kiitzingx	x			x			
<i>Caulerpa prolifera</i> (Forsskaal) Lamouroux		x	x	x	x	x	x
<i>Derbesia tenuissima</i> (Moris et De Notaris)		x	x				
Bryopsidales- Bryopsidaceae							
<i>Bryopsis plumosa</i> (hudson) C. Agardh, 1823			x				
Dasycladales-Polyphysaceae							
<i>Acetabularia acetabulum</i> (Linnaeus) P.C.Silva	x						
Rhodophyceae							
Acrochaetiales-Acrochaetiaceae							
<i>Audouinella codii</i> (Crouan) Garbary	x		x				
<i>Gelidium latifolium</i> (Grey.) Born. et Thur.	x		x				
<i>Gelidium pusillum</i> (Stackhouse) Le Jolis	x		x				x
Gigartinales							
<i>Gigartina acicularis</i> (Roth) Lamouroux	x	x		x		x	x
<i>Hypnea musciformis</i> (Wulfen) Lamouroux	x			x			
<i>Gigartina acicularis</i> (Roth) Lamouroux			x	x		x	x
<i>Gymnogongrus griffithsiae</i> (Turner) Martens			x				
<i>Caulacanthus ustulatus</i> (Mertens) Kiltzing	x			x			
Gracilariales-Gracilariaceae							
<i>Gracilaria armata</i> (C.Agardh) J.Agardh		x	x	x		x	
<i>Gracilaria bursa-pastoris</i> (S.G.Gmel.) Silva .1952	x	x					
<i>Gracilaria verrucosa</i> (Hudson) Papenfuss		x	x	x		x	x
<i>Gracilaria gracilis</i> (Stackhouse) M. Steentoft, L.M. Irvine & W.F. Farnham,1995			x			x	x
Cryptonemiales							
<i>Grateloupia filicina</i> C. Agardh	x						
Rhodymeniales							

x : presence

Stations									
<i>Gastroclonium clavatum</i> (Roth) Ardissonne									x
<i>Gastroclonium clavatum</i> (Roth) Ardissonne	x								
Ceramiales - Ceramiaceae									
<i>Laurencia obtusa</i> (Hudson) Lamouroux								x	
<i>Spyridia filamentosa</i> (Wulfen) Harvey								x	
<i>Antithamnion cruciatum</i> (C.Agardh) Ndgeli						x			
<i>Centroceras clavulatum</i> Montagne	x								x
<i>Ceramium diaphanum</i> (Lighfoot) Roth		x	x						
<i>Ceramium rubrum</i> (Hudson) C. Agardh		x	x						
<i>Halopitys incurva</i> (hudson) Batters									x
<i>Ceramium tenerimum</i> (Martens) Okamura		x	x						
<i>Griffithsia tenuis</i> C. Agardh						x			
<i>Dasya baillouviana</i> (Gmelin) Montagne						x			
<i>Alsidium corallinum</i> C. Agardh 1827						x		x	x
<i>Chondria tenuissima</i> (Good. et Woodw.) C. Agardh		x	x						
<i>Polysiphonia fruticulosa</i> (Wulfen) Sprengel	x	x							
<i>Jania rubens</i> (L.) Lamouroux	x	x							x
Fucophyceae									
Ectocarpales- Acinetosporaceae									
<i>Ectocarpus siliculosus</i> (Dillwyn) Lyngbye	x								
Fucales									
<i>Cystoseira compressa</i> (Esper) Gerloff et Nizamuddin								x	
<i>Cystoseira crinita</i> (Desfontaines) Bory	x	x							
<i>Cystoseira barbata</i> (Stackhouse) C.Agardh		x							
Phanerogam									
<i>Zostera noltii</i> Hornemann, 1832						x	x	x	x
<i>Cymodocea nodosa</i>	x					x	x	x	x
x : presence									

Whereas, the maximum number of species with 38 taxa was found at station 3 near the new pass. This station is close to the exchange between the lagoon and the Mediterranean Sea and the minimum with 10 taxa was at station 7 representing the south of the lagoon (Fig. 2). It should be noted that some stations are sterile to algae, notably station 4 (in the sector of the pass) and station 11 (in the center of the lagoon).

There were the spatial and temporel differences in the seaweeds, the number of species and species diversity. We noticed the dominance and diversity of rhodophyceae which are represented by the order *Ceramiales* (13 species) at stations 2, 3 and the order *Gigartinales* (10 species) at station 10, followed by the filamentous chlorophyceae: *Enteromorpha* and *Ulves*. *Ulves* are present in the north-east, south and south-west of the lagoon.

The algal flora is rich diversity in the north-western part (near the new pass) and decreases remarkably at the lido cord (Mohandiss area) as well as towards the continental edge (along the Bou Areg plain).

In spring, this period characterized by the beginning of the temperature increase, we noticed a high diversity of chlorophyceae, namely the ulvales (11 species) (*Enteromorpha* and *Ulva*) with maximum dominance at stations 1, 2, 6 and 8, of Chladophora (13 species) mainly the *Chaetomorpha*, at stations 1 and 6. Knowing that in the Kariat-Arekman station (S6), chlorophyceae are the most dominant. In autumn and winter, we have recorded a diversity and abundance of rhodophyceae which correspond to the most numerous species compared to the other groups, they are dominated by *Gracilaria sp.* and *Sargassum*, located mainly in continental areas where they are situated near the Oued Tirkâa (S10), Boukana (S2), near Oued Selouan (S8), and near the new pass (S3).

Moreover, the difference between the total number of taxa (59) and the number of taxa encountered at station 3 indicates that more than 21 species are rhodophyceae capable of withstanding strong variations in environmental conditions and better adapted to the ecological conditions of the lagoon.

Discussions

In this study, the seaweeds was composed of 59 taxa, 26 species of which were chlorophyceae, 29 species were rhodophyceae and 4 fucophyceae, which showed the qualitative importance of Marchica lagoon. In general, the most important groups were rhodophyceae in species numbers. There are many studies that were conducted in lagoons mediterranean and some of those were focused on seaweeds. In the studies carried out in the Thau lagoon (Verlaque 2001), Venice lagoon (Sfriso, et al 2020), rhodophyceae were found to be dominant compared to the other classes.

In the present work, the taxonomic composition of algal populations in the Marchica lagoon is largely influenced by the seasons, with an increase in algal population during spring and winter and a decrease during summer and autumn. While that Li et al (1984) and Marinho-Soriano et al (2006) found that the growth rate of marine plants increases during spring and summer and decreases during autumn and winter. Chlorophyceae make up the majority of the stand during the spring period, but during the summer

period the stand experiences a decrease in chlorophyceae and an increase in rhodophyceae. These species are mainly located on the continental edge where they are situated near Oued Tirkâa (S10), which is characterized by anthropic inputs and nutrient richness at the southeast and southern end of the lagoon (Aknaif et al 2017). We noticed an abundance of *Gracilaria* and a proliferation of *Ulve*. According to phenology, the spring period shows great diversity, as vegetative growth is increased with a greater presence of reproductive organs, while the autumn and winter periods show low diversity throughout the lagoon. For the two stations (4 and 11) have conned of sterility, could be explained by the strong hydrodynamics related (station 4) to the increase in the strength of the currents which, consequently, leads to the removal and/or prevention of the fixation of spores and the installation of young shoots, and at station 11, could be explained by the absence of nutrients which are a limiting factor for the development of the algae (Quaratnta et al 2021).

Numerous studies have shown that the growth and development of algae is mainly related to physico-chemical factors such as light, temperature, pH and enrichment of the medium with nutrient salts and carbonates (Quartino et al. 2005; Yakovleva et al. 2001). Indeed, the growth of most algal species shows seasonal fluctuations due to variations in these environmental factors (Silva and Santos 2003). In spring periode, the chlorophyceae are the most dominant in station 6, this could be due to the environmental factors that interact with them, giving the best conditions for the development and growth of algae, especially water temperature (23.7°C), salinity (38.25 g/l), site oxygen (9.83 mg/l), and nutrients (Aknaif et al. 2017c). In contrast, during the summer period, there is a clear increase in temperature and a decrease in dissolved oxygen content, causing an episodic phenomenon of strong eutrophication (Aissa 1991; Dridi 1977; Dellali and Aissa 1998), caused by the nitrogen and phosphate enriched nutrients in the lagoon (El Madani 2012) which the nitrogen is the limiting factor for the algal growth (Quaranta et al. 2021). This is evidence of the increase in the degree of eutrophication recognised in previous studies (Bloundi et al. 2008), and we have also noticed that when salinity increases, algae become less abundant during the summer period. In autumn and winter have experienced an abundance of rhodophyceae, mainly at the stations (2, 3, 8 and 10), can be explain this diversity, the higher nutritive elements concentrations (Aknaif et al 2017c). While for the fucophyceae, we noticed the dominance of *Cystoseira*, we cite: *C. barbata*, *C. compressa*, *C. crinite*. The species *Cystoseira barbata* (Fig. 3) has not been reported by Gonzalez and Conde (1991); it has been observed in abundance in the deeper areas of the lagoon and the present parts of the substrate. This species is competitive with *Alsidium corallinum* and *Gracilaria sp.*

About rhodophyceae, the order Ceramiale is associated with other species such as *Hypnea musciformis* and *Gigartina acicularis*, as well as with chlorophyceae such as *Enteromorpha* and with Fucophyceae (*Cystoseira*). These species are mainly located in north-east of lagoon (stations 1 and 2). This great diversity of algae is related to the sandy areas and gastropod shell of the lagoon, while the muddy and sandy habitats, dominant in the lagoon (Aknfa et al. 2021), are particularly rich in chlorophyceae: *Chaetomorpha sp.* and *Enteromorph sp.*, *Cladophora sp.* and *Caulerpa prolifera*. This last species is the most dominant among the chlorophyceae, it has been encountered in association with *Zostera noltii* and *Cymodocea nodosa*. They are fixed on muddy and sandy-muddy substrates, the same result was noted

by Najih et al (2016), but rhodophyceae, we have noticed that a few species are fixed on bivalves mainly at stations 3 and 8.

Specific richness of seaweeds in Marchica lagoon were compared with others lagoons (Mar menor, Ghar El Mellah, Venis lagoon and Thau lagoon) in Mediterranean Sea (Table 2). The comparison revealed that the difference observed concerns mainly the algae, since the number of phanerogams varies between 1 and 4, while for the seaweeds; the number of species oscillates between 15 and 323. For the lagoon Marchica the algal poverty comparing with the lagoon of Venice (Italy) and Thau (France) can be explained by the quasi absence of solid substrates (rocks/ gravel) except on the continental border of the lagoon.

Table 2
Comparison of the Floristic richness (NT) of Marchica lagoon with others lagoons in the Mediterranean for Rhodophyceae (Rh), Chlorophyceae (Ch), Fucophyceae (Fu) and Phanerogams (Ph)

Locality	Ch	Rh	Fu	Ph	NT	References
Mar menor-Spain	27	29	19	4	79	Perez-Ruzafa (1990)
Ghar El Mellah- Tunisia	11	0	0	4	15	Romdhane et Chakroun (1986)
Venise (Italy)	84	179	59	1	323	Sfriso et al 2019
Thau-France	42	99	55	1	179	Verlaque, 2001
Marchica lagoon-Morocco	26	29	4	2	61	Present study

The dominant species were a total of 10 species are: *Ulva rigida*, *Ulva fasciata*, *Chaetomorpha area*, *Enteromorpha intestinalis*, *Enteromorpha compressa* and *Caulerpa prolifera* about Chlorophyceae. For Rhodophyceae, *Alsidium corallinum* and *Gracilarea gracilis* and for Fucophyceae, *Cystosiera compressa* and *Cystoseira compressa*. This study indicate that temperature and nutrients played important roles in the variation of distribution of seaweeds in Marchica lagoon.

Declarations

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Conflict of Interest The authors declare no conflict of interest.

Ethical Approval Not applicable.

Sampling and field studies Samples were produced in collaboration with the National Institute of Fisheries Research in Nador.

Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contribution AA was responsible for the planning of the work, sampling and taxonomy, AA, MB and BO, M A, M L, M B and BO, performed the methodology and analysis, and AA and BO had a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Network of Seaweeds sampling sites

Figure 2

Spatial distribution of algae in the Marchica lagoon

Figure 3

Brown algae (Phaeophyta)