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Characteristics of the Oualidia-Sidi Moussa lagoonal complex

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WELCOME TO FSE

Frontiers in Science and Engineering, an International Journal edited by The Hassan II Academy of Science and Technology and part of the new *Hassan II Academy Press*, uses author-supplied PDFs for all online and print publications. The objective of this journal is to provide an exchange platform of high-quality research papers in science and engineering. Instead of a broad spectrum, it is organized in a transparent and straightforward interactive manner so that readers can focus on their direct interests.

All papers are processed through the usual peer-review process; publication criteria are based on:

- Novelty of the problem or methodology and problem-solving,
- Salience of the approach and solution techniques,
- Technical correctness and outputs,
- Clarity and organization.

Papers are first reviewed by the Executive Board Director, who receives the document and, if relevant, and meets the overall requirements, it is then proposed to one of the most appropriate associate editors on the field to select 2 to 3 expert reviewers. Submitting papers in electronic format will save considerable time and reduce the submission period drastically (three to six months). Therefore, authors are invited to submit their contributions for evaluation with the same standards as those used in paper journals. Submission processes are detailed in another section (see the FSE website).

Authors are informed of the acceptance, need for correction, or rejection of the submitted paper. It should be noted that it will not be possible to resubmit rejected articles to the Academy Journal.

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- review articles reflecting the development of science and technology,
- the (partially) publication of the proceedings of the plenary sessions of the Academy or scientific events sponsored by the Academy,
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Papers should contribute to fundamental and applied aspects or original notes indicating a significant discovery or a significant result. The topics of this multidisciplinary journal covers, amongst others: Materials Science, Mathematics, Physics, Chemistry, Computer sciences, Energy, Earth Science, Biology, Biotechnology, Life Sciences, Medical Science, Agriculture, Geosciences, Environment, Water, Engineering, and Complex Systems, Science education, Strategic and economic studies, and all related modeling, simulation and optimization issues, etc.

Once a certain number of papers in a specific thematic is reached, the Academy might edit a special paper issue parallel to an electronic version.

Prof. Dr. Driss OUAZAR
FSE Executive Director

Prof. Dr. Ahmed EL HASSANI
FSE Associate Editor

FORWORD

The Oualidia - Sidi Moussa lagoonal complex, located on the Moroccan Atlantic coast between El Jadida and Safi, is a unique marine natural ecosystem of significant national and international importance with a biological and ecological richness and is recognized worldwide as a Ramsar site. This complex is a veritable "open-air laboratory" for national and international marine scientific research and living sciences. it is the subject of various national and international academic and institutional research. In addition to the scientific work carried out by these different institutions, we should also note the great efforts made by the public authorities to improve the environment of this lagoonal complex.

This special volume is dedicated to this complex and describes its lagoons and coastal marine ecosystem. It is organized into ten separate papers and highlights the recent works on this ecosystem by dealing with various aspects: meteorology, oceanography, chemistry, biology, modeling, morphology, avifauna, bibliometric analysis, management and valuable ecosystem services.

The two lagoons, located in a very active upwelling area during the summer seasons, are under its influence and contributing to their biological and ecological richness. Regarding the meteorological/climatic, oceanographic and pollution aspects, three papers in this volume (hereafter papers 1, 2 & 3 deal respectively: i) with the meteorological and oceanography of the lagoons offshore and their interaction within the lagoons observed between 1958-2019 (more than 60 years); ii) the nutrient assessment of Oualidia waters and iii) the natural and anthropic metals input into the lagoonal complex of the Oualidia-Sidi Moussa and assess their sediment quality by applying the international sediment quality guidelines. Paper 4 focuses on the mid-term (ten years of observation) sedimentation and morphology exchanges of the tidal delta and adjacent beaches in the Oualidia lagoon The water marine circulation inside the Oualidia lagoon (paper 5) is described by a 3D hydrodynamic model which explains the tidal marine functioning of this lagoon. Due to the importance of the RAMSAR site, another contribution (paper 6) focuses on the Sidi Moussa lagoon to determine the composition of the waterbird population that frequents this spot and to define the status of the various encountered species. The biodiversity aspects of the Oualidia lagoon in this volume concern: i) macroalgal communities and seagrass distribution (paper 7) and ii) the spatiotemporal distribution of the endobenthic fauna community (paper 8). Paper 9 presents a synthetic and the evolution of scientific production based upon a bibliometric study from 1974 to May 2021, including aspects such as the progress, trends, and hotspots of coastal research in Oualidia and Sidi Moussa lagoons. Finally and due to the increasing urbanization, agriculture growth, oyster farms demand and tourism trends among other activities, paper 10 focuses on assessment and complex evaluation management components of multi-aspects issues covering social, environmental, economic and policies parts.

This book is an example of the very close cooperation between the experts of the Hassan II Academy of Sciences and Technologies (College of Sciences and Technologies of the Environment, Earth, and Sea). It is also the result of collaboration with several institutes and NGOs (CRMEF, CNESTEN, GREPOM-Birdlife, INRH, ISEM), Moroccan universities (Rabat, Casablanca, Marrakech, El Jadida, Kenitra, Tetouan, Beni Mellal) and, finally, with some Moroccan researchers diaspora settled in Portugal (University of Algarve), Lithuania (University of Klaipeda) and the United Kingdom (Murray Foundation).

Prof. Driss OUAZAR
FSE Executive Director

Prof. Ahmed EL HASSANI
Associate Editor

Dr. Karim HILMI
Guest editor

Long-term offshore meteorological and oceanographic characteristics of the Oualidia-Sidi Moussa lagoonal complex (Morocco) under the period 1958 – 2021

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Abstract. We focused our study on the offshore lagoonal complex of Oualidia-Sidi Moussa at long term period. The seasonal upwelling area influences this area on the Moroccan Atlantic coast with rich marine biodiversity and significant fisheries resources. This lagoon complex's meteorological and oceanographic characteristics have been analyzed monthly between 1958 and 2021, and concern wind, swells, surface water currents, surface ocean water temperature and salinity. We present and discuss the climate interaction between the marine and lagoon environment in this study.

Key words: Moroccan Atlantic coast, Oualidia-Sidi Moussa lagoonal complex, Long-term meteorological and oceanographic characteristics, Upwelling area, Morocco.

1. Introduction

Coastal ecosystems are essential for maintaining human well-being and global biodiversity. These ecosystems provide many benefits and services that contribute to climate regulation, such as erosion protection, hydrological regimes, flood risk reduction, and water purification (SAINTILAN et al. 2018; SUTTON-GRIER & SANDIFER 2019). In addition, the biodiversity richness of these ecosystems plays an essential role in local economies. There are five main lagoons from the Mediterranean to the Atlantic coast in Morocco: Mar Chica and Smir lagoons on the Mediterranean coast and Oualidia, Sidi Moussa, Khnifiss lagoons on the Atlantic coast. Due to their socio-economic importance for the region, many scientific works and projects are (and have been) carried out on these lagoons, some of which are subject to various national and international publications. We focus in this work on the Oualidia-Sidi Moussa lagoonal complex, which is located in the central part of the Moroccan Atlantic coast (Fig. 1). This area, located off the Moroccan Atlantic coast, is under seasonal upwelling, which is very strong in summer, with rich marine biodiversity and important fisheries resources (BENAZZOUZ et al. 2014; BESSA et al. 2021; HILMI et al. 2017, 2020, 2021; MAKAOUI et al. 2005, 2018; ORBI et al. 1998, 2008). The lagoon waters are strongly influenced by upwelling waters and by inland freshwater sources (HILMI et al. 2005, 2009, 2017; ELYAAGOUBI et al. 2022). As a traditional national oyster's site, Oualidia lagoon has been the subject of various studies, targeting:

- Sedimentological & geological aspects: BIDET & CARRUESCO 1982; CARRUESCO 1989; EL KHALIDI et al. 2011; MAANAN et al. 2014 a & b; MEJJAD et al. 2016, 2020 ; SARF 1999);

- Pollution, biogechemical and nutrients aspects: BENMHAMMED et al. 2021; BOUCHRITI et al. 2021; CHAIRA et al. 2021; CHEGGOUR et al. 1999; DAMSIRI et al. 2015, 2017; HASSOU et al. 2014 ;

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Hennani et al. 2012, 2014; Idardar et al. 2008, 2013; Jayed et al. 2015; Laissaoui et al. 2018; Lakhdar et al. 2005 ; Lakhlalki et al. 2020; Maanan et al. 2014, Mejjad et al. 2018; Makaoui et al. 2018, 2020; Zourarah et al. 2007;

- Biodiversity and aquaculture aspects : Bennouna et al. 2002; Chaouti et al. 2019; Doukilo et al. 2021; El Asri et al. 2015, 2021; Kaddioui et al. 2018; Kamara et al. 2005, 2008; Mejjad et al. 2020; Rharbi et al. 2001, 2003; Shafee & Sabatie 1986; Soumoue et al. 2020;

- Environmental vulnerability and socio-economic assessments: Bouchkara et al. 2021; El Mahrad et al. 2020 ; Khoukhouchi et al. 2018 ; Maanan et al. 2018.

- Studies on hydrodynamic aspects are very few comparatively to others topics: Hilmi et al. 2005, 2009, 2017; Koutitonsky et al. 2006, 2007, 2012.

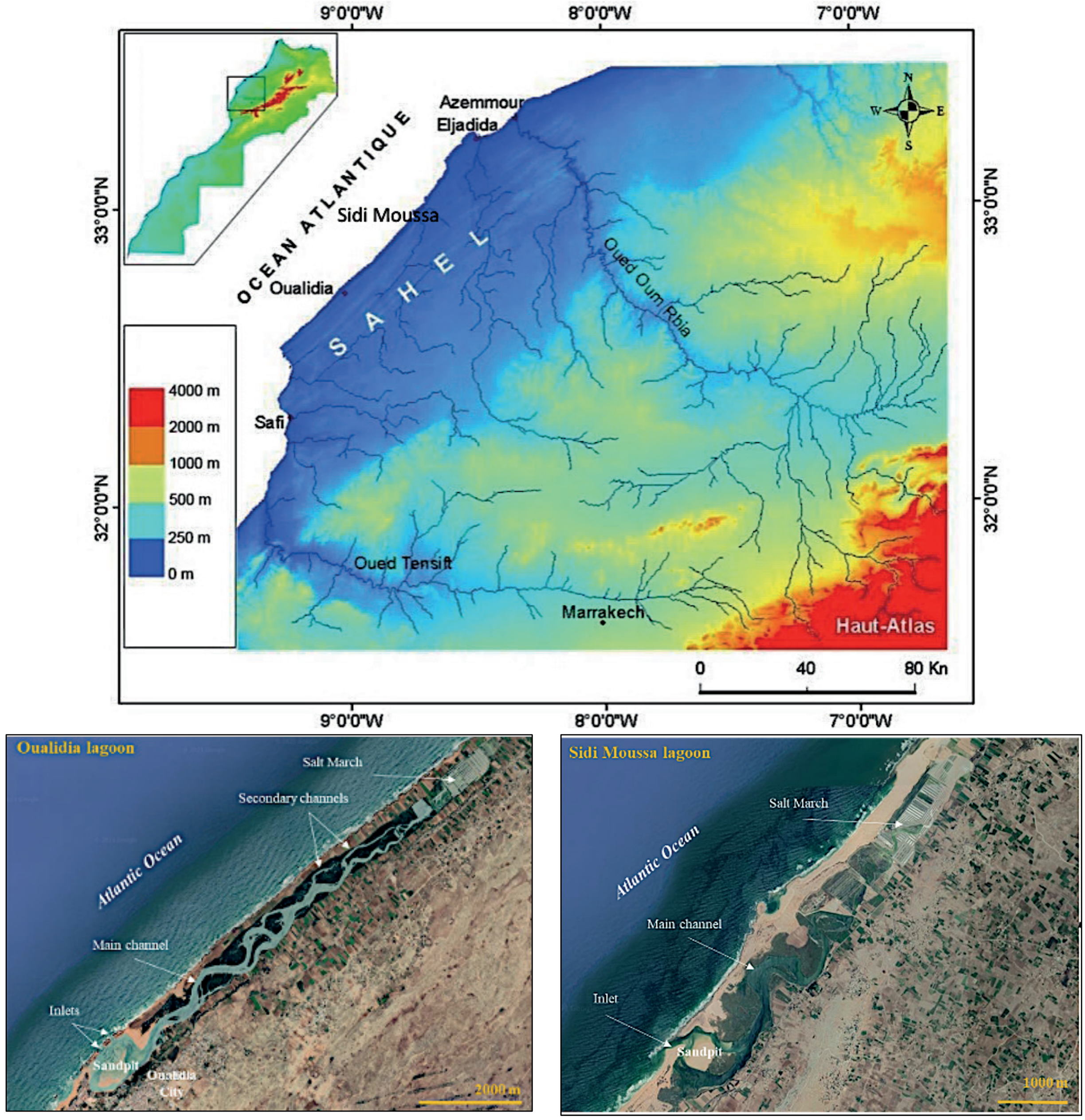

Figure 1: Location of the study area, with satellite photos of the Sidi Moussa lagoon (right) and the Oualidia lagoon (left).

Recent works about the marine circulation and 3D hydrodynamic model in the Oualidia lagoon are presented by ELYAAGOUBI et al. 2022 and BOUCHKARA et al. (this volume). Concerning the Sidi Moussa lagoon, they are very few studies compared to Oualidia lagoon. The main studies in this lagoon concern marine pollution aspects: BENMHAMMED et al. 2021; MAANAN et al. 2004; aquaculture aspects: KADDIOUI et al. 2018; DOUKILO et al. 2021; phenology aspects: JOULAMIE et al. 2013 and geomorphogical aspects (KHOUKHOUCHI et al. 2018).

Generally, most of the studies mentioned above are focused on short and/or medium-term periods in the lagoons. This study is focused on the offshore lagoonal complex of Oualidia-Sidi Moussa at long term period between 1958 – 2021, by analyzing the monthly meteorological and oceanographic parameters governing the climate and the marine aspects of these lagoons (i.e., wind, swell, surface water currents, surface ocean water temperature and salinity). Therefore, our study aims to contribute to understanding the meteorological/oceanographic functioning and the long-term temporal variability and their inter-action inside these lagoons.

2. Material and methods

To meet the needs of this study and to achieve the assigned objectives, we used the monthly mean data coming from Puertos del Estado[1] and the Copernicus Marine European Service[2], namely the meteorological and oceanographic data coming from the Station Punto Simar (Ref 1044032 : 09°W-33°N) located at 15.5 Nautic Miles (around 28.5 km) offshore from Oualidia lagoon and 12.5 Nautic Miles (around 23 km) offshore from Sidi Moussa lagoon. The monthly mean data used from Puertos del Estado concerns the wind parameters (rose and histogram) and swell parameters (rose and histogram of significant weight) since 1958. They are provided from the Iberian Biscay Irish (IBI) Ocean reanalysis (Source CEMS). The IBI Ocean Reanalysis system has provided 3D monthly (and also daily ocean fields and hourly mean values) for some surface variables since 1993. Monthly (and daily averages) of 3D Temperature, Salinity, Mix Layer Depth, Sea Bottom Temperature, Zonal and Meridional Velocity components, and Sea Surface Height are provided. The IBI model numerical core is based on the NEMO v3.6 ocean general circulation model, which runs at 1/12° horizontal resolution. Altimeter data, in situ temperature and vertical salinity profiles, and satellite sea surface temperature are assimilated.

3. Results and discussion

We present in this section the synthesized results for the monthly meteorological and oceanographic parameters (wind, swell, surface current, surface water temperature and salinity) observed under the period 1958-2021 at Punto Simar Station 1044032 (09°W-33°N), located off shore at 15.5 Nautic Miles from Oualidia lagoon and 12.5 Nautic Miles offshore from Sidi Moussa lagoon:

3.1 Wind

Figure 2 shows the characteristics of the wind observed at Punto Simar Offshore Station (Ref 1044032 : 09° W-33° N) under the period 1958-2019, in terms of velocity (Fig. 2a) and direction (Fig. 2b). Concerning the wind velocities (Fig. 2), these intensities are very variable, and their range is between 0.1 m/s (minimum) to 18 m/s (maximum). The most frequent velocities are between 1.5 and 10.5 m/s, their occurrence frequencies are varying between 1% and 8.5%. The weakest intensities (<1.5 m/s) are less than 1% and the strongest (> 10.5 m/s) also less than 1%, between 1.5 and 9.5 m/s (Fig. 2a). Regarding the wind directions (Fig. 2b), the most dominant wind directions are in sectors ENE to NNW. The occurrence frequencies are:

[1] https://www.puertos.es/oceanografia

[2] https://marine.copernicus.eu/

- approximately 10% for winds from the ENE,
- 30% for winds from the NNE,
- between 20 to 25% for winds from the N,
- less than 10% for those from the NNW.

The prevailing winds along the Moroccan Atlantic coast are the Trade Winds, whose origin of depressions corresponds to an atmospheric circulation from the east; the winds blow throughout the year with great regularity (MOUJANE et al. 2011). According to DGM (2021), large-scale circulation at mid-latitudes strongly influences the climate of Morocco, particularly in winter, through the North Atlantic Oscillation (NAO). The climate modulation of Morocco (MELE/DGM 2020) benefits from additional indicators such as ENSO, Mediterranean, and tropical Atlantic SST, Pacific Decadal Oscillation (PDO), Quasi-Biennial Oscillation (QBO), Solar Flux (SF), and Sea Ice Concentration (SIC), as well as Eurasian snow cover (SC). However, according to CARRUESCO (1989), it is generally the trade winds that dominate the Oualidia lagoon. The other wind directions observed at this station and between NNW and WSW areas are highly variable and represent less than 10% in occurrence frequency (Fig. 2b).

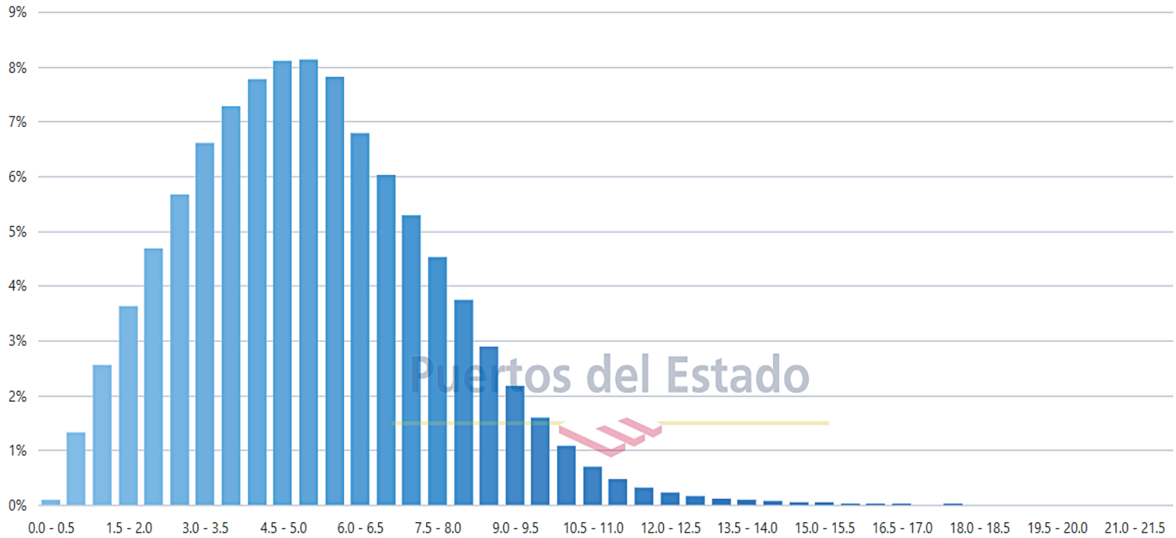

Figure 2-a : Wind intensity at Punto Simar Offshore Station (1958-2016; Source: Puertos del Estado).

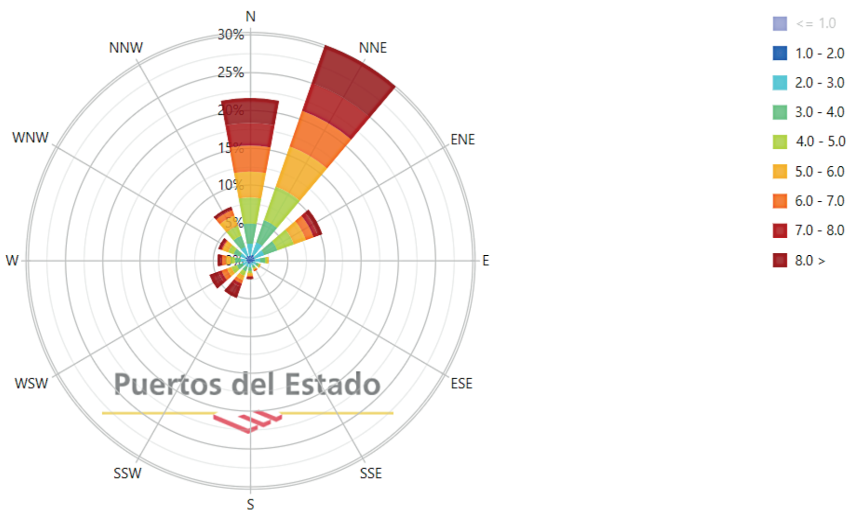

Figure 2-b: Wind direction at Punto Simar Offshore Station (1958-2016; Source: Puertos del Estado).

3.2 Swell

Figure 3 shows the characteristics of the mean offshore swell observed at Punto Simar Offshore Station (Ref 1044032 ; 09 ° W-33 ° N) under the period 1958-2021. The dominant swell directions of this study area are from sectors N, NNW and WNW. Swells from NNW area are dominant and the most frequent (50%), followed by the WNW area (less than 30%) and the N sector (less than 20%) (Fig. 3a). Regarding the mean significant heights, they are varying between 0.1 to 6.5 m. Average heights between 0.5 and 2.5 m represent more than 10%; those between 1 and 2 m are more than 20%. On the other hand, significant heights less than 1 m represent less than 15%, and those greater than or equal to 3m are less than 5% (Fig. 3b).

3.3 Surface current

The averaged seasonal marine surface current along the Moroccan Atlantic coast is represented with variable velocities between the seasons (Fig. 4a). Seawater velocity reaches its maximum in summer, especially near the coast, about 0.3 m/s (BESSA et al. 2021). During the autumn, a weak seawater velocity compared to other seasons is observed. The wind affected the surface seawater velocity speed and direction. The equatorward surface current is developed along the Moroccan Atlantic coast in response to the northward movement of winds. This current leads to the filaments formation that carries cold upwelled water offshore, especially in summer where the wind speed is maximum (BESSA et al. 2021). Concerning our study area, the seawater current surface velocity at Punto Simar Offshore Station under the period 1993-2019 is represented in figure 4b (Source Copernicus Marine Service). For this coastal station area, the average surface current velocity is generally less than 0.1 m/s. Nevertheless, we note specific periods where the average current surface velocity is higher than 0.1 m/s (Fig. 4b and Table 1). It concerns mainly the winter seasons of 1995, 1996, 2009, 2010 and 2013 (Table 1).

Table 1: Maximal seawater current velocity observed (m/s) at Punto Simar Offshore Station (1993-2019 ; Source : Data Copernicus Marine Service):

Month/Year	Surface Current Average Velocity (m/s)
Dec 1995	0.112
Janv 1996	0.162
Dec 1996	0.126
Dec 2009	0.106
Fev 2010	0.162
Dec 2010	0.129
Mars 2013	0.154

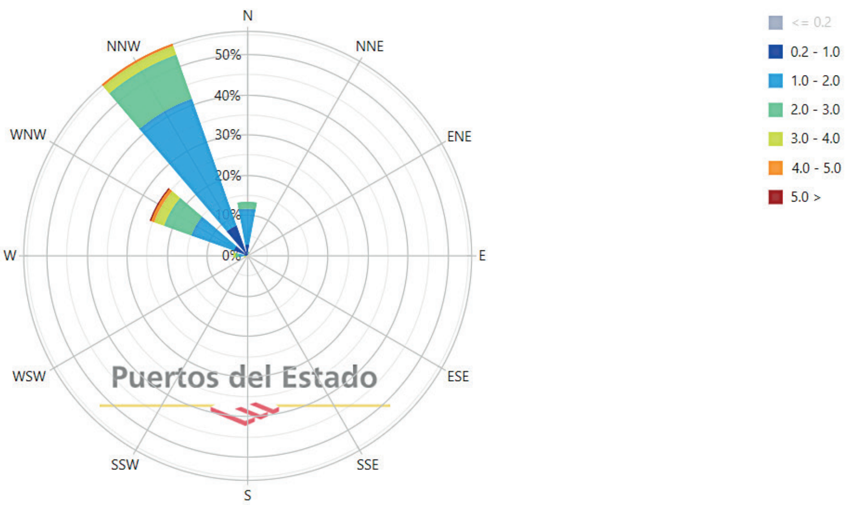

Figure 3-a: Rose swell characteristics at Punto Simar Offshore Station (1958-2016; Source: Puertos del Estado).

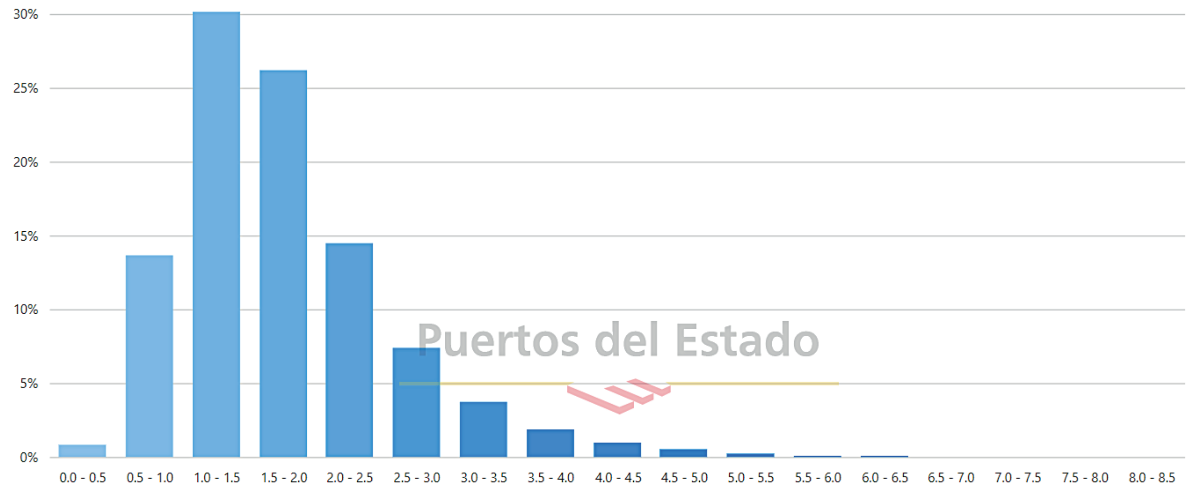

Figure 3-b: Characteristics of the swell significative weight observed at Punto Simar Offshore Station (1958-2016; Source: Puertos del Estado).

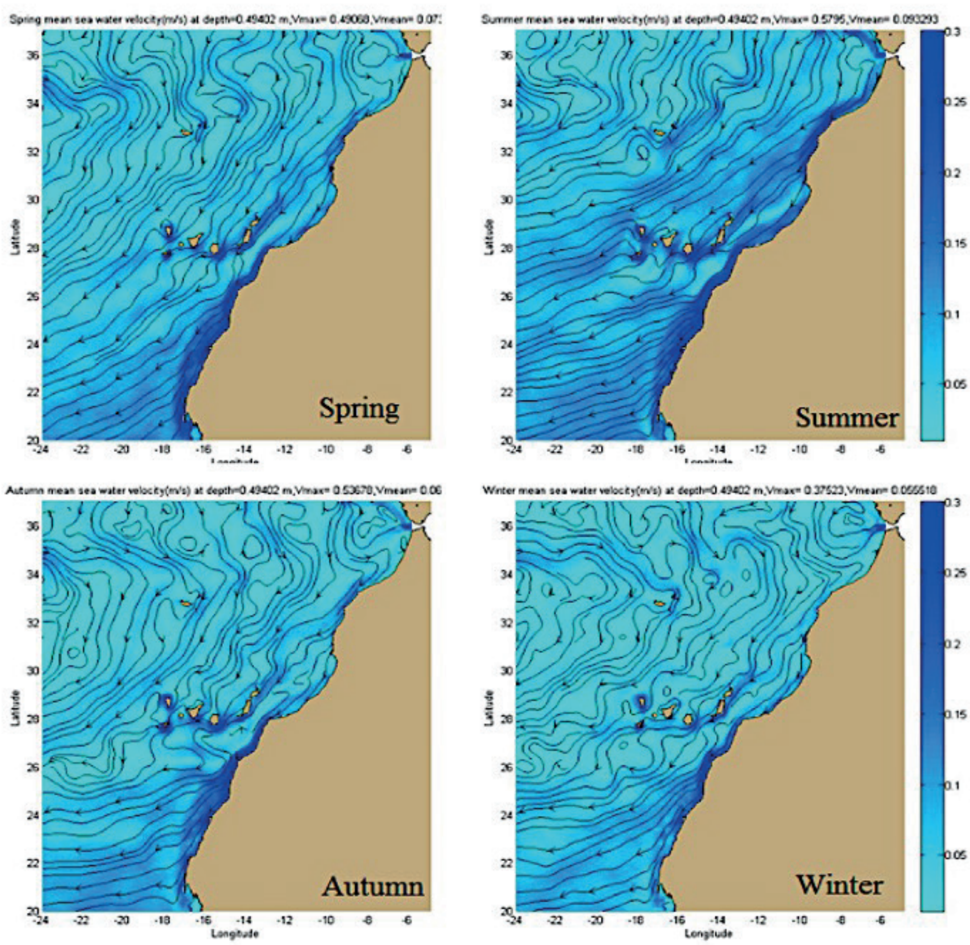

Figure 4-a : Mean seasonal marine surface circulation along the Moroccan Atlantic coast (BESSA et al., 2021).

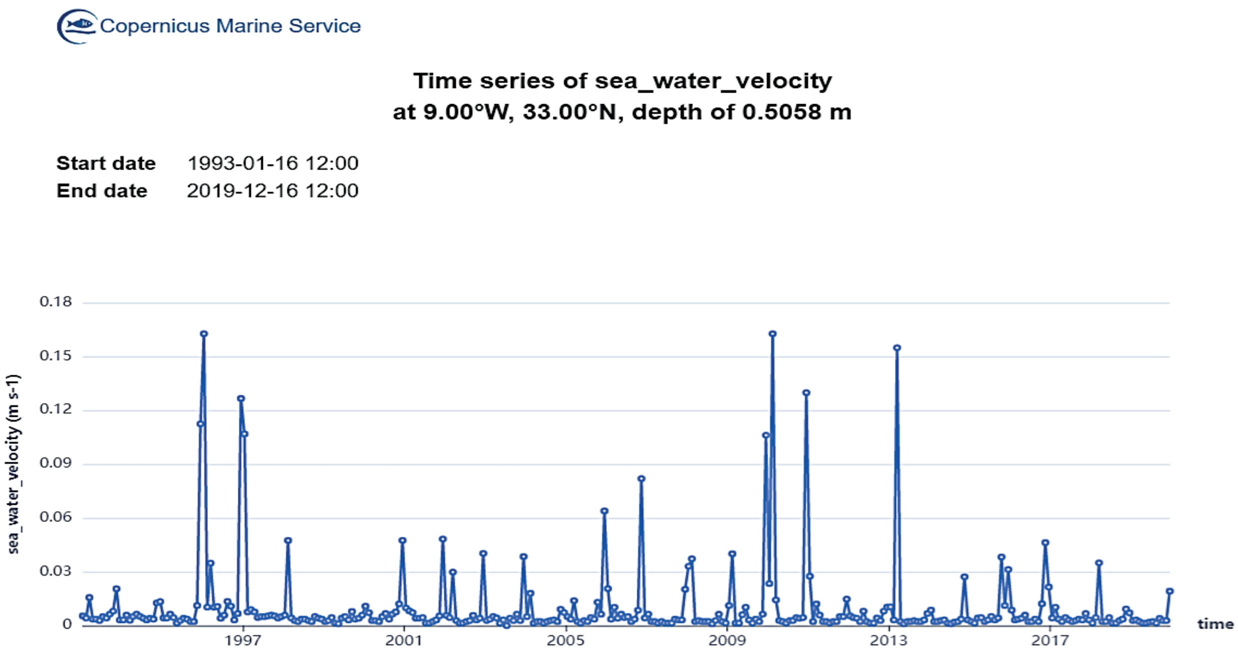

Figure 4-b: Times series of seawater current surface velocity at Punto Simar Offshore Station (1993-2019 period ; Source: Copernicus Marine Service).

Deeper investigations are needed to explain these particular situations. They are very strong currents, inside the lagoons, particularly near the inlets, under the influence of the tides and the tidal currents (HILMI et al. 2005, 2009, 2017 ; ELYAAGOUBI et al. 2021 ; BOUCHKARA et al. this volume).

3.4 Surface Water Temperature and Salinity

The surface water temperature and salinity observed at Punto Simar Offshore Station under the period 1993-2019 are represented in figure 5. The offshore surface water temperature varies between 15°C and 23°C, and they correspond to the seasonal upwelling temperatures in this area (MAKAOUI et al., 2005 & 2018; HILMI et al., 2017, 2020 & 2021). They follow the seasonal cycles, particularly with high values in summer and low values in winter (Fig. 5a). The offshore sea surface water salinity (Fig. 5b) are varying between 35.8 and 36.8 PSU and represent the upwelling salinities in this area. Due to the strong influence of tides and tidal currents inside them, upwelling temperature and salinity strongly influence the water masses of Oualidia and Sidi Moussa lagoons due to the strong effect of tidal currents inside them (HILMI et al., 2005 & 2009; ELYAAGOUBI et al., 2022; KOUTITONSKY et al., 2012). Inside the lagoon, Oualidia lagoon has the particularity to be under the influences and effects of the submarine groundwater discharges, which strongly reduce the temperatures and salinities (HILMI et al., 2005 & 2009; ELYAAGOUBI et al., 2022; MAKAOUI et al., 2020, and this volume).

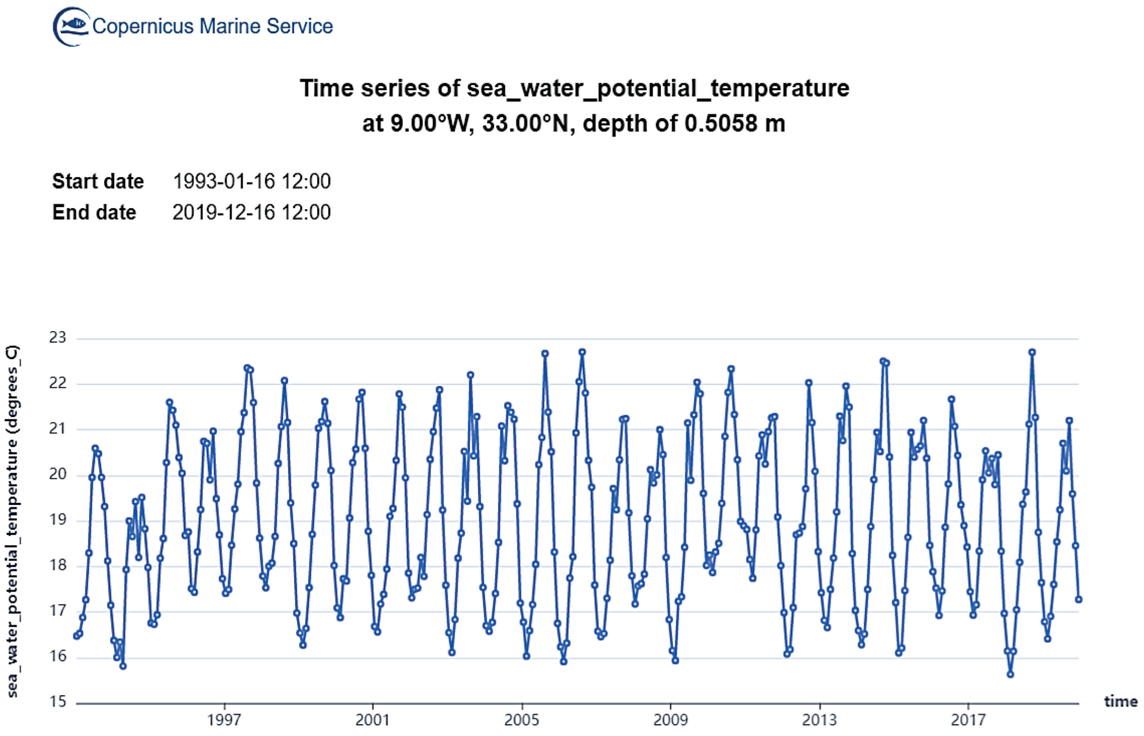

Figure 5-a : Sea Surface temperature (°C) at Punto Simar Offshore Station (1993-2019 period ; Source: Copernicus Marine Service)

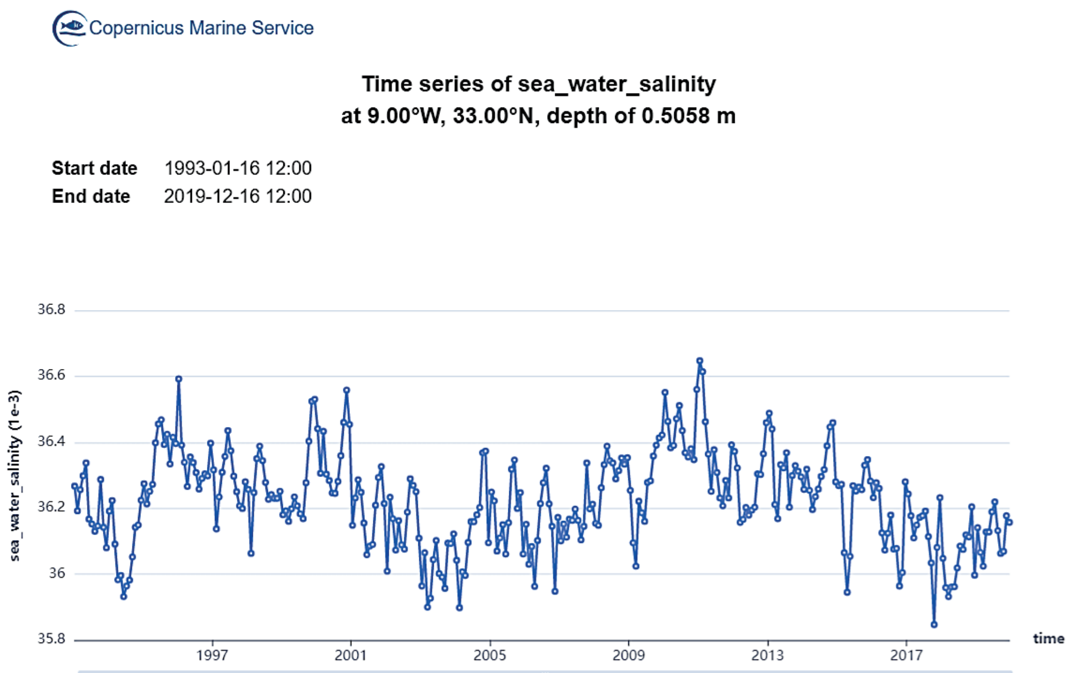

Figure 5-b : Sea Surface Salinity (PSU) at Punto Simar Offshore Station (1993-2019 period ; Source: Copernicus Marine Service).

4. Conclusion

This study focuses on the offshore meteorological and oceanographic parameters analyzed between 1958-2021 on the lagoonal complex of Oualidia-Sidi Moussa. This area is influenced by the seasonal upwelling area on the Moroccan Atlantic coast, with rich marine biodiversity and significant fisheries resources. The monthly average meteorological and oceanographic off shore parameters (i.e. wind, swell, surface water current, sea surface water temperature and sea surface salinity) are analyzed in this work for this period. The results obtained from the wind analysis show that this area is under the influence of the Trade Winds, which is generally the case for the entire Moroccan Atlantic coast and favors seasonal upwelling activities in this area. The upwelling activities (temperature and salinity in particular) affect the water masses in Oualidia/Sidi Moussa lagoons. Submarine groundwater discharges in Oualidia lagoon have a strong impact and change its water masses. The swell observed offshore of the Oualidia-Sidi Moussa lagoon is from NNW sectors which are 50% of frequency, followed by the WNW sector (less than 30%) and N sector (less than 20%). Their mean significant heights vary between 0.1 to 6.5 m. Average heights between 0.5 and 2.5 m represent more than 10%; those between 1 and 2 m are more than 20%. Significant heights less than 1m represent less than 15%, and those greater than or equal to 3m are less than 5%. The offshore averaged surface water currents' velocity is less than 0.3 $m.s^{-1}$ and their direction followed the general circulation on the Moroccan Atlantic coast.

Acknowledgements

The authors wish to thank Copernicus Marine Service and Puertos Del Estado for providing the data as well as to the anonymous reviewers of FSE. This work is dedicated to the memory of INRH colleagues who have worked extensively on Oualidia/Sidi Moussa lagoons: Dr J.I. Lakhdar passed on October 2010 and Mr A Laaouina passed on February 2019.

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Nutrient Assessment in the waters of the Oualidia lagoon, Moroccan Atlantic

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Abstract. The Oualidia lagoon is a shallow, nutrient-poor system that suffers from the expansion of oyster farming and agricultural drainage discharges. From an ecological point of view, this lagoon is probably one of the minor conserved wetlands in the Moroccan Atlantic zone. Therefore, the distribution of nutrients (PO_4^{3-}, NH4+, and NO_2^-) and physicochemical parameters (temperature, dissolved O_2, and salinity) were evaluated during 2011-2012. For this purpose, the monitoring of nutrients in the Oualidia lagoon was carried out in four stations. The first results showed a considerable spatial and temporal variability of the physicochemical parameters. Indeed, nutrients of anthropogenic origin have been transported from agricultural areas to the Oualidia basin. However, these inputs were compensated by water exchanges with the adjacent open sea. These exchanges exerted a dynamic dilution effect and induced a short residence time in the water, thus limiting the enrichment and accumulation of nutrients for long periods. An overview of the previous studies, a comparison, and a hydrochemical characterization were performed to evaluate this work's results and give a general picture of the Moroccan Atlantic lagoons (i.e., Moulay Bousselham, Sidi Moussa, Oualidia, and Khnifiss).

Key words: nutrients, spatio-temporal variation, lagoons, Morocco (Atlantic coast).

1. Introduction

In recent decades, anthropogenic nutrient enrichment has significantly impacted coastal areas such as lagoons, mainly due to increased human activities (LEONE et al., 2020). Coastal lagoons, transitional water bodies located at the continent-ocean interface, constitute ecologic, economic, and social ecosystems (PERILLA et al., 2012; NEWTON et al., 2018).These systems are partially confined and weakly connected to the open sea; on the other hand, they are fed with waters from the watershed. In addition, coastal lagoons are spatially complex environments FIANDRINO et al., 2017). One of the main concerns in these semi-enclosed systems is represented by nutrients enrichment, which often results in water quality deterioration (eutrophication) (HATVANI et al., 2017; SANDONNINI et al., 2021), with consequences for the ecology and biological communities (Nixon et al., 1995; PÉREZ-RUZAFA et al., 2019).

The main source of nutrients is due to human activities occurring inland and in-situ (i.e., agriculture, urbanization, aquaculture : ROSELLI et al., 2009; BOUDOURESQUE et al., 2020). Therefore, knowledge of these elements distribution is important for understanding the ecology and biogeochemistry of these environments. Coastal ecology studies a short and large-scale system that exhibits significant interannual variability. The latter takes into account wind climate (TIESSEN et al., 2014), hydrodynamic effect (HILMI et al., 2017), climate change (BEDNARŠEK et al., 2016; SMERDON, 2017), and finally, habitat destruction and pollution (BIJMA et al., 2013).

To capture this variation in time and space, when possible, present studies rely more on better resolution data and integration over reasonable spatial scales. Data from local field observations can still, however, help in resolving cause-effect relationships. In addition, the spatial distribution uses a smaller sample to make a more precise estimation relative to conventional sampling techniques important in developing countries like Morocco (COCHRAN, 1977; WANG et al., 2013) by taking good spatial variability (HAINING, 2003; WANG et al., 2010) and spatial correlation into account.

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Morocco has four lagoons on the Atlantic coast; Moulay Bousselham, Sidi Moussa, Oualidia, and Khnifiss. This lagoon wealth require special attention for better management of their resources. For example, the Oualidia lagoon (Atlantic coast) is situated between El Jadida and Safi. This lagoon is one of the Moroccan complex sites where oyster aquaculture has been developed in an artisanal way since 1950. Given the importance of the lagoon to the economy and tourism plans, a better understanding of how this ecosystem works is necessary to improve and streamline the management of aquatic resources of this site. Several studies have been conducted in the Oualidia lagoon: biology (BEAUBRUN, 1976 ; CHBICHEB , 1996; DAGHOR et al., 2016 ; NATIJ et al., 2016), hydrology (ORBI et al., 1998; RHARBI et al., 2001), geology (CARRUESCO, 1989; FAKIR, 2001), sedimentology (SARF, 1999), quality and safety (BENNOUNA, 1999; EL ATTAR, 1998), currentology (HILMI et al., 2005; 2017), biogeochemistry (DAMSIRI et al., 2017) and ecological modeling (DAMSIRI et al., 2015).

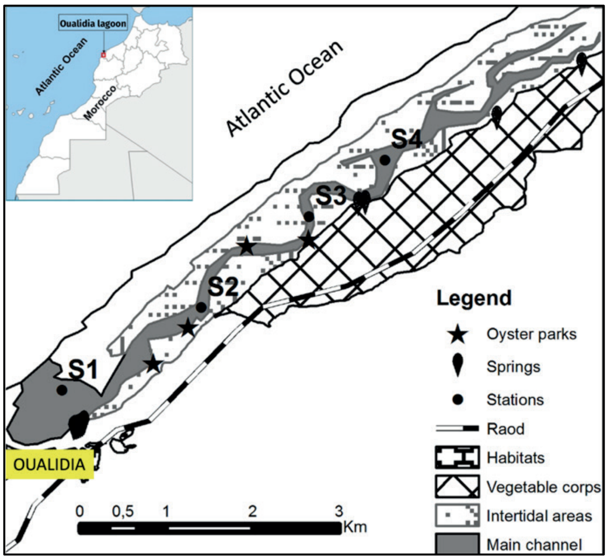


Figure 1: General map of the Oualidia lagoon and the position of the four sampling stations S1 to S4

2. Materials and Methods

The present work aims to study the spatiotemporal distribution of the nutrients and physicochemical parameters in the Oualidia lagoon during two years at four stations. It discusses the most appropriate sampling approaches in specific conditions, dynamic environments, and limited funding. This approach to water sampling may be helpful in other aquatic area research and management. The ideas of this work; is to start by evaluating the nutrient status of the Oualidia lagoon and compare the results with the three other Moroccan Atlantic lagoons.

2.1. Study Site

The Oualidia lagoon is alkaline, shallow, slightly brackish and anthropized (NATIJ et al., 2014; HILMI et al., 2017). The lagoon lies between latitude 32°40′42″N–32°47′07″N and longitude 8°52′30″W–9°02′50″W (Fig.1). It has an irregular elongated shape, with a depth between 0.5 m and 6 m. The deepest part lies at the lagoon entrance and contains two outlets. The tide currents can reach 77 cm/s during spring tides (DAMSIRI et al., 2017). The tidal range varies between 2 m during spring tides and 0.6 m during neap tides. Intertidal areas on both sides of the channels cover about 53% (1.6 km2) of the 3 km2 surface area of the lagoon at low tide (ZOURARAH et al., 2007; HILMI et al., 2017). Flood tides cover more than 75% (2.25 km^2) of the lagoon surface, bringing salt water up to the inner reaches of the lagoon and into a saline marsh beyond the second dam (CARRUESCO, 1989). The biological and ecological importance of this system was demonstrated by its recognition as an international Ramsar site.

2.2. Sampling and analytical methods in Oualidia lagoon

Twenty-four sampling surveys were carried out during the spring and summer periods of 2011 and 2012, along with the Oualidia lagoon at high tide. Water samples were collected from the first 10 cm of surface water for nutrient analysis, and physicochemical parameters were measured in-situ. In addition, four stations were selected in the Oualidia lagoon, from the downstream sea side (station: S1) to the upstream land side (station: S4), to determine the spatiotemporal variability of physicochemical parameters, as well as the gradient and influence of several human activities, such as oyster aquaculture and agriculture (Fig. 1).

The physicochemical parameters: temperature, dissolved O_2, and salinity were measured using a calibrated multiparametric probe Multi340i (wtw82362 Weilheim). Water samples were collected in triplicate using 1-liter HD-PE plastic bottles for nutrient analysis. Water samples were stored at 4°C, brought to the laboratory, and rapidly analyzed within 48 hrs. Water samples were filtered using a Millipore system with fiberglass Whatman GF/C filters of 47 mm diameter and 0.45µm porosity. The filtration is essential to eliminate any suspended matters that are susceptible to absorb light during the colorimetric analysis. It also allows for modifying the chemical composition of the analyzed solution. In addition, nutrient concentrations (ammonium, nitrite and orthophosphate) were determined by colorimetric approach. The latter uses a spectrometer (BIOMATE 3) according to the standard method AFNOR[1] (P: NF T 90-023, NO_2^- NF T90-013 and NH_4^+: NF T90-015) (AFNOR, 1983). Specifying the triplicate measurements were performed on each sample for each nutrient.

2.3. Cartography

The data processing allowed the calculation of seasonal and annual averages and maximum and minimum values. In addition, the contour maps created by operating ArcGIS (version 10.x, Esri), which used yearly averages, allowed the characterization of the physicochemical parameters variability and nutrient concentrations in the lagoon surface waters.

3. Results

3.1. State of the art of the study rate of Moroccan lagoons on the Atlantic coast

A bibliographic synthesis was carried out to determine the importance of Moroccan lagoons in ecological, economic, and tourism terms. Indeed, the comparative bibliographic synopsis of the Moroccan Atlantic lagoons has shown that the most studied fields are biology and geology. In addition, a few studies concerned the hydrodynamic, chemical, ecological, and biogeochemical areas. Finally, we note the absence of a complete nutrient balance in this bibliographic synthesis (Fig. 2).

3.2. Measurement

3.2.1. Seasonal distribution

3.2.1.1. Physicochemical water quality parameters

Distribution of surface water temperature in spring-summer 2011 in the Oualidia lagoon showed a minimum of 16°C for station S1 (downstream) in spring and a maximum of 25°C for station S4 (upstream) in spring (Fig. 3-A, A'), with an average of 20.02°C (Table 1).

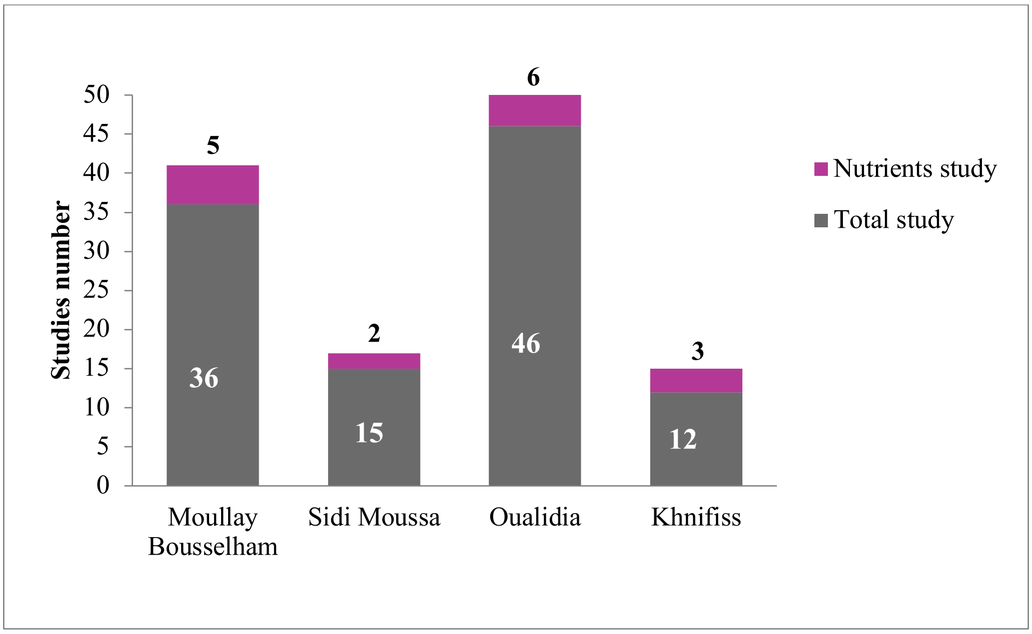


Figure 2: Number of studies of the Moroccan Atlantic coast lagoons (1930 - 2020).

[1]Association Française de NORmalisation

In spring-summer 2012, the surface water temperature varied between a minimum of 10.5°C for station S2 (downstream) in spring and a maximum of 24.1°C for station S4 (upstream) in summer (Fig. 3-B, B'), and the average value being 18.4°C (Table 1). Salinity showed a seasonal trend in 2011, varying between 22.5 g/l for station S4 (upstream) in summer and 35.9 g/l for station S1 (downstream) in spring (Fig. 3-C, C'), with an average of 33.22 g/l (Table 1). In spring-summer 2012, the surface water salinity varied between 24.4 g/l for station S4 (upstream) in spring and 36.3 g/l for station S3 (downstream) in spring, the average value being 32.6 g/l (Fig. 3-D,D'; Table 1). The Oualidia lagoon surface water was well oxygenated in 2011, with a minimum value of 5.81 mg/l in summer and a maximum weight of 13.17 mg/l in spring for station S4 (upstream) (Fig. 3-E, E') with an average of 9.88 mg/l (Table 1). In spring-summer 2012,the surface water dissolved O_2 varied between a minimum of 7.2mg/l in spring for station S1 and a maximum11.1 mg/l for station S4 (Fig. 3-F, F'), the average value being 8.77 mg/l (Table 1).

3.2.1.2. Nutrients concentrations

Surface water PO_4^{3-} concentrations varied in the Oualidia lagoon in spring-summer 2011 from a minimum of 0.7 µmol/l in spring for station S1 (downstream) to a maximum of 88.5 µmol/l in summer for station S1 (upstream) (Fig. 3-G,G'), the average value being 18.97 $\mu mol.l^{-1}$ (Table 1). In spring-summer 2012, surface water PO_4^{3-} concentrations fluctuated between a minimum of 0.1 $\mu mol.l^{-1}$in spring for station S1 (downstream) and a maximum of 79.2 $\mu mol.l^{-1}$ in summer for station S1 (upstream) (Fig. 3-H, H'), the average value being 20.67 µmol/l (Table 1).

NO^{2-} surface water concentrations varied in spring-summer 2011 from a minimum of 0.07 µmol/l in spring for station S1 (downstream) to a maximum of 18.4 µmol/l in summer for station S4 (upstream) (Fig. 3- I, I'), the average value being 3.65 µmol/l (Table 1). In spring-summer 2012,water surface NO^{2-} concentrations fluctuated between a minimum of 0.1 µmol/l in spring for station S2 and a maximum of 17.8 µmol/l in summer for station S4 (Fig. 3-J, J'), the average value being 20.67 µmol/l (Table 1).

NH_4^+ surface water concentrations varied in 2011 between a minimum of 0.1 µmol/l in spring for station S1 (downstream) and a maximum of 75.56 µmol/l in summer for station S3 (upstream) (Fig. 3-K, K'), the average value being 14.62 µmol/l (Table 1). In spring-summer 2012, the lowest NH_4^+ concentration of 0.2 µmol/l was recorded in summer for station S3 (upstream) and the highest one of 100.3 µmol/l in spring for station S4 (upstream) (Fig. 3-L, L'), the average value being 30.23 µmol/l (Table 1).

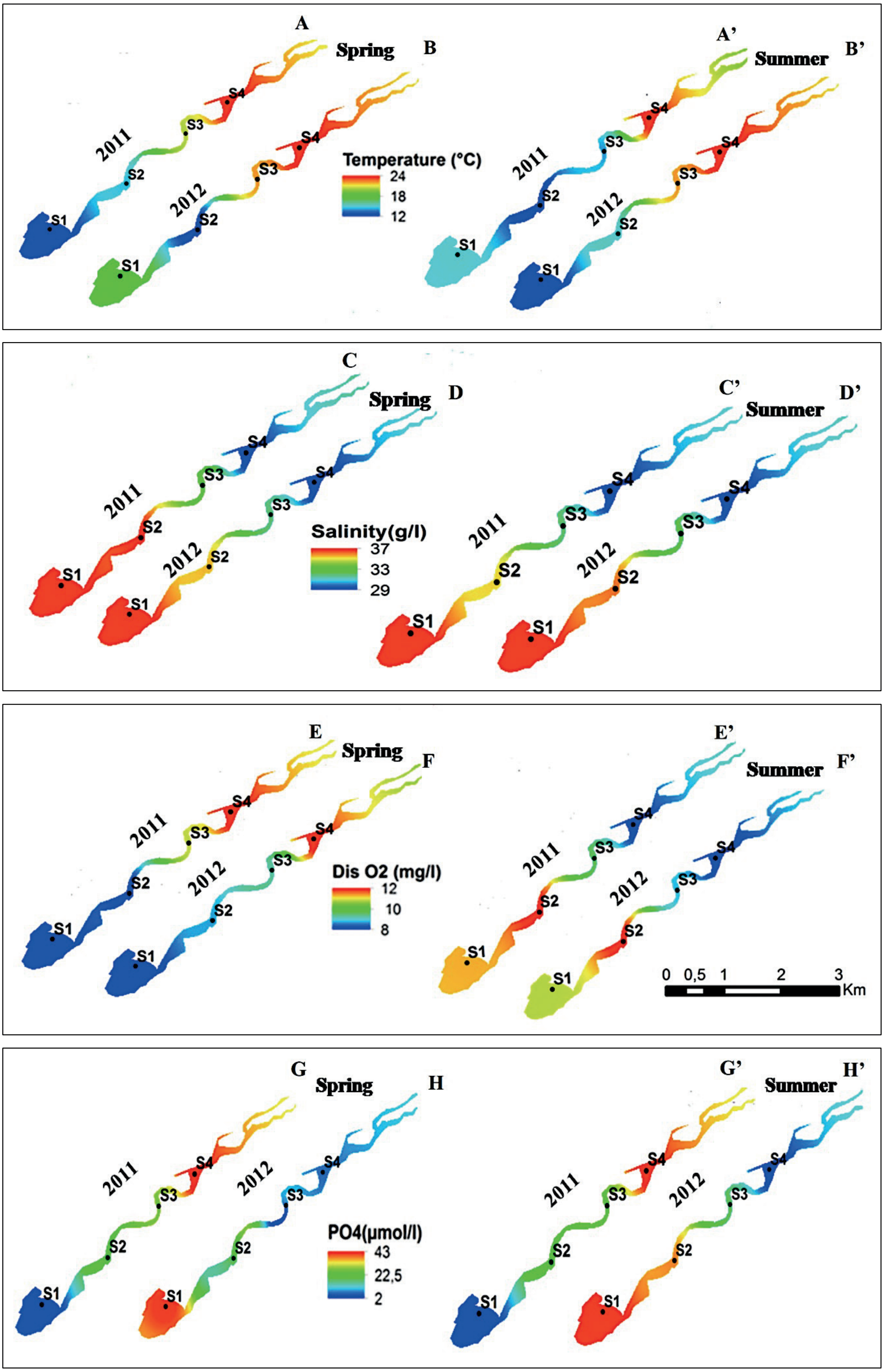
3.2.1.3. Annual Distribution of physico-chemical parameters and nutrients water

The surface water temperature in the Oualidia lagoon decreased from upstream (S4) to downstream (S1) and was higher in 2011 compared to 2012 (Fig.4-A). The surface water salinity in the Oualidia lagoon increased from upstream to downstream (Fig.4-B) and was higher in spring 2011 than in 2012 and inversely during summer. The surface water dissolved O_2 in the Oualidia lagoon increased from upstream to downstream in summer and decreased in spring (Fig.4-C).

In 2011 dissolved O_2 levels were higher than those recorded in 2012 (Fig.4- C). Surface water PO_4^{3-} concentrations recorded in spring-summer 2011 were higher than in 2012 (Fig.4-D). A decreasing gradient from upstream to downstream was recorded for that nutrient PO_4^{3-} (Fig.4-D). NO_2^- concentrations were higher in 2012 than in 2011 (Fig.4-E). In addition, a decreasing gradient from upstream to downstream was recorded for that nutrient (Fig.4-E). NH_4^+ concentrations were higher in 2012 than in 2011 (Fig.4-F). The lagoon surface water NH_4^+ concentration decreased from upstream to downstream (Fig.4-F).

Table 1: Seasonal variability of physicochemical parameters and nutrients of surface water of the Oualidia lagoon for spring-summer 2011 and 2012

		Spring-Summer 2011						Spring-Summer 2012					
Parameters	Sites	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Temperature	**Mean**	18,2	18,8	19,8	20,2	21	21,85	16,4	16,95	17,95	18,95	20,05	20,4
	Median	19,65	18,2	19,15	19,9	20,55	21,15	16,4	16,95	17,95	18,95	20,05	20,4
	Min	18,7	17,7	18,9	19,6	20,3	20,6	16,2	16,5	17,1	17,4	18,1	18,6
	Max	20,6	18,7	19,4	20,2	20,8	21,7	16,6	17,4	18,8	20,5	22	22,2
	Total Average	**19,9**						**18,4**					
Salinity	**Mean**	34,5	33,7	33,2	32	30,8	29,4	35,6	35,1	34,2	32,75	31,05	29,45
	Median	34,5	33,7	33,2	32	30,8	29,4	35,6	35,1	34,2	32,75	31,05	29,45
	Min	34,5	33,7	33,2	32	30,8	29,4	35,1	34,9	34,1	32,7	30,8	29,2
	Max	34,5	33,7	33,2	32	30,8	29,4	35,3	34,9	34,1	32,8	31,3	35,1
	Total average	**32,3**						**33,0**					
Dissolved O_2	**Mean**	9,735	9,66	9,99	10,205	10,225	10,335	8,655	8,705	8,845	8,875	8,57	8,98
	Median	9,735	9,66	9,99	10,205	10,225	10,335	8,655	8,705	8,845	8,875	8,57	8,98
	Min	9,37	9,44	9,58	9,11	9	8,75	8,29	8,36	8,52	8,81	8,32	8,82
	Max	10,1	9,88	10,4	11,3	11,45	11,92	9,02	9,05	9,17	8,94	8,82	9,14
	Total average	**10,02**						**8,77**					
PO_4^{3-}	**Mean**	17,6765	20,396	20,461	21,0745	20,057	22,8525	23,8825	19,0695	23,009	17,9305	18,3535	17,458
	Median	17,6765	20,396	20,461	21,0745	20,057	22,8525	23,8825	19,0695	23,009	17,9305	18,3535	17,458
	Min	2,166	2,865	2,604	2,766	2,903	3,183	22,48	18,694	21,678	15,363	17,492	16,734
	Max	33,187	37,927	38,318	39,383	37,211	42,522	25,285	19,445	24,34	20,498	19,215	18,182
	Total average	**20,42**						**19,95**					
NO_2^-	**Mean**	3,496	3,179	3,788	3,9485	3,728	4,129	6,124	8,624	6,877	9,0215	7,4355	7,7505
	Median	3,496	3,179	3,788	3,9485	3,728	4,129	6,124	8,624	6,877	9,0215	7,4355	7,7505
	Min	0,065	0,13	0,215	0,196	0,518	0,594	5,833	6,502	6,625	7,608	7,363	7,679
	Max	6,927	6,228	7,361	7,701	6,938	7,664	6,415	10,746	7,129	10,435	7,508	7,822
	Total average	**3,71**						**7,64**					
NH_4^+	**Mean**	14,9925	10,7635	15,3145	15,376	14,843	15,373	30,894	28,454	29,74	29,797	30,137	30,9935
	Median	14,9925	10,7635	15,3145	15,376	14,843	15,373	30,894	28,454	29,74	29,797	30,137	30,9935
	Min	2,839	2,725	3,063	3,044	2,756	2,788	25,708	21,354	23,292	23,094	23,604	24,719
	Max	27,146	18,802	27,566	27,708	26,93	27,958	36,08	35,554	36,188	36,5	36,67	37,268
	Total average	**14,44**						**30,00**					


A
Spring
B
A'
Summer
B'
2011
2012
S1
S2
S3
S4
Temperature (°C)
24
18
12
C
Spring
D
C'
Summer
D'
Salinity(g/l)
37
33
29
E
Spring
F
E'
Summer
F'
Dis O2 (mg/l)
12
10
8
0 0,5 1 2 3
Km
G
Spring
H
G'
Summer
H'
PO4(µmol/l)
43
22,5
2

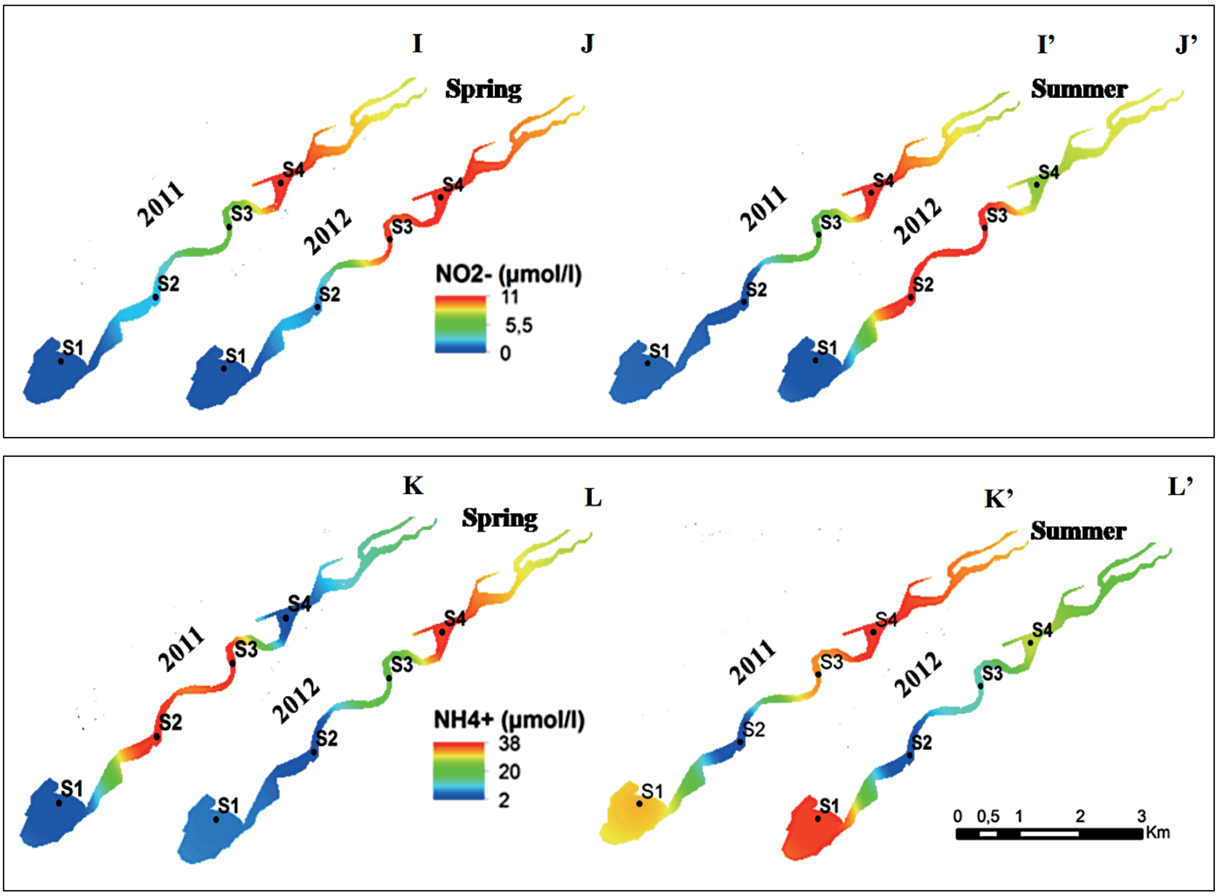


Figure 3: Fortnightly variation of mean temperature ((A, A'); (B, B')), Salinity ((C, C'); (D, D')), dissolved O_2 ((E, E'); (F, F')), PO_4^{3-} ((G, G'); (H, H')), NO_2^- ((I, I'; (J, J')) and NH_4^+ ((K, K'); L, L')) monitored in surface water at four stations (S1 to S4) of the Oualidia lagoon (Atlantic Coast, northwestern Morocco) during spring – summer 2011 and 2012.

4. Discussion

The Oualidia lagoon water temperature ranges were between 16 - 25°C during spring-summer 2011 and 2012. That observation was consistent with previous studies on this lagoon (BENNOUNA, 1999; CHBICHEB, 1996; DAMSIRI, 2015; EL ATTAR, 1988; OULDESSAIB, 1997; NATIJ et al., 2014; DAGHOR et al., 2016). temperature variability could be explained by the ocean and atmospheric temperature (12°C in winter and 24°C in summer) (HILMI et al., 2017; SHAFEE et al., 1986) on the freshwater feeding the lagoon. The present study showed a gradual rise in temperature from spring to summer. That seasonal increase in temperature could explain the phytoplankton blooms observed in spring (NATIJ et al., 2014).The higher surface water temperature recorded in upstream stations could be explained by the inflow of warmer freshwater (ASHA et al., 2007; DAMSIRI et al., 2017; HILMI et al., 2017). The rapid temperature decrease recorded throughout the lagoon at the beginning of the survey in May and late June 2011 can be explained by the dredging of a defile and installation of pumping equipment and pressure at sea (part of Oualidia Halieutis project; 2011-2020).

The oceanic influence on the surface water's lower temperature was noticed throughout the lagoon and especially near the passes (downstream) due to the importance of water exchanges between the lagoon and the coastal ocean. Indeed, the important renewal of water in the Oualidia lagoon at each tidal cycle (RHARBI et al., 2001) influences the temperature regime and salinity (ELHIMER, 2011).

A homogeneous salinity rate can explain the salinity variability in the Oualidia lagoon during rising tides where the values are similar to those of the ocean.

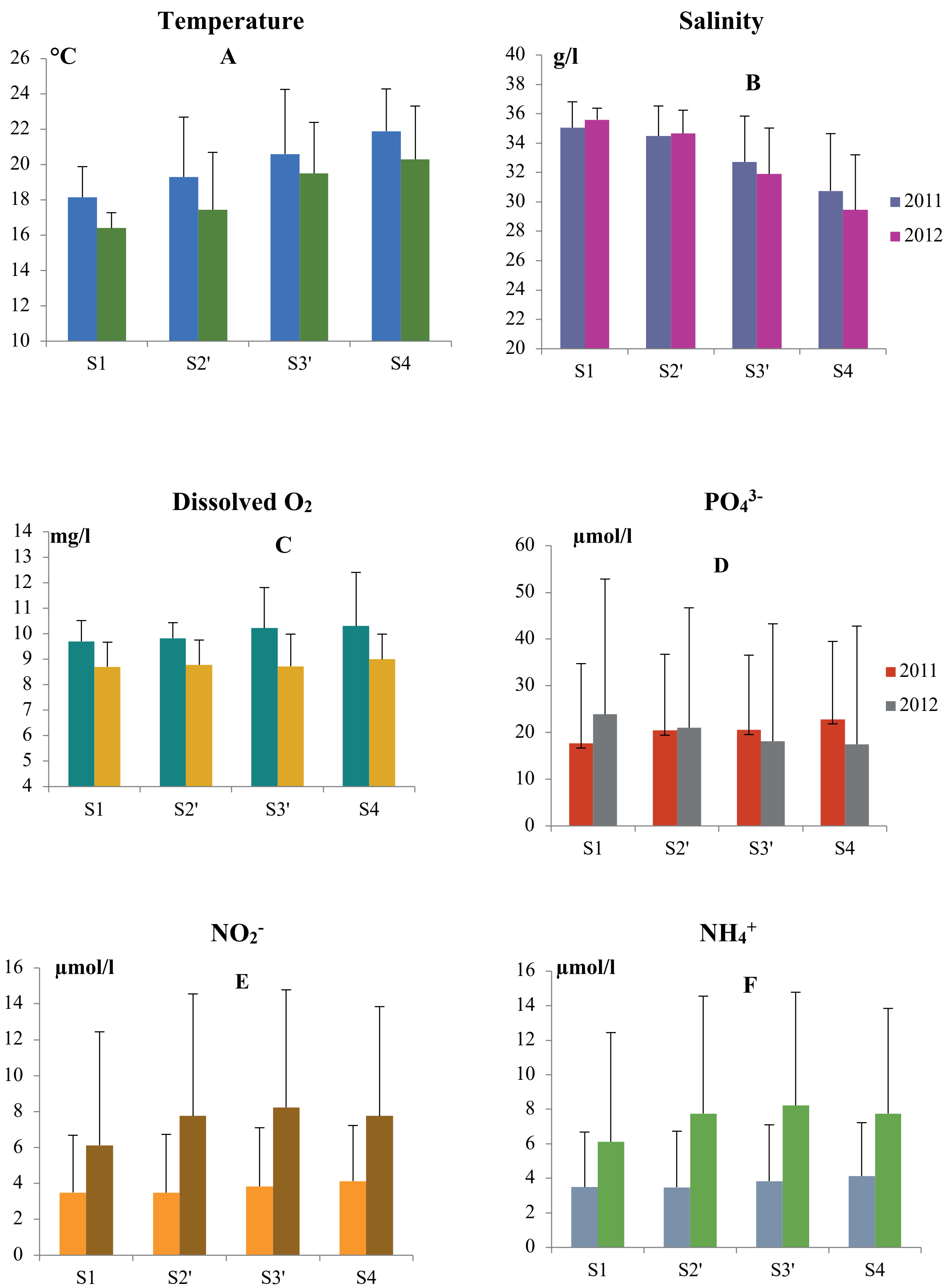


Figure 4: Seasonal mean values of temperature, salinity, dissolved O_2, PO_4^{3-}, NO_2^- and NH_4^+monitored in surface water at four stations (S1 to S4) of the Oualidia lagoon (Atlantic coast, northwestern Morocco) during Spring-Summer 2011 and 2012.

The freshwater (28% of inputs of continental waters) that permanently flows into the upstream part of the lagoon (ELHIMER, 2011) can influence the general salinity of the lagoon surface water by decreasing its salinity. Studies conducted by (CREMER et al., 2007) showed similarities with our results.

Globally, surface water agitation, upstream freshwater inflow, and the low bathymetry of the Oualidia lagoon are the possible indicators that contributing to the good oxygenation of the water body (ELHIMER, 2011; HILMI et al., 2017). Our study's analysis of dissolved O_2 revealed a subdivision of the Oualidia lagoon into two distinct parts in spring: a less oxygenated zone downstream (S1, S2) and a more oxygenated one upstream (S3, S4). That spring gradient was inversed in summer. These results were compatible with previous works on the lagoon (BENNOUNA, 1999; DAMSIRI et al., 2017) and could be explained by the influence of oceanic surface water. Indeed, downstream dissolved O_2 levels were similar to those measured in the open ocean. The higher values of dissolved O_2 estimated upstream, they resulted from the spring phytoplankton bloom (NATIJ et al., 2014).The dissolved O_2 values gradually decreased post-bloom period, probably due to the increased organisms' respiration (i.e., organic matter degradation by aerobic heterotrophic bacteria), and the summer water temperature increased the dissolution of O_2 limits.

The present study measured PO_4^{3-} concentrations higher than those recorded for NO_2^- and NH_4^+. This finding could confirm the influence of oceanic water, which is the main source of phosphate for coastal waters. The higher PO_4^{3-} values and the low dissolved O_2 concentrations reported during summer could be related to reduce primary production rates. The higher concentration of nutrients is due to the influence of muddy sediment in the lagoon's shallow depth (BARBANTIA et al., 1992).. Moreover, leaching agriculture areas, which are rich in phosphate fertilizers, and phosphate mines between the two Moroccan cities El Jadida and Safi (KAIMOUSSI et al., 2001) potentially, contribute to the water quality of the interior part of the lagoon. PO_4^{3-} enrichments of surface waters noted in Oualidia lagoon were higher than those recorded in other lagoons (Table 2) (BADSI et al., 2010; TRAORE et al., 2012).

The results analysis of this study clearly showed higher maximum nitrogen concentration in the Oualidia lagoon compared with other coastal waters (BADSI et al., 2010; TRAORE et al., 2012; Table 2), although relative scarcity of these elements near the lagoon passes during the study period were noticed. The spatial variation of NO_2^- could be explained by an important sediment-water exchange in the downstream lagoon. This feature disadvantages nitrifying bacteria's residence time and causes nitrification inhibition (SARF, 1999). This is particularly the case in the upstream lagoon, characterized by lower depth and further influenced by continental inputs (fertilizers, mudflat, etc.). On the other hand, the lowest value of NO_2^- was recorded downstream, which can be caused by a freshwater runoff between S1 and S2 (34 springs) (DAMSIRI et al., 2017; ELHIMER, 2011), which makes dilution of the seawater.

The seasonal variation showed that the highest NO_2^- values observed in summer might be controlled by phytoplankton and zooplankton excretion.

Recorded higher concentrations of NH_4^+ could be partially due to the death and subsequent phytoplankton decomposition and the ammonia excretion by planktonic organisms (SEGAR & HARIHARAN, 1989). Our results remain close to those registered in Nador lagoon (DAOUDI et al., 2013). The nutrient concentrations recorded in this work show a significant increase from the summer of 2011. That increase could be explained by sediment resuspension (DE CASABIANCA et al., 1997) by the Oualidia Halieutis project activities from May 2011 (dredging of a defile and installation of pumping equipment and wastewater treatment).

The data analysis results show low inter-stations (S1 to S4) hydrological parameters and nutrient concentration variability. Different water masses are mixed by the lagoon dynamics, which probably prevents the vertical stratification establishment (although not monitored) and lead to the observed upstream-downstream decreasing gradient of the investigated variables. Unlike the spatial variation, the measured parameters showed significant seasonal variations. Our results showed that the Oualidia lagoon waters could be split into two ecological entities: Zone 1, represented by stations S1 and S2, marked by oceanic influence, and zone 2, defined by stations S3and S4, influenced by the freshwater resurgence and by anthropogenic activities.

Integration of continuous nutrient evaluation to our data monitoring system operating in the lagoon offers an improved design to facilitate a comprehensive analysis of trends and patterns in space and time. In addition, they help estimate nutrient dynamics and primary and secondary production and assess C, N, and P fluxes associated with biogeochemical cycling and toxicant transport.

5. Conclusion

The higher nutrient concentration of Oualidia lagoon surface water recorded from the summer of 2011 was due to increasing human activities (intense agricultural, fishing, and tourism activities. Spatial sampling is to sample a target population, drawing several sample units from the geographically distributed target and then using the sample to infer the properties of the target. The present study showed clearly that the lagoon dynamics mixed different water masses, preventing the establishment of vertical stratification and, in the same way, decreasing the upstream-downstream gradient. Unfortunately, appropriate sampling approaches have rarely been documented on the African Atlantic coast. The results presented in this study provide a good example of sampling techniques and lagoon ecological study in Morocco. It provided simple information on the spatial and seasonal changes of water quality parameters in a coastal area (the Oualidia lagoon).

The present study shows a richness of nutrients in the Oualidia lagoon, with seasonal and low spatial variability. Our results indicate that this lagoon is an attractive aquatic system but can be weakened by over-exploitation.This system needs further study and a scientific management plan to avoid its environmental degradation. It will help to prevent drastic and potentially irreversible changes to the ecological character of the lagoon. It is a question of temporal trends in nutrient (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, and Si) and biological (phytoplankton and zooplankton) dynamics should be continuously monitored.

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Time-tracking of the natural and anthropogenic metals input into the Oualidia-Sidi Moussa lagoonal complex, Morocco

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Abstract. The present work aims to track the natural and anthropogenic metals input into the lagoonal complex of the Oualidia-Sidi Moussa and assess their sediment quality by applying the International sediment quality guidelines. We compared the concentrations of metals (Cu, Cr, As, Zn, Ni and Pb) measured in the sediment of the lagoonal complex of the Oualidia-Sidi Moussa between 1976 and 2017 with a range of sediments quality guidelines values. The comparison showed a decreasing trend of metals concentration in the last decade in the Oualidia lagoon except for As, Cr and Cd. Similarly, Cd and Cr displayed higher concentrations exceeding the threshold effect level values signifying possible toxic risk for marine biota living in the Sidi Moussa lagoon.

Keywords: Oualidia lagoon, Sidi Moussa lagoon, sediment, S.Q.G., pollution assessment.

1. Introduction

Coastal lagoons are vital and productive ecosystems which provide many services, goods and resources to human welfare. The biodiversity richness of these ecosystems plays an important role in local economies. Nevertheless, the growth of human activities in these ecosystems negatively impacts these ecosystems' environmental health.

Many studies on the coastal lagoon were carried out, which were mainly focused on their biology (MEJJAD et al., 2020A; MONIQUE et al., 2021), morphology (JAUBET et al., 2021; BRUNEAU et al., 2011, ZONTA et al., 2007), hydrology (BEHRENS et al., 2015; ELSHINNAWY et al., 2021) and ecological classification. Whereas, in the last two decades, almost all studies are focused on evaluating the pollution levels and the potential effect of human activities growth on such ecosystems environment (MEJJAD et al., 2020A; 2020B; 2018) and discussed the need for implementing management projects, policies and strategies allowing better governance and resilience for conserving and protecting these vital environments (EL MAHRAD et al., 2020).

Morocco houses five lagoons from the North to the South (Nador lagoon, Moulay Bousselham Lagoon, Oualidia lagoon, Sidi Moussa lagoon, and Khnifis lagoon). These lagoons present many services and goods to the population, especially aquaculture (in Oualidia, Khnifis), tourism, fishing, and agriculture. Moreover, the increase in human activities around such ecosystems has negatively influenced their environmental quality.

The Oualidia-Sidi Moussa lagoon complex, located in the central part of the Moroccan Atlantic coast, has a valuable and rich landscape.

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Due to their ecological and cultural interest, the lagoonal complex was designed as a protected area by the Ramsar Convention (Ramsar site no. 1474.). In addition, the site is classified as a Permanent Hunting Reserve and was recognized as a priority 1 S.I.B.E. (No. L24). The complex hosts' different habitats of international interest for birds' (DAKKI et al., 1998), especially limicolous birds or warders (JOULAMI, 2013). According to BirdLife International (BIRDLIFE INTERNATIONAL, 2021), the complex is an important wintering site and passage for Palearctic migrants, while about 80 species have been registered, including two of the Mediterranean North Africa biome. In general, in the spring and summer periods, the complex is almost deserted by waterbirds, but only a few species breed because of the significant levels of human disturbance.

In the late '50s, the Oualidia lagoon has known as the start of the first Oyster farming activities along its shores, and then it became the Oyster capital of Morocco as it presents 72% of the Moroccan aquaculture production (KADDIOUI et al., 2018). In 1970 approximatively, different activities were developed in/and around the lagoon, and the region has known a significant demographic growth (H.C.P.) (MAANAN et al., 2014). The increase in human activities in this lagoon was accompanied by increased natural resource exploitation for economic purposes, especially during the summer when many national and international visitors come to this lagoon to enjoy its landscape and taste its unique oyster.

Sidi Moussa lagoon is situated 30 km north of the Oualidia. It is one of the most important Moroccan wetlands as a stopover and wintering site for different waterbird species found in large expanses of mudflats of the Sidi Moussa lagoon, with adequate and favorable ecological conditions (EL HAMOUMI et al., 2000). In addition, it is worthily noting that the lagoon presents more services other than a habitat; many activities are practiced around and in the lagoon and have grown in recent years, including grazing on its edges, agricultural activities, fishing, shellfish harvesting, and salt exploitation (KHOUKHOUCHI et al., 2018).

In recent decades, almost all studies in the Oualidia-Sidi Moussa lagoon complex focused on studying the changes in the environmental conditions, monitoring and evaluating the water quality and sediment quality. Other studies were focused on assessing the historical inputs of pollutants, including heavy metals (MAANAN et al., 2004; ZOURARAH et al., 2007; MEJJAD et al., 2018; KHOUKHOUCHI et al., 2018: MEJJAD et al., 2020B; BENMHAMMED et al., 2021a), rare earth elements (MEJJAD et al., 2016, BENMHAMMED et al., 2021b, MEJJAD et al., 2022), and radioactive elements (MEJJAD et al., 2016; LAISSAOUI et al., 2018; BENMHAMMED et al., 2021a). Other authors have combined the history of human activities growth with the evolution of pollutants concentrations by establishing the relation age-depth to understand better the source of pollution (MEJJAD et al., 2020B).

In the present research work, we review the studies carried out in the Oualidia lagoon and Sidi Moussa lagoon during the last 50 years to establish the historical evolution of heavy metal pollution lagoonal ecosystems and define the common source of pollution in this complex. In this sense, the study seeks to understand the tendency of pollution accumulation in the lagoon's sediments and identify the possible source of pollution to suggest and provide better recommendations for the sustainable growth of these ecosystems.

2. Materiel and methods

2.1 Study Area description

The Oualidia Sidi Moussa lagoon complex, situated on Morocco's Atlantic coast (Fig.1), entails two main coastal lagoons and several wetlands separated from the sea by sandy dunes. While the site is protected by the Ramsar Convention (site no. 1474) as a biologically and ecologically significant wetland and migratory bird protection area, it is subjected to significant environmental stresses mainly caused by anthropogenic activities such as agriculture, animal husbandry, oyster farming, saltworks, fishing, tourism and the growing industry with NORM as a by-product.

The Oualidia lagoon is an area of high economic growth potential. The site is wealthy in natural resources and has a high diversity of fauna and flora in terms of wading birds, marine invertebrates, and seagrass beds. It also provides a habitat for many migrating birds and some species of turtles. Fishing and aquaculture, particularly oyster farming, have expanded since about 1970 and now support many local fishers, and the area offers several investment opportunities. In addition, agricultural production and livestock farming are carried out near the Oualidia lagoon and involve considerable amounts of phosphate fertilizer. The lagoon has been the subject of many multidisciplinary studies investigating its environmental status with respect to its chemistry, radiochemistry and biology (Zourarah et al., 2007; Maanan et al., 2018; Mejjad et al., 2016).

The Sidi Moussa lagoon has an area of about 4 km^2, and it is separated from the Atlantic Ocean by consolidated dune ridges that protect the lagoon from strong waves and currents. It comprises the main channel linked to the Atlantic Ocean by a narrow and quiet channel and many secondary channels. The maximum depth is about 5 m and decreases gradually upstream of the lagoon. Several human activities are concentrated around the lagoon; one of the most important is the phosphate processing complex of Jorf Lasfar, located 15 km from the coastal ecosystem of Sidi Moussa, which started in 1986.

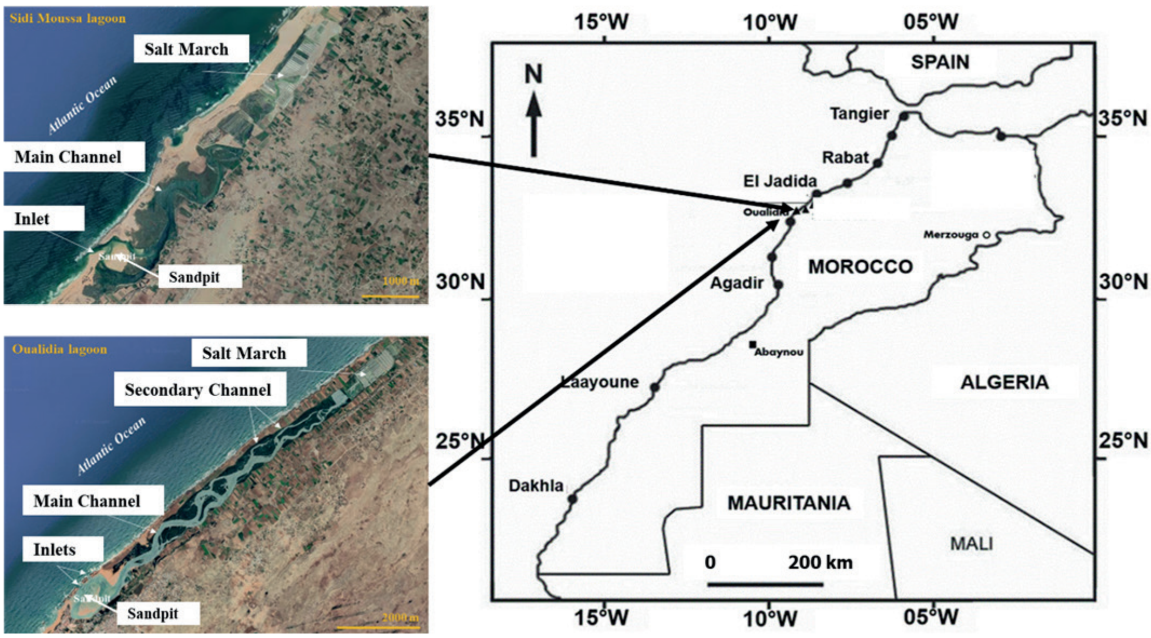

Figure 1: Geographical location of Moroccan lagoons, including Oualidia and Sidi Moussa lagoons.

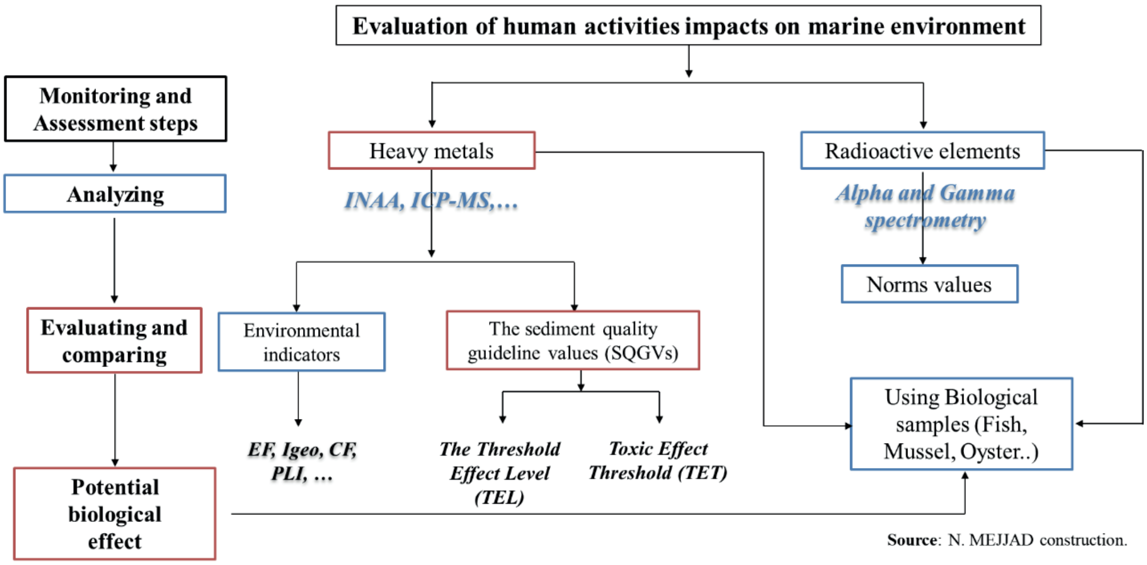

Figure 2: Steps related to the evaluation of contaminants concentrations in sediments. *In red are the monitoring steps studied in the present paper.*

2.2 Bibliographical literature

The searches were mainly focused on all studies aimed at evaluating and analyzing the environmental quality of these lagoons sediments (Fig. 2). Others studies related to the management, strategies and related policies were reviewed as well.**2.3 Oualidia-Sidi Moussa complex lagoons sediments compared to a range of sediment quality guidelines values (S.Q.G.V.s)**

The important role that sediment plays as a habitat for marine microorganisms implies their use to define pollution. Furthermore, the sediment acts as a sink for pollutants as it is the final receptor of all kinds of pollutants. Additionally, sediments are used to track the natural and anthropogenic sources of pollutants in marine ecosystems allowing a better understanding of pollutant evolution. In this order, the sediments have gained more importance among other classical samples used to monitor and assess marine environmental quality such as biota and water by defining numerous sediments quality guidelines (S.Q.G.s) deriving from chemical databases sediments considered as not contaminated.

Traditionally, sediment contamination level was determined by evaluating chemical concentrations and often comparing the sediment concentrations with reference values such as those of the upper continental crust (U.C.C). concentrations or the local background (MCLENNAN 2001). In the latest 40 years, S.Q.G.s have incorporated the biological effects, including sediment ecology and toxicity effects, to establish the relationship between toxic response-sediment contamination (BURTON, 2002). These S.Q.G. were defined to protect and predict adverse effects on marine biological resources, especially sediment serving as a habitat for marine organisms (BURTON, 2002; SCHAEFER, 2013).

Since the 1980s, many S.Q.G.s have been developed, including specific factors, criteria, and approaches that consider the diverse condition of sediment contamination occurrence and deposit. Generally, these approaches could be defined as (WENNING, 2005) :

(i) Empirical relationships are based on determining the sediment contamination level at which a toxic response could occur.

(ii)Theoretical relationships (equilibrium partitioning, EqP) (DI TORO, 1991) allow describing the bioavailability of the contaminant.

Generally, S.Q.G.s outline two concentration thresholds: Threshold Effect Limit (T.E.L) and Probable Effect Limit (P.E.L.). However, we can find in literature diverse empirical S.Q.G.s that have been established to derive numerical standard values for chemical elements in marine sediments (Table 1).

Table 1: Empirical S.Q.G.s for marine sediments.

Empirically derived sediment quality guidelines	References
Effects range–low (E.R.L.) and effects range–median (ERM).	LONG & MORGAN 1991; MACDONALD,1992; LONG et al., 1995
Threshold effects level (TEL) and probable effects level (P.E.L.).	MACDONALD et al.,1996
The Threshold Effect Level (TEL) and the Toxic Effect Threshold (TET).	BABUT et al., 2003
Apparent effects threshold (A.E.T.).	BARRICK et al., 1988; PTI, 1991
Screening level concentrations (S.L.C.).	NEFF et al., 1987
Summed PAH model (R.P.A.H.), and negligible concentration (NC) and maximum permissible concentration (M.P.C.).	VAN VLAARDINGEN et al, 2005

As there are not yet guideline values for Moroccan sediments, in the present analytical study, we used different S.Q.G.s values defined by agencies worldwide and the local background of both lagoons sediments. Using the guideline values will help better understand the metals concentrations values, local background values, and S.Q.G.V.s.

3. Results and discussion

3.1 Metallic contamination of the Oualidia lagoon sediment

The measured concentrations of metals determined in sediments samples retrieved from the Oualidia lagoon between 1976 to 2014 are listed in Table 2. The concentrations of metals display an increasing tendency, especially for Cr, Zn, and Cd, as shown in the sediment retrieved from the lagoon in 1998. On the other hand, for the studied sediments by IDARDARE et al., 2008, the concentrations of metals are relatively low compared to those found by ZOURARAH et al., 2007. The sampling period of these sediments coincides with the opening of a breach in 2005 in the downstream dyke constructed in the lagoon in 1945. Thus, this may explain the observed decrease in metal concentrations. This breach was created to purify the lagoon from fine sediments and protect it from the confinement phenomena; thus, this abrupt change in metal concentration is linked to the opening of this breach. Besides, the vertical distribution of metal content shows a decreasing tendency in the layers dated between 2005 and 2008, according to IDARDARE et al. (2008). The concentrations continue to decrease except for Pb, Cd, Cu and Zn, as reported in MAANAN et al., 2014. This enrichment was explained by the human activities pressures on the lagoon, especially the lagoon has an economic, ecological and cultural interest and the region, in general, is among the most attractive touristic destination in Morocco, especially during the summer. It should be noted that other activities practiced in and near the lagoon, such as animal grazing and agricultural activities, were reported as the possible primary origin of metals such as Cd, Cr, and As. The use of fertilizer and pesticides to increase yield productivity and quality may raise these metal concentrations.

The latest study carried out in the lagoon sediments showed that the concentration of almost all metals reported higher in MAANAN et al. (2014), and ZOURARAH et al., (2007), such as Pb, Cu, and Zn have decreased while Cd and Cr exhibit higher concentrations. Arsenic was measured for the first time in MEJJAD et al. (2018); thus, there are no previous values to compare and assess the As concentration evolution with time. The recorded concentrations showed higher values than upper continental crust values and other similar ecosystems' measured concentrations (e.g., Moulay Bouselham lagoon ALAOUI et al., 2010).

Table 2: Metals concentrations measured in the Oualidia lagoon sediments between 1976 and 2014.

Study References	Sampling date	Cu	Cr	As	Pb	Zn	Cd	Ni	Main events
MEJJAD et al., 2018	2014	17.72	**102.2**	10.99	10.99	75.86	**0.66**	19	Usual activities including Tourism, Aquaculture, Agriculture..,
MEJJAD et al., 2016	2012	-	55.93	11.58	9	78.15	0.58	-	2012: Creation of wastewater treatment plant
MAANAN et al., 2014	2008	**58**	64	-	**73.6**	**229**	0.3	20.6	Usual activities including Tourism, Aquaculture, Agriculture..,
IDARDARE et al., 2008	2004-2006	17	68	-	6.8	104	0.58	28	2005: The opening of a breach
ZOURARAH et al., 2007	1998	36.4	52.4	-	54.4	227	0.2	-	Usual activities including Tourism, Aquaculture, Agriculture..,
BIDET & CARRUESCO, 1982	1976	23	-	-	8	63		21	Since 1970: Demographic and human activities growth
MEJJAD et al., 2018	LBV	5.27	43.47	11.89	0.71	23.57	0.127	19	Before the acceleration of human activities in the study area
MAANAN et al., 2013	LBV	26.6	38.4	nd	24	142.3	0.15	20.6	Before the human activities increase in the study area

3.2. Metallic contamination of the Sidi Moussa lagoon sediment

Compared to the Oualidia lagoon, the Sidi Moussa lagoon received relatively little attention. Few studies have investigated the sediment level contamination by metals (MAANAN et al., 2004; BENMHAMMED et al., 2021A; BENMHAMMED et al., 2021B; CHEGGOUR et al., 1999). Almost all studies were focused on biological investigations as it presents an interesting role as a habitat for many types of migratory birds. Table 3 investigates the studies carried out between 2001 and 2021 for samples collected in the last three decades. The metal concentrations determined for top layers of sediments (4cm) are comparable to the Oualidia lagoon's (Table 2), and an apparent decrease in concentrations of metals during the last decades. However, the latest study exhibited a high concentration of Cr, As, and Cd higher than the local background values, while the Cd values exceed the values found in the Oualidia lagoon sediment. The location of the Sidi Moussa lagoon near the phosphate processing plants in Jorf Lasfar is the possible source of the higher values of Cd recorded in this lagoon sediment, as reported in CHEGGOUR et al. (1999). Another source of marine origin could also contribute to the enrichment by Cd, which is the upwelling phenomena that characterize the Moroccan Atlantic coast (BRULAND et al., 1983), as this phenomenon is permanent along the coast between El Jadida and Safi regions, including the Sidi Moussa lagoon (ORBI et al., 1997). MAANAN et al. (2004) have reported that the increase in human activities, including the intensification of the traffic skirting in the Sidi Moussa lagoon, agricultural activities, growth and development of fishing boats equipped with motors (CHEGGOUR et al., 1999) are the main sources of heavy metals such as Zn, Cu, and Pb.

Table 3: Metals concentrations measured in the Sidi Moussa lagoon sediments between 1999 and 2017.

Study Reference	Sampling date	Cu	Cr	As	Pb	Zn	Cd	Ni	Main events
BENMHAMMED et al., 2021a	2017	16.69	102.2	6.82	27.7	61.3	1.68	28.2	Coastal road traffic, tourism, fishing activities and agriculture
JOULAMI et al., 2013	2011	11.70	90.2	31.87	17.3	102	2.05	nd	Coastal road traffic, tourism, fishing activities and agriculture
MAANAN et al., 2004	2001	30.4	96.9	nd	22.7	49.8	nd	29.1	Coastal road traffic, tourism, fishing activities and agriculture
CHEGGOUR et al., 1999	1992-95	36.9	nd	nd	33	144	3.67	nd	Coastal road traffic, tourism, fishing activities and agriculture
BENMHAMMED et al., 2021a	LBV	5.89	34.5	3.92	11.6	19.1	0,23	11.9	Before the acceleration of human activities in the study area
MAANAN et al., 2004	LBV	25	38	nd	nd	24	nd	25	Before the acceleration of human activities in the study area

3.3. Oualidia and Sidi Moussa lagoons sediment quality and biological effects

The values recorded in the studies carried out for sediment of the Oualidia and Sidi Moussa lagoons were retrieved in 2014 (MEJJAD et al., 2018) and 2017 (BENMHAMMED et al., 2021a), respectively, were compared to a range of S.Q.G.V.s reported in table 4. Therefore, in the Oualidia lagoon, only Cr and As that show values slightly superior to the Threshold Effect Level (TEL), indicating a probable effect on the marine organism. The chromium concentration exceeds even the probable effect level (P.E.L.) (90 mg/kg) defined by MACDONALD et al. (1996), highlighting the need to investigate further this metal concentration and its origin in the Oualidia lagoon. The other elements exhibited values lesser than TEL, effects range low (E.R.L.), lowest effect level (L.E.L.); minimal effect threshold (M.E.T.), signifying that Cu, Pb, Ni, and Zn did not pose a toxicity risk for the lagoon organisms. It is worthily noting that Zn's recorded concentrations in 1998 and 2008, as reported in previous studies, were 227 and 229 mg/kg, respectively, higher than TEL values suggesting probable effects on marine organisms living. However, the decreasing trends of the Zn values could be related to the management projects carried out in the lagoon between 2008 and 2012.

Concerning the Sidi Moussa lagoon, the values of Ni, As, Cd, and Cr show higher values exceeding those of TEL, suggesting a potential toxicity risk for marine biota. In contrast, the Zn, Pb, and Cu have shown lesser values indicating no potential effects on marine organisms. Except for Ni, the three metals, As, Cd, and Cr, present higher concentrations in both lagoons suggesting probably a similar origin (the use of fertilizer, up-welling activities along the El-Jadida-Safi coast).

The present investigation highlights the need to consider the ecological, cultural, and economic interest that this lagoonal complex presents for the whole country and the local population.

Table 4: range of S.Q.G.V.s.

	Type	References	Cu	Cr	As	Pb	Zn	Cd	Ni
No effect									
ANZECC ISQG-low	ED	Babut et al., 2003	65	80	20	50	200	1.50	21
TEL	ED	MacDonald et al., 2000	35.7	37.3	5.9	35	123	0.6	18
TEL	ED	Buchman, 1999	18.70	52.30	7.24	30.24	124	0.68	15.90
ERL	ED	MacDonald et al., 2000	70	80	33	35	120	5	30
ERL	ED	Buchman, 1999	34	81	8.20	46.70	150	1.20	20.90
LEL	ED	MacDonald et al., 2000	16	26	6	31	120	0.6	16
MET	ED	MacDonald et al., 2000	28	55	7	42	120	0.9	35
TEC (I)	CB	Apitz & White 2003	38.18	78.33	16.11	52.99	153.5	1.04	23.20
Probable Effects									
ANZECC ISQG-high	ED	Babut et al., 2003	270	370	70	220	410	10	52
NOAA-ERM	ED	Buchman, 2008	270	370	70	218	410	9.6	51.6
ERM	ED	MacDonald et al., 2000	390	145	85	110	270	9	50
ERM	ED	Buchman, 1999	270	370	70	218	410	9.6	51.60
PEL	ED	MacDonald et al., 2000	197	90	17	91 .3	315	3.53	36
PEL	ED	Buchman, 1999	108.2	160.4	41.60	112.2	271	4.21	42.80
AET	ED	Buchman, 1999	390	62	35	400	410	3	110
TEC (I)	CB	Apitz & White 2003	214.6	268.4	54.32	396	369.2	5.76	58.28
Extreme effect									
E.E.C. (I)	CB	Apitz & White 2003	1,076	1,038	227	1,056	1,645	29.21	298.4

*Sampling date – L.B.V.: local background value calculated from the deeper layers of sediment cores– E.D.: empirically derived- C.B.: consensus-based S.Q.G.; Sediment quality guideline; TET, toxic effect threshold; P.E.C., probable effect concentration; P.E.L., probable effects level; ERM, effect range median; NOAA, National Oceanic and Atmospheric Administration; N.Z.E.C.C., Australian and New Zealand Environment and Conservation Council; E.R.L., effects range low; L.E.L., lowest effect level; M.E.T., minimal effect threshold; M.E.L., Median Effect Level.

4. Conclusion

Preserving and conserving a country's culture and resources is mandatory. Therefore, valuing and assessing the environmental quality of such marine ecosystems is an urgent need for social, economic, and cultural sustainability.

The increase of human activities and overexploitation of natural resources, specifically marine resources, for meeting and satisfying human needs and wants cause biodiversity losses and indirectly affect the next generation's well-being.

The study highlights the need for further evaluation of biological samples for a more accurate and precise definition of the environmental quality of those precious lagoons. Increasing the awareness among the local population about the importance of conserving and protecting these ecosystems is required. In addition, creating new plans and strategies for sustainable use of marine resources for touristic purposes in the region is necessary.

However, our investigation exhibits an evident deterioration of the environmental quality of the lagoonal complex of the Oualidia-Sidi Moussa. This complex is one example of numerous ecosystems in Morocco and worldwide suffering from the human activities pressure and overconsumption of their resources. Thus, this existing unbalance between human activities-resources exploitation, and the environment requires further investigation and practical management projects.

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Multi-date tidal delta morphodynamics of the Oualidia lagoon: Decadal and annual scale change assessment

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Abstract. Changes in sedimentation and morphology of the tidal delta and adjacent beaches of the Oualidia lagoon were studied using bathymetric data and aerial photographs. This lagoon has been classified as a RAMSAR site since 2005, offering great ecological and socio-economic value for the local population. However, in recent decades, the lagoon of Oualidia has experienced several types of degradation, including the phenomenon of confinement of water and sediment The present study evaluates the evolution of the morphological and sedimentary change of the downstream area of this lagoon on a 10-year time scale between 2006 and 2016.Bathymetric data and aerial photos showed good agreement and provided many interesting results in sedimentary and morphological changes in the downstream area of the lagoon. Thus, the notable changes mainly concern three morphological units of the lagoon, namely the tidal delta, the adjacent beaches and the main channel. These changes are related to natural (hydrodynamics, waves, currents...) and anthropogenic (dikes, sediment traps...) factors. This study assessed the anthropogenic actions and their impacts to support effective decision-making.

Key words: Tidal delta, Morphodynamic, Topo-bathymetry, Photo-interpretation, Oualidia lagoon.

1. Introduction

Environmental lagoons are shallow water bodies connected to the sea by one or several entrance inlets, with limited freshwater influence (OLIVEIRA et al., 2006). They are standard worldwide, being shallow aquatic ecosystems that develop at the interface between terrestrial and marine coastal (ETHEM GONENC & WOLFLIN, 2004). The lagoons communicate with the sea through one or more inlets that allow the inflow of marine water according to the tidal regime. However, the dynamics of these morphological units are very complex. It involves many processes (BRUNEAU et al., 2011; HUBBARD et al., 1979; ISLA, 1997; TAMBRONI et al., 2010), such as:

- The contribution of waves to nearshore currents and total water level,
- The influence of tide and wave breaking on water depth,
- Refraction of waves by depth and current,
- Sediment resuspension and feedback of morphological evolution on hydrodynamics.

Moreover, the connection to the ocean can strongly influence sedimentation budget, water quality, and ecology (DUCK & DA SILVA, 2012).

Coastal lagoons are considered among the most valuable ecosystems in the world, supporting critical environmental services such as fisheries and aquaculture (CAÑEDO-ARGÜELLES et al., 2012; PAULY & YANEZ-ARANCIBIA, 1994). However, these vital ecosystems face many challenges due to their ecological and socio-economic interests. For example, they contribute to the increase of human pressure around them, implying overexploitation of their natural resources. In addition, they impact the environmental quality of these ecosystems (e.g., eutrophication, metal pollution, water, and soil pollution) (ESTEVES et al., 2008; WOLANSKI et al., 2013).

The modification of natural hydrology of the lagoons, mainly through the artificial connection with the ocean, represents the most common threat affecting them(CONDE et al., 2015). Several alternatives have been used to stop the closure or opening of lagoon passes, for examples:

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- River diking to reduce the sediment budget (BOATENG, 2012),
- Reforestation of unstable areas in the upper watershed to reduce erosion problems (GUEVARA et al., 2019)
- and structures that block nearshore currents (BOYAUZAN & IRZI, 2015).

In very complex and severe cases, the reopening of passes may require dredging (ZOURARAH et al., 2015).

The Oualidia lagoon, which is the study area, is located on the Moroccan Atlantic coast, (32°45.440 N - 09°00'.870 W; 32°44.950 N – 09°01'.520W) (Fig. 1). The RAMSAR Convention classified this lagoon as a protected area of international importance in 2005. Due to the ecological and socio-economic value of this lagoon, many studies were carried out on the Oualidia lagoon from different aspects, such as environmental monitoring and assessment, modeling of the sediment exchange sea-lagoon using physical, geological, and biological samples (BIDET & CARRUESCO, 1982; BOUCHKARA et al., 2022; BOUCHKARA et al., 2021; EL KHALIDI et al., 2011; GEME, 2003; HILMI et al., 2005; HILMI et al., 2005, 2009; KOUTITONSKY et al., 2007; LAISSAOUI et al., 2018; MAKAOUI et al., 2018; MEJJAD et al., 2016; 2020a, 2020b; ZOURARAH et al., 2007).

Sedimentation in the Oualidia lagoon has been a significant concern over the last decades, as the lagoon suffers from confining and erosion phenomena resulting from the development of human activities in the area adjacent to the lagoon (MEJJAD et al., 2020). Besides, the confinement of sediments in the Oualidia lagoon has been the subject of several studies (GEME, 2003; KOUTITONSKY et al. 2007; 2012). Therefore, the present study continues the listed research work based on bathymetric data.

The main objective of this research is to study the spatial dynamics of sediments in the downstream area of the Oualidia lagoon. First, we calculated the sediment budget and evolution rate using 3D GIS analysis techniques based on bathymetric evolution data and aerial photographic missions. Second, we performed a profile analysis on this area's 2006 and 2012 bathymetric data, plotted in the GIS software,and we created three profile sections to calculate the average evolution. Finally, we discussed the leading natural and anthropogenic factors that cause the lagoon dynamics changes.

2. Methods and Materials

2.1. Study Area description

The Oualidia lagoon is located on the Atlantic coast of Morocco, about 75 km South of El Jadida city (32° 44'.42 N - 9° 02'.50 W) (Fig. 1). It is characterized by a warm temperate climate and average rainfall, which vary according to natural rainfall fluctuations. The lagoon runs parallel to the coast for about 7 km. Three entrance inlets ensure communication with the ocean. Further upstream, a closed dike separates the salt basins from the lagoon. Underground freshwater springs distributed along the lagoon give it a suitable salinity for oyster farming.

This lagoon constitutes a space of ecological importance (natural nurseries for several species of shellfish and oyster beds) and a refuge for migratory birds. According to the Protected Areas Management Plan, this lagoon is a wetland of great biological and economic importance and a priority Site of Biological and Ecological Interest (SIBE). Its preservation is an absolute necessity due to its certification as a wetland of international importance by the International Convention of Ramsar 1971.

The lagoon suffers from the asymmetric nature of the lagoon's tidal propagation, with a duration of the flood (tide rising) shorter than that of the ebb (tide ebbing). Thus, for the same volume of incoming and outgoing water, the maximum velocities of the flood (ebb) currents are greater than those of the flood (flood) currents. This tidal asymmetry and sediment transport are presented in the report by (KOUTITONSKY et al., 2007). The study also showed that mud transport in the channel zone is directed upstream. In the long term, this contributed to decreased depths and confinement of water upstream. Therefore, it was recommended in 2006 to create a sediment trap in the upstream dike to trap this sludge transported upstream by the strongest currents during the flood.

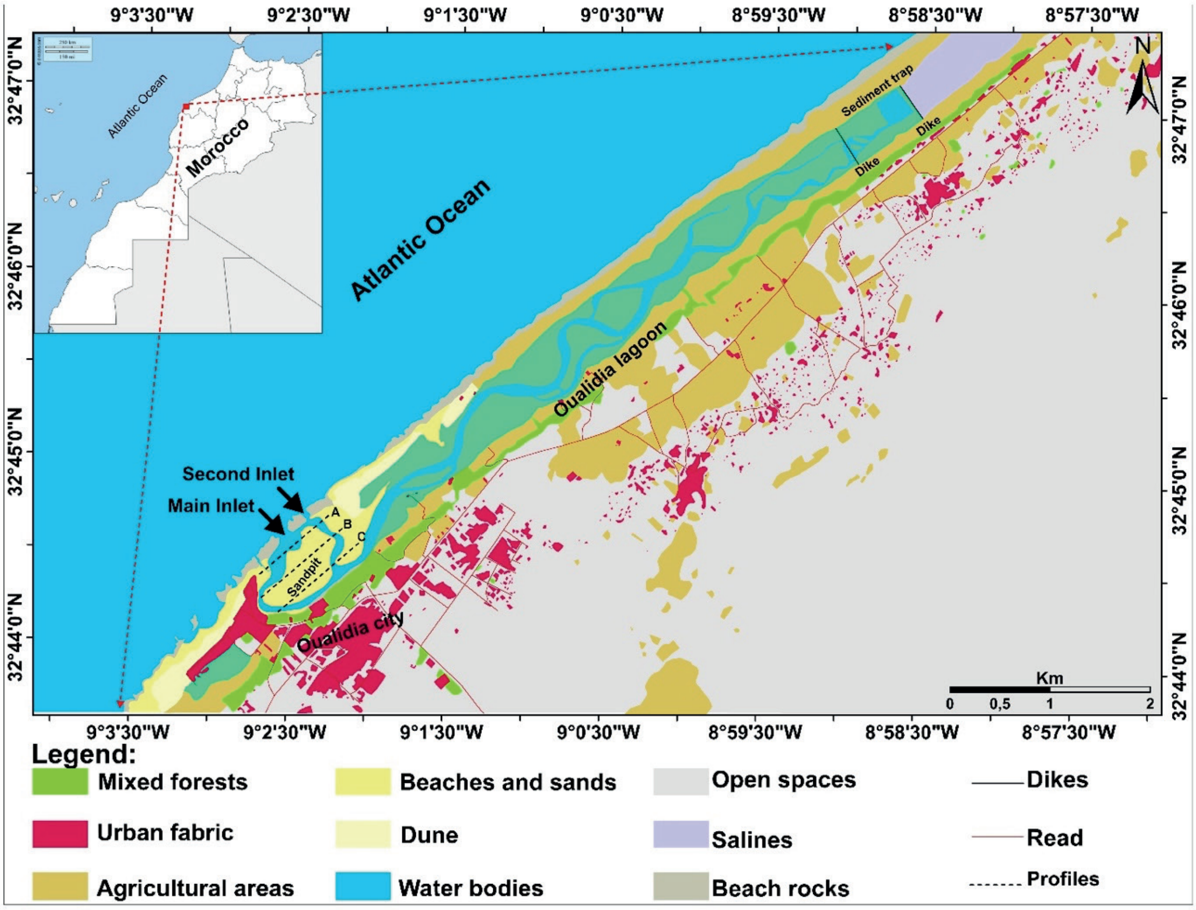

Figure 1: Geographic location of the Oualidia lagoon

2.2 Multi-dates morphological study

The main objective of this study is to evaluate the sediment budget change in the downstream area of the lagoon, including the tidal delta, adjacent beaches, and the main, taking into account the role that the three inlets play in ensuring the process of sediment evolution. For this purpose, we used aerial photographs and satellite images of multi-temporal time series. The data used are listed in table 1. This diachronic study consists of superposing photos with different scales. The steps of this process can be summarized as follows:

1st step: the georeferencing of all the topographic maps in the identical projection system. In our case, the datum is Merchich, and the projection is Lambert Conformal Conic North Morocco.

2nd step: the georeferencing of aerial photos using the previously established map as a reference, it is a matter of calibrating the aerial photos on the ANCFCC[1] topographic maps using the same projection system, by entering homologous points projection, by entering homologous points (landmarks) between the two images distributed over the entire photograph and easily identifiable to obtain a consistent result.

3rd step: Geometric corrections; this step involves correcting the geometric distortions due to the variations of the Earth-sensor geometry and transforming the satellite images into valid coordinates.

4th step: The digitalization and database nourishing. The different georeferenced photos are assembled by year, and then the landscape

[1]National Agency of Land Conservation, Cadastral Surveying and Cartography, Morocco.

objects identified above are digitized. Thus, the attribute tables of each layer are completed

Two topo-bathymetric surveys were processed, collected respectively in 2006 and 2012. The used data are provided by the Moroccan Directorate of Ports and Maritime Public Domain (DPDPM), while the surveys were collected using a single-beam echo sounder and a real-time kinematic differential GPS. To identify the bathymetric variation of the Oualidia lagoon, we developed three maps (two bathymetric and one differential). The data interpolation was done using the most commonly used method in GIS software, the kriging method (GRATTON, 2002), especially for data sets larger than 1000 points, as it is one of the most flexible and efficient methods to obtain the optimal maps. We obtained a differential map by subtracting the two bathymetric maps of 2006 and 2012 in GIS software, allowing users to get the morphological variation that the lagoon has experienced between these two dates.

The calculation of deposited and extracted material volumes was performed using the "cut fill" tool in GIS software. This is a procedure in which the elevation of a land surface is changed by removing/adding surface material. This methodology summarizes the areas and volumes changed, at two different times, by identifying areas where surface materials have been removed and added. It also allows defining the areas where the surface has not been modified. The results are obtained in the form of a map that illustrates the sedimentary state of the study area with a table calculating the different volumes and surfaces identified. In addition, to detail the morphological characteristics of the lagoon, we extract profiles perpendicular to the tidal delta of the lagoon through three transverse profiles (A, B, and C) to compare their evolution over the period 2006-2012 (Fig. 1).

Table 1: Data used in the study of morphological changes in the downstream area of the Oualidia lagoon**.**

Acquisition Year	Number	Type of document	Source
2010	2	Topographic maps 1/25000	ANCFCC*
2003	1	Satellite image	Landsat USGS
2006	1	Aerial photo	ANCFCC*
2010	1	Aerial photo	ANCFCC*
2011	1	Satellite image	Google Earth Pro
2013	1	Satellite image	Google Earth Pro
2016	1	Satellite image	Google Earth Pro
2017	1	Satellite image	Google Earth Pro

* National Agency for Land Conservation, Cadastral Surveying and Mapping.

3. Results and Discussions

3.1. Long term morphological changes of the tidal delta and adjacent beaches

The research conducted by (EL KHALIDI et al., 2011) highlighted the significant growth of the flow delta of the Oualidia lagoon over the period 1954-2006. This study complied with the previous studies with photo-interpretation using aerial photographs and satellite images taken from 2006 to 2017.

The results obtained (Fig. 2, Table 2) highlight the fact that there are two different periods of evolution:

The period from 2006 to 2011, characterized by a decrease in the surface area of the tidal delta. During five years, more than 14696.18 m^3 were eroded from the tidal delta. This may be due to the opening of one of the lagoon's upstream dikes in 2005. This opening probably played a positive role in improving the internal hydrodynamics, but only to a minimal degree.

This period is also characterized by the beginning of a southwestward migration of the main channel and, consequently, the adjacent beach's erosion. We observed that the secondary channel to the northeast of the flow delta migrated further northeast and became more active and more dynamic.

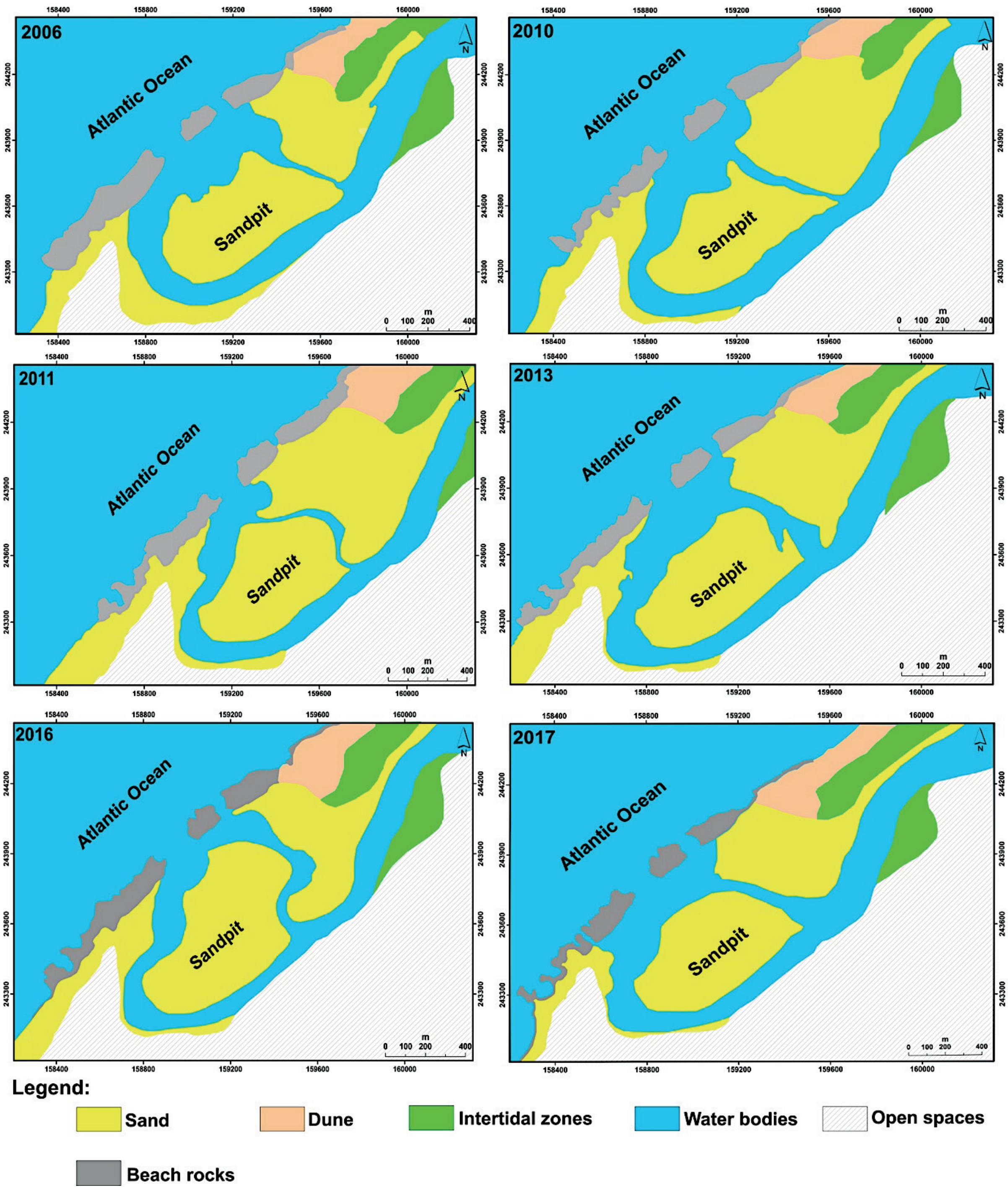

Figure 2: Diachronic changes in the downstream area of the Oualidia lagoon between 2006 and 2017.

The period from 2011 to 2016, characterized by an increase in the surface area of the tidal delta. It increased from 227982 m^2 in 2011 to 297184 m^2 in 2016, representing a progression of around 69202 m^2. This filling is observed after creating a sediment trap, resulting in an important water call inducing more sediment charge.

The flow delta thickening resulted from the main channel's migration to the lagoon's southwest. It thus caused erosion of the adjacent beach and activation of the northeast channel, increasing its function and intensifying the hydrodynamic force. The effect of the sediment trap is manifested in the upstream part of the lagoon by changes of the morphology in this part of the lagoon

Table 2: Morphological indicator changes of sandpit area in the Oualidia lagoon from 2006 to 2016.

Year	Area (m²)	Length (m)	Width (m)
2006	242679	736	325
2010	221272	631	404
2011	227982	716	426
2013	245242	748	391
2016	297184	857	471

3.2. Short term topo-bathymetric changes in the downstream part of the lagoon.

The spatial changes of sediment in the downstream part of the Oualidia lagoon (tidal delta and the adjacent beaches) show that an area of about 434996 m² was submerged by accretion with about 504931 m^3 of sediment volume gained and an erosion area of 393204 m² with a volume lost reaching -275710 m^3 (Fig. 3, Table 3). This means that the downstream part of the lagoon, including the main channel, the entrances inlets, the tidal delta and the adjacent beaches, has undergone a significant change from a morphological point of view.

A distribution map of the calculated volumes has been established to better represent the areas that have undergone accumulation or erosion (Fig. 3). In this figure, blue areas determine the sites that have experienced a loss of sediments and coincide precisely with the main and some secondary channels. While the areas indicated in red show the localities that have undergone material deposition, they mainly concern the tidal delta and the northern beach of the downstream part of the lagoon.

The downstream zone of the Oualidia lagoon shows an alternation of erosion and deposition patterns combined with the migration of the main channel over the southern part of this area due to the interaction of waves and tidal currents during ebb tides (KOUTITONSKY et al., 2007). However, the migration of the channel has changed its morphology and contributed to the creation of a zone of significant sedimentation (tidal delta), having a maximum average evolution of +0.63m and an annual rate of change reaching +0.10m/year (Fig.4, Profile A).Given the sand deposited by tidal currents, this evolution ended up with the appearance of a second small channel over the northern part of the tidal delta, which reached a depth of 2m in some localities. According to (Koutitonsky et al., 2007), the new channel, in turn, migrates southwards until it chokes, and so on. This migration cycle can last between 10 and 20 years or more (CARRUESCO, 1989 ; El KHALIDI et al., 2011). The study carried outby (El KHALIDI et al., 2011)on the morphological modifications of the tidal delta showed the permanent existence of two channels ensuring communication with the ocean: a southern channel (or main channel) and a northern channel (or secondary channel). This morphology was significantly marked by the advance of the main channel towards the south part, which allowed an individualization of the downstream in two zones: convex and concave (Taghia et al., 2014). In addition, the small adjacent beaches surrounding the tidal delta have also changed. The southern shore (open zone) was confronted with erosion resulting from the southward migration of the main channel with an average evolution reaching -1.84 m; -0.31 m/year (profile A) and -2.58m; -0. 43m/year (profile B), while the northern beach (convex zone) of the lagoon gained a significant amount of sediment during this period, the spatial evolution of profile B in this zone had shown an average evolution of +0.21m with an annual variation rate of +0.04 (Fig.4, profile B).

The morphological evolution of the downstream part of the Oualidia lagoon is mainly controlled by the sediment dynamics and hydrodynamics of currents and especially by the effect of tidal movement (KOUTITONSKY et al., 2007; TAGHIA et al., 2014).

Table 3: Calculated area and volume eroded/accumulated in the downstream area of the Oualidia lagoon (2006 to 2012)

Sediment status	Deposited	Eroded
Volume	504931	-275710
Area	434996	393204

The studies by KOUTITONSKY et al. (2007) revealed that the Oualidia lagoon had been dominated by flow, i.e., the flow (upward tidal currents) is of shorter duration than the ebb (downward tidal currents), and the speeds of the flow are higher than those of the ebb. This clearly explains why the transport of fine sediments and sludge is directed towards the upstream part of the lagoon, causing the confinement of the water. A sediment trap was created, in 2011, to resolve this problem as a management option. The creation of the sediment trap in 2011 has induced the extension of the tidal currents of the Oualidia lagoon. In addition, an increase in their intensity has allowed more sediment transport into the basin. In addition, this management plan increased the current speed inside the lagoon and facilitated hydrodynamics (KOUTITONSKY et al., 2012; MAKAOUI et al., 2018), which led to an augmentation of the depth in some areas and especially in the main channel of the lagoon.

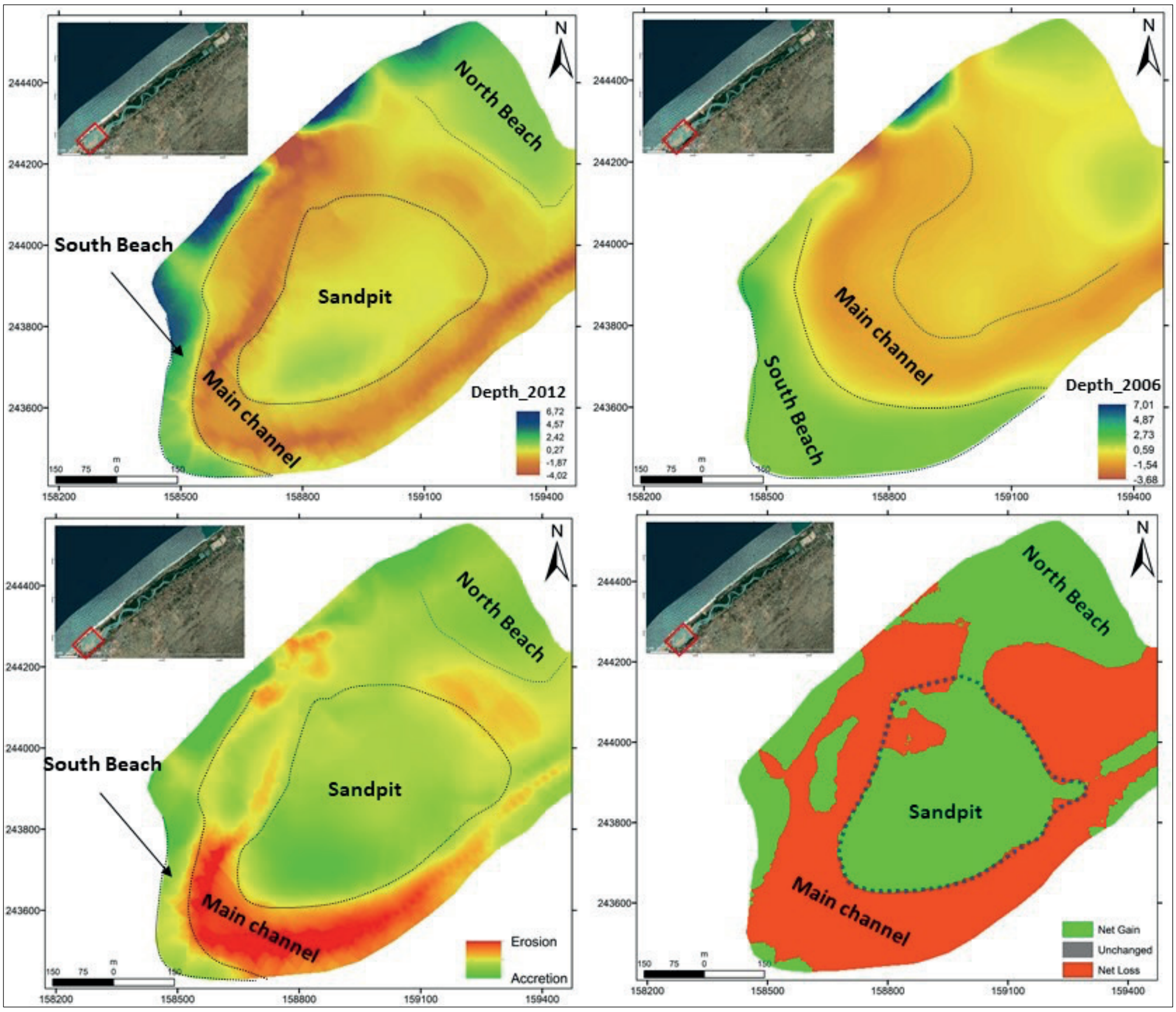

Figure 3: Topo-Bathymetric changes in the downstream area of the Oualidia lagoon between 2006 and 2012

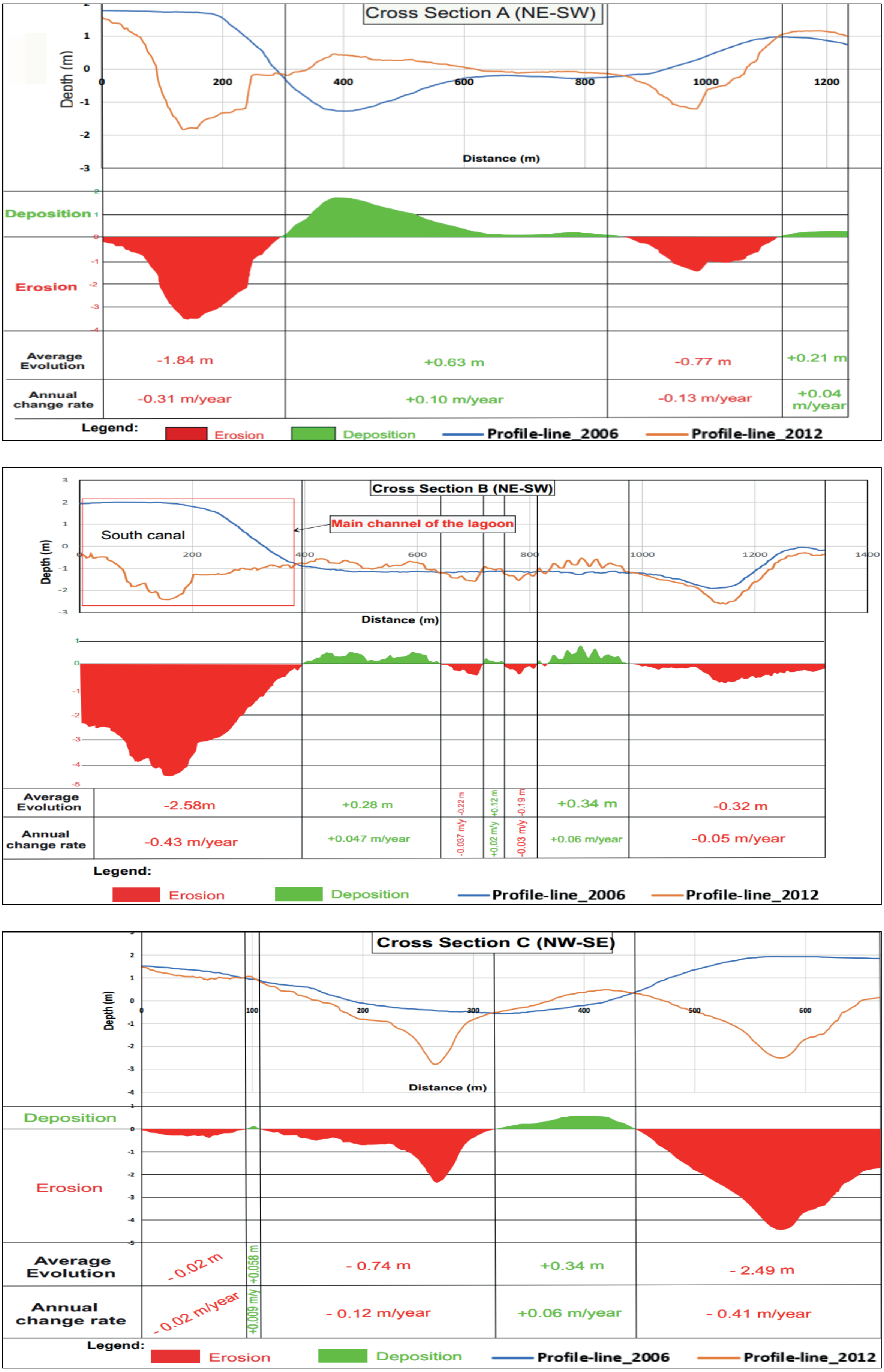

Figure 4: Morphological changes of the profiles studied: A, B and C.

4. Conclusion

This study aimed to assess morphological changes in the downstream area (tidal delta and adjacent beaches) of the Oualidia lagoon and to identify eroded and accumulated areas by coupling topo-bathymetric monitoring and photo-interpretation analysis. Bathymetric data collected in situ and aerial photographic data cover ten years between 2006 and 2016. The data analysis revealed several interesting results, including the migration southwards of the main channel with a significant increase in depth and silting of the tidal delta. In addition, remarkable changes on the adjacent beaches, which are the result of hydrodynamic modifications, were caused by the installation of several management projects in the lagoon, particularly the sediment trap. Moreover, the downstream area of the Oualidia lagoon has changed during the last few years. It is due to the increase of its tidal prism and the availability, outside it, of mobilizable sediments. The results obtained from photo interpretation perfectly agree with those obtained from topo-bathymetric monitoring.

Further studies on sediment transport should complete these results by using 3D modeling based on actual bathymetric surveys combined with hydrodynamic data, including long-term measurements of sea level, currents, temperature, and salinity throughout the lagoon, to describe the dynamics of the lagoon in more detail, to support or modify the stated assumptions.

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Hydrodynamic modeling of the Oualidia lagoon, Atlantic Coast of Morocco

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Abstract. A hydrodynamic finite element model was used to describe the water circulation in the lagoon of Oualidia (Morocco). Tides and wind are the main forces that allowed the hydrodynamic simulation of the lagoon. This study aims to understand the variability of current velocities mainly induced by winds and semi-diurnal tides of type M2 (period 12.42h) using a two-dimensional hydrodynamic model for the period from 01 to 15 April 2020. The wind-current and tidal variability on the mesoscale are well described. As a result, current velocities exceed 1 m/s during spring tides and decrease to 0.3 m/s during neap tides. The directions of the current follow the main axes of the channel, reversing 180 degrees between incoming and outgoing tides.

Key words: Current speed, hydrodynamics, SHYFEM, Oualidia lagoon.

1. Introduction

Lagoons represent 13% of the world's coastline (BARNES, 1995) and are among the most economically productive environments (DUCK & DA SILVA, 2012; KNOPPERS, 1994). In addition, they deliver many important environmental services (ES) (CAÑEDO-ARGÜELLES et al., 2012) that provide a wide range of ecological, cultural, and socio-economic values and support many natural services highly valued by human society (GONENC & WOLFLIN, 2004; NEWTON et al., 2018). Therefore, they are considered the most valuable coastal area components (GONENC & WOLFLIN, 2004). However, worldwide, coastal lagoons are experiencing significant environmental degradation (Eutrophication, pollution, urbanization, and various forms of changes) (ESTEVES et al., 2008; WOLANSKI et al., 2013). For this reason, studying hydrodynamic circulation in lagoons is of primary importance.

Understanding the dynamics of water in lagoon environments can help to (i) identify environmental problems related to eutrophication, contaminant transport, seabed erosion, siltation, and waste disposal (MEŽINE et al., 2019), (ii) appropriate management of these important ecosystems and mitigation of human impacts (FERRARIN et al., 2016). Unfortunately, direct observation of these dynamics would require an enormous effort, which is often impractical (FERRARIN et al., 2016).

To better understand the morphological evolution of coastal ecosystems, the scientific community uses numerical modeling tools (AMOUDRY & SOUZA, 2011; LUMBORG & PEJRUP, 2005). These tools integrate field data by applying hydrodynamics, sediment transport, meteorology, ecology, and climate change models (PÉREZ-RUZAFA et al., 2019).
The Oualidia lagoon, is located on the Atlantic coast of Morocco (32° 44',42 N - 9° 02',50 W). Different aspects of this lagoon have been studied, including the coastal erosion and geomorphology (BOUCHKARA et al., 2022; EL KHALIDI et al., 2011; TAGHIA et al., 2014), the study of the environmental impact of management on the hydrodynamics and sediment transport mechanisms within the lagoon (GEME, 2003; HILMI et al., 2005; KOUTITONSKY et al. 2007; 2012; MAKAOUI et al., 2018), geo-eco-tourism and heritage (KHOUKHOUCHI et al., 2018), biological state (BOUCHRITI et al., 1992; EL ASRI et al., 2015; HASSOU et al., 2014; JGHALEF et al.,

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2016; HENNANI et al., 2014; SOMOUE et al., 2020) and the assessment of sediment and water pollution by heavy metals (BIDET & CARRUESCO, 1982; DAGHOR et al., 2016; LAISSAOUI et al., 2018; MEJJAD et al., 2016, 2020 a & b; ZOURARAH, 2002; ZOURARAH et al., 2007).

The hydrodynamic investigations of the Oualidia lagoon have started in the last decades (HILMI et al., 2005, 2017; Koutitonsky et al., 2007, 2012). The physical parameters measured (Salinity and temperature) and water currents were initially used to describe the water circulation patterns (GEME, 2003; HILMI et al., 2017). Only recently, hydrodynamic models have been applied to the Oualidia Lagoon (HILMI et al., 2005; Koutitonsky et al., 2012). A 3D finite volume model (Mike 21) was applied to the Oualidia lagoon to study sediment transport and hydrodynamic circulation in different scenarios.

We used the two-dimensional (2D) hydrodynamic model (SHYFEM) to describe water circulation in the Oualidia lagoon and understand the processes governing its hydrodynamic functioning. This SHYFEM model has allowed us to simulate the current regimes taking into account different forcing parameters, such as wind and tides in the Oualidia lagoon.

2. Materials and Methods

2.2. Study area

The lagoon of Oualidia is located on the Moroccan Atlantic coast in the province of Sidi Bennour (32° 44',42 N - 9° 02',50 W) and extends parallel to the coast over a distance of about 7 km long and 0.5 km wide (Fig. 1).

The communication of the lagoon with the ocean is ensured by three inlets located downstream: a permanent main inlet (150 m wide and 3 m deep on average) and a secondary inlet (50 m wide and 2 m deep), and a third small one, active only during the periods of high tides.

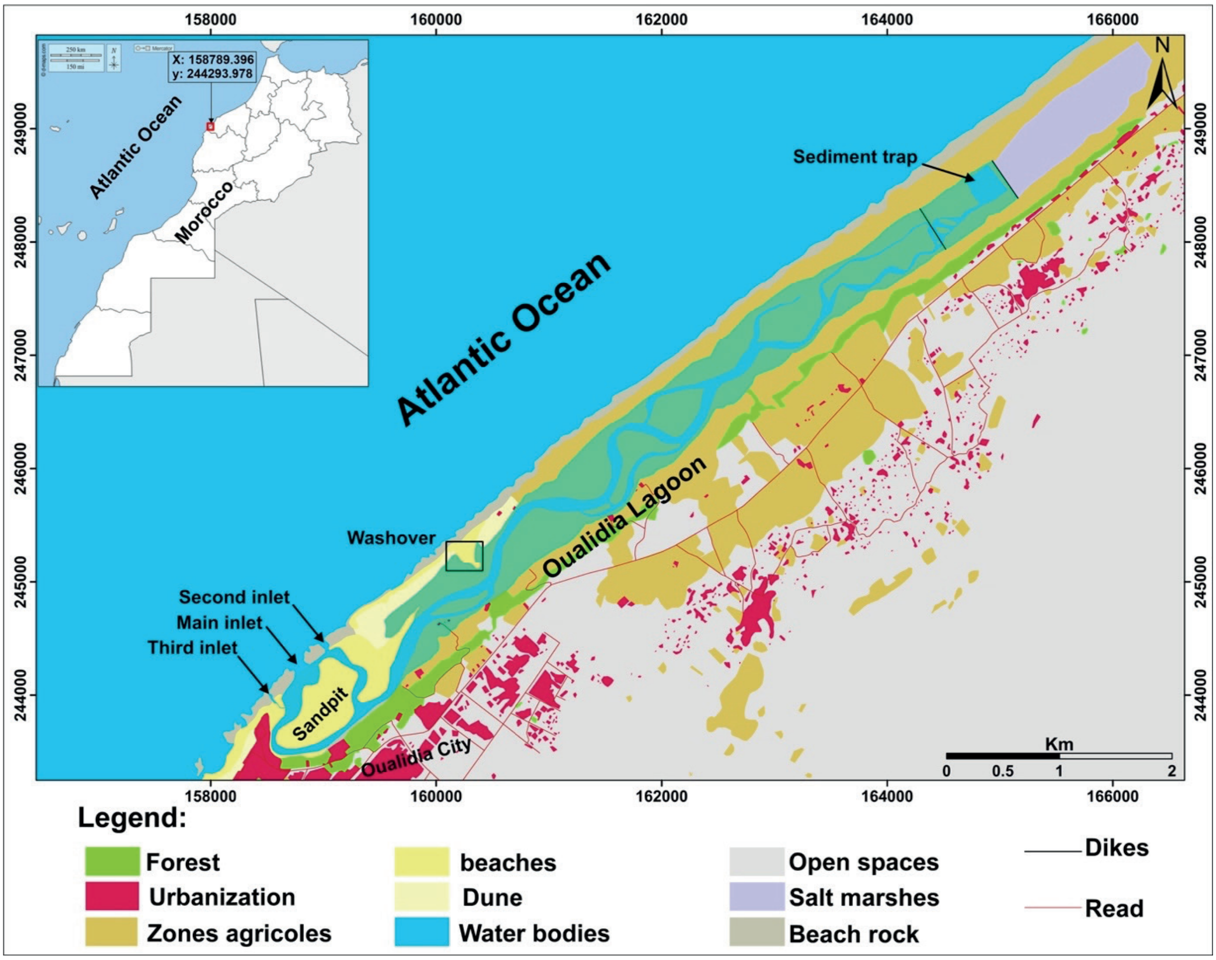

Figure 1: Geographic location of the Study area

This lagoon is among the most important coastal wetlands in Morocco. Today, with its ornithological importance, this site has been classified as a site of biological and ecological interest (SIBE) through the Master Plan of Protected Areas, and as a Ramsar site since 2005. This site, of international value, constitutes a migratory stopover and a winter refuge appreciated by the various species of waterbirds

2.2. The SHYFEM hydrodynamic model

The two-dimensional (2D) model, implemented for the Oualidia lagoon is the SHYFEM model developed at ISMAR-CNR in Venice (UMGIESSER et al., 2018)[1]. This Modeling system has already been implemented successfully in several coastal areas (FERRARIN et al., 2009, 2021; Mezine et al., 2019; UMGIESSER et al., 2004). It is an open-source software that consists of a hydrodynamic module, particularly adapted to shallow waters, which uses the finite element method for spatial resolution and a semi-implicit scheme for temporal integration (UMGIESSER et al., 2018). This set of programs can be used to solve hydrodynamic equations in lagoons, seas, estuaries and lakes, using finite elements to resolve hydrodynamic equations. These finite elements, together with an efficient algorithm for semi-implicit time resolution, make this program particularly suitable for applications in areas with complex geometry and bathymetry (UMGIESSER, 2004). The SHYFEM model can solve the primitive equations, vertically integrated on each layer. The horizontal diffusion and the baroclinic pressure gradient in the moment equation are treated explicitly.

2.3. Numerical grid

The bathymetric data of the Oualidia lagoon were collected in 2012. These data are provided by the Moroccan Directorate of Ports and Maritime Public Domain (DPDPM). These surveys were collected using a single-beam echo sounder and a real-time kinematic differential GPS (BOUCHKARA et al., 2022).

The numerical simulation was performed on a spatial domain representing the lagoon of Oualidia through a finite element grid that consists of 7730 triangular elements (4483 nodes) with high resolution in the whole lagoon (Fig. 2). The Finite Element Method provides high flexibility by partitioning the numerical domain into variable shape and size triangles. It is especially suited to reproduce the complex geometry and hydrodynamics of shallow water basins such as the Oualidia lagoon with its major channel and small islands.

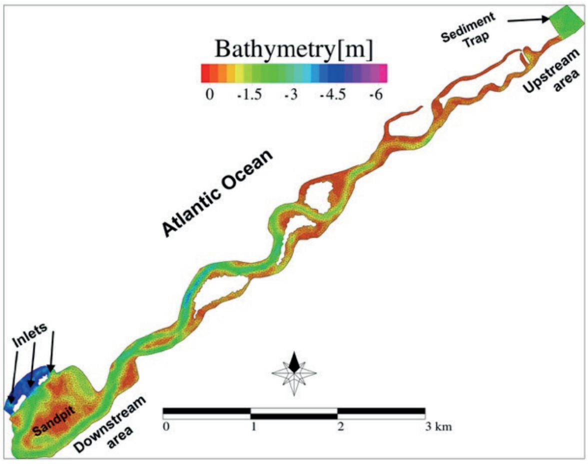

Figure 2: Bathymetry of the Oualidia Lagoon obtained by using the grid of the numerical model, interpolated.

The duration of the simulations is 15 days, between 01 and 15 April 2020. This duration includes two spring tides and two neap tides (Fig. 3a). This simulation makes it possible to follow the evolution of the simulated parameters during an entering and outgoing spring tide and an entering and outgoing neap tide. The main forcing parameters for this simulation are tides and winds, which are well described in the results section.

3. Results and discussions

3.1. Sea level

The sea level data used in this study was mainly collected from Iberia Biscay Irish – Monitoring Forecasting Centre (IBI MFC[2]) (Fig. 3b). The analysis of these data has shown that the lagoon of Oualidia is strongly influenced by tides of the M2 semi diurnal type (of period 12.42h) (HILMI et al., 2005, 2017). The same results have been carried out by (HILMI et al., 2005); this study showed

[1] https://github.com/SHYFEM-model/shyfem.

[2]https://marine.copernicus.eu/about/producers/ibi-mfc

water circulation in the lagoon is mainly influenced by tidal currents, with the predominance of the semi-diurnal component M2 (12 h 25 periods). Accordingly, the studies of HILMI et al. (2017) have also shown that the amplitude of the tide at the entrance of the lagoon of Oualidia is dominated by the semi-diurnal harmonic M2 (amplitude 0.97m), followed by the amplitudes of the harmonics S2 (amplitude 0.35 m) and N2 (amplitude 0.20 m). Concerning the diurnal harmonics, the harmonics K1 (amplitude 0.07m) and O1 (amplitude 0.06 m) follow with lower amplitudes. The same conclusions were mentioned in the work of (FANJUL et al., 1997; HILMI et al., 2005; KOUTITONSKY et al., 2007), which denote the dominant tides in Morocco (Atlantic and Mediterranean facades) as semi-diurnal.

As a result of the 2D model outputs, we present examples of hydrodynamic circulation patterns of this lagoon under the following situations: during spring tides with a rising and falling tide and neap tides with a rising and falling tide (Fig. 3a).

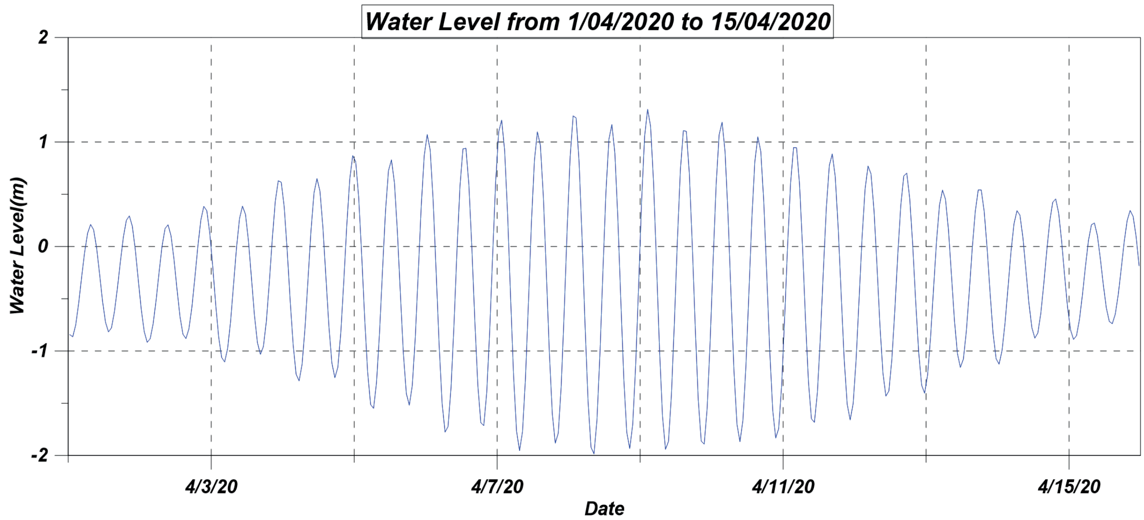

Figure 3.a: Tide observed at the entrance inlets of the Oualidia lagoon over the period from 1/04/2020 to 15/04/2020.

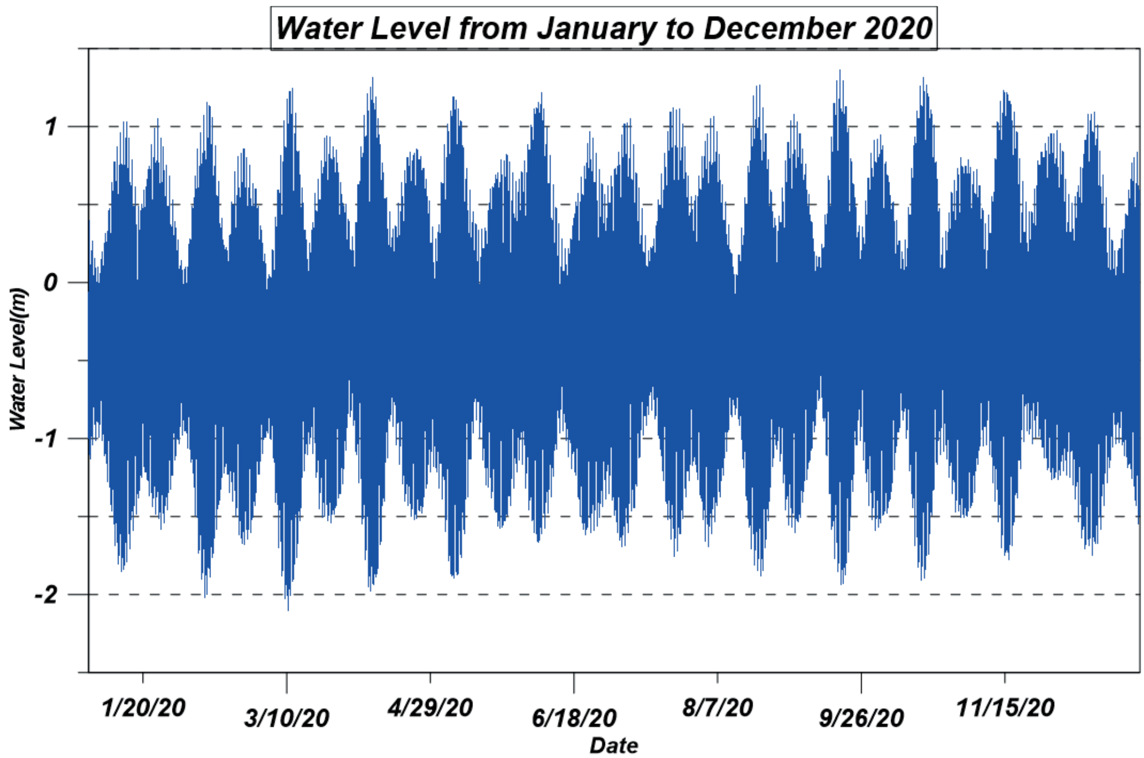

Figure 3.b: Tide observed at the entrance inlets of the Oualidia lagoon for the year 2020.

3.2. Winds

The wind rose of one-year data (2020) at the entrance inlets of the lagoon of Oualidia is shown in Figure 4a[3]. The analysis of the wind rose shows that the dominant winds are generally from the northwest, north to northeast, with a very strong predominance of the north to northeast winds as described by (KOUTITONSKY et al., 2007; HILMI et al., 2017). Annual wind statistics offshore of the Oualidia lagoon indicate that the average annual winds have speeds varying between 2 and 10 $m.\ s^{-1}$. Thus, the study of (KOUTITONSKY et al., 2007) has shown that the mean annual winds have speeds varying between 4 and 9 m/s, with predominantly northeast and north directions.

Whatever the season, the maximum intensities of north and northeast winds are often higher than 9 m/s. The percentage of the dominant wind speed presents variable frequencies of occurrence according to the seasons:

- 4% and 12% for a wind speed varying between 4 and 6 m/s;
- 12% to 21% for a maximum wind speed arriving up to 8 m/s;
- 21% and 23%, with wind speeds ranging between 8 and 10 m/s.

Figure 4b shows the hourly wind rose observed during the study period between 1st and 15th April 2020. The winds are of variable sectors over this period, with dominant winds of N to NE sectors (frequency > 12%) with intensities between 6 and 8 m/s. These are the dominant winds generally observed in the study area. Winds from the East, West, and North-East are also observed with less frequency and intensities less than 4 m/s (Fig. 4b).

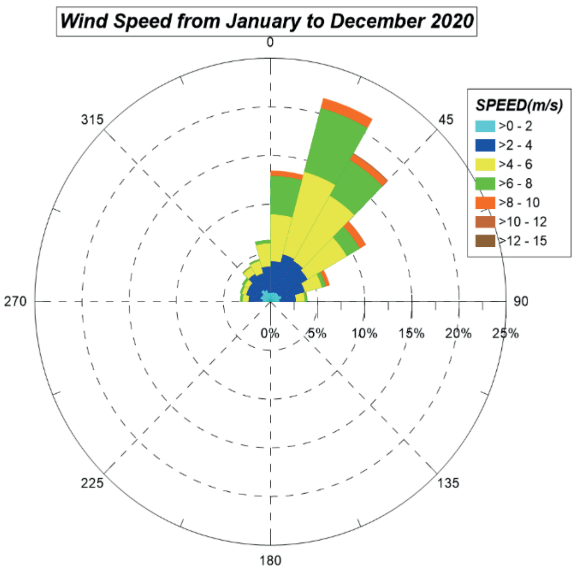

Figure 4.a: Wind rose observed at the entrance inlets of the Oualidia lagoon for the year 2020 and the period from 1st to 15th April, 2020 (simulation period).

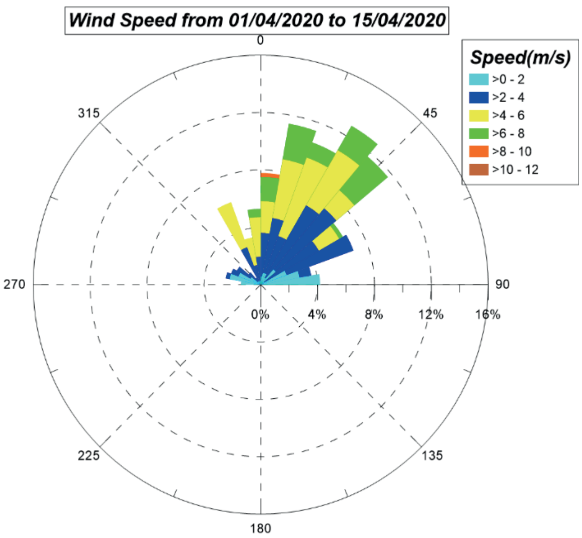

Figure 4.b: Wind rose observed at the entrance inlets of the Oualidia lagoon during the period from 1st to 15th April, 2020 (simulation period).

3.3. Water circulation during neap tide.

In periods of neap tides (ebbor flood tides), the currents are generally of low intensity (< 0.7 m/s) (Fig. 5a). However, exceptional situations exist, such as on April 2nd, 2020, at 01:00 a.m., during the outgoing neap tide period, the current speed reached more than 0.7 m/s. This speed was recorded in the southern part of the main channel on the way to the inlets. This day coincided with a neap tide period, with extreme NE winds of more than 9 m/s occurring in the study area (Fig. 5a). The model outputs show an excellent reproduction of this condition, and the direction of the observed currents is mainly SW following the tidal channel.

3.4. Water circulation during spring tide.

The tidal currents are oriented NW-SE around the coves and sandpit during the spring. However, when

3 See: https://www.ecmwf.int/en/research/climate reanalysis

moving towards the lagoon upstream, the direction of the currents turns SW-NE with intensities between 0.1 m/s and 1 m/s. For example, this phenomenon was observed on April 08th, 2020, at 00:00, during an ebb tide that coincided with NE winds (Fig. 5b). This change of direction of the currents is due to the morphological features of the lagoon. At the main channel of the lagoon, we observed the strongest currents where they register a maximum velocity of up to 1 m/s. These become weaker, with lower amplitude intensities (< 0.2 m/s), as they move toward the upstream area of the lagoon (Fig. 5b). These results show a good agreement with the study of HILMI et al. (2005), which has shown that the maximum speeds observed in the lagoon during the spring tide, were about 0.77 m/s; the tidal flood time was 7 h 25 min, and the tidal ebb time was 5 h during the reflux (Hilmi et al., 2005).

In spring outflow tide (Fig. 5b), and considering April 8th, 2020, at 05:00, the Oualidia lagoon currents tend to be oriented towards the SW following the direction and morphology of the main channel, with intensities ranging between 0. 1 m/s and 1 m/s. A low intensity of current speeds, ranging between 0.1 m/s and 0.3 m/s, characterize the upstream part of the lagoon. The current intensities are higher than 0.5 m/s (Fig. 5b) when we move towards the inlets of the lagoon; the maximum velocities of the currents are mainly concentrated in the main channel, with an amplitude intensity of over 1 m/s, particularly at the extremity of the inlets

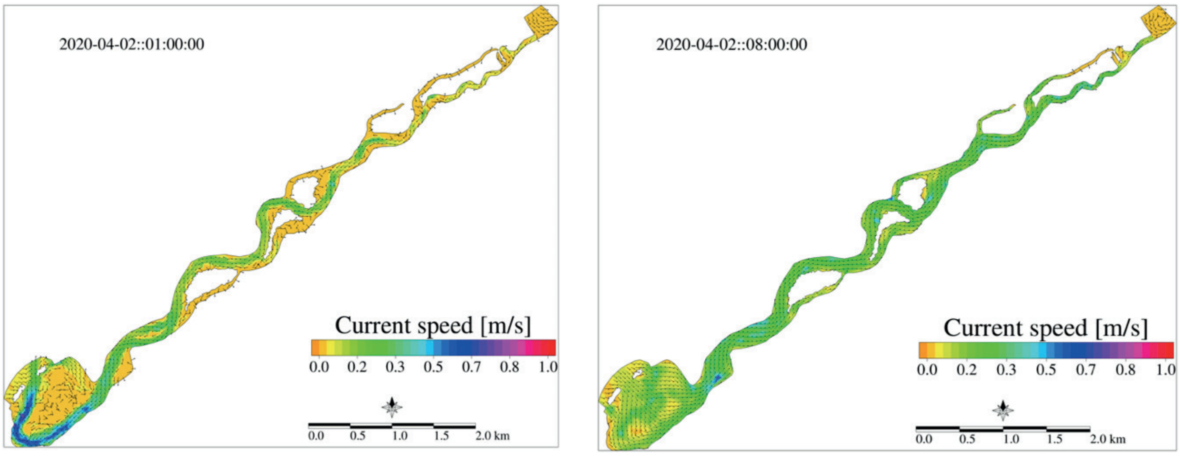

Figure 5.a: (Left) modeled current in the lagoon of Oualidia during the incoming tide for neap tides on 02-04-2020 at 8:00 am, (Right) modeled current in the lagoon of Oualidia during the outgoing tide for neap tides on 02-04-2020 at 1:00 am.

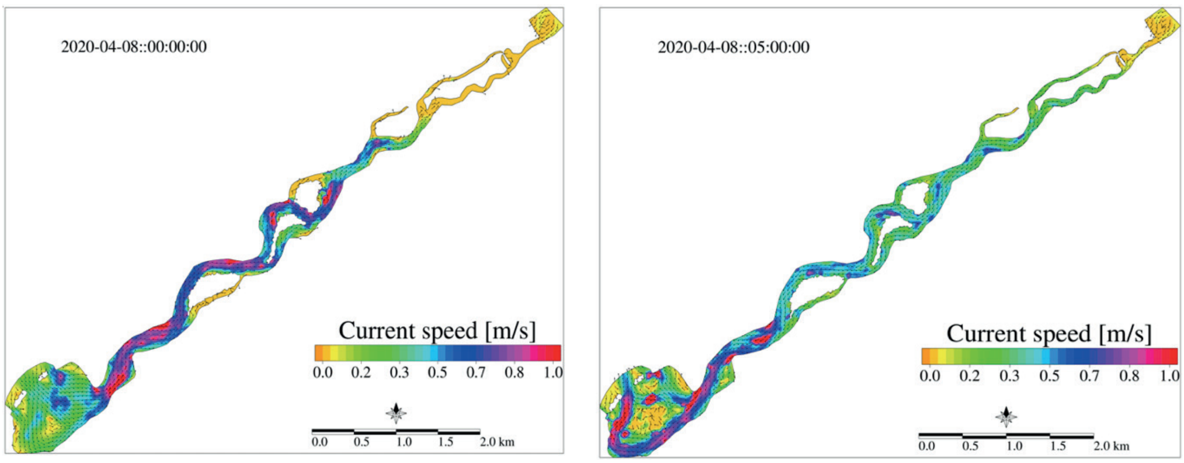

Figure 5.b: (Left) Current modeled in the lagoon of Oualidia in period of incoming tide for spring tides on 08-04-2020 at 00h00, (Right) Current modeled in the lagoon of Oualidia in period of outgoing tide for spring tides on 08-04-2020 at 05h00.

In terms of sediment distribution, current dynamics could be the main factor controlling this distribution. Based on previous studies, the spatial distribution of sediments in the Oualidia lagoon indicates that the upstream part of the lagoon presents muddy facies (LAISSAOUI et al., 2018; MAKAOUI et al., 2018; MEJJAD et al., 2020b; ZOURARAH et al., 2007), and low hydrodynamic circulation (Fig. 5a and 5b). On the contrary, the downstream part is sandy with strong hydrodynamic circulation (Fig. 5a and 5b). Although vertically, the sediments of the Oualidia lagoon show a change in grain size distribution, the sediments are coarser (marine influences) on the bottom and more refined on the surface (continental influences) (BIDET & CARRUESCO, 1982; ZOURARAH, 2002). The sedimentary facies change results from the sediment distribution, the sedimentation regime, and the hydrodynamic conditions (MEJJAD et al., 2020b). The sediment accumulation and sedimentation rate values were shallow in the upstream part compared to the downstream. This indicates that the hydrodynamic circulation controls the distribution of sediments in the lagoon (MEJJAD et al., 2020b).

The renewal time of the waters of the Oualidia lagoon is an important parameter in understanding its hydrodynamic functioning, as reported in (KOUTITONSKY et al., 2007). It was found that the local renewal time (LRT) of the Oualidia lagoon varies between 1 day near the lagoon's entrance inlets to 30 days at its artificial downstream dike, and the integral renewal time (IRT) is 15 days on average (KOUTITONSKY et al., 2007).

4. Conclusion

This paper aims to study the marine circulation of the lagoon of Oualidia (Morocco) through a 2D hydrodynamic model from April 1st to 15th, 2020. The circulation is mainly induced by winds and by the influence of semi-diurnal tides of type M2 (period 12.42 h). The currents have intensities generally higher than 1 m/s during spring tides, while the average current intensity reaches 0.7 m/s during neap tides. The currents inside the lagoon, mainly influenced by the North to Northeast trade winds, follow two different directions depending on the type of tide and the morphology of the main channel of the lagoon.

During the rising tide, the currents are directed in an NW-SE direction in the downstream part of the lagoon. Then, these currents change their direction to SW-NE in the upstream area. During the ebb tide, these currents switch to NE-SW direction in the upstream area and then SE-NW in the downstream area close to the inlets, by 180 degrees according to the channel ax. This study has therefore allowed us to understand the lagoon hydrodynamic functioning, but further work by 3D hydrodynamic modeling of the lagoon must be undertaken; mainly, we need to understand in more detail the hydrodynamics of this ecosystem and the water renewal time of the lagoon, which is a physical parameter taking into account the recurrent changes in the morphology of the main channel.

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The Sidi Moussa-Oualidia wetland complex : A Bird Paradise between land and sea

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Abstract. The Sidi Moussa-Oualidia wetland complex is a unique natural ecosystem of significant national and international importance, as designated by the Ramsar Convention. Located in the Moroccan Atlantic zone between El Jadida and Oualidia, this wetland fulfils many functions. The most important are the rich biodiversity, ecological, hydrological, and economic functions are the most important. Regular censuses, carried out during winter between 1993 and 2022 in the Sidi Moussa-Oualidia lagoon complex, made it possible to determine the composition of the waterbird population that frequents this site and to define the status of the various encountered species. Emphasis was also made on the value of this complex, particularly for breeding, based on monitoring work and our unpublished observations. Ninety-six (96) species frequented the site, 51 of which are regular. Waders represent the most dominant group, followed by Laridae and Anatidae. The remaining groups, poorly represented in numbers, total some 29 species, of which twelve (12) are accidental or rare, and nine (9) are mainly observed outside the wintering period. However, some species are particularly interesting, such as the Greater Flamingo, the Eurasian Spoonbill, and the Red-knobbed Coot. Of the 51 regular species in the site, 16 are breeding ones, including species classified as threatened or near-threatened on the global red list (Marbled Teal, Ferruginous Duck) and others considered threatened in Morocco (Purple Swamphen, Red-crested Pochard), rare (Little Tern) or remarkable (Red-knobbed Coot). Despite this ornithological richness, the site is subject to multiple constraints. Creating a specific administrative structure similar to an 'Agency for the development of the Sidi Moussa-Oualidia complex' could be a potential solution for the control, rational management, and sustainable local development.

Key words: Wetlands, Sidi Moussa-Oualidia lagoons, Waterbirds, Morocco.

1. Introduction

Wetlands provide important ecosystem services for humans and nature (Millennium Ecosystem Assessment, 2005). In addition, they can be a source of protection by mitigating climate change effects through carbon sequestration and acting as buffers against sea-level rise, extreme events, and consequences of floods and droughts, thus ensuring a regular rainfall distribution throughout the year. This dynamism and regularity explain why many plant and animal species (birds, mammals, reptiles, amphibians, fish and invertebrates) depend on these environments for survival.

Wetlands offer considerable global economic benefits: water supply (quantity and quality), fisheries, agriculture, timber, energy resources, wildlife, transport, recreation and tourism opportunities (Schuyt & Brander 2004). In Morocco, as in other arid countries, the sustainability of these ecosystems ensures the sustainability of services that guarantee local and even national development.

They are also seen as connecting points between habitats and ecosystems. Thus, major bird migratory flyways depend to a large extent on wetlands. This role led to the first Global Intergovernmental Treaty on the conservation and wise use of natural resources, the Ramsar Convention: Convention on Wetlands of International Importance, especially Waterbird Habitat.

Waterbirds have contributed significantly to the conservation and dissemination of the values of these natural areas. These populations provide ecosystem services (Wenny et al. 2011; Green & Elmberg 2014). Several aspects of their ecology

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make them sound like bioindicators of good environmental functioning, production, and biological richness (AMAT & GREEN 2010; EGWUMAH 2017 Bird species are susceptible to known ecological stressors. They can generally assess these factors' effects on the biotope and the response of other taxa present in the habitat. These populations are at the top of the food chain and are sensitive to changes occurring along that chain.

Located on the East-Atlantic flyway, one of the most used migration routes in the Western Palearctic, Morocco's wetlands are a migratory stopover and winter refuge for various species of waterbirds. Morocco is one of North Africa's wealthiest countries for wetlands (estuaries, lagoons, lakes, temporary ponds, rivers, etc.). It has four main lagoons on a marine coast of about 3600 km. Among the three lagoons on the Moroccan Atlantic coast, the Sidi Moussa-Oualidia lagoon complex is known for its ornithological importance. Waterbirds find the lagoon's resting, feeding and breeding sites (EL HAMOUMI et al. 2000). This ornithological interest allowed their selection during the project "Identification of a Network of Protected Areas in Morocco" as a "Site of Biological and Ecological Interest" (AEFCS 1996). They have also been included in Morocco's list of " Importance Birds Area" (I.B.A.). The entire site, previously subject to significant hunting pressure, has been classified as a 'Permanent Hunting Reserve' since 1984. Since 2005, the site has been classified as a RAMSAR site of international importance (EL HAMOUMI et al. 2011). It is also one of the 11 "Emerald" pilot sites designated in Morocco under the Bern Convention.

Several studies have been carried out on this site's avian biodiversity. They focused on the assessment of:

- the seasonal phenology and the distribution of birds using the Sidi Moussa–Oualidia wetlands (EL HAMOUMI 2000; El HAMOUMI Et al. 2000; EL HAMOUMI & DAKKI 2010),

- the birds monitoring of Sidi Moussa lagoon and salinas; and the trophic relationship between birds and macrobenthos (JOULAMI 2013; JOULAMI et al. 2013; 2019)

- the monitoring of breeding birds (BENAJAH et al. 2010; EL HAMOUMI et al. 2014; EL MALKI 2017; El Malki et al. 2013; 2018).

This article aims to synthesize the ornithological richness of this complex. This synthesis aims to determine the composition and abundance of the wintering birds of this complex and to evaluate the conservation status and heritage species (patrimonial species) that frequent it.

2. Materials and methods

2.1. Study Area

The Sidi Moussa-Oualidia lagoon complex is a set of coastal wetlands stretching over 40 km between the village of Sidi El Abed in the north (GPS: 33° 02' 49" N), 35 km south of El Jadida, and the small town of Oualidia in the south (GPS 32° 44' 03" N), 66 km north of Safi. It comprises two tidal lagoons (Sidi Moussa to the north and Oualidia to the south), several salt pans, and brackish marshes (El Hotba-Wlad Salem marshes) (Fig. 1).

This complex is organized along a sea-land transect: coastal habitats (beaches, dune environments), lagoons, and peripheral marshes covered by plant formations typical to wetlands (reedbeds and salt meadows) and cultivated areas of the coastal plain. Each biotope is characterized by several habitat types corresponding to the different physiognomic types encountered (Fig. 5).

Lagoons

Two lagoons are found in the complex, the Sidi Moussa lagoon to the north and the Oualidia lagoon to the south. Their permanent communication with the ocean makes them similar to the coastal marine environment. They are under the influence of tidal regime (ebb and flow). They are formed by a sandpit (Fig.2) followed by a Salicornia meadow crossed by the main channel lined with secondary channels partially covered by algae and eelgrass meadow. The substrate is sandy near the channels and becomes increasingly muddy towards the bottom of the lagoon. The banks of these channels are made of soft mud forming the slikke (intertidal mud flats area).

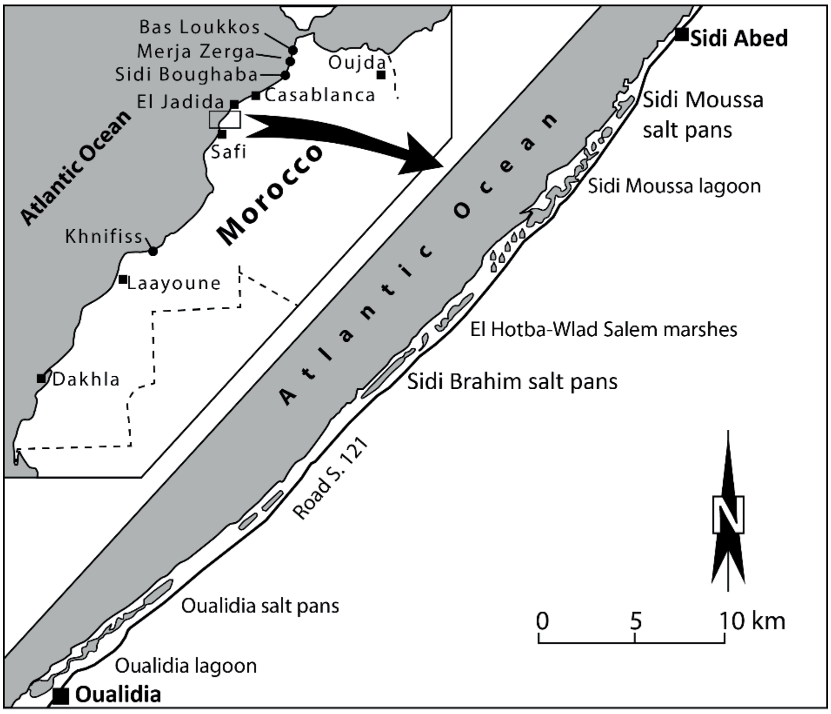

Figure 1 : Location of the Sidi Moussa-Oualidia complex (EL HAMOUMI et al. 2000)

Figure 2 : Photo of the Oualidia lagoon sandpit (January 2022)

El Hotba-Oulad Salem brackish marshes

It is a large body of brackish water called El Hotba-Wlad Salem marshes, fed mainly by groundwater supplemented by rainwater. This area lacks emergent marsh vegetation but has abundant submerged algal vegetation. A halophilic meadow surrounds the latter in the form of a band of vegetation of variable width, generally flooded in winter. It consists mainly of *Junccus rigidis*, *J. acutus* and S*arcocornia*. This halophilic grassland is flooded in winter.

The emerging vegetation is a strip of *Phragmites australis*, which is found in the permanently wet parts of marshes on sandy soils. This zone, alternately emerged and immersed depending on the season, is shallow and can be largely or even completely submerged during the dry season, revealing wide muddy beaches on the borders (Fig.3).

Saltpans (Salinas)

Saltpans are composed of a series of evaporation basins separated by partitions covered generally by halophytic vegetation. *Sarcocornia fruticosa* dominates the latter; however, the separations bordering the overly saline ponds are unvegetated (Fig.4).

2.2. Data collection

The diagnosis is based on our winter census results to understand the site's avifauna state. These counts have been carried out regularly in the Sidi Moussa-Oualidia wetland complex by the Centre-Atlantic Research Group for the Protection of Birds in Morocco (GREPOM/Birdlife) and the Hassan II University of Casablanca since 1993.

2.3. Species of interest status

The site's ornithological value is evaluated by considering the species' heritage importance and protection status regarding Morocco's national legislation and international agreements. These are essentially The Master Plan for Protected Areas (AEFCS 1996) and the World Red List according to the International Union for Conservation of Nature (IUCN)[1].

Figure 3 : El Hotba-Ouald Salem marshes (May 2021)

Figure 4 : Sidi Moussa Salines (May 2021)

[1] www.redlist.org

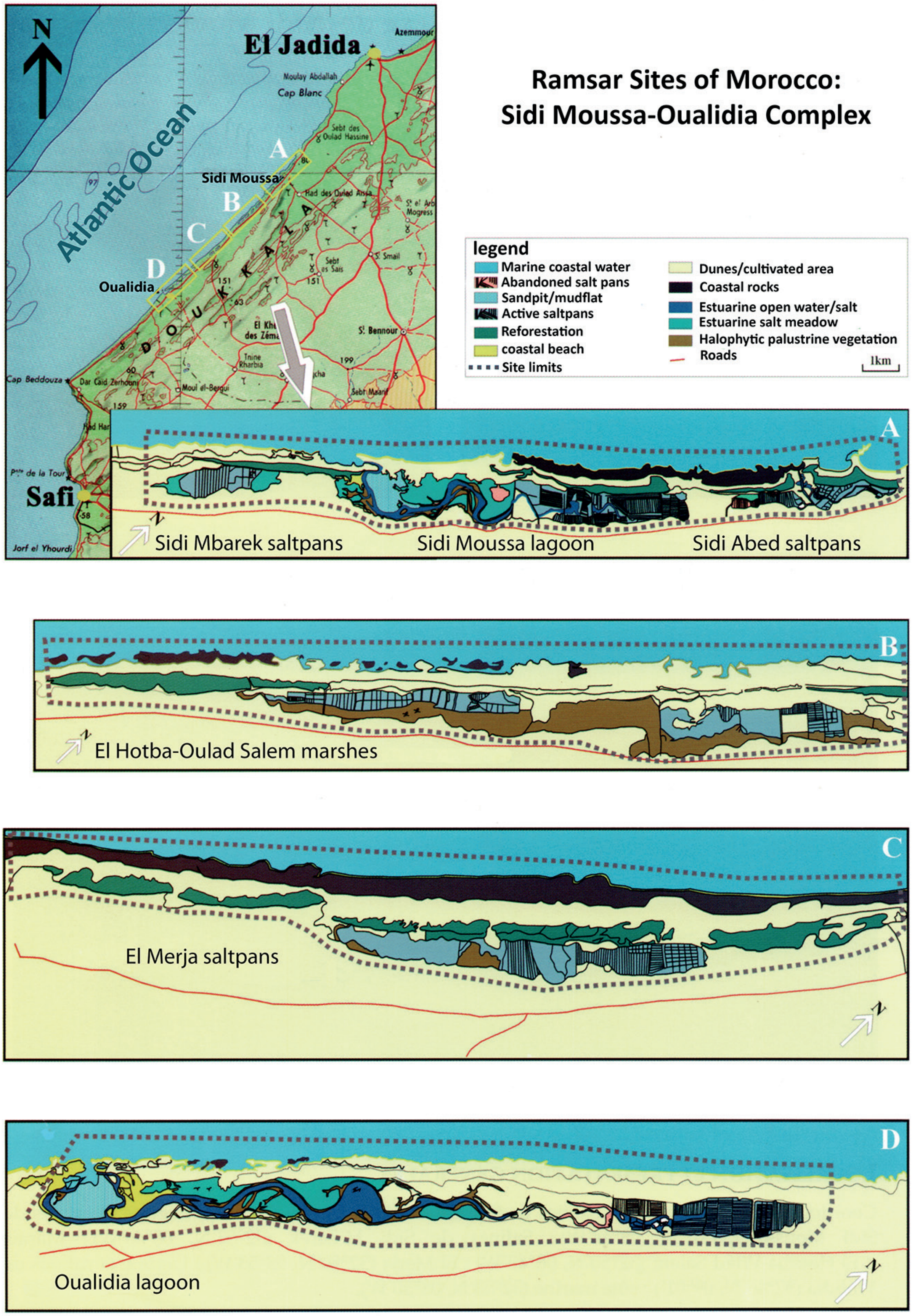

Figure 5 : Sidi Moussa-Oualidia complex habitat map (El Hamoumi & al. 2011

3. Results

3.1. Wintering waterbird composition and structure

Almost all birds using the East-Atlantic route pass through the Sidi Moussa-Oualidia wetland complex and nearly all species regularly wintering in Morocco were recorded there. Ninety-six (96) species of waterbirds were registered at the complex during the winter period 1993-2022. Fifty-one (51) were regular visitors, most of them represented in relatively high numbers. In addition, it should be noted that several of these species observed in the site are incidental (*Anas carolinensis, Spatula discors, Aythya marila, Egretta gularis, Calidris melanotos and Phalaropus lobatus*) or rare species in Morocco (*Branta bernicla, Calidris temminckii Phalaropus fulicarius, Hydrocoloeus minutus* and *Chlidonias leucopterus*). Similarly, some migratory and/or summer breeding species occasionally visit the site during winter: *Anas querquedula, Nycticorax nycticorax, Ardea purpurea, Sternula albifrons, Gelochelidon nilotica, Sterna hirundo, Sterna paradisaea, Chlidonias niger* and *Chilodinias hybrid*.

An average of 15,070 birds (1993-2022) are hosted by these wetlands, representing more than 3% of the wintering waterbird population in Morocco. These numbers have exceeded the 20,000 thresholds (Criterion 5 of Ramsar sites criteria) for several years (Fig. 6). Total numbers show considerable fluctuations over the period under review, ranging from 6,188 (in 2015) to 35,193 (in 2001). Similarly, numbers vary greatly with the species, as three groups account for 87% of winterers: waders (53%), larids (17%), and Anatidae (17%). The other groups: Divers and Grebes, Ibises, Spoonbills and Storks, Rallidae and Cranes, Flamingos, Ardeidae, and Cormorants, account for only 13% (Fig. 7).

3.2. Representativeness of wintering bird groups

Waders

Waders, with a mean number of 8006 individuals, are the most abundant and frequently encountered group et the site, representing more than 50% of the wintering waterbird population; they are dominant in terms of species number, followed by Anatidae and Laridae (Fig. 7). Moreover, this complex is considered among the best sites for waders wintering and passage in Morocco after Merja Zerga lagoon and Dakhla Bay.

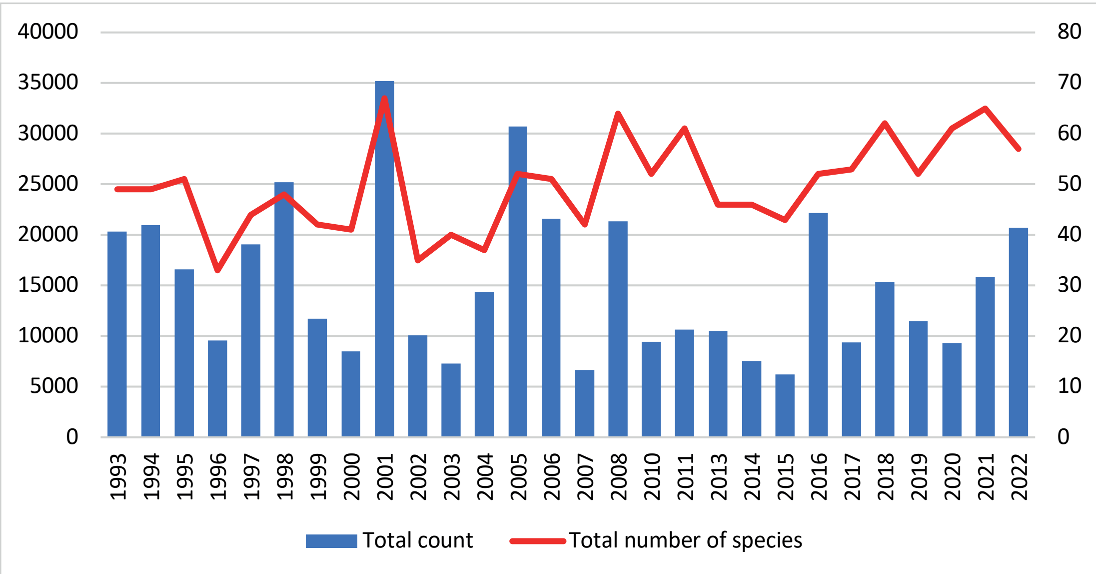

Figure 6: Annual changes in the abundance and species richness of waterbirds at the Sidi Moussa–Oualidia wetland complex, between 1993 and 2022.

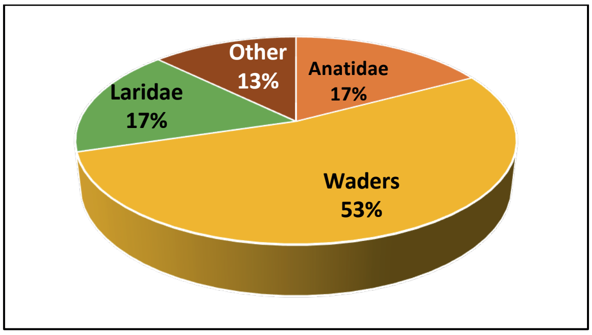

Figure 7: Representativeness of different groups of wintering waterbirds in the Sidi Moussa-Oualidia complex (1993-2022)

Ten species alone represent more than 86% of the waders. In decreasing order of representation, these are *Calidris alpina, Pluvialis apricaria, Himantopus himantopus, Pluvialis squatarola, Calidris minuta, Limosa limosa, Charadrius hiaticula, Recurvirostra avosetta, Tringa totanus* and *Charadrius alexandrinus.*

Anatidae

Although the arrival of the first migratory Anatidae begins in September, the most significant concentrations are reported in the wintering period, with 20 species and an average number of 2589 of ducks during the period under consideration. The maximum recorded was in 2005 with 9015 ducks. The majority of these ducks frequent the El Hotba-Wlad Salem marshes. However, it has been noted in recent years that a relatively large number of ducks can be observed in Sidi Moussa and Oualidia salinas following the abundant salt production activity. Therefore, constructing a reservoir (Souille) at the northern end of the Oualidia lagoon reduces its confinement and improves the quality of its waters.

The Northern Shoveler *Spatula clypeata* is still predominant, with an average proportion of over 58% of the total Anatidae population; the Marbled Teal *Marmaronetta angustirostris* is second with 13%, followed by the Common Pochard *Aythya ferina* (7%), while the Eurasian Wigeon *Mareca penelope*, the Northen Pintail *Anas acuta* and the Mallard *Anas platyrhynchos* are poorly represented (4 to 5%). The remaining species represent a tiny proportion of the Anatidae population.

Laridae

A total of 16 species of Laridae are observed in winter at Sidi Moussa-Oualidia. They are often represented in relatively low numbers in the complex, with an average number of 2553 of individuals. In 2016, a maximum of 13,000 specimens was recorded, including 9,000 lesser black-backed gulls. Three species together account for 91% of the total number of Laridae: The Lesser Black-backed gull *Larus fuscus*, the Black-headed Gull *Chroicocephalus ridibundus* and Audouin's Gull *Ichthyaetus audouinii*. Despite their small numbers, the Mediterranean Gull *Ichthyaetus melanocephalus*, the Slender-billed Gull *Chroicocephalus genei*, the Gull-billed Tern *Gelochelidon nilotica* and the Caspian Tern *Hydroprogne caspia* are interesting visitors as they are rare in Morocco.

3.3. Ornithological Values of the Site

3.3. 1. Heritage species in Morocco

According to the Moroccan Protected Areas Master Plan (AEFCS, 1996), the waterbird contingent of the complex includes several heritage species: one (1) endemic subspecies, two (2) species of global interest, nine (9) nationally threatened species, six (6) nationally rare species, and one (1) remarkable species of Afro-tropical origin (Table 1).

3.3.2. Species classified on the red list of International Union for Conservation of Nature (IUCN)

Among the wintering species observed in the site during the period under review, three (3) species are threatened by the extinction of their wild populations; they are classified on the IUCN red list as **Vulnerable (VU)**. These are the Marbled Teal *Marmaronetta angustirostris*, the Common Pochard *Aythya farina,* and the Audouin's Gull *Ichthyaetus audouinii*. Seven (7) other species observed are classified as **Near Threatened (NT)**, i.e., they are nearly to meet the criteria of vulnerable or are likely to do so, in the near future dependent on conservation efforts (Table 2).

Table 1: List of heritage species in Morocco

Scientific Name	English Name	Latin Name	English Name
Endemic subspecies of Morocco			
Phalacrocorax carbo maroccanus	Great Cormorant		
Species of Global Interest (2)			
Marmaronetta angustirostris	Marbled teal	*Ichthyaetus audouinii*	Audouin's Gull
Species of National Interest, Threatened (5)			
Ardea purpurea	Purple Heron	*Netta rufina*	Red-crested Pochard
Aythya nyroca	Ferruginous Duck	*Rallus aquaticus*	Water Rail
Porphyrio porphyrio	Purple Swamphen		
Nationally rare species (4)			
Sternula albifrons	Little Tern	*Gelochelidon nilotica*	Gull-billed Tern
Hydroprogne caspia	Caspian Tern	*Tringa stagnatilis*	Marsh Sandpiper
Notable species at the Western Palearctic scale: Species of Afro-tropical origin			
Fulica cristata	Red-knobbed Coot		

Table 2: List of species classified on the IUCN Red List
(VU: Vulnerable; NT Near Threatened)

Nom Scientifique	English Name	Statut de conservation
Marmaronetta angustirostris	Marbled Teal	**VU**
Aythya ferina	Common Pochard	**VU**
Ichthyaetus audouinii	Audouin's Gull	**VU**
Aythya nyroca	Ferruginous Duck	NT
Haematopus ostralegus	Eurasian Oystercatcher	NT
Vanellus vanellus	Northern Lapwing	NT
Numenius arquata	Eurasian Curlew	NT
Limosa lapponica	Bar-tailed Godwit	NT
Limosa limosa	Black-tailed Godwit	NT
Calidris canutus	Red Knot	NT

3.4. The complex's importance for breeding waterbird.

Compared to other wetlands on the Atlantic coast of Morocco, the diversity of breeding aquatic birds in the complex is generally lower than in the Bas Loukkos marshes, Merja Zerga, Merja de Sidi Boughaba (CHERKAOUI et al. 2013; 2016) or the Oued Massa estuary, but higher than in Khnifiss lagoon. However, new surveys of the El Hotba Wlad-Salem marshes during the breeding season will undoubtedly provide further information on the breeding of several species and confirm doubts regarding other species' nidification.

Due to the constant disturbances in the Sidi Moussa-Oualidia area, breeding numbers are often low and unstable, except for waders. Therefore, annual disturbances, mainly grazing and cutting of marsh vegetation, and seasonal disorders, such as egg collection, massive tourist frequentation, and marshes drying, occur during the breeding season.

Sixteen (16) species have chosen the complex's wetlands for breeding. These are four (4) species of duck (*Marmaronetta angustirostris* Marbled Teal and *Anas platyrhynchos* Mallard, *Netta rufina* Red-crested Pochard, *Aythya nyroca* Ferruginous Duck), one (1) species of Grebes (*Tachybaptus ruficollis* Little Grebe), one (1) species of Ardeidae (*Bubulcus ibis* Cattle Egret), four (4) species of Rallidae (*Gallinula chloropus* Common Moorhen, *Porphyrio porphyrio* Purple Swamphen, *Fulica cristata* Red-knobbed Coot, *Fulica atra* Eurasian coot), one (1) species of Stork (*Ciconia ciconia* White Stork), three (3) species of Waders (*Himantopus himantopus* Black-winged Stilt (Fig. 8), *Charadrius alexandrinus* Kentish Plover, *Glareola pratincola*, Collared Pratincole (Fig.9)) and two (2) species of Laridae (*Chroicocephalus ridibundus* Black-headed Gull (Fig.10), *Sternula albifrons* Little Tern).

Figure 8: Black-winged stilt nest, Sidi Moussa Salines (May 2021)

Another species that does not frequent wetlands but nests in the adjacent fields is the Common Buttonquail Turnix sylvaticus. Once known as a common resident, the subspecies T. s. Sylvaticus, which lives in Andalusia (southern Spain) and Morocco, is endangered due to its severe population decline in the early 20th century. The last wild population of this subspecies occupies the coastal area between Sidi Abed (El Jadida) in the north and Cap Bedouzza (Safi) in the south, as well as in the hinterland of the Oualidia lagoon (9 to 15 km from the coast). The species' history and its current distribution in Morocco have been described recently by Gutiérrez Expósito et al. (2020). A tiny population frequents the different crop fields (alfalfa, pumpkin, maize, carrots, tomato, cereals, and potato) and fallow fields in the coastal zone and mixed vegetation (Doum palm, Retama, and Broom shrubs) in the hinterland. This rare and very localized bird is threatened by hunting because of its strong resemblance to the common quail. Poaching and disturbance by farmers are other threatening factors to be considered.

Figure 9: Collared Pratincole nest, Sidi Moussa Salines (May 2021)

Figure 10: Black-headed Gull nest, Oualidia Salines (May 2021)

4. Conclusion

The Sidi Moussa-Oualidia wetland complex is an area of exceptional importance, notable for the biological richness of its ecosystems and forming a vital relay for avifauna. Although the site is considered a highly humanized coastal plain landscape, it has not lost its originality and biodiversity. However, strategic management axes need to be considered for its conservation and the protection of its avian diversity, particularly waterfowl. These include the restoration and rehabilitation of degraded natural environments to enable the development of sustainable biological resource management activities.

Developing a communication, information, or training strategy is necessary to raise the awareness of decision-makers, various local stakeholders, and the general public about the importance of conserving birds and their habitats. However, this can only be effective if accompanied by the creation in the area as a whole of incentive activities, by and for the local populations, on sustainable management of natural resources (agro-pastoralism, eco-tourism, artisanal fishing, management and valorization of pharmacopoeia, etc.) to reduce the pressure on these complex wetlands and their resources.

The area has excellent tourism potential due to its landscape beauty, rich biodiversity, and accessibility (presence of a reasonably busy road reinforced by a highway). In addition, numerous opportunities exist to preserve this complex and its biodiversity, particularly avian biodiversity. Nevertheless, the region has some constraints that the administration must overcome to ensure sustainable development.

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Macroalgal communities and seagrass distribution in Oualidia lagoon (Moroccan Atlantic).

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Abstract. We study the biodiversity status of macrophyte communities and seagrass in Oualidia lagoon and assess species composition in the area. The sampling site is located on the Atlantic coast of Morocco, considered as one of the four Moroccan sites that the RAMSAR Convention considered for the conservation of wetlands of international interest. In a 50 cm× 50 cm quadrat, we used scuba diving to collect samples from sixty-eight stations on 2021. Our study recorded 17 macroalgae species and seagrass with *Sargassum muticum*, noted as a new record for this area. The most dominant division with the highest species richness was Rhodophyta, with 9 species representing 53% of the total species recorded, and Chlorophyta and Phaeophyta, with three species for each one making up 18% of the total species richness, respectively. Seagrass was represented by two species contributing 11% of the total species richness. This study will contribute to the seaweed database of Morocco for future references, which may help conserve seaweeds.

Key words: Oualidia lagoon, Flora, Algae, *Gracilaria*, *Sargassum*, spatial distribution.

1. Introduction

Coastal lagoons are transitional environments between riverine-terrestrial and marine ecosystems. Shallow lagoons are important land-margin ecosystems worldwide, constituting at least 14% of the world's coastline (CROMWELL 1971). They play a key role as spawning grounds for fish and shellfish and are extensively exploited for aquaculture. They are considered as important centers for economic, social and cultural development and were early sites for human settlement (LASSERRE 1979; BARRAQUÉ et al., 1998). Lagoons are highly dynamic environments controlled by physical processes, subjected to marine and continental influences (BARNES 1980).

These shallow coastal systems are often characterized by unpredictable hydrological, geomorphological and chemical conditions (MAGNI et al., 2006 ; KANAYA et al., 2015), which vary widely on a seasonal or even daily basis, and cause changes in the structure and the distribution patterns of inhabiting organisms. These soft bottom systems provide extensive areas for seagrasses and macroalgae (NORTON et al., 1983 ; SAND-JENSEN et al., 1991 ; BOYTON et al., 1996). Seagrasses and low density algal mats are important habitats, providing nursery grounds for fish, substrate for attachment of sessile organisms, shelter from predation, food supply, and amelioration of adverse stresses such as desiccation (NORKKO et al., 1998 ; NORKKO et al., 2000).

Several lagoons are located along the Atlantic and Mediterranean coasts of Morocco. Among them the lagoon of Oualidia is one of the most historical and socio-economic important Moroccan lagoons. Several studies have been carried out there in biology (BEAUBRUN, 1976 ; CHBICHEB, 1996 ; EL ASRI et al., 2015), hydrology (ORBI et al. 1998 ; RHARBI et al. 2001), Geology (CARRUESCO, 1989 ; FAKIR, 2001), sedimentology (SARF, 1999), quality and safety (BENNOUNA, 1999 ; CHAFIK et al., 1996 ; EL ATTAR, 1998) and currentology (HILMI et al., 2005). However, information on the occurrence and distribution of flora remains very limited. The results of the present study are important to complete our knowledge about the richness of the flora in the Moroccan Atlantic coast. The main goal of this research was to conduct a short-term study:

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- to provide a first quantitative data set of macroalgal distribution patterns in the Oualidia lagoon,
- to assess taxonomic richness, and abundance of key species and,
- to give a record of macroalgae distribution with focus on Gracilaria species and *Sargassum muticum*.

2. Material and methods

2.1 Study area

The Oualidia lagoon (34°47'N-6°13'W and 34°52'N-6°14'W) is located on the Atlantic coast of Morocco, between El Jadida and Safi (Fig. 1). The lagoon measures 7 km long and about 1 km wide. Lateral channels, connected to a meandering main channel, with an average depth of 2 m and a maximum depth (during flood tides) that does not exceed 5-6 m (CARRUESCO, 1989), characterize the lagoon morphology. The lagoon opens to the Atlantic Ocean by two inlets (first field). A main (150 m wide), permanent and active throughout the year, and an active secondary inlet (50 m wide), only during the tidal period of spring tides (CARRUESCO, 1989). In Oualidia, the mean annual rainfall and temperature are respectively 307 mm and 18.3°C. The wettest month is November and the driest period is May to July. The temperature of the surface water of the Oualidia lagoon ranges from a minimum of 15.1°C recorded in January 2018 and a maximum of 27.6°C in August 2017 (ANHICHEM et al. 2021).

The Oualidia lagoon is one of the four Moroccan sites considered by the RAMSAR Convention for the conservation of wetlands of international interest. It provides a valuable coastal environment for the various bird, fish, plant, and wildlife species. The Oualidia lagoon is the primary resource for the livelihood of local fishers. In addition, it has many resources, such as water birds, aquatic animals, seaweeds, and sea grass; therefore, it is considered a natural park area and the most important wintering site for migratory birds in Morocco. Aquaculture activities are significant, especially oyster farming, which has been conducted since 1950. The main activities are agriculture (essentially cereals and vegetables) and cattle rearing (practiced by more than 90% of the population), shell-fishing (15%), and tourism. Agro-chemical products are used in 78% of the cultivated area around the lagoon (Maanan et al., 2014). The main activities in the neighborhood of the site are agriculture, livestock raising, salt production, tourism, ...

2.2 Sampling procedure and laboratory analyses

This study presents the distribution and density of different macroalgae species. Sampling in the Oualidia lagoon was carried out in February 2021 by scuba diving in 68 stations and using a 50cm x 50cm quadrat. We took a triplet for each station to characterize the hydrological parameters and recorded the stations with zero biomass. Temperature, salinity, and dissolved oxygen were recorded using a calibrated multiparameter probe (ProDSS, USA). In addition, we measured the pH with a portable pH meter (pHScan WP 1/2). We note that the characteristics of the marine water were constant throughout the study period. Samples of macroalgae and seagrasses and their composition and abundance were evaluated in the laboratory. First, they were rinsed with water to remove associated sediments. They were sorted by species, weighed, and dried at 60°C until we obtained a constant weight. Finally, the subsamples were preserved in formaldehyde buffered seawater (5%) for subsequent microscopic examination, and some specimens were subjected to morphological and anatomical investigations for identification.

3. Results

3.1 Environmental data

Different types of substrata were observed in Oualidia lagoon. Six sedimentary types were identified: muddy, sandy-mud, rock, rock-sand, sand, and seashell sand. Mud was predominant with 46% spatial coverage, followed by sand (23%) and muddy sand (21%). rocks, shell sand and sandy rock are marked by a low presence, respectively 6%, 3% and 2% of the covered area (Fig. 2).

Temperature variation in the Oualidia lagoon presented an increasing gradient downstream upstream, which was recorded in the range of 15.3-17.7 °C in February 2021 (Fig. 3). These values are close to the minimum ones known in values are close to the minimum ones known in the region, characterized by a water surface temperature range from a minimum of 15.01 ° C recorded in January 2018 to a maximum of 27.60° C in August 2017 (ANHICHEM et al. 2021). Overall, the temperature was homogenous with depth due to the shallowness of the study area. The distribution of salinity followed a decreasing gradient from downstream to upstream of the lagoon. Salinity ranged from a minimum of 17.3 ‰ to the maximum value of 35.1‰ recorded at the middle of the lagoon. (Fig.4). The higher dissolved oxygen values (9. 8 mg/l) were recorded downstream in the main channel : the lower ones (7.5 mg/l) were recorded also downstream, in the area in front of the "Ostrea oyster farming station" (Fig.5). The pH distribution was recorded in the range 7.6 just before the sandpit and 8.1 downstream in the beginning of the main channel.

3.2. Macroalgal and seagrass community

The biological study of the Oualida lagoon flora has identified 17 macroalgae species and seagrass. The Rhodophyta class is the most dominant with the highest species richness, i.e., 9 species representing 53% of the total species found in the lagoon (Fig.6). Four families represent this class: Gracilariaceae, Gigartinaceae, Phyllophoraceae, and Rhodomelaceae. The Chlorophyta and Phaeophyta classes occupy the second rank, with 18% of the species diversity:

- the Phaeophyta is represented by two families (Fucaceae and Sargassaceae),
- chlorophyta is represented by only one family (Ulvaceae),
- the seagrass, represented by two species, contributes to 11% of the species richness. Each species corresponds to one family: *Cymodoceaceae* and *Zosteraceae*.

The check-list of seaweeds and seagrass found in oualidia lagoon is presented in table 1.

3.3. Macroalgal and seagrass density

The dominant species identified along the Oualidia lagoon were *Gracilaria gracilis* among Rhodophyta, *Sargassum muticum* among Phaeophyta and *Enteromorpha sp* among Chlorophyta. These species indicated a biomass average of 0.84kg/m², 0.90kg/m², and 0.20 kg/m² respectively.

3.4. Macroalgal and seagrass distribution

The distribution of algae and phanerogams in the Oualidia lagoon differs from one species to another. This is linked to the requirements of each species with the environmental conditions and their tolerances to the physicochemical parameters.

Table 1 : Summary of species richness by taxonomic group in the Oualidia lagoon

Family	Species
Chlorophyta	*Enteromorpha intestinallis* (LINNAEUS) NEES 1820
	Ulva fasciata (DELILE 1813)
	Ulva lactuca (LINNAEUS 1753)
Phaeophyta	*Cystoseira humilis* (SCHOUSBOE EX KÜTZING 1860)
	Fucus lutuaris (CHAUVIN EX J. KICKX F.) KÜTZING 1860)
	Sargassum muticum (YENDO) FENSHOLT 1955)
Rhodophyta	*Gigartina teedii* (ROTH) LAMOUR
	Gracilaria multipartita (CLEMENTE) HARVEY 1846)
	Gracilaria sp
	Gracilaria gracilis (STACKHOUSE) STEENTOFT, IRVINE & FARNHAM 1995)
	Gracilaria longissima (S.G.GMELIN) STEENTOFT; IRVINE & FARNHAM 1995)
	Gymnogongrus norvegicus (GUNNERUS) J. AGARDH 1851)
	Halopithys incurva (HUDSON) BATTERS 1902
Seagrass	*Cymodocea nodosa* (UCRIA) ASCHERSON 1870
	Zoostera noltii (HORNEMANN 1832)

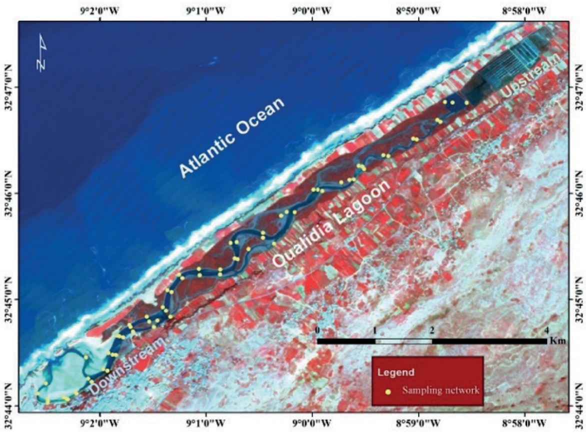

Figure 1: Geographical position of the Oualidia lagoon and location of the sampling stations.

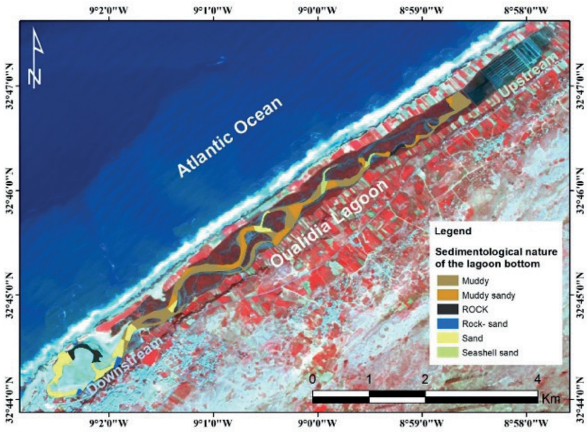

Figure 2: Different types of substratum in Oualidia lagoon (February 2021

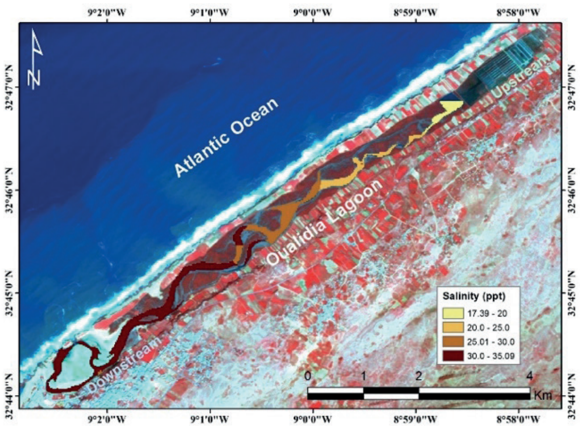

Figure 3: Temperature variation in Oualidia lagoon (February 2021).

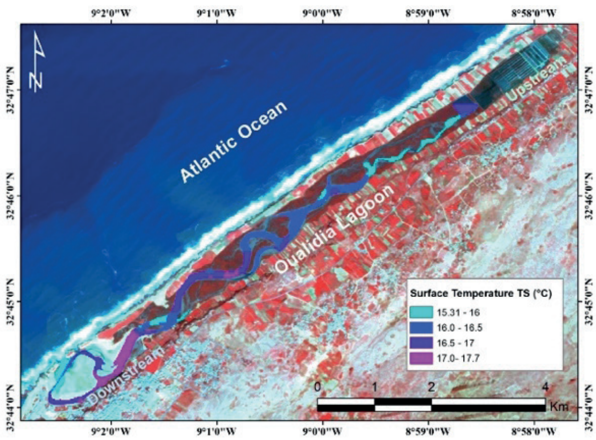

Figure 4: Salinity variation in Oualidia lagoon (February 2021).

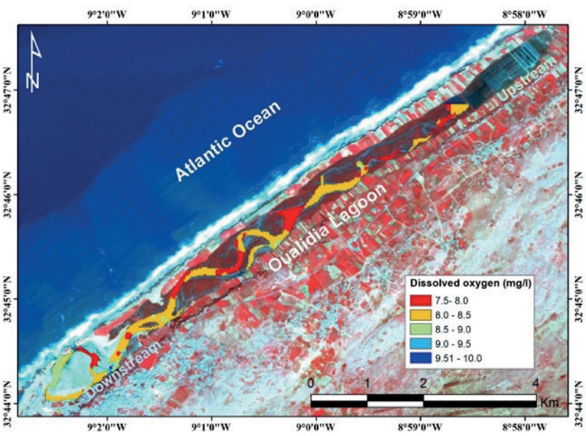

Figure 5: Dissolved oxygen variation in Oualidia lagoon (February 2021).

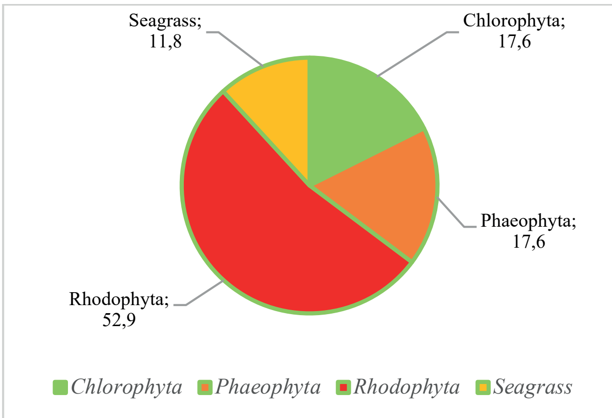

Figure 6 : Macroalgal and seagrass classes in Oualidia lagoon (February 2021).

4. Discussion

As mentioned above, the Oualidia lagoon is one of the most historical and socio-economic important Moroccan lagoons where several studies have been carried out in biology (BEAUBRUN, 1976 ; CHBICHEB, 1996 ; EL ASRI et al, 2015), hydrology (ORBI et al 1998 ; RHARBI et al 2001), geology (CARRUESCO, 1989 ; FAKIR, 2001), sedimentology (SARF, 1999), quality and safety (BENNOUNA, 1999 ; CHAFIK et al, 1996 ; EL ATTAR, 1998) and currents (HILMI et al, 2005). However, information on the occurrence and distribution of flora remains very limited. The present study allows us to obtain an overall picture of the macroalgal and seagrass communities of the Oualidia lagoon. A total of 17 benthic macroalgae and seagrass species were identified in this lagoon. Nevertheless, this number is relatively low compared with the floral diversity of the Atlantic Ocean. It is controlled by environmental stress factors, where fewer species survive and species richness is lower (Menge, 1975). In the present study, the lower species richness recorded in Oualidia lagoon can be explained by the combination of :

- smaller lagoon (3.5 km²),
- time of sampling (winter),
- habitat unavailability and,
- species tolerancy.

Repeated collections at different seasons and investigation would likely capture more taxa. In this survey, the Oualidia lagoon was represented mainly by nine species of red algae (53% of the macroflora) in particular the Gracilaria species. This floristic composition was different from that encountered in some Mediterranean lagoons, in particular the Marchica lagoon (Nador) and Smir lagoon (near M'diq). Indeed, the Marchica lagoon is represented by only 4 species of red algae dominated by *Alsidium helminthocorton*. The *Gracilaria* species were not well represented on the whole Marchica lagoon. They were only present in some stations where nutrient inputs were available (NAJIH et al, 2016). The red algae were represented, in the Smir lagoon, by the species *Gracilaria verrucosa* and *Chondrachantus acicularis* in addition to a few epiphytes (BENHISSOUNE et al, 2005).

The Oualidia lagoon is represented by 3 species of *phaeophyceae* (*Cystoseira humilis*, *Fucus lutuarius* and *Sargassum muticum*). The *phaeophyceae* were represented by a single species in the lagoons of Marchica (NAJIH et al, 2016) and Smir (BENHISSOUNE et al, 2005. In addition, green algae were present in the Smir lagoon as well as in the Oualidia and Marchica lagoons.

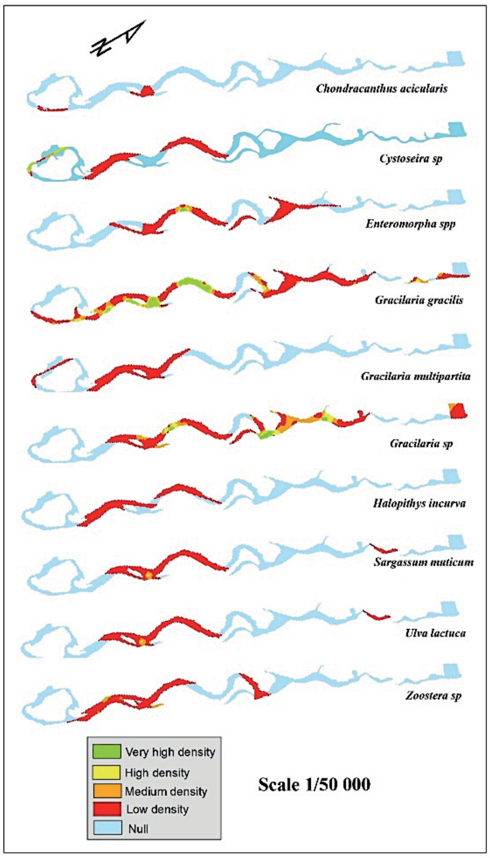

Figure 7: Algal species and seagrass distribution in Oualidia lagoon (February 2021).

With regards to Chlorophyceae, in our survey, we found that they belonged mainly to Ulvaceae. The same result was reported by (BENHISSOUNE et al, 2005) in Smir lagoon. Nevertheless, at the lagoon of Nador, in addition to *Ulvaceae*, *Chlorophyceae* are also represented by *Caulerpaceae* (*Caulerpa prolifera*) and *Cladophoraceae* (*Chaetomorpha linum*) (NAJIH et al, 2016). The spatial distribution analysis of the different species of algae in the

Oualidia lagoon provides information on the species tolerance level to the lagoon's physicochemical conditions. Indeed, the species that resist to environmental physicochemical parameters' significant variations, i.e., temperature, salinity, pH, dissolved oxygen, luminosity, substrate nature, and current speed, can live in different places in the lagoon. In addition, species that do not tolerate these large fluctuations or are demanding for one parameter or another are confined to specific places where living conditions seem to be favorable. For example, in the case of Chlorophycea, the two species *Ulva lactuca* and *Enteromorpha intestinalis*, which occupy a large area of the lagoon, seem to be more tolerant to variations in the environment. Unlike the *Ulva fasciata* species found in a single station, near the downstream side of the lagoon. The presence of *Ulva lactuca* has been observed in different substrates: mud, sandy and rocky mud, at temperatures varying from 15.6 to 17.1°C, salinities from 17.9 to 35 PSU, in an environment with dissolved oxygen, which fluctuates between 7.6 and 8.6 mg/l and at depths ranging from 0.4 to 2.5m. These results are in agreement with other studies showing that these species are widely recognized as resistant to stress. These are plants that tolerate the fluctuating and high temperatures associated with shallow water environments (LITTLER et al, 1980 ; RIVERS et al, 1995 ; RAFFAELLI et al, 1998). *Enteromorpha intestinalis* seems to be more tolerant to environmental conditions but in a lesser degree than *Ulva lactuca*, in particular with regard to salinity (absent at salinities below 22 PSU).

These results agree with other studies where salinity has been reported to be an important parameter in controlling the growth of *Enteromorpha intestinalis* populations (MARTINS et al., 1999). However, *Ulva fasciata* found in a single station can be explained by its more demanding environmental conditions or life cycle. Therefore, its distribution remains limited to particular places in this time of the year. This result agrees with AGUILAR-ROSAS (2005) who found that *Ulva fasciata* plants grow on rocks in the midtidal and upper intertidal zones. They attain maximum development during late summer and early autumn (September), gradually decrease during autumn-winter, and disappear during spring (April). Regarding *Phaeophyceae*, three species were found in the Oualidia lagoon, namely *Cystoseira humilis*, *Fucus lutuaris* and *Sargassum muticum*. Unlike the lagoons of Marchica and Smir where only a single species has been observed (*Cystoseira humilis*). Living in distinct ecological niches, the latter adopt very different strategies to maintain their populations. (PARDI et al., 2000) proved that in the Mediterranean, the individuals of *Cystoseira humilis* can hardly reach the age of 2 years. In Oualidia lagoon, *Cystoseira humilis* was found in a sandy or muddy substratum with temperature between 16.6 and 17.7°C, salinity fluctuated between 31 and 34.7, at depths varying between 0.5 and 1.5 m. *Cystoseira humilis* must be particularly resistant to changing environments, and so it can colonize the upper shore. The invasive species *Sargassum muticum* was found in Oualidia lagoon in five stations, characterised by rocky, sandy or rocky-sandy substratum, with temperature variying between 16.9 and 17.7°C, salinity fluctuated between 31.7 and 33.5 psu and in depth not exceding 1.7m. Since this alga had previously been recorded only off El Jadida coast (North Atlantic Moroccan coast, SABOUR et al., 2013). This result is a new and first record for the species in the Oualidia lagoon. This invasive species was found fixed on rocky substrates and oyster breeding cages. The vector of the introduction of *Sargassum muticum* to the Oualidia lagoon is unknown until now. It will be linked to the marine circulation at the lagoon, although shellfish transfers seem to be the most likely introduction vector. In the Pacific ocean, shellfish transfers have been identified as the most common introduction vector for the arrival and quick expansion of *Sargassum muticum* along the Northeast Pacific, spreading over 5,000 km in less than 30 years (DRUEHL, 1973; PEDROCHE et al., 2008).

Similarly, it spread more than 2,000 km along the Northeast Atlantic coast (Sweden to the Iberian Peninsula) shortly (CRITCHLEY, 1983 ; RUENESS, 1989 ; ENGELEN et al., 2009). This species was absent in the Smir and Nador lagoons. Regarding Rhodophyta class, four *Gracilaria* species were present in Oualidia lagoon, but the most abundant were *Gracilaria gracilis* and *Gracilaria sp* (unidentified species). They were encountered in temperatures varying between 15.3°C and 17.7°C, the salinity fluctuated between 18 and 35 PSU. These species were found in different substratum (i.e., Mud, muddy sand, Rockey sand and sandy bottom) in depth varying between 0.1 and 2.5 m. *Gracilaria gracilis* is present in several world regions (GUIRY et al, 2018). It is present in Oualidia, Sidi Moussa and Marchica lagoons in Morocco. *Gracilaria gracilis* is probably more dependent on a stable substrate than other species for its survival up to adulthood. Nevertheless, *Gracilaria sp* studied have probably specific ecological requirements for their growth. The horizontal distribution of each species group was related to the type of substratum, wave exposure or salinity, or a combination of these factors. Our results are in agreement with those reported by other studies. A wide range of environmental tolerances has been reported for *Gracilaria* species. Several species are euryhaline (such as *G. gracilis* found in oligohaline lagoons, with 0.5 to 5 PSU) to euhaline (characteristic of European lagoons (PEREZ-RUZAFA et al., 2011) with 30 to 40 PSU. Moreover, *Gracilaria gracilis* has several potentially beneficial characteristics, including a broad tolerance to abiotic factors, remarkably light, temperature, and salinity (Yakovleva et al., 1997; TITLYANOVA et al., 1995; SKRIPTSOVA et al., 2001). In the Oualidia lagoon, various organisms, including green seaweed, brown seaweed, red seaweed, gastropod, bivalvia, polychaete, ophiuroidea, and ectoprocta were found together with *Gracilaria gracilis*. This suggests that *Gracilaria* assemblages are one of the important habitats that support a wide range of living organisms, including flora and fauna, where it protects against tides, predators, waves, and food sources. In addition to these two species of *Gracilaria*, which were very present in the lagoon of Oualidia, we noted the presence of two other *Gracilaria* species, namely *Gracilaria longissima* and *Gracilaria multipartita*. The other species of Rhodophyta were rarely observed in the lagoon of Oualidia. This may be linked to their low tolerance to fluctuations in the environmental parameters.

5. Conclusion

Our results constitute the first published checklist and distribution of macroalgae and seagrasses for the Oualidia Lagoon. However, a more comprehensive assessment of species diversity in this lagoon is necessary to understand marine macrophyte biogeography better. This should mainly involve molecular identification techniques. The results showed apparent domination of the agarophyte *Gracilaria* species, *mainly Gracilaria gracilis*. These species are an essential source of agar and need reasonable exploitation. The appearance of invasive species in the Oualidia lagoon requires us to continue our observations throughout the year to study its biology and monitor its expansion, as well as a possible "negative" impact on the oyster activities of all services associated with this lagoon. Attention must be given to stopping this invasion in this important lagoon system. Future studies should be conducted to verify changes in macrophyte patterns and abundance in the context of installing a new structure in the lagoon.

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Spatio-Temporal distribution of the endobenthic fauna community in the Oualidia lagoon (2013 and 2019)

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Abstract. The benthos plays an essential role in establishing estuaries and lagoon ecosystems. The present study explored the spatial distribution of the endobenthic fauna of the Oualidia lagoon (Moroccan Atlantic coast). The benthic macroinvertebrates of Oualidia lagoon were studied during the winter of 2013 and 2019 after the rehabilitation of the lagoon and the establishment of sediment trap of the sludge built in 2011. Samples were collected from the same 23 stations, during the two surveys (2013 and 2019) spread over the entire lagoon using a Van Veen grab with 0.0625 m² in sampling surface. Forty-two taxa from seven phyla have been identified with 1,870 specimens, including two polychetes *Owenia fusiformis* and *Corophium volutator* newly reappeared in the lagoon in this study and two amphipods *Corophium volutator* and *Lembos websteri* and the isopod *Eurydice pulchra*. These species clearly show that the lagoon of Oualidia has regained its ecological and environmental conditions, mainly the improvement of its hydrodynamics which will protect the lagoon from any confinement. Also, the Oualidia lagoon has a good organization of the benthic population by fairly important indices of biodiversity represented by diversity with Shannon index H'(1.56 bit per indvidual and evenness Pielou J' (0.57).

Key words: Macrobenthic diversity, Community structure, Oualidia lagoons, Morocco.

1. Introduction

The Oualidia lagoon is one of the most important shellfish ecosystems in Morocco. It comprises primary and secondary channels, marshy areas, and salt marshes, sheltering various exploitations of great economic value (artisanal fishing, aquaculture, exploitation of natural mollusk deposits, sand extraction, etc). Since 2005, it has become an international Ramsar site. In addition, this lagoon offers valuable socio-economic and environmental benefits to its inhabitants. Thus, the Oualidia lagoon is part of Moroccan ecosystems directly affected by human activities. Therefore, it contributes to generating pressures that may impact biodiversity and cause ecosystem malfunctioning (DAUER et al. 2000; BORJA & DAUER 2007 ; MEJJAD et al. 2016; ZOURARAH et al. 2007), which requires management and protection interventions to achieve sustainable blue growth.

Several studies have been carried out in this lagoon complex and focused on aspects of sedimentology, geology, and biogeochemistry (CARRUESCO 1989; SARF 1999; ZOURARAH 2002; ELKHALIDI et al. 2011 ; MAANAN et al. 2014 et DAMSIRI et al. 2015), biology (BENNOUNA, 1999 ; BENNOUNA et al. 2002 et OULDESSAIB. 1997), aquaculture (SHAFEE et SABATIE 1986; BERRAHO 1998; RHARBI et al. 2001; RHARBI et al. 2003; KAMARA et al. 2005; KAMARA et al., 2008), hydrodynamic and oceanography (ORBI et al., 2008; HILMI et al. 2005a; HILMI et al. 2005b; HILMI et al. 2009; KOUTITONSKY et al. 2006; KOUTITONSKY et al., 2007 ; KOUTITONSKY et al. 2012; ZOURARAH et al. 2012; MEKAOUI et al. 2018). Others studied environmental aspects linked to pollution (CHEGGOUR & HAMPSHIRE 1999; LAKHDAR et al. 2005 et IDARDARE et al. 2008). Concerning research work on aspects of benthic macrofauna and their ecological structure, they are more recent but remain limited (CHBICHEB 1996; CHAOUTI et al. 2019; ELASRI et

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al. 2015; ELASRI et al. 2017 & ELASRI et al. 2021).

The objective of this study is to make an inventory of the benthic species colonizing the lagoon after its rehabilitation, analyze the spatial distribution of this fauna and evaluate the relations with the main environmental factors.

2. Materiel and methods

2.1 Study area

The Oualidia lagoon, located at 34°47'N-¬6°13'W and 34°52'N - 6°14'W along the Atlantic coast, measures 7 km long and about 1 km wide. The basin occupies a north-south depression bordered by a continental cliff and a consolidated coastal dune ridge. The water exchanges with the ocean occur through a major inlet about 150 m wide. There is also a secondary, shallower inlet about 50 m wide during spring tides. The lagoon is characterized by the main channel, where the mean depth is 2 m, and the maximum depth is about 5 m during flood tides (ZOURARAH et al. 2006).

Flood tides cover more than 75% (2.25 km²) of the lagoon surface, bringing salt water to the upstream reaches of the lagoon and into a saline marsh beyond the second dam (MAANAN et al. 2013). Changes of salinity are observed in the extremity of the lagoon, where the mixing of the water column is very low (stratification of the water column is very weak). The organic matter in the Oualidia lagoon presents a spatial variability of 1.94 to 31.97%, with a maximum at the level of freshwater resurgence zones and a minimum near the sand pit. The grain size is mainly sandy in the outer zone and varies from sandy loam to loamy sand in the interior of the lagoon. Chlorophyll, "a" in the sediment, exhibited a heterogeneous distribution and varied between 1.19 and 23.41 mg / m^2 (EL ASRI et al. 2015; 2021). The main activities of the Oualidia lagoon are oyster farming and natural shellfish fishing (15%). Agriculture, mainly cereals and vegetables, and cattle breeding are practiced by more than 90% of the population. Agrochemicals are used in 78% of the cultivated area around the lagoon (MAANAN et al. 2014; 2017).

2.2 Sampling and laboratory analysis

In this work, we use the data collected during two sampling campaigns, in the Oualidia lagoon during the winter season of 2013 and 2019. Twenty-three stations distributed along the lagoon (Fig. 1) are explored using a Van Veen grab (0.0625 m² in sampling surface). At each station, we collected three replicates and measured water salinity and temperature with a multiparametric probe. When required, values are reported as average ± standard deviation.

Macrofaunal samples were fixed with a 10% seawater/formalin solution, then sieved through a 1 mm mesh and preserved in 70% alcohol. All invertebrates were sorted under a binocular microscope, identified to the lowest possible taxonomic level, and counted.

3. Statistical analysis

We characterized the macrobenthic assemblages according to their species richness (number of species per sample), density (number of individuals per square meter), diversity (H', Log2 Shannon index), (SHANNON.1948) and evenness (J'), (PIELOU 1966). All maps were drawn using ArcGIS 10.5.

4. Results

4.1 Environmental data

During the two studied periods (winter 2013 and 2019), the Oualidia lagoon was characterized by a strong temporal variability of environmental parameters, particularly temperature and salinity. The maximum values of the water temperature recorded in 2013 and 2019 were 19.9°C and 22.4°C, respectively. The salinity decreases with the distance to the lagoon's entrance, thus characterizing the lagoon's waters with resurgences of fresh water and marine waters. The pH showed a slight spatial trend with higher values in the upstream and downstream lagoon (pH 8.14 and 8.43). In addition, the pH decreased towards the middle part of this lagoon (pH between 8 and 7.6), but without any significant difference between the stations (p>0.05).

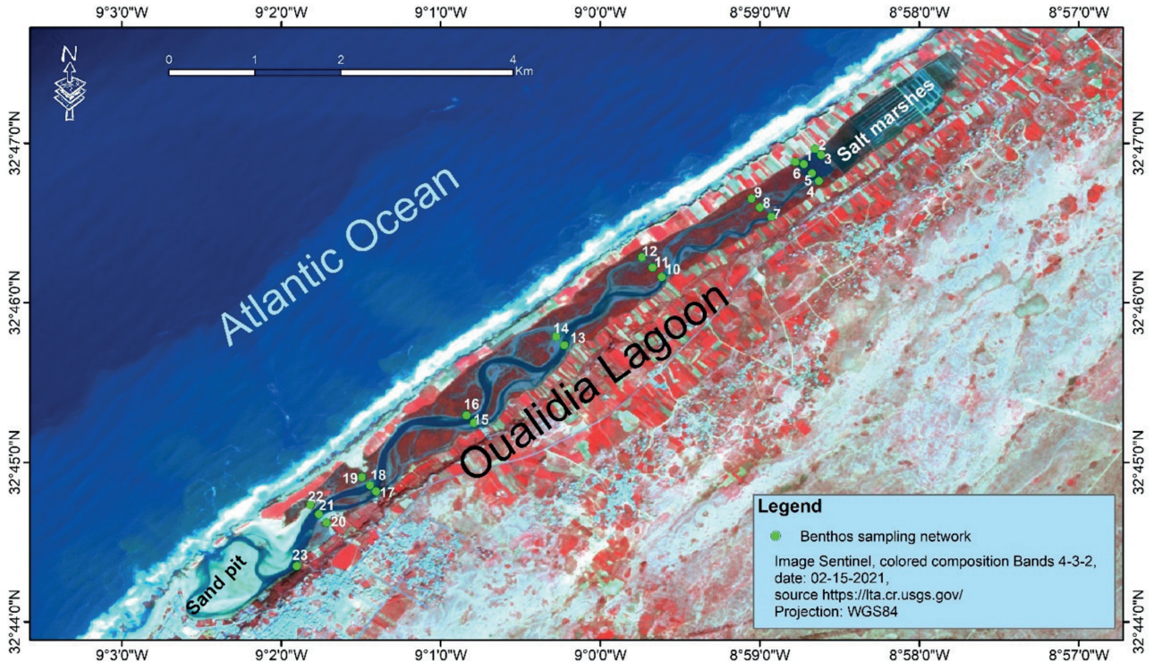

Figure 1: Localization and sampling survey of the Oualidia Lagoon

4.2. Biological data

4.2.1. Faunal composition

In March 2019 (Tableau 1), 42 taxa from 7 phyla, composed of 1,870 specimens, were identified. Most of them were typical of brackish and marine waters. Mollusks and polychaetes were the most abundant, with a frequency of 30.9%. They were followed by crustaceans (23.8%), echinoderms (4.76%), cnidarians, and arthropods, which did not exceed 2.5%. Mollusks, polychaetas and crustaceans were the most abundant in terms of total individuals and accounted for 50.9% (925 ind.), 24.6% (448 ind.), and 21.4% (390 ind.), Respectively. The numerically dominant mollusks species were *Abra alba* (W. WOOD, 1802) (51%), *Peringia ulvae* (PENNANT 1777) (31%), *Cerastoderma edule* (LINNAEUS 1758) (6%) and *Tritia pfeifferi* (PHILIPPI, 1844) (5.5%). Those of the crustaceans were the *amphipods Lembos websteri* (SPENCE BATE 1857) (40%) and *Corophium sp*. (25%) and the isopods *Sphaeroma serratum* (FABRICIUS 1787) (11%) and *Eurydice pulchra* (LEACH 1815) (9%) and Tanaidacea *Tanais dulongii* (PALLAS 1766) (5.7%). Those of the polychaetes were *Hediste diversicolor* (O.F. MÜLLER 1776) (47.8%), *Capitella sp* (25%), *Lagis cf. koreni* (MALMGREN 1866) (6%), and *Nephtys hombergii* (4%; Savigny in LAMARCK 1818).

Concerning surveys carried out in March 2013 (Table 1), 38 taxa, from 7 phyla, composed of about 10,468 specimens have been identified. Most of them were typical of brackish and marine waters. Mollusks is the most abundant with 43%, followed by crustaceans with 35.4%, polychaetes 16%, the Echinodermata (5.4%), and insect 2.7%. Mollusks, polychaetes and crustacea were the most abundant in terms of total individuals and accounted for 91% (95096 ind.), 7% (734 ind.) and 1% (126 ind.), Respectively. The numerically dominant mollusks species were *hydrobia sp* (70%), *Abra alba* (W. WOOD 1802) (24%), *Cerastoderma edule* (LINNAEUS 1758) (2.7%), *Tritia pfeifferi* (PHILIPPI, 1844) and *Cymbula safiana* (LAMARCK 1819) with 2.5% each on. Those of the crustaceans were the isopoda *Sphaeroma serratum* (FABRICIUS 1787) (42.8%) and Tanaidacea *Tanais dulongii* (PALLAS 1766) (25.4%). The other species do not exceed 6.3%. Those of the polychaetes were *Hediste diversicolor* (MÜLLER 1776) (76.6%), *Capitella sp* (21.1%), and the other species do not exceed 2.3% in totality.

4.2.2 Species Composition and Diversity

Across the lagoon, abundances of benthic fauna collected in 2013 and 2019 were variable in time and space (Figs. 2a and 2b). The lowest average densities were recorded in 2019 (100 ± 130 ind.m^{-2}), compared to those observed in 2013 which was 634 ± 1054 ind.m^{-2}. Likewise, the distribution and abundance of benthic species by zone (downstream-middle-upstream) is very varied even if the difference was not significant (ANOVA; $p>0.05$). In addition, in each zone one or a few species stood out for their great abundance such as: *Abra alba*, which reached a maximum abundance of 1283 ind.m^{-2} in two stations in the upstream zone of the lagoon (S7 and S8) in 2013 and 2019 the same bivalve recorded a maximum density of 131 ind.m^{-2} at station S1. In 2013, the three parts of the lagoon were richer in *hydrobia sp* in particular the stations S8, S13 and S20 whose registered high abundances (>700 ind/m). However, in 2019, the high abundance was observed in the upstream zone, in particular at stations S2 and S4 corresponding to the abundance of two species: gastropod *Peringia ulvae* and the crustaceans *Lembos websteri* (>140 ind.m^{-2} each).

The specific richness varies from 1 to 12 species per station in 2013, while in 2019, it is from 0 to 22 species per station. The spatial distribution of specific richness (Figs. 3a and 3b) follows the mapping of abundance with a significant difference between the two sampling periods; indeed, the high specific richness recorded in 2019 remains very limited in space, with the year 2013. It was limited to a few cores distributed over the oyster farms of the lagoon. The spatial variability of the univariate measures the Shannon diversity (H) and Pielou's equitability (J) along the lagoon did not show any clear spatial trends or gradients. On the other hand, the benthic community diversity indices showed a clear and homogeneous distribution pattern along the Oualidia lagoon during two surveys.

H diversity was also significantly correlated with S ($r = 0.718$; $p <0.01$) in 2019 so when in 2013 it was weakly correlated with S (0.3; $p <0.01$). The Shannon (H) index ranged from 1 to 2.80 bits. Overall, the diversity of the benthic fauna community along the Oualidia Lagoon was medium due to the number of species (S) rather than their abundance (Figs. 4a and 4b).

As for the Shannon index, the spatial distribution of this index does not show a very distinct spatial trend or gradient for the two periods studied (Figs. 5a and 5b). The values of this index vary between 0 and 0.97, with an average of 0.65 ± 0.18 in 2019 and 0.65 ± 0.2 in 2013. In 2013, seven stations posted values less than 0.5; in 2019, only four stations indicate values less than 0.5. In 2019, this index was slightly higher, and most stations display values above 0.6.

Tableau 1 : Comparative analysis of list of faunal composition established by this study with the previous study of EL ASRI et al. (2015) ; CHBICHEB (1996) in Oualidia lagoon.

Taxonomic groups	Family	Species	2019, this study	El Asri et al., 2015 ; sampling 2013	Chbicheb 1996
Mollusca	Cardiidae	*Cerastoderma edule* (Linnaeus, 1758)	*	*	*
		Cerastoderma glaucum (Poiret, 1789)			*
	Donacidae	*Donax trunculus* Linnaeus, 1758		*	
	Semelidae	*Abra alba* (W. Wood, 1802)	*	*	
		Scrobicularia plana (Da Costa, 1778)	*	*	*
	Lucinidae	*Loripes orbiculatus* (Poli, 1791)	*	*	*
		Lucinoma borealis (Linnaeus, 1767)		*	
	Mactridae	*Spisula solida* (Linnaeus, 1758)		*	
		Spisula subtruncata (Da Costa, 1778)		*	
		Spisula sp.		*	
	Veneridae	*Ruditapes decussatus* (Linnaeus, 1758)		*	*
		Venerupis Pullastra (Linné, 1758)			*
	Tellinidae	*Tellina Linnaeus, 1758*	*		
		Macomangulus tenuis (Da Costa, 1778)	*		
	Solemyidae	*Solemya togata* (Poli, 1791)	*		
	Cystiscidae	*Gibberula miliaria* (Linnaeus, 1758)	*		
	Mytilidae	*Mytilus galloprovincialis* (Lamarck, 1819)	*	*	
	Haminoeidae	*Haminoea cf. japonica* (Pilsbry, 1895)	*	*	
	Aplysiidae	*Aplysia punctata* (Cuvier, 1803)		*	
	Onchidiidae	*Onchidella celtica* (Cuvier, 1817)		*	
	Naticidae	*Cochlis vittate* (Gmelin, 1791)		*	
	Hydrobiidae	*Peringia ulvae* (Pennant, 1777)	*	*	
	Nassariidae	*Tritia pfeifferi* (Philippi, 1844)	*	*	
		Tritia reticulata (Linnaeus, 1758)	*	*	*
		Tritia mutabilis (Linnaeus, 1758)			*
	Trochidae	*Gibbula umbilicalis* (Da Costa, 1778)		*	*
		Gibbula divaricata (Linnaeus, 1758)			*
		Phorcus lineatus (Da Costa, 1778)			*
	Patellidae	*Cymbula safiana* (Lamarck, 1819)		*	
	Cerithiidae	*Cerithium vulgatum* (Bruguiere, 1792)			*
Polychaeta	Nereididae	*Hediste diversicolor* (O.F. Müller, 1776)	*	*	*
	Polynoidae	*Harmothoe sp.*	*	*	
	Phyllodocidae	*Phyllodoce sp.*	*	*	
	Glyceridae	*Glycera cf. tridactyla* (Schmarda, 1861)	*	*	
		Glycera alba (O.F. Müller, 1776)	*	*	
	Nephtyidae	*Nephtys kersivalensis* (McIntosh, 1908)	*	*	
		Nephtys hombergii (Savigny in Lamarck, 1818)	*	*	
		Nephtys caeca (Fabricius, 1780)			*
	Lumbrineridae	*Lumbrineris coccinea* (Renier, 1804)	*	*	
	Onuphidae	*Diopatra cf. marocensis* (Paxton, Fadlaoui & Lechapt, 1995)	*	*	
	Ampharetidae	*Alkmaria romijni* (Horst, 1919)		*	
	Pectinariidae	*Lagis cf. koreni* (Malmgren, 1866)	*	*	
	Capitellidae	*Capitella sp.*	*	*	
		Capitella capitata (Fabricius, 1780)			*
	Sabellidae	*Panousea Africana* (Rullier & Amoureux, 1969)	*	*	
	Oweniidae	*Owenia fusiformis* (Delle Chiaje, 1844)	*		*
Crustacea	Melitidae	*Melita palmata* (Montagu, 1804)	*	*	
	Corophiidae	*Corophium sp.*	*	*	
		Corophium volutator (Pallas, 1766)	*		*

	Caprellidae	*Caprella liparotensis* (Haller, 1879)		*	
	Ampithoidae	*Ampithoe sp.*	*	*	
	Anthuridae	*Cyathura carinata* (Krøyer, 1847)		*	
	Sphaeromatidae	*Sphaeroma serratum* (Fabricius, 1787)	*	*	
	Idoteidae	*Idotea balthica* (Pallas, 1772)	*	*	
	Tanaididae	*Tanais dulongii* (Audouin, 1826)	*	*	
	Cirolanidae	*Eurydice pulchra* (Leach, 1815)	*		
	Aoridae	*Lembos websteri* (Spence Bate, 1857)	*		
	Apseudidae	*Apseudes* sp.		*	
	Cumacea	Cumacea indet		*	
	Paguridae	*Pagurus bernhardus* (Linnaeus, 1758)	*	*	
	Portunidae	*Portunus* sp.			*
		Carcinus maenas (Linnaeus, 1758)	*	*	
	Balanidae	*Balanus* sp.	*	*	
Insecta	Chironomidae	*Chironomus* sp.	*	*	
Cnidaire	Actiniidae	*Anemonia sulcata* (Pennant, 1777)	*		
Echinodermata	Holothuriidae	*Holothuria poli* (Delle Chiaje, 1824)	*	*	*
	Ophiuridae	*Ophiura* sp.	*	*	
	Parechinidae	*Paracentrotus lividus* (Lamarck, 1816)			*

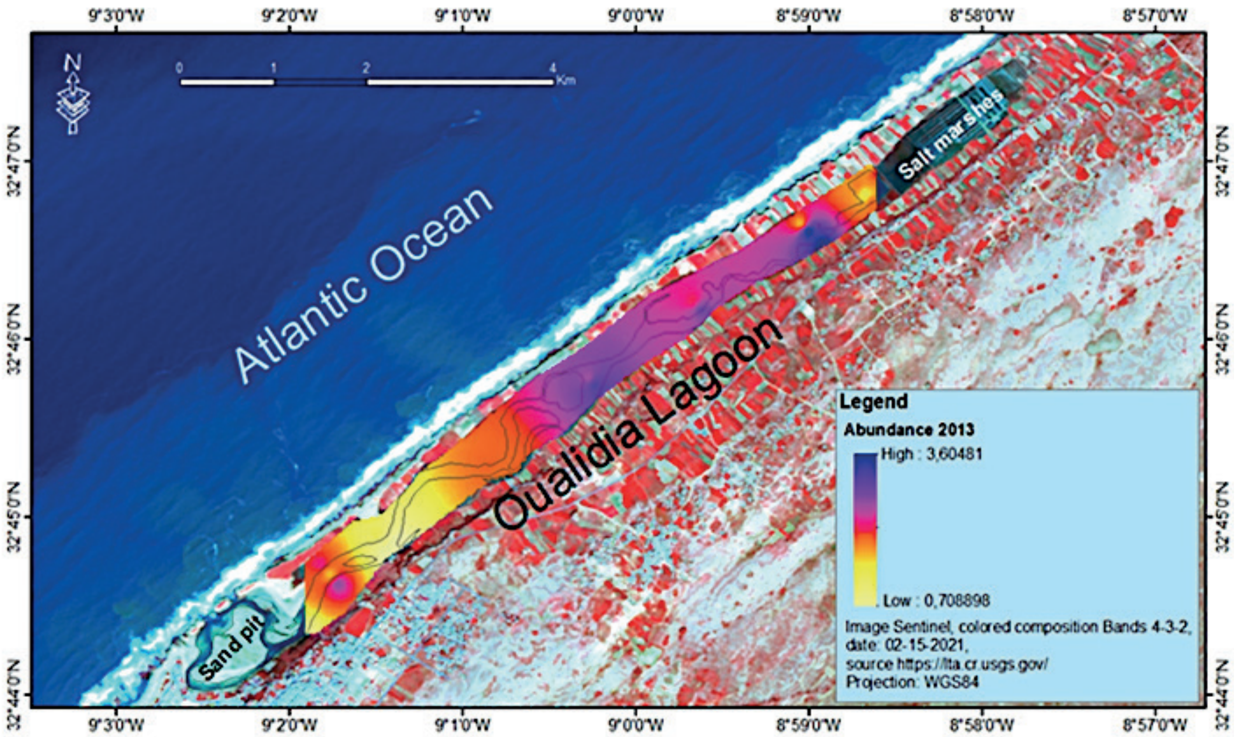

Figure 2 a: Distribution of the density abundance of benthic fauna in the Oualidia lagoon (2013)

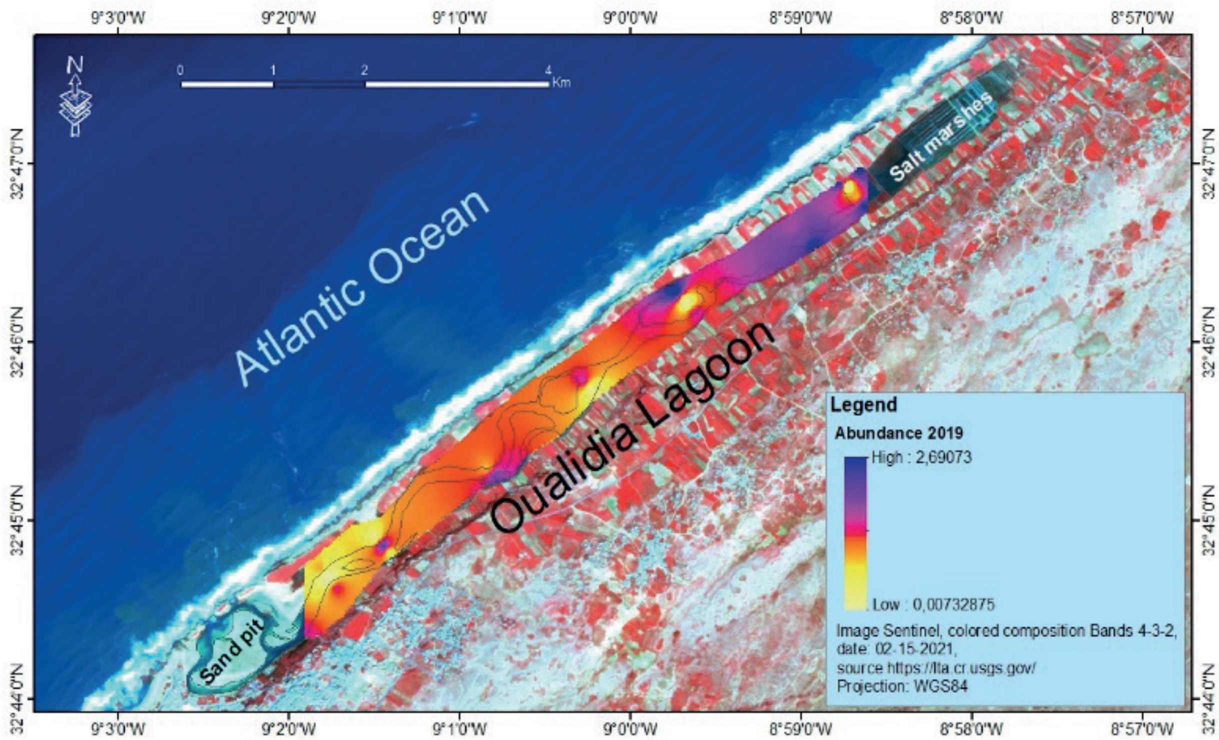

Figure 2b: Distribution of the density abundance of benthic fauna in the Oualidia lagoon (2019)

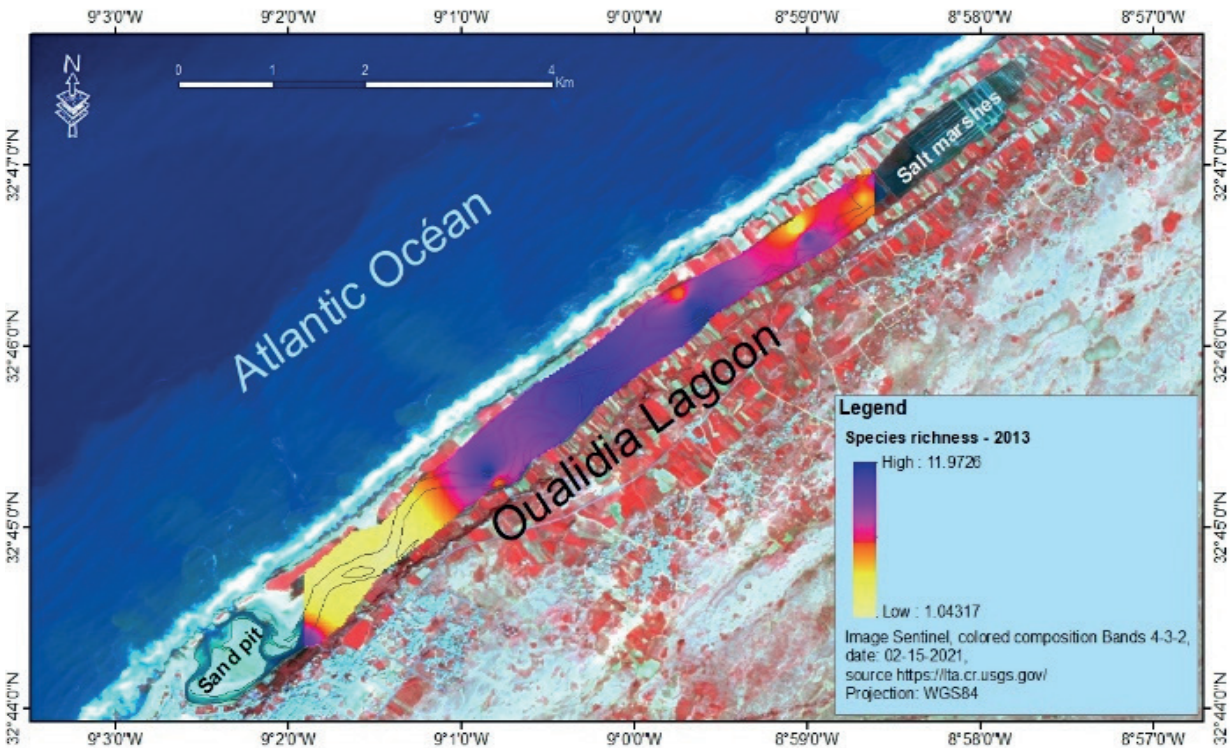

Figure 3 a : Distribution of specific richness in the Oualidia lagoon 2013

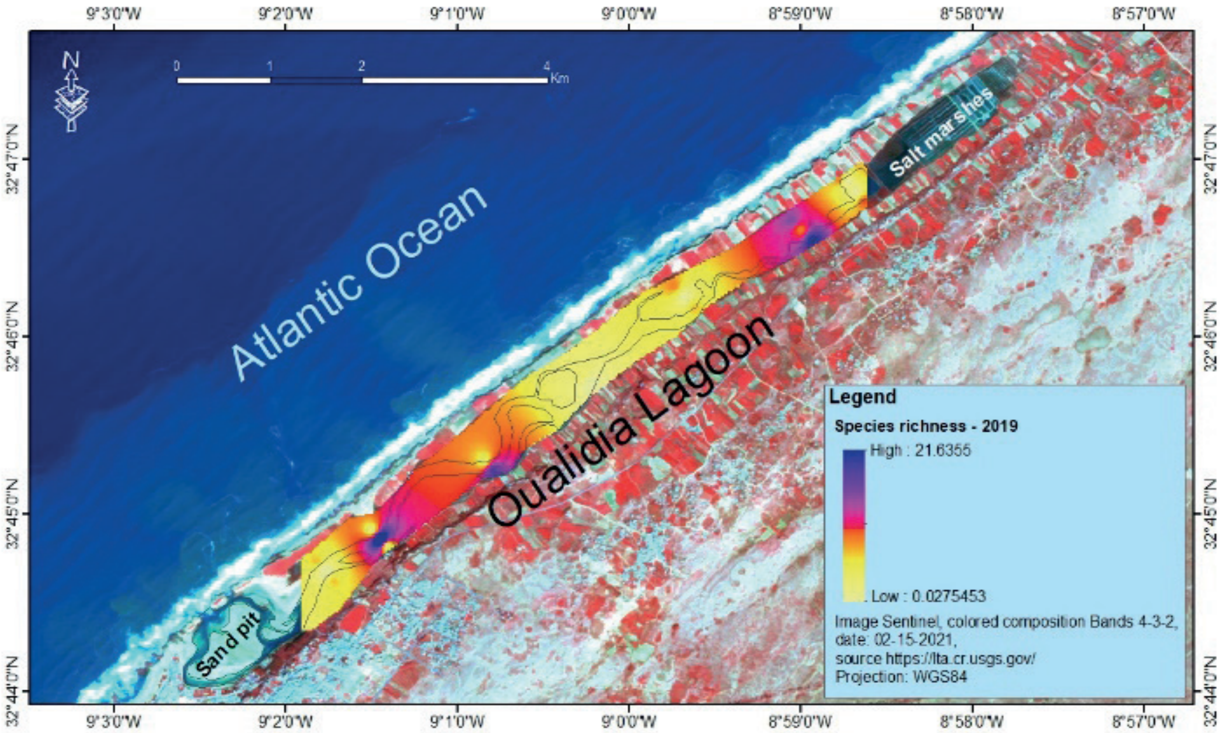

Figure 3 b : Distribution of specific richness in the Oualidia lagoon 2019

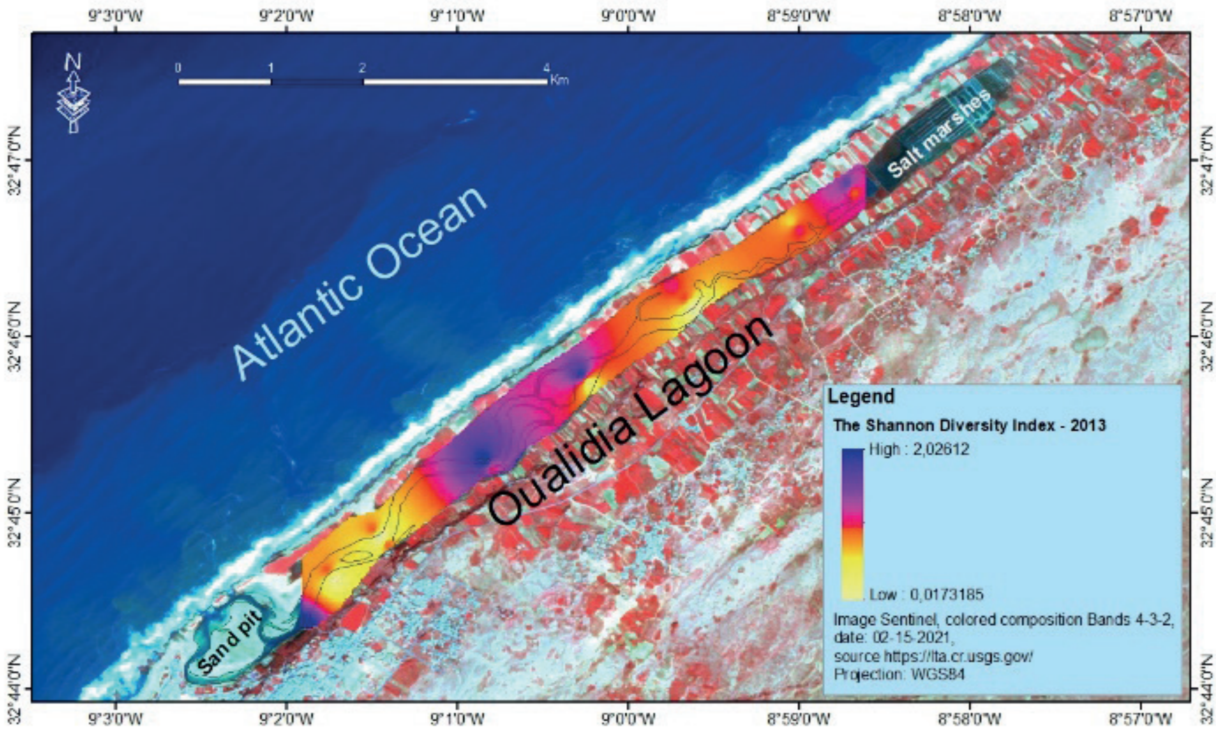

Figure 4a: Distribution of the Shannon diversity index in the Oualidia lagoon 2013

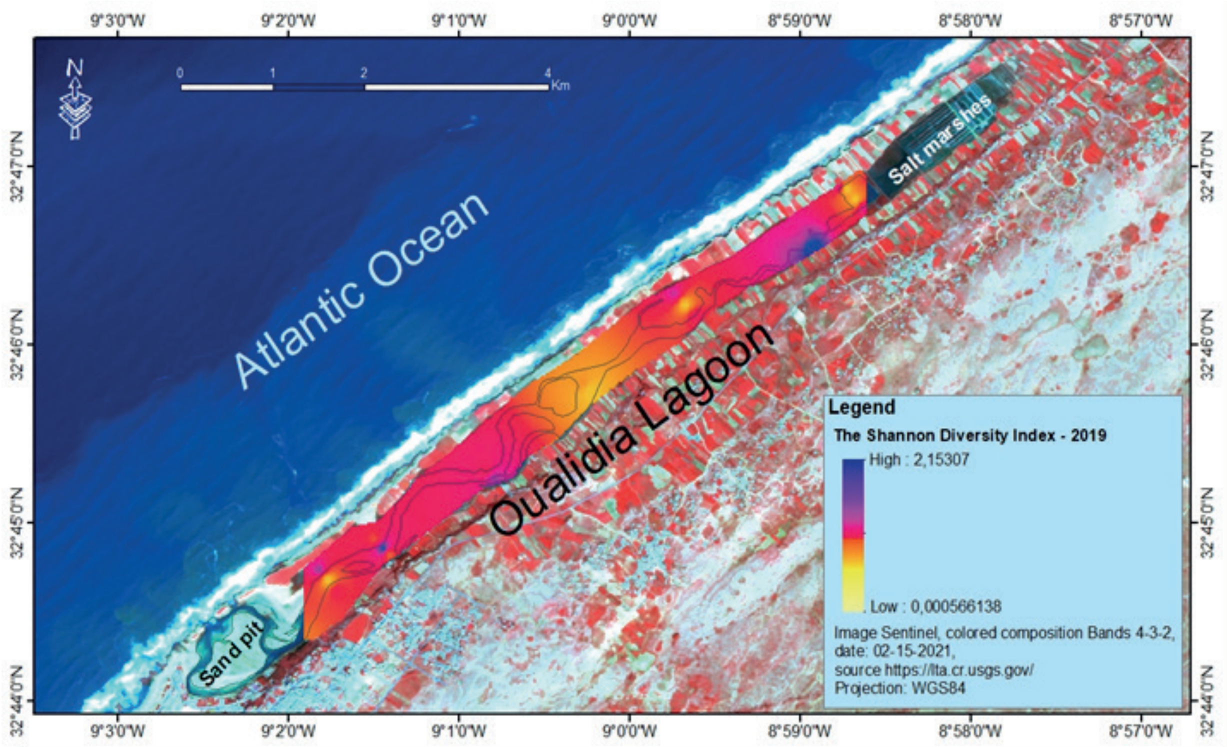

Figure 4b: Distribution of the Shannon diversity index in the Oualidia lagoon 2019

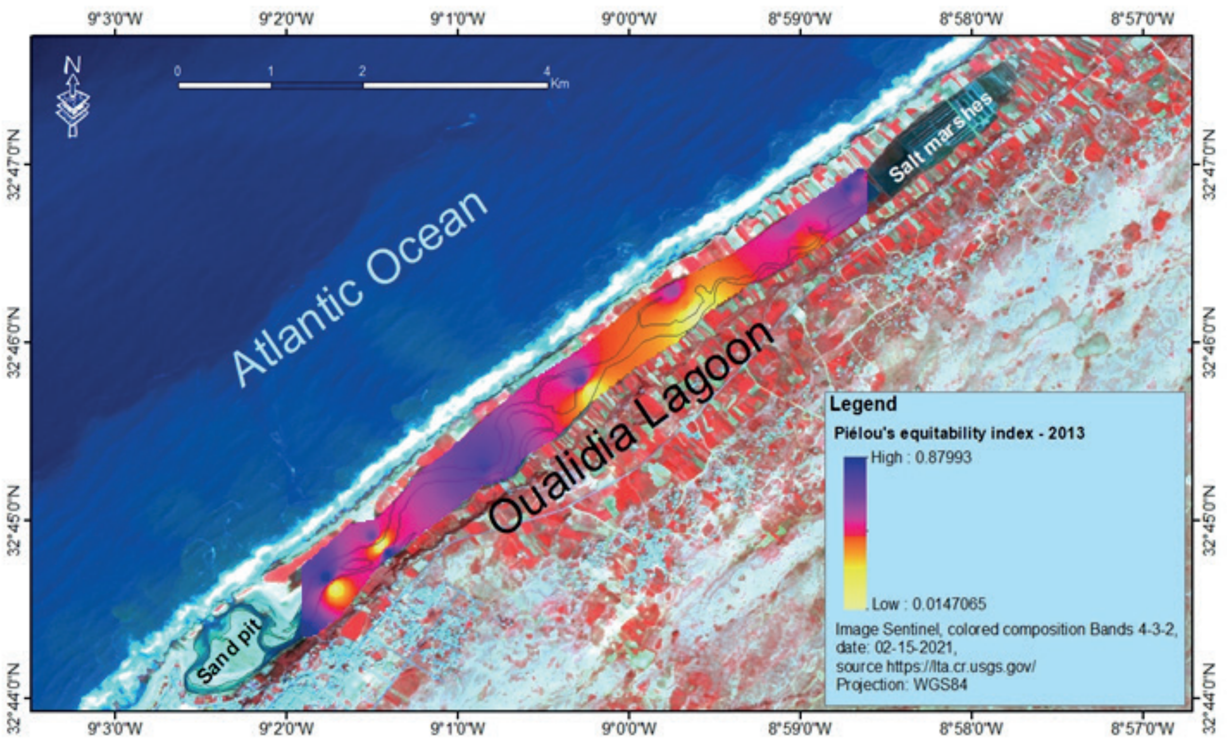

Figure 5a: Distribution of the Pielou's equitability index in the Oualidia lagoon 2013

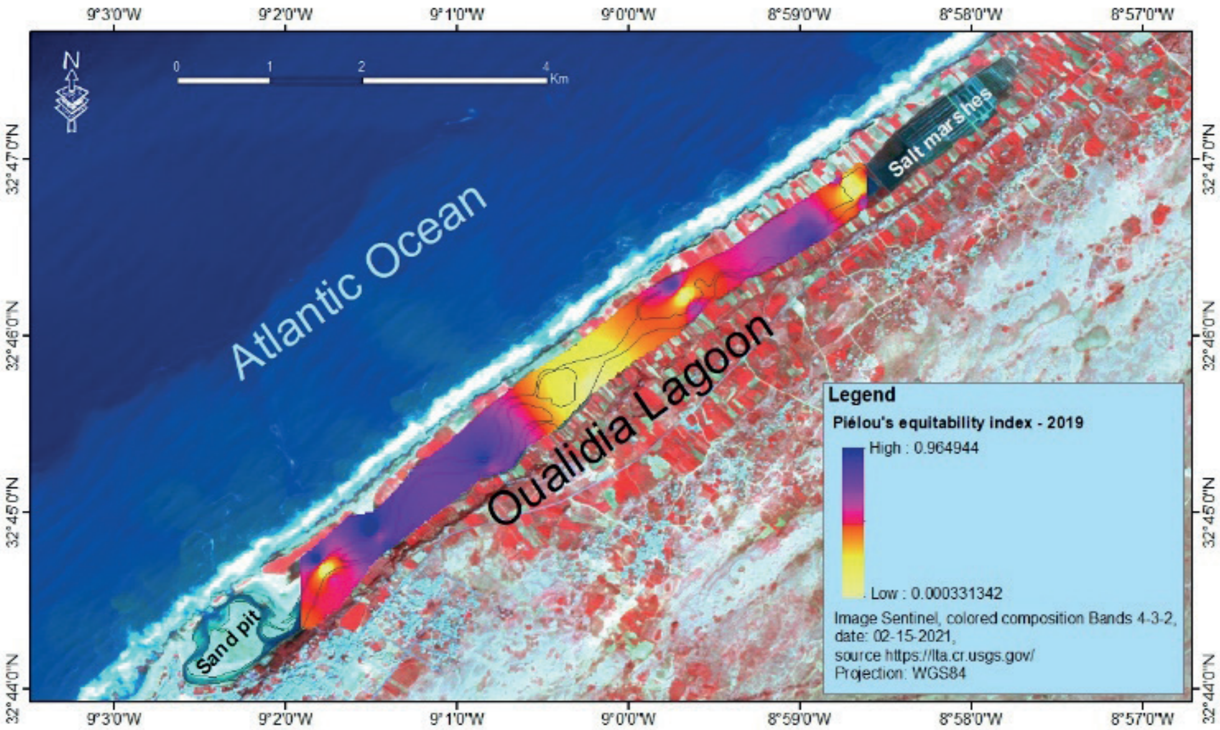

Figure 5b: Distribution of the Pielou's equitability index in the Oualidia lagoon 2019

5. Discussion

The benthos plays an essential role in establishing estuaries and lagoon ecosystems. It is a preferred food source for many higher-ranking consumers (fish, birds, decapods, etc.) on the one hand and a good indicator of variations in the environment on the other (DAUVIN 1993). Our study significantly contributes to the updating of endobenthic species living in the Oualidia lagoon after the operation of the soil built-in 2011-2013. The number of species reported is nearly three times higher than those reported by (CHBICHEB 1996) during four seasons from December 1992 to November 1993, and remains broadly similar to that identified by EL ASRI et al. (2015). In contrast, 8 species recorded in 2019 weren't listed in the previous survey (2013), and that the two species of polychaetes *Owenia fusiformis* and *Corophium volutator* in 1996 saw their reappearance in the samples of the year 2019.

In terms of structure and diversity, this change in benthic species can probably be explained by anthropogenic pressures (HERNANDEZ-GUEVARA et al. 2008) and the species' ability to react to these environmental changes. Also, existing biological interactions such as competition or predation or the intrinsic characteristics of the species itself (ARTEMIS et al. 2006) can explain this variation.

The polychaete *Owenia fusiformis* is one of the organisms that directly or indirectly modulate the availability of resources for other species by causing changes of state in biotic or abiotic materials (RABAUT in prep). These organisms, called "Ecosystem Engineers", modify, maintain, and / or create habitats (JONES et al., 1994). By reshaping the landscape, these "Ecosystem Engineers" modify the abiotic context on which biotic interactions strongly depend (BYERS et al. 2006).

In the present work, the polychaete *O. fusiformis* is identified at stations 9 and 18, thus locating muddy sediment from the community of the bivalve *Abra alba* and characterizing a maximum flow of suspended matter; the same findings were identified in the Bay of Seine (DAUVIN et al. 1991).

According to AMBROGI et al. (1995) the presence of this species of polychaetes has significant implications on the richness and density of species explaining the stabilizing effects in a very dynamic environment. This agrees perfectly with our results. Indeed the stations of the presence of these species perfectly reflect a good organization of the benthic population by fairly important indices of biodiversity represented by H ’(1.56 bit / ind) and J’ (0.57).

For the crustacean group, we also observed, in the samples taken in 2019, a reappearance of three species, the amphipods *Corophium volutator*, *Lembos websteri* and the isopod *Eurydice pulchra*. These species indicate that the Oualidia lagoon has returned to its ecological conditions, contributing to these species' development and growth. It is probably due to the changes of the hydrodynamic conditions. These findings are consistent with the life history experiments carried out by researchers on *C.volutator* (WILSON & PARKER 1996; PEER et al. 1986). As regards the amphipod *Lembos websteri*, is a species characteristic of the habitat of the herbarium *Cymodocea nodosa* (Poore & Hill 2006). This herbarium is present in the lagoon of Oualidia with a percentage of 11% in association with *Zoostera noltii* (REZZOUM: pers. comm.).

Regarding the phylum of mollusks, in terms of the number of species or abundance, *Abra alba* and *Peringia ulva* overwhelmingly dominate the faunistic composition of the Oualidia lagoon in 2019, since they represent more than 80% of the total abundance of the fauna.

As in most aquatic ecosystems, *Abra alba* is one of the pioneer species and is most common in subtidal muddy and sandy sediments (LASTRA et al. 1993). This species tolerates physicochemical changes in sediments (HILY 1984) and adapts rapidly to environmental variations. The significance of A. alba in the food web may thus be as food for juvenile fish or intermediate-level predators that prey on larger fish (RAINER, 1985).

By coupling the findings cited in the following points:

- the environmental characteristics, namely a significant increase in nutrients, mainly in nitrogenous elements (IDARDARE et al. 2008).
- the hydrodynamic, which manifests itself upstream by a decrease in organic matter, is due, on the one hand, to the trapping of fine sediments and, on the other hand, downstream to a modification of the morphology of the sand pit which has created some modification of the main channel (EL KHALIDI et al. this volume).
- the structure of the endobenthic composition with the reappearance of the new species mentioned in the lagoon in the 90s.

With the establishment of the sediment trap, we can conclude that the Oualidia lagoon will regain its ecological qualities from the previous years.

6. Conclusion

The taxonomic diversity and spatial distribution of the endobenthic fauna of the lagoon of Oualidia allowed the identification of 42 taxa. Thus, we noticed the reappearance of specific species: two species each of polychaetes and amphipods and a single species of isopod. The new reorganization of the hydrodynamic and sediment composition after the trench construction were the main factors affecting the number of species and the biodiversity of the benthic communities. Compared to the taxonomic list of the previous years, the Oualidia lagoon sees its endobenthic biodiversity enriched with new species indicating progressive ecological stability. However, the increasing anthropic disturbances in this lagoon are not without effect. Therefore, this ecosystem's excellent ecological and aquacultural conservation requires regular endobenthic monitoring.

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This work is dedicated to the memory of INRH colleagues, J.I. Lakhdar and M. Laouine, who have worked intensively on Oulaidia and Sidi Moussa lagoons

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Bibliometric research analysis on the Oualidia and Sidi Moussa lagoons, Moroccan Atlantic coast

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Abstract. This investigation presents the evolution of scientific production, based upon a bibliometric study from 1974 to 2021, including aspects such as the progress, trends, and hotspots of coastal research in Oualidia and Sidi Moussa lagoons (Moroccan Atlantic coast). In addition, the research investigation includes publication year, document type, language, and mainstream journals. Co-words, co-country and co-authorship analysis were conducted using VOSviewer software. A total of 351 publications were extracted from these publications, 276 (78.63%) were academic papers. The study revealed a disparity in the research distribution: 62.11% of the total publications were referred to Oualidia lagoon and only 37.89% to Sidi Moussa lagoon. 57.26% of them were produced between 2011 and 2021. Morocco, France, and Spain are the most important countries for international cooperation in this research area. Studies did exhibit heterogeneity regarding research priorities. Some prioritized environmental monitoring and water quality issues, while others focused more on topics such as heavy metal pollution. In contrast, the application of new monitoring methods for lagoons investigation, new technologies, processes, and models of ecological restoration received little attention.

Keywords: Coastal research, Oualidia lagoon, Sidi Moussa lagoon, Moroccan Atlantic coast, bibliometric analysis.

1. Introduction

Coastal areas can serve as laboratories where researchers investigate coastal change for several reasons. First, they host many habitats with significant ecological, social-cultural, and economic values (SELIG, 2018). Second, they are densely populated, with more than 2.4 billion people (40% of the world's human population) living within roughly 100 km of the coastline (Butchart et al., 2005). Third, coastal areas are highly vulnerable to climate change, sea-level rise, over-exploitation of coastal resources, land-based pollution, and habitat degradation (AERTS, 2014; JACQUET & JACKSON, 2018).

In recent years, scientific management of coastal areas has emerged worldwide. However, significant efforts have been made to collect information needed to understand better coastal ecosystems' functioning, such as integrating various data sources, using simulation models, monitoring observatories, etc. (PATRICIO et al., 2016). Although scientists are more aware of the research needs of coastal management, they are expected to provide robust and reliable research pertinent to managers (Roux et al., 2015). Many gaps between data generated by science and data used during the implementation of a management plan. As a result, scientists and coastal managers have called for more flexible management forms by building new relationships, increasing knowledge exchange, sharing more ideas, implementing internal and external collaborations, and increasing research productivity. Research productivity has been widely assessed by investigating the publication characteristics, such as trend and evolution, countries, authors, language, institutions, journals, affiliations, collaboration, research fields, and citations (BIRCH & REYES, 2018; HU et al., 2019). Knowledge gaps have been identified in studies related to assessing research state on the Moroccan Atlantic coast via the qualitative and quantitative analysis of the research productivity. However, to our knowledge, no attempts have been made to investigate Moroccan coastal lagoons' research efforts.

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This paper reviews the research on coastal science in the Oualidia and Sidi Moussa lagoons via bibliometric analysis using VOSviewer software. A total of 351 documents were analyzed from 1971 to May 2021. Therefore, the distribution of records by year of publication, document type, publication language, and journal cover is addressed. Then, the co-occurrence analysis of keywords, authors, and countries is analyzed.

2. Research methodology

2.1. Data source

A literature review of available documents was conducted through major search databases, including Scopus (https://www.scopus.com/), Web of Science (https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/), and Google Scholar (https://scholar.google.com/). In addition, more websites were used in searching the defended PhDs, such as: theses.fr (http://www.theses.fr/), Hal (https://hal.archives-ouvertes.fr/), and Otrohati (https://otrohati.imist.ma/). The keywords ‘‘Oualidia lagoon’’ ‘‘Sidi Moussa lagoon’’ were explored without language restriction to generate a well-defined database of the literature published between 1971 to May 2021. As a result, 540 documents were extracted.

2.2. Data analysis

The collected documents were first downloaded into a reference manager, « Mendeley », with duplicates removal and then exported to VOSviewer software using binary counting (Van Eck & Waltman, 2010; 2011) for further examination. After data cleaning, 351 documents were analyzed.

The general information of the documents includes the year of publication, document type, language, journal coverage; lagoon type was selected as metadata. We considered document types: journal article, book section, scientific report, conference paper, scientific bulletin and thesis. We considered the number of journal papers per scientific journal based on the journal's name and the impact factor.

The bibliometric analysis was used to visualize the relationships between the most productive keyword co-occurrences, authors, countries, and institutions. The relationships were depicted by a network with nodes and links between them. Nodes usually represent the different items such as author, country, institution, and keywords. The connection size between the nodes reflects the number of relationships between the items, so the bigger the connection, the larger the relationship between those items (Van Eck, 2011; Gao et al., 2019). Each node is represented by a succession of tree rings in different colors. The link reflects the nodes' common authorship, occurrence, or citations (Peng & Dai, 2020). The node's color and links define different clusters or years (Liang et al., 2017; Li et al., 2019).

3. Results

3.1. Research tendencies

3.1.1. Trend, document type and language of publication

The resulting numbers of published literature referring to Oualidia and Sidi Moussa lagoons between 1971 and May 2021 are illustrated in Figure 1. Results show that research grew slowly but steadily up to 1997 and more rapidly from 1997 to 2021. A total of 351 documents were identified, and approximately two-thirds of them (201 publications; 57.26%) were published between 2011 and 2021. The publishing peak was in 2017 (29 publications). The year 2021 was represented by 16 publications considering January to May. Three-quarters of the total document was published as a journal paper (78.63%) and less than one-fifth as a report (7.9%) and thesis (6.55%). The others performing less significance were conference papers (5.41%) and book chapters (1.42%) (Fig. 2a). Most of the studies were published in English (61.9%). French accounted for 38 % of the total publications and Spanish only 1% (Fig. 2b).

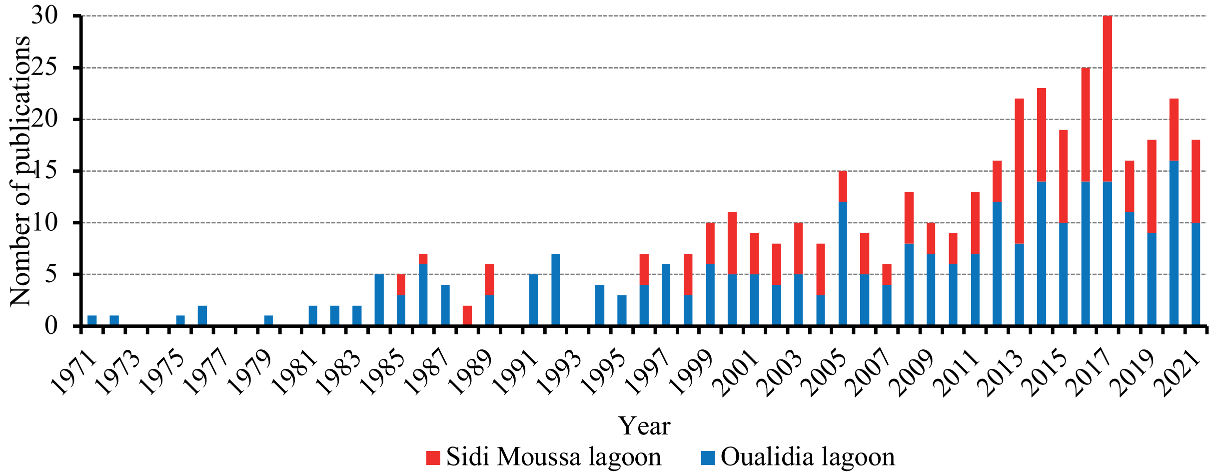

Figure 1: Time evolution of the publication number according to the lagoon-type between 1971 and May 2021

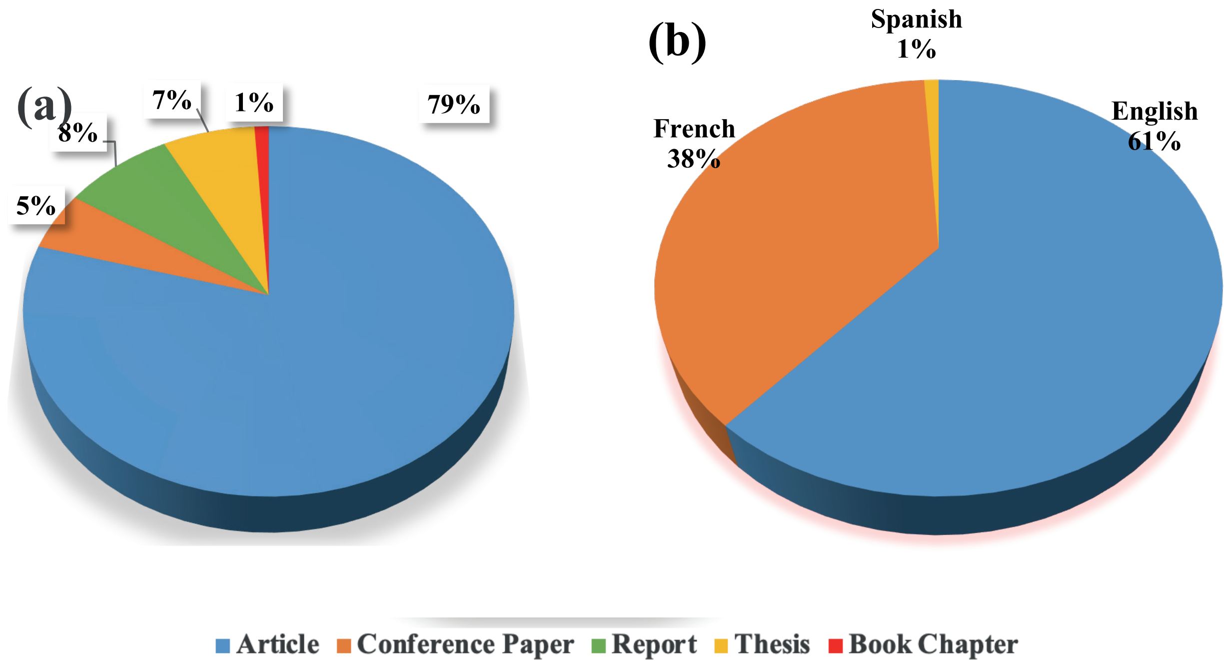

Figure 2: Distribution of publication according to the document type (a) and language of publication (b)

3.1.2. Journal publication

The 276 articles were published in 167 national and international journals. Table 1 summarizes the top 9 journals in terms of the total number and percentage of articles published, impact factor, and subject category. Most represent a wide range of research fields, from Earth and Oceanography to eco-toxicology, Behavior, and Systematics. For example, the "*Bulletin de la Société Géologique de France*" with ten articles, which accounts for 5.9% of all articles, followed by the "*Journal of Materials and Environmental Sciences*" (8 articles; 4.8%) were the most preferred journals in which scientists have published their research. From the journals in table 1, "*Environmental Pollution*" has the highest impact factor (8.07) compared to other journals. In contrast, the "*Journal of Materials and Environmental Sciences*" exhibit the lowest (0.654).

Table 1: Top active journals between 1971 and May 2021 with the number of Published Papers (PP), Impact Factor (IF) and Subject category.

Journal Title	PP (%) (n = 167)	IF (2020-2021)	Subject category*
Bulletin de la Société Géologique de France	10 (5.9)	1.46	Earth and Planetary Sciences
Journal of Materials and Environmental Sciences	8 (4.8)	0.654 (2015)	Environmental Chemistry, Pollution, Waste Management and Disposal
Oceanologica Acta	7 (4.2)	1.431	Aquatic Science, Oceanography
Regional Studies in Marine Science	7 (4.2)	1.624	Animal Science and Zoology, Aquatic Science, Ecology, Evolution, Behavior and Systematics
Environmental Pollution	5 (3)	8.07	Health, Toxicology and Mutagenesis Pollution
International Journal of Advanced Research	5 (3)	7.337	Environmental Chemistry, Pollution
Aquaculture	5 (3)	4.242	Aquatic Science
Environmental Monitoring and Assessment	5 (3)	2.513	Environmental Science (miscellaneous)
European Journal of Entomology	5 (3)	1.225	Agricultural and Biological Sciences

* Data provided from SCImago Journal and Country Rank (SJR)

3.2. Bibliometric mapping

3.2.1. Keywords co-occurrence

The analysis of words in titles, author keywords, and Key Words Plus has been proved to be a valuable tool for identifying research hotspots (CHIUAND HO, 2007; LI et al., 2009). As shown in the network view map (Fig. 3), the keywords are defined by the circles; the keyword's occurrence presents each circle size. The color describes the cluster to which a keyword is inserted, and the lines indicate the keywords links. The distance between the keywords reflects the degree of the relationship; keywords that are closer together are more closely linked than keywords that are farther apart.

The minimum number of keyword occurrences is fixed to 5. Of all 1763 keywords, 91 are visualized. From Figure 3, the keywords Morocco, Oualidia lagoon, phytoplankton, and environmental monitoring (largest circles), attracted much attention in lagoons research. Five clusters were observed. The red one constituted the largest group with keywords, including terms more focused on water quality and study of phytoplankton and algal bloom. The green cluster comprised related assessment of water quality pollution and environmental monitoring of heavy metal contamination. For example, some items from this group included controlled study, heavy metal, bioaccumulation, and cadmium, copper. The blue cluster grouped terms mainly concerning environmental monitoring and chemical analysis of groundwater. Finally, the yellow cluster referred mainly to the metal pollution and biotic diversity of the two lagoons.

3.2.2. Active countries, institutions, and authors

A co-occurrence analysis of the top productive countries is presented in Figure 4. Among the top 8 countries, Morocco played a central position with the highest number of publications and collaboration intensity (LS = 78), followed by France and Spain. The link between Morocco and France was maximum (LS = 52).

The network of co-occurrence can be also used to locate important institutions and possible collaborators. The top conductive institutions were visualized in Figure 5. The thicker link line describe the collaboration and the closer between institutions (Niu et al., 2021). It is noteworthy that "Institut National De Recherche Halieutique (INRH)" has the highest publications and collaboration with other institutions. Furthermore, it performed the authorship analysis to select a threshold with a minimum of 5 publications of an author that led to 91 thresholds (Fig. 6). Referring to the number of publications by each author, the largest number of publications were authored by "MAANAN M." and "BAZAIRI H.". The cluster analysis reveal a strong evidence between the number of publications produced by authors. Thus, the stronger the total link strength, the more authored publications. Hence, "MAANAN M." has the highest publications and corporation number among other researchers.

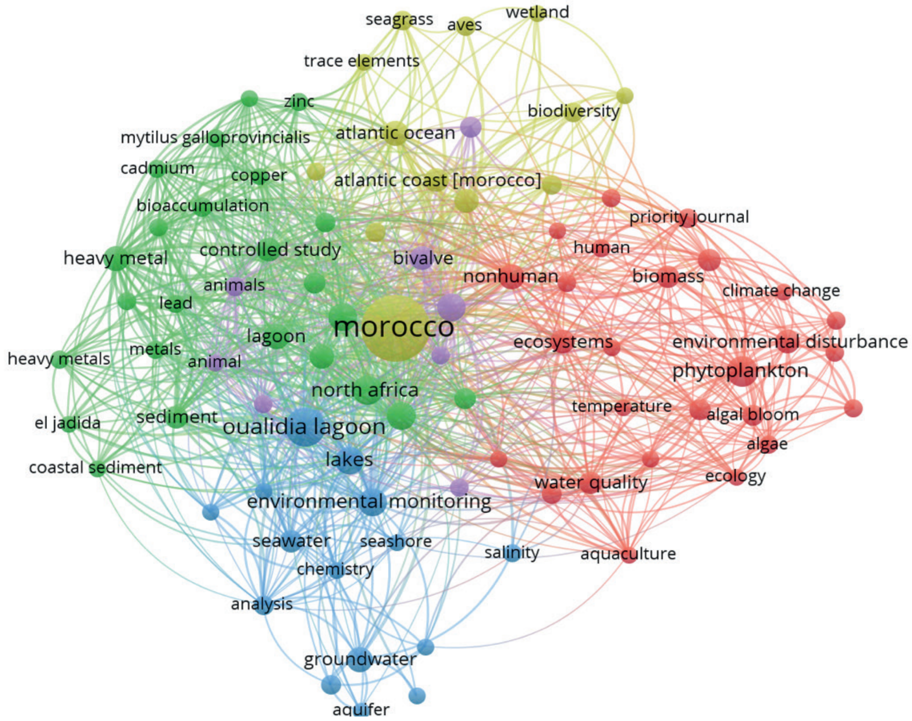

Figure 3: Keywords co-occurrence

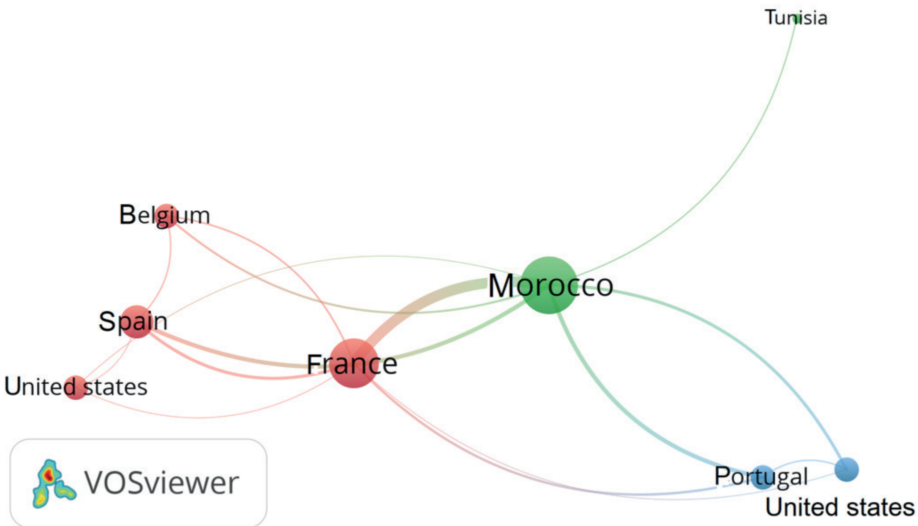

Figure 4: Co-country network analysis

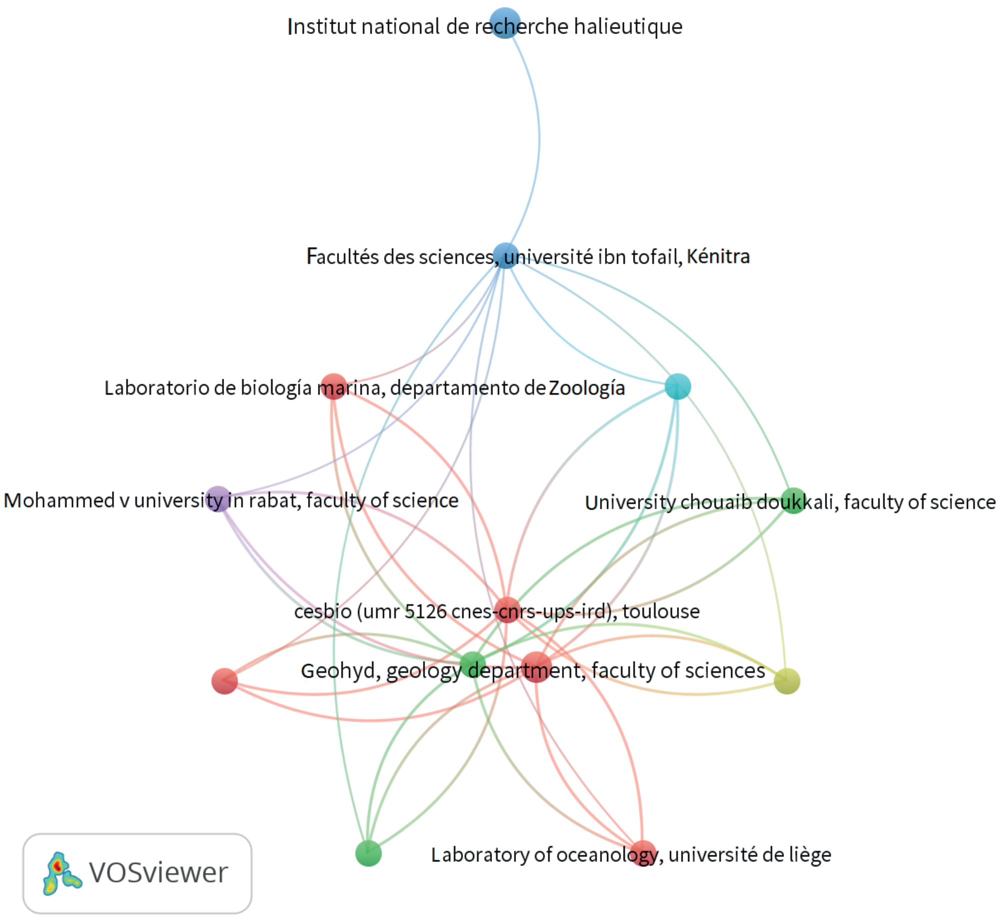

Figure 5: The top conductive institutions

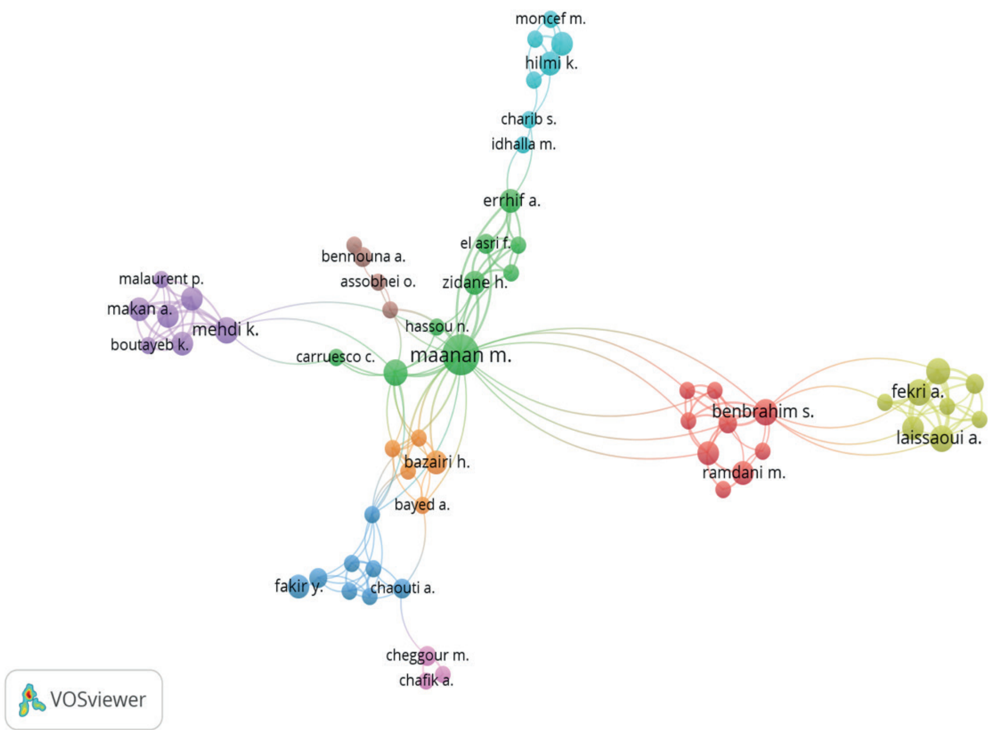

Figure 6: Co-authors analysis

4. Conclusion and discussion

Investigations into the Oualidia and Sidi Moussa lagoons were partly motivated by the importance of the complex Sidi Moussa-Oualidia Wetland as a biological reserve of high international interest according to the RAMSAR Convention for the conservation of wetlands of international interest. In addition, they are considered among the most important Moroccan wetlands. They are classified as a site of biological and ecological interest (SIBE), performing a great socio-economic role in the area (fishing, aquaculture, salt exploitation, tourism). Given these two lagoons' ecological and economic importance, scientific studies showed an increasing trend in the number of publications in recent years (DAMSIRI et al., 2017; MAANAN et al., 2018).

In the present document, we provide a bibliometric analysis to review 351 papers published from 1971 to May 2021. We identify the research trend and hotspots for future directions. Results highlight the disparity in the distribution of publications between Oualidia and Sidi Moussa lagoons. Oualidia lagoon receives the most attention with 218 publications. Regarding the influential journals, "*Bulletin de la Société Géologique de France*" has the most significant number of publications (5.9%), followed by the "Journal of Materials and Environmental Sciences" (4.8%). About the institutional collaboration network, the INRH needs to develop more collaboration with the national partners and universities. Morocco is the main contributor with the most extensive publication in this field, followed by China (145.21%). International collaboration with more developing countries needs to be progressed.

On the other hand, the most prominent authorship collaboration network is dominated by "MAANAN M." Regarding research hotspots, the co-occurrence of keywords revealed that the main research hotspots could be summarized as environmental monitoring, water quality, phytoplankton, and heavy metals. In contrast, the application of new monitoring methods for lagoons investigation, new technologies, processes, and models of ecological restoration received little attention. In conclusion, this short investigation is expected to benefit researchers interested in Atlantic coastal lagoons. Furthermore, we believe our findings can provide ideas about the development trends and research hotspots in the lagoons.

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A Decision support Framework for the Management of Sidi Moussa-Oualidia Lagoons: Moving toward Sustainability

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Abstract. The Moroccan lagoon's Oualidia – Sidi Moussa complex, located between land and sea, is important for its environment and the valuable ecosystem services provided to the local population. However, increasing urbanization, aquaculture, agriculture growth, fishery demand, and tourism trends, among other activities, have created several problems that affect natural resources and human interest as an obstacle to achieving sustainable development. In this paper, we used the Drivers-Activities-Pressures-State Change-Impact (on welfare)-Responses (as Measures) framework (DAPSI(W)R(M)) to assess and evaluate complex management components of multi-aspects issues covering social, environmental, economic and policies parts. The responses provided under the Sustainable Development Goals will help provide a structured tool that local managers and decision-makers could use to improve the environmental health of ecosystems, the socio-economic aspects of the surrounding population towards a resilient ecosystem, and achieve sustainability on a large scale.

Keywords: Oualidia lagoon, Management Framework, DAPSI(W)R(M), Sustainability, SDG

1. Introduction

Coastal lagoons ecosystems provide several goods and services with different benefits to human welfare and well-being, making them complex social-economic and ecological systems (NEWTON et al. 2018). Society highly values these benefits (GÖNENÇ & WOLFLIN 2005; NEWTON et al. 2018). However, in the case of the Oualidia and Sidi-Moussa lagoons complex, they have a long history of human occupation and land use utilization (EL MAHRAD et al. 2020b). The lagoons complex is located in the middle of the Atlantic shore of Morocco between both cities of El Jadida and Safi. They are restricted lagoons, paralleled to the coast and connected to the sea by narrow inlets, allowing water circulation. Furthermore, these lagoons and the surrounding region are part of a vast natural coastal area called "sahel", which belongs to the large structural unit, the Western Moroccan Meseta.

Besides their geographical and geomorphological characteristics, these lagoons provide multiple goods and services, including food provisioning (mainly fish, shellfish, and agriculture), touristic attractions from nature watching to touristic facilities, and coastal infrastructures. Therefore, these ecosystem services are valuable economically and societal, cultural, and aesthetic value that can contribute to improving the mental and psychological health of locals and visitors (SANDIFER et al. 2015). Moreover, international conventions provide Oualidia and Sidi-Moussa with legal protection, such as Ramsar sites. During the last centuries, these lagoons were heavily affected by the set activities behind several

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pressures and state changes, which impacted the population welfare of the region. Several previous studies and projects tried to tackle these issues (MAANAN et al. 2014; MEJJAD et al. 2018 ; 2020). However, most of them addressed a single aspect using a unique disciplinary approach instead of a multidisciplinary approach taking into consideration ecological, social, economic, and political aspects. A conceptual framework is needed to understand, organize and manage information that highlights the activities and issues of these lagoons. This will help clarify the problems in a logical, standard, and hierarchical approach (PATRÍCIO et al., 2016). Many frameworks have been developed for this purpose, such OSTROM approach, System Approach Framework 'SAF', and DAPSI(W)R(M). The first two approaches need a stakeholder's implication in the study. Thus, the DAPSI(W)R(M) was the most appropriate framework for the following research to analyze, assess and provide measures for local managers. This approach will be linked to the sustainable development goals as achievement objectives toward sustainability of these ecosystems.

2. Methodology: DAPSI(W)R(M) Framework

The adaptive management framework, Drivers-Activities-Pressures-State Changes-Impact (on welfare) and Responses (as Measures), known briefly as DAPSI(W)R(M) (Elliott et al. 2017), is widely used framework among environmental managers and especially coastal managers. It was also widely used among lagoons scientists (BOUCHKARA et al. 2021; EL MAHRAD et al. 2020a; GARCIA-AYLLON 2017; GARI et al. 2015; NEWTON et al. 2014; ROZYNSKI et al. 2019; SMITH et al. 2016). Drivers can be conceptualized as basic human needs that require specific activities in economic sectors such as fishing, tourism, and agriculture. These result in pressures such as overfishing and the input of harmful elements that change the environmental state, which in turn cause mainly negative impacts on human welfare such as loss of jobs. Thus, to confront these changes, management actions must be implemented as a measure to deal with the entire lagoon ecosystem.

3. Results and Discussion

3.1 Drivers

The Drivers in the context of Oualidia-Sidi Moussa lagoons are referred to Maslow's pyramids (MASLOW 1943), such as the basic human needs such as food, shelter, security, and life fulfillment. These drivers will put in context with the activities in the region (Fig. 1).

3.2 Activities

Each driver requires one or different activities to achieve all needs. The main associated activities by sectors to each driver are shown in figure 1, which represents the connection between both. The major common economic activities by sectors are agriculture, fish and shellfish, tourism, recreation and extraction of non-living resources, followed by inlet change, construction, boating, and land-based industry. For instance, oyster farming is well known in the region; the agriculture activities are based mainly on cereals, and non-living resources are based on salt production and seaweed harvesting. About 157 douars surround both regions.

3.3 Pressures

The economic activities in this region depend mainly on the lagoon's ecosystem services, which exert multiple pressures on their environmental quality, which may impact them negatively and lead to deterioration. However, there are different typical pressures in both ecosystems, including the presence of underwater noise from boating activity, presence of litter, presence of synthetic compounds such as pesticides, nitrogen and phosphorus enrichment from agriculture fertilizers, and input of organic matter from shell fishing other pressures.

For instance, 78% of the cultivated area surrounding the Oualidia lagoon used agrochemical products (MAANAN et al. 2014), representing the source of high nutrient concentrations such as nitrate and ammonium (DAMSIRI et al. 2015; 2017). This reached the lagoon through the freshwater and groundwater influx and led to an increase in chlorophyll-a in the lagoon (EL ASRI et al., 2015). Moreover, the high pressure from traditional, oysters farming, seaweed harvesting, and sand extraction (BERYOUNI et al. 2012; EL ASRI et al. 2017; MAANAN et al. 2014) has led to the input of organic matter death and subsequent decomposition of phytoplankton (DAMSIRI et al. 2017).

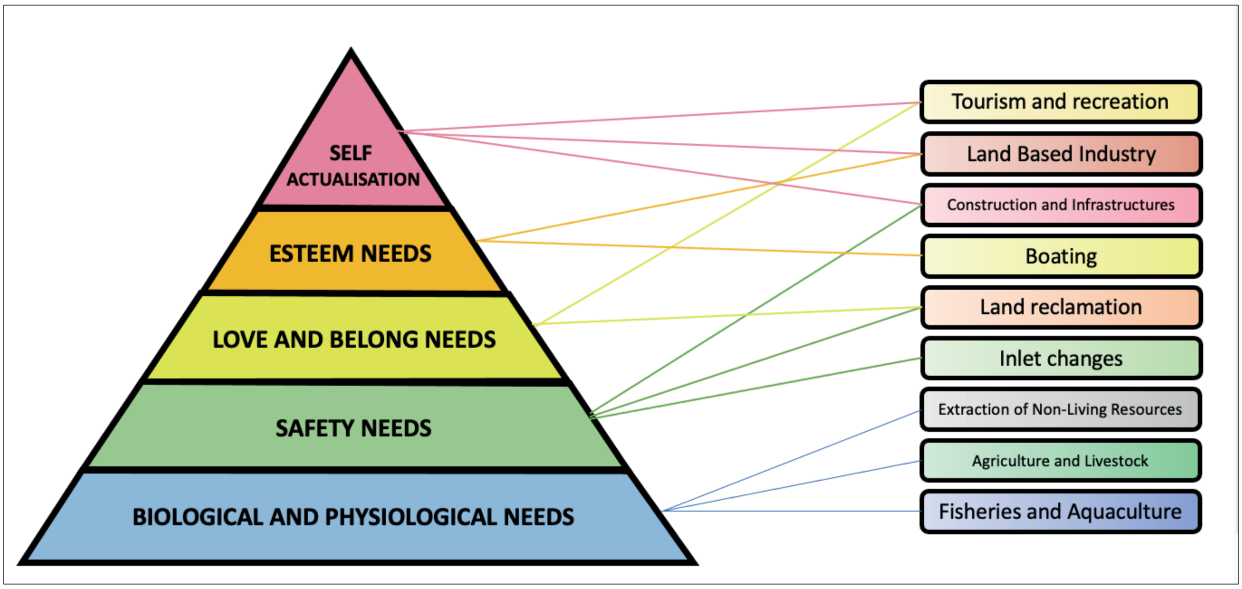

Figure 1: Interconnection between common drivers and sectorial activities in the Oualidia and Sidi-Moussa lagoons

According to BENMHAMMED et al. (2021), the historical inputs of metals such as Cd and U into the Sidi Moussa lagoon are linked to the industrial activities practiced in the surrounding areas since 1986, while a slight decline in metals concentrations was recorded between 2000 and 2017 attributed to the previous management plans. Similarly, in the Oualidia lagoon, (MEJJAD et al. 2018) revealed moderate and severe contamination by Cd, Cr, and As since the 70s, which was attributed to the development of human activities in the lagoon, including agriculture activities. Due to the attractive nature of both lagoons, tourism influx increases during summer. Figure 2 shows some impacts on the tourism activities in the Sidi Moussa area (summer 2020), where the high tide of the lagoon flooded the parking. Figure 2 also displays the mismanagement of tourism-related waste, where the litter is discarded in the broad water line of the lagoon with the absence of beach trash bins.

3.4 State Changes

The environmental state of both lagoons has been changing over time due to the mentioned components above. The relative magnitude of environment state changes might be associated with a particular level of each pressure, which may reflect changes in the physical, chemical, and ecological parameters of both environments. Both lagoons have known a state change in their coastal ecosystems, including components (e.g., habitat and species) and processes (e.g., food web dynamic and hydrological processes. Furthermore, intermediate services were also impacted, including supporting services (e.g., nutrient cycling) and regulating services (e.g., biological control). Moreover, final ecosystem services were also affected, including provisioning services, regulating services (e.g., clean water and sediment) and finally, cultural services (Fig. 2). In case of contamination of oysters, the Ministry of Agriculture and Fisheries issues regular notices to prevent the non-consumption of oysters for a certain period.

Figure 2: Examples of Input of Litter and impact of tourism to Sidi-Moussa Lagoon

3.5 Impact (on welfare)

Changes in the state of natural systems are reflected in many aspects (see the section on changes in-state), resulting in changes in the provision of societal and economic goods and benefits. This demonstrates the cause of the Oualidia and Sidi-Moussa lagoon. For instance, both regions have registered a drop of fish catch as a provisioning service (e.g., food: fish and shellfish). In 2017, the harvesting and selling of oysters in Oualidia were prohibited by an official press release from the Department of Marine Fisheries of Morocco, which led to the loss of revenue or jobs or at least yearly working days. Similar events, if they occur, will put at risk public health because of the consumption of contaminated seafood (toxins or chemicals) and consequently affect the tourism industry in the region (Mejjad et al. 2021).

4. Discussion

4.1 Holistic Integration of Management Components

All previous components of DAPSI(W)R(M) show the complexity of management systems in both lagoons due to the link and interference among components at individual and multiple levels. Thus, a conceptual model to connect all framework elements through a causal chain is represented in Figure 3. The resulting schema will provide insights to trace each component to its activities, pressures, state change, and impact on human welfare. This will order the priorities to tackle primarily important issues.

4.2 Holistic Integration of Management Components

Several countries are signatories of several international conventions for protecting the environment, human rights, and welfare through social and economic instruments. Morocco is one of the leaders in the African continent that joined those international components, including, the Sustainable Development Goals (UN, 2015), as the main focus of this study, where targets of SDGs need to be achieved by 2030. Therefore, Local region and communities needs to include these targets in the management process of a region as part of the project of advanced regionalization of the country, which was announced in 2010, leading to significant changes in the power structure of the Moroccan Kingdom. This will show how local managers can contribute to national-scale policies to achieve the country's SDGs target.

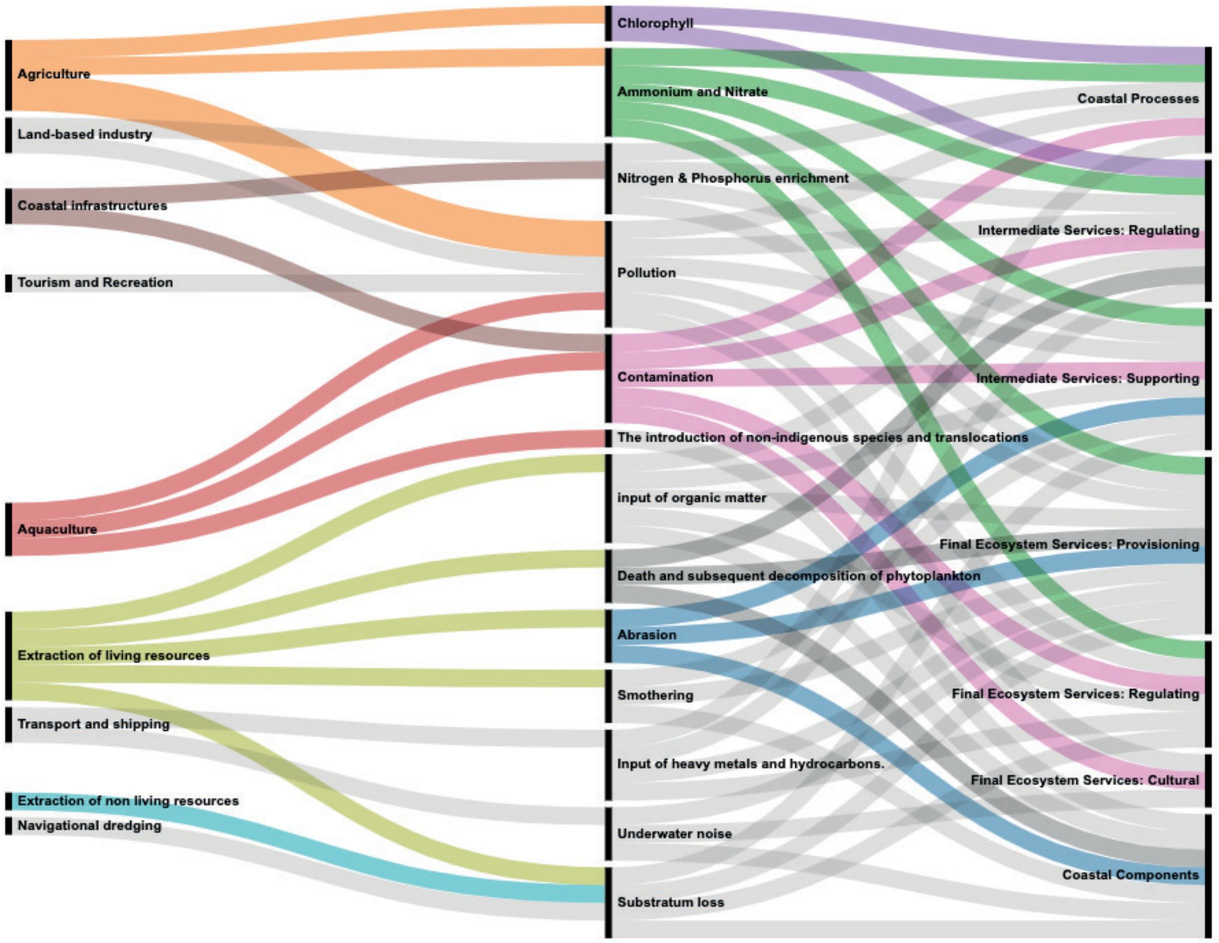

Figure 3: Causal chain among examples of Activities-Pressures and State Changes

This section will highlight a set of management responses as measures within their link to SDG targets. Only direct links will be mentioned to get a deep understanding of each target. More information can be found at https://sdgs.un.org/goals) :

- Providing more garbage bins, especially during summer, linked to SDG11, SDG14, and SDG15 (Figure 2 shows the main need) while encouraging 3R (Reduce, Reuse, Recycle) associated with SDG13 & SDG14 by providing the beach with recycling bins or containers.
- Local schools and organizations organize awareness campaigns and educational field trips to raise future generations' awareness about the importance of these ecosystems. This is linked to SDG4.
- Implementing a wastewater treatment plant for effluents near Sidi Moussa lagoon. This is linked to SDG3, SDG6, SDG14, and SDG15.
- Implementing monitoring programs that include hydrology, biology, and physicochemical parameters. These are linked to SDGs, SDG6, SDG13, SDG15, and SDG15.
- Developing eco-friendly projects related to the blue growth sector in several sectors such as medical sea plants, marine renewable energy, biotechnology, ecological boating without fuel engine, and diving, among other activities. This can contribute to SDG1, SDG4, SDG7, SDG10, and SDG13.

- Protection of surface water and Groundwater surrounding the lagoon can be linked to SDG3, SDG6, and SDG15.
- Reuse of WWTP, which is linked to SDG6.

We can also implement several other recommendations concerning the lagoons' ecosystems and surrounding population through a willingness to change from the local manager and decision-makers. This shows the usefulness of DAPSI(W)R(M) as a causal chain framework that brings an overview of issues covering different management aspects from ecological to social, economic, and political responses as measures that can bring these ecosystems towards sustainability.

5. Conclusion

The Oualidia and Sidi-Moussa complex lagoons provide valuable goods and benefits to surrounding economics. However, unsustainable use and bad practices by users, extractors (inputters), beneficiaries, and regulators may affect this ecosystem's services. The DAPSI(W)R(M) approach helped assess the issues and indicators with link causality of each aspect. A detailed integrated assessment for each lagoon, separately, will provide further in-depth knowledge about issues, which will help take rights measurable decisions following the suggested responses and measures. An overview of the link to SDG targets was provided, which shows the power of local scale application in national and international convention achievement.

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