Mapping the Spatial Distribution of Seagrass Meadows and Non-Indigenous Species in the Associated Benthos in the Marchica Lagoon: First Indicators of the Integrated Monitoring and Assessment Program (IMAP)

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Keywords: Mediterranean Sea, UNEP/MAP/IMAP-MPA project, Common Indicator, Seagrass Meadows, Non-Indigenous Species, GIS Distribution.

Abstract

The objective of this study consists to conduct the first monitoring of seagrass meadows and two non-indigenous species (NIS) in the associated benthos (*Bursatella leachii* and *Callinectes sapidus*) as indicators of the Integrated Monitoring and Assessment Program (IMAP) in the Ramsar site of the Marchica lagoon located on the north-eastern coast of Morocco. This lagoon has been the focus of a succession of restoration actions since 2010 aimed at conserving its biodiversity and improving its environmental state. Thirty sampling stations were monitored during the 2022-2023 winter season to determine the spatial distribution of seagrass meadows and of two non-Indigenous species above mentioned. Our results showed the presence of two marine species *Cymodocea nodosa*, the most widespread species, and *Zostera noltei*. The spatial distribution revealed the presence of the species only on the borders of the lagoon and their absence in the central area. For NIS, the results showed 143 *Callinectes sapidus* and 45 *Bursatella leachii* in different sizes ranging from small to large. To protect the marine phanerogams in the Marchica lagoon, it is recommended to develop this preliminary study by a spatiotemporal survey considering a seasonal pattern (winter, spring, summer and autumn) and by monitoring others stations in order to examine the existence of other species of seagrass and identified the benthos associated. The results of field monitoring will be used for future seagrass monitoring using satellite remote sensing as recommended by IMAP guidelines.

1. Introduction

Seagrasses are one of the most productive habitats in shallow waters, playing an important role in fish reproduction and biodiversity, carbon storage, coastal protection, and climate change mitigation (Hu et al., 2022; Tahir et al., 2019). A variety of research studies have been conducted to improve understanding of meadows and their habitats, and for the majority of species, meadow distribution has been described (Short et al., 2001; Mukai, 1993; Phillips and Menez, 1988; Den Hartog, 1970). The presence of seagrass meadows can increase the surface area for colonizable flora and fauna compared to bare sediment (Auby, 1991). In coastal ecosystems, seagrass serves as a crucial primary producer while offering a vital habitat for a variety of animal assemblages (Talbot et al., 2016).

Over the previous decades, severe seagrass decreases have been reported globally (Waycott et al., 2009; Short and Wyllie-Echeverria, 1996). In coastal lagoons, the biodiversity of seagrass meadows is often impacted by socioeconomic development activities (Tu et al., 2021). The most important factors that have strongly impacted the decline in seagrass populations concern human activity, in particular the excessive discharge of nutrients and chemical pollutants, as well as overfishing and the introduction of invasive species (Insalaco et al., 2024). The International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species' Categories and Criteria indicate that the 72 seagrass species worldwide are in danger of going extinct (Short et al., 2011).

In the Mediterranean Sea, seven types of seagrass meadows have been identified (Boudouresque et al., 2009; Ruíz et al., 2009). *Posidonia oceanica* being the only endemic species (Boudouresque et al., 2009). *Cymodocea nodosa*, *Zostera marina*, and *Zostera noltei* have a more widespread temperate distribution (Boudouresque et al., 2021). *Ruppia maritima* has been found in brackish lagoons and salt marshes (Shili et al.,

2007). The other two species, *Halophila stipulacea* and *Halophila decipiens*, have been shipped in via ballast water and the Suez Canal (Boudouresque et al., 2021).
In the Mediterranean coast of Morocco, four of the seven Mediterranean species have been reported (*Posidonia oceanica, Cymodocea nodosa, Zostera marina, and Zostera noltei*) (Bazairi, 2015). Seagrass meadows have not been the subject of detailed scientific study, particularly with regard to their diversity, distribution and extent (Boutahar, 2021). *Zostera noltei* has been found on the Atlantic coast in Dakhla Bay, Sidi Moussa lagoon, Oualidia lagoon, Khnifiss lagoon and Moulay Bousselham lagoon; and on the Mediterranean coast, it has also been found in Smir lagoon and Marchica lagoon (Rezzoum et al., 2022; Boutahar, 2021).

This work is part of the IMAP-MPA project "Towards achieving the Good Environmental Status of the Mediterranean Sea and coast through an ecologically representative and efficiently managed and monitored network of Marine Protected Areas ". This project contributes to the application of the Barcelona Convention and Protocol related to Mediterranean Biological Diversity and Specially Protected Areas (https://www.rac-spa.org/protocol). Coordinated and implemented by the United Nations Environment Programme's Secretariat of the Mediterranean Action Plan (UNEP/MAP), the project is executed by the program for the assessment and control of marine pollution in the Mediterranean region (MED POL) and the Regional Activity Centre for Specially Protected Areas (UNEP/MAP/SPARAC).

The objective of this study is to conduct the first spatial distribution of seagrass meadows and two non-indigenous species *Callinectes sapidus* and *Bursatella Leachii* in the associated benthos as indicators of "Biodiversity and Non-Indigenous Species" component of the IMAP (Common Indicator CI2 and CI6) in the Marchica lagoon classified as site under pressures.

2. Methodology

2.1 Study Area

The Marchica lagoon, also known as Sebkha Bou Areg or Nador lagoon, is located on the north-eastern coast of Morocco, in the Nador province. This lagoon is the biggest along the Mediterranean coast in Morocco with a surface area of approximately 115 km^2 and a maximum depth of 8 m. The lagoon and the Mediterranean Sea are separated by a 25 km-long sandbar traversed by an artificial inlet 300 m wide and 6 m deep, which ensures the exchange of water between these two ecosystems (Figure 1). The climate around the lagoon is a Mediterranean with moderate and rainy winters, and hot dry summers. The renewal time of lagoon waters varies according to the seasons and sectors of the lagoon, it is higher at the level of the two eutrophication zones of Beni Ensar and Kariat Arekmane according to Maicu et al. (2021).

The Marchica watershed has an area of approximately 700 km^2, consisting of multiple stream valleys, most of which provide a significant contribution during precipitation events (Figure 1). The Marchica lagoon and its watershed have experienced urban growth in recent years (Aitali et al., 2022). An ecological restoration plan has been implemented since 2010 for the Marchica lagoon (Oujidi et al., 2024). The main actions are 1) the creation of the Marchica Lagoon Site Development Agency; 2) the opening of a new pass in 2011 between the lagoon and the Mediterranean Sea to improve water exchanges between the two ecosystems; 3) the installation of wastewater treatment plants (WWTP) as well as the extension of the sewage network to the communes surrounding the lagoon.

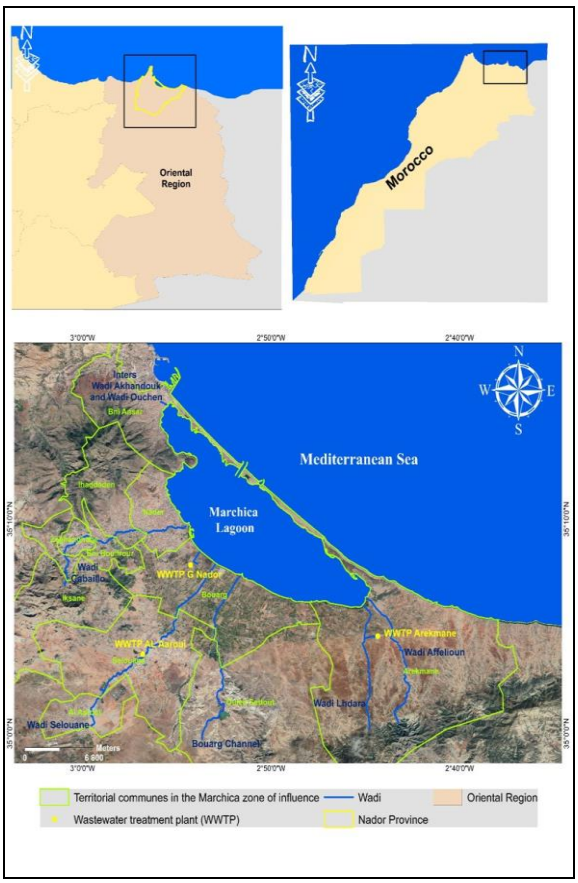

Figure 1. Map of the Marchica lagoon and its watershed.

2.2 Environmental Sampling and Analysis Methods

Thirty sampling stations have been monitored during the last week of December 2022 and the first week of January 2023 to determine the spatial distribution of seagrass meadows and benthos associated. For seagrass, sampling was conducted by scuba diving. The seagrass meadows were collected into a quadrat of 0.5m x 0.5m surface at each seagrass-colonized zone. After being placed in numbered zipped transparent plastic bags, the samples were transported to the laboratory in coolers for species identification. The benthos was sampled using a VAN VEEN grab sampler (0.25 m^2) and 3 replicates per station were collected. The benthos samples were sieved on the site using a 1 mm pore size mesh, then fixed and preserved in 5% formalin diluted in lagoon water. Sampling operations were conducted from a zodiac by a scientific diver. The environmental parameters of the surface water were measured in situ using a multiparameter (Temperature, Dissolved Oxygen, and Salinity). The geographical coordinates and depth were taken using equipment integrated into the Zodiac. Figure 2 showed the seagrass meadows sampling network.

In the laboratory, the identification of seagrass was based on the classification of Den Hartog (1970) and Green and Short (2003). The benthos samples are first washed in a sieve with a mesh size of 0.1 mm to remove all traces of formalin. Sorting

consists of extracting the macro-benthic organisms and separating the various individuals according to their zoological group. Only *Callinectes sapidus* and *Bursatella leachii* were in consideration in this study as indicators of IMAP program.

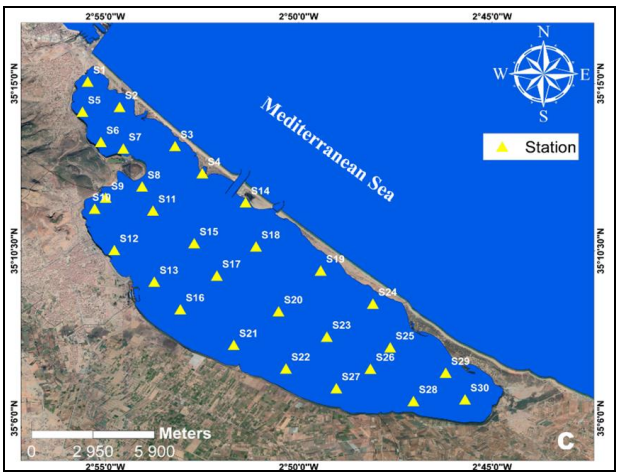

Figure 2. Sampling network for seagrass meadows and benthos associated in the Marchica lagoon during the winter season of 2022-2023.

2.3 Statistical Analysis and Maps

To assess the relationship between the distribution of the seagrass meadows, non-indigenous species and the physicochemical parameters, the spearman's rank coefficient was used with IBM's SPSS statistics software version 25. ESRI software ArcGIS Desktop 10.4 was used to create all the maps.

3. Results

3.1 Environmental Data

The spatial distribution of physicochemical parameters in the Marchica lagoon (Figures 3, 4 and 5) showed that the water temperature on the surface of the lagoon varied from 15°C to 18.3 °C with a mean value of 16.6 °C. The salinity ranged from 36.3 to 38.5 g/l with a mean value of 38 g/l. The dissolved oxygen contents in the surface water ranged from 8.7 mg/l to 12 mg/l with a mean value of 9.76 mg/l.

3.2 Seagrass meadows, *Callinectes sapidus* and *Bursatella leachii* characteristics

The seagrass species, abundance of *Callinectes sapidus* and *Bursatella leachii* are illustrated in Table 1.

Spatial Distribution of Seagrass Meadows

The results revealed the presence of two marine species: *Cymodocea nodosa* the most widespread species, and *Zostera noltei*. The spatial distribution revealed the presence of the species only on the borders of the lagoon and their absence in the central area (Figure 6). Depth varied between 0.5 m and 4.9 m for *Cymodocea nodosa* and between 0.5 m and 1.3 m for *Zostera noltei*.

Spatial Distribution of *Callinectes sapidus*

The spatial distribution of *Callinectes sapidus* in the benthos of the Marchica lagoon (Figure 7) revealed a presence of 143 individuals at 13 of the 30 stations sampled: on the continental border (S12, S16, S21, S22, S27 and S28), on the Arekmane side (S24), in the central areas (S20, S23 and S26), and in the Marina d'Attalayoun area (S8, S9 and S10). The highest abundance was recorded at station S21 with 30 specimens and depth of 4.6 m.

Spatial distribution of *Bursatella leachii*

The spatial distribution of *Bursatella leachii* in the benthos of the Marchica lagoon (Figure 8) revealed a presence of 45 specimens at 15 of the 30 stations sampled: in the center of the lagoon (S15, S17, S18, S20, S25 and S26), at the continental border of Bouarg (S13, S16 and S21), on the sandbar border (S2 and S24) and near the Atalayoun Marina (S5, S6, S7 and S8). The highest abundance was recorded at station S18 with 8 specimens and depth of 7.2 m.

Station	Seagrass species	Depth (m)	*Callinectes sapidus* Abundance	*Bursatella leachii* Abundance
S1	*C nodosa*	1.9	-	-
S2	-	1.3	-	2
S3	*C nodosa*	1.1	-	-
S4	*C nodosa*	2.6	-	-
S5	*C nodosa*	2	-	3
S6	*C nodosa*	4.9	-	4
S7	-	1.5	-	1
S8	-	6.1	7	2
S9	*C nodosa*	2.4	7	-
S10	-	2.8	11	-
S11	-	5.2	-	-
S12	*C nodosa*	0.5	7	-
S13	-	4.4	-	4
S14	*Z noltei*	0.5	-	-
S15	-	6.8	-	6
S16	-	2.8	20	1
S17	-	6.1	-	5
S18	-	7.2	-	8
S19	-	7	-	-
S20	-	7	15	1
S21	-	4.6	30	3
S22	*C nodosa*	4.5	11	-
S23	-	7	13	-
S24	*Z noltei*	1.3	3	1
S25	-	6		2
S26	-	6.4	5	2
S27	*C nodosa*	4.5	4	-
S28	*C nodosa*	3.8	10	-
S29	*C nodosa*	1.7	-	-
S30	-	2.4	-	-

- Not found, *C nodosa: Cymodocea nodosa, Z noltei: Zostera noltei.*

Table 1. Characteristics of seagrass meadows, abundance of *Callinectes sapidus* and *Bursatella leachii* in the Marchica lagoon during the winter of 2022-202

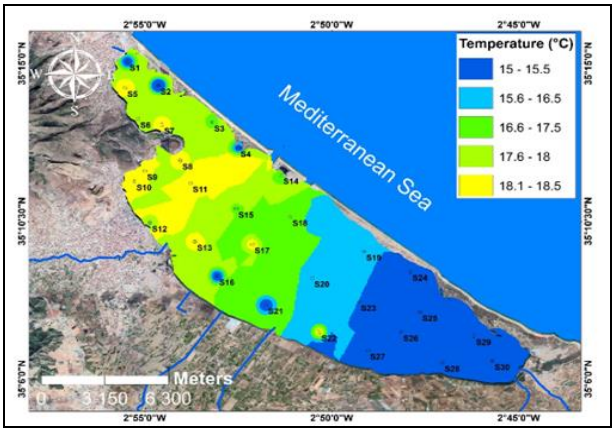

Figure 3. Spatial distribution of temperature of superficial water in the Marchica lagoon during the winter season of 2022-2023.

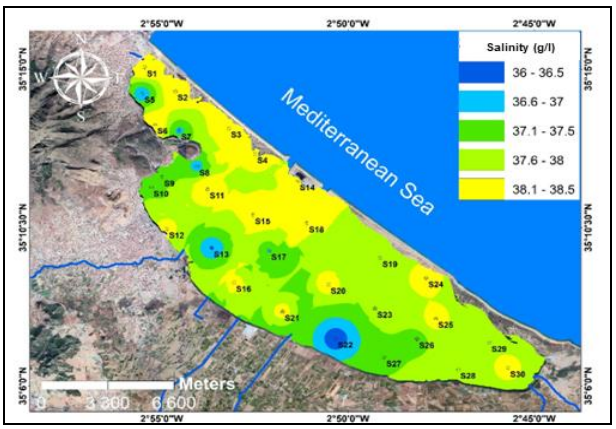

Figure 4. Spatial distribution of salinity of superficial water in the Marchica lagoon during the winter season of 2022-2023.

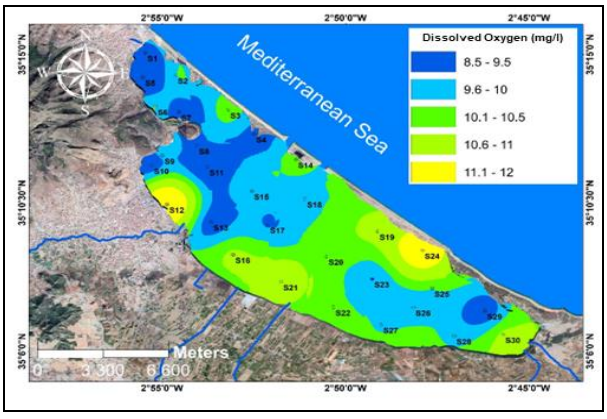

Figure 5. Spatial distribution of dissolved oxygen of superficial water in the Marchica lagoon during the winter season of 2022-2023.

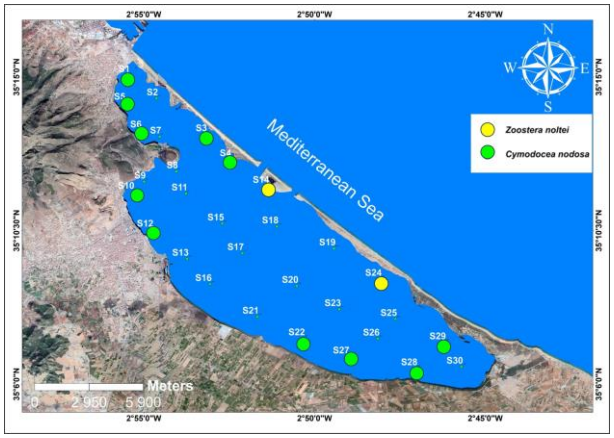

Figure 6. Spatial distribution of seagrass meadows in the Marchica lagoon during the winter of 2022-2023.

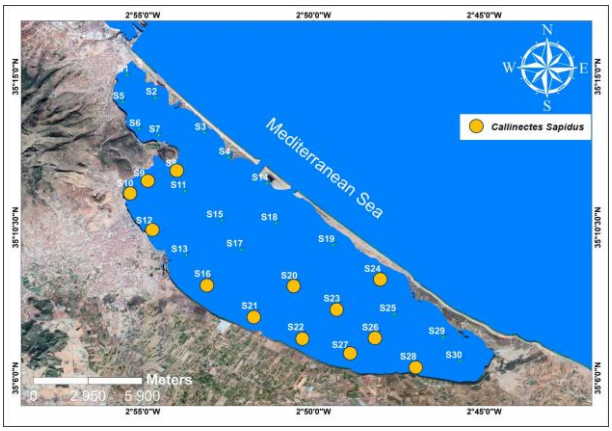

Figure 7. Spatial distribution of *Callinectes sapidus* in the Marchica lagoon during the winter of 2022-2023.

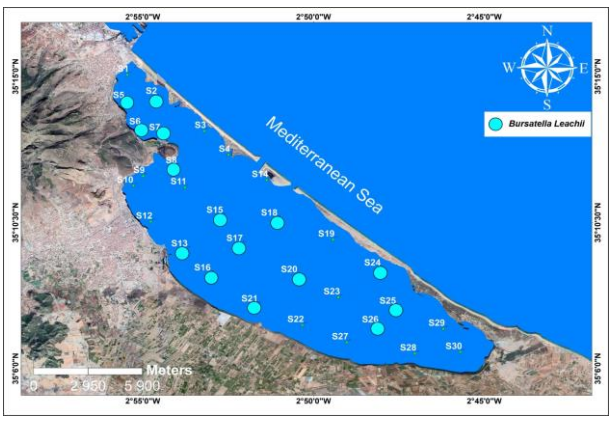

Figure 8. Spatial distribution of *Bursatella leachii* in the Marchica lagoon during the winter of 2022-2023.

4. Discussion

Coastal zones usually provide a variety of ecological services which contribute to local people's economic well-being, but they are also becoming increasingly susceptible to both natural and human stresses (Aitali et al., 2020; Millennium Ecosystem Assessment, 2005). The Marchica lagoon was designated as a hotspot for pollution in the Mediterranean Sea in 2005 as a result of pollution from industrial and urban effluent as well as coastal urbanization without environmental protection measures (UNEP/EEA Report No. 4, 2006). Since the development and restoration of this lagoon, significant changes in water quality and sediment distribution in the lagoon have been observed, as a result of the modified hydrological regime and the reduction in pollution factors (Ngadi et al., 2023; Rahhou et al., 2022; Oujidi et al., 2021a; Najih et al., 2017). However, this lagoon is still negatively impacted by the watershed which classified the lagoon as a site under pressure (Oujidi et al., 2021b).

The results of our study revealed the presence of two species *Cymodocea nodosa* and *Zoostera noltei*. Seagrass distribution is generally affected by water temperature and salinity (Morris et al., 2022). In seagrass habitats, elevated temperatures and salinities can constitute major stress factors in the context of climate change (Tsioli et al., 2022). The temperatures recorded in our study are those of the winter season, with an average of 16.64°C, and the minimum salinity recorded being 36.33 at station 22 located on the continental border of the lagoon influenced by wastewater treatment plant discharges (WWTP) via the wadis. This station recorded the highest abundance of *Cymodocea nodosa*.

Spearman correlation analysis showed a significant negative correlation between the presence of seagrass and depth ($p < 0.01$) ranging from 0.5 m to 4.9 m for colonized stations. These seagrasses are found only on the continental borders of the lagoon and not found in the central stations where the depth exceeds 4.9 m. Similar results were found by Morris et al. (2022) who reported that light is essential for the growth and survival of seagrass meadows, and that light availability is strongly affected by depth. No correlation was found between the abundance of *Callinectes sapidus* and the environmental factors, nor with the presence of seagrass meadows in the Marchica lagoon. This result corroborates the findings of other studies showing that invasive species have a high ecological valence and that the factors limiting their spread are very limited (Taybi et al., 2023). The appearance of *Callinectes sapidus* in a variety of environmental conditions in the lagoon highlights the invasive nature of the species and its ability to spread rapidly over wide salinity ranges (Oussellam et al., 2021; Shaiek et al., 2021; Taybi and Mabrouki, 2020; Stasolla and Innocenti 2014). A positive correlation was found between the abundance of *Bursatella leachii* and depth ($p < 0.05$), while a negative correlation was found for the presence of seagrass meadows. Previous studies have reported the presence of *Bursatella leachii* in various coastal environments colonized by seagrass meadows (Monnier et al., 2024; Trainito & Doneddu, 2016). However, the negative correlation highlighted in our study between seagrass meadows and *Bursatella leachii* is consistent with other observations in the Mediterranean (Castriota et al., 2025) where the species is more frequently associated with lagoons characterized by high algal blooms as Marchica lagoon.

Concerning seagrass meadows, comparison with previous studies shows the presence of *Ruppia spiralis* species in addition to *Cymodocea nodosa* in the lagoon according to Guelorget (1987), the presence of *Zostera marina* in addition to *Zoostera noltei* according to González García and Conde Poyales (1994 and 1991). Pergent et al. (2014) confirm that *Zostera marina* has disappeared from certain Mediterranean localities, including the Marchica lagoon. According to Bazairi (2015), *Zostera marina* has disappeared from the Marchica lagoon. Ramdani et al. (2015) and Natij et al. (2014) confirmed the presence of *Zostera noltei* and the absence of *Zostera marina*. Our results are in accordance with the study ANDA/INRH (2021) which reported that two species of seagrass were identified in the Marchica lagoon in 2018 *Cymodocea nodosa* widely distributed in the Marchica lagoon and *Zostera noltei* found in very limited areas especially in the area near the sandbar of the Marchica lagoon. Our results also agree with the study by Boutahar et al. (2021) which indicated the presence of *Cymodocea nodosa* near the coast of the lagoon and the study by Aknaf et al. (2022) which reported that after the restoration action, only *Zostera noltei* and *Cymodocea nodosa* were found in the lagoon. Seagrass meadows under pressure require the protection of existing populations against all forms of pollution, particularly untreated sewage, industrial pollution and waste. Protection also requires the establishment of marine protected areas (Short et al., 2011).

As invasive alien species are one of the world's biggest environmental problems and the main cause of biodiversity loss worldwide, it is essential to monitor their invasion patterns, sensitive areas, and pathways (Castriota et al., 2022). NIS pose a significant menace to marine biodiversity since they have adverse impacts on coastal ecosystems (Bazairi et al., 2022; Katsanevakis et al., 2014). Comparison with previous studies shows that the *Callinectes sapidus* (American blue crab native to western Atlantic estuaries) was recorded for the first time in 2017 in the coastal Marchica lagoon (Kaddouri and Ouamari, 2022; Oussellam and Bazairi in Chartosia et al., 2018) followed by systematic observations of this species with the expansion of its range into the Marchica lagoon. In July 2020, 62 *Callinectes sapidus* specimens were collected from the Marchica lagoon (Oussellam et al., 2021) while 143 specimens were recorded in the current work. The presence of *Callinectes sapidus* in the Marchica lagoon may be explained by the study area proximity to all of eastern Morocco's ports (Beni Ensar and Melilla), and it has spread throughout Morocco's Eastern Mediterranean coastline, including the estuaries of Moulouya and Kert (Taybi and Mabrouki 2020). The *Callinectes sapidus* have generated negative impacts on fishing activities, in particular damage to nets and catch quality, and maritime activity is considered the most probable way by which these invasive species entered the lagoon (Bazairi et al., 2022). For the mollusc *Bursatella leachii Blainville*, 1817, its first presence in the Marchica lagoon dates back to April 2016 (Kaddouri and Ouamari, 2022; Selfati et al., 2017).

5. Conclusion

We conducted the spatial distribution of seagrass meadows and two non-indigenous species (*Callinectes sapidus* and *Bursatella Leachii*) in the benthos associated during the wet season of 2022 - 2023. Our study showed the presence of two species of seagrass meadows: *Cymodocea nodosa* and *Zostera noltei* only on the borders of the lagoon and their absence in the central area. For *Callinectes sapidus*, the presence in a range of environmental conditions indicates the invasive nature of the species and its ability to spread rapidly. For *Bursatella Leachii*, the highest abundance was found in the central zone of the

lagoon. To ensure the protection of seagrass meadows in the Marchica lagoon, it is recommended to conduct a spatiotemporal survey covering all seasons (winter, spring, summer, and autumn). This survey would assist in confirming the presence of other seagrass species mentioned in previous studies and identifying any related NIS in the benthic community. The field monitoring results will serve as a basis for future satellite remote sensing of seagrass meadows in the Marchica lagoon.

Acknowledgements

This study has been supported by the National Laboratory for Studies and Pollution Monitoring (LNESP) under the framework of the Morocco IMAP - MPA project financed by the European Union. Thanks to the IMAP-MPA project and to the IMAP-MPA national expert Pr Mohamed MENIOUI and Pr Nasser-Eddine ZINE for their help and assistance. We thank Pr Abdelkhaleq Fouzi TAYBI for his valuable comments.

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