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First Inventory of the Biodiversity, Abundance, and Distribution of Jellyfish (Cnidaria) in Relation to Depth in the Bay of Al Hoceima, North Coast of Morocco, the Mediterranean Sea

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ABSTRACT

Jellyfish are considered the most important components of plankton in the oceans. However, in the Moroccan Mediterranean, data on jellyfish populations are scarce. Jellyfish are organisms belonging to the phylum Cnidaria, characterized by the presence of cnidocysts, and stinging cells. In carrying out our research on the jellyfish that proliferate in Al Hoceima Bay over the period 2019 to 2022, great importance was placed on studying the diversity of jellyfish species present in the bay. This is due to the risks associated with their proliferation, particularly during the summer months. This study aimed to analyze the species composition, abundance, and frequency of occurrence of the jellyfish community in the bay of Al Hoceima, located on the northern coast of Morocco. To achieve this objective, the gelatinous zooplankton sampling method was used, which enabled the researchers to collect samples in the epipelagic layer, between 0 and 80m depth, at nine different stations. In addition to this method, field surveys were carried out specifically for macromedusae. During this study, a total of 16 species of Hydromedusae and Scyphomedusae belonging to 15 genera were discovered in the study area. Among these, there were ten new records for the Moroccan Mediterranean and thirteen new records for the bay of Al Hoceima. The populations of Hydromedusae consisted of six species of Trchymedusae, three species of Anthomedusae, and four species of Leptomedusae. In terms of the Scyphomedusae populations, three species were identified: *Pelagia noctiluca*, *Rhizostoma pulmo*, and *Rhizostoma luteum*. Notably, *Pelagia noctiluca* and *Rhizostoma pulmo* formed dense aggregations in the bay during the summer periods.

INTRODUCTION

Jellyfish play a crucial role in the marine ecosystem, comprising a diverse group of pelagic cnidarians, including Scyphozoa, Hydrozoa, and Cubozoa **(Bouillon & Boero, 2000; Brotz & Pauly, 2012)**. These jellyfish are primarily distinguished by their formation mode from polyps, either through strobilation (Scyphozoa), metamorphosis (Cubozoa), or budding (Hydrozoa) **(Bouillon & Boero, 2000)**. Despite being commonly categorized as zooplankton, implying their drift with ocean currents, larger scyphozoans are, in fact, proficient swimmers capable of independent movement **(Fossette *et al*., 2015; Schlaefer *et al*., 2018)**. Additionally, the life cycle of jellyfish is relatively short, lasting for approximately eight months **(Spring *et al*., 2000)**.

Blooms of these gelatinous organisms have been widely documented in many coastal regions of the world **(Purcell *et al*., 2007; Richardson *et al*., 2009; Brotz & Pauly, 2012)**. These blooms have been attributed to human-induced alterations to the marine ecosystem, such as overfishing, climate change, eutrophication, and marine construction and development **(Purcell *et al*., 2007; Richardson *et al*., 2009; Canepa *et al*., 2014)**.

These blooms have been traced back to human-induced variations in the marine ecosystem, such as overfishing, climate change, eutrophication, and marine construction and development **(Purcell *et al*., 2007)**. For example, jellyfish can have a negative effect on fishing activity by damaging nets and reducing fish catches **(Bosch-Belmar *et al*., 2020)**. They have been described as the main competitor of zooplanktivorous fish **(Pauly *et al*., 2009)**. Furthermore, they affect tourism and aquaculture **(Bordehore *et al*., 2016)**. Although it is well known that jellyfish can be voracious predators and therefore play important roles as consumers, they have often been historically considered as trophic dead-ends **(Verity & Smetacek, 1996)**. This view is supported by their generally low nutritional value **(Hays *et al*., 2018)**. However, jellyfish have also contributed to human benefits **(Doyle *et al*., 2014)**. These gelatinous organisms are used as food in Asia and also as a source of biomolecules **(Doyle *et al*., 2014)**. Additionally, jellyfish have played an important role in the marine ecosystem by regulating phytoplankton populations and are also prey for numerous animals. Nevertheless, these ecological and societal benefits are probably outweighed by the negative effects they have on socioeconomic activities **(Doyle *et al*., 2014)**.

In recent years, frequent jellyfish blooms have been recorded in the Mediterranean, resulting from the increasing populations of these gelatinous organisms **(Mills, 2001; Purcell *et al*., 2007; Brotz & Pauly, 2012; Canepa *et al*., 2014)**. Knowledge of jellyfish populations in the Mediterranean has been enhanced by several studies that are more numerous and diversified in the northern basin **(Goy, 1997; Buecher & Gibbons, 1999; Batistić *et al*., 2007; Sabatés *et al*., 2010; J. E. Purcell, 2012)**. However, efforts in the southwestern Mediterranean zones are relatively scarce. A few studies along the Tunisian coast **(Daly Yahia *et al*., 2003; Touzri *et al*., 2012)** have aimed to conduct taxonomic inventories of jellyfish and investigate their spatiotemporal distribution in relation to environmental parameters (hydrological, trophic) of the environment. There has also been some research on the Algerian coast **(Ounissi *et al*., 2016; Kherchouche & Hafferssas,**

2020), which describe the biodiversity of gelatinous zooplankton and its quantitative distribution on the Algerian coast.

In Morocco, the few studies on the distribution and abundance of jellyfish in the Mediterranean have been limited to jellyfish species that were washed up on the Moroccan coasts **(Mghili *et al*., 2020, 2022)** Additionally, a recent qualitative study of jellyfish was conducted in the bay of Al Hoceima **(Benyoub *et al*., 2023)**. Consequently, the distribution of these gelatinous organisms in the Moroccan Mediterranean has not been adequately studied and remains poorly understood; this is also true for the Al Hoceima region, where a renowned marine protected area known for its rich marine biodiversity is located. Repetitive and seasonal jellyfish blooms can also have negative effects on tourism, fisheries, local economies, and regional biodiversity **(Tomlinson *et al*., 2018; Ruiz-Frau, 2022)**. Therefore, studies on the jellyfish assemblage and its spatiotemporal distribution in Al Hoceima Bay are of great interest to understand the factors influencing the structure of this community in the region, as well as their ecological and economic impacts.

In the context of a research study on the entire population of jellyfish proliferating in the bay of Al Hoceima (2019- 2022), a qualitative and quantitative investigation of the bay's jellyfish appeared to be necessary to evaluate their species composition, abundance, and spatiotemporal distribution. The primary objective of this work was to conduct an initial taxonomic inventory of jellyfish in Al Hoceima Bay and to determine their spatiotemporal distribution by comparing the seasonal dynamics (summer, autumn, and winter) of jellyfish species with depth and environmental parameters (temperature, salinity). The main aim of the research was to identify potential variations among different zones within the bay.

MATERIALS AND METHODS

Characterization of the study area

The study area is located in the central part of northern Morocco in the western Mediterranean Sea, specifically the Alboran Sea. It encompasses a maritime section of the Moroccan Mediterranean coastal zone known as the bay of Al Hoceima. The bay covers an area of approximately 100km², making it one of the largest bays in the Mediterranean. Its maximum depth reaches 90m. The bay is flanked by two capes: Quilates to the east and Maure (Ras Al Abed) to the west (Fig. 1). The bay of Al Hoceima plays a crucial role in the region's tourism development and is a significant economic asset.

The tidal pattern in the area is of the semi-diurnal type, characterized by relatively low amplitude. Similar to other parts of the Mediterranean, there is a gradual decrease in tidal range when moving eastwards, since it is influenced by the Atlantic tide, as outlined by **UNEP/MAP-SPA/RAC (2020)**. The hydrodynamics of the bay of Al Hoceima are closely connected to the overall dynamics of the Mediterranean. Notably, an east-to-west-oriented anticyclonic eddy is present in the marine area **(Khouakhi *et al*., 2013)**. The most frequent swells in this zone originate from the west-northwest direction **(Khouakhi *et al*., 2013)**. However, it is essential to consider swells predominantly coming from the northeast to east-northeast direction. These northeast swells lead to coastal transport towards the west of the bay. On the other hand, wind patterns exhibit clear seasonal variation. In winter and spring, winds predominantly have a west-to-southwest component, while in summer, east-northeast winds prevail.

The Al Hoceima region is home to the largest marine protected area on Morocco's Mediterranean coast. It is characterized by great biological diversity, with the presence of vulnerable and endangered species. Additionally, it serves as an important area for commercial fishing, industry, and tourism, as outlined by **UNEP/MAP-SPA/RAC (2020)**. The bay is located in a relatively pristine zone of the Mediterranean coastline, in contrast to other areas, due to the low human population density and the absence of heavy industrial or agricultural activities. However, it is still subject to various anthropogenic pressures, such as plastic pollution and domestic wastewater. Notably, when comparing the two sides of Al Hoceima Bay, it becomes evident that the west coast faces a higher anthropogenic pollution burden than the east coast. This can be primarily attributed to the impact of the Al Hoceima port, pollution from urban wastewater and tourist facilities, as well as the presence of a desalination plant discharging brine into the bay at Sfiha Beach (Fig. 1).

Sampling strategies

The sampling network comprises nine study stations (Table 2), which were explored during five scientific sampling campaigns from August 2021 to June 2022 (Table 1), within the bay.

Table 1. Dates and periods of the sampling missions

Mission 1	Mission 2	Mission 3	Mission 4	Mission5
14- 08- 2021	17- 09- 2021	29- 10- 2021	21- 11- 2021	07- 01- 2022
Summer period		**Autumn period**		**Winter period**

Sampling was carried out in the epipelagic layer (between 0 and 80m) using vertical tows from the bottom to the surface, employing a working party 2 (WP2) plankton net. This allows for an estimation of the average abundance in the water column (which is overall homogeneous) per unit volume (m^3). The collected samples are immediately preserved in 1-liter jars and fixed with 4% formaldehyde. Larger species are counted on-site and photographed before preservation (if their size allows). In the laboratory, jellyfish species were identified and counted using microscopic sorting. This process involved utilizing an Optika-SZM-2 trinocular zoom stereomicroscope. Each jellyfish was individually examined, and the size of its umbrella was measured using a centimeter ruler. The collected jellyfish samples were identified to the lowest possible taxonomic level to obtain the abundance (ind/ m-3) based on the total count in each sample. Temperature and salinity measurements were taken *in situ* at each station, carried out in parallel with the fishing operations, using a Hach HQ 40D multiparameter device.

For coastal sampling, ten stations were established along the coasts, where surveys were conducted to identify and count specimens occasionally stranded or visible in shallow waters. The observation frequency varies from once a week to once a month, depending on the station and season. Moreover, data were collected from various sources. A meeting with "Fishermen from the port of Al Hoceima" association on December 26, 2019, allowed us to gather essential data. Furthermore, we included artisanal fishing ports located to the east of the bay of Al Hoceima, at the level of Cape de Quilates, such as "Ahdid, Assihar, Thsammat, and Ifri nidbein." Data from these ports were collected between August 15 and August 30, 2020. We conducted data collection missions along the bay's coastline, including sites, such as the port of Al Hoceima, Isri beach, Sfiha, Souani, and Elharche. The data collected for these sites covered the period from 2019 to the end of May 2023. Monthly and bimonthly surveys were specifically dedicated to the study of Scyphozoaires' phenology. Besides field sampling, observations of jellyfish posted on Facebook were also collected. Data on the absence/presence of jellyfish between 2019 and 2023 were collected through reports. The obtained data were first examined to detect duplicates, then cleaned and recorded in a database. To facilitate species identification, we used powerpoint presentations and recognition tools such as identification guides and posters in Arabic and French. Qestionnaires written in Arabic and French were also used.

Table 2. Location and depth of the sampling stations in AL Hoceima Bay

Station	**Longitude**	**Latitude**	**Depth in meters**
P1	**3°54'21''**	**35°15'21''**	50
P2	**3°54'9,72''**	**35°14'31,08''**	45
P3	**3°53'55,92''**	**35°13'36,54''**	30
P4	**3°50'58''**	**35°15'30,2''**	80
P5	**3°50'59''**	**35°14'4''**	40
P6	**3°50'58''**	**35°12'39''**	15
P7	**3°47'18,78''**	**35°15'56,76''**	50
P8	**3°47'34,02''**	**35°15'1,92''**	40
P9	**3°47'38,1''**	**35°13'58,92''**	20

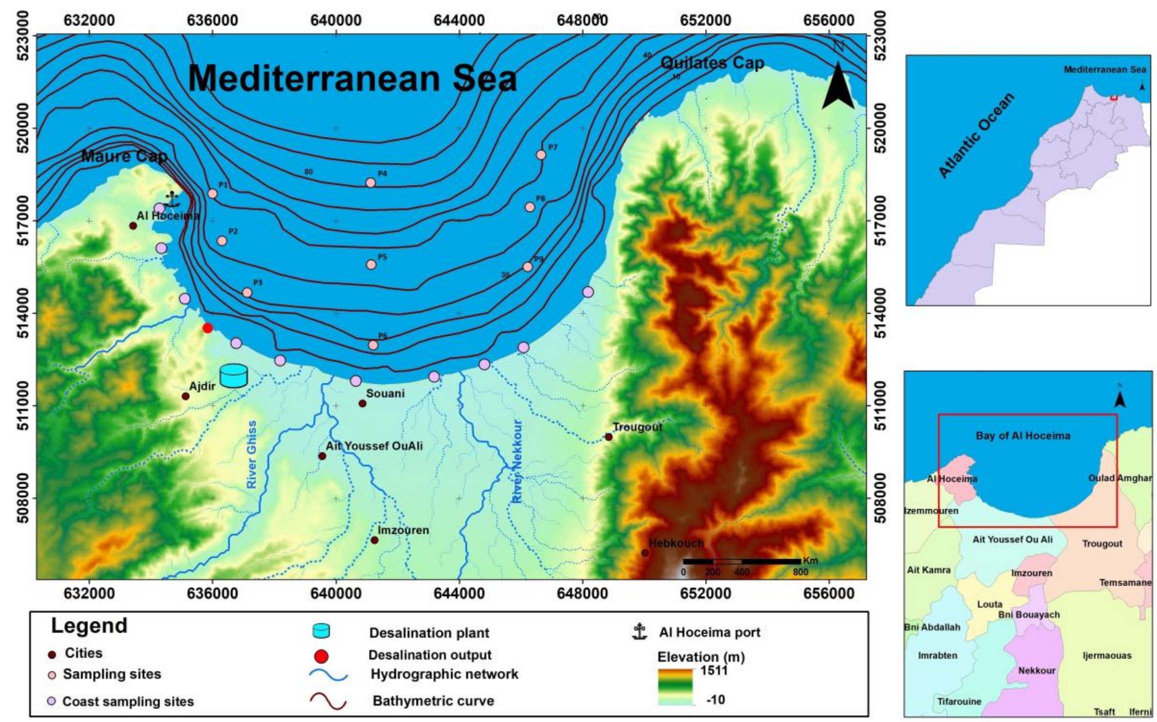

Fig. 1. Location of the sampling stations in Al Hoceima Bay

Data analysis

Jellyfish abundances were calculated by determining the number of individuals per cubic meter of filtered seawater to obtain the abundance (ind/ m-3) based on the total count. The frequency of occurrence (Fr) of each species was calculated by dividing the number of samples in which at least one individual of species was present by the total number of samples taken. This measure made it possible to assess the distribution and presence of each species across the entire sample. We determined two diversity indices to assess the jellyfish community in the bay, such as the Shannon-Wiener index (H′) and the Pielou regularity index (J′), for different seasons, stations and depths, based on the total composition and abundance of the sampled jellyfish. In order to analyse the relationship between the depth of the sampling stations and the biodiversity index (Shannon index), Pearson correlation index was employed, which assesses the linear correlation between two continuous variables.

RESULTS

1. Environmental data

During the summer of 2021, the sea surface temperature fluctuated between 22 and 24.5°C during the day. In autumn 2021, this temperature was between 17 and 19°C, while in January 2022, during the winter period, it was around 15 to 15.5°C.

Salinity measurements showed insignificant differences between the different stations within the same company. However, slight variations were observed between the summer and autumn seasons in 2021, as well as during the winter of 2022. In general, the salinity of the water in the bay varied between 36 and 36.5g/ l.

2. Biodiversity composition

A total of 275 individuals were collected during the sampling missions, of which 16 species of jellyfish were identified as part of this study (Table 3). These species are grouped into two classes (hydromedusae and scyphomedusae) and five orders (Leptomedusae, Trachymedusae, Anthomedusae, Rhizostomesae, and Semaeostomeae). Spatiotemporal variability was recorded. Based on the results of the five sampling companies, eight species of jellyfish were identified during the summer period, nine species during the autumn, and six species during the winter. The jellyfish *Aglaura hemistoma* (Fig. 2g) was widely distributed in the bay since it was found in eight sampling stations, with a frequency of occurrence Fi> 44% during the summer period, Fi> 55% in the autumn period, and Fi> 33% during the winter season. In addition, the Fi occurrence frequencies of the other species varied between 5 and 44% during the three sampling periods.

The most abundant jellyfish species in this study were *A.hemistoma* (23.27%), *Mitrocomella brownei* (16.36%), *Rhopalonema vlatum* (13.45%), *Eutima gegenbauri* (9%), *Clytia* spp. (8%), and *Geryonia proboscidalis* (5.45%). Together, these species represented up to 75% of the total number of jellyfish collected in the bay. In addition, six species of jellyfish were considered rare in the bay. In descending order, the rarest species in the study area were *Liriope tetraphylla*, *Persa incolorata*, *Zanclea sessilis*, *Cytaeis tetrastyla*, *Pantachogon militare*, and *Rhizostoma luteum.*

Table 3. Biodiversity, distribution, and frequency of occurrence of jellyfish in Al Hoceima Bay

Class	Order	Species	P1	P2	P3	P4	P5	P6	P7	P8	P9	Frequency of occurrence
Hydromedusae	**Leptomedusae**	*Obelia* spp. (Peron & Lesueur, 1810)										**2,2%**
		Clytia spp. (Lamoureux, 1812)										**17,7%**
		Mitrocomella brownei (Kramp 1930)										**17,7%**
		Eutima gegenbauri (Haeckel, 1864)										**20%**
	Anthomedusae	*Zanclea sessilis* (Goss,1853)										**2,2%**
		Cytaeis tetrastyla (Eschscholtz, 1829)										**2,2%**
		Velella velella (Linnaeus, 1758)										**2,4%**
	Trachymedusae	*Liriope tetraphylla* (Chamisso & Eysenhardt, 1828)										**8,8%**
		Geryonia proboscidalis (Forsskal 1775)										**13,3%**
		Rhopalonema velatum (Gegenbaur, 1856)										**22,2%**
		Aglaura hémistoma (Péron et Lesueur, 1810)										**46,6%**
		Persa incolorata (McCrady, 1859)										**8,8%**
		Pantachogon militare (Maas, 1893)										**4,4%**
Scyphomedusae	**Semaeostomeae**	*Pelagia noctiluca* (Forsskål, 1775)										**8,8%**
	Rhizostomeae	*Rhizostoma pulmo* (Macri, 1778)										**2,2%**
		Rhizostoma luteum (Quoy & Gaimard, 1827)										**2,2%**

Echelle **Rare species** **Frequent species** **Abundant in summer**

2.1 Description and ecology of jellyfish

A detailed description of the found species is provided in Table (4) and the paragraph below. The species reported in this study are described with indications of the number of oral arms/ tentacles, distribution, and any other identifying characteristics, such as distinct patterns and coloration.

Table 4. Occurrence frequency (Fr), maximum abundance (Ab), range of umbrella diameter, range of fishing depths, range of water temperatures, and range of water salinity during the 5 campaigns of 2021 and 2022

Species	Fr %	Max. Ab (Ind/m³)	Range Size (mm)	Fishing depth	Temperature (°C)	Salinity (g/l)
***Obelia* spp.**	2,2	0,001	1 – 3	50	17 – 17,80	36,25 – 36,40
***Clytia* spp.**	17,7	0,01	3 – 4	5 – 50	17,5 – 18,2	36,25 – 36 ,40
Mitrocomella brownei	17,7	0,3 (0,04	4 – 7	15 – 80	17,5 – 15,70	36,1 – 36,40
Eutima gegenbauri	20	0,02	1 – 3	15 - 80	15,5 – 20,6	36 -36,3
Pantachogon militare	4,4	0,002	7 - 10	50	20,6 – 23,5	36 -36,1
Zanclea sessilis	2,2	0,001	3 – 5	50	15,6	36,2
Cytaeis tetrastyla	2,2	0,002	3 – 4	50	20 - 21	36,12
Velella velella	4,4	7	3 – 8	-	20 -21	36,12
Liriope tetraphylla	8,8	0,03	6 – 12	40	15,5 – 20,5	36,1 – 36,4
Geryonia proboscidalis	13,3	0,023	7 – 10	40 – 80	18,5 – 23,5	36,1 – 36,2
Rhopalonema vlatum	22,2	0,1	4 – 6	40 – 80	15,6 - 24,4	36 – 36,4
Aglaura hemistoma	46,6	4	2 – 4	15 – 80	15,5 – 24,4	36 – 36,4
Persa incolorata	8,8	0,004	2 – 5	15 – 80	15,5 – 18,4	36,1 - 36,3
Pelagia noctiluca	4,4	4	50 – 105	30 - 50	23,2 – 24, 59	36,1 - 36,4
Rhizostoma pulmo	2,2	0,5	50 - 170	15- 30	24,8 – 24,5	36,12
Rhizostoma luteum	2,2	-	650-780	40	24,8 – 24,5	36,12

Leptomedusae

***Obelia* spp. (Peron & Lesueur, 1810): (Kramp, 1961; Berhaut, 1969; Goy, 1972, 1991; Pagès *et al*., 1992; Buecher, 1996; Daly Yahia *et al*., 2003; Touzri *et al*., 2004; Guerrero *et al*., 2018; Kherchouche & Hafferssas, 2020)**

The umbrella is almost flat, with a diameter of 1- 3mm, and a central stomach; short manubrium; mouth with 4 simple lips; 4 radial canals, and 4 sac-shaped gonads at the end of the canals; no velum; numerous, short tentacles (Fig. 2a). It was recorded only once in October 2021 at St P1 (0.001ind/ m^3).

***Clytia* spp. (Lamoureux, 1812)**: **(Kramp, 1961; Razouls & Thiriot, 1968; Goy, 1972; Brinckmann-Voss, 1987; Buecher, 1996; Daly Yahia *et al*., 2003; Touzri *et al*., 2004; Guerrero *et al*., 2018; Kherchouche & Hafferssas, 2020)**.

The diameter of the umbrella varies from 3 to 4mm. Its frequency of occurrence is > 44%, it was collected in autumn, October 2021 at stn P1 and in November at stations P1, P2, P3, P6, P7, P8, and P9, with a maximum density of 0.01ind/ m^3.

***Mitrocomella brownei* (Kramp 1930) : (Madin, 1991)**

Diameter 4- 7mm, hemispherical umbrella; velum quite wide. Stomach small, short manubrium, mouth with four small simple lips; 4 very narrow radial canals . Gonads oval, swollen , near the distal end of the radial ducts. The number of tentacles is 8 to 16 marginal tentacles (Fig. 2b). This species was recorded with low density in September 2021 at St P4 and P7 (density <0.003ind/ m^3). On the other hand, its density increased remarkably in November 2021, reaching 0.23ind/ m^3 at St P7 and 0.1ind/ m^3 at St P8. However, its density decreased in January (density <0.01ind/ m^3).

***Eutima gegenbauri* (Haeckel, 1864) : (Kramp, 1961; Madin, 1991; Guerrero *et al*., 2018)**

Umbrella wide and hemispherical, with a diameter of 1-3 mm. Four radial canals, a long peduncle with a fairly wide base, a mouth with four very short lips, and four gonads located on the narrow part of the peduncle or closer to the stomach (in young specimens) (Fig. 2c). 8 to 16 tentacles. It was recorded only once in summer at St P1 (<0.001ind/ m^3). In autumn, it was found at stations P1, P4, P5, P7, P8, and P9, with maximum densities at St P8 (>0.01ind/ m^3).

Anthomedusae

***Zanclea sessilis* (Gosse, 1853) : (Guerrero *et al*., 2018; Yilmaz *et al*., 2020)**

Bell-shaped umbrella, diameter 3-5mm, with 4 radial canals and 4 tentacles (Fig. 2d). It is rare in the bay, with only a single specimen collected in January 2022 at station P7.

Cytaeis tetrastyla **(Eschscholtz, 1829) : (Madin, 1991)**

Diameter 3- 4mm, bell-shaped umbrella, with 4 tentacles and 4 radial canals (Fig. 2e). It was recorded only once in October 2021 at station P1 (0.002ind/ m^3).

Velella velella **(Linné, 1758) : (Larson, 1980; Brinckmann-Voss, 1987; Daly Yahia *et al.*, 2003)**

The diameter of the float varies between 3 and 8cm (Fig. 2f). These elements were observed only once at stations P4 and P5 during the mission on 29/10/2021, with a density of about 7 individuals per cubic meter. The species *Velella velella* is cosmopolitan, inhabiting open ocean waters. It arrives on the Mediterranean coast, carried by west to northwest winds,

Trachymedusae

Aglaura hémistoma **(Péron et Lesueur, 1810) : (Russel, 1953; Kramp, 1961; Razouls & Thiriot, 1968; Berhaut, 1969; Goy, 1972; Brinckmann-Voss, 1987; J.-M. Gili *et al*., 1987; Goy, 1991; Pagès *et al*., 1992; Buecher, 1996; Daly Yahia *et al*., 2003; Zakaria, 2004; Hosia *et al*., 2008; Guerrero *et al*., 2018; Kherchouche & Hafferssas, 2020; Benyoub *et al*., 2023)**

The height of the umbrella varies between 2 and 4mm (Fig. 2g). This species is found in all Mediterranean inventories and is considered cosmopolitan. It was frequently observed in the study areas, recorded in eight sampling stations except St P9, with a frequency of occurrence reaching 100% in St P7. It is abundant in stations located in deep waters, with a density greater than 0.15ind/ m3, while in coastal stations, its density is less than 0.13ind/ m3. These observations confirm its oceanic nature. Additionally, it was particularly abundant during the month of November.

Rhopalonema velatum **(Gegenbaur, 1856) : (Russel, 1953; Kramp, 1961; Berhaut, 1969; Brinckmann-Voss, 1987; J.-M. Gili *et al*., 1987; Goy, 1991; Buecher, 1996; Daly Yahia *et al*., 2003; Zakaria, 2004; Hosia *et al*., 2008; Guerrero *et al*., 2018; Kherchouche & Hafferssas, 2020; Benyoub *et al*., 2023)**.

The umbrella is hemispherical with a diameter of 6mm, featuring a developed velum and eight radial canals, each with a gonad (Fig. 2h). Rhopalonema velatum was observed in the Bay of Al Hoceima during all three seasons (summer, autumn, and winter), particularly in the deep stations (St P1, P4, P5, P7, P8), which confirms its warm-water, oceanic nature as suggested by **Russel (1953)**, likely associated with high salinities **(Berhaut, 1969)**. On the other hand, the highest densities were recorded during the winter season at St P8, with a density > 0.01ind/ m^3.

Liriope tetraphylla **(Chamisso & Eysenhardt, 1828) : (Kramp, 1961; Goy, 1972, 1991; Daly Yahia *et al*., 2003; Zakaria, 2004; Guerrero *et al*., 2018; Kherchouche & Hafferssas, 2020; Benyoub *et al*., 2023)**

It is an oceanic species, cosmopolitan and the most common in the Mediterranean **(Daly Yahia *et al*., 2003)**. Moreover, it is commonly found in warm epipelagic waters **(Kramp, 1961)**. The diameter of the umbrella varies between 10 and 12mm, with four radial canals, each having a gonad, along with four long perradial tentacles and four small interradial tentacles (Fig. 2i). *L.tetraphylla* was recorded only at two deep stations (P5 and P7) with a low density < 0.03ind/ m³ in November. Its presence seems to be associated with oligotrophic waters **(Goy, 1997)**.

Geryonia proboscidalis **(Forsskal, 1775)** : **(Kramp, 1961; Vives, 1966; Goy, 1972; Brinckmann-Voss, 1987; Daly Yahia *et al*., 2003).**

Hemispherical umbrella with a diameter of 10 to 15mm, seven centripetal canals in each space between the six radial canals; leaf-shaped gonads ; six long tentacles (Fig. 2j). It has been observed in the bay of Al Hoceima during the summer and winter seasons at offshore stations (P4 and P5) where the depth reaching 70m and at St P7, with maximum densities of around 0.023ind/ m³.

Persa incolorata **(McCrady, 1859) : (Kramp, 1957; J. M. Gili *et al*., 1998; Benovic, 2004; Batistić *et al*., 2007; Guerrero *et al*., 2018)**

With a width of 2mm and a height of 3mm (Fig. 2 k), *P. incolorata* is one of the common species in the Mediterranean. It is present in shallow coastal waters during winter, as it was found in the bay at the end of November and in January at stations (P4, P6, P7, and P8), with a density of 0.004ind/ m³.

Pantachogon militare **(Maas, 1893): (J. M. Gili *et al*., 1998)**

Umbrella has a conical shape with a diameter of 7- 10mm wide, 6mm high, lancet-shaped gonads on the 8 radial canals; 48 tentacles (Fig. 2i). *P. militare* was recorded only once in September 2021 at station P1 (0.002ind/ m³).

Description and ecology of Scyphomedusae

Semaeostomeae

Pelagia noctiluca **(Forsskål, 1775) : (Kramp, 1961; J.-M. Gili *et al*., 1987; Goy *et al*., 1989; Buecher, 1996; Daly Yahia *et al*., 2003; Hosia *et al*., 2008; Touzri *et al*., 2010; Kherchouche & Hafferssas, 2020; Mghili *et al*., 2020; Benyoub *et al*., 2023)**

It is a common pelagic oceanic Scyphomedusa found in most of the world's oceans **(Kramp, 1961)**. It is also common in the Mediterranean Sea. The diameter of its umbrella can vary considerably, ranging from 5 to 10.5cm (Fig. 2m). In Al Hoceima Bay, its presence is irregular, with absence during the winter period and bloom densities during the summer period. Between July and early September of the years 2021 and 2022, it was regularly observed along the coasts, with densities reaching up to 4ind/ m^3.

Rhizostomes

Rhizostoma pulmo **(Macri, 1778)**: **(Kramp, 1961; Morand & Dallot, 1985; Buecher, 1996; Daly Yahia *et al*., 2003; Touzri *et al*., 2010; Gueroun *et al*., 2022; Benyoub *et al*., 2023)**

It is an endemic species in the Mediterranean (**Kramp, 1961**), and is a large Scyphomedusa. In Al Hoceima Bay, the diameter of the umbrellas of true jellyfish species varies between 5 and 17cm. The umbrella is generally flat and flattened, with a domed and smooth upper surface, of a milky bluish-white color, bordered by a blue edge (Fig. 2n). The presence season of *R. pulmo* extends from late spring (May) to early autumn (October). During the months of July and August, this species is very common along the coasts of Souani beach, near the estuaries of Oued Ghis and Oued Nekkour. Maximum densities of 0.5 individuals per cubic meter have been recorded at station P6 during this period. However, in other parts of the bay, limited abundance is observed, ranging from a single individual to a few specimens.

Rhizostoma luteum **(Quoy & Gaimard, 1827) : (Grenacher & Noll, 1876; Prieto *et al*., 2013; Kienberger & Prieto, 2018)**

Two specimens were observed, one stranded on the west coast of the bay (Sfiha beach) and the second one swimming near the Cape of Maure shore. Both individuals were large, with a dome-shaped umbrella and a diameter ranging between 45 and 50cm. They were of pale yellow to golden brown color with orange shades (Fig. 2o). The jellyfish caught near the shore was actively swimming with long appendages (between 65 and 78cm).

Fig. 2. Jelly fish species found in the present study: (a) *Obelia* spp., (b) *Mitrocomella brownei,* (c) *Eutima gegenbauri,* (d) *Zanclea sessilis,* (e) *Cytaeis tetrastyla* , (f) *Velella velella* , (g) *Aglaura hémistoma,* (h) *Rhopalonema velatum,* (i) *Liriope tetraphylla,* (j) *Geryonia proboscidalis,* (k) *Persa incolorata,* (l) *Pantachogon militare,* (m) *Pelagia noctiluca,*(n) *Rhizostoma pulmo,* and (o) *Rhizostoma luteum*

2.2 Spatial and temporal distribution

The results of the total micro jellyfish abundance indicate a spatiotemporal variation in the Al Hoceima Bay (Fig. 3). Some coastal stations (P2 and P3) exhibited either nil or very low values, while others showed higher values, with a maximum abundance recorded in November at station P7 (0.015ind/ m3). November was characterized by significantly higher abundance values compared to other months. The spatial distribution of jellyfish revealed an increasing species richness trend toward the eastern part of the bay, particularly at stations P7 (9 species), P8 (7 species), and P4, P5 (7 species). On the other hand, the lowest abundance was observed at station P3. Coastal stations generally exhibited either zero or very low abundance values.

Statistical tests were conducted to assess the correlation between the total abundance values at each sampling point and the station's depth. The correlation analysis showed a weak positive correlation between depth and total abundance at each station, with a Pearson correlation coefficient of 0.119. Notably, November had significantly higher abundance values compared to other months, with an average abundance of 0.04ind/ m^3. Based on the results of the five sampling companies, eight jellyfish species were identified during the summer period, nine species during autumn, and six species during the winter period.

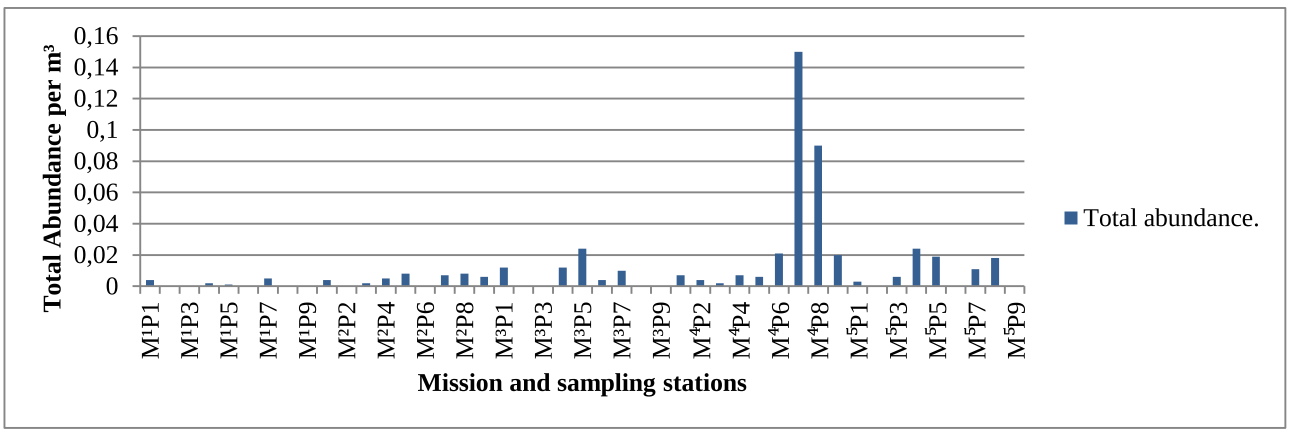

Fig. 3. Total Abundance per m^3 of jellyfish in each station during the five sampling campaigns. (M: Mission, P: Sampling point)

2.3 Biodiversity index

The biodiversity index (Shannon-Wiener (H')) was calculated for each station sampled, giving an overview of the species richness and diversity of the jellyfish community (Hydromedusae) at each location (Fig. 4). For the Shannon-Wiener index (H'), values varied between 0.69 and 2.16. Stations P5 and P7 recorded the highest values, which suggests that these stations have a greater diversity of species with a more balanced distribution of individuals between these species, while stations P2, P3, and P6 recorded relatively low values, indicating lower diversity at these stations.

For the Pielou index, the recorded values varied between 0.32 and 1. Stations P5 and P7 recorded values of 1, indicating a balanced distribution of individuals between species at these stations, on the other hand Stations P2, P3, and P6 recorded lower values, which means that they have a less balanced distribution of individuals between species.

To establish a relationship between depth and jellyfish biodiversity, Pearson's correlation coefficient was used to assess the relationship between the depth of each sampling station and the Shannon biodiversity index calculated from the jellyfish samples taken. The results of the correlation analysis revealed a moderate positive correlation between the variables depth and biodiversity index (r = 0.419).

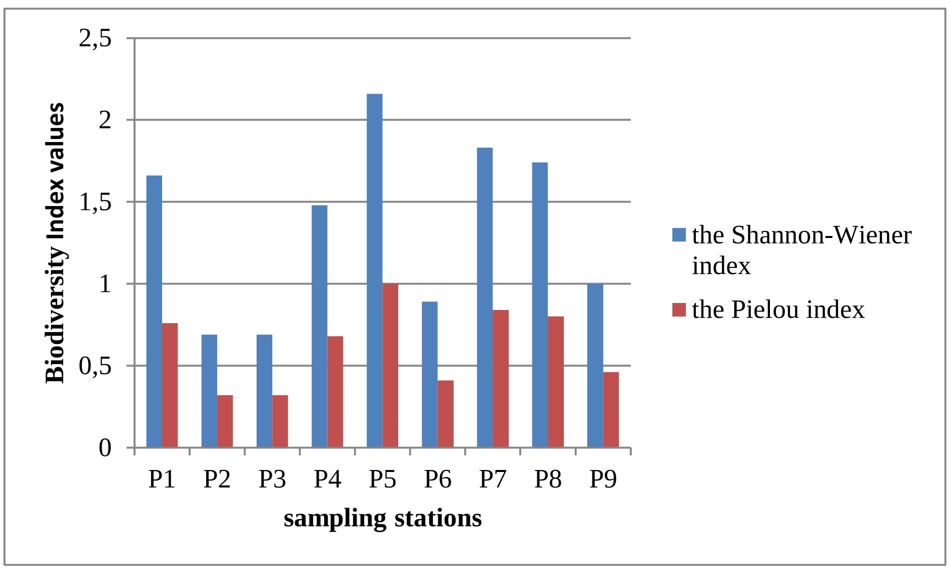

Fig. 4. Biodiversity index values for the nine sampling stations

DISCUSSION

This study represents the first qualitative and quantitative inventory conducted in the Bay of Al Hoceima on the Moroccan Mediterranean coast. It provides an integrated description of the various recorded jellyfish species. A total of 16 jellyfish species were identified in Al Hoceima Bay, classified into two classes (Hydrozoa and Scyphozoa) and six orders. However, our understanding of jellyfish diversity and distribution remains incomplete due to the limited availability of studies and records. Early explorations of hydrozoans in Moroccan waters were carried out by the expeditions of **Ramil and Vervoort (1992)** although they did not include abundance data. In a study conducted by **Mghili *et al*. (2022)**, a list of Moroccan jellyfish was published based on stranding data collected along the Moroccan Mediterranean coast and added two new Hydrozoa species to the list. Furthermore, eight new observations of hydrozoans in Al Hoceima Bay were reported by **Benyoub *et al*. (2023)**. On the other hand, in the Alboran Sea (southwestern Mediterranean), **Dallot *et al.* (1988)** reported 27 species, and along the Algerian coast, **Kherchouche and Hafferssas (2020)** collected 14 species, as reported by **Mills (1996)**. In Tunisia, around twenty species have been recorded in studies by **Daly Yahia *et al*. (2003)**, **Touzri *et al*. (2012)**, and **Gueroun *et al*. (2022)**. The Adriatic Sea documented more than 18 species according to **Pestorić *et al*. (2012)**. Across the entire Mediterranean region, the diversity of jellyfish has been estimated to comprise 510 species, including 457 hydrozoans, 20 scyphozoans, and one cubozoan **(Bouillon *et al*., 2004)**. However, the species identified in this study have already been recorded in neighboring regions of the Mediterranean, and the results are similar for some of them. Specifically, *Obelia* spp., *Clytia* spp., *L.tetraphylla, R. velatum, A. hemistoma, G. proboscidalis,* and *Z. sessilis* have been previously documented in studies conducted in the Mediterranean region **(Daly Yahia *et al*., 2003; Touzri *et al*., 2010; Kherchouche & Hafferssas, 2020)**. On the other hand, the species *P. incolorata, P. militare, G. proboscidalis, E. gegenbauri, C. tetrastyla,* and *M. brownei* are newly recorded on the southern Mediterranean coast.

The results obtained show a qualitative and quantitative difference between the bay of Al Hoceima (16 species) and other areas such as the Alboran Sea and the southern Mediterranean coast. This difference can be explained by variations in the sampling period and frequency since jellyfish are fast swimmers and can often evade sampling nets **(Hamner *et al*., 1975)**. Furthermore, the lower number of species observed in the southern Mediterranean is likely more attributable to the lack of studies conducted in that region, compared to the northern coasts, rather than a genuine scarcity of species. This disparity in research on Hydrozoa biodiversity in the southern Mediterranean has been previously highlighted in a study by **Bouillon *et al*. (2004)**. It was noted that the diversity of Hydrozoa species is greater in the western Mediterranean compared to the eastern basin and the south-eastern coast of the Mediterranean, which seems to be linked to a higher sampling effort in the western region **(Bouillon *et al*., 2004)**. A similar pattern has also been observed along the Tunisian coast, where the majority of jellyfish species (78.5%) have been recorded on the northern coasts due to a longer history of biodiversity studies compared to the eastern coasts **(Gueroun *et al*., 2022)**.

The jellyfish *Aglaura hemistoma* is a cosmopolitan species widely distributed in the bay since it was identified in eight sampling stations (P1, P2, P3, P4, P5, P6, P7, P8), with a frequency of occurrence reaching Fi= 100% in certain stations (P7, P4, P5) and a maximum abundance during the month of November 2021. Its presence in deepwater stations can be explained by its oceanic nature **(Daly Yahia *et al.*, 2003)**. This species is recorded in all Mediterranean inventories. In the bay of Al Hoceima, it ranks the 1st in the frequency of occurrence among all jellyfish species in the bay.

The oceanic trachymedusa *Rhopalonema velatum* is also highly prevalent in the waters of the bay. According to **Russel (1953)**, it would be more abundant in winter than in summer; indeed, the maximum values of its abundance were recorded in January 2022. However, it was present in the bay during all three seasons. It ranks the 2nd in the frequency of occurrence of jellyfish in the bay. Both species, *A. hemistoma* and *R. velatum*, are the most common and abundant, with both adult and larval stages recorded, suggesting that they are likely to be continuously present in this region. The fact that the observed species in Al Hoceima Bay are holoplanktonic suggests that the bay exhibits a certain level of stability since holoplanktonic species are generally associated with stable hydrological conditions. Similar results have been observed in other regions of the Mediterranean, including Marseille **(Berhaut, 1969)**, the Ligurian Sea **(Goy, 1972)**, the Catalan Sea **(J.-M. Gili *et al.*, 1987)**, the Adriatic Sea **(Lucic *et al.*, 2009)**, the Tunisian coast **(Touzri *et al.*, 2010)**, and along the Algerian coast **(Kherchouche & Hafferssas, 2020)**.

However, it should be noted that meroplanktonic jellyfish species, such as Leptomedusae, were predominant in autumn. Among these, there was a high abundance of *E. gengenbauri*, *M. brownei*, and *C.* spp. jellyfish, with a maximum abundance of 0.3ind/ m³ and an occurrence frequency reaching 77% during the autumn period. Additionally, the medusa *Obelia.* spp. was caught for the first time in the bay at station P1 in November. Therefore, it can be assumed that in the bay of Al Hoceima, the autumn season is the period of jellyfish release by hydroids. Indeed, according to **Russel (1953)**, hydroids release their jellyfish only once a year.

Scyphomedusae is represented by three species in Al Hoceima Bay. *Pelagia noctiluca* dominates the scyphomedusa population, appearing from late spring (May) to early autumn (October). During the summer, it is very abundant, forming bloom densities, with a peak abundance reaching 4ind/ m³. Massive invasions of adults on the bay's beaches were observed throughout the summer of 2022. Similar results have been reported in the northern Mediterranean **(Goy *et al.*, 1989)** and on the Algerian coast **(Kherchouche & Hafferssas, 2020)**. These results are consistent with the breeding period of *Pelagia noctiluca* in the Mediterranean, which extends from May to November **(Goy *et al.*, 1989)**. The good weather during this period could have a positive effect on the species' reproduction, potentially reducing larval mortality due to vertical mixing and favoring unexplored intermediate trophic processes, such as an increase in the production of microzooplankton, which constitutes the main source of food for ephyrae larvae **(Goy *et al*., 1989)**. Examination of the abundance of this jellyfish over the last century in the Mediterranean basin reveals a cyclical pattern of around 12 years **(Goy *et al*., 1989)**. However, our observations for the bay, from the start of our study in 2019 to the summer of 2022, indicate the presence of Pelagia blooms during the summer period and it remains abundant throughout the years from 2011 to 2020 on the west coast of the Moroccan Mediterranean **(Mghili *et al*., 2020)**. The period of the presence of this jellyfish in the Moroccan Mediterranean does not correspond to the pattern proposed by **Goy *et al*. (1989)**.

R. pulmo is the second dominant scyphomedusa species in the jellyfish community of Al Hoceima Bay. *Rhizostoma pulmo* is found in the eastern and western Mediterranean, mainly in the Adriatic Sea, the Ionian Sea, the Ligurian Sea, Tunisian waters, and the Black Sea **(Mariottini & Pane, 2010)**. This species is also highly abundant during the summer of 2022, with high densities near the Oued Ghis and Nekkour estuaries. Aggregations comprising both adults and young jellyfish have been observed, suggesting the reproduction of the species in the bay. Indeed, the relationship between a warmer winter and an early season for *R. pulmo* has been demonstrated by **Leoni *et al*. (2021)**. A higher temperature not only induces earlier hatching of jellyfish but also increases the abundance of the *R. pulmo* population **(Gueroun *et al*., 2022)**.

Based on the statistical results of the correlation coefficient between depth and total abundance of gelatinous species, as well as the Shannon index and depth, it was observed that the diversity and abundance of these species are not uniformly distributed. Stations located offshore have higher levels of diversity and abundance compared to those close to coastal regions. Additionally, a decrease in diversity is observed when moving from the east to the west of the bay, which corresponds to the orientation of the anticyclonic gyre (East- West) characteristic of Al Hoceima Bay **(Khouakhi *et al*., 2013)**. Consequently, it is reasonable to assume that the richness of stations P4, P5, P7, and P8 is influenced by the influx of offshore water entering the bay through the marine current. These results suggest a significant influence of depth and water circulation on the diversity and abundance of gelatinous species in Al Hoceima Bay. Furthermore, it is noteworthy that most of the jellyfish species reported in Al Hoceima Bay are not harmful to human health.

However, two specific jellyfish species have painful stings. Moreover, these jellyfish can disrupt fishing and recreational activities in the study area. A better understanding of these environmental factors is crucial for assessing the bay's ecosystem and implementing appropriate management measures. Further studies are necessary to delve deeper into this analysis and gain a better understanding of the underlying mechanisms behind these observations. Additionally, it is important to assess the impact of jellyfish on human activities.

Furthermore, it is essential to emphasize that diversity monitoring should not be limited to a specific timeframe. Climate change, habitat modifications, and coastal developments, such as the construction of Nador Port West Med, pose an increased risk of introducing invasive alien species through ballast water from ships. These non-native species can disrupt the ecological balance and have adverse effects on biodiversity.

CONCLUSION

This article presents the first qualitative and quantitative inventory carried out in the Bay of Al Hoceima and along the Moroccan Mediterranean coast. The study provides valuable information on the diversity and phenology of jellyfish present along the Moroccan Mediterranean coast, as well as on the species that proliferate in Al Hoceima Bay. The faunal composition identified in this study is specific to the northern Moroccan coast and indicative of the southwestern Mediterranean region. This first step is an important milestone for future research aimed at studying the biodiversity, temporal occurrence, and spatial distribution patterns of jellyfish communities in the bay and other Mediterranean ecosystems in Morocco. A total of 16 species of jellyfish were identified in this study, divided into six orders. Populations of Trachymedusae were predominant from a qualitative point of view, with the presence of six species. In terms of phenology, the Leptomedusae were predominant during the autumn season. Among the outstanding results, we recorded the presence of new species on the southern Mediterranean coast, including Persa incolorata, *Pantachogon militare*, *Geryonia proboscidalis*, *Eutima gegenbauri*, *Cytaeis tetrastyla*, and *Mitrocomella brownei*. It should be noted that two Scyphomedus species, *Pelagia noctiluca*, and *Rhizostoma pulmo*, showed massive aggregations during the summer period (from 2019 to 2022) in the bay

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