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EXPANSION OF THE NON-INDIGENOUS SPONGE *PARALEUCILLA MAGNA* KLAUTAU, MONTEIRO & BOROJEVIC, 2004 (PORIFERA: CALCAREA) ALONG THE MEDITERRANEAN COAST OF MOROCCO

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The Mediterranean Sea is experiencing an increase in the impact of biological invasions, including along the Mediterranean coastlines of North Africa. The non-indigenous sponge *Paraleucilla magna* Klautau, Monteiro & Borojevic, 2004 was detected recently in the western Mediterranean coast of Morocco. In this paper we document for the first time the occurrence of this non-indigenous species (NIS) in the Marchica Lagoon, a Ramsar site and protected area situated on the eastern Mediterranean coast of Morocco. Additionally, we report it from the Saidia Marina, the easternmost location in the country where the species has been found, demonstrating its rapid expansion. The Marchica lagoon and Saidia marina have become hotspots for the proliferation of NIS, underscoring the pressing need for monitoring and management strategies to address the issue of biological invasions in this region.

Keywords: North Africa, protected area, Marchica lagoon, Saidia Marina, non-indigenous species, range-expanding species.

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Sredozemno more doživljava sve veći utjecaj bioloških invazija, uključujući i sredozemne obale sjeverne Afrike. Alohtona spužva *Paraleucilla magna* Klautau, Monteiro & Borojevic, 2004 nedavno je zabilježena na zapadnoj sredozemnoj obali Maroka. U ovom radu prvi put dokumentiramo pojavu ove alohtone vrste (NIS) u laguni Marchica, Ramsarskom lokalitetu i zaštićenom području smještenom na istočnoj sredozemnoj obali Maroka. Osim toga donosimo i njen nalaz iz marine Saidia, najistočnijeg lokaliteta u zemlji na kojem je vrsta pronađena, što pokazuje njezino brzo širenje. Laguna Marchica i marina Saidia postale su žarišta za širenje alohtonih vrsta, što naglašava hitnu potrebu za monitoringom i strategijom upravljanja u cilju rješavanja problema bioloških invazija u ovoj regiji.

Ključne riječi: sjeverna Afrika, zaštićeno područje, laguna Marchica, Saidia Marina, alohtone vrste, proširenje rasprostranjenosti vrste

INTRODUCTION

The introduction and invasion of invasive and non-indigenous species represent a significant threat to biodiversity and ecosystem functioning on a global scale, resulting in substantial environmental and economic costs (DIAGNE *et al.*, 2021). In the Mediterranean region, the

biological invasion of non-indigenous species has been on the rise since the 1970s, posing a serious threat to the region's native biodiversity (OJAVEER *et al.*, 2013; FRISTOE *et al.*, 2021). The number of reported invasive species in the Mediterranean is one of the highest worldwide (STREFTARIS *et al.*, 2005). Consequently, the study of invasive species has become a pressing research priority for the conservation of indigenous biodiversity (DUKES & MOONEY, 2004; TAYBI *et al.*, 2020a).

Paraleucilla magna Klautau, Monteiro & Borojevic, 2004 is a calcareous sponge of tubular or massive outer shape, presenting numerous flexible digitations of very variable size and terminated by an oscule of 5 to 20 mm in diameter. It was originally described from the Brazilian coast in the Atlantic Ocean, where it is the most abundant calcareous sponge (KLATAU *et al.*, 2004). The sponge is an important component of marine nutrient cycling and the filtration of large volumes of ambient water. However, when invasive it also poses a significant threat to native sponge communities. Previous studies have demonstrated that *P. magna* can displace native species through competition for space and resources, thus potentially changing the ecological balance in invaded ecosystems (LANNA & KLAUTAU, 2010; GUZETTI *et al.*, 2019). The first record of *Paraleucilla magna* in the Mediterranean was in Mar Piccolo and Mar Grande in Taranto (north-western Ionian Sea) in 2001 (LONGO *et al.*, 2004). The species has certainly persisted in Mar Piccolo since then. However, local mussel farmers claim that the species colonised this environment 20–30 years earlier (LONGO *et al.*, 2004, 2007). Subsequently, the species has been found in various other locations in Italy, as well as in Spain, Malta, Croatia, Montenegro, Turkey, Cyprus, Greece, Tunisia and Algeria (GEROVASILEIOU *et al.*, 2017; BACHETARZI *et al.*, 2019; TIRALONGO *et al.*, 2022). In Morocco, the non-indigenous sponge was recorded recently from the western coast of the Mediterranean from where it was found at aquaculture facilities in Amsa and M'diq during February and March 2024 (EL MOUSSAOUI *et al.*, 2024). In this paper we provide the first record of *Paraleucilla magna* in the Marchica lagoon and Saidia Marina, representing the most eastern record of this species in the Mediterranean coast of Morocco.

MATERIAL & METHODS

Several sampling and prospecting trips were carried out along the Eastern Mediterranean coast of Morocco from June of 2019 (and still ongoing) in order to follow the spread of non-indigenous species (part of a structured survey), from the western side of Al Hoceima to the eastern side of Saidia, with a special interest to the protected areas of Morocco, such as the Marchica lagoon. The sampling gathered through looking in the brackish and marine waters

near the shore using a hawk net (mesh size: 1×1 mm / 0.5 mm) at a depth ranging between 0.5 and 2 m. Two voucher specimens of *Paraleucilla magna* were deposited at University Mohamed Premier of Oujda Morocco under the accession codes: F_A_T: spong.PM032023/1 and F_A_T: spong.PM032023/2. And two additional specimens from Marina Saïdia were catalogued under F_A_T: spong.PM062025/1 and /2. The species was identified using the spicule morphology and squelettic architecture reported by Longo et al. (2007).

Specimens were kept in 70% ethanol. Each specimen has been analysed using an optical microscope to study its external morphology. Spicules were visible, fragments at oscula lateral and apical levels have been cut at its end. Samples were dehydrated through a graded ethanol series, rinsed with distilled water, and sectioned. The sections were then stained with eosin and photographed using a Leica Microsystems microscope fitted with a digital camera.

Duplicated profiles (n = 3 per site) were collected *in situ* at depths of 0.5–1 m in Marchica Lagoon and 1–3 m in Saïdia Marina using a WTW MPP 350 probe, which simultaneously logs temperature, pH, conductivity, salinity and dissolved oxygen.

RESULTS

Several individuals of *Paraleucilla* magna were found in the Marchica lagoon Ramsar site (35°11'09.2"N 2°55'25.9"W) on 15 March 2024 and in the Saidia Marina (35°06'36.9"N 2°17'47.8"W) on 1 January 2025, at an average depth of 0.5-1 m, representing the easternmost records of the species on the Mediterranean coast of Morocco to date. The distance between the two sites is 70 km (Fig. 1). These results highlight the species' expansion across the Mediterranean. The means values of physicochemical parameters of the water in the studied localities are presented in Tab. 1. Other non-indigenous species were found alongside of *P. magna* in both Marchica lagoon and Saidia Marina, such as the fanworm *Branchiomma luctuosum* (Grube, 1870), the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 and different non-indigenous cryptogenic tunicate species e.i. *Botrylloides niger* Herdman, 1886, *Microcosmus squamiger* Michaelsen, 1927, *Polyandrocarpa zorritensis* (Van Name, 1931) and *Styela plicata* (Lesueur, 1823).

Tab. 1. Mean values (± SD) values of the physico-chemical water parameters measured at each sampling site (n = 3 replicates per site).

Sampling site	**Sampling depth** (m)	**Temperature** (°C)	**Dissolved oxygen** (mg/l)	**Electrical conductivity** (ms/cm)	**Salinity** (g/l)	**pH**
Marchica lagoon	0.5 – 1	24.0 ± 1.3	9.7 ± 0.42	55.5 ± 3.4	38.2 ± 1.8	8.1 ± 0.1
Saidia Marina	1 – 3	22.3 ± 2.2	10.3 ± 0.37	43.5 ± 2.7	4.0 ± 1.3	8.6 ± 1.7

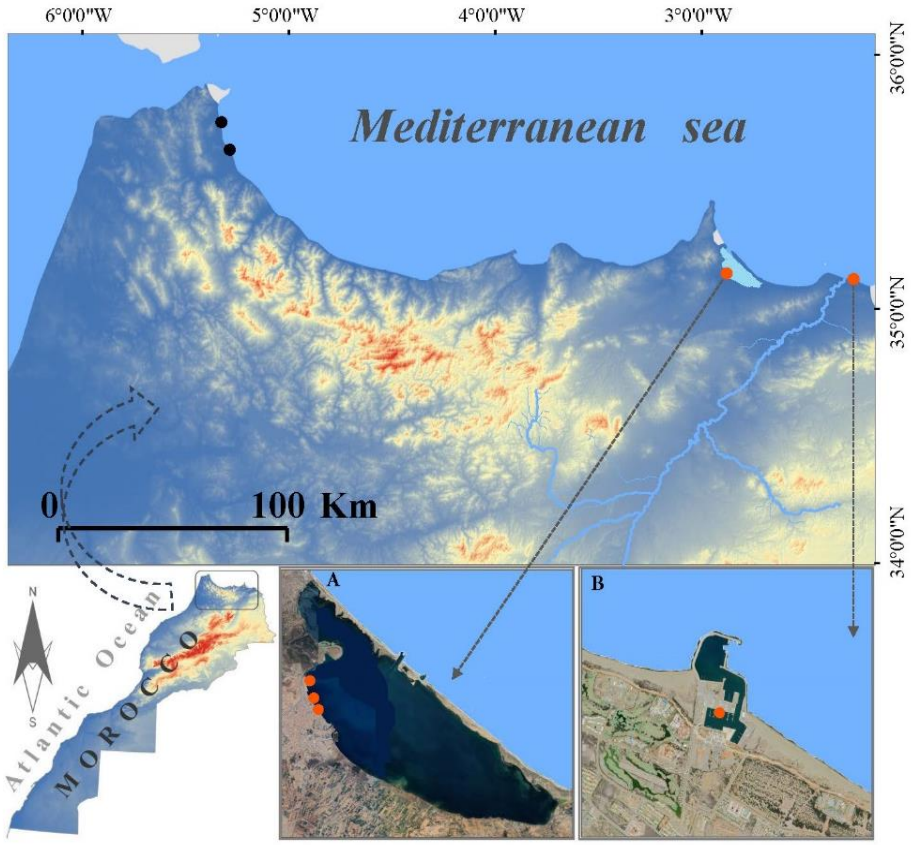

Fig. 1. The updated distribution of *P. magna* in Morocco (new records red dots, old record black) in the Marchica Lagoon (A) and Saidia Marina (B).

The sponges were found attached to solid surfaces. The adult specimens were predominantly white to cream in colour and had a generally robust, massive body with an irregular, lobate outline. The surface bore numerous short, angular protrusions or digitiform branches of varying lengths and thicknesses, giving the sponge an uneven, dendritic appearance (Fig. 2). The measured specimens ranged in size from 0.5 to 8 cm in the Marchica lagoon and from 0.5 to 5 cm in the Saidia Marina area. The body generally consisted of a broad basal mass or stalk, with dozens of cylindrical to finger-like branches arising at irregular intervals from this. Oscula (exhalant openings) were visible in many areas, particularly near the tips of the branches; these were relatively large, measuring 10–20 mm in diameter, and were positioned at the ends of the tubular branches.

In the cortical region, the spicules included numerous triactines (three-rayed spicules) and tetractines (four-rayed spicules). The triactines exhibited variable symmetry (see Fig. 3). Many of them were sagittal, with one unpaired actine differing in length or angle from the other two. The remaining paired actines were roughly equiangular and typically pointed and conical. Relatively large cortical spicule actines had lengths ranging up to ~400 µm (mean ≈287 µm) and widths up to ~40 µm (Tab. 2). The atrial skeleton consisted entirely of sagittal triactines.

Fig. 2. Photo of live specimens of *Paraleucilla magna* in the Marchica lagoon (left) and Saidia Marina (right).

The unpaired actines in the atrial triactines were consistently shorter than the paired actines. The paired triactines were long, slender and pointed, lying approximately parallel to the atrial surface. The unpaired (intratriatal) actine of these atrial triactines is markedly shorter than the paired actine (e.g. the mean length of unpaired actin is ~92 µm, compared to ~196 µm for paired actine in one population). These short unpaired actines give the atrial triactines their distinctive T-shaped appearance (see Fig. 3). No tetractines were observed as part of the true atrial mesh. All spicule dimensions were consistent with those of *Paraleucilla magna* (Tab. 2).

Tab. 2. Measurements taken from *P. magna* spicules from eastern Morocco.

Spicules	Actine	Length (µm)	Thickness (µm)
Cortical triactine	Paired	90–320 (200 ± 60)	8–25 (16 ± 5)
	Unpaired	63–307 (180 ± 70)	7–22 (14 ± 6)
Cortical tetractine	Apical	170–550 (410 ± 100)	16–48 (30 ± 11)
	Basal	149–430 (315 ± 80)	14–40 (32 ± 9)
Subatrial triactine	Paired	65–272 (185 ± 55)	9–27 (18 ± 6)
	Unpaired	70–334 (225 ± 75)	8–29 (19 ± 7)
Subatrial tetractine	Paired	115–390 (255 ± 80)	12–45 (26 ± 10)
	Unpaired	95–380 (210 ± 70)	10–40 (22 ± 8)
Atrial triactine	Paired	122–315 (220 ± 60)	10–30 (20 ± 5)
	Unpaired	45–175 (104 ± 35)	5–18 (12 ± 4)

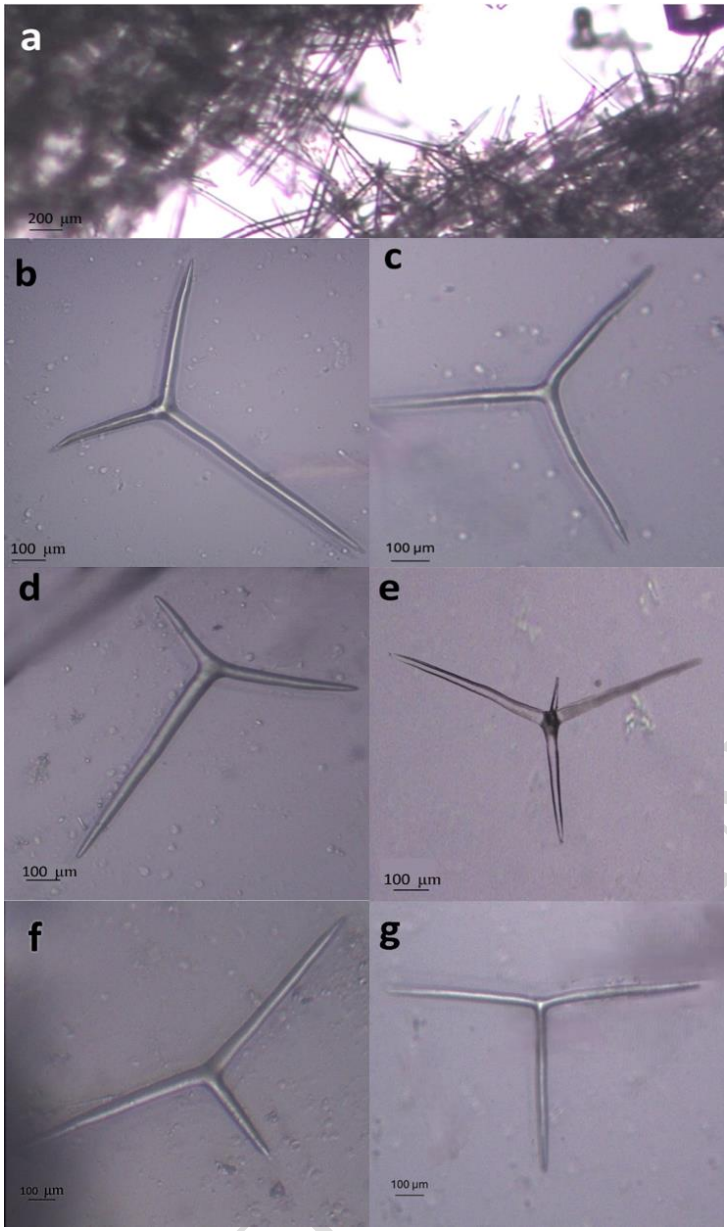

Fig. 3. The skeletal organisation and diagnostic spicules of *Paraleucilla magna*: Cortical tetractines with inward-pointing apical actines (A); Cortical triactines (B-C); Primary sub-auricular triactine (D); Primary sub-auricular tetractine (E); Atrial triactines (choanoskeletal) (G-F).

DISCUSSION

Morphological and microscopic examinations confirmed the identity of the non-indigenous calcareous sponges collected from the Mediterranean coast of eastern Morocco. *Paraleucilla magna* can be distinguished by its cortex bearing equiangular triactines and robust tetractines with very long apical actines. The sub-atrial layer contains smaller sagittal triactines and tetractines, and lacks diactines and pentactines. The atrial lining consists solely of T-shaped sagittal triactines (KLAUTAU *et al.*, 2004; LONGO *et al.*, 2007; MASTROTOTARO *et al.*, 2007; EL MOUSSAOUI *et al.*, 2024). This combination of characteristics clearly distinguishes *P. magna* from similar species such as *P. cucumis* (Haeckel, 1872) and *P. crosslandi* (Row, 1909) (BOROJEVIC *et al.*, 2002; LONGO *et al.*, 2007).

Paraleucilla magna has been present in the Mediterranean Sea for over several decades, including regions such as the Ionian Sea, Adriatic Sea, Tyrrhenian Sea, and the Sea of Marmara (MAČIĆ & PETOVIĆ, 2017). This non-indigenous calcareous sponge has also been reported on the southern shores of the Mediterranean in North Africa, specifically in Algeria and Tunisia (BACHETARZI *et al.,* 2019; BENSARI *et al.,* 2020; SGHAIER *et al.,* 2019) and recently from the western coast of Morocco (EL MANSOURI *et al.,* 2024). Here, we document the first record of *P. magna* on the eastern Mediterranean coast of Morocco. This finding highlights its well-established presence across much of the Mediterranean basin and underscores its ability to colonize diverse environments, including those on the southern coasts of the region. In the studied area, *P. magna* has never been observed before June 2019, which means that the invasion process could be in its early stages. In invaded areas where the non-indigenous Porifera exists, the species has been reported to occur at shallow depths, in eutrophic environments with low water movement (LONGO *et al.,* 2007), as it is case at the studied area of Marchica lagoon and Saidia Marina. The non-indigenous species has demonstrated its invasiveness by its ability to colonize different environments with high abundance in a short period of time (CVITKOVIĆ *et al.,* 2013; LONGO *et al.,* 2021). The same scenario is expected along the Moroccan coasts, where drastic measures are needed to increase monitoring and management of the invasion process.

The Mediterranean coast of eastern Morocco is located in a key area for the conservation of marine areas in the Alboran Sea, which is considered a very productive area and has an important socio-economic role in the region (ROBLES, 2010; EL HAMOUTI *et al.,* 2023). However, due to its geographical position and concomitant intensification of maritime traffic, this area has become an important recipient of biological invasions in recent years, with a large number of NIS, including invertebrates and vertebrates, having been documented in recent years (MABROUKI *et al.,* 2021, 2025a, b; TAYBI & MABROUKI, 2020; TAYBI *et al.,* 2020a, b, 2024). Most of these biological invasions have been documented in semi-enclosed coastal environments such as lagoons and marinas (MABROUKI & TAYBI, 2024; TAYBI *et al.,* 2023, 2025; GOURARI *et al.,* 2025). The Marchica Lagoon and the Saidia Marina have emerged as prominent destinations of interest, attracting both national and international travellers. The accessibility of the Mediterranean coastlines of eastern Morocco, which can be achieved through recreational boating and maritime transport, makes this region vulnerable to the introduction of non-indigenous species. Furthermore, the phenomenon of biofouling has been demonstrated to increase the risk of such introductions and international travel. The

identification and monitoring of NIS at regional and national levels has become an urgent requirement.

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