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Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Portunidae, Malacostraca) could lead to local extinction of few endemic freshwater species in the Eastern Morocco

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Abstract. The protected area of the Moulouya River mouth, also known as a SIBE (Site of Biological and Ecological Interest), is one of the most important and vulnerable freshwater reserves in the southern Mediterranean. This site is characterized by a wide variety of habitats that support rich aquatic biodiversity with a high degree of endemism. It was also one of the first wetlands in Morocco to be invaded by the marine and invasive American blue crab, *Callinectes sapidus* Rathbun, 1896, following its initial establishment in the Marchica Lagoon. Since its first detection in 2019, the blue crab has been expanding its range upstream in the Moulouya River, now reaching areas home to some of the last populations of endemic and patrimonial species in Eastern Morocco. In this paper, we compare the abundance of certain patrimonial species in the Moulouya SIBE before and after the arrival of the blue crab, focusing on the Moroccan endemic freshwater mussel *Unio foucauldianus* Pallary, 1936, and the freshwater crab *Potamon algeriense* Bott, 1967. We observed a complete disappearance of these species in certain areas of the lower Moulouya, which could likely be attributed to predation by the blue crab. The predation and migration behaviour of the blue crab in the Moulouya River aligns with what has been described in the literature for its non-native range.
Keywords: Moroccan naiad, freshwater crab, last populations, marine species, biological invasion, threatened populations

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Introduction. Alien and invasive species pose a significant threat to global ecosystems, as they can reduce the genetic diversity of native biodiversity and drive biotic homogenization through various mechanisms and interactions (Canonico et al., 2005). The Mediterranean Sea, recognized as a biodiversity hotspot, has not escaped the widespread invasion of alien species. It has become one of the world's most affected regions, with a high prevalence of introduced species among benthic fauna, particularly crustaceans (Galil et al., 2002).

Among these invasive species, the American blue crab, *Callinectes sapidus* Rathbun, 1896, is listed as one of the world's most problematic invaders and is ranked among the 100 worst invasive species in the Mediterranean. Native to the Atlantic coasts of the Americas, ranging from southern Canada to northern Argentina (Williams, 1984), *C. sapidus* was first recorded in Morocco in 2017 when it was caught by fishermen in the Marchica Lagoon (Chartosia et al., 2018). Since then, the species has continued to expand its range along Morocco's Mediterranean and Atlantic coasts, invading several national parks and protected areas. Its southernmost limit has now been recorded in the Dakhla wetlands, located on the Atlantic Sahara coast of Morocco (Taybi et al., 2023; Mabrouki et al., 2025).

One of the first protected areas in Morocco to be invaded by the blue crab was the Moulouya wetland (Taybi, Mabrouki, 2020). The wetland of Moulouya River mouth is among the most important and vulnerable freshwater ecosystems in the southern Mediterranean. It has been designated as a Ramsar site, with Morocco committing to its protection since 2005. Additionally, it has been listed as a Site of Biological and Ecological Interest (SIBE) by the National Commission responsible for the Master Plan for Protected Areas (https://ma.chm-cbd.net/fr/protected-areas/embouchure-de-la-moulouya). This site is characterized by diverse wetland habitats that sustain rich aquatic biodiversity, with a high degree of endemism. In some cases, the range of endemic species is strictly confined to this section of the Moulouya River or to the SIBE (Gloër et al., 2020; Mabrouki et al., 2018, 2020; Taybi et al., 2021).

In this paper, we present the first data on the upstream migration of *C. sapidus* in the Moulouya River. We also report the local extinction of the freshwater crab *Potamon algeriense* Bott, 1967, and the bivalves *Unio foucauldianus* Pallary, 1936, and *Corbicula fluminea* (O. F. Müller, 1774) within the Moulouya SIBE.

Material and Methods. *Study Area.* The Moulouya River is one of the longest rivers in Morocco and the Maghreb region, with a length of approximately 600 km. It is

located in the north-eastern part of the country and flows into the Mediterranean Sea. The Lower Moulouya Site of Biological and Ecological Interest (SIBE) spans an area of nearly 3,000 hectares along a 25 km stretch of the river (Fig. 1).

This site encompasses a variety of aquatic ecosystems, including the Moulouya River mouth and its floodplain, a 6 km-long coastal marine strip, a dune ridge, semi-temporary salt marshes, and a 7 km-long river channel. Within the reserve, five distinct habitat systems are identified: marine, estuarine, riverine, palustrine, and lacustrine.

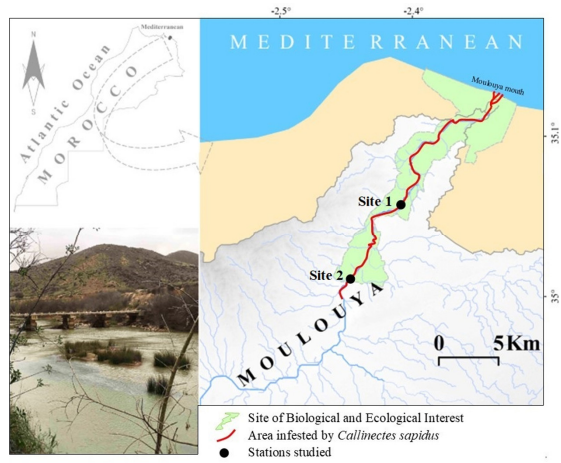

Fig. 1. The location of the Moulouya SIBE protected area with an example of habitat invaded by the blue crab

Field Surveys. Since 2014, we have conducted regular surveys and sampling campaigns in the Lower Moulouya reserve for various hydrobiological studies, including assessments of benthic and fish fauna. Following the first detection of the blue crab (*C. sapidus*) in the SIBE in 2019, we began monitoring its progression within the river (ongoing study) and investigating its potential predation effects on Morocco's endemic and patrimonial freshwater species.

Two stations within the Moulouya SIBE, previously known to host populations of the endemic species *P. algeriense* and *U. foucauldianus*, were sampled bimonthly during three campaigns conducted both before (March–August 2018) and after (March–August 2024) the blue crab's arrival. Each sampling site covered an area of 100 m^2.

Sampling Methodology. For *P. algeriense*, sampling was conducted using a turbid net in aquatic environments, while searches for adults outside the water were performed manually, either by hand or with clamps. These operations involved approximately one hour of excavation per station. All captured specimens were re-leased back into their natural habitats after being sexed, measured, and recorded for additional data (see Taybi et al., 2018).

At each site, macroinvertebrates, including freshwater bivalves, were collected using a Surber sampler (surface area: 20×25 cm; mesh size: 0.4 mm). This method ensured coverage of the full range of microhabitat heterogeneity represented at each site (see Taybi et al., 2017).

For *C. sapidus*, both quantitative and qualitative sampling methods were employed. Quantitative sampling in clear, shallow waters near the shore (depth: 0.5–1 m) involved the use of a hawk net, which was dragged randomly through aquatic vegetation or used to directly catch visible crabs. In deeper, murkier waters, a fishing net was deployed. Additionally, adapted trawl nets baited with small pieces of sardine were deployed and left for 24 hours to attract blue crabs.

Qualitative surveys extended beyond the SIBE boundaries to monitor the spread of *C. sapidus* further upstream and downstream in the Moulouya River.

Results. For the first time since its detection at the mouth of the Moulouya River in 2019, the blue crab (*C. sapidus*) has been observed in large numbers in the freshwater sections of the river, at locations far from the sea and with very high population densities (Table), reaching distances of up to 15 km inland (Figs. 1 & 2*a*).

Table. Mean Abundance (Individuals per 100 m^2) of *Callinectes sapidus* and its three prey species at two sampling stations within the Moulouya SIBE, recorded before (18 March–25 August 2018) and after (15 March–18 August 2024) the blue crab invasion

Studies localities within the Moulouya SIBE	*Callinectes sapidus*	*Potamon algeriense*		*Unio foucauldianus*		*Corbicula fluminea*	
		pre-invasion	post-invasion	pre-invasion	post-invasion	pre-invasion	post-invasion
Site 1: 35°00'09.9" N, 2°27'25.9" W	38	5	0	8	0	25	0
Site 2: 34°54'27.53" N, 2°38'8.86" W	21	3	0	4	0	46	4

Our study revealed that at both surveyed locations, the endemic freshwater crab (*P. algeriense*) and the freshwater mussel (*U. foucauldianus*) have disappeared. Additionally, the density of the non-native Asian clam (*C. fluminea*) decreased significantly – by an order of magnitude at one station and to complete absence at another. At the northern limit of their distribution within the SIBE, at the Hassan II Bridge (Table, site 1), these species have entirely vanished, with only empty shells remaining (Fig. 2, *a*, *b*).

Notably, a blue crab was observed actively preying on an endemic *P. algeriense* (Fig. 2, *c*; 34°58'50.8" N, 2°27'06.7" W). Additionally, a partially alive *P. algeriense* specimen, missing its claws, was found under a rock on the riverbank outside the protected area (Fig. 2, *d*; 34°57'48.9" N, 2°28'01.5" W).

Discussion. Since its first detection at the mouth of the Moulouya River in 2019, the blue crab (*C. sapidus*) has been observed in large numbers in the freshwater sections of the river, far from the sea. Its expansion may be facilitated by the effects of climate change and the deteriorating water quality of the river (Taybi et al., 2020). The upstream migration of the blue crab in the Moulouya River closely mirrors patterns observed in both its native range and other areas of introduction (Pla Ventura et al., 2018; Scalici et al., 2022; Bedmar et al., 2024). Although typically a marine species, *C. sapidus* is highly euryhaline and capable of effective osmoregulation across a broad range of salinities,

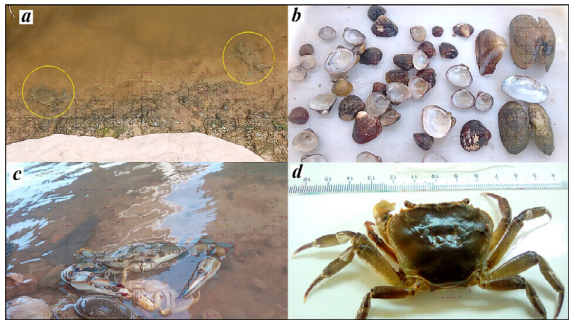

Fig. 2. Occurrence and documentation of predation by *Callinectes sapidus* in the Moulouya SIBE: *a* – blue crab in situ; *b* – empty shells of *Unio foucauldianus* and *Corbicula fluminea*; *c* –predation by *C. sapidus* on the freshwater crab *Potamon algerience*; *d* – *P. algerience* with lost claws

allowing it to establish populations in freshwater environments. This physiological adaptability, combined with its other ecological traits, has contributed to its successful establishment in the Mediterranean (Galil et al., 2002; Mancinelli et al., 2013).

Predation by blue crabs on native and non-native freshwater bivalves has been documented in Europe, notably in Spain, where large numbers of blue crabs were observed in the summer of 2018 in the Ebro River, up to 50 km from its mouth. This predation poses a significant threat, potentially leading to the local extinction of certain populations of European naiads, such as *Anodonta anatina* (Linnaeus, 1758), *Unio mancus* Lamarck, 1819, and *Potomida littoralis* (Cuvier, 1798), as well as the alien *C. fluminea* (Pla Ventura et al., 2018). A similar scenario could occur in Moroccan rivers, particularly for native freshwater bivalves. Since the detection of the blue crab in the Moulouya SIBE, we have monitored its population structure and documented its seasonal and spatial migrations between upstream and downstream habitats (ongoing study). Our findings suggest that the invasion of the blue crab has likely contributed to the decline of native species in the protected areas of the Moulouya River.

The freshwater mussel *U. foucauldianus*, an endemic species of Moroccan rivers, is critically endangered and listed by the International Union for Conservation of Nature (IUCN) (Van Damme, Ghamizi, 2010). Its distribution includes Morocco's major basins, from the southern Atlantic coast to the northeastern Mediterranean coast (Gomes-dos-Santos et al., 2019). Within its easternmost range, *U. foucauldianus* occupies the potamon reaches of the Moulouya River, characterized by high flow rates and well-oxygenated water throughout the year (Taybi, 2016; Taybi et al., 2017). The disappearance of *U. foucauldianus* from the Moulouya SIBE is likely linked, at least in part, to predation by the invasive blue crab.

The Maghrebian endemic freshwater crab *P. algeriense* is restricted to northwestern Africa, including Morocco, Algeria, and Tunisia (Cumberlidge, 2009). Recent phylogenetic studies have identified two distinct clades: an eastern clade, comprising populations from Tunisia and Numidia, and a western clade, which includes populations from central Algeria and Morocco (Marrone et al., 2020). Despite its wide distribution in the Maghreb, populations of *P. algeriense* are fragmented and discontinuous. The lower Moulouya basin likely supports the last remaining population of this species in eastern Morocco (Taybi et al., 2018). The decline of *P. algeriense* in Morocco is already a concern due to insufficient conservation measures, and our findings suggest that the invasion of *C. sapidus* may accelerate this trend.

Additionally, the Moulouya wetland serves as one of the last refuges for the critically endangered European eel (*Anguilla anguilla*) in Morocco, as well as for other endemic fish species such as *Luciobarbus yahyaouii* Doadrio, Casal-López & Perea, 2016, and *Alosa* spp. (Doadrio et al., 2016; Ford et al., 2020, unpublished data). However, this important refuge has become a hotspot for biological invasions in eastern Morocco (Taybi et al., 2023). The wetland is now home to multiple alien animal and plant species across various taxonomic groups (Mabrouki et al., 2019; Taybi et al., 2016, 2020*b*, *c*).

Conclusions. The American blue crab (*C. sapidus*) is arguably the most significant invasive species currently present in the Moulouya SIBE reserve, owing to its rapid adaptability, high invasiveness, and remarkable biological plasticity in both marine and

freshwater habitats. Under the ongoing scenario of climate warming, higher rates of evapotranspiration are expected to intensify the salinization of freshwater ecosystems, creating conditions that may further favor invasive species like *C. sapidus*.

To mitigate the potential impacts of this invasive species on native communities and to safeguard the integrity of Moroccan freshwater ecosystems, it is essential to implement robust monitoring programs to track its expansion within the invaded areas. Proactive measures will be critical to minimizing ecological damage and preserving the biodiversity of these vulnerable habitats.

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Атлантический голубой краб *Callinectes sapidus* Rathbun, 1896 (Portunidae, Malacostraca) может привести к локальному исчезновению эндемичных пресноводных видов в восточной части Марокко

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Аннотация. Охраняемая территория в устье р. Мулуя, также известная как SIBE (Site of Biological and Ecological Interest), является одним из наиболее важных и уязвимых пресноводных заповедников в южном Средиземноморье. Она характеризуется широким разнообразием сред обитания, которые поддерживают богатое водное биоразнообразие с высокой степенью эндемизма. Она также стала одним из первых водно-болотных угодий в Марокко, куда проник морской инвазивный вид – американский голубой краб (*Callinectes sapidus* Rathbun, 1896), после его первоначального появления в лагуне Марчика. С момента своего первого обнаружения в 2019 г. голубой краб расширяет свой ареал вверх по течению р. Мулуя, ныне достигая районов, где обитают одни из последних популяций эндемичных и охраняемых видов в восточном Марокко. Мы сравниваем численность некоторых видов в SIBE Мулуя до и после появления там синего краба, уделяя особое внимание эндемичной для Марокко пресноводной перловице (*Unio foucauldianus* Pallary, 1936) и пресноводному крабу (*Potamon algeriense* Bott, 1967). Наблюдается полное исчезновение этих видов в некоторых районах нижнего течения р. Мулуи, что, вероятно, можно объяснить хищничеством голубого краба. Хищническое и миграционное поведение голубого краба в р. Мулуя соответствует описанному в литературе для его неаборигенного ареала.
Ключевые слова: марокканская перловица, пресноводный краб, последние популяции, морские виды, биологическое вторжение, угрожаемые популяции

Соблюдение этических норм. Отлов крабов для настоящего исследования проводился в соответствии с законодательством Марокко и был одобрен факультетом естественных наук Дхар Эль Мехраз Университета Сиди Мохамед Бен Абделла (Фес, Марокко).

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