Rapid Communication

The invasive Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 expands its distributional range southward to Atlantic African shores: first records along the Atlantic coast of Morocco

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Abstract

The occurrence of the exotic Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Crustacea: Decapoda: Portunidae) is reported for the first time from the Moroccan Atlantic coast. Working with local fishermen, we gathered 160 records of the Atlantic blue crab from several estuarine, coastal and marine areas, in the period between June and August 2021. These new records confirm its establishment in the Atlantic coasts of North Africa, suggesting a southern range expansion. These findings, likely exacerbated by growing populations along the Atlantic coast of Morocco and temperate coastal waters, provide new insights into the invasion dynamics of this species in the northeast Atlantic Ocean.

Key words: alien range expansion, marine invasions, non-native species, northeastern Atlantic, northern Africa, Portunidae

Introduction

The Atlantic blue crab *Callinectes sapidus* Rathbun, 1896, belonging to the family Portunidae, is native to the western Atlantic Ocean. Its natural geographical distribution ranges from Nova Scotia in Canada down to northern Argentina, including Bermuda and the Antilles (Williams 1974; Nehring 2011; Castriota et al. 2012). This species was accidentally or intentionally introduced into Asia, Europe and Africa, where it has extended its geographical distribution range and rapidly increased its viable populations. It was first recorded in Europe in 1900 on the Atlantic coast of France (Bouvier 1901). In the Mediterranean Sea, the blue crab was first recorded in the Northern Adriatic Sea (Giordani-Soika 1951). Subsequently, the species has been widely recorded in the Mediterranean Sea, especially in its eastern basin (Galil et al. 2002; Nehring 2011) and has greatly expanded its range and is currently widespread throughout the Mediterranean and Black Seas (Cilenti et al. 2015; Mancinelli et al. 2017a, 2021). While ballast water is considered the most likely introduction vector for this species, some of these introductions have resulted from deliberate releases (Giordani-Soika 1951; Nehring 2011).

The Atlantic blue crab is currently recognized as one of the most invasive alien species in the Mediterranean area due to the high number of records (Streftaris and Zenetos 2006). This is likely mediated by outstanding swimming capacity (using the flattened rear pair of legs as paddles (Zibrowius 2002) for rapid movement), passive transport in ballast waters, high dispersal abilities (moving away from the site of introduction toward other locations, covering long distances of several hundred kilometers (Labrune et al. 2019; Box et al. 2020)), high survival rates, high fecundity and reproductive capabilities, adaptations to a wide range of environmental conditions (e.g., a high tolerance to extreme variation in water temperature, living in muddy and sandy bottoms of estuaries, lagoons and marine ecosystems as well as nearshore coastal habitats up to 220 m depth (Daban et al. 2016)), and opportunistic predatory behaviour with pronounced aggressiveness (Cardeccia et al. 2018) mediated by swimming paddle-like legs, pointed toothed and spined claws and carapace (Poore 2004). This key species can impact native biota in invaded areas (Cardeccia et al. 2018). However, the negative effects of the blue crab on invaded benthic communities and on ecosystem functioning and delivery of goods and services are only assumed (Mancinelli et al. 2017a), and there is a general lack of ecological information. Intriguingly, in its native area (the western Atlantic Ocean), the blue crab is considered a valuable seafood item and supports an important commercial and recreational fishery (Sharov et al. 2003; Castriota et al. 2012; Perry 2015).

This crustacean species is euryhaline with a life cycle that includes both inshore brackish and marine habitats. Adult males prefer more brackish waters (< 25 PSU) where they tend to settle in upper and middle parts of esuarine systems, while adult and ovigerous females congregate and spawn in more saline waters (> 30 PSU) (Aguilar et al. 2005; Hines 2007; Mancinelli et al. 2013; Czerniejewski et al. 2020). After mating, inseminated mature females migrate to the lower estuarine and coastal areas to spawn. Larval stages shift offshore before returning as megalopae to settle and ingress into and distribute throughout estuarine habitats, where they reach maturity (Hines 2003, 2007). Larvae of the Atlantic blue crab (zoeae stage 7 and megalopa stage 1) require high salinities (> 25 PSU) for their survival and growth, hence the low salinity in brackich estuarine waters prohibits reproduction (Czerniejewski et al. 2020).

In the eastern United States, *C. sapidus* is an omnivorous predator, feeding on fish, molluscs, and other crustaceans, but also showing scavenger and cannibalistic behaviour (Hines et al. 1987); it can eat algae as well (Kampouris et al. 2019). In invaded Mediterranean habitats, it feeds on a wide range of species, including economically important fish, molluscs and crustaceans (Mancinelli et al. 2016, 2017b, c; Kampouris et al. 2019). In its native habitats, the Atlantic blue crab carries out several ecosystem functions, playing an important role in energy transfer within estuarine and nearshore coastal/offshore habitats (Johnson and Eggleston 2010), and a key role in the structure and function of coastal benthic food webs, either as a keystone species or by inducing trophic cascades (Hines 2007).

Valuable information has been gathered by fishermen and other citizen scientists monitoring biological invasions worldwide (Encarnação et al. 2021), and the case of the blue crab in Europe and North Africa is a remarkable example of such collaborations (Suaria et al. 2017; Benabdi et al. 2019; Morais et al. 2019; Taybi and Mabrouki 2020). Previous notes of the presence of *Callinectes sapidus* in Morocco date back to 2018 and 2020 along the Mediterranean coast in northern Morocco and include Marchica lagoon (Chartosia et al. 2018) and Moulouya estuary and the mouth of Oued Kert (Taybi and Mabrouki 2020). It has also been reported in other neighbouring African southwestern Mediterranean countries, from transitional brackish and nearshore coastal waters (Abdel Razek et al. 2016; Benabdi et al. 2019; Mili et al. 2020; Ragkousis et al. 2020; Corsini-Foka et al. 2021; Hamida and Kara 2021; Kara and Chaoui 2021; Shaiek et al. 2021). The present paper provides the first records on the occurrence of *Callinectes sapidus* along the Atlantic coast of Morocco, using citizen science data, and confirms the expansion of this species along North African and eastern Atlantic coasts.

Materials and methods

The presence of the Atlantic blue crab was reported based on specimens caught with gillnets by local/professional fishermen along the Moroccan Atlantic coast (Figure 1) from June to August 2021. Specimens were captured from several localities distributed along the Moroccan coastline from north to south, including estuaries, lagoons, nearshore coastal and offshore waters (between 35°36′N; 5°59′W and 28°39′N; 11°08′W). These include Tahaddart estuary (Asilah), Loukkos estuary (Larache), Moulay Bousselham/Merja Zerga lagoon, off Kénitra, Sebou estuary, Bou Regreg estuary (Rabat), off Bouznika, off Mohammedia, off Casablanca Sidi Abderrahmane, off Dar Bouazza, off Sidi Rahal, Oum Er Rbia river estuary (Azemmour), off El Jadida, off Sidi Abed, Sidi Moussa lagoon, Oualidia lagoon, off Safi, off Essaouira, Oued Sous estuary (Agadir Bay) and Oued Drâa estuary (Tan Tan) (see Supplementary material Table S1).

Captured blue crab specimens were frozen for morphological analysis and then fixed and preserved in 70% ethanol. Specimens were identified following the identification keys and descriptions provided by Williams (1974), Millikin and Williams (1984), and Ogburn et al. (2011). Identification was based on the following diagnostic characters of *Callinectes*: carapace broader than wider; two broad-based frontal teeth between the inner orbitals; nine antero-lateral teeth; chelipeds similar in length and longer than the ambulatory

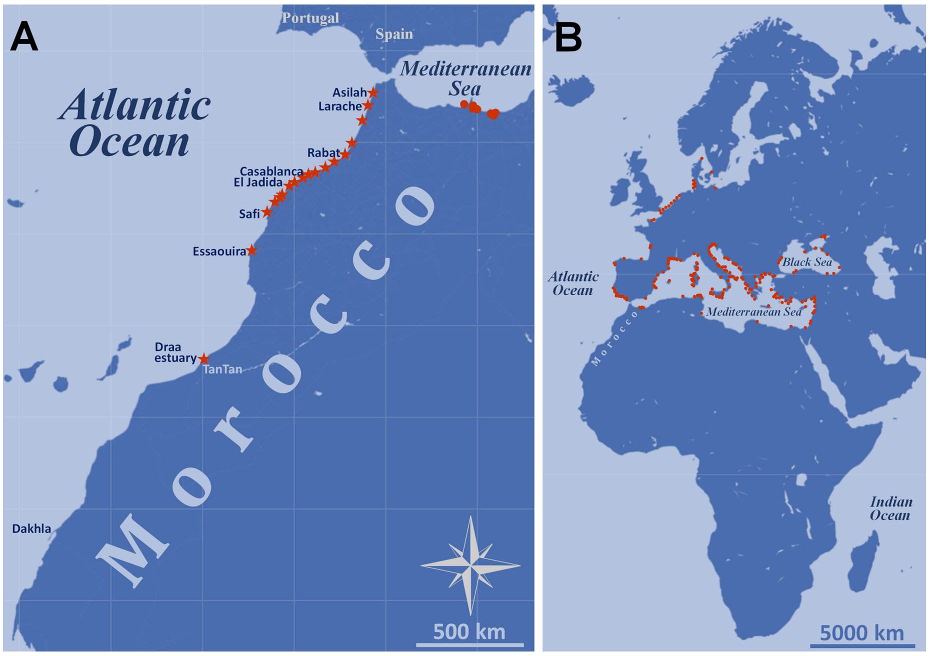

Figure 1. Updated distribution maps of *Callinectes sapidus*, indicating new records reported along the Moroccan Atlantic shores and including earlier records from the Mediterranean coast (A) and previous literature records in Europe, Mediterranean basin and the Black Sea (B) based on maps according to Garcia et al. (2018); Labrune et al. (2019); Mancinelli et al. (2021) and Shaiek et al. (2021). Coordinates of locations and dates of all the records of *C. sapidus* are provided in Supplementary material Table S1.

legs; and fifth pereiopods natatorial, with flattened propodus and dactylus. Most of the captured specimens were directly identified by morphological criteria (carapace morphology and coloration pattern) and characterized on morphometric data (length, width and weight). Other specimens were identified based on appropriate photographs.

Captured individuals were sexed through the marked sexual dimorphism in the morphology of the abdomen/pleon and telson. Males have a long, narrow and roughly inverted T-shaped apron with acute tip, while females have a wide, triangular-shaped (immature ♀) or semi-circular-shaped (mature ♀) apron. Females were recorded as ovigerous or not.

Only undamaged and intact specimens were measured for carapace total length (CL = distance between the center of the anterior interorbital margin and the center of the posterior margin of the carapace) and total carapace width including lateral spines (CW = maximal distance between the posterior anterolateral spines) with an electronic/digital calliper and weighed for total wet weight (WW) on a top-loading digital balance, with an accuracy of 0.1 grams. Unfortunately, for some specimens, it was not possible to collect biological and biometric information because we had only photos provided by the fishermen from localities far from the Doukkala and Abda regions (see Table S1).

Results

A total of 153 adult blue crabs and 7 juveniles of indeterminate sex were reported between June and August 2021 (Table 1). Fifty-six males (Figure 2A)

Table 1. Minimal and maximal values relative to morphometric characteristics. Carapace width (CW), carapace length (CL), and wet weight (WW) of different sex and life stages of *Callinectes sapidus* from Moroccan Atlantic localities. Only fully mature adults were sexed and only live and intact individuals were considered. N: number of captured specimens. For more details, see Table S1.

Life stages	N	CL (mm)	CW (mm)	WW (g)
Juveniles	7	19.2–31.3	41.8–72.0	51.0–78.6
Adult males	94	55.1–84.9	109.1–185.4	108.0–412.6
Immature females	4	47.9–66.1	97.1–118.8	68.2–111.6
Mature females	51	64.0–80.4	140.1–179.7	148.5–242.3
Ovigerous females	4	80.0–104.4	143.8–173.5	184.2–273.5

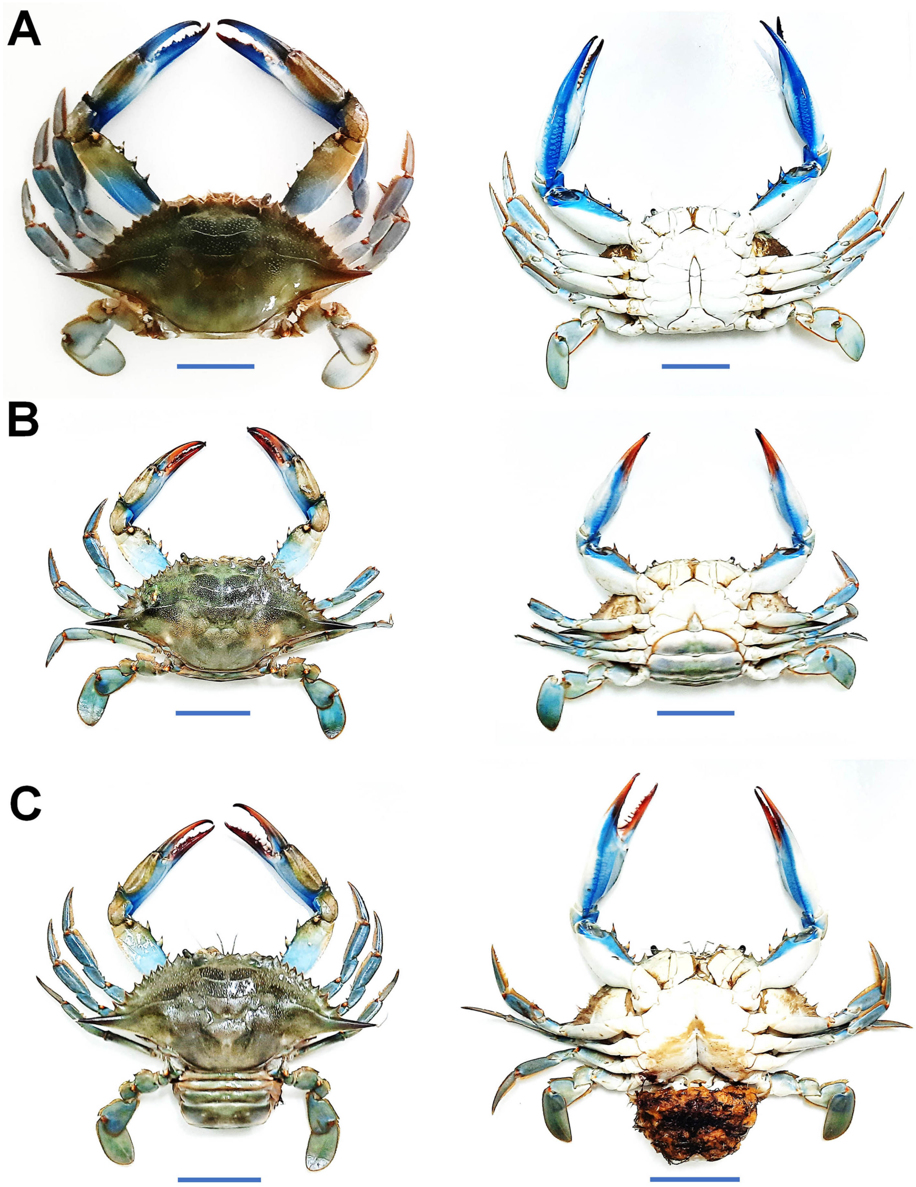

Figure 2. Dorsal (left side photos) and ventral (right side photos) views of an adult male (A: CL = 85 mm, CW = 185 mm, WW = 412 g), a mature female (B: CL = 80 mm, CW = 171 mm, WW = 242 g), and an ovigerous female (C: CL = 104 mm, CW = 173 mm, WW = 266 g) of *Callinectes sapidus* caught in the Atlantic Moroccan coast. Scale bar = 5 cm.

and 28 females (Figure 2B, C) were caught in brackish waters at 3–6 m depth; 38 males and 31 females were found 6 to 11 km off the coast at 10 to ≤35 m depth (Table S1). Males predominated, and females were typically slightly smaller than males, but the sizes of the males were somewhat more variable than females (Table 1).

All of the crabs were ascribed to the genus *Callinectes* based on the lack of spines in the inner margin of the carpus of cheliped (Figure 2). The specimens were identified as *C. sapidus* due to the presence of two interorbital triangular teeth in the frontal margin of the carapace (Figure 2). The carapace had also nine marginal teeth on each side; the ninth teeth were strong lateral spines. The examined blue crabs had three pairs of walking legs and paddle-shaped rear swimming legs. Males and females of *C. sapidus* were distinguished by the sexual dimorphism in the shape of the abdomen. Females were recognized by a broad, rounded and crescent-shaped/half-moon shaped/ dome-shaped abdomen and by the blue and white color of the claws (cheliped fingers) and red dactyls (Figure 2B); males had a strongly tapered abdomen, or "apron", that resembled an inverted T, and white and blue claws and dactyls (Figure 2A). Across all sites and dates (Table S1), the measurements of captured specimens were the following: mature females (n = 59), CW: 136.2 ± 11.5 mm, CL: 72.0 ± 18.5 mm, WW: 175.3 ± 77.1 g and mature males (n = 94), CW: 144.6 ± 23.3 mm, CL: 70.0 ± 8.6 mm, WW: 224.9 ± 92.6 g. The rest of the individuals were not measured because some spines and part of the carapace were broken.

Specimens of both sexes were caught in across different habitats, including inshore brackish waters, nearshore coastal marine waters as well as offshore localities. Specimens were captured in areas with salinities between 18 and 35.6 PSU and water temperatures ranging from 21 to 30–32 °C and water depths from 3 to ≤ 35 m. Higher salinity values corresponded to offshore locations, external channels closer to the sea and nearshore coastal habitats where a higher number of females were found. Lower salinity values corresponded to the inner parts of estuarine systems that were characterized by a relatively higher abundance of males. The largest and heaviest specimens measured were males collected in brackish and inshore coastal waters.

Discussion

This study reveals widespread distribution of the Atlantic blue crab *C. sapidus* along the Atlantic coast of Morocco and the presence of multiple stages of the life-cycle. The collected individuals represent different life stages (juveniles and adults) and sexual maturity stages (immatures and matures, ovigerous and non-ovigerous) for both sexes and were collected from different habitats including coastal lagoons, estuaries and nearshore coastal areas. Considering the high abundance and frequency of catches in fishing nets, as well as reports (*in verbalis*) of the presence of juveniles and ovigerous females, the population of the Atlantic blue crab can be considered as established in Moroccan waters. Furthermore, these areas are rich in trophic resources (e.g., clams, oysters, mussels, molluscs, annelids, smaller crustaceans, fish and freshly dead fish, and plant and animal detritus), providing suitable feeding conditions for this new predator.

Several characteristics of the region suggest that the species could continue to spread to new locations. The life cycles of *Callinectes* sp. are linked to estuarine/lagoon habitats (Cuesta et al. 2015); thus the existence of a plethora of such habitats along the Atlantic coast of Morocco compared to the Mediterranean coast could contribute to the expansion of the Atlantic blue crab. The Moroccan coast has several suitable lagoons and estuaries for this species that would likely provide the required temperature and salinity ranges conducive to population growth and sexual maturity (Cilenti et al. 2015; Türeli et al. 2017). For example, the annual water temperature and salinity for estuaries from Tahaddart to Oued Drâa ranged from 11 to 30–32 °C and from 12 to 41 PSU, respectively (Correia et al. 2020). According to Vasconcelos et al. (2019) hypothesis, the seawater temperature regimes along the Moroccan coast (15–32 °C) have facilitated the acclimation of the blue crab and ultimately promoted its continuous southward expansion along the African Atlantic coasts (Mauritanean province). Noticeably, the new findings presented here confirm the ongoing expansion and settlement in the eastern Atlantic coasts at middle and high latitudes, where marine waters are warmer than the western Atlantic due the effects of the Gulf Stream (Buckley et al. 2019). However, at a global scale, the blue crab *C. sapidus* is rapidly shifting its distribution worldwide (Mancinelli et al. 2021). Considering the high rate of spread of the species and its high fecundity, wide ecological tolerance and opportunistic predatory behaviour with pronounced aggressiveness, it could soon colonize all African coasts, becoming a serious problem for the whole area.

The arrival of new alien invasive species is a growing concern (Box et al. 2020) because they may have an adverse effect not only on ecosystems and human health (Streftaris and Zenetos 2006) but also on economically valuable activities such as fisheries (Occhipinti-Ambrogi and Savini 2003). Many of these impacts can be quantified as economic costs (Zenni et al. 2021). In this context, there is increasing concern about the ecological and economic impacts of the blue crab (Nehring 2011). Its rapid and ongoing expansion in Moroccan Atlantic waters may have economic consequences on valuable human activities since some of the invaded localities support commercially important fisheries and aquaculture. The Atlantic blue crab is a major predator of the commercially important soft-shelled clam fishery, i.e. *Mya arenaria* Linnaeus, 1758 (Seitz et al. 2005) and may negatively impact shellfish in the present study area. Further population increases in established areas might lead to further losses due to the capture and entanglement of blue crabs in fishing nets (e.g., damaging fish and other crustaceans caught in traps and nets and damaging fishing gears, i.e. tearing gillnets) (Mancinelli et al. 2017c; Garcia et al. 2018; Kara and Chaoui 2021).

In addition to the direct economic impacts, the expansion of this invasive crab may cause detrimental impacts on local biodiversity and changes in native populations, community dynamics, and major ecosystem processes including disruption of trophic dynamics, and disturbance and degradation of habitats. This species can interact, by competition or predation, with a wide spectrum of native crab and fish species resulting in potentially high ecological impacts (Mancinelli et al. 2017a; Labrune et al. 2019). For instance, *C. sapidus* is a major predator of the green crab *Carcinus maenas* (Linnaeus, 1758), and at high densities can limit green crab populations (deRivera et al. 2005), which are native to this region and important food web components. However, despite all the negative impacts, the Atlantic blue crab could potentially support an important fishery along the Atlantic coast of Morocco if it is exploited and commercialized in Moroccan markets.

Although a detailed study should be conducted to know the full distribution of the blue crab around the entire Atlantic coast of Morocco, it seems that there is no definitive evidence of any particular pathway that could explain the arrival of *C. sapidus* to these northeastern Atlantic coasts. This could be due to natural migration/dispersion of adults, the dispersion of larvae by sea currents or ballast tanks of ships, intentional introduction for commercial purposes (Giordani-Soika 1951; Morais et al. 2019), or a combination of these vectors. However, at this time, there is not a sufficient amount of available information to provide a definite answer although natural dispersal remains the most plausible introduction pathway in this case.

Further studies on the Atlantic African populations of *C. sapidus* and on the potential dispersal of this species in adjacent areas would be of interest to provide more information on its population structure and dynamics along the Atlantic Moroccan coast. In addition, the possible impact of this introduced crab on native species is unknown, and further research in this field should be undertaken as well as its effect on current coastal food-webs and fisheries. Alien species represent a recognized worldwide threat to the integrity of the native communities, to the economy and even to human health (Streftaris and Zenetos 2006); hence increased understanding of invasive processes and impacts on invaded ecosystems is essential in order to provide a complementary basis for informed decision making in environmental conservation and management.

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Authors' contribution

AC, AN and ZB performed the fieldwork and laboratory analysis including the taxonomic analysis of the specimens. AR, BS and EAS conceptualized the research. AT, BS, and JE analyzed the data. AC, AR and BS drafted the manuscript, whilst AT, EAS and JE edited and reviewed the manuscript. All authors participated and commented in various aspects of discussing the results to achieve the final manuscript. The authors read and approved the final manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Records of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 collected along the Moroccan Atlantic coast (northeast Atlantic) by local fishermen between June and August 2021.

This material is available as part of online article from:
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