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Agenda Item 4: Progress report on the implementation of SPA/RAC activities under the UNEP/MAP Programme of Work for the biennium 2024-2025

Status and management of blue crabs in the Mediterranean, best practices and measures

UNEP/MAP
SPA/RAC - Tunis, 2025

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Note by the Secretariat

1. With regards to the updated Action Plan concerning Species Introductions and Invasive Species in the Mediterranean Sea, adopted by the Contracting Parties to the Barcelona Convention in 2023, an activity was launched by SPA/RAC in support of its effective implementation for the biennium 2024–2025, as requested in Decision IG.26/14 adopted during COP 23 (Portorož, Slovenia, 5–8 December 2023).

2. The activity is being implemented under the framework of the bilateral agreement between UNEP/MAP and the Italian Ministry of Environment and Energy Security (MASE). It focuses on priority actions related to the management of invasive alien species (IAS), with particular attention to the recent and significant spread of two invasive Portunidae blue crabs in the Mediterranean: *Callinectes sapidus* and *Portunus segnis*.

3. Invasive alien species, including those whose spread is exacerbated by climate change, are recognized as a major threat to marine biodiversity in the Mediterranean. These species impact native ecosystems by altering species composition and functioning and may also pose risks to socio-economic values and human health.

4. Within the scope of this activity, SPA/RAC is undertaking the following components: A stocktaking of available environmental and socio-economic data on the two invasive blue crab species in the Mediterranean; the preparation of a guidance document on measures and best practices to mitigate the spread and impacts of blue crabs; and; the organization of a workshop with relevant public institutional actors to present findings and facilitate coordination on blue crab management across the region.

5. This work aligns with the SPA/BD Protocol (Article 13), which calls on the Contracting Parties to take all appropriate measures to regulate species introductions and to endeavor to eradicate established alien species where they pose demonstrated or likely harm to ecosystems, habitats, or species, based on scientific assessment.

6. The rapid expansion of *C. sapidus* and *P. segnis* has raised significant concern due to their dual perception as both a threat to biodiversity and a potential resource of economic interest. This ambiguity—product or invader; threat or resource; manage or not manage—has presented new challenges for regional coordination and response.

7. This activity is consistent with the obligations of the SPA/BD Protocol (Article 13), which calls upon Contracting Parties to regulate the introduction of non-indigenous species and, where necessary, to take steps to eradicate those already introduced that are deemed harmful to ecosystems or species following scientific assessment.

8. The outcomes of the workshop, which took place on 24 January 2025, included: the presentation of available environmental and socio-economic data on *C. sapidus* and *P. segnis*; the identification of effective practices and measures to mitigate ecological and economic impacts; and the discussion of outlines for context-specific management plans and a possible regional mitigation strategy.

9. This document is expected to guide further implementation of the updated Action Plan concerning Species Introductions and Invasive Species in the Mediterranean Sea and to contribute toward achieving Good Environmental Status in the Mediterranean with regard to non-indigenous species.

UN environment programme | Mediterranean Action Plan Barcelona Convention | SPA/RAC

STATUS AND MANAGEMENT OF BLUE CRABS IN THE MEDITERRANEAN, BEST PRACTICES AND MEASURES

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STATUS AND MANAGEMENT OF BLUE CRABS IN THE MEDITERRANEAN, BEST PRACTICES AND MEASURES

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Introduction

The latest report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) raises alarms about the global proliferation of Non-Indigenous Species (NIS) (Roy *et al.*, 2023). Among the **37,000 recorded NIS**, **3,500 are Invasive Alien Species (IAS)**, contributing to **60 % of global species extinctions**, **impacting biodiversity** through ecosystem modifications, resource competition, and predation (Roy *et al.*, 2023). **Climate change exacerbates species distribution changes**, indirectly facilitating IAS spread, often at the expense of indigenous species. Monitoring both indigenous and invasive species is crucial for understanding the impacts of climate change and implementing effective conservation measures (DeLong *et al.*, 2018).

The introduction of Non-Indigenous Species (NIS) has profound and **dramatic ecological and socioeconomic impacts** and is considered a major threat to biodiversity conservation (Bright, 1998; Carlton, 1996; Occhipinti-Ambrogi, 2007). With the continued increase in the number of species, specimens, and/or individuals being transported, as well as the speed of these transports (Sheppard *et al.*, 2018), the threat to biodiversity posed by NIS (i.e., populations introduced by humans and expanding in regions beyond their past or current ranges) has become particularly concerning. This phenomenon is all the more worrisome as it is irreversible on both human and even geological timescales, especially in marine environments (Boudouresque *et al.*, 2005).

The Mediterranean Sea is one of the world's regions most severely affected by biological invasions, with **1 011 NIS identified** (Galanidi *et al.*, 2022). Approximately **half of the NIS in the Mediterranean are introduced primarily via the Corridor pathway**, likely entering through the **Suez Canal** (Galanidi *et al.*, 2022). **Shipping vectors**, including **Ballast Water and Fouling**, collectively account for the introduction of nearly one-third of NIS in the Mediterranean (Galanidi *et al.*, 2022).

Among the 91 exotic species of decapod and stomatopod crustaceans recorded in the Mediterranean since 1870, **85 are believed to have an anthropogenic origin** (6 species are thought to have migrated), **and 18 are considered invasive**, including two species of blue crabs from the Portunidae family: the American blue crab *Callinectes sapidus* and the blue swimming crab *Portunus segnis*.

Currently present throughout the Mediterranean, **the American blue crab**, *Callinectes sapidus* (Rathbun, 1896) — **native to the temperate and subtropical Atlantic coasts of the Americas** — has recently become **emblematic of significant socio-economic and environmental impacts**. This invasive species raises concerns among oyster farmers, lagoon fishermen, and scientists. It is considered **one of the most invasive species in the Mediterranean** (Streftaris and Zenetos, 2006). Indeed, this crustacean proliferates rapidly and possesses the biological and physiological capabilities to expand across the entire Mediterranean basin. With its distinctive morphology, it can travel up to 15 km in a single day.

In 2023, a historic shift occurred in the invasion dynamics of the **Red Sea swimming blue** crab, *Portunus segnis* (Forskål, 1775), in the Mediterranean Sea. **The unprecedented warming of Mediterranean waters facilitated its exponential expansion**, with new sightings in the Gulf of Cadiz (Spain) and the Italian Adriatic coasts, surpassing its previous confinement to the southeastern Mediterranean (de Carvalho-Souza *et al.*, 2023; Grati *et al.*, 2023). **Originating from the Indo-Pacific**, *P. segnis*, **an early Lessepsian invader**, was first recorded in Egypt in 1898 after the Suez Canal's construction. Since the 2000s, it has established across the south Mediterranean, posing threats to local biodiversity and artisanal fisheries (Marchessaux *et al.*, 2023d; Tureli and Yesilyurt, 2017). While the crab's aggressive behavior negatively impacts native species and habitats, the challenge lies in devising effective conservation measures for such invasive organisms reaching new habitats (Blackburn *et al.*, 2011). The potential expansion of *P. segnis* underscore the urgency of implementing robust conservation strategies to mitigate local biodiversity losses and safeguard ecosystem integrity.

These two blue crab species from the Portunidae family share numerous similarities: rapid colonization capabilities, aggressive behavior, voracious omnivorous predation, and significant ecological and socio-economic impacts.

The current situation regarding the invasion of these two species is alarming, and significant management measures must be implemented to counter the spread of these blue crabs, thereby protecting Mediterranean biodiversity and human activities.

In this report, we present the current state of knowledge and the challenges related to the invasion of blue crabs in the Mediterranean. This report is divided into different parts:

- The state of knowledge on the American blue crab *Callinectes sapidus*,
- The state of knowledge on the Red Sea swimming blue crab *Portunus segnis*,
- The challenges associated with the presence of these two species in the Mediterranean,

1 Methodological note

The aim of this document is to review the current state of knowledge on the invasive Portunidae blue crabs Callinectes sapidus and *Portunus segnis* in the Mediterranean. A search of the relevant literature was carried out to explore several aspects for each species: (i) morphological characteristics, (ii) distribution and invasion history, (iii) population dynamics and life cycle, (iv) ecology, and (v) socio-economic and ecological impacts. Information was extracted from existing scientific literature available from the SCOPUS, Google Scholar and Web of Science platforms. Keywords were used for each category of information:

Categories	Keywords used
General characteristics	Morphological, Anatomy, Morphological characteristics
Distribution and invasion history	Distribution, Invasion history, Occurrences
Population dynamics and life cycle	Population dynamics, Life cycle, Larvae, Larval connectivity, Allometry, Sexual maturity, Reproduction, Larval growth rate, Population structure
Ecology	Diet, Stable isotopes, Ecology, Food consumption, Food items, Thermal tolerance, Salinity tolerance, Habitat, Feeding ecology
Socio-economic and ecological impacts	Impacts, Fisheries, Socio-economic impacts, Ecological impacts, Net damage, Aquaculture

* for each categories, the specific name of each species was used: for *Callinectes sapidus:* "American Blue crab" OR/AND "Callinectes sapidus"; for *Portunus segnis*: "Swimming blue crab" OR/AND "Portunus segnis".

2 Current knowledge of the American blue crab *Callinectes sapidus*

2.1 General characteristics of the species

The American blue crab *Callinectes sapidus* (Rathbun, 1896), whose etymology means "savory graceful swimmer", is a decapod crab in the Portunidae family, subfamily Portunidae. This species is easily recognized by its **"electric" blue color** (Figure 1). The carapace is brownish in color and more than twice as wide as it is long; 9 spines on the arched anterolateral margin on the front of the carapace and 2 large spins on the extremities. Most of the convex dorsal surfaces are smooth and granular. The claws are robust and longitudinally ridged; the fifth legs are flattened in the shape of paddles. The claws are blue in males and rather red at the tip in adult females. Legs are blue (Chace and Hobbs, 1969; Churchill, 1919).

The maximum dimensions recorded are **carapace length: 9 cm and width** (measured from one end of the large lateral spines to the other): **23 cm** (Holthuis, 1987). In terms of weight, a 17 cm wide individual can weigh 331 g, and a 20.5 cm wide one can weigh 585 g.

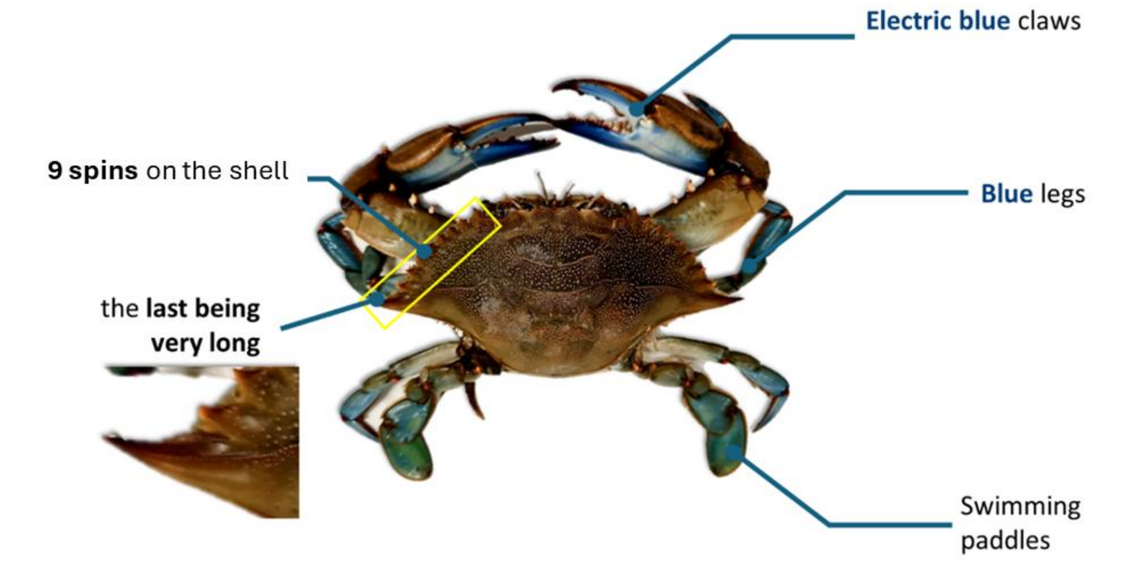


Figure 1. Morphological characteristics of the American blue crab *Callinectes sapidus*. Photography: Guillaume Marchessaux.

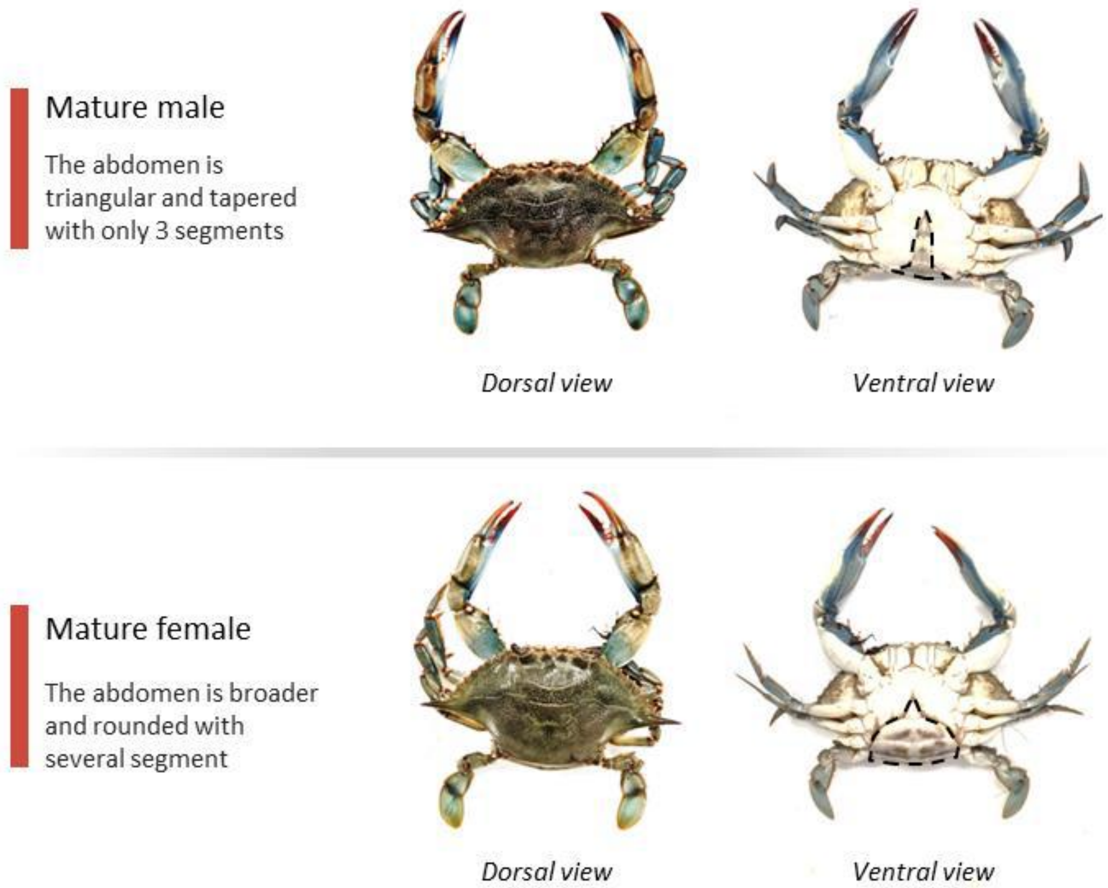


Figure 2. Morphological characteristics of males and females of the blue crab *Callinectes sapidus*. Photography: Guillaume Marchessaux.

Although females tend to have red claw tips, the difference between males and females is identifiable on the ventral side of the abdomen (Figure 2). In **males**, the **abdomen is triangular**, **T-shaped** and tapered with only 3 segments. In females, the abdomen is wider and rounded, with several segments. In **females**, the shape of the abdomen is a **key indicator for differentiating mature from immature females**. In **immature females,** the **abdomen is triangular**, **narrow** and **pointed**, and **fused with the plastron** (underside of the carapace). In **mature females**, the abdomen is **rounded or broadly dome-shaped**, often **compared to a horseshoe**. The abdomen is wider and more pronounced to accommodate eggs during reproduction (egg sac or sponge). These differences are linked to the morphological evolution of females as they reach sexual maturity, a change essential to their reproductive role.

2.2 Distribution and invasion history

Callinectes sapidus is native to the **temperate and tropical Atlantic coasts of America** (Rathbun, 1930). It is found from Nova Scotia (southern Canada), where the species does not reproduce, to northern Argentina, the southern limit of distribution in its native range (Williams, 1984). Mancinelli *et al.*, (2021) have carried out a large world-wide inventory based on bibliographical data (Figure 3). Introduced to the Mediterranean region during the 20th century, probably via ballast water from ships, *Callinectes sapidus* has successfully established itself in numerous coastal habitats. In recent years, the species appears to be expanding its range northwards in the Northern Hemisphere (Johnson, 2015; Mancinelli *et al.*, 2021).

The first record of the American blue crab *Callinectes sapidus* in Europe was in 1900 on the French Atlantic coast (Figure 4). Individuals were subsequently detected in the North Sea (1932), Mediterranean Sea (1949, probably as early as 1935), Baltic Sea (1951), Black Sea (1967) and Sea of Azov (1967). It would appear that several independent introduction vectors have taken place, such as ballast water and the introduction of the species for aquaculture purposes, which remains the most likely introduction vector (Nehring, 2011).

Since 2011, the species has greatly expanded in Europe, particularly in the Mediterranean (Labrune *et al.*, 2019; Mancinelli *et al.*, 2017). *Callinectes sapidus* has spread to the German and Danish coasts (Nehring and van der Meer, 2010), the northernmost area where it has been recorded. The American blue crab is therefore located at higher latitudes than its range due to warmer waters linked to the Gulf Stream (Mancinelli *et al.*, 2021). *Callinectes sapidus* is now reported throughout the Mediterranean basin, with the exception of a few regions such as the Libyan coast (Figure 4) (Castriota *et al.*, 2024; Mancinelli *et al.*, 2021).

Since the last review of the species' distribution by Mancinelli *et al.* (2021), **the distribution of the American blue crab has continued to increase**, particularly on European coasts, where it is now present from the southern coasts of Portugal (Atlantic coast), to Spain, France, the whole of Italy, the Adriatic Sea and the Aegean Sea (Figure 4).

In the southern Mediterranean, the species is present from Morocco to Egypt. Numerous hot spots have recently been identified, notably in the Balearic Islands (western Mediterranean), the islands of the Western Basin (Corsica, Sardinia), the Strait of Sicily and the Adriatic Sea (Figure 4) (Castriota *et al.*, 2024). Castriota *et al.* (2024) showed that the invasion of *Callinectes sapidus* in Europe and the Mediterranean was long, with a latency period of almost 60 years before populations exploded in the 2000s.

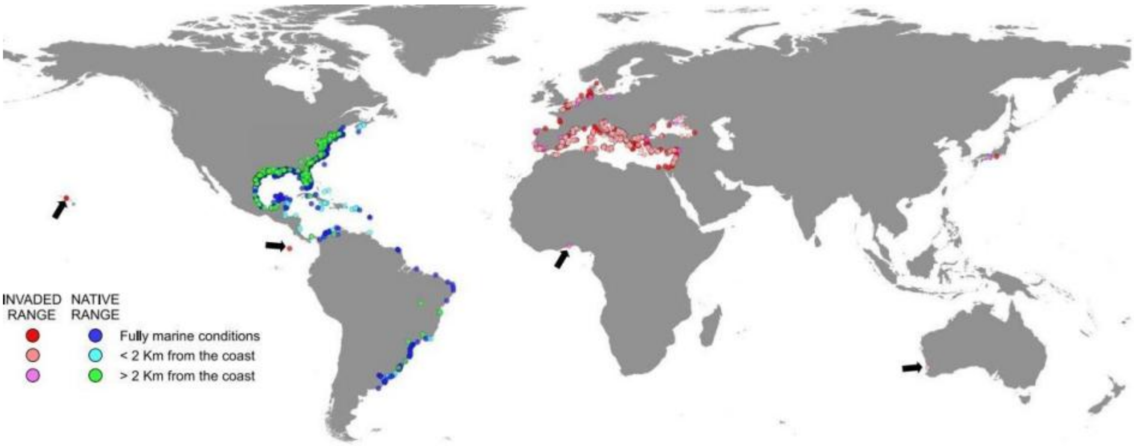


Figure 3. Global distribution of *C. sapidus* according to coastal distance of census, geographical area of origin and geographical area of introduction (figure taken from Mancinelli *et al.*, 2021).

In the Mediterranean, however, **the species' expansion phase became particularly strong from 2014** onwards, whereas it was much slower in Northwest Europe. In the Mediterranean, the American blue crab *Callinectes sapidus* **is considered established**, and the species **is currently expanding rapidly.**

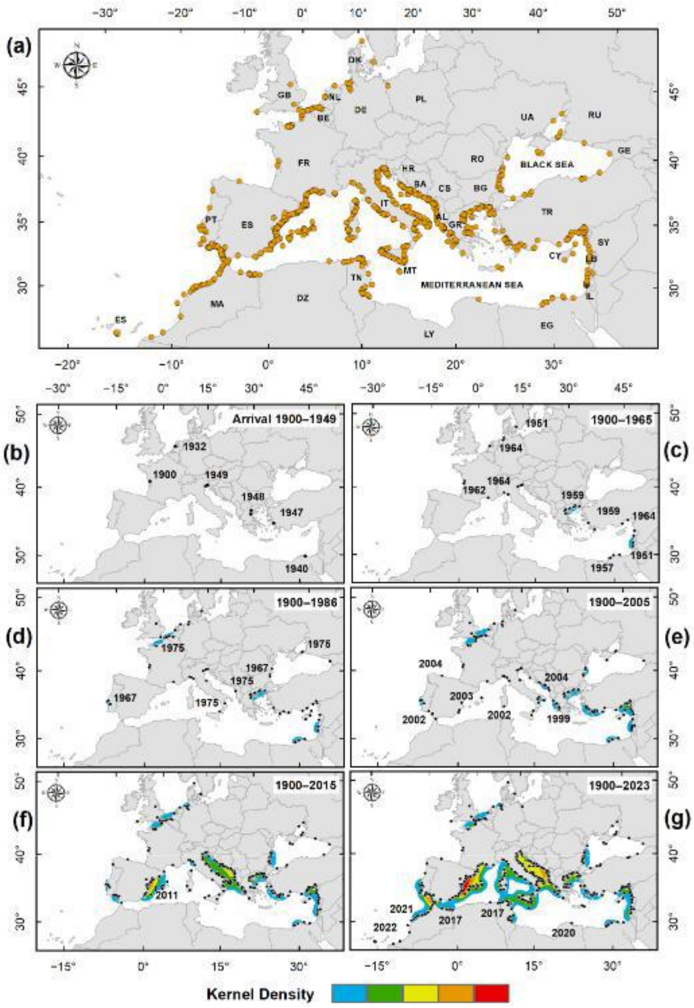


Figure 4. Distribution of *Callinectes sapidus* in Europe and the Mediterranean, Figure extracted from Castriota *et al.* (2024).

2.3 Population dynamics and life cycle of *Callinectes sapidus*

2.3.1 Population dynamics and size spectra

Size spectra analysis is a powerful approach to **describe the relationship between species size and abundance with environment** (Petchey and Belgrano, 2010). Especially, in the case of invasive species, this approach in very useful **to define the sensitives periods** to implement management measures (Buba *et al.*, 2017; Petchey and Belgrano, 2010). The analysis of the size spectra distribution showed integrative results on how environment was driving the blue crab's population in term of growth, sexual maturity and copulation.

The population dynamics of *Callinectes sapidus* show significant differences across its native range and in the Mediterranean (Mancinelli *et al.*, 2024; Marchessaux *et al.*, 2023c, 2024c). It has been observed that **each *Callinectes sapidus* population is unique**, and **size-weight relationships vary** from one area to another **due to environmental conditions** (e.g., temperature, salinity) influencing these relationships. Table 1 highlights the differences in size-weight relationship coefficients reported in the literature, revealing significant variations between males and females as well as between sites.

Table 1. Allometric parameters of *Callinectes sapidus.* Source: https://www.sealifebase.se

a	b	Doubtful?	Sex	Length (cm)	Length type	No.	Country	Locality
0.3913	2.199	No	female	5.5 - 17.5	CW	317	Türkiye	Beymelek Lagoon Lake, Antalya/2000
0.2489	2.396	No	female	6.8 - 14.7	CW	55	Egypt	Bardawil Lagoon, Sinai Peninsula/2015
0.2331	2.413	No	female	7.6 - 18.6	CW	1342	Türkiye	Beymelek lagoon/2009-2010
0.2016	2.554	No	male		CW		Türkiye	Mediterranean Sea/2006
0.2186	2.561	No	mixed	6.5 - 15.5	CW	140	Egypt	Bardawil Lagoon, Sinai Peninsula/2015
0.1752	2.568	No	female		CW		Brazil	Babitonga Bay, Santa Catarina/2003-2004
0.1263	2.570	No	female		CW		USA	Chesapeake Bay
0.1646	2.589	No	female		CW		Türkiye	Mediterranean Sea/2006
0.1834	2.613	No	male	5.1 - 18.1	CW	710	Türkiye	Beymelek Lagoon Lake, Antalya/2000
1.3898	2.626	No	male		CL		Türkiye	Mediterranean Sea/2006
0.1256	2.639	No	female		CW		USA	Galveston Bay, Texas
0.1216	2.670	No	male		CW		USA	Chesapeake Bay
0.1284	2.700	No	mixed		CW		Türkiye	Mediterranean Sea/2006
0.1764	2.769	No	male	6.5 - 15.5	CW	85	Egypt	Bardawil Lagoon, Sinai Peninsula/2015
0.1182	2.772	No	male	6.0 - 21.3	CW	869	Türkiye	Beymelek lagoon/2009-2010
0.1084	2.775	No	male		CW		USA	Galveston Bay, Texas
0.1193	2.775	No	female	6.7 - 16.3	CW		Egypt	Bardawil Lagoon/2016-2018
0.0887	2.899	No	mixed	6.3 - 16.3	CW		Egypt	Bardawil Lagoon/2016-2018
0.6825	2.931	No	female	3.6 - 7.7	CL	55	Egypt	Bardawil Lagoon, Sinai Peninsula/2015
0.7490	2.943	No	mixed		CL		Türkiye	Mediterranean Sea/2006
0.0805	2.954	No	male		CW		Brazil	Babitonga Bay, Santa Catarina/2003-2004
0.7005	2.971	No	female		CL		Türkiye	Mediterranean Sea/2006
0.5310	3.123	No	mixed	3.6 - 7.7	CL	140	Egypt	Bardawil Lagoon, Sinai Peninsula/2015
0.5433	3.133	No	male	4.4 - 7.5	CL	85	Egypt	Bardawil Lagoon, Sinai Peninsula/2015
0.3220	3.307	No	male	6.3 - 15.2	CW		Egypt	Bardawil Lagoon/2016-2018

The largest blue crab specimen are generally **caught in spring-summer** and **the smallest** specimens in **autumn-winter** as observed in populations in the Mediterranean Sea (e.g. Lesina Lagoon, Italy (Cilenti *et al.*, 2015) and Monolimni Lagoon, Agean Sea (Kevrekidis *et al.*, 2023), Trapani Saltmarshes (Marchessaux *et al.*, 2023c), Corsican lagoons (Marchessaux *et al.*, 2024c)). Local conditions are indeed crucial factors in addressing local presence of species as showed by the analysis of size spectra. **The recruitment period of juveniles** was identified between **September and November** and at the **end of winter** (Marchessaux *et al.*, 2023c). The population's growth period was identified from the end of winter to early summer. For many populations in native areas and Mediterranean Sea, it is known that *Callinectes sapidus* hibernates during the winter at temperatures **below 14°C putative critical lower thermal threshold** making local conditions unfavorable to the metabolism of *C. sapidus* (Hines *et al.*, 1987; Lipcius and Van Engel, 1990; Mancinelli *et al.*, 2013; Pereira *et al.*, 2009).

2.3.2 Sexual maturity and reproduction

American blue crabs reach sexual maturity after numerous post-larval molts (between 18 and 19 molts for males and 18 to 20 molts for females) (Van Engel, 1958). **The time required to reach sexual maturity varies according to geographic area, mainly latitude**; the warmer the water, the faster the development of the species (Churchill, 1919). As an example, sexual maturity is reached between 10 and 12 months for individuals studied in the Gulf of Mexico and up to 20 months for individuals in Chesapeake Bay (Millikin, 1984; Van Engel, 1958).

Size at sexual maturity (L_{50}) is a **good indicator in terms of species management**, particularly for invasive species, since it gives an estimate of when male and female populations are sexually mature (Hasan *et al.*, 2021). Recent studies in the Mediterranean have shown that **sexual maturity is reached differently from one area to another** (Table 2), depending in particular on environmental conditions (e.g. temperature, salinity) (Marchessaux *et al.*, 2023c, 2024c). For example, in Sicily (Italy), males were mature at 11.75 cm, while in Corsica they were mature at 16.16 cm (Biguglia Lagoon), and 14.38 cm (Palo Lagoon) (Marchessaux *et al.*, 2023c, 2024c). For females, the results are the same: in Sicily, sexual maturity was reached at 12.0 cm, while it was expected at 16.79 cm and 14.38 cm in Biguglia and Palo lagoons respectively. Differences were also noted in other areas of the Mediterranean and in its native range (Table 1).

Table 2. Comparison of the size at first maturity for *Callinectes sapidus* in the information available in the literature in native and introduced areas. Extracted from Marchessaux *et al.*, (2024c).

Country	Study site name	Native (N) / Introduced (I)	Sex	Size at maturity (cm)	References
France	Biguglia Lagoon	I	Males	16.16	(Marchessaux *et al.*, 2024c)
France	Palo Lagoon	I	Males	14.38	(Marchessaux *et al.*, 2024c)
Italy	Trapani saltmarshes	I	Males	11.75	(Marchessaux *et al.*, 2023c)
Brazil	Babitonga Bay	N	Males	8.9	(Pereira *et al.*, 2009)
USA	Sarah's Creek and Purtan Bay	N	Males	10.7	(Van Engel, 1990)
USA	Chesapeake Bay	N	Males	11.2	(Perry, 1975)
France	Biguglia Lagoon	I	Females	16.79	(Marchessaux *et al.*, 2024c)
France	Palo Lagoon	I	Females	13.86	(Marchessaux *et al.*, 2024c)
Italy	Trapani saltmarshes	I	Females	12.00	(Marchessaux *et al.*, 2023c)
Greece	Evros River	I	Females	12.39	(Kevrekidis *et al.*, 2023)
Turkey	Beymelek Lagoon	I	Females	11.85	(Sumer *et al.*, 2013)
Brazil	Lagoon-Estuarine of Iguape and Cananéia	N	Females	10.33	(Severino-Rodrigues *et al.*, 2013)
Brazil	Babitonga Bay	N	Females	10.2	(Pereira *et al.*, 2009)
USA	St. Johns River	N	Females	15-16	(Tagatz, 1968)
USA	Tampa Bay	N	Females	13.0	(Steele and Bert, 1994)
USA	-	N	Females	12.5	(Guillory and Hein, 1997)
USA	Maryland bays	N	Females	11.6	(Lycett *et al.*, 2020)
USA	Texas bay	N	Females	12.0	(Fisher, 1999)
USA	Chesapeake Bay	N	Females	14.7	(Prager *et al.*, 1990)
USA	Chesapeake Bay	N	Females	12.0	(Rugolo, 1997)
USA	Chesapeake Bay	N	Females	11.2	(Perry, 1975)

The life cycle of *Callinectes sapidus* takes place in different types of habitats: bays, lagoons and estuaries. It includes (i) population stratification, (ii) migratory activities mainly linked to genus, ontogeny and reproduction, and (iii) trophic aspects (Marchessaux *et al.*, 2023a; McClintock *et al.*, 1993; Ramach *et al.*, 2009). **Despite its preference for medium-salinity** waters, **the American blue crab has also been described in very low-salinity or even freshwaters** (Churchill, 1919). **In lagoon environments, estuaries and low-salinity regions, juveniles of both sexes predominate**. While **adult males remain in the estuary or lagoon**, **adult and ovigerous females migrate to saltier waters** (Aguilar *et al.*, 2005; Archambault *et al.*, 1990; Ortiz-Leon *et al.*, 2007; Ramach *et al.*, 2009). In summer, blue crabs are found in shallow waters, and in winter they migrate to deeper waters (Churchill, 1919).

The life cycle of *Callinectes sapidus* is divided into **two phases**: the juvenile/adult **benthic phase**, and the **planktonic** (larval) **phase** (Figure 5). American blue crab reproduction is influenced by several factors, including the salinity and temperature of the waters frequented. **Reproduction takes place in brackish water**. Males can mate several times a year, unlike females, who lay eggs only after their terminal molt. Females migrate upstream from the estuaries/lagunes where the males are located (Williams, 2004). The male carries and seems to protect the female before her terminal molt (this behavior is called "prenuptial strolling") so as to be able to mate and fertilize her as soon as she

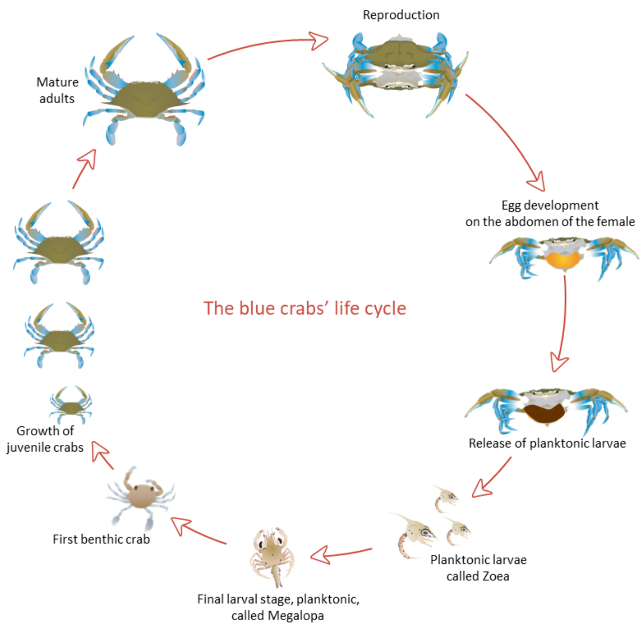


Figure 5. Schematic representation of the life cycle of *Callinectes sapidus*, figure by Guillaume Marchessaux.

has molted. As the female's carapace is still soft, fertilization can only take place during this period (Churchill, 1919). Mating can take place day or night, and lasts between 5 and 12 hours (Van Engel, 1958).

In its native area, **oviposition begins in May, with a peak** (100 % of females caught oviposit) **from June to August** (Havens and McConaugha, 1990). However, ovigerous females have been observed throughout the year in Brazil, with a peak between December and March (corresponding to the summer period in this part of the world; Severino-Rodrigues *et al.*, 2013). *Callinectes sapidus* reproduction periods vary from one area to another in the Mediterranean Sea. **Ovigerous females are generally observed between April and October,** but in certain areas ovigerous females are also observed in November and December, as is the case in the Biguglia lagoon in Corsica (France).

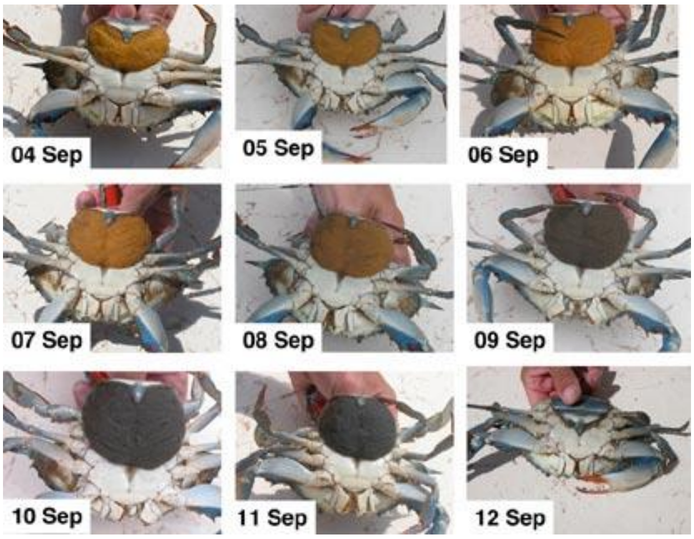


Figure 6. Photographs of ovigerous females of *Callinectes sapidus* at different stages of egg maturation. Figure taken from Hench *et al.*, (2004).

Female eggs are yellow/orange when laid, but turn brown and then black before hatching as incubation progresses (Figure 6) (Hench *et al.*, 2004). The **number of eggs per clutch ranges from 700,000 to 2,100,000 depending on female size** (Churchill, 1919; Graham and Beaven, 1942; Pyle and Cronin, 1950; Van Engel, 1958), in the Mediterranean the number of eggs appears to be equivalent (Cilenti *et al.*, 2015). At the end of eggs incubation, in their native range and in the Mediterranean Sea, fe**males migrate to the open sea or to waters with high salinity**, so that the eggs can hatch and the larvae can complete their development cycle off the coast. **Eggs hatch between 14 and 17 days after laying in water at 26°C** and between 12 and 15 days in water at 29°C (Churchill, 1919), all at a salinity of at least 20 psu (Millikin, 1984). **Larval development** can last **between 1 and 2 months**, depending on water temperature. Zoe larvae, averaging 1 mm in length, go through 7 to 8 stages before becoming megalopas. The size of the megalops is between 1 and 3 mm long (Churchill, 1919; Costlow and Bookhout, 1959). Zoe larvae need between 31 and 49 days to complete all the Zoe stages before becoming a megalops (Costlow and Bookhout, 1959).

The megalopa stage lasts several days and completes its cycle in the benthos, generally in coastal areas. Costlow and Bookhout (1959) proved, through an experimental study, that the time from metamorphosis of the megalopa stage to a juvenile crab (Figure 7) was dependent on salinity at a temperature of 25°C (between 6 and 9 days for a salinity varying between 20.1 and 26.7 psu and between 10 and 20 days for a salinity higher than 31.1 psu). A recent study characterized the larval phase of *C. sapidus* populations on the Balearic Islands in Spain (Png-Gonzalez *et al.*, 2021). Costlow and Bookhout (1959) remains the benchmark study of larval development; however, this work is based on observations in the geographical area of origin of *C. sapidus*.

Figure 7. Photography of a juvenile American blue crab, caught in Sicily (Italy). Guillaume Marchessaux.

The megalopa will then differentiate into juvenile crabs, which are considered benthic. These juveniles will tend **to camouflage themselves in seagrass beds** (e.g. Sea Grasses, *Cymodocea, Ruppia*, etc.) and/or silted up **in muddy substrates to avoid predators** (Marchessaux *et al.*, 2023a, 2023c).

Cheng *et al.* (2022) have shown that coastal vegetation and bathymetry are the main features influencing the relative abundance and distribution of adult *C. sapidus* over wide spatial scales (a few meters to several kilometers). Indeed, adult crabs seem to be found in deeper water than young individuals or juveniles; **juveniles can be found in just a few centimeters of water** (Marchessaux *et al.*, 2023c). In general, the closer to the shore, the smaller the individuals (Churchill, 1919). The various factors that can influence the distribution of the American blue crab in its native range have been studied/observed and have enabled us to highlight local distribution preferences through: the presence of sparse grass beds, depth, salinity and temperature (Cheng *et al.*, 2022; Churchill, 1919). For example, on the Virginia coast, the maximum number of observed males and females (both grained and un-grained) was found in sparse seagrass beds, corresponding to a density of 200 to 300 clusters per m² (Cheng *et al.*, 2022). A study carried out during the summer in Croatia showed that females were concentrated mainly in waters with high salinity (above 30 psu), while males seemed to prefer brackish waters between 20 and 25 psu (Jakov and Glamuzina, 2011).

As in almost all crustaceans, growth is linked to molting (Gray and Newcombe, 1938; Newcombe *et al.*, 1949). Autotomy and regeneration occur, especially in growing juveniles (Churchill, 1919). After molting, the cuticle hardens in 2 or 3 days (Churchill, 1919). Contrary to the general rule, this crab does not molt throughout its life; it has a pubertal molt which is also the terminal molt; the latter is linked to the regression of the Y organ or molting gland (Carlisle, 1957; Haefner and Shuster, 1964). Growth is rapid. During its lifetime, the crab molts around 18 (females) to 20 times (males); males grow slightly faster than females. **An average growth of 120 % per molt has been observed**, with an average intermolt duration of 16 days (Bilen and Yesilyurt, 2014). The usual lifespan does not exceed 3 or 4 years (Churchill, 1919; Van Engel, 1990, 1958); however, a lifespan of up to 5 to 8 years has also been suggested (Fischler, 1965). **The frequency of molting depends on the age of the crab and the temperature**; the higher the temperature, the more often the crab molts (Churchill, 1919). Conversely, individuals with parasites such *Loxothylacus texanus* Boschma, 1933 molt less frequently.

2.3.3 Larval connectivity

The larvae of *Callinectes sapidus* are planktonic, meaning **they are transported by ocean currents** throughout their development. Therefore, it is essential to understand the role of ocean currents in the Mediterranean to determine the larval connectivity of *C. sapidus* populations. A study showed that the larval dispersion dynamics for *C. sapidus* different **clusters of connectivity in the Mediterranean Sea** (Marchessaux *et al.*, 2023b) (Figure 8). There are several connectivity clusters in the Mediterranean:

- Balearic Islands, Spanish coasts and mainland France
- Northern Italy, Corsica, Sardinia, Sicily and Tunisia
- Morocco, Algeria, Tunisia
- Sicily, Southern Italy
- All Adriatic Sea countries
- All Aegean Sea countries
- Turkey, Cyprus to Egypt.

These clusters clearly identify the importance of collaboration between countries. The distance traveled by *C. sapidus* larvae ranged from 0 km to 600 km, with the highest frequencies observed for **distances < 100 km** (64.2%), highlighting recruitment near the release zones and emphasizing **medium-scale connectivity challenges** (Marchessaux *et al.*, 2023b).

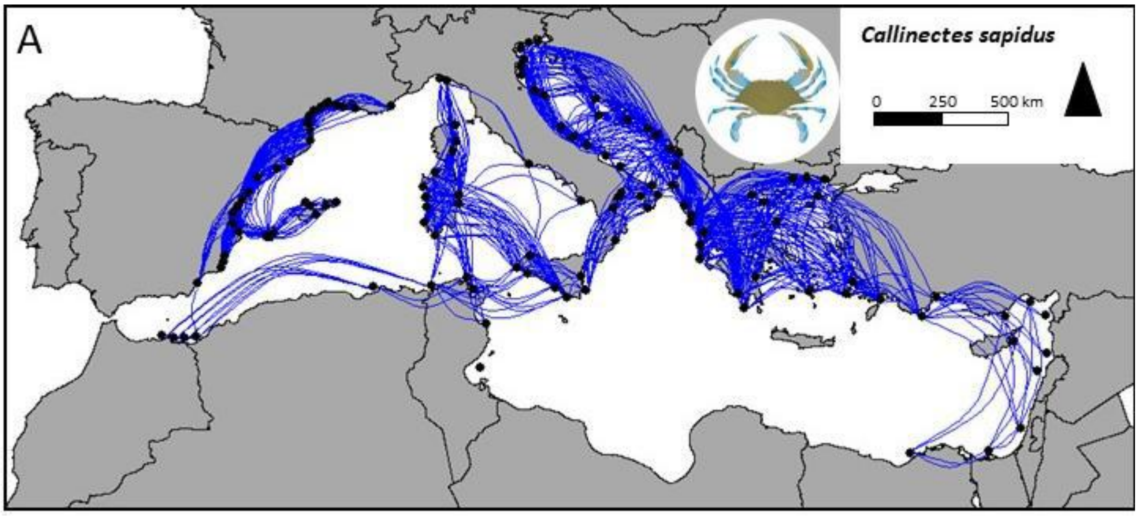


Figure 8. Clusters of larval connectivity identified in the Mediterranean Sea for *Callinectes sapidus*. Figure extracted from Marchessaux *et al.*, (2023a).

2.4 Ecology of *Callinectes sapidus*

2.4.1 Habitat

The American blue crab *Callinectes sapidus* primarily inhabits environments with **significant salinity gradients**. It is predominantly found in **estuaries and brackish lagoons** in both its native range and the Mediterranean. However, it is also often encountered at the interface of these habitats, in coastal marine zones, where it can survive at **depths of up to 35 meters**. *Callinectes sapidus* is an **active**, **aggressive** and **epibenthic omnivore** abundant in shallow habitats. Juveniles are frequently observed in shallow macroalgal fields, while larger crabs are found in deeper waters (Churchill, 1919; Epifanio *et al.*, 2003).

The American blue crab occupies diverse habitats due to its life cycle, living in different environments on **sandy or muddy substrates**, in coastal waters, lagoons, and estuaries with salicornia vegetation (Holthuis, 1987; Mancinelli *et al.*, 2013; Powers and LW, 1977). It is also **present in seagrass meadows**, which serve as critical nursery grounds for juveniles and adults (Heck and Thoman, 1984; Orth and van Montfrans, 1990). Additionally, *C. sapidus* can be found **in mangrove** ecosystems in its tropical native areas. The species is **euryhaline**, capable of surviving in waters with **salinity ranging from 0 to 65 g/L** (Marchessaux *et al.*, 2024a), and even up to 117‰ in the Laguna Madre de Tamaulipas in Mexico (Diez-García *et al.*, 2013). It is also **eurythermal**, tolerating temperatures between **3°C and 40°C** (Marchessaux *et al.*, 2022a).

2.4.2 Environmental tolerance

The invasion of *Callinectes sapidus* in Europe and the Mediterranean has demonstrated the American blue crab's ability to adapt to a wide variety of environments and habitats. This is due in part to its **tolerance to temperature and salinity**, as well as the unique characteristics of its life cycle, including reproduction in brackish waters and larval release and growth in marine environments.

One of the challenges associated with the invasion of *Callinectes sapidus* in the Mediterranean was determining its metabolic tolerance to temperature. Identifying the thermal window of the American blue crab was essential to anticipate the species' expansion and/or persistence in the Mediterranean under climate change scenarios (Marchessaux *et al.*, 2022a). Analyzing the shape of its tolerance curve, along with lethal and optimal temperatures, provided crucial insights into the environmental limits of the species.

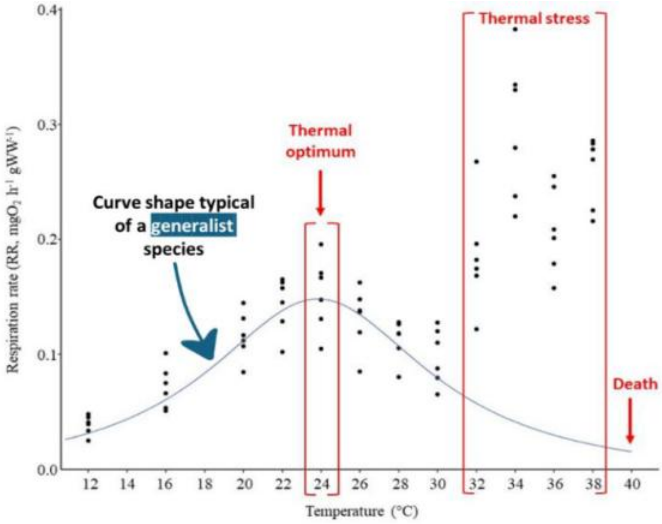


Figure 9. Thermal tolerance curve of *Callinectes sapidus.* Figure extracted and modified from scenarios Marchessaux *et al.*, (2022).

Adult *Callinectes sapidus* exhibited a broad thermal tolerance curve, characteristic of a **generalist species in terms of temperature** (Figure 9). Models estimated a minimum lethal temperature of 0°C and a maximum lethal temperature of 40°C. The species' **optimal temperature was determined at 24°C**, but *C. sapidus* tolerates a very wide temperature range, allowing it to survive under almost all seasonal conditions (Marchessaux *et al.*, 2022a).

Determining the temperature tolerance curve not only helped define the species' thermal window but also allowed researchers to map favorable thermal habitats for *C. sapidus* across the Mediterranean under current and future conditions (Figure 9).

Predictive metabolic maps revealed that the Thermal Habitat Suitability (THS) of *Callinectes sapidus* in the Mediterranean Sea varies seasonally across different sections of the basin (Figure 9).

Under future climate scenarios (IPCC RCP 4.5 optimistic and RCP 8.5 pessimistic), the monthly **THS increased by an average of +0.2**. This indicates that under both current and future conditions, *C. sapidus* will likely find favorable conditions year-round for its persistence. Consequently, the species may expand its range and maintain long-term stability in the Mediterranean. **This ability to adapt to a wide range of thermal conditions underscores the importance of monitoring *Callinectes sapidus* populations and developing management strategies to mitigate its ecological and economic impacts in invaded regions** (Marchessaux *et al.*, 2022a).

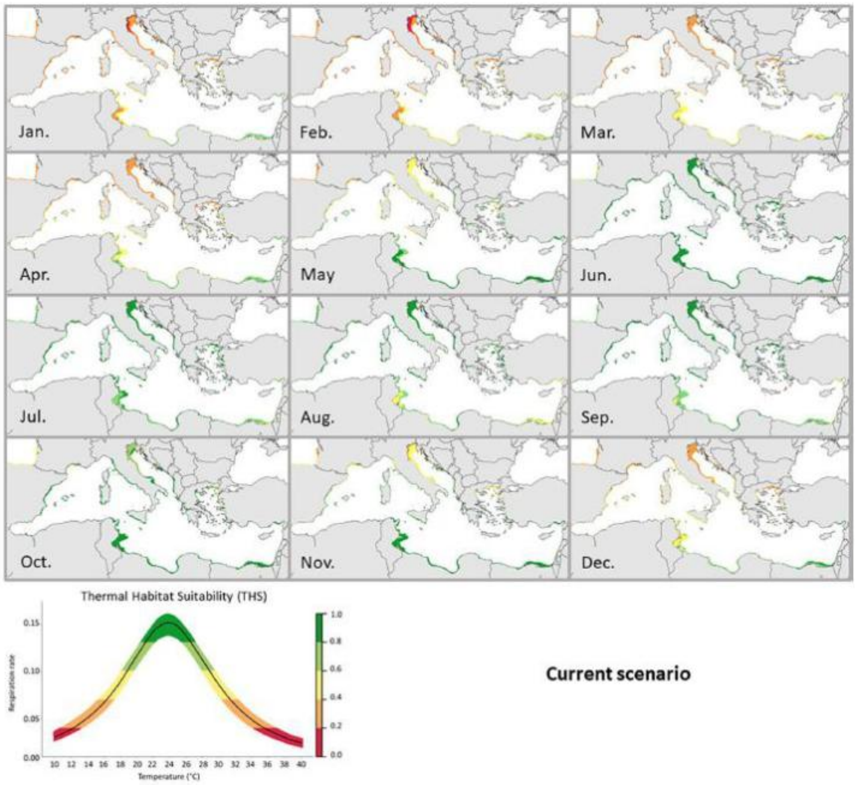


Figure 10. Distribution of thermal habitats based on the thermal tolerance curve of *Callinectes sapidus* in the Mediterranean Sea. Figure extracted from scenarios Marchessaux *et al.*, (2022).

Another **critical aspect** to consider in the study of the environmental tolerance of *C. sapidus* is its **salinity tolerance**. As previously mentioned, (Section III.3.1.), **salinity gradients play a crucial role in the species' reproduction**. To recall, males and females' mate in brackish environments near rivers, eggs mature at higher salinity levels, and planktonic larvae develop in marine environments.

A recent study explored the salinity tolerance of adult *C. sapidus* (both males and females) across a broad range of salinities (from 0 to 65 psu) (Marchessaux *et al.*, 2024a). The results indicated no significant differences between males and females, both displaying a wide range of salinity tolerance (Figure 11). **In freshwater** (salinity = 0 psu), **specimens did not survive**, with an estimated survival time of 18 hours in freshwater conditions. However, starting at a salinity of 5 psu, all specimens survived. **The optimal conditions for the American blue crab were estimated at 18.5 psu**, corresponding to brackish water. Beyond this optimum, the metabolism of *C. sapidus* decreased (Figure 11). **Mortality began to occur at salinities of 55 psu, and all specimens were dead at 65 psu.**

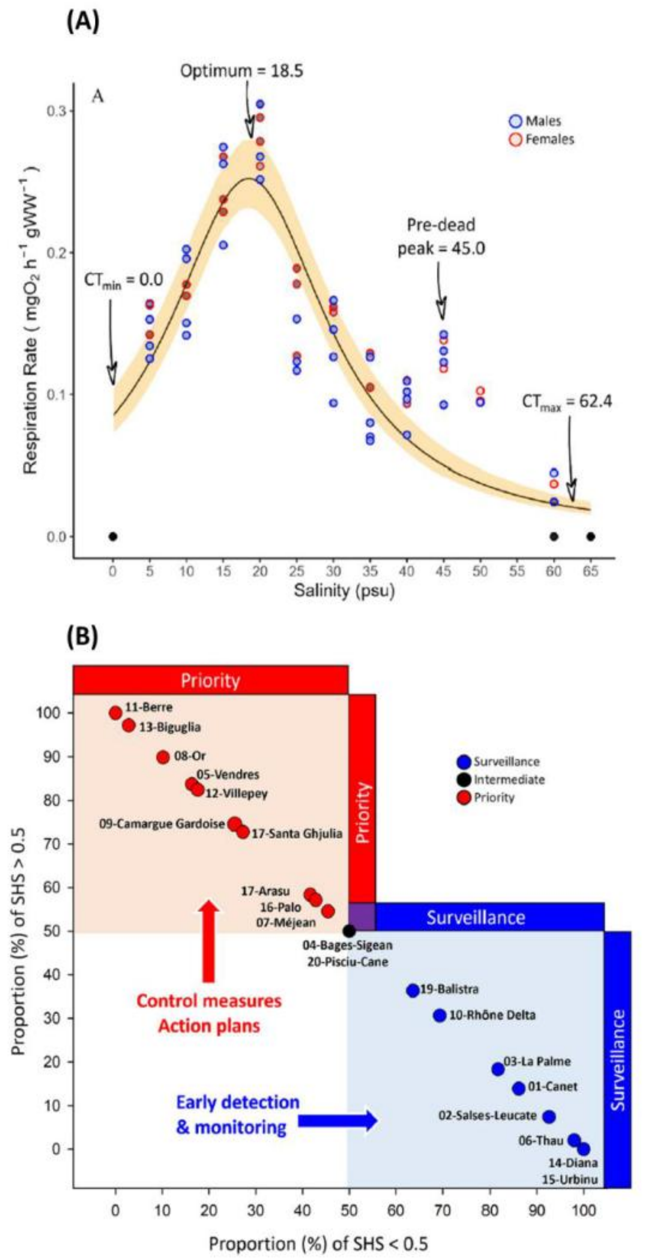


Figure 11. (A) Tolerance of *Callinectes sapidus* to various salinities, and (B) priorization plot based on habitat suitability in 20 french Mediterreanean Lagoons. Figures extracted and modified from Marchessaux *et al.*, (2024a)

This study highlighted a previously underexplored aspect of the American blue crab, the effect of salinity on its metabolism.

Similarly to temperature, the authors also mapped the distribution of salinity-related favorable habitats on a small-scale lagoon level, which are crucial environments for the species' reproduction. Mapping efforts were conducted across 20 French Mediterranean lagoons exhibiting varying levels of invasion (refer to the article for detailed maps).

Based on the mapping and available data on favorable habitats for the American blue crab, the authors proposed a prioritization index for management measures based on the species' tolerance across the 20 studied lagoons. Using this tool, the lagoons were classified into three categories: priority, intermediate, and monitoring, with specific recommendations provided for each category.

In conclusion, these two studies on the temperature and salinity tolerance of *Callinectes sapidus* have provided significant new insights into the species' biology and the anticipation of its expansion. Additionally, leveraging this data enables the development of support tools for the management and control of the species in the Mediterranean.

2.4.3 Diet and Feeding Ecology of *Callinectes sapidus*

Callinectes sapidus is an omnivorous and opportunistic predator. It is a highly aggressive crab. Its diet consists of various trophic groups, varying according to prey availability and the individual's developmental stage. Studies show that this crab primarily consumes mollusks, crustaceans, fish, decomposed organic matter, and algae.

The American blue crab is also necrophagous and cannibalistic (Peery, 1989) competing with other crabs, including *Callinectes similis*, *C. ornatus*, *Panopeus herbstii*, *Menippe mercenaria*, and *Carcinus maenas* (Gennaio *et al.*, 2006).

The diet of the American blue crab, adapted to a wide variety of trophic resources, is a key factor in its success as an invasive species:

- **Mollusks |** Mollusks, especially bivalves and gastropods, constitute a significant portion of *C. sapidus*' diet. In the Mediterranean, mussels (*Mytilus galloprovincialis*), clams (*Ruditapes decussatus*), and wedge shells (*Donax trunculus*) are frequently predated (Mancinelli *et al.*, 2016). Predation on another invasive mollusk *Rapana venosa* was also reported (Harding, 2003). These prey items are often abundant in the lagoonal and estuarine habitats where the blue crab lives.
- **Crustaceans |** Crustaceans, including small decapods and amphipods, also represent a significant component of the diet of *C. sapidus* (Seitz *et al.*, 2011). The crab is known for its cannibalistic behaviors, a phenomenon documented both in its native range and in the Mediterranean (Dittel *et al.*, 2006).
- **Fish |** *Callinectes sapidus* preys on fish in particular in the fishers' nets.
- **Plant Matter and Detritus |** In addition to living organisms, the blue crab consumes decomposed organic matter and algae (Annabi *et al.*, 2018; Aslan and Polito, 2021; Seitz *et al.*, 2011). This behavior allows it to survive in environments where animal prey is scarce (Davie, 2021; Lee *et al.*, 2021). Algae from the genus *Ulva sp.* and grasses from the genus *Spartina sp.* (Gennaio *et al.*, 2006).
- **Cannibalism |** The American blue crab is also known for its cannibalistic behavior. Cannibalism can account for up to 13% of the species' diet (*bluecrab.info*; (Peery, 1989). Individuals most likely to be consumed by their peers are those that are: (i) in poor health, (ii) missing significant appendages, (iii) molting or immediately post-molt, and (iv) heavily fouled by other organisms (*bluecrab.info*).
- **Jellyfish |** Predation on the hydromedusa *Gonionemus vertens* (Carman *et al.*, 2017) living in seagrasses was recorded.

In their native range, the diet composition of blue crabs generally consists of **mollusks** (from 30 % to 40 %; mussels, clams, oysters), from 15 % to 20 % of **crustaceans** (decapods, amphipods), 15–20 % of **fishes**, <5 % of **polychaetes**, and a highly variable percentage of **algae**, **sediment**, and **detritus** (Belgrad and Griffen, 2016).

Adaptability and Feeding Ecology in the Mediterranean

There is still limited information available on the trophic characteristics of the crab in the Mediterranean. However, *C. sapidus* appears to compete with native crab and fish species, potentially causing significant ecological impacts (Labrune *et al.*, 2019; Nehring, 2011). The establishment of *C. sapidus* in the Mediterranean is **largely tied to its opportunistic feeding habits**. Its ability to exploit a wide variety of trophic resources, combined with its tolerance for salinity and temperature variations, supports its invasion of coastal ecosystems (Nehring, 2011). In the Mediterranean Sea, *C. sapidus* was identified as a fully carnivorous predator and share the same set of trophic resources with these benthivores fish species in Croatia (Mancinelli *et al.*, 2016). Due to the aggressiveness and omnivorous diet, the impact of blue crabs species (like *C. sapidus*) is important especially on the commercial species witch are decreasing (Öndes and Gökçe, 2021) as perceived by the artisanal small-scale fishermen in this present study.

In Mediterranean lagoons such as the Berre Lagoon and the Po Delta, studies have shown that *C. sapidus* exerts significant **predatory pressure on local species**. This **includes economically important species** such as **oysters** (*Crassostrea gigas*) and **clams** (Aslan and Polito, 2021; Kara and Chaoui, 2021; Longmire *et al.*, 2021). These trophic interactions have **major ecological consequences**, including increased competition with native predators and disruptions to local food webs.

The study by Clavero *et al.* (2022) demonstrated that ecosystems dominated by *C. sapidus* **cause decrease and consistent declines in several species**, including those that are threatened or commercially exploited (Figure 12). The impacts of the blue crab seem to manifest even at low abundances, likely hindering the recovery of declining species. The blue crab is becoming a keystone species in invaded systems.

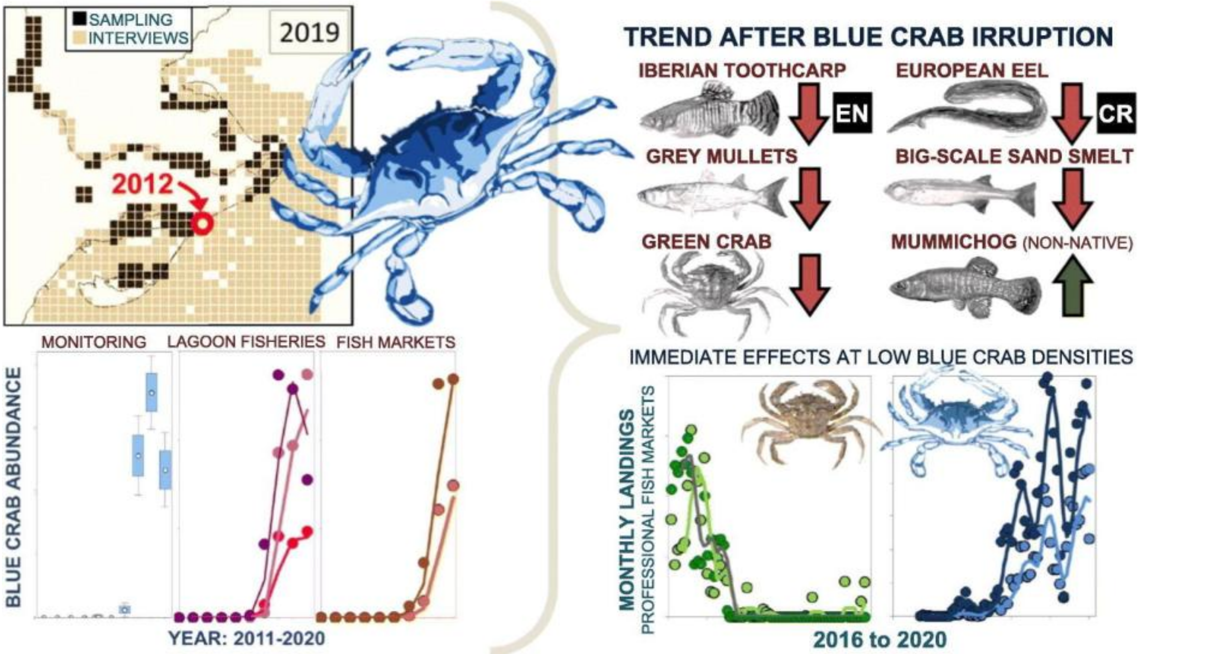


Figure 12. Summary of impacts of *Callinectes sapidus* on Mediterranean biodiversity (Spain). Figure extracted from Clavero *et al.* (2022).

The dietary diversity of *Callinectes sapidus* **causes significant impacts on Mediterranean biodiversity**, with local species extinctions observed in areas invaded by *Callinectes sapidus*. In Spain for example the increase in *C. sapidus* abundances has caused a decline in apple snail stocks in the Elbro delta (Céspedes et al., 2024). In the Po Delta (Italy), the explosion of populations of *C. sapidus* in summer 2023 has caused the drastic decline of clams up to 100%, clam shells showing signs of blue crab predation up to 56%, and the absence of seed in natural recruitment areas (Chiesa et al., 2025).

Predators of *Callinectes sapidus*

The predators of the American blue crab (*Callinectes sapidus*) in its native range are well-documented and numerous. They include:

- **Starfish**: For example, the Forbes Sea star (*Asterias forbesi*) (Auster and DeGoursey, 1994).
- **Marine Turtles**: Such as the olive ridley sea turtle (*Lepidochelys olivacea*) (Wildermann and Barrios-Garrido, 2012).
- **Fish**: Including the red drum (*Sciaenops ocellatus*), the Atlantic croaker (*Micropogonias undulatus*) (Overstreet and Heard, 1978), the black drum (*Pogonias cromis*), and the American eel (*Anguilla*

rostrata) (Jaworski, 1972). An observation of predation of *Dicentrachus labrax* on juveniles of *C. sapidus* was recorded in Corsica by fishermen (pers. Com.)

- Seabirds: Including the herring gull (*Larus argentatus*) (Kent, 1981), the double-crested cormorant (*Phalacrocorax auritus*), and various heron species (Kent, 1986).
- Other Crabs: The green crab (*Carcinus maenas*) is known to dominate *C. sapidus* in direct competition at equal size (MacDonald *et al.*, 2007; Seed, 1980).
- Cephalopods: Potential predators that can include squids and octopuses. In the Mediterranean, few studies have been conducted on the predators of the American blue crab. However, a recent study (Prado *et al.*, 2024) demonstrated that Mediterranean octopuses are capable of consuming *Callinectes sapidus* in aquariums (Figure 13). These observations were further corroborated in Corsica at the end of 2024, where underwater photographers documented octopuses preying on blue crabs.

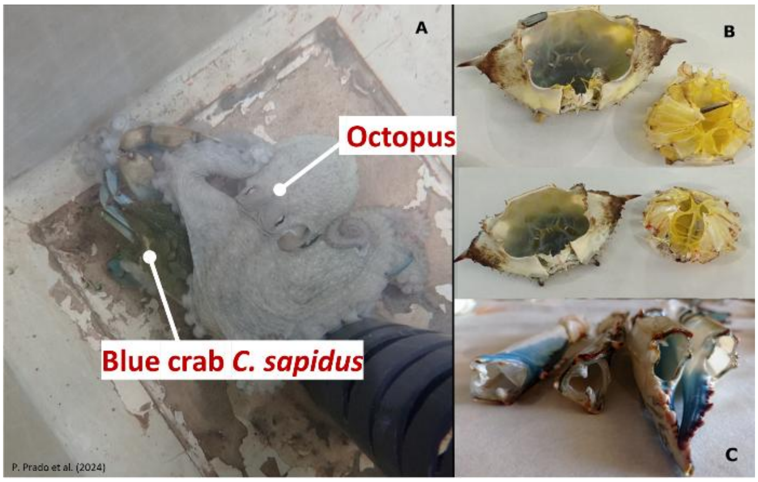
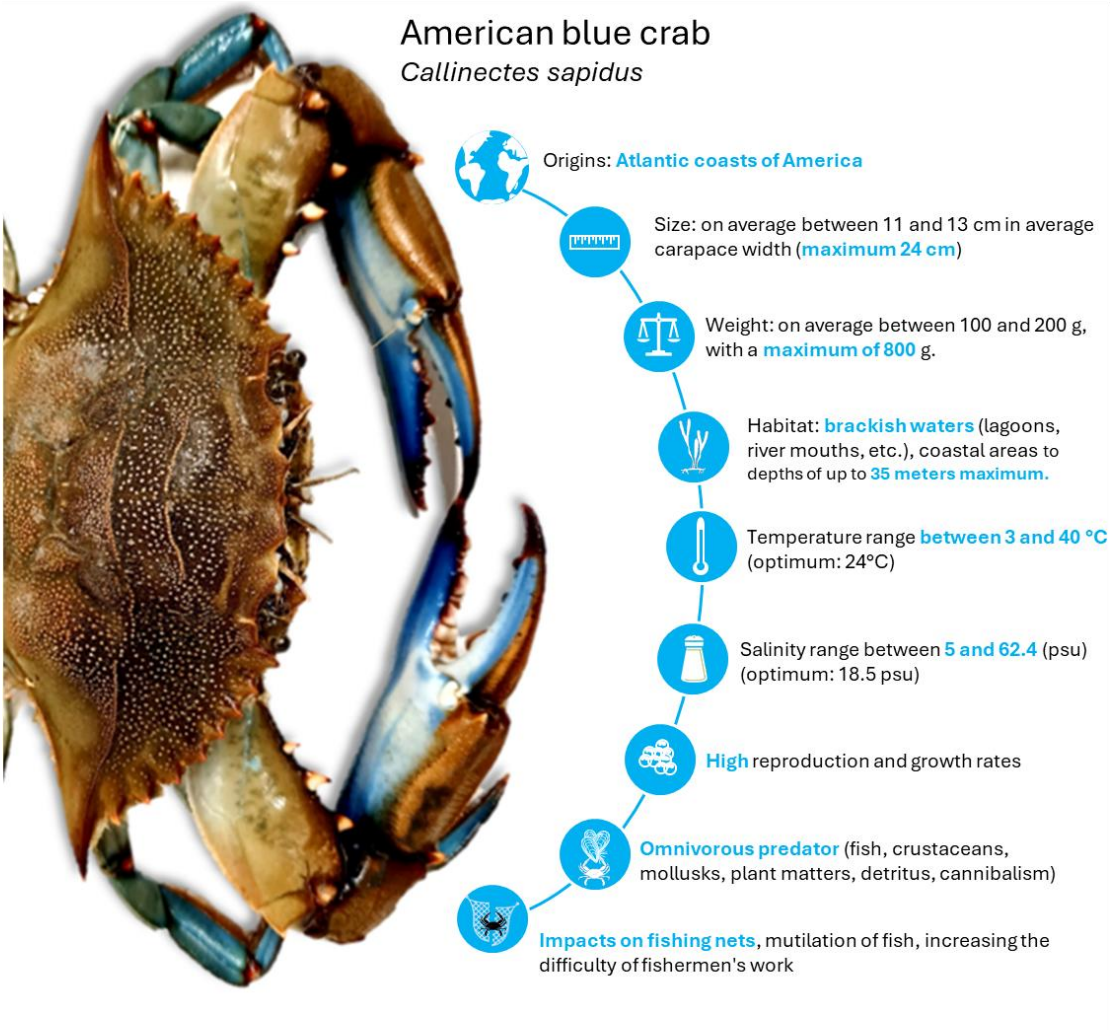


Figure 13. Pictures of a Mediterranean octopus feeding on *Callinectes sapidus*. Pictures extracted and modified from Prado *et al.*, (2024).

- Cannibalism: Particularly on juvenile stages, is well-documented (Hines and Ruiz, 1995; Peery, 1989).

2.5 Summary of information on *Callinectes sapidus*



3 Current knowledge of the swimming blue crab *Portunus segnis*

3.1 General characteristics of the species

The blue swimming *Portunus segnis* (Forskål, 1775) crab is generally recognizable by its oval carapace, which is twice as wide as it is long (Figure 14). The carapace surface is rough to finely granular, with 9 marginal spines or spines symmetrically arranged along each side of the anterior lateral edge, and a more pronounced median spine known as the frontal spine. The other legs are laterally flattened, with the last two segments of the posterior pair shaped like paddles for swimming.

Male coloration is dark blue with subtle white spots on the carapace, sometimes merging into a network of fine lines. **Females have similar coloration, but their claws are red instead of blue, with spots on the posterior third of the carapace** (Figure 15). Males are generally larger and more colorful than females, with bright blue legs and claws.

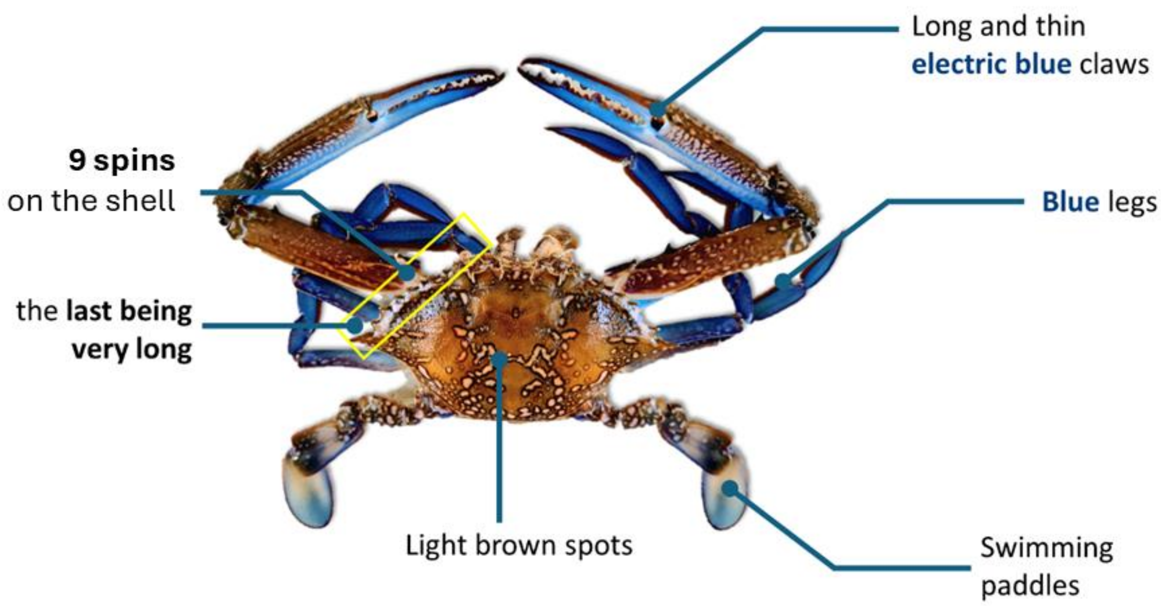


Figure 14. Morphological characteristics of the Swimming blue crab *Portunus segnis*. Photography: Guillaume Marchessaux.

Although females tend to have red claw tips, the difference between males and females is identifiable on the ventral side of the abdomen (Figure 15). In **males**, the **abdomen is triangular**, **T-shaped** and tapered with only 3 segments. In females, the abdomen is wider and rounded, with several segments. In **females**, the shape of the abdomen is a **key indicator for differentiating mature from immature females**. In **immature females,** the **abdomen is triangular**, **narrow** and **pointed**, and **fused with the plastron** (underside of the carapace). In **mature females**, the abdomen is **rounded or broadly dome-shaped**, often **compared to a horseshoe**. The abdomen is wider and more pronounced to accommodate eggs during reproduction (egg sac or sponge). These differences are linked to the morphological evolution of females as they reach sexual maturity, a change essential to their reproductive role.

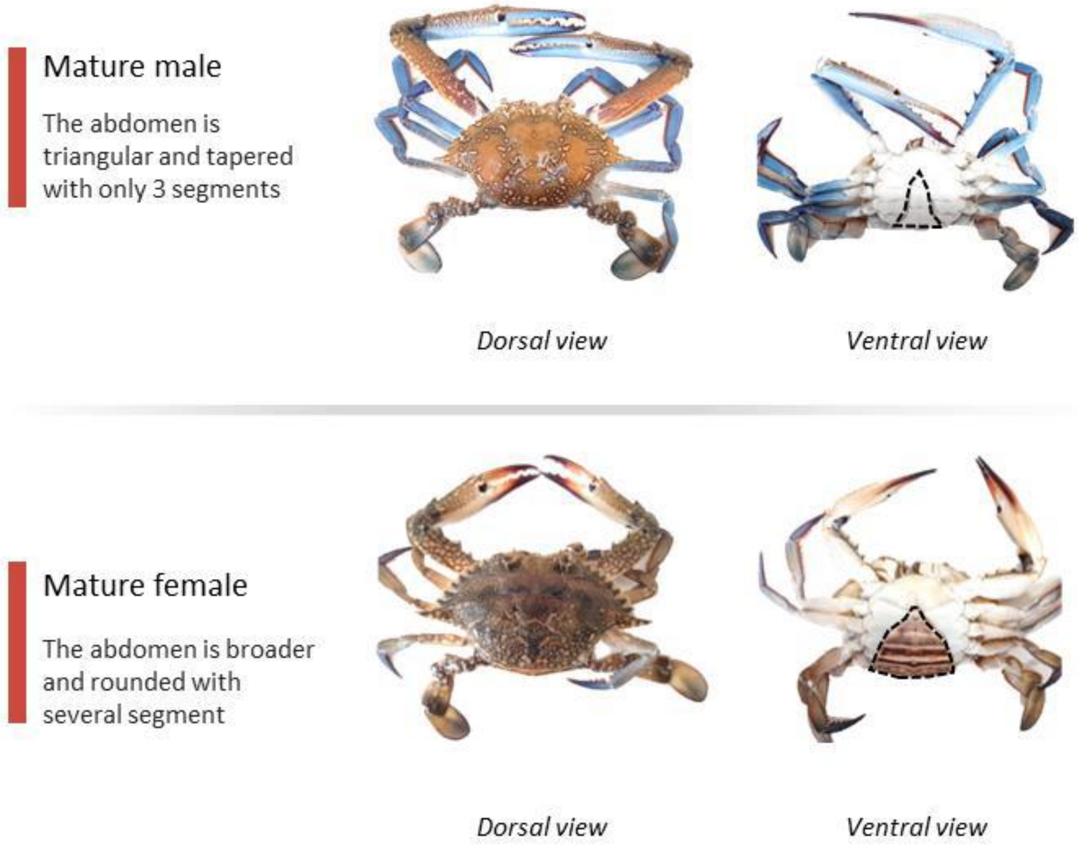


Figure 15. Morphological characteristics of males and females of the blue crab *Portunus segnis*. Photography: Guillaume Marchessaux for males, Jamila Ben Souissi for females.

3.2 Distribution and invasion history

Portunus segnis is **native to the western Indian Ocean**, west of the Indian subcontinent, including the East African coast, the Red Sea, the Arabian Gulf, and the Gulf of Oman. *Portunus segnis* is **one of the first Lessepsian species reported in the Mediterranean** (Fox, 1924; Lai *et al.*, 2010). Initially, *P. segnis* was incorrectly described as *Portunus pelagicus* (Linnaeus, 1758). According to Lai *et al.* (2010), morphological, genetic, and biogeographical studies have identified four distinct species: *Portunus pelagicus* (Linnaeus, 1758), *Portunus reticulatus* (Herbst, 1799), *Portunus armatus* (Milne-Edwards, 1861), and *Portunus segnis* (Forskål, 1775). Some authors refer to these species collectively as the "Portunus complex." In fact, interspecific hybridizations within the *Portunus* genus are frequently observed.

As early as 1898, just a few years after the opening of the Suez Canal, *P. segnis* was reported almost everywhere in the Mediterranean. In Tunisia, it was first observed in the Gulf of Gabès (Rabaoui *et al.*, 2015; Rifi *et al.*, 2014) and more recently in the southern Gulf of Hammamet (Bdioui, 2016). The species was certainly present in southern Tunisia before 2014. In fact, a sample of *Portunus sp.* (incorrectly identified as another genus) was preserved in formalin in the INSTM crab collection, with records dating back to the 1990s. This aligns with the conclusions proposed by Lai *et al.* (2010) regarding interspecific hybridizations within the *Portunus* genus.

After its first report in Egypt in 1898 (Castriota *et al.*, 2022), *P. segnis* was gradually documented in various areas of the Mediterranean, extending from the Levantine Basin to the **eastern Aegean Sea, eastern Sicily, and the northern Tyrrhenian Sea** (Figure 16). The species is known from Cyprus, Egypt, Syria, Palestine, Israel, Turkey, Tunisia, Lebanon, Italy, Greece, and Albania. In 2023, it **has also been reported along the Adriatic coasts** of Italy (Grati *et al.*, 2023) and in **Spain** (Gulf of Cadiz) (de Carvalho-Souza *et al.*, 2023).

Portunus segnis likely entered the Mediterranean via the Suez Canal. The study by Castriota *et al.* (2022) identified **significant hotspots in Tunisia** (Gulf of Gabès) and **in the Eastern Mediterranean** (from Egypt to southern Turkey). Furthermore, Castriota *et al.* (2022) showed that the invasion of *P. segnis* in the Mediterranean, which has been ongoing for a long time, is **currently considered to be expanding**.

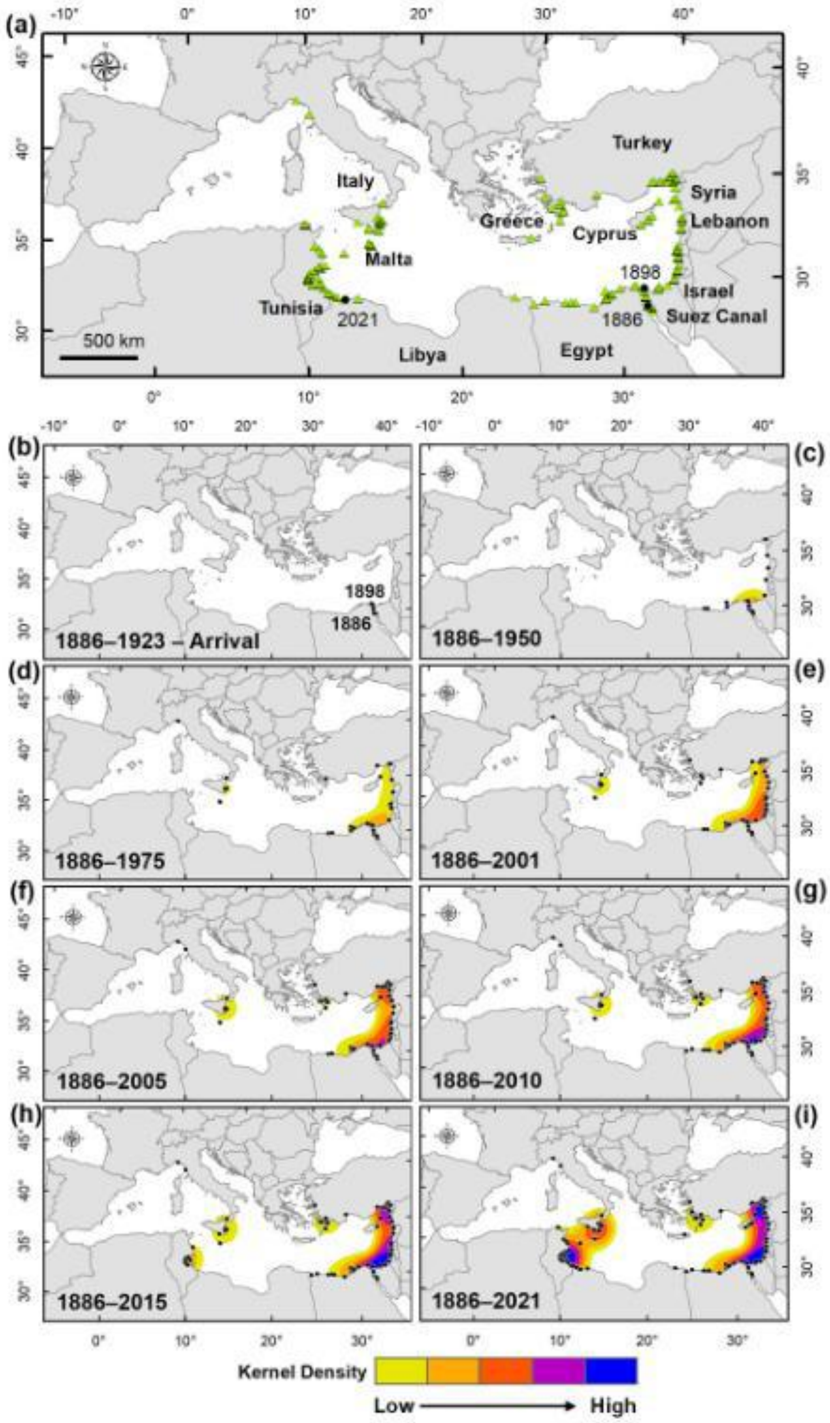


Figure 16. Distribution of *Portunus segnis* in the Mediterranean Sea and history of invasion. Figure extracted from Castriota *et al.* (2022).

3.3 Population dynamics and life cycle of *Portunus segnis*

3.3.1 Population dynamics and size spectra

The populations of *Portunus segnis* are **generally dominated by adults during the winter and spring months**, while **juveniles are more abundant in summer and autumn**. This reflects a seasonal dynamic where reproduction and recruitment strongly influence size composition (Mohsen Safaie *et al.*, 2013; Safaie *et al.*, 2015).

Carapace widths typically range between 38 and 168 mm. Adults (> 100 mm) predominate in winter and spring, while smaller size classes (< 100 mm) increase in summer (Safaie *et al.*, 2015). **The average size at sexual maturity is between 115 and 120 mm** carapace width for females and between 113 and 125 mm for males, depending on the region (Tureli and Yesilyurt, 2017).

The growth pattern follows an allometric relationship, with von Bertalanffy parameters indicating rapid growth rates in the warm, saline waters of the Mediterranean (Yeşilyurt *et al.*, 2022). This observed allometry generally shows faster growth in males. This allometric difference reflects distinct energy strategies between the sexes (O. B. A. H. Hamida *et al.*, 2019). As observed for *Callinectes sapidus*, **each *P. segnis* population is unique**, and **size-weight relationships vary from one area to another**, primarily due to environmental conditions (e.g., temperature, salinity) that influence these relationships. Table 3 highlights the differences in size-weight relationship coefficients reported in the literature, showing significant variations between males and females as well as between sites. The allometric relationships differ across regions, influenced by environmental parameters such as temperature and salinity, as well as prey availability, for instance.

Table 3. Allometric parameters of *Portunus segnis.* Source: https://www.sealifebase.se

a	b	Doubtful?	Sex	Length (cm)	Length type	No.	Country	Locality
0.0062	2.443	No	female	7.0 - 16.5	CW		Iran	Persian Gulf/2011-2012
1.6873	2.511	No	female	5.1 - 7.2	CL	24	Tunisia	Gulf of Gabes
0.1108	2.743	No	female	3.4 - 14.9	CW	299	Tunisia	Gulf of Gabes/2015-2016
0.6418	2.904	No	female	1.8 - 7.5	CL	299	Tunisia	Gulf of Gabes/2015-2016
0.0735	2.980	No	mixed	3.4 - 15.6	CW	634	Tunisia	Gulf of Gabes/2015-2016
0.5268	3.023	No	mixed	1.8 - 7.9	CL	634	Tunisia	Gulf of Gabes/2015-2016
0.0643	3.030	No	female	8.5 - 16.3	CW	154	Iran	Bandar Abbas/2012-2013
0.0587	3.033	No	male	4.0 - 8.0	CL		Iran	Persian Gulf/2011-2012
0.5849	3.068	No	male	2.0 - 7.9	CL	335	Tunisia	Gulf of Gabes/2015-2016
0.0558	3.144	No	male	3.9 - 15.6	CW	335	Tunisia	Gulf of Gabes/2015-2016
0.0491	3.214	No	male		CW	1839	Iran	Persian Gulf and Gulf of Oman/2010-2011
0.0341	3.232	No	mixed		CW	3608	Iran	Persian Gulf and Gulf of Oman/2010-2011
0.0199	3.299	No	female		CW	1769	Iran	Persian Gulf and Gulf of Oman/2010-2011
0.0240	3.380	No	female	11.8 - 15.6	CW	24	Tunisia	Gulf of Gabes
0.0074	3.443	No	female	3.5 - 8.0	CL		Iran	Persian Gulf/2011-2012
0.0254	3.450	No	male	8.1 - 14.9	CW	148	Iran	Bandar Abbas/2012-2013
0.2306	3.552	No	male	7.5 - 17.5	CW		Iran	Persian Gulf/2011-2012

***Portunus segnis* prefers shallow areas (< 10 m) with high biomass and density**. The catch per unit effort (CPUE) is **highest in October**, **making this month the optimal period for fishing**. Biomass shows an increasing trend from June to October, reflecting seasonal recruitment and rapid growth. Adult crabs contribute the most to the total biomass (Safaie *et al.*, 2015).

3.3.2 Sexual maturity and reproduction

The life cycle of the blue swimming crab *Portunus segnis*, includes several characteristic stages typical of brachyuran crustaceans. **Its life cycle is therefore similar to that of *Callinectes sapidus*** (described in section II.3.2.). The primary difference between the two species is that ***Portunus segnis* mates and reproduces in marine environments**, whereas *Callinectes sapidus* mates in brackish waters.

In *Portunus segnis*, **adults reach sexual maturity at approximately 93 mm carapace width** (Hadj Hamida *et al.*, 2022). **Males and females mate after the female's molt** (pre-copulatory molt). The male transfers spermatophores into the female's spermathecae. Fertilized females lay eggs, which they carry on their abdomen in the form of an egg mass. A single female can carry between **142,000 and 2.6 million eggs**, depending on her size (Hadj Hamida *et al.*, 2022). In its native range, the Persian Gulf and the Gulf of Oman, ovigerous females are present year-round, with the highest proportion observed in autumn; spawning occurs throughout the year, peaking in winter (Kamrani *et al.*, 2010; Safaie *et al.*, 2013). Interestingly, two regional studies provide different data on fecundity: between **277,421 and 1,114,348 eggs, with an average fecundity of 662,978 eggs** (Kamrani *et al.*, 2010), and between 521,027 and 6,656,599 eggs, with an average fecundity of **2,397,967 eggs** (Safaie *et al.*, 2013). In the Mediterranean, the average number of eggs (fecundity) observed in 12 ovigerous females (with an average carapace width of 143.3 ± 6.2 mm) was 777,642 ± 80,684 (Rabaoui *et al.*, 2015).

The eggs change color as they develop, transitioning from yellow-orange (immature eggs) to dark brown just before hatching (Figure 17). In *Portunus segnis*, development takes approximately 10 to 15 days, depending on the water temperature.

Figure 17. Photographs of ovigerous females of *Portunus segnis* at different stages of egg maturation. Figure taken from (Safaie *et al.*, 2013).

After hatching, the larvae go through several stages:

- **Zoea**: Zoea larvae feed on plankton. They have a distinct carapace with long dorsal and lateral spines. Growth occurs through several molts.
- **Megalopa**: This is an intermediate stage between larva and juvenile, where the larvae begin to resemble crabs. They migrate to shallow coastal areas, often in seagrass meadows or muddy bottoms, to undergo metamorphosis.

The blue swimming crab can reproduce multiple times a year, with spawning peaks varying by region. For example**, in the Gulf of Gabès (Tunisia),** three main spawning periods have been identified: **May, July, and October-November** (Hadj Hamida *et al.*, 2022).

3.3.3 Larval connectivity

Portunus segnis showed little dispersion and variability regardless of the simulation time (Figure 18) (Marchessaux *et al.*, 2023b). ***Portunus segnis*** **is less widely distributed than** ***Callinectes sapidus*** **in the Mediterranean**, resulting in fewer connectivity clusters. Currently, **two major clusters** are identified: one **between Sicily and Tunisia**, and another in the **Eastern Mediterranean**, **spanning from Turkey to Egyp**t. Additionally, a smaller cluster exists in southern Turkey, connecting populations from mainland Turkey to the islands. The highest frequencies of distances traveled by *Portunus segnis* **larvae were observed for distances <100 km** (63.6%), highlighting recruitment near release areas and indicating a **medium-scale dispersal** challenge (Marchessaux *et al.*, 2023b).

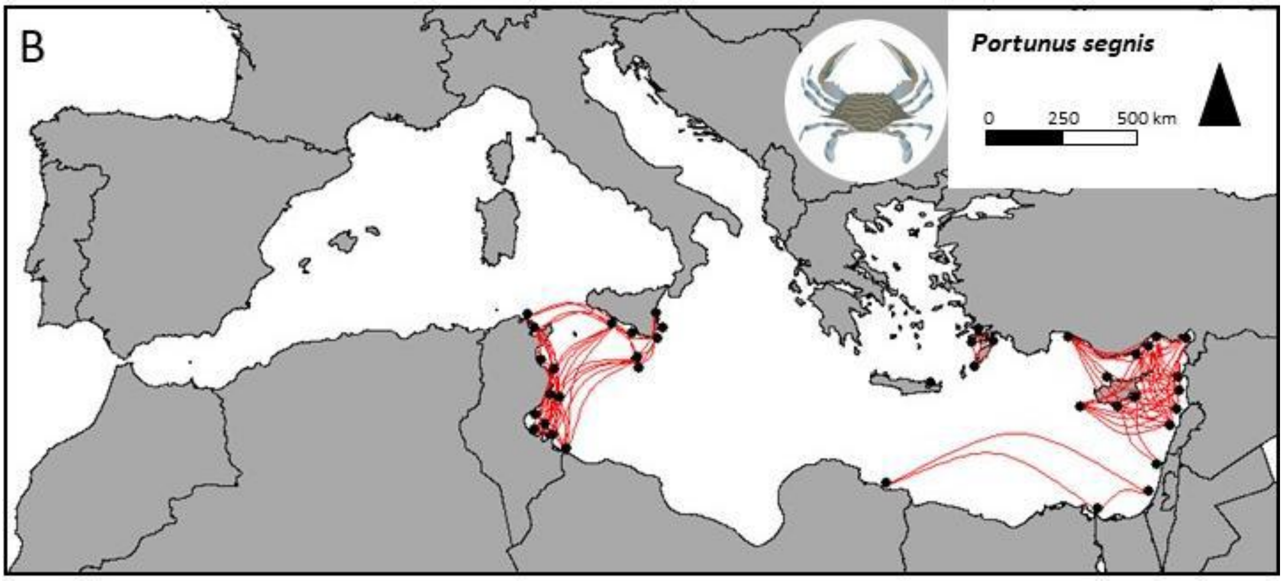


Figure 18. Clusters of larval connectivity identified in the Mediterranean Sea for *Portunus segnis.* Figure extracted from Marchessaux *et al.*, (2023a).

3.4 Ecology of *Portunus segnis*

3.4.1 Habitat

The blue swimming crab inhabits **coastal areas**, **ranging from rocky or stony intertidal zones to depths of up to 65 meters** (Naderloo and Tuerkay, 2012), primarily on sandy and muddy substrates near reefs, in mangroves, seagrass beds, and algal mats. It is an **active nocturnal predator**, **buried during the day** with only its eyes, antennae, and gill openings visible. When disturbed, it burrows into the sand but is a **fast swimmer** and an **opportunistic predator**, primarily carnivorous, voraciously feeding on a variety of benthic animals and to a lesser extent on marine plants and seagrasses. Juveniles tend to remain in shallow intertidal zones.

3.4.2 Environmental tolerance

Portunus segnis is **euryhaline** (adaptable to a wide range of salinities), moving between brackish estuaries, marine environments, and even hypersaline waters (e.g., the Bitter Lakes, Suez Canal). In Tunisia, for instance, the blue swimming crab is observed in the Bizerte Lagoon, a brackish lagoon. It appears that *Portunus segnis* tolerates salinity ranges between 20 and 33 psu.

Regarding the temperature tolerance of *Portunus segnis*, a recent study showed that the species is a **tropical specialist** (Marchessaux *et al.*, 2024c). Its invasive success in the Mediterranean is explained from its physiological plasticity and ability to adapt to global temperatures.

Portunus segnis thermal tolerance discloses a **thermal optimum at 33.64°C, CT_{min} at 11.33∘C, and CT_{max} at 41.13°C**, and contributing to understanding its distribution dynamics in response to temperature changes.

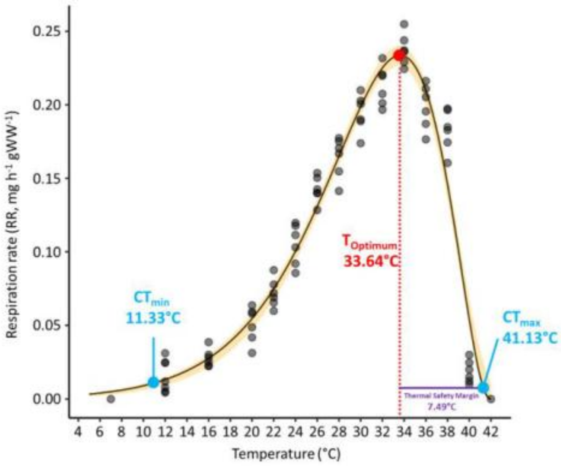


Figure 19. Thermal Performance Curve (TPC) of the Red Sea swimming blue crab *Portunus segnis.* Figure and legend extracted from (Marchessaux *et al.*, 2024c)

The Thermal Habitat Suitability (THS) probability of *P. segnis*, based on its thermal performance, revealed a North-South division in Mediterranean Sea thermal habitats (Figure 20) (Marchessaux *et al.*, 2024c). Throughout winter and early spring (January to May), THS were unfavorable (THS < 0.2) across the Mediterranean. However, in summer-autumn (June to October), particularly in the Gulf of Gabès, Tunisia, southern Mediterranean coasts became suitable (THS > 0.6).

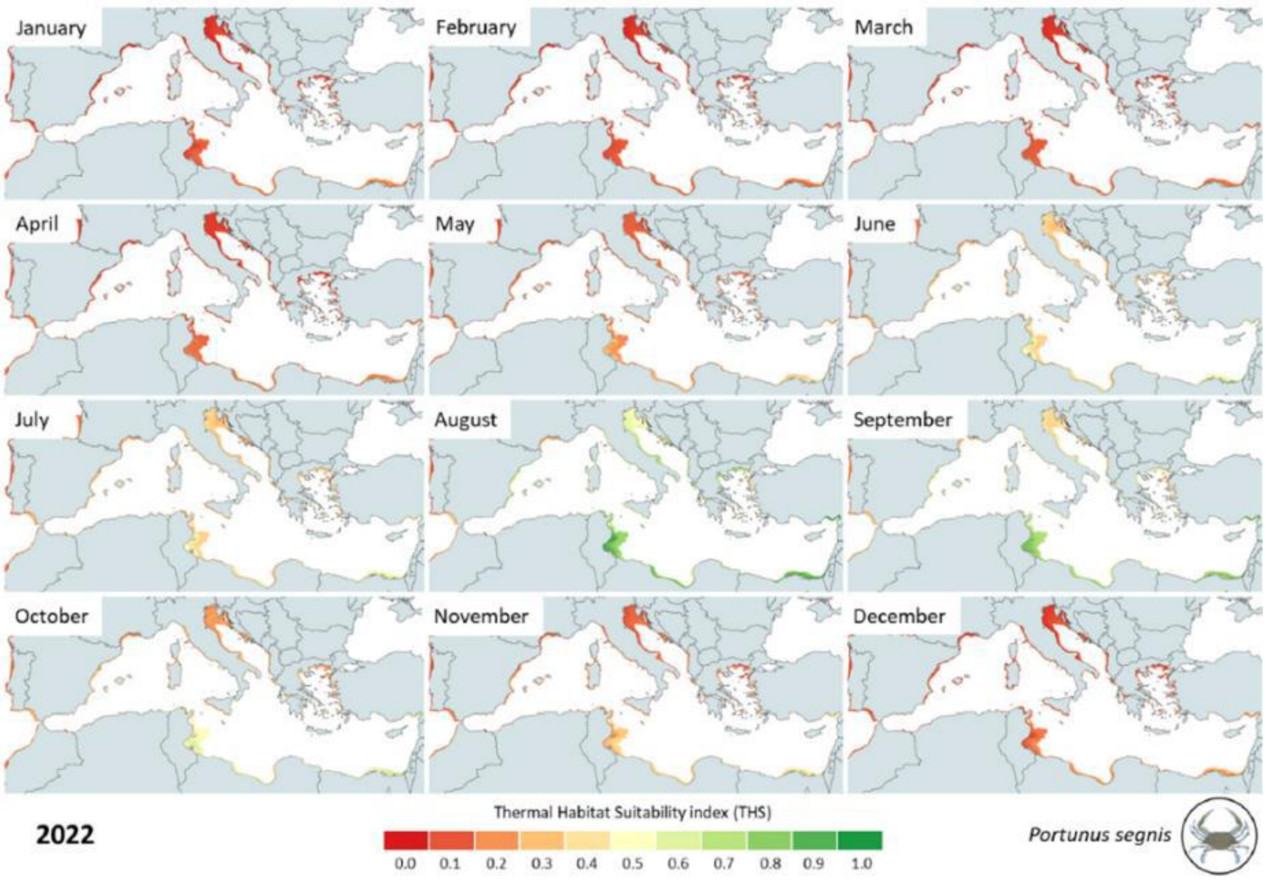


Figure 20. Current predicted Thermal Habitat Suitability (THS) of *Portunus segnis* in the Mediterranean Sea based on the species metabolic performance. THS values at 0 = not favorable; and THS at 1 = favorable). Different colors (representing the species THS) would correspond to: optimum temperature range (THS > 0.8; green colored), lower and upper *pejus* ranges (0.5 < THS < 0.8; light green and yellow colored), *pessimum* (0.2 < THS < 0.5; orange colored), and lethal ranges (THS < 0.2; red colored). Figure and legends extracted from Marchessaux *et al.*, (2024c).

During summer (June to September), all southern Mediterranean coasts provided favorable thermal habitats. In the North, THS were favorable along Spanish, Tyrrhenian and Adriatic Italian coasts to Greek Aegean coasts. For both future scenarios, an increase of THS was observed earlier in the year in the North-Western Mediterranean (Marchessaux *et al.*, 2024c).

The change in Thermal Habitat Suitability (THS) probability between the 2050 RCP 4.5 scenario and the situation in 2022 varied across countries. In the Eastern Mediterranean (Israel, Egypt, Lebanon, Syria), THS was negative, indicating a decrease. Tunisia and Cyprus showed stability (THS ~ 1) with minor changes. Increases in THS were observed in Greece, Malta, and Italy. At the Mediterranean Sea level, 2050 RCP 4.5 showed-0.7 ± 8.9 %, contrasting with +0.1 ± 8.7 % for the 2050 RCP 8.5 scenario. In 2050 RCP 8.5, Cyprus, Italy, and Malta decreased in THS, while Syria, Greece, Turkey, Lebanon, Tunisia stabilized. Egypt, Libya, and Israel had positive THS changes for this scenario (Marchessaux *et al.*, 2024c). Generally, **at the Mediterranean Sea level, the species distribution will increase.**

3.4.3 Diet and feeding ecology of *Portunus segnis*

The blue swimming crab is **carnivorous, scavenging, and a voracious predator** that can compete with local fauna. *Portunus segnis* is an **opportunistic omnivore**, with **dietary variations depending on seasons, developmental stages, and habitats.** This species demonstrates **ecological flexibility**, which significantly contributes to its invasion success. The main dietary categories consumed include:

- **Crustaceans** including shrimps, crabs and benthic copepods (Hosseini *et al.*, 2014). Crustaceans**, such as shrimp and other crab species** (Hosseini *et al.*, 2014), **dominate its diet throughout the year**, representing more than 65% of stomach contents (Hamida *et al.*, 2019; Hosseini *et al.*, 2014).
- **Fish**, although less frequent in the diets of juveniles, become an important component as the crab reaches adulthood.
- **Mollusks** like *Cardita bicolor, Cerithium erythraeonense, Circenita callipyga, Marcia hiantina* (Hosseini *et al.*, 2014)). Primarily bivalves such as *Tellina sp.* and *Cardita bicolor*, as well as gastropods like *Cerithium erythraeonese*, are also common prey, particularly during winter and spring (Hamida *et al.*, 2019).
- **Polychaetes** (Zainal, 2013).
- **Unidentified organic matter and detritus** (Zainal, 2013).

Studies have also revealed **significant seasonal variations in the diet of *Portunus segnis***. For instance, **crustaceans dominate during the summer**, **while mollusks and fish become more prevalent in stomach contents during autumn and winter**, respectively, due to changes in prey availability. According to studies of stomach contents, juvenile crabs (< 90 mm CW) prefer crustaceans (48.6 %) to mollusks (21.5 %) and fish (17.5 %), adults (CW 111-150 mm) shift their diet to a higher proportion of fish (26.7 %), though crustaceans and mollusks remain principal components (40.5 %, 24.5 %, respectively), and the largest adults (CW 151-170 mm) consume more fish (29.4%), and reduce the proportions of crustaceans and mollusks (37.5 %, 21.6 %, respectively) (Hosseini *et al.*, 2014; Pazooki *et al.*, 2012)

Furthermore, the presence of unidentified organic matter and plant debris in the diet indicates the ability of *P. segnis* to exploit unconventional resources when animal prey is scarce. (Tadi Beni *et al.*, 2018). In ovigerous females, a significant increase in food consumption has been observed, likely to meet the high energy demands associated with reproduction. Moreover, *P. segnis* has demonstrated dietary flexibility in the presence of introduced species, which could amplify its ecological impact in Mediterranean ecosystems (Mancinelli *et al.*, 2022).

This dietary plasticity highlights the ability of *P. segnis* to **occupy different trophic levels and adapt to a wide range of environments**. Its varied diet, combined with the continuous availability of prey in Mediterranean ecosystems, reinforces its role as an effective invasive species and contributes to its demographic success. However, this flexibility can also lead to significant ecological impacts, including exerting predation pressure on local species and disrupting trophic networks (Hamida *et al.*, 2019; Mancinelli *et al.*, 2022; Tadi Beni *et al.*, 2018).

The impact of *Portunus segnis* on benthic fauna in the Mediterranean is not well understood. It is likely that *P. segnis* exe**rts significant pressure on local ecosystems by altering trophic dynamics and directly competing with native species for food resources and habitat** (Mancinelli *et al.*, 2022). Through its diverse diet, *P. segnis* may reduce the populations of many local species, causing imbalances in trophic chains. In Tunisia, the **consumption of mollusks species particularly impacts populations of bivalves and other benthic invertebrates, which play a crucial role in maintaining the ecological balance of coastal zones** (Hamida *et al.*, 2019).

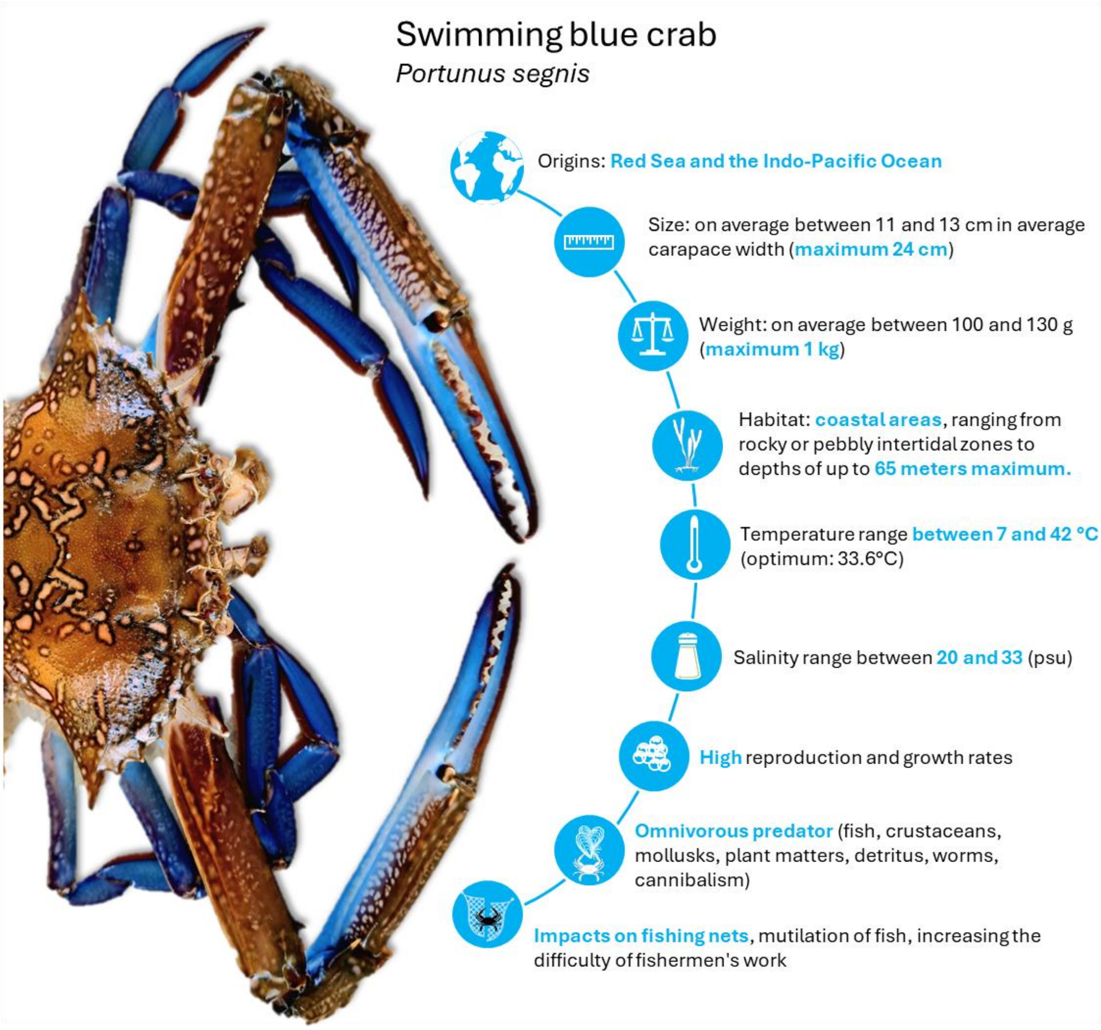
Furthermore, *P. segnis* demonstrates a **high trophic niche and significant dietary flexibility**, enabling it to rapidly adapt to varied environments and efficiently colonize new habitats, often at the expense of less competitive native species. For instance, in Elounda Bay, Greece, its occupation of a h**igh trophic position has been associated with increased competition with other native predators, potentially contributing to their decline** (Mancinelli *et al.*, 2022).

Another concerning aspect is the **indirect impact of *P. segnis* on human activities**, particularly fishing. By exploiting the same resources as some commercial species, this crab can negatively affect stocks of economically important fish and mollusks, leading to conflicts with local fishers. For instance, in Turkey, *P. segnis* catches are often associated with a decline in native fish catches, indicating increased interspecific competition in these already stressed environments (Yeşilyurt *et al.*, 2022).

Predators of *Portunus segnis*

In its native habitat, this crab is often **preyed upon by carnivorous fish** such as groupers (*Epinephelus spp.*) and barracudas (*Sphyraena spp.*), which occupy higher trophic niches in tropical marine ecosystems. In the Mediterranean, where *P. segnis* is a recent invader, its trophic network is still being structured. Isotopic analyses conducted in Crete have shown that it occupies a **high trophic position, making it vulnerable to certain local predators such as large carnivorous fish**. However, these interactions remain limited due to the lack of co-evolution with these species (Annabi *et al.*, 2018).

3.5 Summary of information on *Portunus segnis*



4 *Callinectes sapidus* vs. *Portunus segnis*: Many similarities

Morphological Similarities

- Swimming adaptations: both species have specialized fifth legs modified into swimming paddles, making them efficient swimmers. They can cover 15 km per day.
- Broad carapace: both crabs have a wide, flattened carapace with lateral spines, aiding in hydrodynamics.
- Coloration: while *C. sapidus* is known for its distinct blue claws, *P. segnis* exhibits a more variable coloration, often greenish or brownish.

Habitat Preferences

- Brackish and marine waters: both species thrive in estuaries, brackish lagoons, and coastal marine environments.
- Tolerance to temperature: both species are capable of surviving in a wide range of temperature: *Callinectes sapidus*: 0 to 40°C ; *Portunus segnis*: 7 to 42°C.
- Tolerance to salinity: both are euryhaline, capable of surviving in a wide range of salinities, from nearly freshwater to hypersaline conditions.
- Depth range: both species can inhabit shallow waters and extend to deeper zones (up to ~50 meters for *P. segnis* and 35 meters for *C. sapidus*).

Diet and Feeding Ecology

- Omnivorous predators: both crabs are omnivores, feeding on a mix of mollusks, crustaceans, fish, algae, and detritus.
- Cannibalistic and aggressive behavior: both species exhibit cannibalism, especially during molting stages.
- Trophic impact: both are opportunistic feeders, capable of preying on a wide range of species and altering local food webs
- Competition with native species: both crabs compete with native crustaceans for food and habitat, impacting local biodiversity

Reproductive Strategies

- High reproductive potential: both species produce a large number of eggs per reproductive cycle, contributing to their rapid population growth.
- Planktonic larvae: their larvae are planktonic, allowing long-distance dispersal via ocean currents, which supports their invasive potential. Larvae can cover > 100 km.

Invasive Success

- Environmental adaptations: both species are highly adaptable, with broad tolerances to temperature and salinity fluctuations.
- Human-mediated introduction: both species were introduced to the Mediterranean through human activities, including ballast water discharge and the Suez Canal (*P. segnis*).

5 Blue crabs and artisanal fisheries: what challenges?

5.1 Socio-economic impacts

These two Portunidae species, due to their **many similarities**, **cause significant socio-economic impacts**. Through their **aggressive behavior and high abundances**, the two blue crabs **exert considerable socio-economic pressures, particularly on artisanal fisheries**. Marchessaux *et al.* (2023c) studied the impact of *Callinectes sapidus* and *Portunus segnis* on artisanal fisheries in France, Italy, and Tunisia, interviewing 102 fishermen.

Artisanal small-scale fishermen were the social component and economic sector to be most affected by the presence of blue crabs and considerable negative effects on fishing activities are recognized by local populations (Mancinelli *et al.*, 2017; Marchessaux *et al.*, 2023c). The invasion of blue crab species affects **3 aspects** on artisanal fisheries: **fishing activities**, the **number and quality of catches in nets**, and the associated **economic revenues** (Figure 21).

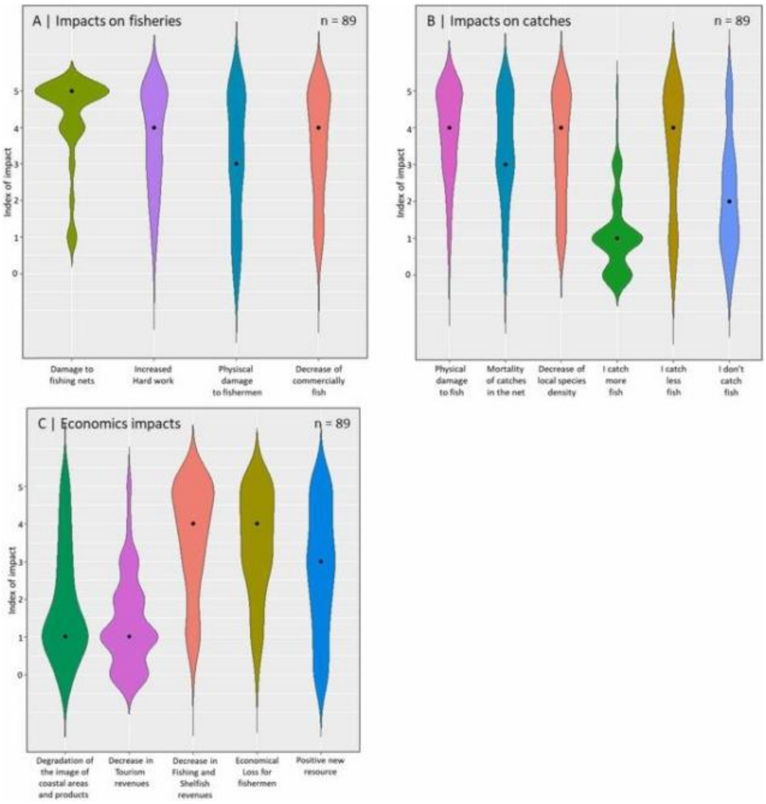


Figure 21. Distribution of perceived impacts of blue crabs (*C. sapidus* and *P. segnis*) on (A) artisanal fisheries activities, (B) on catches, and (C) economics impacts. Black dots represent the median. Figure and legend extrated from Marchessaux *et al.* (2023c).

The primary impact caused by the presence of blue crabs is the **damage to fishing nets**, followed by an **increase in the labor intensity** required for net maintenance and **physical injuries** sustained by fishermen (Figure 21A). **The clogging nets can be huge and can represent 150 kg per day in Tunisia** (Khamassi *et al.*, 2019) increasing the frequency of net hauling to avoid clogging (Culurgioni *et al.*, 2020; Khamassi *et al.*, 2019). Blue crabs are capable of **shredding nets** (Öndes and Gökçe, 2021) and in Tunisia, ***P. segnis* damages the catches in the nets reducing fish catches resulting in a 37 % loss of catch** (Khamassi *et al.*, 2019).

The **prey caught in fixed nets were also damaged** by the presence of blue crabs (Figure 21B), which are highly voracious and active scavengers that attack other dead species, in this case, those entangled in the nets (Figure 21B). Small-scale fishers specifically reported catching fewer fish and noted that blue crabs caused significant damage to fish, leading to **high mortality rates among fish caught in fyke nets**, a type of net commonly used in coastal and lagoon systems (Figure 21B). This results in a **decrease in the quantity of captures** and, more generally, a **reduction in the density of local species**, according to the artisanal fishers.

The combination of these impacts on fishing gear and catches has led to economic losses for small-scale fishers (Figure 21C), representing a major disruption in the supply chain of small-scale artisanal fishing. The proliferation of blue crab species **results in decreased revenues from fishing and aquaculture and significant economic losses for small-scale artisanal fishers**.

The combination of the time and financial costs of mending and changing nets (Khamassi *et al.*, 2019; Öndes and Gökçe, 2021) imply a significant economic loss for the fishing sector. In **Tunisia the average annual income *per* fisherman decreased from 73,000 € to 20,500 € after the invasion of *P. segnis*** (Khamassi *et al.*, 2019). **In Croatia, the cost of damages on the nets caused by *C. sapidus* represented $20 per week per artisanal small-scale fishermen** (Glamuzina *et al.*, 2021).

In general, to address the economic loss associated with the invasive species, the artisanal small-scale fishermen deployed different strategies showing a true professional culture of adaptation (Deldrève, 2000; Marchessaux *et al.*, 2022b). Indeed, this profession had always been exposed to environmental hazards, leading to develop a culture that "manage" the problems that may arise with a strong capacity to adapt (Andersen, 2011; Bataille and Deldrève, 2009; Candau *et al.*, 2015; Deldrève, 2000; Marchessaux *et al.*, 2022b). But, in the case of the blue crabs, these temporary adaptations (e.g. reduced net setting time, change of nets or fishing technique) tend to be costly and restrictive. The main solution for the management of blue crabs' populations in the Mediterranean Sea would be represented by **exploitation as also reported by 72 % of the artisanal small-scale fishermen** interviewed in Marchessaux *et al.*, (2023c).

5.2 Can we control blue crabs by eating them?

Consuming blue crabs is a highly anticipated measure among artisanal fishers (Marchessaux *et al.*, 2023c). Despite the significant impacts on fishing activities and nets, **fishers sometimes perceive blue crabs as both negative and positive** (Figure 22A). This is not the case in France, where the species (*Callinectes sapidus* specifically) is still expanding. However, in Italy and particularly in Tunisia, both blue crab species are viewed as having both negative and positive aspects (Figure 22B).

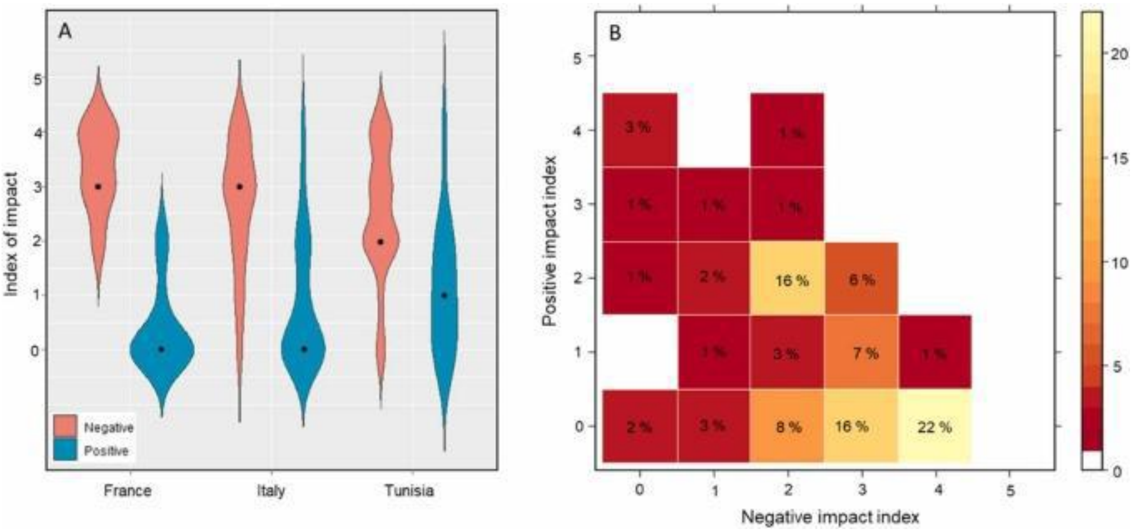


Figure 22. A) Positive and/or negative impacts of blue crabs (*C. sapidus* and *P. segnis*) as perceived by stakeholders, and (B) a comparison of the percentage of responses in each impact index category (positive vs. negative). The black dots on plot A represent the median. Figure and legend extracted from Marchessaux *et al.* (2023c).

The valuable meat and commercial potential of blue crabs are seen as a new source of income for small-scale artisanal fishers. In this context, it is clear that the **creation of a blue crab industry seems to be necessary**, but it is equally important for the general public to be willing to consume blue crab. Two large-scale studies were conducted in 2023 in Italy and France (Azzurro *et al.*, 2024; Marchessaux *et al.*, 2024b).

In Italy | The population explosion of *Callinectes sapidus* in 2023 in the northern Adriatic had significant impacts on the Italian shellfish industry (Azzurro *et al.*, 2024). This invasion garnered considerable media attention and raised questions about the management and commercial exploitation of this species. The survey, named **UseIt**, interviewed 2,466 Italian participants to assess consumer perceptions, their acceptance of *C. sapidus* as a food product, and their willingness to pay.

Interest in *C. sapidus* increased significantly after the media coverage in August 2023 (Azzurro *et al.*, 2024). A majority of participants discovered the species through social media (59% via Facebook) and traditional media. However, only 38% of respondents had observed blue crabs available for sale in Italy. A majority (69.5 %) had never tasted the species, but those who had largely approved of its organoleptic qualities (Azzurro *et al.*, 2024). Participants positively rated *C. sapidus* for its taste, smell, and ease of preparation. Pric**es dropped by €2.62/kg after the population explosion, reflecting an increased supply** (Azzurro *et al.*, 2024) (Figure 23).

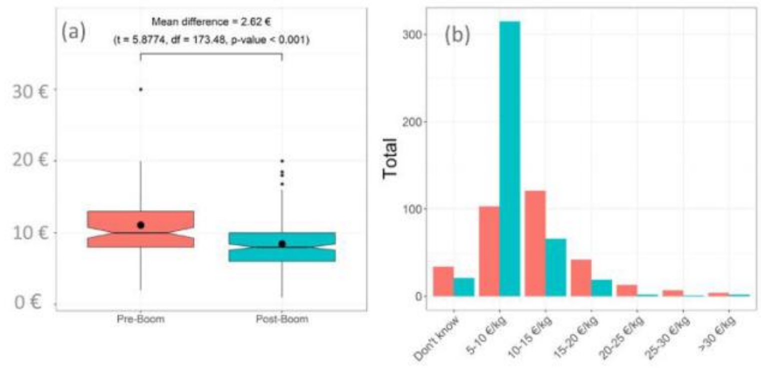


Figure 24. Consumer perception of blue crab price: (a) Boxplots showing the current distribution of reported market prices for 1 kg of *Callinectes sapidus* in Italy, black dots represent the mean values; (b) Distribution of optimal and (c) maximum price ranges the respondents would pay for 1 kg of blue crab. Pre-boom period (in red) and post-boom (in green). Figure and legend extracted from Azzurro *et al.* (2024).

In France | The study by Marchessaux *et al.* (2024b) addresses the management of the American blue crab (*Callinectes sapidus*) invasion in France and explores the possibility of managing it through its consumption as a food resource. A national survey was conducted in France with 2,040 participants between March and May 2023 to assess their perception of blue crab consumption and their willingness to pay for this product.

A total of 96% of respondents were willing to consume blue crab, with motivations including the discovery of a new product (68%), its exotic appeal (11%), and its taste (10%) (Marchessaux *et al.*, 2024b). Respondents were willing to **pay €15–19 for a dish at a restaurant** and **€8–10 per kilogram at fish markets** (Figure 24). Consumption was perceived as a civic and ecological act by the majority, particularly among younger generations.

Restaurants were the preferred place for consumption (78% positive responses), while fish markets and supermarkets generated moderate interest (Figure 24). Blue crab consumption is perceived as a solution to mitigate its ecological impact while supporting local fishers.

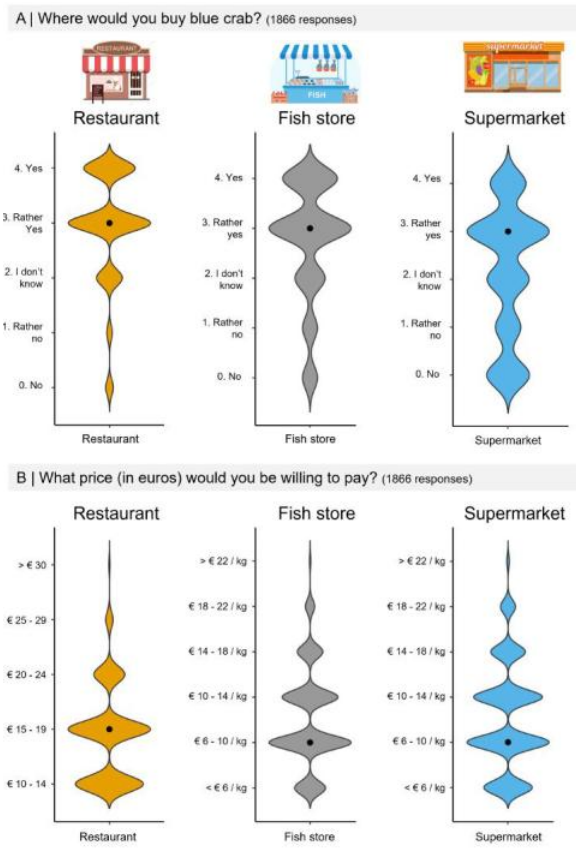


Figure 23. People's perception of the place where they are able to buy blue crabs for consumption (on the top) and how much they are able to pay (on the bottom). Figure and legends extracted from Marchessaux *et al.*

The two studies highlights a gap between consumer interest and the actual availability of the product on the market . **Italian and French respondents expressed a willingness to integrate this species into their diets, which could represent an effective strategy to manage the invasion while supporting local fisheries**. These studies emphasize the potential of *C. sapidus* as a new commercial resource in Italy and in France. However, efforts are needed to harmonize the supply chain, improve market access, and develop sustainable exploitation and management strategies.

5.3 Fishing gear to catch the blue crabs

The commercialization of blue crabs in the Mediterranean appears to be the best option to control populations and limit ecological and socio-economic impacts. However, it is clear that to implement effective commercialization of blue crabs, it is necessary to **determine which fishing gears to use for their efficient and selective capture**.

Castriota *et al.* (2024) reviewed the scientific literature to identify the types of fishing gears used in the Mediterranean to capture the American blue crab, *Callinectes sapidus* (Figure 25). The authors found that **traps** were the most commonly used fishing gear in the Mediterranean (31.6%) and were widely adopted across many countries. **Gillnets and entangling nets** were also extensively used (24.2%), primarily along Mediterranean coasts.

Regarding *Portunus segnis*, the FAO proposed a specific type of trap for its capture (Bdioui *et al.*, 2020). Similar to *Callinectes sapidus*, several types of fishing gears are also used to catch *Portunus segnis*. For instance, **gillnets** are commonly employed by artisanal fishers to capture a variety of species, including the blue swimming crab (Khamassi *et al.*, 2019). **Traps**, **such as specific pots or baited devices**, are also used to target crabs, allowing for selective capture and reducing bycatch (Khamassi *et al.*, 2019). **Bottom trawls** are additionally utilized, particularly in Tunisia and Turkey, although these are primarily intended for other species; they frequently capture blue swimming crabs as bycatch (Yeşilyurt *et al.*, 2022). It appears that bottom trawls are the most frequently used fishing gear to catch *Portunus segnis* specially in Tunisia (O. B. A. H. Hamida *et al.*, 2019). These capture methods have been documented in various scientific studies, particularly those conducted in the Gulf of Gabès, Tunisia, where the species is notably prevalent.

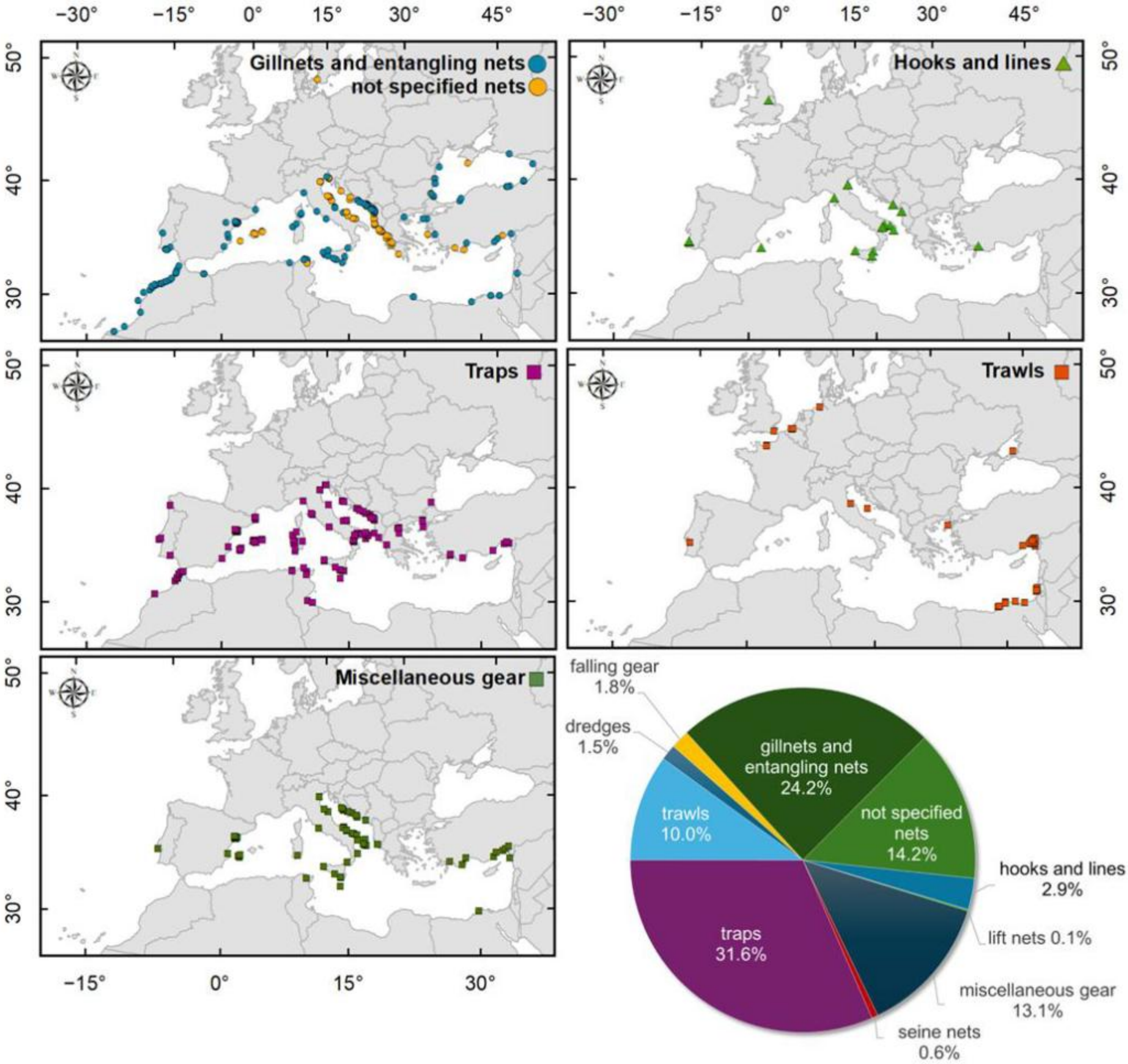


Figure 25. Fishing gear categories used to catch the American blue crab *Callinectes sapidus* and frequency. Figures extracted and modified from Castriota *et al.* (2024).

6 EU policies framework on invasive species management

At international level, there are several major international conventions on biodiversity that take account of the problem of invasive alien species:

- the **Convention on Biological Diversity** requires each contracting party to "prevent the introduction of, control or eradicate alien species that threaten ecosystems, habitats or species". The new post-2020 strategic framework currently being negotiated includes a target for reducing the introduction of invasive alien species.
- the **Convention on the Conservation of European Wildlife and Natural Habitats**, or **Bern Convention**, makes numerous recommendations concerning invasive alien species. It also establishes a European strategy on invasive alien species. The obliges its parties to strictly control the introduction of exotic species, or to manage and eliminate those that have already been introduced.
- the **Convention on Wetlands, or Ramsar Convention**, requires parties to take measures to identify, eradicate and control invasive alien species on their territory.

At European level, several regulatory frameworks are tackling the problem of invasive species, including blue crabs:

- The **Marine Strategy Framework Directive (MSFD)** is the main European tool for maintaining healthy, productive and resilient marine ecosystems. This directive (n°2008/56/CE) recognizes that the introduction of exotic species endangers European biodiversity and calls on member states to include these species in the description of "good ecological status".
- The **Marine Strategy Framework Directive (WFD)** (n°2008/56/EC) recognizes that the introduction of exotic species endangers European biodiversity and calls on member states to include these species in the description of "good environmental status".
- **Regulation on the use of alien and locally absent species in aquaculture**. The aim of this regulation (n°708/2007) is to ensure that Member States take all appropriate measures to avoid any harmful effects on biodiversity resulting from the introduction or transfer of aquatic organisms or species for aquaculture purposes, as well as the spread of these species in the wild.
- **The European regulation on the prevention and management of the introduction and spread of invasive alien species**. Adopted on October 22, 2014, Regulation n°1143/2014 aims to prevent, reduce and mitigate the adverse effects on biodiversity of the introduction and spread of invasive alien species within the European Union. It establishes, based on a risk assessment, a list of invasive alien species of concern. Each Member State may draw up a list of species of concern on its territory, using the same method.

In the Mediterranean:

- The **Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean** was adopted on February 16, 1976 in Barcelona.
- The **SPA/BD Protocol** to the Barcelona Convention was adopted in 1995 and came into force in 1999. The SPA/BD Protocol provides the regional framework for the conservation and sustainable use of biological diversity in the Mediterranean. It calls on the Parties to protect areas of particular natural or cultural value, through the creation of Specially Protected Areas (SPAs) or Specially Protected Areas of Mediterranean Importance (SPAMIs), and to protect threatened or endangered plant and animal species listed in its annexes. The SPA/BD Protocol provides the regional framework for the conservation and sustainable use of biological diversity in the Mediterranean. It calls on the Parties to

protect areas of particular natural or cultural value, through the creation of Specially Protected Areas (SPAs) or Specially Protected Areas of Mediterranean Importance (SPAMIs), and to protect the threatened or endangered plant and animal species listed in its annexes.

7 Actions already carried out in the Mediterranean to fight the blue crabs' invasion

7.1 Action plans for controlling the blue crab

7.1.1 Spain | Action plan for controlling the blue crab

The American blue crab *Callinectes sapidus* is listed as a commercial species and is not included in the national catalog of invasive alien species in Spain, in accordance with Decree 630/2013. The Spanish Department of Fisheries has developed a **professional fishing plan for the exploitation of blue crabs to reduce their abundance**. Catalonia pioneered the regulation of American blue crab landings in fish markets in September 2016. **Commercial catches increased from 15.8 tons in 2017 to over 450 tons in 2019**, a figure that has remained stable since and generates approximately 1.5 million euros annually.

The main objective was to **reduce abundance and control the blue crab population, although a sustainability plan for blue crab fisheries at the Mediterranean scale is currently being developed**. What is considered a conservation (rather than fishing) organism is counterproductive for controlling and rebuilding declining indigenous species populations, as well as for the indigenous fishery products affected by the proliferation of crabs. From a conservation standpoint, in the current situation, a ban on commercial fishing of blue crabs would represent a serious and unnecessary social conflict, especially because the main group affected by this hypothetical ban would be coastal fishermen, the very group most impacted by the invasion.

However, **commercial fishing should not be equated with an "invasion control" activity**. On the one hand, the possibility of controlling the crab population through fishing has not been demonstrated, and on the other hand, generating an economic activity around the species would make it difficult to implement effective control actions, should they be developed. **Blue crab fishing is only allowed for professional fishing and not for recreational fishing** in Catalonia. These objectives imply that fishing activities should not be guided solely by the maximization of economic profit but should focus efforts on areas and periods that have the greatest impact on blue crab populations. Such targeted fishing would require smooth collaboration between research centres, administrations, and fishermen, as well as the availability of economic resources. In this regard, a blue crab co-management committee was established in Catalonia with the participation of all relevant sectors, which could serve as a model for other regions.

In the **Balearic Islands**, **American blue crabs are captured by both professional and recreational fishermen, but recreational fishermen primarily carry out the capture**. **Common methods include the use of crab pots, nets, and baited traps**. These methods are effective and widely used to manage the crab population and prevent its spread. The captured blue crabs are mainly sold in local and international markets, where they are considered a delicacy.

In **mainland Spain**, there is a **dedicated commercial line for blue crabs**, available in markets throughout the country. However, in the Balearic Islands, the blue crabs seen in markets actually come from mainland Spain rather than local waters. **While commercial capture is permitted in the Balearics, it is not economically viable, and recreational fishermen are not allowed to sell their catches**.

In **Mallorca**, the Consell Insular de Mallorca has shown that granting **recreational fishing permits can be an effective strategy to reduce local populations**. Balancing these approaches is key to effective management.

7.1.2 France | Territorial Plan for the Control of the American Blue Crab

A **Territorial Plan for the Control of the American Blue Crab** (*Callinectes sapidus*) was implemented in 2024 for the Corsica region (France). This strategic management document for the American blue crab is a **regional adaptation of the national strategy for controlling invasive alien species** (IAS).

The overall goal is to **provide a framework guided by the five pillars of the national strategy** (NS), aiming to **strengthen and structure collective action**. Specific actions are also implemented, based on robust scientific foundations and a shared territorial control strategy for greater effectiveness, while aligning financially with project funding requirements. **Ten objectives** from the NS related to IAS have been broken down into **25 operations**, each including precise actions to be deployed at the regional level. Extensive scientific work has informed these actions and will continue to refine them. For example, the type of actions and their prioritization in lagoon areas (where physico-chemical monitoring exists), as well as the definition of periods and individuals to target for more effective site-specific action, are being clearly identified. The overall objective of this Territorial Action Plan is to provide a working framework guided by the five pillars of the national strategy, namely:

- **Action 1: Prevention, Early Detection, and Monitoring** – Prevention of the introduction and spread of new invasive alien species.
- **Action 2: Management and Restoration** – Species management interventions and ecosystem restoration.
- **Action 3: Knowledge** – Improvement and sharing of knowledge.
- **Action 4: Communication** – Communication, awareness-raising, mobilization, and training.
- **Action 5: Governance** – Governance.

7.1.3 Italy | Italian Containment plan 2025-2026: measures to protect biodiversity

The **Italian Blue Crab containment plan** funded with a total of 10 million euros as outlined in the Legislative Decree on Agriculture for the 2025-2026 period, aims to safeguard biodiversity in affected habitats, control and combat the spread of invasive species, prevent further economic losses, and support the recovery of farming and fishing activities:

- Decree "omnibus" n. 104 - 10 August 2023: economic support to crab fisheries - 2.9 M Euros.
- Ministerial Decree n. 628456 - 13 November 2023: economic support to compensate loss in investment for clam seeds and expenses incurred for farm protection - 10 M Euros.
- Decree Agricultura n. 63/2024: further economic support - 27 M Euros.
- National solidarity fund – Law 102/2004 - 3.7 M Euros.

Key measures include controlling and disposing of the blue crab, protecting aquaculture infrastructure, promoting alternative uses for biomass, and providing financial support to businesses in the sector.

The plan foresees the broadening of management measures to other regions in Italy (e.g., 2025-2026). For effective implementation there is the need for multilevel cooperation among institutions, stakeholders, and research institutes. Adaptation to new conditions (e.g., commercial fishing development) could be needed. Effective monitoring will allow adaptation – integration of ongoing monitoring under another legislation/framework (e.g., DCF, MSFD, WFD, EcAp) is critical.

The measures aim at combating invasive alien species focus on safeguarding local biodiversity, conserving natural ecosystems, and protecting economic activities and human health, with different objectives:

1. Targeted fishing, when conducted with the appropriate methods, is recognized as an effective measure to protect biodiversity.
2. Establishment of a Working Group (WG) has been proposed to oversee the implementation of measures that ensure the sustainability of lagoons, such as morphological modifications to facilitate seawater exchange between marine and lagoon environments.
3. Target females (ovigerous) to reduce populations
4. Selective fishing carried out mainly with passive gears (pots, nets), refund to fishers per kg (about 1 Euro/Kg).
5. Commercial fraction (blue crab) can be sold.
6. Incidental catch of other commercial species caught cannot be sold.
7. Incidental catch of C. sapidus from other fishing can be refunded.
8. Economic support for the disposal of crabs (about 0.5 Euro/Kg).

Further supports are implemented to enable the implementation of the fishing activities:

- Activate fish markets, cooperatives, local administrations to enable the landing of crabs, their quantification, and disposal.
- Support scientific testing of innovative fishing gear.
- Support the adoption of gears, where needed and justified.
- Ensure addressing the feasibility of economic uses of crabs beyond human consumption.

7.1.4 Tunisia | Strategy for Blue Crab Valorisation

Following the invasion of *Portunus segnis* in Tunisia in 2014, the Tunisian government implemented significant measures to limit the spread of the blue swimming crab and support local fisheries. In 2017, a national plan to encourage fishing, promotion, and commercialization of blue crabs was officially enacted including different actions (Ben Souissi *et al.*, 2024):

1. **Establishment of collection zones for blue crabs retained in the fishing nets to avoid their release to the sea and ensure income for fishermen.**
2. **The government purchases all blue crab catches without limits at a rate of 0.8 USD per kg,** with 0.4 USD funded by the government and 0.4 USD by industrial stakeholders.
3. **Stimulating demand through the national marketing** of blue crabs and exploring international markets.
4. **Encouragement of both national and international investments** to establish processing factories.
5. **Strengthening scientific research for the rational management** of this new edible resource, including stock assessments and the development of appropriate fishing technologies.

Tunisia was one of the first countries to implement industrial commercialization of the blue crab to limit its invasion.

In collaboration with various institutions (laboratories, associations, fishermen's groups, etc.), the Tunisian government has implemented several **awareness-raising actions to encourage citizens to consume and exploit blue crab**.

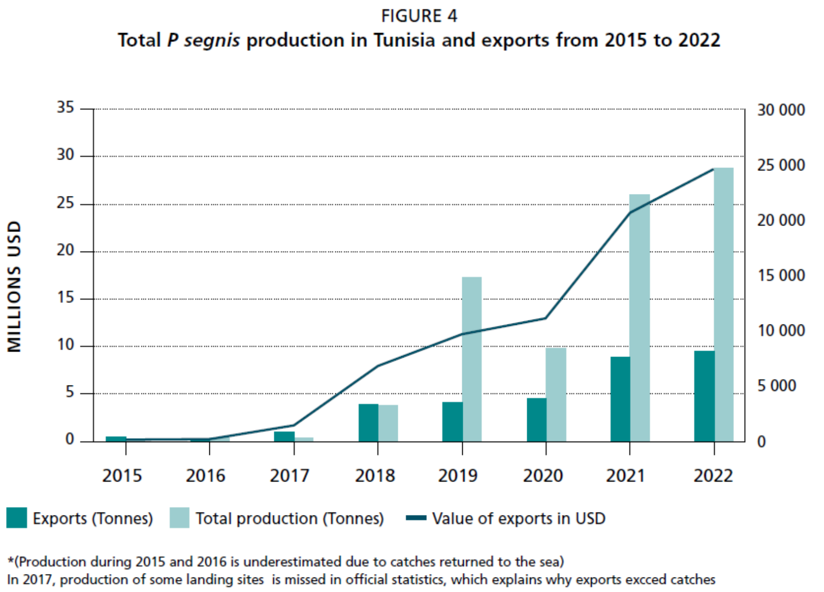


Figure 26. Evolution of blue crab production and value in Tunisia from 2015 to 2022. Figure extracted from (Ben Souissi *et al.*, 2024).

Currently, there are **49 seafood processing factories, 17 of which specifically focus on processing blue crabs** (Ben Souissi *et al.*, 2024). The largest investment in a blue crab processing factory in Ghannouch comes from the Middle East, amounting to 70 million dollars (Ben Souissi *et al.*, 2024). This investment has created 1,600 jobs, 1,400 of which are for women. The factory has a production capacity of 110 tons per day, primarily for export, and features a large cold storage room with a capacity of up to 6,000 tons (Ben Souissi *et al.*, 2024).

In 2022, approximately **25,000 tons of blue crabs were caught in Tunisia**, with around 6,000 tons exported worldwide. The blue crab fishing industry in Tunisia generated nearly 30 million USD in revenue in 2022 (Figure 1).

7.1.5 Turkey | Valorisation of blue crabs

In Turkey, **the American blue crab (*Callinectes sapidus*) has become an important economic resource**, particularly in regions such as the Göksu delta, Dalyan and the Akyatan lagoon. Initially a threat to local fisheries due to its tendency to damage nets, the species is now exploited commercially.

Events such as the "Mavi Yengeç Koşusu" (blue crab race) raise public **awareness and promote its presence**. Crabs fetch high prices, **between 8 and 10 euros per kg**, and **are exported to Eastern Asia**, where their meat is a highly prized delicacy (source here) and the shells, used in cosmetics, are much sought-after (source here). However, despite the economic benefits, the blue crab's non-indigenous status and its potential impact on the environment remain largely ignored.

In Turkey, **around 300 to 500 tons of blue crabs are exported every year**, making a significant contribution to the local economy. Efforts are underway to create an **industrial zone for the processing and export of these crabs**. **The species is actively promoted** for its sustainability, but these campaigns unintentionally contribute to the spread of the species, **potentially introducing it to new areas**. In Dalyan, efforts to preserve female crabs are aimed at sustaining the population, but they also encourage the uncontrolled growth of the species. Furthermore, as Turkey is not an official member of the EU, it is not obliged to adopt EU regulations concerning invasive species. As a result, there is **no national alien species management policy** and, despite ongoing international projects, there is still no comprehensive action plan to address the potential risks of the blue crab to local biodiversity. The lack of awareness and regulatory measures raises serious concerns about the ecological consequences of promoting this species without proper management.

7.2 Raising awareness about the consumption of the blue crab

7.2.1 Italy | UseIt: Using Operational Synergies for the Integrated Management of Invasive Alien Species in Italy

The USEit project aims to **establish an integrated and collaborative approach to enhance IAS management in both marine and terrestrial environments**. This objective will be achieved through technical and technological innovations, coupled with studies **to optimize information management** and **explore the economic potential of IAS**.

7.2.2 Italy | WWF: Transforming small-scale fisheries

WWF is engaged in several countries on working on NIS, including Italy, Tunisia, and Greece. The issue is addressed also through the work on small-scale fisheries which is coordinated in a regional initiative (Transforming small-scale fisheries | WWF). The WWF work in Italy highlights collaborations with fishers, chefs, and restaurants to raise awareness about the invasive Blue Crab's culinary potential. For this work WWF partnered with famous restaurants and chefs, including Harry's Piccolo (Michelin 2-star restaurant) and Mimi e Cocotte in Triest, to create innovative dishes using the crab (from dinner menus to street food), showcasing it as a valuable resource. Training sessions for Harry's Bistro staff reinforced the sustainability message behind the dishes, emphasizing a shift in perspective on invasive species. Mimi e Cocotte also participated in the "Ciacola di Mare" talk, sharing sustainable food practices and offering Blue Crab panino samples to engage the public. Additionally, Michelin-starred chef Antonia Klugmann hosted a live cooking show, preparing Blue Crab dishes and advocating for local, underutilized ingredients. In Northern Italy, the WWF Transforming Small-Scale Fisheries project hosted a hands-on cooking competition with a specialized business development company that also supports the development in the field of transnational cooperation ENAIP VENETO, allowing participants to explore Blue Crab's versatility. Local fishers acted as judges in the event, which fostered collaboration and innovative solutions.

WWF also facilitated cross-border knowledge exchange between Italian and Tunisian fishers by introducing traditional Tunisian crab traps, promoting sustainable practices and better management of Blue Crab populations across the Mediterranean.

Figure 27. Examples of WWF´s work in Italy: Event with famous Chefs on the WWF Ambassador boat "Blue Panda" in Trieste, training with the kitchen staff of famous restaurants, cooking competitions including different stakeholders (fishers, NGO, researchers, fisheries management organization representatives), and the winner dish creations. (from left to right and top to bottom). Photos' credits: Clementine Laurent

7.2.3 Greece | Pick the Aliens

"Pick the Alien" project **aims to address the dual challenges of invasive species proliferation and overfishing in the Mediterranean**, particularly in Greece. It seeks to **mitigate ecological impacts by promoting the consumption of edible alien species** such as lionfish, spinefoots (*Siganus spp.*), and blue crabs (*Callinectes sapidus*). The project emphasizes collaboration among fishers, chefs, seafood processors, and consumers to create a sustainable supply chain and raise awareness about responsible seafood consumption. Key outcomes include:

1. **Sustainable Fisheries Practices**: Experimental traps for lionfish have been tested, although their efficiency varies due to technical and environmental factors.

2. **Market Integration**: Alien species have been introduced to menus in restaurants and hotels, with efforts to develop processed products like salted spinefoot fish.

3. **Public Engagement**: Gastronomic festivals and cooking competitions have highlighted the culinary potential of invasive species, with strong public participation and media coverage.

4. **Community Benefits**: Training initiatives for women in seafood processing and educational campaigns aim to enhance local economies and involve stakeholders in sustainable practices.

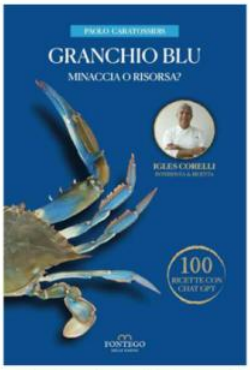
The project's successes in engaging diverse stakeholders and promoting invasive species as a culinary resource underline its potential to balance ecological and socioeconomic goals in managing marine ecosystems. More information: https://isea.com.gr/pick-the-alien-eng/?lang=en).

7.2.4 Italy | BlueEat project

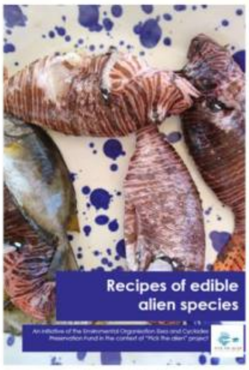
Blueat **explores new possibilities for the management and utilization of alien species**, which are becoming increasingly prevalent in the Mediterranean due to changes in the marine environment. The goal of the Blueat project is to **integrate these NIS species into the Italian gastronomic traditions the as quickly as possible, transforming an environmental challenge into an economic opportunity for the Italian agri-food sector**. The project aims to generate positive outcomes for the sea, the ecosystem, indigenous fauna, fishing, and coastal tourism, while minimizing the impact on both the environment and the socio-economic system, which could otherwise suffer if this "invasion" is left unmanaged. The objectives are to: (**i**) **promotes and transition small-scale and traditional fishing** into sustainable practices. Collaborate with fishermen and their local cooperatives to sustainably capture alien species; experiment with new fishing tools and methods; involve universities and research organizations in the process, (**ii**) E**ncourage the consumption and culinary use of alien species** with the goal of incorporating them into traditional Italian cuisine. Promote these species in markets, restaurants, and the Horeca sector; publicize them through social media, television, and other mass media outlets, as well as through innovative apps; organize fairs, events, congresses, research and study labs, and show-cooking demonstrations, **(iii) Shift fish market demand from traditional species to alien species**. Assist in creating an innovative micro-supply chain for alien species that can be replicated in coastal regions across the country; raise awareness of the environmental and socio-economic sustainability objectives; highlight the nutritional and gastronomic benefits of these species. More information: https://www.blueat.eu/

7.2.5 Books of recipes on blue crabs in the Mediterranean Sea

Cookbooks have been published to raise awareness among citizens about consuming blue crabs and to provide guidance on how to prepare them. For instance, in 2023, a book titled *"Granchio blu: Minaccia o risorsa"* was published in Italy, featuring 100 recipes using blue crabs. The *Pick the Aliens* project also produced a recipe book focused on cooking invasive edible species in the Mediterranean.



Book of receipes entitled "Granchio Blu. Minaccia o Risorsa?: 100 Ricette con ChatGPT (Italian Edition)". Paolo Caratossidis. Fontego Delle Farine Editions, 2023.



Book of receipes entitled « Recipes of edible alien species". Pick the Alien project,

Book of receipes entitled "From invasion to the dish: receipes made with blue crabs", Bleu-Adapt Project.

Book of receipes entitled "The American blue crab: an invader to be savored", Environmental Agency of Corsica.

The Italy-Tunisia *Bleu-Adapt* project published a book titled *"From Invasion to the Dish: Recipes Made with Blue Crabs"*, containing 30 blue crab recipes created by the fisherwomen of the Kerkennah Islands. This book is available in Italian, French, and English, and is distributed free of charge.

In Corsica (France), a cookbook was also published by the Environmental Agency of Corsica during a public awareness event held in September 2024.

7.3 International cooperation programs

7.3.1 Italy-Tunisia | Bleu-Adapt project

The goal of the BLEU-ADAPT (Interreg Italy-Tunisia) project was to **provide a rapid response to the biological invasion of blue crabs and to support adaptive management of the issue in Italy and Tunisia**. This objective led to a series of **specific actions**, closely aligned with local realities. The bilateral collaboration facilitated an in-depth risk analysis, driven by ecological and socio-economic information collected through participatory approaches with the fishing community. **Geographic data combined with environmental data** were also used to model the potential geographical expansion of the species. The information gathered during the project was used to **implement adaptive management practices**. The communication strategy targeted key stakeholders in species management and potential end-users, encouraging the natural responsiveness of civil society through specific training. Finally, **considering the commercial potential of the blue crab**, a series of pilot actions were directed towards **promoting and developing the value chain of this species in the Italian and Tunisian markets**, involving all socio-economic actors and even the general public, thus creating new market opportunities with the ultimate goal of stimulating a socio-economic dynamic around the invasive species fishing activities. This adaptation strategy provided a **concrete and immediately effective solution to tackle the blue crab** issue in Tunisia and served as an effective model for its expansion into other fishing regions in Italy and Tunisia. More information: https://bleu-adapt.eu/apropos/#presentation.

7.3.2 Italy-Slovenia | BLUECRAB project

The BLUECRAB project (Interreg Italy-Slovenia) objectives are to bring long-term benefits to both fishing operators and local communities, who are currently the most affected by the blue crab invasion, particularly from an economic and environmental perspective. The BLUECRAB project also involves **creating a cross-border partnership that includes business support organizations**, **public authorities, NGOs, specialized universities, and research centers, as well as numerous associated partners such as regions, development agencies, and other institutions**. This partnership is essential to tackling the environmental crisis, requiring an integrated approach and a combination of scientific, technical-operational, and local expertise. To safeguard the biodiversity of Upper Adriatic areas threatened by the blue crab invasion through sustainable **monitoring, surveillance, and management systems**, with the active involvement of institutions, local communities, and fishing operators. BLUECRAB project will establish a permanent observatory for scientific and economic studies aimed at mitigating the harmful effects of the blue crab. It will also develop a cross-border strategy and two action plans, tested through two pilot activities: systematic monitoring of the blue crab's spread using apps and IT tools, and selective fishing practices based on sex and reproduction. Additionally, guidelines will be developed to encourage the consumption of this species as a means of controlling its population locally. More information: https://www.ita-slo.eu/en/bluecrab.

7.3.3 Spain-Portugal | CRABMEDPOL project

The CRABMEDPOL project, led by the Spanish Institute of Oceanography (IEO-CSIC), focuses on using the **Atlantic blue crab as a model species to evaluate the effects of chemical pollution and microplastics on marine organisms**. It also explores the species' potential role as a sentinel for pollution in Mediterranean ecosystems. The project involves analyzing and validating various chemical and biological indicators at different levels of biological organization in the blue crab, ranging from proteomics to behavioral biomarkers. These analyses aim to provide insights into the bioaccumulation of environmental contaminants, including micro- and nano-plastics, and their impacts on the health of the species. Spanning three years, the project is divided into three phases. The first phase involves the development and validation of experimental procedures. The second phase consists of two controlled laboratory experiments, known as microcosm studies. The final phase includes an environmental analysis using the Mar Menor coastal lagoon as a case study to assess real-world impacts.

7.3.4 International | General Fisheries Commission for the Mediterranean – GFCM – Research programme on blue crabs

General Fisheries Commission for the Mediterranean
Commission générale des pêches pour la Méditerranée

The GFCM issued Recommendation GFCM/42/2018/7 on the implementation of a regional research programme on blue crab in the Mediterranean Sea, in order to properly evaluate their population status and maintain sustainable fisheries. The main objective of this research programme is to **set up a coordinated science-based framework for the sustainable management of blue crab fisheries**, taking into account both economic and environmental objectives. The research programme has **six specific objectives**, each corresponding to as many work packages (WP):

1. Collect as much information as possible on the **biological and ecological characteristics** of the two species of blue crabs in order to **support responsible fisheries management**.
2. Collect **fisheries independent data** to provide valuable additional information on catch composition and on the overall affected faunistic community.
3. Collect **fisheries-dependent data** on Mediterranean blue crab to provide a foundation for an effective management structure and process.
4. **Establish an ad hoc framework for blue crab stock assessment**, considering both the habitats of the crabs and the particular characteristics of the fisheries.
5. Understand both the **technical/technological and socio-economic aspects** of blue crab fisheries.
6. Develop adaptive **management measures at local, national and regional levels** to keep blue crab populations at low levels.

More information: https://www.fao.org/gfcm/researchprogramme-bluecrabs/en/).

8 Recommendations for the management of blue crab species in the Mediterranean

Concerns about the invasion of blue crabs, Portunidae *Callinectes sapidus* and *Portunus segnis*, have been growing for several years. Even at the beginning of their invasion, intensive fishing and canning were identified as the only defences against their spread. However, in addition to these control measures, it is necessary to carry out a number of important actions for the effective implementation of control measures for these species in the Mediterranean.

As in Spain, France and Italy, action plans to combat the invasion of blue crabs have been put in place to limit their impact on economic activities and biodiversity.

An **international workshop was organized in Rome (Italy) on January 24, 2025** at the Ministry of Agriculture, Food Sovereignty and Forestry (MASAF), bringing together **43 participants and experts of invasive species from 16 Mediterranean countries** to present the current situation of the invasion of the two blue crabs *Callinectes sapidus* and *Portunus segnis* in the Mediterranean, and to present local initiatives in each country to mitigate and combat blue crabs. **A round-table discussion** was organized to **propose recommendations for the implementation of an action plan against blue crabs in the Mediterranean.**

It became clear that **eradication** (i.e. the removal of all individuals from an invaded area) **is impossible** in the case of blue crabs, which currently have viable, reproducing populations that are integrated into ecosystems. However, the challenge now is to **find ways of mitigating blue crabs** to **protect biodiversity** by reducing blue crab abundance, and to **reduce the socio-economic impacts** on artisanal fishing and aquaculture.

The recommendations proposed in this report to combat the blue crab invasion have the overall aim of **helping Mediterranean countries to adapt these measures to their country's socio-economic and ecological context**.

The aim is to propose **five national and international strategies**, and to strengthen and structure collective actions as well as specific actions based on solid scientific foundations and a common Mediterranean control strategy for greater effectiveness.

The proposed plan of recommendations comprises **five actions** and **one action of governance**:

- ❶ Monitoring blue crabs and quantifying ecological impacts (national/regional scales)
- ❷ Spatial control and fisheries (national/regional scales)
- ❸ Awareness on consumption and socio-ecological implications (national/regional scales)
- ❹ Early detection and rapid response (national/international scales)
- ❺ International cooperation programs (international scales)

Action plan to fight the blue crab invasion in the Mediterranean Sea

National & Regional scales

1 Monitoring blue crabs and quantifying ecological impacts

- **Population dynamics** → Monitor **population structure**, sexual maturity, reproduction to **determine sensitive periods for the species.** A **stock assessment analysis is essential .**
- **Biological studies** → **Reproduction and growth** rates, **habitat** use (acoustic telemetry) and migrations.
- **Ecological impacts** → **Food web analysis** (isotopes, stomach contents), **species functional response** to quantify impacts on local biodiversity

2 Spatial control and fisheries

- **Control periods** → Based on population monitoring, set up **intensive fishing operations during sensitive periods** for the species (e.g. breeding season, migration periods of females at sea) to extract as many individuals as possible.
- **Fishing gears** → Develop **efficient catching methods**: test types of **fishing gears adapted** to blue crabs and local substrate conditions
- **Blue crab chain** → On a national scale, develop a **blue crab marketing chain**. The national chain will enable **short-line sales of specimens without international exports**, to limit economic competition between countries.

3 Awareness on consumption and socio-ecological issues

- **Education** → Public education and awareness is essential to the development of a blue crab chain. **Public events on blue crab consumption** (show cooking, TV programs, recipe books, etc.) **are essential.**
- **Engagement** → Raising public awareness of **the impact of blue crabs on socio-economic activities and biodiversity** is essential. Explain that **commercialization is a method of population control** to help preserve ecosystems.
- **Stakeholders** → **Include stakeholders and conduct Local Ecological Knowledge (LEK) studies** to determine **management expectations** and **perceptions of blue crab impacts.**

International scale

4 Early detection and rapid response

- **Education** → Raise public awareness and **provide information on best practices to be used when encountering a blue crab** (e.g. don't release it into the water, destroy the specimen, report its presence), **based on European and international regulations on invasive species.**
- **Citizen science** → Develop **harmonized citizen science programs to report the presence of blue crabs** for **early detection** and **monitoring of species persistence.**
- **Monitoring** → Scientists and managers need to **set up monitoring systems in areas not invaded by blue crabs and/or at the start of the local invasion**, to **detect their presence and implement containment and removal measures.** This is **particularly the case for *Portunus segnis*, which is still in its expansion phase.**

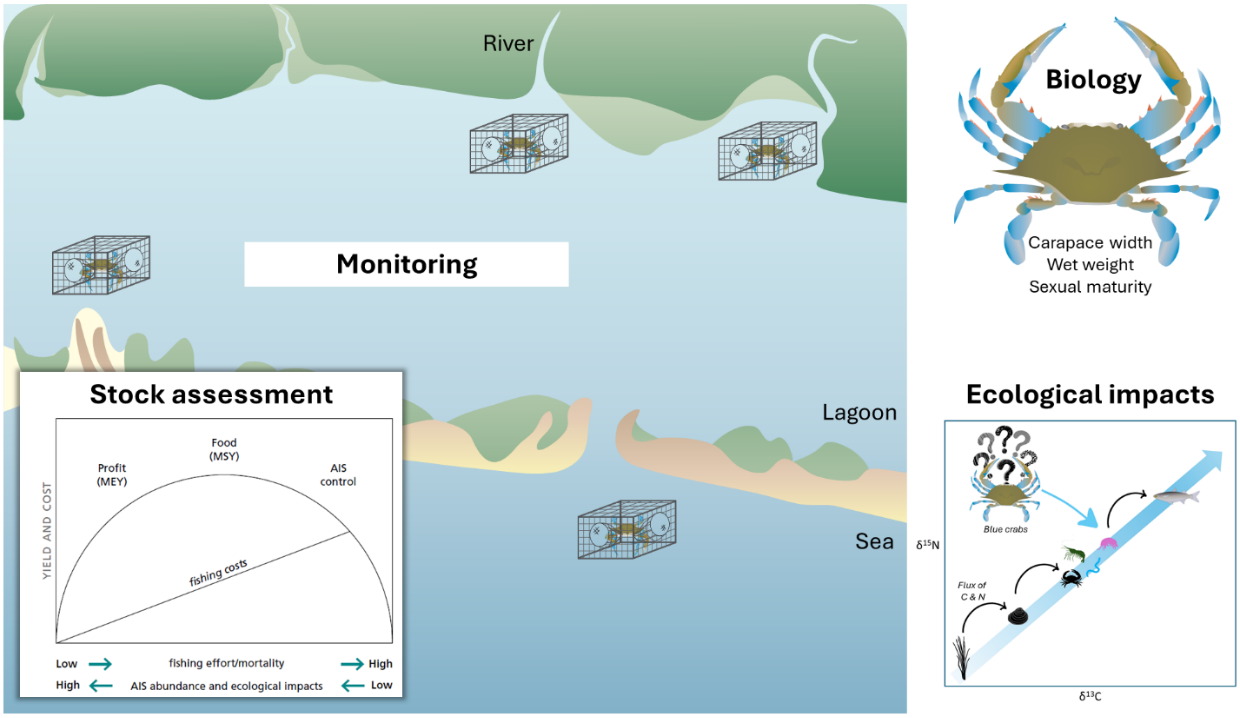
5 International cooperation programs

- **Transboundary projects** → Increase **cross-border projects between the north and south of the Mediterranean** to **combine expertise** between researchers/institutions **for a better understanding of international issues.**
- **Best practices** → **International meetings and workshops** will provide an **opportunity to exchange best practices** in terms of blue crab response and **management in Mediterranean country.**
- **Harmonized actions** → An **international Mediterranean blue crab action committee** should be set up **to harmonize all the proposed recommendations.**

Gouvernance

- **Program evaluation using indicators defined for each operation**, and will make it possible to monitor the progress of each action according to the initial schedule.
- **Inclusion of all stakeholders in the governance process:** ministries, scientists, managers, fishermen/fish farmers, government departments, **to ensure a global vision of the issue.**
- Set up **meetings twice a year** (one interim, one annual) **to review progress and production of deliverables.**

❶ Monitoring blue crabs and quantifying ecological impacts



To analyse populations structures and ecological impacts of blue crabs, it is essential to **identify pilot sites** that are representative of invaded sites on a national/regional scale. **These pilot sites will serve as laboratories for carrying out the action 1 tasks**.

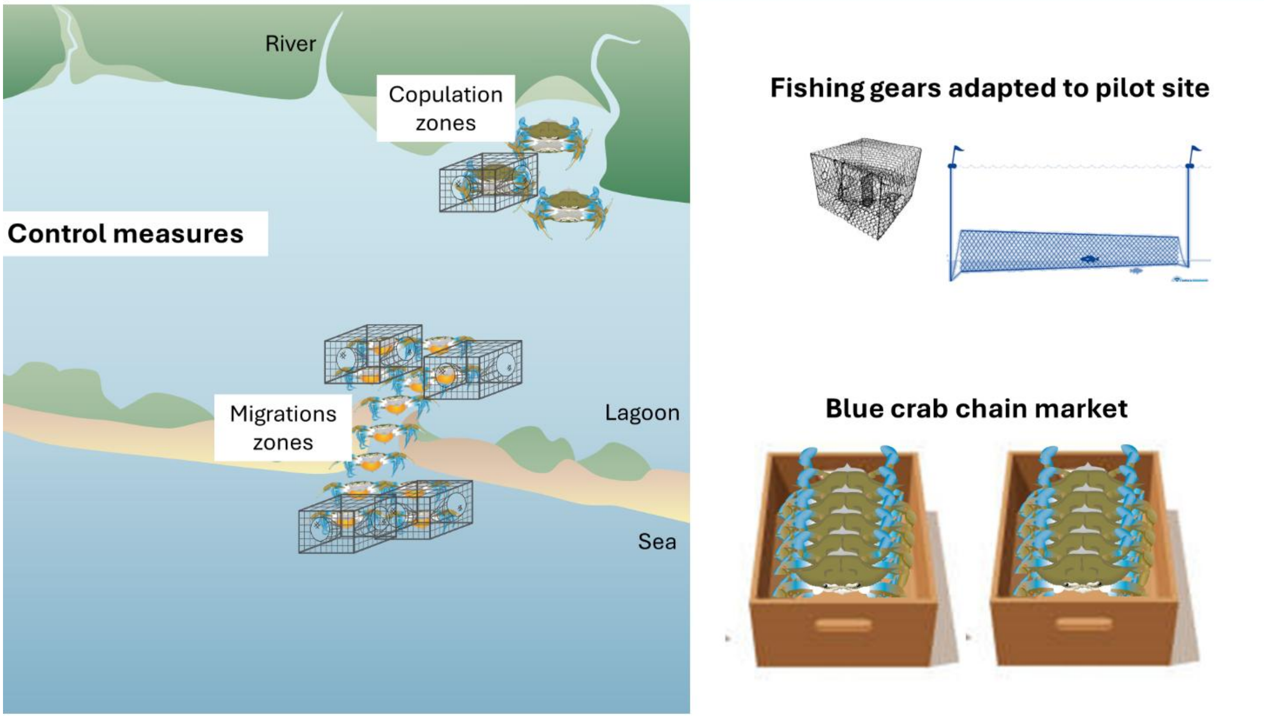
The first action involves **monitoring the population dynamics** of blue crabs, including their **structure, sexual maturity, and reproduction**, to identify **sensitive periods** for the species. This involves measuring carapace length, wet weight, sexual maturity, egg mass and egg colour. Indicators such as the proportion of each size class will help determine **population structure and growth rates**. **Long-term, high-frequency population monitoring** (minimum 1 to 2 times a month) should be implemented to obtain robust data on blue crab populations. It is also recommended to carry out **spatial monitoring** in the same area (i.e. several fisheries in different areas of invaded sites on a local scale) to determine the spatial distribution of blue crabs and their habitat use, in order to gain a better understanding of which areas should be prioritized for population control. The monitoring needs to include the **measurements of environmental parameters** as temperature, salinity, oxygen, etc. to identify the effect of environment on population structure.

Stock assessment is also crucial to implement effective actions. Biological studies focus on **reproduction** (sexual maturity, males/females' ratio, reproduction periods, eggs)**, growth, and migrations** (using techniques such as acoustic analysis for the last). **Assessment stock models need to be developed**, based **on classic fishing models**, to **determine the quantities of blue crabs that need to be fished** to have a significant control effect on populations and avoid population sustainability.

Finally, **ecological impacts need to be assessed** through food web analyses (e.g., isotopes, stomach content) to evaluate the effects of blue crabs on local biodiversity and ecosystem functions. The analysis of ecological impacts will need to consider **analyses of ecosystem services**, including fisheries and aquacultures, **to determine how the blue crab invasion mitigates ecosystem services** at the pilot sites.

Also, if available, a **comparison could be made with baselines on native species/biodiversity before** blue crab invasion, to compare the effects of blue crabs on biodiversity.

❷ Spatial control and fisheries

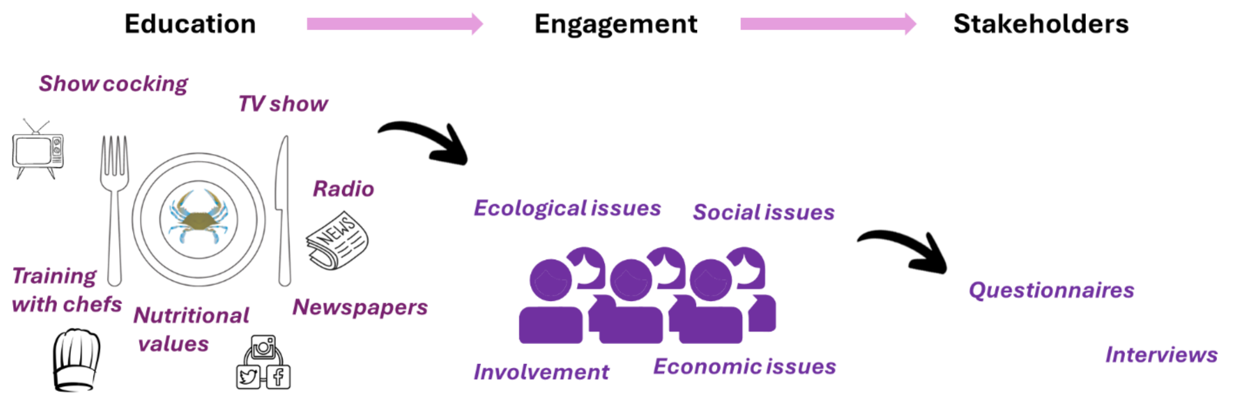


To control blue crab populations, it is proposed to **establish control periods** based on population monitoring, particularly **during sensitive periods for the species** such as reproduction. **Females are often the limiting element in blue crab populations**. Then it is important to **determine where, when and how** to catch as many females as possible during key periods. It has been recognized that it is **during the copulation and migration periods of ovigerous females that action should be taken**. For each pilot site, the aim will be to **locate the migration routes** of the females before they go out to sea, by setting up **barriers between the lagoons and the sea, for example**.

The control action must be carried out with efficient fishing equipment to capture as many individuals as possible. Then, developing adapted fishing tools is also necessary, with **tests on specific gear** designed to capture blue crabs while minimizing impacts on local substrates. Many types of fishing equipment are used in the Mediterranean, but not all work in the same way in all areas. Therefore, as part of action 1 of the monitoring program, it is **recommended to test the different types of fishing gears to determine which are the most effective, depending on the substrate** in the pilot site.

On a national scale, **creating a blue crab marketing chain** will allow for the quick sale of specimens **without relying on international exports**, reducing competition between countries and supporting local fishers. The creation of a blue crab chain is of great interest, particularly to enhance the value of catches made during control operations. This will make it possible to compensate for economic losses linked to the impact of blue crabs on small-scale fishing and aquaculture, and to use marketing as a control measure. The creation of a blue crab chain needs to be discussed, framed and set up in collaboration between **government departments, fishermen/fish farmers, restaurateurs and seafood marketing** companies, to ensure the distribution and eventual transformation of blue crabs for consumption.

❸ Awareness on consumption and socio-ecological implications

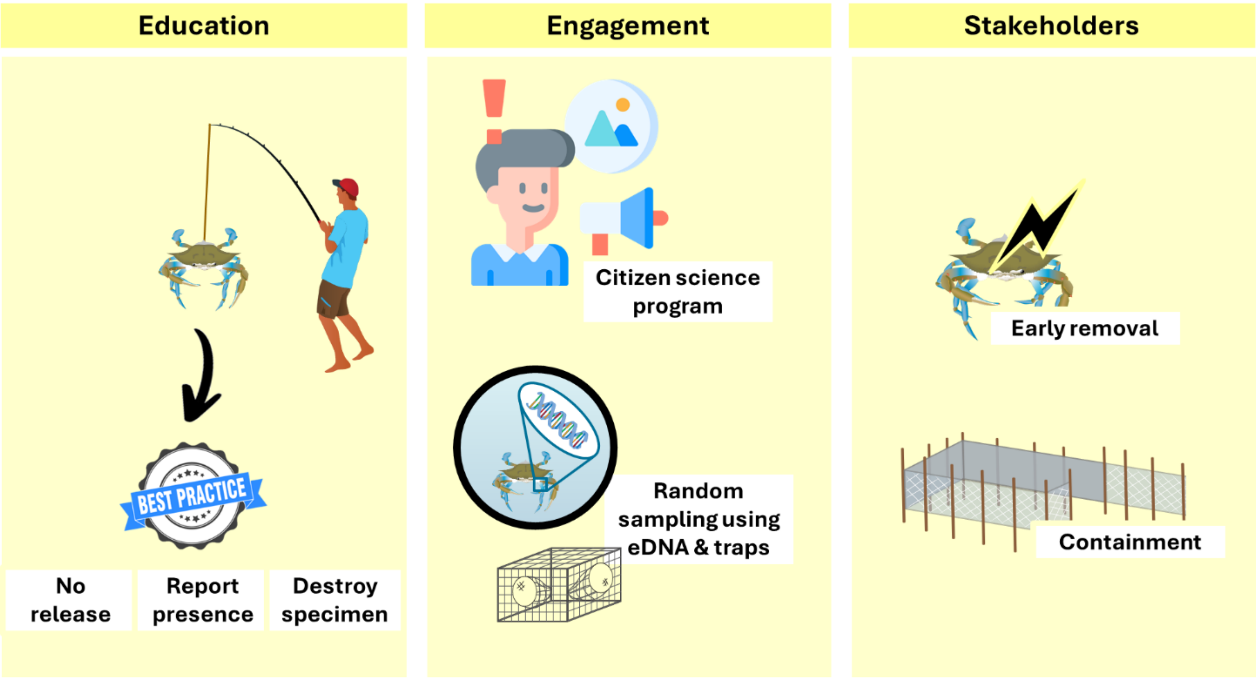


Engaging stakeholders is an inevitable part of creating a blue crab chain. **Public awareness** is critical to **promoting the consumption of blue crabs and develop a blue crab market chain**. Events such as **cooking workshops, television programs, and cocking trainings recipe contests,** can help integrate this species into dietary habits. Explain the nutritional value of blue crabs could help consumers to buy and eat blue crabs. Raising public awareness of the possible uses of blue crab will encourage citizens to use blue crab either as a **new food resource** or for **industrial purposes**. Indeed, the chitin in blue crab shells can also be used for food, cosmetic and medical purposes, and this opportunity also represents another application in the use of blue crabs as an industrial resource.

Additionally, it is **important to highlight the socio-economic and ecological implications of their proliferation, explaining that commercialization can serve as a control measure**. Events for the general public, in collaboration with government departments, managers, fishermen and scientists, should be set up, combining **conferences and communications tools on the impacts of blue crabs**, games and animations on the socio-economic and ecological challenges of blue crab management. Documentaries, television programs, radio broadcasts and press articles will be used to communicate these aspects.

Stakeholders' engagement is also essential. Stakeholders, including fishers and local managers, consumers, should be involved through **Local Ecological Knowledge** (LEK) studies to enhance perceptions and improve the effectiveness of management measures. **Questionnaires and interviews** should be carried out on a regular basis throughout the implementation of the action plan to **monitor the evolution of stakeholders' perceptions of the effectiveness of the actions** taken and the **evolution of the impacts** caused by blue crabs. This is an important **indicator for determining the success of these actions**. Stakeholders should be involved in the **removal control operations** with scientists and managers where stakeholders could contribute to the species control actions.

❹ Early detection and rapid response

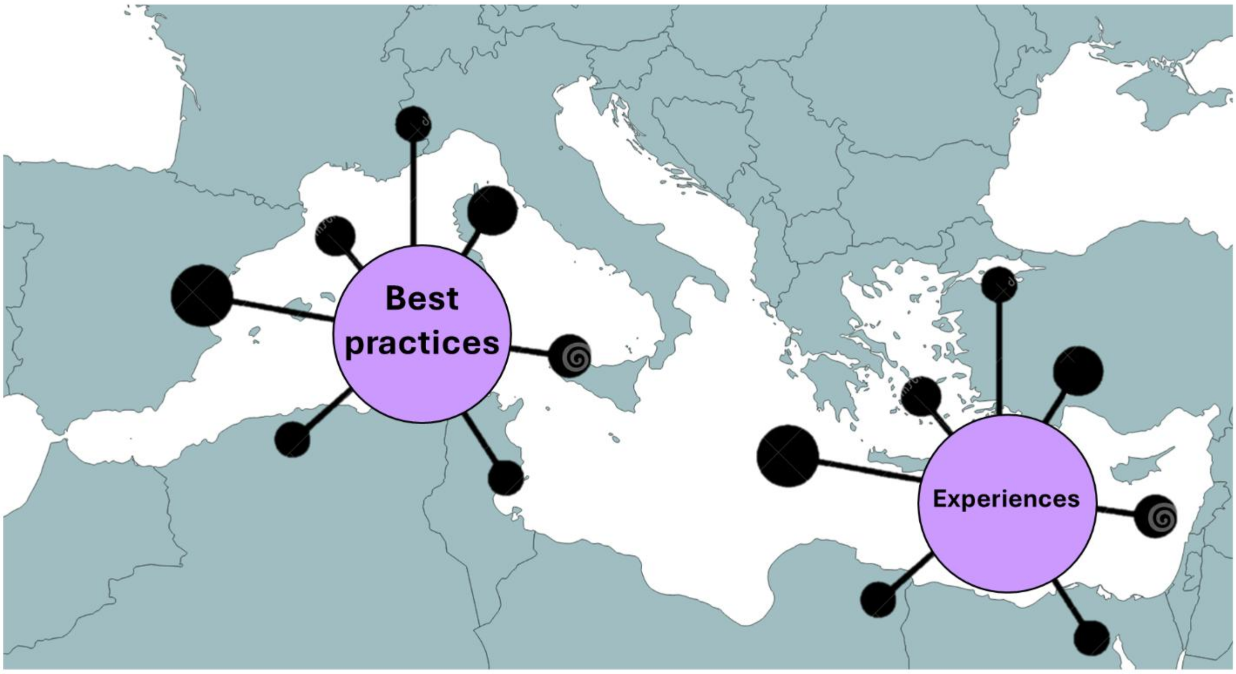


Increased awareness and dissemination of **best practices for handling encounters with blue crabs** (e.g., not releasing them, reporting their presence, etc.) are essential. To avoid accidental or unfortunate introductions, **public awareness campaigns should be set up to pass on good practices when encountering a blue crab**. Whether in the form of brochures, workshops, via social networks or organizing **control actions events**, these awareness campaigns will help prevent the release of specimens accidentally caught by recreational fishing, for example.

Harmonized **citizen science programs** are needed to **effectively monitor the expansion of blue crabs** to contribute to the **Early detections and rapid response (EDRR) programs** to limit the expansion of the both species. These citizen science programs should consist of easy-to-use platforms for reporting the presence of a blue crab, allowing users to enter information about the capture site (GPS coordinates, date, etc.) and photos. At the same time, **monitoring systems need to be implemented**, in particular **using eDNA** to detect the potential presence of blue crabs. These programs will enable scientists and managers to take action to implement containment or intensive fishing measures to limit the establishment of a new population.

Surveillance systems should be established in areas not yet invaded to enable early detection and apply containment measures, especially for *Portunus segnis*, which continues to expand.

❺ International cooperation programs



International cooperation is crucial for effectively managing blue crab invasions. **Cross-border projects between the northern and southern Mediterranean regions should be developed** to combine expertise and address global challenges. **International meetings and workshops** provide opportunities to exchange best practices for managing and utilizing blue crabs. By responding to **large-scale calls for projects** (e.g. European, regional, etc.), this will enable Mediterranean countries to collaborate, exchange practices and implement harmonized protocols to help compare data.

Lastly, the **creation of a Mediterranean Blue Crab Action Committee** is recommended to harmonize efforts and implement coordinated actions at the regional level. The establishment of this committee/consortium could be facilitated through the GFCM Blue Crabs program.

Gouvernance

1. Composition

- **Action plan governance is an important body for the proper implementation of the actions proposed** in the action plan. Governance must bring together all stakeholders, in particular ministries, scientists, fishermen and aquaculturists, managers and, where appropriate, those involved in catering and value chains.
- The governance group must **meet at least twice a year**, i.e. every 6 months, to monitor the progress of the actions undertaken. Progress indicators must be defined by the governance group in order to define successes or failures in the implementation of actions.
- **The governance group must include all stakeholders in the process:** ministries, scientists, managers, fishermen/fish farmers, government departments, **to ensure a global vision of the issue.** The governance group ensures fluid communication between stakeholders.

2. Strategy development

- Develop short-, medium- and long-term objectives.
- Define priorities according to the seriousness of the threat, the areas affected and the resources available.
- Ensure consistency of actions with national and international regulations.

3. Resource management

- Ensure efficient allocation of financial, human and material resources for control actions.
- Identify additional sources of funding (subsidies, public-private partnerships, etc.).

4. **Monitoring and follow-up**
   - Set up systems to monitor and evaluate actions taken, in order to measure their effectiveness.
   - Encourage scientific research to better understand invasive species and their impacts.
   - Adapt the strategy according to the results obtained and new information.

5. **Reporting results**
   - Produce regular reports to inform partners, decision-makers and the public on progress made.
   - Highlight good practices and lessons learned to inspire other similar initiatives.

Action plans on a regional and/or national scale purposed in this document should also be implemented as part of the research and actions carried out and in collaboration with the Research programme on blue crabs run by the General Fisheries Commission for the Mediterranean (GFCM).

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