



## Review

# New kid in town: the Mediterranean outbreak of *Callinectes sapidus*, its road to valorization and the Italian paradox

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## ABSTRACT

The invasion of the Atlantic blue crab, *Callinectes sapidus*, in the Mediterranean has evolved from a 20th-century lag phase into an explosive demographic surge. Driven by tropicalization and marine heatwaves, this expansion has triggered a systemic ecological and socio-economic crisis, particularly in the Northern Adriatic. We review current knowledge on the invasion history of *C. sapidus* in the Mediterranean, the environmental drivers underpinning the demographic expansion that started in 2019-2020, and its impacts on biodiversity, aquaculture, and ecosystem services. This review identifies a critical "Italian paradox": while biomass reached unprecedented levels in 2025, exceeding 2,200 tonnes in the Po Delta alone, the management response remains reactive, focusing on costly disposal rather than high-value exploitation. A transition toward a Blue Biorefinery model is suggested to be the key to resolve this paradox. Beyond its culinary value, *C. sapidus* is a reservoir of high-value compounds, including medical-grade chitosan, antihypertensive peptides, and astaxanthin, with very high market value. By implementing green extraction technologies, a biological threat can be transformed into a self-sustaining circular economy. However, industrial scaling must integrate rigorous monitoring of heavy metal bioaccumulation and emerging pathogens to ensure safety.

## 1. Introduction

Marine biological invasions are a major driver of biodiversity change and ecosystem degradation in coastal environments (Bax et al., 2003). This is particularly evident in semi-enclosed seas like the Mediterranean. In this region, intensive maritime transport, coastal development, and climate warming facilitate the establishment of numerous non-indigenous species (Streftaris et al., 2006; Occhipinti-Ambrogi et al., 2011; Zenetos et al., 2012; Galil et al., 2014; Katsanevakis et al., 2014).

Within this framework, the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 represents a paradigmatic case of a late-stage marine invasion. Its presence has profound ecological and socio-economic implications (Mancinelli et al., 2021; Tiralongo et al., 2024). Native to the western Atlantic (Kennedy and Cronin, 2007), *C. sapidus* is a highly mobile and euryhaline predator. It is also an opportunistic feeder capable of exploiting various habitats and prey (Hines et al., 1987; Eggleston et al., 1992). Early Mediterranean records from the mid-20th century were sporadic (Giordani Soika, 1951; Nehring, 2011). However, recent years have seen widespread establishment and population growth across the basin (Dulčić et al., 2011; Mancinelli et al., 2017a; Castriota

et al., 2024; Galil et al., 2020). Evidence suggests these outbreaks are linked to both environmental changes and anthropogenic drivers. These factors lead to significant impacts on native biodiversity and local fisheries, including declines in commercial species and altered ecosystem dynamics (Marchessaux et al., 2023a; Siddiolo et al., 2025).

The demographic outbreak of *C. sapidus* represents a multi-scale challenge that varies significantly from the basin-wide Mediterranean level to specific local hotspots. At the Mediterranean scale, the species' success contrasts with its native range; while in the Chesapeake Bay the blue crab is a strictly managed and protected resource (Zohar et al., 2008), in the Mediterranean it is often regarded as a pervasive invasive pest (Mancinelli et al., 2017a). Furthermore, a divergence is emerging between different Mediterranean countries: while some regions have successfully integrated the species into commercial markets (Clavero et al., 2022), at the Italian national level, the situation remains in an emergency phase, characterized more by "waste management" than resource exploitation.

Focusing on the Italian lagoons of the Northern Adriatic (the primary case study of this review), a profound economic paradox has emerged. Despite *C. sapidus* being a high-value global commodity, its predatory

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behavior has led to the near-bankruptcy of local clam and mussel farmers, whose livelihoods are decimated by the very resource that could, in theory, be valorized (Chiesa et al., 2025). To address these overlapping scales, this review aims to: (i) international scale: reconstruct the invasion history of *C. sapidus* across the Mediterranean basin; (ii) regional scale: identify the drivers behind the recent population explosion along the Italian coasts; (iii) impact analysis: synthesize evidence of impacts on biodiversity and aquaculture; (iv) strategic scale: discuss emerging socio-economic responses and the "blue biorefinery" as a scalable management option for both EU and non-EU Mediterranean contexts.

## 2. New kid in town

### 2.1. Bibliographic search and study selection

To provide a quantitative assessment of the invasion history and scientific interest regarding *Callinectes sapidus* Rathbun, 1896, in the Mediterranean-Pontic basin, a systematic literature search was conducted following the PRISMA approach (Moher et al., 2009). We queried major electronic databases (Google Scholar, WoS) for peer-reviewed articles published between 1950 and 2025. To ensure high specificity and capture papers where the species is the central topic, the *intitle:* operator was employed. The following Boolean string was utilized: (*intitle:"Callinectes sapidus" OR intitle:"blue crab"*) AND (*"Mediterranean Sea" OR "Adriatic" OR "Ionian" OR "Tyrrhenian" OR "Aegean" OR "Levantine" OR "Black Sea" OR "Sea of Azov" OR "Marmara Sea"*) NOT (*"Atlantic Ocean" OR "Chesapeake Bay" OR "Gulf of Mexico" OR "Indo-Pacific" OR "Red Sea"*). The screening process involved the following criteria: (i) inclusion: peer-reviewed original research, short communications, and systematic reviews published in English or Mediterranean regional languages (e.g., Italian, Spanish) that focused on the ecology, distribution, or management of the blue crab within the Mediterranean-Pontic basin; (ii) exclusion: gray literature (e.g., theses), duplicates, and misidentifications. Following the PRISMA guidelines, the literature selection process is synthesized in Table S1 (Supplementary Materials). The systematic search initially yielded 382 records. After the removal of duplicates, grey literature, and misidentifications with other species colloquially named *blue crab* (such as *Portunus segnis*), a total of 225 records were considered valid and included in the final qualitative and quantitative synthesis. In Fig. 1, the temporal trends in scientific research on *C. sapidus* in the Mediterranean-Pontic basin (1950–2025) is shown. The bar chart illustrates the decadal number of peer-reviewed publications identified: the data highlights a prolonged lag phase

(1950–1999) characterized by sporadic taxonomic records, followed by an establishment phase (2000–2014) and a subsequent exploding rising phase (2015–2025). The sharp increase in the last decade (accounting for >80% of total records) reflects the transition from anecdotal sightings to intensive research on biomass expansion, socio-economic impacts, and fisheries management.

### 2.2. The Mediterranean invasion of the Atlantic blue crab

The invasion history of the Atlantic blue crab in the Mediterranean is a complex narrative of biological resilience and expansion. Native to the western Atlantic, this portunid species possesses several key physiological traits. These include high fecundity, aggressive foraging, and a wide tolerance for varying salinities and temperatures (Hines et al., 1987; Eggleston et al., 1992). Such characteristics have facilitated its transition from an exotic curiosity to a dominant benthic component across the basin (Galil et al., 2011; Mancinelli et al., 2017a; Marchessaux et al., 2023a).

The initial invasion phase was characterized by a lag period lasting over half a century. In European waters, *C. sapidus* was first recorded near Rochefort, France, in 1901 (Bouvier, 1901). The first official Mediterranean record was a female specimen collected in 1949 from the Gulf of Venice (Giordani Soika, 1951). However, earlier arrivals in the Aegean Sea may date back to the 1930s (Enzenroß et al., 1997). Throughout the late 20th century, the crab's presence remained stable and restricted. It established self-sustaining but geographically limited populations, primarily in the eastern Mediterranean (Cavaliere and Berdar, 1975; Streftaris and Zenetos, 2006; Kampouris et al., 2020). In the Black Sea, the species was first recorded in Bulgaria in 1967 (Bulgurkov, 1968).

The secondary phase began in the early 2010s and marked a shift toward explosive spread. This acceleration is often attributed to the "tropicalization" of the Mediterranean, where rising minimum winter temperatures have exceeded the threshold required for the survival of the species' larval stages (Mancinelli et al., 2017a; Clavero et al., 2022; Marchessaux et al., 2022). In the western Mediterranean, the Ebro Delta emerged as a major colonization hub. From there, the species spread rapidly along the Iberian coast, into the Gulf of Lions, and the Ligurian Sea (Suaria et al., 2017; Labruno et al., 2019). By 2020, the central Mediterranean witnessed a similar surge. In Italy, the species bridged former distribution gaps, moving from the Adriatic (Cilenti et al., 2019) into the Ionian and Tyrrhenian Seas (Tiralongo et al., 2021) and reaching Malta (Deidun et al., 2022). As of 2025, the species is recorded almost ubiquitously across the Mediterranean and Black Seas (Nehring,

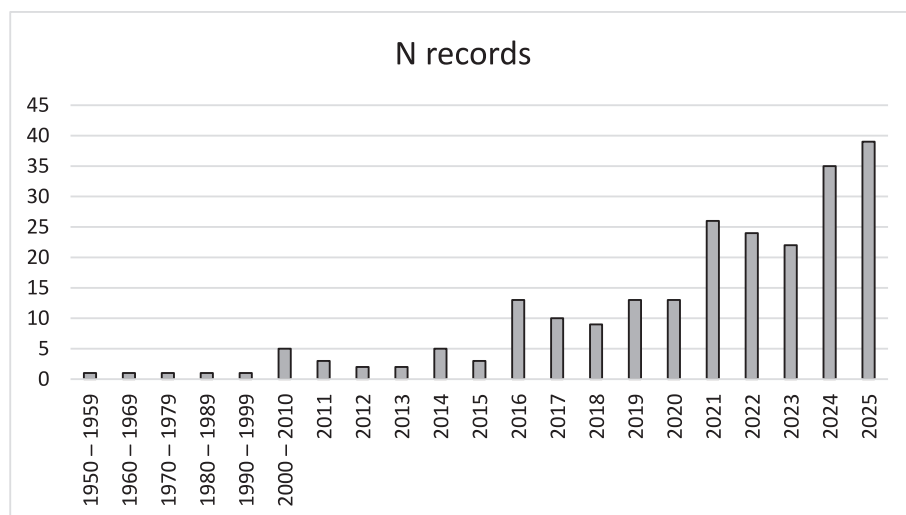


Fig. 1. Temporal trends in scientific research (number of peer-reviewed publications per year) on *Callinectes sapidus* in the Mediterranean-Pontic basin (1950–2025).

2011; Pashkov et al., 2012; Castejón and Guerao, 2013; Chartosia et al., 2018). Table 1 summarizes the chronological records of *C. sapidus* in the Mediterranean.

At present, no conclusive evidence identifies the specific pathway of the first introduction into the Mediterranean. Some authors suggest a deliberate release for fisheries purposes (Giordani Soika, 1951). However, most researchers attribute the introduction to ballast water transport (Galil et al., 2011; Nehring, 2011; Garcia et al., 2018; Deidun et al., 2022). Genetic data supports the involvement of both pathways through multiple introduction events (Schubart et al., 2023). Following establishment, ballast water likely drove secondary spread, aided by the species' pelagic life stages (Png-Gonzalez et al., 2021; Galil et al., 2022).

Ongoing climatic changes also appear to enhance the metabolic performance and expansion of *C. sapidus*. Between 2023 and 2025, the invasion reached new frontiers along the North African coastline. Extensive populations now exist from the Gulf of Gabès in Tunisia to the Atlantic coasts of Morocco. This suggests the species is using the Alboran Sea as a corridor between the Mediterranean and the eastern Atlantic (Kara and Chaoui, 2021; Hamiche and Aksissou, 2024).

Furthermore, recent monitoring highlights the species' extraordinary ecological plasticity. In 2025, researchers confirmed that *C. sapidus* maintains its entire reproductive cycle within hypersaline lagoons. One example is the Stagnone di Marsala in Sicily, where salinity levels significantly exceed those of the open sea (Cicala et al., 2025). This ability to thrive in extreme environments, from brackish waters to hypersaline ponds, explains why the Atlantic blue crab is one of the most successful decapod invaders in Mediterranean history (Cicala et al., 2025; Gaglio et al., 2025).

### 2.3. Biological traits and environmental tolerance of *Callinectes sapidus*

The success of *Callinectes sapidus* in the Mediterranean is rooted in its

**Table 1**  
Chronological records of *Callinectes sapidus* in the Mediterranean Sea.

Area	Year	Invasion phase	Reference
Gulf of Venice (Northern Adriatic)	1949	First confirmed Mediterranean record	Giordani Soika, 1951
Black Sea (Bulgaria)	1967	First confirmed Black Sea record	Bulgurkov, 1968
Sicily (Central Mediterranean)	1970-1972	Early sporadic recordings	Cavaliere and Berdar, 1975
Aegean Sea (Eastern Mediterranean)	1983	Early sporadic recordings	Riedl, 1983
Croatia (Eastern Adriatic)	2004	First record	Onofri et al., 2008
Albania (Eastern Adriatic)	2009	Expansion	Beqiraj and Kashita, 2010
Spain (Ebro Delta)	2012	First record	Castejón and Guerao, 2013
Italy (Western Adriatic)	2012	Expansion	Castriota et al., 2012
Po Delta (Northern Adriatic)	2015	Expansion	Manfrin et al., 2015
Egypt (South-eastern Mediterranean)	2016	First record	Moussa et al., 2016
Straits of Sicily (Central Mediterranean)	2018-2019	Establishment evidence	Pipitone et al., 2020
Northern Adriatic	2018	Establishment evidence	Munari and Mistri, 2019
Balearic Islands (Western Mediterranean)	2018	First record	Garcia et al., 2018
Morocco (South-western Mediterranean)	2017-2018	First record	Oussellam et al., 2023
Algeria (South-western Mediterranean)	2019	Expansion	Benabdi et al., 2019
Tunisia (Southern Mediterranean)	2020	Expansion	Mili et al., 2020
Malta (Central Mediterranean)	2022	Expansion	Deidun et al., 2022

life history and physiological plasticity. As a euryhaline and eurythermal species, the blue crab thrives across broad environmental gradients. These range from oligohaline river estuaries to hypersaline coastal ponds (Galil et al., 2011; Mancinelli et al., 2013, 2017a; Cicala et al., 2025). This adaptability is supported by a high osmoregulatory capacity. Such traits allow the species to maintain homeostasis where native Mediterranean decapods often struggle (Nehring, 2011; Hamiche and Aksissou, 2024).

The life cycle of *C. sapidus* follows a migratory pattern that exploits estuarine salinity gradients (Eggleston et al., 2015). Adults typically mate in low-salinity brackish waters. After copulation during the female's final soft-shell molt, females migrate toward high-salinity offshore waters to spawn (Hines, 2007; Nehring, 2011).

A critical driver of its invasive potential is high fecundity. A single female can produce between 2 and 8 million eggs per brood (Prager et al., 1990). Larvae (zoeae) are released into the marine environment and undergo several stages. They eventually return to estuaries as megalopae to join the benthic population (Png-Gonzalez et al., 2021).

In the warmer Mediterranean, the spawning season is longer than in the species' native range (Kampouris et al., 2020). Some populations in the eastern and central sectors now exhibit year-round reproductive activity (Kevrekidis et al., 2025). This continuous recruitment ensures a steady supply of larvae. These are transported by coastal currents, facilitating the rapid colonization of new territories (Mancinelli et al., 2017a; Marchessaux et al., 2023b; Gavioli et al., 2025a).

Larval development is a potential bottleneck that the species has navigated through thermal adaptation. The transition from zoea to megalopa requires temperatures above 15°C to 18°C (Costlow and Bookhout, 1959; Costlow, 1967; Marchessaux et al., 2024a, 2024b). The "meridionalization" of the Mediterranean has expanded the geographical area suitable for larval survival, especially during winter (Mancinelli et al., 2017a; Marchessaux et al., 2022).

Furthermore, the blue crab's aggressive foraging and generalist diet provide a competitive advantage over native species, such as *Carcinus aestuarii* (Pani et al., 2025; Piccardi et al., 2025). The combination of rapid growth, high reproductive output, and environmental tolerance creates a synergistic effect. This has allowed *C. sapidus* to become an ecologically dominant species within the Mediterranean's unstable coastal ecosystems (Nehring, 2011; Marchessaux et al., 2022, 2023a).

### 2.4. Synergistic drivers of the Mediterranean expansion: focus on the Northern Adriatic and Po Delta outbreaks

The population explosion of the blue crab is a phenomenon affecting much of the Mediterranean basin, as evidenced by the sharp increase in scientific publications since 2016. However, this surge appears to have reached its peak intensity within the lagoons of the Po Delta. The dramatic increase in *Callinectes sapidus* abundance observed in the Northern Adriatic since 2022 may be attributed to a synergy of environmental, ecological, and anthropogenic factors. Collectively, these interacting drivers appear to have enhanced recruitment, survival, and expansion at both regional and local scales.

A major driver at the basin-wide scale is the climate-linked warming of Mediterranean waters. Rising sea surface temperatures have improved the suitability of previously marginal habitats and reduced winter mortality (Gil-Fernández et al., 2024; Martellucci et al., 2025). Such warmer conditions are thought to facilitate faster growth, earlier maturation, and extended reproductive periods (Glandon et al., 2019). These shifts in phenology likely shorten the development time from zoea to megalopa (Costlow and Bookhout, 1959), potentially reducing the time crabs spend in vulnerable larval stages and thereby contributing to recruitment success. Furthermore, higher winter temperature minima might reduce dormancy periods, potentially facilitating year-round reproductive activity (Glandon et al., 2019).

In the Northern Adriatic lagoons, the invasion chronology follows a classic pattern of arrival, establishment, and expansion (Crooks and

Soulé, 1999). Early low detectability has been succeeded by an exponential rise (Shauer et al., 2025), a dynamic previously observed in other alien species in the Po Delta, such as *Anadara inaequalis* (Mistri et al., 1988) and *Arcuatula senhousia* (Mistri, 2002, 2004). While these earlier invasions initially alarmed clam producers, those species eventually integrated into the benthic community once the outbreak phase concluded.

Broad trophic flexibility and low predation pressure likely further facilitated demographic growth in Italian coastal waters (Mancinelli et al., 2016, 2017b; Shauer et al., 2025). Specifically, Adriatic lagoons provide high habitat suitability; abundant food resources and structural complexity support high benthic productivity (Mistri et al., 2001) and offer refugia for juveniles (Hines Jr. et al., 2001; Marchessaux et al., 2022; Gavioli et al., 2025a). While some models suggest temperature and salinity play lesser roles than habitat depth, nutrient-rich shallow environments appear to be major drivers of success (Gavioli et al., 2025a; Gavioli et al., 2026).

However, environmental drivers alone may not fully explain the extreme demographic explosion observed at the local scale of the Po Delta. This surge appears to be linked to anthropogenic pressures and the artificial concentration of resources. These transitional systems host intensive aquaculture of the Manila clam, *Ruditapes philippinarum* (Pellizzato and Da Ros, 2005; Munari et al., 2009). While recommended stocking densities are 3–4 kg m<sup>-2</sup> (Vincenzi et al., 2006), actual peaks in several concessions exceed 15 kg m<sup>-2</sup> (Mistri, 2009). This creates hundreds of hectares of lagoon floor densely packed with clams, sustained by high chlorophyll concentrations (Gavioli et al., 2026). Such conditions provide an exceptionally concentrated and predictable food resource. Without this human-mediated "all-you-can-eat" supply, the blue crab's success would likely have been far more limited. This is clearly evidenced by the situation in the hypereutrophic sub-basins of the Valli di Comacchio, such as Magnavacca and Fossa di Porto. Despite traditionally exceptionally high phytoplanktonic productivity (Sorokin et al., 1996, 1999), these areas are devoid of any aquaculture activities and characterized by extremely limited commercial fishing (Munari and Mistri, 2014). This limited anthropogenic exploitation resulted in a lower presence of *C. sapidus*, particularly in the central lagoon areas, far from fishing stations, compared to the intensive lagoonal aquaculture sites of the Po Delta (Parco Delta Po, pers. comm.).

In conclusion, while warming waters and nutrient influx likely support the surge across the Northern Adriatic, the availability of high-quality prey in confined areas may represent a decisive local anthropogenic driver. This intersection of factors creates the "Italian Paradox": while climate-driven biomass increases (Bhuiyan et al., 2026), management remains trapped in a cycle of costly disposal rather than strategic exploitation, as detailed in Section 4.

### 3. Impacts of *Callinectes sapidus* in the Mediterranean and Northern Adriatic Systems

#### 3.1. Impact on biodiversity

The establishment of *Callinectes sapidus* has led to significant alterations in native biodiversity and community structures across the Mediterranean, with extreme effects observed in Northern Adriatic transitional waters (Mancinelli et al., 2013; Vivas et al., 2025). The primary driver of this loss is the crab's aggressive, generalist predatory strategy. The species exerts strong top-down pressure on benthic assemblages, preying on a wide range of invertebrates (Hines, 2007; Mancinelli et al., 2016, 2017b; Aslan and Polito, 2021; Vivas et al., 2025).

Its superior crushing force allows the blue crab to outcompete native decapods and exploit hard-shelled prey (Mancinelli et al., 2021). This has caused the collapse of bivalve populations in the Ebro Delta and the Northern Adriatic (Clavero et al., 2022; Chiesa et al., 2025). Such losses may trigger trophic cascades, reducing the lagoons' filtration capacity

and negatively affecting water clarity and nutrient cycling (Pranovi et al., 2006).

Competitive exclusion of native crustaceans is another critical dimension of the invasion (Piccardi et al., 2025). The Mediterranean shore crab, *Carcinus aestuarii*, has been largely displaced in areas where *C. sapidus* is established (Mancinelli et al., 2017b; Prado et al., 2020). This displacement occurs through both direct aggression and superior resource acquisition. Multiple studies document population declines in *C. aestuarii* driven by exploitative competition and direct interference (Masi et al., 2022; Tiralongo et al., 2024; Piccardi et al., 2025).

This replacement disrupts trophic interactions and reduces functional diversity within benthic communities. Due to its larger size and faster growth, the blue crab tends to dominate preferred habitats. This may displace native species into less suitable habitats and, in some cases, contribute to local population declines (Prado et al., 2020; Piccardi et al., 2025). Furthermore, the crab's high salinity tolerance allows it to invade refuges previously exclusive to specialized native fauna (Cilenti et al., 2019; Marchessaux et al., 2024a, 2024b).

Beyond biological interactions, *C. sapidus* acts as a transformative ecosystem engineer. Its foraging behavior involves significant bioturbation as it digs into the substrate for prey. This "pitting" behavior causes the mechanical destruction of seagrass meadows, leading to rhizome fragmentation and patchiness (Cigarra et al., 2022). In the Mediterranean, where seagrasses provide essential structural complexity, this loss reduces the availability of nursery grounds. Consequently, coastal biodiversity declines as the "shelter effect" is compromised, leaving juvenile fish more vulnerable to predation (Mancinelli et al., 2017b).

Additionally, the introduction of *C. sapidus* raises concerns regarding the transmission of novel pathogens. As a carrier of various *Vibrio* strains and parasites (Esposito et al., 2026), the blue crab may introduce biological stressors to which native species have no immunity. This could trigger cryptic population declines that are difficult to monitor in the short term. Collectively, these effects suggest that *C. sapidus* acts as a powerful ecosystem modifier. Its effects are not limited to individual species declines, but are reflected in more subtle shifts in community composition, trophic interactions, and ecosystem functioning across Mediterranean and Northern Adriatic lagoons.

#### 3.2. Impact on mollusc aquaculture

The invasion of *Callinectes sapidus* has caused severe disruptions in Mediterranean mollusc aquaculture, particularly in the production of Manila clams (*Ruditapes philippinarum*) and mussels (*Mytilus galloprovincialis*). These species represent the basin's most economically significant shellfish sectors. At a regional level, the impacts have been most acute in the Northern Adriatic lagoons, historically among Europe's most productive areas for clam farming. During the 2023 spring–summer period, massive outbreaks coincided with a near-total loss of cultured stocks in several Italian concessions (Chiesa et al., 2025).

Local reports from the Po Delta indicate mortality rates reaching 100% in Sacca del Canarin and exceeding 75% in Sacca degli Scardovari. These declines represent an estimated loss of approximately 1,000 tonnes of clam biomass within just three months, with annual economic impacts for regional producers exceeding €250 million (Mispeces, 2024; Chiesa et al., 2025; Tiralongo et al., 2025). Field assessments corroborate these collapses; shells in these lagoons frequently exhibit characteristic predation marks, while natural seed beds show a stark lack of recruitment. This suggests a cumulative impact on both harvestable stocks and future population stability (Chiesa et al., 2025). Statistically, the collapse of yields in early 2024 shows a strong correlation with the surge in blue crab density (Tiralongo et al., 2025).

This crisis involves a complex interaction between two non-indigenous species: *C. sapidus* and *R. philippinarum*. The Manila clam, introduced in the 1980s, had already significantly altered the structure of Mediterranean lagoons (Bartoli et al., 2016); the blue crab invasion is

now further reorganizing these novel ecosystems. Experimental dietary studies confirm a strong feeding preference for bivalves (Blundon and Kennedy, 1982; Ebersole and Kennedy, 1995; Micheli, 1995). In mesocosm trials, daily predation rates on *R. decussatus*, *M. galloprovincialis*, and *Cerastoderma glaucum* ranged from 11% to 33%, depending on prey species and size (Pani et al., 2025). Preference hierarchies suggest that smaller, more vulnerable specimens, such as seed and juvenile stages, are disproportionately affected.

Comparative research from other Mediterranean hotspots, such as the Ebro Delta, found predation rates on mussels ranging from 38% to 96%. Conversely, Pacific oysters remained largely resistant to predation until reaching a specific size threshold, illustrating the protective role of shell hardness (Prado et al., 2020). Collectively, these findings imply that in Mediterranean aquaculture settings, blue crab predation leads to extensive biomass loss, particularly for smaller size classes essential for biological stock replenishment.

In response to the crisis at the national scale, the Italian government has implemented legislative and financial measures to mitigate production losses. Authorities have established a structural support framework, including economic compensation for the capture and disposal of crabs, reimbursement for clam seeding costs, and investments in protective barriers (Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2023a, 2023b). Multiple decrees in 2023 and 2024 allocated substantial funding, reaching tens of millions of euros, to compensate for immediate financial losses and provide long-term protection for farms (Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2024a, 2024b). This expenditure underscores the economic strain on the sector and the perceived urgency of a coordinated transboundary response (UNEP/MAP-SPA/RAC, 2025).

Data in Table S2 (Supplementary Materials) highlight a gradient of vulnerability among Mediterranean mollusc species. Manila clams exhibit the most severe declines, followed by mussels and oysters (*Ostrea edulis* and *Crassostrea gigas*). While quantitative data on long-term mussel losses are comparatively limited, field observations suggest significant risks; blue crabs can potentially disrupt both benthic and suspended culture operations, indicating an underestimated risk as invasion fronts expand (Prado et al., 2020). Oysters exhibit size-dependent vulnerability; recent studies (Di Martino and Stancanelli, 2025) indicate high mortality for juvenile *O. edulis*, raising concerns for restoration initiatives (Brundu et al., 2025). Conversely, *C. gigas* shows lower predation rates once individuals exceed critical size thresholds, suggesting that impacts might be mitigated through modified husbandry practices (Prado et al., 2020).

Overall, the evidence indicates that the blue crab invasion represents a substantial threat to Mediterranean aquaculture, particularly for species reliant on benthic culture. The magnitude of losses in the Po Delta underscores the urgency of developing targeted mitigation strategies, ranging from physical exclusion to adaptive farming practices, to prevent similar collapses in other mollusc sectors across the basin.

### 3.3. Impact on small-scale fisheries

The invasion of *Callinectes sapidus* has generated substantial ecological and socio-economic impacts on Mediterranean capture fisheries. Small-scale and artisanal sectors operating in lagoons, estuaries, and shallow coastal waters are particularly affected (Table S3; Supplementary Materials). These fisheries are highly vulnerable due to their reliance on fixed gear and benthic resources that spatially overlap with blue crab habitats. At a basin-wide scale, studies and fisher reports document significant catch declines in traditional target species, such as the European eel (*Anguilla anguilla*), flatfishes (*Solea solea*), mullets (*Mugilidae*), and native crustaceans, coinciding with increased blue crab abundance (Mancinelli et al., 2021; Gavioli et al., 2025b).

These declines likely result from a combination of direct predation on juveniles, competition for benthic prey, and habitat disturbance

caused by the crab's foraging and burrowing activity. Beyond ecological interactions, *C. sapidus* directly interferes with fishing operations at the operational scale. The species often causes extensive damage to nets, fyke nets, and traps, preys on captured fish, and increases labor costs related to sorting and bycatch handling (Cilenti et al., 2019; Masi et al., 2022; Marchessaux et al., 2023c).

In several Adriatic and Ionian lagoons, blue crab biomass now frequently dominates daily catches during peak seasons, sometimes exceeding the biomass of traditional commercial species. While this may create opportunities for targeted exploitation of the invader, it simultaneously reduces the total economic value of mixed catches and increases operational overhead. Quantitative socio-economic assessments at the national and regional levels indicate significant income reductions for artisanal fishers. In the Po Delta and other Northern Adriatic transitional systems, revenue losses ranging from 30% to over 70% have been reported for traditional fisheries, primarily due to gear degradation and the reduced availability of target species (Masi et al., 2022; Gavioli et al., 2025b).

Similar patterns appear to exist in eastern and southern Mediterranean lagoons, where blue crab expansion has altered catch composition and seasonal dynamics (Kara and Chaoui, 2021; Marchessaux et al., 2023c; Kevrekidis et al., 2025). These impacts exacerbate existing pressures on small-scale sectors already facing stock declines and climate-driven changes. Overall, *C. sapidus* acts as both an ecological stressor and an operational nuisance. The effects are disproportionately severe for small-scale fishers who may lack the capital to rapidly adapt gear or strategies. While commercial exploitation is a potential mitigation strategy, current data suggest that without coordinated management and market stabilization, the negative impacts on traditional fisheries could continue to outweigh the benefits in many invaded systems.

### 3.4. Impact on ecosystem services

The invasion of the Atlantic blue crab has affected biodiversity and economic activities while simultaneously eroding multiple ecosystem services. At the local scale, a quantitative assessment in the Sacca di Goro lagoon, the most productive site for Manila clam aquaculture in the Northern Adriatic, documented significant declines in provisioning services. In 2024, clam production in this specific system fell by 71.8%, representing annual economic losses of approximately €65 million directly attributable to *C. sapidus* predation (Gaglio et al., 2025).

In addition to these provisioning losses, small-scale fisheries in the same lagoon system experienced reduced catches of native commercial species. In 2024, this resulted in estimated revenue reductions of approximately €0.18 million per year for local fishers. Conversely, revenues from emerging blue crab supply chains remained negligible or negative after accounting for disposal costs and market price volatility (Gaglio et al., 2025).

At a broader ecological scale, the invasion also appears to undermine supporting and regulating services. By restructuring benthic communities through selective predation on bivalves and infauna, *C. sapidus* likely alters sediment bioturbation, organic matter processing, and nutrient cycling (Fanjul et al., 2015; Tiralongo et al., 2025). Furthermore, the species' opportunistic omnivory may reshape trophic transfer pathways across Mediterranean coastal food webs. This potentially influences the accumulation and redistribution of contaminants, such as heavy metals and organic pollutants, which complicates the use of benthic organisms as bioindicators (Çoğun et al., 2017; De Giorgi et al., 2024).

Cultural ecosystem services are also affected across the Mediterranean, though these remain less easily quantified. The decline of emblematic fisheries and traditional harvesting practices may erode cultural identity, local ecological knowledge, and the recreational value of lagoon environments (Cannarozzi et al., 2023; Marchessaux et al., 2023c). In several invaded areas, stakeholder perceptions indicate a loss

of ecosystem quality and reduced confidence in long-term sustainability. These concerns often persist even where blue crab fisheries are promoted as partial economic compensation (Kevrekidis et al., 2025).

Collectively, the evidence suggests that the blue crab invasion induces a systemic erosion of ecosystem services across provisioning, supporting, regulating, and cultural dimensions. These multi-dimensional impacts indicate that single-sector responses may be inadequate. Instead, they emphasize the potential need for Ecosystem-Based Management (EBM). Such an approach could integrate invasive species control, habitat restoration, adaptive fisheries management, and socio-economic mitigation to preserve ecosystem service delivery in Mediterranean coastal systems. Table S4 (Supplementary Materials) summarizes stakeholder perceptions regarding these impacts across different regions.

#### 4. Socio-economic dimensions

##### 4.1. Responses and management perspectives: the “Italian Paradox”

The rapid expansion of *Callinectes sapidus* in the Mediterranean has prompted a range of socio-economic responses and management initiatives, reflecting a shift from early-stage prevention to impact mitigation and adaptation. Given the advanced establishment of the species and its high reproductive potential, eradication is widely considered unfeasible; consequently, management strategies increasingly focus on population control, damage reduction, and socio-economic resilience (Mancinelli et al., 2017c; Giangrande et al., 2020).

One of the most widely promoted responses at the basin-wide scale is the valorization of the blue crab as a commercial resource. This approach aims to transform an ecological threat into an economic opportunity through targeted fisheries (Mancinelli et al., 2017c; Arena et al., 2024; Tamburini, 2024). However, the expansion of the blue crab between 2020 and 2024 reveals a stark contrast between North African economic adaptation and European ecological crises. This dual-edged reality is defined by a shift toward an “exploitation-as-control” paradigm, in which management efforts attempt to balance the potential for a lucrative “blue economy” against the ongoing collapse of traditional fisheries (Clavero et al., 2022).

At the regional Mediterranean level, Tunisia, following the first invasion of *Portunus segnis* in 2014, has successfully transitioned blue crabs from an invasive nuisance to a cornerstone of the national fishing economy (UNEP/MAP-SPA/RAC, 2025). Turkey similarly exploits the blue crab commercially, with export channels to East Asia developing alongside public awareness initiatives. Spain has implemented control and commercialization efforts by granting fishing licenses and promoting the species in local gastronomy, though price volatility remains a significant challenge (Marchessaux et al., 2024b). Conversely, Greece reports limited commercial value due to the relative scarcity of the species in certain areas (Marchessaux et al., 2024b). To harmonize these diverse national efforts, the General Fisheries Commission for the Mediterranean (GFCM) supports a research programme aimed at standardizing data collection and management practices across the basin (FAO, 2025).

In contrast to these regional success stories, Italy’s experience has been characterized by significant economic losses despite the implementation of “selective removal” strategies. While emerging supply chains (ANSA, 2025; BLUEAT, 2025) have generated modest revenues through domestic consumption and exports, these gains have been largely dwarfed by over €100 million in damages to the mollusc farming sector (Chiesa et al., 2025; Tiralongo et al., 2025). At the national scale, government subsidies for the disposal of crabs in landfills remain a primary source of economic support (Ministero dell’Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2023a, 2023b; Ministero dell’Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2024a, 2024b).

At the local scale of the Po River Delta, management responses have

included the deployment of physical exclusion devices, such as anti-predator nets and reinforced cages, and temporal adjustments to farming cycles (Azzurro et al., 2024). However, these measures entail substantial additional costs and may not be equally accessible to all producers, potentially exacerbating socio-economic inequalities within the sector. A dedicated funding package of €10 million has been earmarked for the Po Delta region for the 2025–2026 period to support these interventions (Presidenza del Consiglio dei Ministri, 2024). While experimental work on soft-shell crab production in the Lesina lagoon suggests a potential niche market (Cilenti et al., 2024), the broader feasibility of valorization in Italy remains constrained by market volatility, processing capacity, and food safety considerations (Azzurro et al., 2024). Currently, commercial consumption in Italy remains at an early stage, with much of the catch still treated as secondary by-catch compared to other Mediterranean counterparts.

As highlighted in Table S5, the economic trajectory of *C. sapidus* in the Mediterranean basin reveals a stark contrast between proactive and reactive management approaches. In Tunisia, blue crabs have been successfully rebranded from an ecological threat to a strategic resource, with the government facilitating the establishment of numerous processing plants serving the Asian market. Conversely, Italy is currently facing an “economic paradox”: while the biomass available for commercialization is immense (in the Po River Delta alone, 2,200 tonnes of blue crab were harvested in 2025; <https://www.anmvioggi.it/rubriche/attualita/77930-granchio-blu-eccezzionalita-dellevento-in-emilia-romagna.html>; accessed 4 January 2026), the lack of adequate industrial processing infrastructure and the collapse of the lucrative clam fishery caused by crab predation have resulted in a net economic loss for the coastal sector. In the Western Mediterranean (Spain and France), the market is characterized by higher price points driven by a more selective “gastronomic” approach. The Greek and Turkish models balance local consumption with established export routes to North America, where *C. sapidus* is a high-value native delicacy (e.g., [https://shop.lacrawfish.com/Louisiana-Blue-Crab?srsId=AfmBOoqM\\_gjsYsdrk21wL0TuMaFsTGd4NYwdKi0zmapHI6DGXYK5WC9g](https://shop.lacrawfish.com/Louisiana-Blue-Crab?srsId=AfmBOoqM_gjsYsdrk21wL0TuMaFsTGd4NYwdKi0zmapHI6DGXYK5WC9g); accessed 4 January 2026).

Table 2 presents the market prices for the blue crab across selected Mediterranean countries, along with their yield-adjusted equivalents. Market price information for *C. sapidus* was compiled from publicly accessible and verifiable sources, including seafood e-commerce platforms, market-oriented food journalism, and official fisheries export statistics. Where available, multiple contemporaneous price observations per country were included to capture within-market variability.

All prices were standardized to euros per kilogram (€/kg). Prices originally reported in non-euro currencies were converted using annual average exchange rates obtained from authoritative providers, such as the European Central Bank. Mean nominal prices represent simple arithmetic means and are not weighted by traded volume. To facilitate comparison across different product forms, nominal prices were converted into yield-adjusted equivalents (€/kg of edible product).

For whole, hard-shell blue crabs, an average edible yield of 40% was assumed, consistent with values commonly reported in seafood processing literature (Sharov et al., 2003). Soft-shell crabs, which are typically consumed whole, were assumed to have a 100% edible yield. The yield adjustment followed the equation:

$$\text{Price}_{\text{equivalent}} = \frac{\text{Price}_{\text{nominal}}}{\text{Edible yield fraction}}$$

The price patterns reported in Table 2 highlight a marked heterogeneity in the market valuation of the blue crab across Mediterranean countries, reflecting differences in market maturity, product form, and commercial perception. Nominal prices appear lowest in export-oriented or supply-abundant contexts, such as Tunisia and Turkey, where first-sale or Free On Board (FOB) values in Business-to-Business (B2B) transactions remain below €6/kg. Conversely, prices are highest in consumer-facing retail markets, such as France and Greece, where *C. sapidus* is often positioned as a differentiated seafood product.

**Table 2**Comparative market prices of *Callinectes sapidus* in Mediterranean countries, including yield-adjusted equivalents (€/kg).

Country	Market channel	Product form	Observed price (original currency)	Converted price (€/kg)	Nominal mean price (€/kg)	€/kg equivalent (size / yield-adjusted)*	Sources
Spain	Retail (online seafood markets)	Whole, fresh	9.00; 17.90; 19.95 €/kg	9.00–19.95	15.62	≈39.1	[1–3]
Italy	Retail / local fish markets	Whole or live	5–6; 5–10 €/kg	5.00–10.00	6.33	≈15.8	[4–6]
France	Retail (specialised e-commerce)	Whole, fresh (1 kg lots)	24.90 €/kg	24.90	24.90	≈62.3	[7]
Greece	Retail (ethnic/seafood e-commerce)	Soft-shell, frozen	45.00 €/kg	45.00	45.00	45.00	[8]
Tunisia	Export statistics (avg unit value)	Whole (export category)	12.53 TND/kg	≈3.72	3.72	≈9.3	[9,10]
Turkey	Export / B2B (FOB quotations)	Whole, fresh/frozen	5.5–6.5 USD/kg	≈4.68–5.53	5.10	≈12.8	[11,12]

**Sources:** [1] Pescaporta, 2024. Cangrejo azul (*Callinectes sapidus*). Online seafood retail prices, Spain. Available at: [www.pescaporta.com](http://www.pescaporta.com); [2] Esencia del Mar, 2024. Cangrejo azul (*Callinectes sapidus*). Online seafood market, Spain. Available at: [www.esenciadelmar.es](http://www.esenciadelmar.es); [3] Peix a Casa, 2024. Cranc blau (*Callinectes sapidus*). Retail seafood prices, Spain. Available at: [www.peixacasa.cat](http://www.peixacasa.cat); [4] Il Fatto Alimentare, 2023. Il granchio blu arriva sui mercati italiani: prezzi e criticità. Available at: [www.ilfattoalimentare.it](http://www.ilfattoalimentare.it); [5] Dissapore, 2023. Granchio blu: diffusione, consumo e prezzi in Italia. Available at: [www.dissapore.com](http://www.dissapore.com); [6] Italia a Tavola, 2023. Granchio blu al mercato di Rialto: quotazioni e dinamiche. Available at: [www.italiaatavola.net](http://www.italiaatavola.net); [7] Pourdebon, 2024. Crabes bleus (*Callinectes sapidus*), lot de 1 kg. France. Available at: [www.pourdebon.com](http://www.pourdebon.com); [8] EthnicFoods.gr, 2024. Frozen soft-shell blue crabs, 1 kg. Greece. Available at: [www.ethnicfoods.gr](http://www.ethnicfoods.gr); [9] Tunisie Direct, 2024. Statistiques des exportations des produits de la pêche: crabe bleu. Available at: [www.tunisie-direct.com](http://www.tunisie-direct.com) (reported statistics cover both *C. sapidus* and *P. segnis* under the same category); [10] Exchange-Rates.org, 2024. EUR–TND exchange rate history. Available at: [www.exchange-rates.org](http://www.exchange-rates.org); [11] TradeKey, 2024. Blue swimming crab export prices from Turkey (USD/kg). Available at: <https://turkey.tradekey.com/suppliers/frozen-blue-crab.htm>; [12] European Central Bank (ECB), 2025. Euro foreign exchange reference rates. Available at: [www.ecb.europa.eu](http://www.ecb.europa.eu).

Yield-adjusted equivalents further amplify these contrasts: once edible yield is accounted for, whole-crab prices in France and Spain exceed €60 and €39 per kg of edible product, respectively. These figures approach or even surpass values typical of established premium crustaceans (EUMOFA, 2023). In Italy, despite significant media attention and well-documented ecological impacts, prices remain comparatively low. This suggests a potential lack of widespread consumer acceptance and a market still largely dominated by opportunistic supply rather than demand-driven valorization. The soft-shell product in Greece represents a distinct niche, achieving high prices without yield penalties; this illustrates how processing and product transformation could potentially offset some of the economic costs associated with biological invasions. Overall, the data in Table 2 suggest that the economic implications of *C. sapidus* are not inherently uniform; rather, they appear strongly mediated by market structure, regulatory context, and product innovation (Demirel and Tsakas, 2026).

At the policy level, discussions increasingly frame *C. sapidus* within the EU Marine Strategy Framework Directive (European Union, 2008) and the EU Regulation on Invasive Alien Species (European Union, 2014), both of which prioritize monitoring and regional coordination (Giangrande et al., 2020). Nevertheless, as noted by the Aquaculture Advisory Council (2025), governance remains fragmented. While the species' spread is a transboundary reality, most actions continue to be implemented at the national scale. Integrated approaches that combine sustained monitoring, adaptive fisheries management, habitat restoration, and stakeholder engagement are increasingly recognized as important tools to mitigate long-term impacts. Furthermore, the socio-economic consequences of the invasion highlight the importance of involving small-scale fisheries and aquaculture stakeholders in the decision-making process. Such inclusion may help management strategies better balance ecological effectiveness with social equity.

#### 4.2. Potential for a circular economy approach: the "Blue Biorefinery"

The established presence of the blue crab in Italian lagoons and across the Mediterranean suggests a potential transition from purely defensive management toward circular economy frameworks. Beyond its status as a fisheries commodity, the species contains various bioactive compounds with potential applications in the pharmaceutical, cosmetic, and nutraceutical sectors (Arena et al., 2024). This "Blue Biorefinery" concept (Tamburini, 2024) is based on the species' profile of polyunsaturated fatty acids (Çelik et al., 2004), essential amino acids

(Küçükgülmez and Çelik, 2008), and biopolymers within the exoskeleton (Gourari et al., 2025). Processing by-products, specifically shells and non-meat fractions, could potentially be processed into bioactive protein hydrolysates with antioxidant and cytoprotective properties, suggesting a theoretical utility in functional foods (Khamassi et al., 2022; Arena et al., 2024, 2025).

However, the practical and economic feasibility of such biorefineries remains heavily dependent on consistent biomass availability and significant infrastructure investment. While *C. sapidus* populations are currently established in the Northern Adriatic (Mancinelli et al., 2017a), it remains to be seen whether sustained harvesting can provide a stable enough supply for industrial-scale processing without facing the "boom-and-bust" cycles typical of invasive species outbreaks (Mancinelli et al., 2017c).

Exploitation currently generates two primary streams: edible tissues for the food market and a voluminous shell fraction. The latter, characterized by high moisture and susceptibility to rapid microbial degradation, presents a significant logistical challenge. Stabilizing this waste stream to mitigate disposal costs and environmental impacts requires specialized, high-CAPEX (Capital Expenditure) infrastructure that is currently lacking in most Mediterranean coastal regions (Tamburini, 2024). Furthermore, the long-term viability of these biorefinery hubs could be compromised if the crab population declines due to either successful management or natural ecosystem feedbacks, potentially leaving expensive industrial facilities without sufficient raw material.

##### 4.2.1. Nutritional profile and bioactive peptides

Muscle tissue in *C. sapidus* is characterized by high protein content and a specific lipid profile. Characterizations of Mediterranean populations have identified levels of long-chain Omega-3 fatty acids (EPA and DHA) associated with cardiovascular health (Çelik et al., 2004; Ayas, 2016; Arena et al., 2025), alongside vitamins and micronutrients (Tamburini, 2024; Longo et al., 2025; Brai et al., 2026). The meat contains essential amino acids such as arginine and taurine (Kuley et al., 2008; Longo et al., 2025; Brai et al., 2026) and minerals including Ca, Mg, P, and Na (Küçükgülmez et al., 2006; Ali, 2023). Table 3 summarizes this profile. Enzymatic hydrolysis using specific proteases (e.g., alcalase) can produce low-molecular-weight hydrolysates (Antunes-Valcareggi et al., 2017; Arena et al., 2025) with antioxidant and ACE-inhibitory effects (Arena et al., 2024; Longo et al., 2025; Brai et al., 2026).

Analysis reveals a tissue-specific distribution: white body meat is the

**Table 3**  
Integrated nutritional and elemental profile of *Callinectes sapidus* (per 100g wet weight).

Category	Component	Body meat (white)	Claw meat	Brown meat (hepatopancreas)	Reference(s)
Proximate (g)	Proteins	18.5 – 21.2	16.8 – 19.5	10.5 – 13.2	Ayas (2016)
	Lipids	0.8 – 1.2	1.1 – 1.5	6.5 – 12.0	Ayas (2016)
	Carbohydrates	0.1 – 0.5	0.2 – 0.6	1.5 – 3.0	Ali (2023)
	Ash	1.4 – 1.8	1.6 – 2.1	2.5 – 3.8	Ayas (2016)
Macro Minerals (mg)	Calcium (Ca)	85 – 110	120 – 160	350 – 500	Ali (2023)
	Phosphorus (P)	180 – 220	160 – 200	250 – 380	Ali (2023)
	Magnesium (Mg)	35 – 50	40 – 60	80 – 120	Ayas (2016)
	Potassium (K)	280 – 350	250 – 320	380 – 450	Ali (2023)
Trace Elements (mg)	Iron (Fe)	0.8 – 1.5	1.2 – 2.0	4.5 – 8.0	Ayas (2016)
	Zinc (Zn)	3.5 – 5.0	4.8 – 7.5	6.0 – 9.5	Ayas (2016)
	Copper (Cu)	0.5 – 1.2	1.0 – 2.5	15.0 – 45.0	Ali (2023); Ayas (2016)
	Selenium (Se)	0.04 – 0.06	0.05 – 0.08	0.12 – 0.25	Ali (2023)

primary source of proteins for human consumption, while the hepatopancreas (brown meat) contains higher lipid and ash content. However, the hepatopancreas requires toxicological monitoring as it can be a site for lipophilic contaminants and heavy metals. High copper levels in this tissue are attributed to haemocyanin (Depledge and Bjerregaard, 1989). The presence of selenium, zinc, and iron (Ayas, 2016) suggests that by-products could be repurposed into mineral-enriched flours or feeds. The micronutrient density suggests the species may be classified as a functional food source (Institute of Medicine (US) Panel on Micronutrients, 2001; EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA), 2017). Table 4 summarizes its nutritional contribution.

#### 4.2.2. Exoskeleton valorization: chitin, chitosan, and pigments

The carapace serves as a source of chitin and chitosan (Webster et al., 2014), polymers studied for their biocompatibility and antimicrobial properties in wound healing and drug delivery (Baharlouei and Rahman, 2022; Tapia et al., 2025; Saputra and Andreas, 2025). The exoskeleton also contains astaxanthin (Félix-Valenzuela et al., 2001), a carotenoid with high antioxidant capacity (Ni et al., 2015). Table S6 (Supplementary Materials) lists the biochemical composition of the exoskeleton.

Chitin is integrated with proteins and calcium carbonate (up to 55%), the latter of which may be utilized as an industrial abrasive or soil conditioner (Ali, 2023). Modern extraction methodologies utilize ultrasound-assisted extraction (UAE) and supercritical fluid extraction (SFE) to recover pigments (Nunes et al., 2021; Yu et al., 2026). Table S7 (Supplementary Materials) outlines the biorefinery cascade. "Green" methods, such as lactic acid fermentation or Deep Eutectic Solvents (DES), are increasingly investigated as alternatives to traditional chemical demineralization (Younes and Rinaudo, 2015; Li et al., 2025; Arbia et al., 2013). Table S8 (Supplementary Materials) compares these methodologies.

DES technology can simultaneously demineralize and deproteinize

**Table 4**  
Blue crab contribution to human nutrition (per 100g body meat).

Element	Content (avg)	% of adult RDA	Primary biological function
Phosphorus	200 mg	~28%	Bone mineralization and ATP synthesis
Zinc	4.2 mg	~40%	Immune function and DNA synthesis
Copper	0.8 mg	~90%	Iron metabolism and neurotransmission
Selenium	0.05 mg	~91%	Antioxidant defense and thyroid health
Calcium	98 mg	~10%	Skeletal integrity and muscle contraction

**Note:** % RDA (Recommended Dietary Allowance) based on the daily requirements for adults (19–50 years) as defined by the Institute of Medicine (US) Panel on Micronutrients (2001) and EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2017). Benchmarks used: Phosphorus (700 mg), Zinc (11 mg), Copper (0.9 mg), Selenium (55 µg), and Calcium (1000 mg).

shells (Huang et al., 2018). The combination of enzymatic deproteinization with UAE may optimize yield (Fotodimas et al., 2025; Longo et al., 2025; Xu et al., 2025). Sequential valorization, extracting pigments via SFE/MAE prior to chitin recovery via DES, is proposed to increase the economic efficiency of the process (Nunes et al., 2021; Xu et al., 2025).

#### 4.2.3. Market potential and economic feasibility of *Callinectes sapidus* biorefinery

The transition from treating the blue crab as a waste management issue to an industrial feedstock is currently being explored across the Mediterranean. The theoretical economic viability of this model is linked to the high market value of extracted bioactive compounds relative to the low cost of invasive biomass (Arena et al., 2025). Proponents of this model highlight the significant price gap between raw biomass, which currently incurs disposal costs, and refined extracts such as medical-grade chitosan or high-purity astaxanthin (Nunes et al., 2021; Saputra and Andreas, 2025).

In the Italian and broader Mediterranean context, the economic appeal of blue crab biorefineries is rooted in reversing the financial burden currently imposed on the fishing industry. Currently, the massive influx of *C. sapidus* biomass often results in "negative value," with landfilling or incineration costs ranging from €150 to €300/tonne (Mancinelli et al., 2017a, 2017b, 2017c). Through green extraction technologies, this material could potentially be converted into high-value chemical feedstocks. While industrial-grade chitin typically sells for \$15–\$25/kg, specialized extraction methods (e.g., NADES; Yu et al., 2026) may enable medical-grade chitosan to reach prices of \$500–\$1,000/kg (Saputra and Andreas, 2025). Furthermore, natural astaxanthin could provide an additional revenue stream, commanding \$2,000–\$7,000/kg due to its superior antioxidant capacity (Nunes et al., 2021).

However, several critical feasibility constraints must be acknowledged. Achieving the high purity levels required for medical-grade products entails sophisticated, high-cost purification steps and stringent regulatory approvals that represent significant market entry barriers. Furthermore, the global markets for these specialized compounds are relatively niche; a sudden surge in supply from Mediterranean biorefineries could lead to market saturation and price volatility, undermining the long-term profitability of the sector.

Additionally, the logistical costs of transporting and stabilizing large volumes of highly perishable crab waste from decentralized landing sites to a central biorefinery remain a primary hurdle. While integrating these processes could theoretically shift the blue crab outbreak from an emergency management cost to a self-sustaining bio-economic model, such a transition remains contingent on overcoming these significant technological, regulatory, and market-based challenges.

#### 4.2.4. Food safety considerations

Food safety and contaminant accumulation are critical factors for the industrial development of *C. sapidus* nutraceuticals. As benthic opportunistic feeders, blue crabs bioaccumulate heavy metals (Cd, Pb, Hg),

particularly in the hepatopancreas and gills. Studies in Mersin Bay and the Balearic Islands have detected these metals in muscle tissues, raising human health concerns (Çoğun et al., 2017; Perelló et al., 2025). Consequently, while the meat and hydrolysates are promising feedstocks, rigorous screening for contaminants and microbial hazards is essential for consumer protection and regulatory compliance.

Recent research also indicates that the blue crab hosts various pathogens. Molecular surveys in the Lesina Lagoon identified protozoan parasites, including *Toxoplasma gondii* and *Cyclospora cayetanensis*, marking their first record in Mediterranean populations (Marangi et al., 2022). Additionally, the dinoflagellate *Hematodinium* sp., causing Bitter Crab Disease, has been reported in the Adriatic (Pagliara and Mancinelli, 2018; Schott et al., 2025); while not infectious to humans, it significantly reduces meat quality. Furthermore, the isolation of opportunistic bacteria like *Shewanella* spp. underscores the necessity of proper handling (Esposito et al., 2025). Collectively, monitoring parasites and microbial loads is vital for both ecological research and the safe commercialization of this emerging resource.

#### 4.2.5. Potential constraints and limitations of the biorefinery model

While the "Blue Biorefinery" offers a promising pathway for valorization, its practical implementation faces several multi-dimensional challenges that must be addressed to ensure long-term viability. A primary biological limitation is the inherent instability of invasive biomass; the success of a biorefinery depends on a consistent and predictable supply of raw material, yet the "fishing-for-control" strategy aims specifically to reduce *C. sapidus* populations. This creates a "paradox of success" where effective management could lead to a biomass shortage, potentially jeopardizing the return on investment for industrial plants. Furthermore, seasonal fluctuations in crab molting cycles and recruitment significantly affect the yield and quality of chitin and pigments (Nunes et al., 2021).

From an economic and technical perspective, the capital expenditure (CAPEX) required for "green" technologies, such as Supercritical Fluid Extraction (SFE) or Deep Eutectic Solvent (DES) systems, is substantially higher than that of traditional chemical methods. Without dedicated subsidies or public-private partnerships, the transition may be cost-prohibitive for local SMEs. Additionally, the lack of an established logistics network for the rapid stabilization and transport of highly perishable shell waste remains a significant bottleneck (Tamburini, 2024).

Cultural resistance within traditional fishing communities also poses a barrier. Fishers in the Mediterranean are historically accustomed to high-value food markets; transitioning to a model where they act as suppliers for the chemical or pharmaceutical industry requires a significant shift in professional identity and economic expectations. Moreover, the pharmaceutical market demands extreme consistency in the molecular weight and purity of chitosan, which is difficult to achieve when dealing with wild-caught biomass of varying age, sex, and environmental provenance (Arena et al., 2025).

To ensure the long-term viability of the proposed blue biorefinery, it is essential to establish specialized technical education programs. The transition will require a newly trained workforce skilled in biomass processing and the upcycling of marine co-products, bridging the gap between current industrial capabilities and the technical demands of this new bio-based economy.

## 5. Conclusions

The "new kid in town" has rapidly become the dominant landlord of many Mediterranean coastal and transitional waters. The 2022–2025 outbreak of *Callinectes sapidus* demonstrates that the Mediterranean is no longer merely "under siege" (Galil, 2000) but is actively undergoing a structural reorganization of its coastal ecosystems. While the species' success is a testament to its extraordinary physiological plasticity, it also serves as a stark, and perhaps irreversible, indicator of the basin's

shifting thermal regime. The current crisis in the Northern Adriatic serves as a cautionary tale for the "Italian paradox," a situation where biological abundance is currently treated as a waste management problem rather than a potential strategic opportunity.

As climate-linked drivers continue to favor the spread of this thermophilic invader (with others likely to follow, including *Portunus segnis* and *Charybdis feriata*; Castriota et al., 2022; Frogliola et al., 2024), a paradigm shift in management appears urgent. To resolve this paradox, it could be beneficial to transition from reactive damage compensation toward a self-sustaining circular bioeconomy that attempts to internalize ecological costs through technological innovation. Beyond ecological containment, the significant reservoir of bioactive compounds within the blue crab, including Omega-3 fatty acids, medical-grade chitin, and astaxanthin, offers a promising, albeit complex, pathway for bio-economic valorization.

Establishing "Blue Biorefinery Hubs" in hotspots like the Po Delta could potentially transform a costly "biological plague" into premium industrial feedstock, thereby mitigating the financial burden on taxpayers and the fishing industry. However, the economic feasibility of such an endeavor remains to be fully evaluated, as it requires a rigorous framework underpinned by "green extraction" certifications, stabilized "fishing-for-control" supply chains, and harmonized safety protocols to manage bioaccumulation and microbial risks. Furthermore, the high initial capital investment and operational costs of these technologies must be carefully weighed against future market volatility.

At the same time, it is essential to acknowledge that the current abundance of biomass may not remain constant; population fluctuations, regulatory measures, ecosystem feedbacks, or market-driven harvesting pressure could reduce feedstock availability compared to peak outbreak years. Therefore, any bio-economic strategy should be approached with caution and designed with adaptive capacity, scalable infrastructure, and prudent investment planning to avoid structural dependence on a resource whose supply is inherently dynamic. Ultimately, while not a definitive solution, the management of this outbreak might be viewed not merely as a permanent environmental crisis, but as a potential catalyst for sustainable bio-technological innovation under a transboundary framework.

## CRedit authorship contribution statement

**Michele Mistri:** Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Cristina Munari:** Writing – original draft, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2026.119668>.

## Data availability

Data will be made available on request.

## References

- Ali, A.A.H., 2023. Overview of the vital roles of macro minerals in the human body. *J. Trace Elem. Miner.* 4, 100076. <https://doi.org/10.1016/j.jtemin.2023.100076>.
- ANSA, 2025. Al-via-granchio-blu-la-societa-di-export-in-tutto-il-mondo. Available online: [https://www.ansa.it/canale\\_terraegusto/notizie/dal\\_mare/2025/10/23/a-l-via-granchio-blu-la-societa-di-export-in-tutto-il-mondo](https://www.ansa.it/canale_terraegusto/notizie/dal_mare/2025/10/23/a-l-via-granchio-blu-la-societa-di-export-in-tutto-il-mondo). (Accessed 29 December 2025).
- Antunes-Valcareggi, S.A., Ferreira, S.R.S., Hense, H., 2017. Enzymatic hydrolysis of blue crab (*Callinectes sapidus*) waste processing to obtain chitin, protein, and astaxanthin-enriched extract. *Int. J. Environ. Agric. Res.* 3, 81–92.
- Aquaculture Advisory Council, 2025. AAC Recommendation on Blue Crab Emergency in Italy. In: AAC 2025-18, October 2025, Bruxelles, Belgium, 13 pp.
- Arbia, W., Arbia, L., Adour, L., Amrane, A., 2013. Chitin extraction from crustacean shells using biological methods—a review. *Food Technol. Biotechnol.* 51, 12–25.
- Arena, R., Renda, G., Ottaviani Aalmo, G., Debeaufort, F., Messina, C.M., Santulli, A., 2024. Valorization of the invasive blue crabs (*Callinectes sapidus*) in the Mediterranean: nutritional value, bioactive compounds and sustainable by-products Utilization. *Marine Drugs* 22, 430. <https://doi.org/10.3390/md22090430>.
- Arena, R., Manuguerra, S., Gonzalez, M.M., Petrosillo, E., Lanzoni, D., Poulain, C., Debeaufort, F., Giromini, C., Francesca, N., Messina, C.M., Santulli, A., 2025. Valorization of blue crab (*Callinectes sapidus*) by-products into antioxidant protein hydrolysates for nutraceutical applications. *Animals* 15, 2952. <https://doi.org/10.3390/ani15202952>.
- Aslan, H., Polito, M.J., 2021. Trophic ecology of the Atlantic blue crab *Callinectes sapidus* an invasive non-native species in the Aegean Sea. *Biol. Invasions*. <https://doi.org/10.1007/s10530-021-02506-7>.
- Ayas, D., 2016. The effects of season and sex on the nutritional quality of muscle types of blue crab *Callinectes sapidus* and swimming crab *Portunus segnis*. *Nat. Eng. Sci.* 1, 1–14.
- Azzurro, E., Bonanomi, S., Chiappi, M., De Marco, R., Luna, G.M., Cella, M., Guicciardi, S., Tiralongo, F., Bonifazi, A., Straffella, P., 2024. Uncovering unmet demand and key insights for the invasive blue crab (*Callinectes sapidus*) market before and after the Italian outbreak: Implications for policymakers and industry stakeholders. *Mar. Policy* 167, 105560. <https://doi.org/10.1016/j.marpol.2024.105560>.
- Baharlouei, P., Rahman, A., 2022. Chitin and chitosan: prospective biomedical applications in drug delivery, cancer treatment, and wound healing. *Mar. Drugs* 20, 460. <https://doi.org/10.3390/md20070460>.
- Bartoli, M., Castaldelli, G., Nizzoli, D., Fano, E.A., Viaroli, P., 2016. Manila clam introduction in the Sacca di Goro Lagoon (Northern Italy): ecological implications. *Bull. Jpn. Fish. Res. Edu. Agen.* 42, 43–52.
- Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Geeves, W., 2003. Marine invasive alien species: a threat to global biodiversity. *Mar. Policy* 27, 313–323. [https://doi.org/10.1016/S0308-597X\(03\)00041-1](https://doi.org/10.1016/S0308-597X(03)00041-1).
- Benabdi, M., Belmahi, A.E., Grimes, S., 2019. First record of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae) in Algerian coastal waters (southwestern Mediterranean). *Bioinvasions Rec.* 8, 119–122. <https://doi.org/10.3391/bir.2019.8.1.13>.
- Beqiraj, S., Kasha, L., 2010. The establishment of blue crab *Callinectes sapidus* Rathbun, 1896 in the Lagoon of Patok, Albania (south-east Adriatic Sea). *Aquat. Invasions* 5, 219–221. <https://doi.org/10.3391/ai.2010.5.2.16>.
- Bhuiyan, M.K.A., Godoy, O., González-Ortegón, E., Franco Rodil, I., 2026. Invasion dynamics and management of the Atlantic blue crab (*Callinectes sapidus*) in a European salt marsh: evidence from the Bay of Cádiz, Spain. *Mar. Pollut. Bull.* 223, 118972. <https://doi.org/10.1016/j.marpolbul.2025.118972>.
- BLUEAT, 2025. Blueat: la pescheria sostenibile. Available online: <https://blueat.eu/>. (Accessed 29 December 2025).
- Blundon, A.A., Kennedy, V.S., 1982. Mechanical and behavioral aspects of blue crab, *Callinectes sapidus* (Rathbun), predation on Chesapeake Bay bivalves. *J. Exp. Mar. Biol. Ecol.* 65, 47–65. [https://doi.org/10.1016/0022-0981\(82\)90175-7](https://doi.org/10.1016/0022-0981(82)90175-7).
- Bouvier, E.L., 1901. Sur Un *Callinectes sapidus* M. Rathbun Trouvé a Rochefort. *Bull. du Muséum Natl. d'histoire naturelle Paris* 7, 1617.
- Brai, A., Tiberio, L., Chiti, M., Poggialini, F., Vagaggini, C., Consales, G., Marsili, L., Dreassi, E., 2026. From ecological threat to bioactive resource: the nutraceutical components of blue crab (*Callinectes sapidus*). *Int. J. Mol. Sci.* 27, 381. <https://doi.org/10.3390/ijms27010381>.
- Brundu, G., Graham, P., Corrias, M., Frongia, C., Carboni, S., 2025. The invasive alien species *Callinectes sapidus* threatens the restoration of *Ostrea edulis* and *Paracentrotus lividus* in the Mediterranean Sea. *Animals* 15 (24), 3553. <https://doi.org/10.3390/ani15243553>.
- Bulgurkov, K., 1968. Occurrence of *Callinectes sapidus* Rathbun (Crustacea - Decapoda) in Black Sea. In: Proceedings of the Research Institute of Fisheries and Oceanography - Varna, 9, pp. 97–99 [In Bulgarian].
- Cannarozzi, L., Paoli, C., Vassallo, P., Cilenti, L., Bevilacqua, S., Lago, N., Scirocco, T., Rigo, I., 2023. Donor-side and user-side evaluation of the Atlantic blue crab invasion on a Mediterranean lagoon. *Mar. Pollut. Bull.* 189, 114758. <https://doi.org/10.1016/j.marpolbul.2023.114758>.
- Castejón, D., Guerao, G., 2013. First record of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae) from the Spanish Mediterranean coast. *BiolInvasions Rec.* 2, 141–144.
- Castriota, L., Andaloro, F., Costantini, R., De Ascentiis, A., 2012. First record of the Atlantic blue crab *Callinectes sapidus* in Abruzzi waters (central Adriatic Sea). *Acta Adriat.* 53, 467–471.
- Castriota, L., Falautano, M., Maggio, T., Perzia, P., 2022. The blue swimming crab *Portunus segnis* in the Mediterranean Sea: invasion paths, impacts and management measures. *Biology* 11 (10), 1473. <https://doi.org/10.3390/biology11101473>.
- Castriota, L., Falautano, M., Perzia, P., 2024. When nature requires a resource to be used - the case of *Callinectes sapidus*: distribution, aggregation patterns, and spatial structure in Northwest Europe, the Mediterranean Sea, and adjacent waters. *Biology* 13, 279. <https://doi.org/10.3390/biology13040279>.
- Cavaliere, A., Berdar, A., 1975. Presenza di *Callinectes sapidus* Rathbun nello Stretto di Messina. *Boll. Pesca Piscicolt. Idrobiol.* 30, 315–322.
- Çelik, M., Türel, C., Çelik, M., Yanar, Y., Erdem, Ü., Küçükgülmez, A., 2004. Fatty acid composition of the blue crab (*Callinectes sapidus* Rathbun, 1896) in the north eastern Mediterranean. *Food Chem.* 88, 271–273. <https://doi.org/10.1016/j.foodchem.2004.01.038>.
- Chartosia, N., Anastasiadis, D., Bazairi, H., Crocetta, F., Deidun, A., Despalatović, M., Di Martino, V., Dimitriou, N., Dragičević, B., Dulčić, J., Durucan, F., Hasbek, D., Ketsilis-Rinis, V., Kleitou, P., Lipej, L., Macali, A., Marchini, A., Ousselam, M., Piraino, S., Stancanelli, B., Theodosiou, M., Tiralongo, F., Todorova, V., Trkov, D., Yapici, S., 2018. New Mediterranean biodiversity records (July 2018). *Mediterr. Mar. Sci.* 19, 398–415. <https://doi.org/10.1186/s10152-018-0521-7>.
- Chiesa, S., Petoche, T., Boscolo Brusà, R., Raicevich, S., Cacciatore, F., Franceschini, G., Antonini, C., Vallini, C., Bernarello, V., Oselladore, F., Ciani, M., Di Blasio, L., Campolunghi, M.P., Baldessin, F., Boldrin, L., Marino, G., 2025. Impacts of the blue crab invasion on Manila clam aquaculture in Po Delta coastal lagoons (Northern Adriatic Sea, Italy). *Estuar. Coast. Shelf Sci.* 312, 109037. <https://doi.org/10.1016/j.ecss.2025.109037>.
- Cicala, D., Andolina, C., Bardelli, R., Cilluffo, G., Ciriminna, L., Mancinelli, G., Vizzini, S., 2025. Establishment of the blue crab *Callinectes sapidus* (Rathbun, 1896) in a Mediterranean hypersaline basin: evidence of ecological plasticity and range expansion. *Neobiota* 104, 281–300. <https://doi.org/10.3897/neobiota.104.160696>.
- Cigarra, B., Correia, M.J., Chainho, P., 2022. The invasive blue crab *Callinectes sapidus* Rathbun, 1896 in Southern European estuaries: a review of its biological and ecological impacts. *Mar. Pollut. Bull.* 185, 114251. <https://doi.org/10.1016/j.marpolbul.2022.114251>.
- Cilenti, L., Scirocco, T., Manzo, C., Falco, S., Mancinelli, G., Kapiris, K., Katselis, G., 2019. The spread of the blue crab *Callinectes sapidus* in the Adriatic Sea: ecological and economic considerations. *Mediterr. Mar. Sci.* 20, 1–14.
- Cilenti, L., Lago, N., Lillo, A.O., Li Veli, D., Scirocco, T., Mancinelli, G., 2024. Soft-shell production of the invasive Atlantic blue crab *Callinectes sapidus* in the Lesina Lagoon (SE Italy): a first assessment. *J. Mar. Sci. Eng.* 12, 310. <https://doi.org/10.3390/jmse12020310>.
- Clavero, M., Revilla, E., Najafabadi, M.S., 2022. The blue crab invasion of the Ebro Delta: from a 'rare' species to a flagship invader. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* 32 (6), 1058–1071. <https://doi.org/10.1002/aqc.3813>.
- Çoğun, H.Y., Firat, Ö., Aytekin, T., Firidin, G., Firat, Ö., Varkal, H., Temiz, Ö., Kargin, F., 2017. Heavy metals in the blue crab (*Callinectes sapidus*) in Mersin Bay, Turkey. *Bull. Environ. Contam. Toxicol.* 98, 824–829. <https://doi.org/10.1007/s00128-017-2086-6>.
- Costlow, J.D., 1967. The effect of salinity and temperature on survival and metamorphosis of megalops of the blue crab *Callinectes sapidus*. *Helgol Wiss Meeresunters* 15, 84–97.
- Costlow, J.D., Bookhout, C.G., 1959. The larval development of *Callinectes sapidus* Rathbun reared in the laboratory. *Biol. Bull.* 116, 373–396.
- Crooks, J.A., Soule, M.E., 1999. Lag times in population explosions of invasive species: causes and implications. In: Sandlund, O.T., Schei, P.J., Viken, Å. (Eds.), *Invasive Species and Biodiversity Management*. Kluwer Academic Press, New York, NY, pp. 103–125.
- De Giorgi, R., Bardelli, R., Cilenti, L., Falco, S., Fanizzi, F.P., Guerra, M.T., Vizzini, S., 2024. Opportunistic omnivory impairs the use of the Atlantic blue crab *Callinectes sapidus* as a trace-metal biomonitor in invaded Mediterranean coastal waters. *Mar. Pollut. Bull.* 206, 116715. <https://doi.org/10.1016/j.marpolbul.2024.116715>.
- Deidun, A., Galdies, J., Marrone, A., Sciberras, A., Zava, B., Corsini-Foka, M., Gianguzza, P., 2022. The first confirmed record of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda, Brachyura) from Maltese waters. *BiolInvasions Rec.* 11, 238–243. <https://doi.org/10.3391/bir.2022.11.1.24>.
- Demirel, N., Tsakas, C., 2026. Economic instruments for marine invasive alien species management in the Mediterranean. *Mar. Policy* 186, 107006. <https://doi.org/10.1016/j.marpol.2025.107006>.
- Depledge, M.H., Bjerregaard, P., 1989. Haemolymph protein composition and copper levels in decapod crustaceans. *Helgoländer Meeresun.* 43, 207–223. <https://doi.org/10.1007/BF02365475>.
- Di Martino, V., Stancanelli, B., 2025. The Invasive Alien Species *Callinectes sapidus* Threatens the Restoration of *Ostrea edulis* and *Paracentrotus lividus* in the Mediterranean Sea. *Animals* 15, 3553. <https://doi.org/10.3390/ani15123553>.
- Dulčić, J., Tutman, P., Matic-Skok, S., Glamuzina, B., 2011. Six years from first record to population establishment: the case of the blue crab *Callinectes sapidus* in the Neretva River delta (eastern Adriatic Sea). *Crustaceana* 84, 1211–1220.
- Ebersole, E.L., Kennedy, V.S., 1995. Prey preferences of blue crabs *Callinectes sapidus* feeding on three bivalve species. *Mar. Ecol. Prog. Ser.* 118, 167–177.

- EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA), 2017. Dietary Reference Values for Nutrients: Summary Report, 14. EFSA Supporting Publ, e15121. <https://doi.org/10.2903/sp.efsa.2017.e15121>.
- Eggleston, D.B., Lipcius, R.N., Hines, A.H., 1992. Density-dependent predation by blue crabs upon infaunal clam species with contrasting distribution and abundance patterns. *Mar. Ecol. Prog. Ser.* 85, 55–68.
- Eggleston, D.B., Millstein, E., Plaia, G., 2015. Timing and route of migration of mature female blue crabs in a tidal estuary. *Biol. Lett.* 11, 20140936. <https://doi.org/10.1098/rsbl.2014.0936>.
- Enzenroß, R., Enzenroß, L., Bingel, F., 1997. Occurrence of blue crab, *Callinectes sapidus* (Rathbun 1896) (Crustacea, Brachyura) on the Turkish Mediterranean and the adjacent Aegean coast and its size distribution in the Bay of Iskenderun. *Turk. J. Zool.* 21, 113–122. <https://doi.org/10.55730/1300-0179.2971>.
- Esposito, G., Bondavalli, F., Di Nicola, M.R., Pastorino, P., Scala, S., Gini, M., Milanese, G., Turolla, E., Maganza, A., Sciuto, S., Meloni, D., Melillo, R., Acutis, P., Bozzetta, E., Virgilio, S., Faggio, C., Colussi, S., Prearo, M., 2025. Blue crab (*Callinectes sapidus*) haemolymph as a potential reservoir of mesophilic *Shewanella* species. *Animals* 15, 1731. <https://doi.org/10.3390/ani15121731>.
- Esposito, G., Pastorino, P., Scala, S., Gini, M., Milanese, G., Bondavalli, F., Di Nicola, M. R., Turolla, E., Gabetti, A., Mossotto, C., Virgilio, S., Acutis, P.L., Meloni, D., Paolino, G., Melillo, R., Bozzetta, E., Prearo, M., Colussi, S., 2026. Haemolymph of blue crab (*Callinectes sapidus*) as a reservoir of bacteria potentially pathogenic to humans: public health implications. *Water Biol. Secur.* 5, 100426. <https://doi.org/10.1016/j.watbs.2025.100426>.
- EUMOFA, 2023. The EU Fish Market, 2023 edition. European Market Observatory for Fisheries and Aquaculture Products, Brussels, Belgium.
- European Union, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Off. J. Eur. Union* L164, 19–40.
- European Union, 2014. Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. *Off. J. Eur. Union* L317, 35–55.
- Fanjul, E., Escapa, M., Montemayor, D., Addino, M., Alvarez, M.F., Grela, M.A., Iribarne, O., 2015. Effect of crab bioturbation on organic matter processing in South West Atlantic intertidal sediments. *J. Sea Res.* 95, 1–10. <https://doi.org/10.1016/j.seares.2014.12.003>.
- FAO, 2025. Research programme on blue crabs in the Mediterranean sea; General Fisheries Commission for the Mediterranean (GFCM). Available online: <https://www.fao.org/gfcm/researchprogramme-bluecrabs/en/>. (Accessed 29 December 2025).
- Félix-Valenzuela, L., Higuera-Ciagara, I., Goycoolea-Valencia, F., Argüelles-Monal, W., 2001. Supercritical CO<sub>2</sub>/ethanol extraction of astaxanthin from blue crab (*Callinectes sapidus*) shell waste. *J. Food Process Eng.* 24, 101–112. <https://doi.org/10.1111/j.1745-4530.2001.tb00534.x>.
- Fotodimas, I., Vidalis, K.L., Theodorou, J.A., Logothetis, P., Kanlis, G., 2025. Sustainable aquaculture through enzymatic hydrolysis of raw chitin from crab by-products: functional fish feeds targeting fish health with implications for human health. *Fishes* 10, 514. <https://doi.org/10.3390/fishes10100514>.
- Frogliola, C., Grati, F., Azzurro, E., 2024. Notes on the capture of the crucifix crab *Charybdis feriata* (Linnaeus, 1758) (Crustacea: Brachyura: Portunidae) in the Adriatic Sea. *Bioinvasions Rec.* 13 (4), 993–1000. <https://doi.org/10.3391/bir.2024.13.4.12>.
- Gaglio, M., Gavioli, A., Turolla, E., Lanzoni, M., Castaldelli, G., 2025. The costs of an invasion: How the blue crab impaired ecosystem services in the most productive lagoon of northwestern Adriatic. *Sci. Total Environ.* 1007, 180952. <https://doi.org/10.1016/j.scitotenv.2025.180952>.
- Galil, B.S., 2000. A sea under siege – alien species in the Mediterranean. *Biol. Invasions* 2, 177–186. <https://doi.org/10.1023/A:1010057010476>.
- Galil, B.S., Nehring, S., Panov, V., 2011. Comparative notes on the Blue Crab *Callinectes sapidus* Rathbun, 1896 (Crustacea: Decapoda: Brachyura: Portunidae). *Aquat. Invasions* 6, 7–22. <https://doi.org/10.3391/ai.2011.6.1.02>.
- Galil, B.S., Marchini, A., Occhipinti-Ambrogi, A., Minchin, D., Narščius, A., Ojaveer, H., Olenin, S., 2014. International arrivals: widespread bioinvasions in European seas. *Ethol. Ecol. Evol.* 26, 152–171.
- Galil, B.S., Marchini, A., Occhipinti-Ambrogi, A., 2020. The invasion of *Callinectes sapidus* and other alien species in the Mediterranean sea: status and patterns. *Mar. Biodivers. Rec.* 13, 90.
- Galil, B., Frogliola, C., Noël, P., 2022. Crustaceans. In: Briand, F. (Ed.), *Atlas of Exotic Species in the Mediterranean Sea*, 2. CIESM Publishers, Monaco, p. 192.
- García, L., Pinya, S., Colomar, V., París, T., Puig, M., Rebassa, M., Mayol, J., 2018. First recorded occurrences of the invasive crab *Callinectes sapidus* Rathbun, 1896 (Crustacea: Decapoda: Portunidae) in coastal lagoons of the Balearic Islands (Spain). *Bioinvasions Rec.* 7, 191–196. <https://doi.org/10.3391/bir.2018.7.2.12>.
- Gavioli, A., Castaldelli, G., Eggleston, D.B., Christian, R.R., 2025a. From ecological to anthropogenic factors: unraveling the drivers of blue crab *Callinectes sapidus* occurrence along the Mediterranean coasts. *Front. Mar. Sci.* 11, 1515098. <https://doi.org/10.3389/fmars.2024.1515098>.
- Gavioli, A., Mancinelli, G., Eggleston, D.B., Christian, R.R., Turolla, E., Lanzoni, M., Soana, E., Rossetti, E., Gottardo, A., Vidal, L., Zentilin, A., Castaldelli, G., 2026. A potential bottom-up cascade on the abundance of invasive Atlantic blue crab *Callinectes sapidus* in northwestern Adriatic lagoons. *Mar. Environ. Res.* 215, 107801. <https://doi.org/10.1016/j.marenvres.2025.107801>.
- Gavioli, A., Mancinelli, G., Turolla, E., Lanzoni, M., Paesanti, V., Soana, E., Eggleston, D. B., Christian, R.R., 2025b. Impacts of the invasive blue crab *Callinectes sapidus* on small-scale fisheries in a Mediterranean lagoon using fishery landing data. *Sci. Total Environ.* 974, 179236. <https://doi.org/10.1016/j.scitotenv.2025.179236>.
- Giangrande, A., Pierri, C., Del Pasqua, M., Gravili, C., Gambi, M.C., Gravina, M.F., 2020. The Mediterranean in check: biological invasions in a changing sea. *Mar. Ecol.* 41, e12583. <https://doi.org/10.1111/maec.12583>.
- Gil-Fernández, A., Rodilla, M., Prado, P., Falco, S., 2024. Early life stages of the invasive Atlantic blue crab *Callinectes sapidus* in the western Mediterranean Sea. *Estuar. Coast. Shelf Sci.* 296, 108593. <https://doi.org/10.1016/j.ecss.2023.108593>.
- Giordani Soika, A., 1951. I crostacei decapodi dell'Adriatico. *Arch. Oceanogr. Limnol.* 7, 1–36.
- Glandon, H.L., Kilbourne, K.H., Miller, T.J., 2019. Winter is (not) coming: Warming temperatures will affect the overwinter behavior and survival of blue crab. *PLoS One* 14, e0219555. <https://doi.org/10.1371/journal.pone.0219555>.
- Gourari, K., Mabrouki, Y., Taybi, A.F., Essadek, A., Tanduo, V., Crocetta, F., Rahhou, I., Belbachir, C., Rizzo, L., Legssyer, B., 2025. Meat nutritional value and exoskeleton valorisation of *Callinectes sapidus* from three sites of biological and ecological interest in Morocco: scientific insights toward a management strategy in the Mediterranean Sea. *Mar. Drugs* 23, 367. <https://doi.org/10.3390/md23090367>.
- Hamiche, F.Z., Akssissou, M., 2024. The invasive blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda, Portunidae) is rapidly expanding its distributional range in the north-western Mediterranean coast of Morocco. *Biodivers. Data* J. 12, e115875. <https://doi.org/10.3897/BDJ.12.e115875>.
- Hines, A.H., 2007. Ecology of juvenile and adult blue crabs. In: Kennedy, V.S., Cronin, L. E. (Eds.), *The Blue Crab: Callinectes sapidus*. Maryland Sea Grant, College Park, MD, pp. 565–654.
- Hines Jr., A.H., Coen, L.D., Morgan, S.G., 2001. Pre- and post-settlement factors as determinants of juvenile blue crab *Callinectes sapidus* abundance: results from the north-central Gulf of Mexico. *Mar. Ecol. Prog. Ser.* 222, 163–176. <https://doi.org/10.3354/meps222163>.
- Hines, A.H., Lipcius, R.N., Haddon, A.M., 1987. Population dynamics and habitat partitioning by size, sex, and molt stage of blue crabs *Callinectes sapidus* in a subestuary of central Chesapeake Bay. *Mar. Ecol. Prog. Ser.* 36, 55–64.
- Huang, W.C., Zhao, D., Guo, N., Xue, C., Mao, X., 2018. Green and facile production of chitin from crustacean shells using a natural deep eutectic solvent. *J. Agric. Food Chem.* 66, 11897–11901. <https://doi.org/10.1021/acs.jafc.8b03847>.
- Institute of Medicine (US) Panel on Micronutrients, 2001. Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. National Academies Press, Washington, DC. <https://doi.org/10.17226/10026>.
- Kampouris, T.E., Porter, J.S., Papadopoulos, A.I., 2020. Morphometric relationships of the global invader *Callinectes sapidus* Rathbun, 1896 (Decapoda, Brachyura, Portunidae) from Papapouli Lagoon, NW Aegean Sea, Greece. *Fishes* 5, 5. <https://doi.org/10.3390/fishes5010005>.
- Kara, H., Chaoui, L., 2021. Strong invasion of Mellah Lagoon (South-Western Mediterranean) by the American blue crab *Callinectes sapidus* Rathbun, 1896. *Mar. Pollut. Bull.* 164, 112089. <https://doi.org/10.1016/j.marpolbul.2021.112089>.
- Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppäkoski, E., Çinar, M.E., Öztürk, B., Grabowski, M., Golani, D., Cardoso, A.C., 2014. Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. *Aquat. Invasions* 9, 391–423.
- Kennedy, V.S., Cronin, L.E., 2007. The Blue crab: *Callinectes sapidus*. Maryland Sea Grant College, University of Maryland, College Park, MD, p. 131.
- Kevrekidis, K., Kevrekidis, T., Mogias, A., Boubonari, T., Kantaridou, F., Kaisari, N., Malea, P., Dounas, C., Thessalou-Legaki, M., 2025. Fisheries biology and basic life-cycle characteristics of the invasive blue crab *Callinectes sapidus* Rathbun in the estuarine area of the Evros River (Northeast Aegean Sea, Eastern Mediterranean). *J. Mar. Sci. Eng.* 11, 462. <https://doi.org/10.3390/jmse11030462>.
- Khamassi, F., Bahri, W.R., Bhourri, A.M., Chaffai, A., Soufikechaou, E., Ghanem, R., Souissi, J.B., 2022. Biochemical composition, nutritional value, and socio-economic impacts of the invasive crab *Callinectes sapidus* Rathbun, 1896 in central Mediterranean Sea. *Mediterr. Mar. Sci.* 23, 650–663. <https://doi.org/10.12681/mms.28878>.
- Küçükgülmez, A., Çelik, M., 2008. Amino acid composition of blue crab (*Callinectes sapidus*) from the North Eastern Mediterranean Sea. *J. Appl. Biol. Sci.* 2, 39–42.
- Küçükgülmez, A., Çelik, M., Yanar, Y., Ersoy, B., Çikrikçi, M., 2006. Proximate composition and mineral contents of the blue crab (*Callinectes sapidus*) breast meat, claw meat and hepatopancreas. *Int. J. Food Sci. Technol.* 41, 1023–1026. <https://doi.org/10.1111/j.1365-2621.2006.01159.x>.
- Kuley, E., Ozoğul, F., Ozogul, Y., Olgunoglu, A.I., 2008. Comparison of fatty acid and proximate compositions of the body and claw of male and female blue crabs (*Callinectes sapidus*) from different regions of the Mediterranean coast. *Int. J. Food Sci. Nutr.* 59, 573–580. <https://doi.org/10.1080/09637480701451201>.
- Labrone, C., Lavesque, N., Schohn, T., Meunier, T., Grall, J., Amouroux, J.M., 2019. First record of the blue crab *Callinectes sapidus* Rathbun, 1896 (Crustacea: Decapoda: Portunidae) in the Gulf of Lions (Northwestern Mediterranean Sea, France). *Bioinvasions Rec.* 8, 857–863. <https://doi.org/10.3391/bir.2019.8.4.12>.
- Li, L., Fu, Z., Liu, Y., Song, Z., Yang, X., Yu, D., Wang, Q., Chi, H., Zheng, J., 2025. A comprehensive and comparative study on the biochemical composition and non-volatile taste compounds of thirteen shellfish species. *Foods* 14, 1595. <https://doi.org/10.3390/foods14091595>.
- Longo, F., Attanzio, A., Marretta, L., Luparello, C., Indelicato, S., Bongiorno, D., Barone, G., Tesoriere, L., Giardina, I.C., Abruscato, G., 2025. Bioactive molecules from the invasive blue crab *Callinectes sapidus* exoskeleton: evaluation of reducing, radical scavenging, and antitumor activities. *Mar. Drugs* 23, 45. <https://doi.org/10.3390/md23010045>.
- Mancinelli, G., Carrozzo, L., Marini, G., Costantini, M.L., Rossi, L., Pinna, M., 2013. Occurrence of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 in two

- Mediterranean coastal habitats: temporary visitor or permanent resident? *Estuar. Coast. Shelf Sci.* 135, 46–56. <https://doi.org/10.1016/j.ecss.2013.06.008>.
- Mancinelli, G., Glamuzina, B., Petric, M., Carrozzo, L., Glamuzina, L., Zotti, M., Raho, D., Vizzini, S., 2016. The trophic position of the Atlantic blue crab *Callinectes sapidus* Rathbun 1896 in the food web of Parila Lagoon (South Eastern Adriatic, Croatia): a first assessment using stable isotopes. *Mediterr. Mar. Sci.* 17, 634–643. <https://doi.org/10.12681/mms.1724>.
- Mancinelli, G., Chainho, P., Cilenti, L., Falco, S., Kapiris, K., Katselis, G., Ribeiro, F., 2017a. The Atlantic blue crab *Callinectes sapidus* in southern European coastal waters: distribution, impact and prospective invasion management strategies. *Mar. Pollut. Bull.* 119, 5–11. <https://doi.org/10.1016/j.marpolbul.2017.02.050>.
- Mancinelli, G., Raho, D., Zotti, M., Alujevic, K., Guerra, M.T., Vizzini, S., 2017b. Trophic flexibility of the Atlantic blue crab *Callinectes sapidus* in invaded coastal systems of the Apulia region (SE Italy): a stable isotope analysis. *Estuar. Coast. Shelf Sci.* 198, 421–431. <https://doi.org/10.1016/j.ecss.2017.03.013>.
- Mancinelli, G., Chainho, P., Livi, S., Cilenti, L., Falco, S., Kapiris, K., Katsanevakis, S., Belmonte, G., 2017c. On the Atlantic blue crab *Callinectes sapidus* Rathbun 1896 in southern European coastal waters: time to turn a threat into a resource? *Fish. Res.* 194, 1–8. <https://doi.org/10.1016/j.fishres.2017.05.002>.
- Mancinelli, G., Bardelli, R., Zenetos, A., 2021. A global data set on the distribution of the western Atlantic blue crab *Callinectes sapidus* Rathbun, 1896. *Sci. Data* 8, 111. <https://doi.org/10.1038/s41597-021-00888-w>.
- Manfrin, C., Turolla, E., Chung, G.S., Giulianini, P.G., 2015. First occurrence of *Callinectes sapidus* (Rathbun, 1896) within the Sacca di Goro (Italy) and surroundings. *Check List* 11, 1640. <https://doi.org/10.15560/11.3.1640>.
- Marangi, M., Lago, N., Mancinelli, G., Antonio, O.L., Scirocco, T., Sinigaglia, M., Specchiulli, A., Cilenti, L., 2022. Occurrence of the protozoan parasites *Toxoplasma gondii* and *Cyclospora cayatanensis* in the invasive Atlantic blue crab *Callinectes sapidus* from the Lesina Lagoon (SE Italy). *Mar. Pollut. Bull.* 176, 113428. <https://doi.org/10.1016/j.marpolbul.2022.113428>.
- Marchessaux, G., Bosch-Belmar, M., Cilenti, L., Lago, N., Mangano, M.C., Marsiglia, N., Sarà, G., 2022. The invasive blue crab *Callinectes sapidus* thermal response: predicting metabolic suitability maps under future warming Mediterranean scenarios. *Front. Mar. Sci.* 9, 1055404. <https://doi.org/10.3389/fmars.2022.1055404>.
- Marchessaux, G., Gjoni, V., Sarà, G., 2023a. Environmental drivers of size-based population structure, sexual maturity and fecundity: a study of the invasive blue crab *Callinectes sapidus* (Rathbun, 1896) in the Mediterranean Sea. *PLoS One* 18, e0289611.
- Marchessaux, G., Chevalier, C., Mangano, M.C., Sarà, G., 2023b. Larval connectivity of the invasive blue crabs *Callinectes sapidus* and *Portunus segnis* in the Mediterranean Sea: a step toward improved cross border management. *Mar. Pollut. Bull.* 194, 115272. <https://doi.org/10.1016/j.marpolbul.2023.115272>.
- Marchessaux, G., Mangano, M.C., Bizzarri, S., M'Rabet, C., Principato, E., Lago, N., Veyssièr, D., Garrido, M., Scyphers, S.B., Sarà, G., 2023c. Invasive blue crabs and small-scale fisheries in the Mediterranean Sea: local ecological knowledge, impacts and future management. *Mar. Policy* 148, 105461. <https://doi.org/10.1016/j.marpol.2022.105461>.
- Marchessaux, G., Barré, N., Mauclert, V., Lombardini, K., Durieux, E.D.H., Veyssièr, D., Filippi, J.J., Bracconi, J., Aiello, A., Garrido, M., 2024a. Salinity tolerance of the invasive blue crab *Callinectes sapidus*: from global to local, a new tool for implementing management strategy. *Sci. Total Environ.* 954, 176162. <https://doi.org/10.1016/j.scitotenv.2024.176162>.
- Marchessaux, G., Sibella, B., Garrido, M., Abbruzzo, A., Sarà, G., 2024b. Can we control marine invasive alien species by eating them? The case of *Callinectes sapidus*. *Water* 29, 19. <https://doi.org/10.3390/w290119>.
- Martellucci, R., Tiralongo, F., Darmaraki, S.F., D'Alessandro, M., Mancinelli, G., Mancini, E., Simonini, R., Menna, M., Pirro, A., Borne, D., Auriemma, R., Graziano, M., Mauri, E., 2025. Mediterranean marine heatwave 2023: ecosystem and fisheries impacts in Italian waters. *State Planet* 6, 9. <https://doi.org/10.5194/sp-6-9-9-2025>.
- Masi, M.D., Saponari, L., Borne, D., Cilenti, L., Scirocco, T., Manzo, C., Mancinelli, G., 2022. Rapid population growth of *Callinectes sapidus* in Mediterranean lagoons and implications for ecosystem management. *Aquat. Invasions* 17, 1–15.
- Micheli, F., 1995. Behavioural plasticity in prey-size selectivity of the blue crab *Callinectes sapidus* feeding on bivalve prey. *J. Anim. Ecol.* 64, 63–74. <https://doi.org/10.2307/5827>.
- Mili, S., Ennouri, R., Ghanem, R., Rifi, M., Jaziri, S., Shaiek, M., Ben Souissi, J., 2020. Additional and unusual records of blue crabs *Portunus segnis* and *Callinectes sapidus* from northeastern Tunisian waters (central Mediterranean Sea). *J. New Sci., Sustain. Livestock Manage.* 14, 303–311.
- Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2023a. Decreto Ministeriale n. 587931 del 23 ottobre 2023 — “Contrasto alla diffusione del granchio blu *Callinectes sapidus* e *Portunus segnis*”. N. 259. Gazzetta Ufficiale della Repubblica Italiana. Available online: <https://www.masaf.gov.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/20517>. (Accessed 20 December 2025).
- Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2023b. Decreto Ministeriale 690591 del 15 dicembre 2023 — Fondo per sostenere l'attività produttiva dei consorzi e delle imprese di acquacoltura. Available online: <https://www.masaf.gov.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/20921>. (Accessed 20 December 2025).
- Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2024a. Decreto 15 dicembre 2023 — Attuazione dell'articolo 10, comma 2 bis, del decreto legge 10 agosto 2023, n. 104. N. 21. Gazzetta Ufficiale della Repubblica Italiana. Available online: <https://www.gazzettaufficiale.it/eli/id/2024/01/26/24A00349/sq>. (Accessed 20 December 2025).
- Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste (MASAF), 2024b. Svolta pesca: firmati decreti per emergenza granchio blu. MASAF Press Release. Available online: [https://www.masaf.gov.it/Granchio\\_blu\\_moratoria\\_mutui](https://www.masaf.gov.it/Granchio_blu_moratoria_mutui). (Accessed 20 December 2025).
- Mispeces, 2024. Blue crab threatens clam production in the Po Delta. Available online: <https://www.mispeces.com/en/news/Blue-crab-threatens-clam-production-in-the-Po-Delta-00001>. (Accessed 20 December 2025).
- Mistri, M., 2002. Ecological characteristics of the invasive Asian date mussel, *Musculista senhousia*, in the Sacca di Goro (Adriatic Sea, Italy). *Estuaries* 25, 431–440. <https://doi.org/10.1007/BF02695985>.
- Mistri, M., 2004. Effect of *Musculista senhousia* mats on clam mortality and growth: much ado about nothing? *Aquaculture* 241, 207–218. <https://doi.org/10.1016/j.aquaculture.2004.07.022>.
- Mistri, M., 2009. Carta ittica provinciale delle aree lagunari e vallive (zona C). *GreenTime Bologna*, p. 210.
- Mistri, M., Rossi, R., Ceccherelli, V.U., 1988. Growth and production of the ark shell *Scapharca inaequivalvis* (Bruguière) in a lagoon of the Po River Delta. *Mar. Ecol.* 9, 35–49. <https://doi.org/10.1111/j.1439-0485.1988.tb00197.x>.
- Mistri, M., Rossi, R., Fano, E.A., 2001. Structure and secondary production of a soft-bottom macrobenthic community in a brackish lagoon (Sacca di Goro, north-eastern Italy). *Estuar. Coast. Shelf Sci.* 52, 605–616. <https://doi.org/10.1006/ecss.2001.0757>.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., PRISMA Group, 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 6 (7), e1000097. <https://doi.org/10.1371/journal.pmed.1000097>.
- Moussa, K., Kapiris, A., Zenetos, A., 2016. Brachyuran diversity along the Mediterranean coast of Egypt, with the addition of a new introduced species. *Cah. Biol. Mar.* 57, 43–49.
- Munari, C., Mistri, M., 2014. Traditional management of lagoons for fishery can be inconsistent with restoration purposes: the Valli di Comacchio study case. *Chem. Ecol.* 30, 653–665.
- Munari, C., Mistri, M., 2019. A new record of *Callinectes sapidus* Rathbun, 1896 along the Emilia-Romagna coast. *Biol. Mar. Mediterr.* 26, 318–319.
- Munari, C., Rossi, R., Turolla, E., Mistri, M., 2009. Estimating clam recruitment potential in a nursery area in the Sacca di Goro lagoon (Italy). *Ital. J. Zool.* 76, 129–132.
- Nehring, S., 2011. Invasion history and success of the American blue crab *Callinectes sapidus* Rathbun, 1896 in European and adjacent waters. In: Galil, B.S., Clark, P.F., Carlton, J.T. (Eds.), *In the Wrong Place – Alien Marine Crustaceans: Distribution, Biology and Impacts*. Springer, Berlin/Heidelberg, pp. 607–624.
- Ni, Y., Nagashimada, M., Zhuge, F., Zhan, L., Ando, Y., Sugimoto, M., Kaneko, S., Ota, T., 2015. Astaxanthin prevents and reverses diet-induced insulin resistance and steatohepatitis in mice: a comparison with vitamin E. *Sci. Rep.* 5, 17192. <https://doi.org/10.1038/srep17192>.
- Nunes, A.N., Roda, A., Gouveia, L.F., Fernández, N., Bronze, M.R., Matias, A.A., 2021. Astaxanthin extraction from marine crustacean waste streams: an integrate approach between microwaves and supercritical fluids. *ACS Sustain. Chem. Eng.* 9, 3050–3059. <https://doi.org/10.1021/acssuschemeng.0c06534>.
- Occipinti-Ambrogio, A., Marchini, A., Cantone, G., Castelli, A., Chimenz, C., Cormaci, M., Frogia, C., Furnari, G., Gambi, M.C., Giaccone, G., Jiang, Z., Mastroianni, F., Mazziotti, C., Ponti, M., Piraino, S., Russo, G.F., Sheryl, A.S., Taramelli, E., Akoumianaki, I., Badalamenti, F., Baia, D., Bandra, A.L., Buia, M.C., Chemello, R., Colombo, F., Criscoli, A., Curini-Galletti, M., D'Anna, G., Danovaro, R., De Oliveira, C., Dorgham, M.M., Ferrero, V.E., Gil-Rodríguez, M.C., Kashta, L., Kottaras, K., Koukouras, A., Lakkis, S., Lanera, P., Lo Brutto, S., Marchiori, C., Mastaller, M., Milazzo, M., Mariani, S., Morri, C., Najm, S., Nigro, M., Orfanidis, S., Panouci-Papadopoulou, M.A., Papi, I., Pastore, M., Piriz, M.L., Relini, G., Reizopoulos, S., Riggio, S., Schiaparelli, S., Serio, D., Sfriso, A., Sghaier, Y.R., Tagliapietra, D., Terlizzi, A., Todaro, M.A., Tsiakkios, L., Vacchi, M., 2011. Alien species along the Italian coasts: an overview. *Biol. Invasions* 13, 215–237. <https://doi.org/10.1007/s10530-010-9803-y>.
- Onofri, V., Dulčić, J., Conides, A., Matić-Skoko, S., Glamuzina, B., 2008. Occurrence of the Atlantic blue crab *Callinectes sapidus* in the eastern Adriatic Sea. *Crustaceana* 81, 403–409.
- Oussellam, M., Bazairi, H., El Ouamari, N., 2023. First occurrence and expansion of the invasive blue crab *Callinectes sapidus* in the Marchica Lagoon (Mediterranean coast of Morocco). *Biol. Invasions Rec.* 12, 403–416. <https://doi.org/10.3391/bir.2023.12.2.05>.
- Pagliara, P., Mancinelli, G., 2018. Parasites affect hemocyte functionality in the hemolymph of the invasive Atlantic blue crab *Callinectes sapidus* from a coastal habitat of the Salento Peninsula (SE Italy). *Mediterr. Mar. Sci.* 19, 193–200. <https://doi.org/10.12681/mms.13886>.
- Pani, A., Cabiddu, S., Addis, P., Palmas, F., Cau, A., 2025. Feeding behavior and preference of the invasive blue crab (*Callinectes sapidus* Rathbun, 1896) for Mediterranean native bivalves in mesocosm. *Hydrobiologia* 852, 2907–2922. <https://doi.org/10.1007/s10750-025-05803-7>.
- Pashkov, A.N., Reshetnikov, S.I., Bondarev, K.B., 2012. The capture of the blue crab (*Callinectes sapidus*, Decapoda, Crustacea) in the Russian sector of the Black Sea. *Russ. J. Biol. Invasions* 3, 22–28. <https://doi.org/10.1134/S2075111712010067>.
- Pellizzato, M., Da Ros, L., 2005. Clam farming quality as a management tool: a proposal based on recent studies in Northern Adriatic lagoons. *Aquac. Int.* 13, 57–66.
- Perelló, E., Pinya, S., Box, A., Sureda, A., Compa, M., 2025. Assessing heavy metal accumulation in the invasive blue crab (*Callinectes sapidus*): environmental and human health implications. *Environ. Sci. Pollut. Res.* 32, 12579–12593. <https://doi.org/10.1007/s11356-025-36462-9>.
- Piccardi, F., Bortot, C., Brunoni, L., Poli, F., Rosenthal, G.G., Mazzoldi, C., Barausse, A., 2025. Invasive blue vs. local Green: analysis of substrate preference of two crab

- species, *Callinectes sapidus* and *Carcinus aestuarii*. Mar. Environ. Res. 208, 107164. <https://doi.org/10.1016/j.marenvres.2025.107164>.
- Pipitone, C., Zenone, A., Badalamenti, F., D'Anna, G., 2020. First record of the Atlantic blue crab *Callinectes sapidus* from the central and southern Tyrrhenian Sea. Acta Adriat. 61, 101–106.
- Png-Gonzalez, L., Papiol, V., Balbín, R., Cartes, J.E., Carbonell, A., 2021. Larvae of the blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae) in the Balearic Archipelago (NW Mediterranean Sea). Mar. Biodivers. Rec. 14, 21. <https://doi.org/10.1186/s41200-021-00216-x>.
- Prado, P., Peñas, A., Ibáñez, C., Cabanes, P., Jornet, L., Álvarez, N., Caiola, N., 2020. Prey size and species preferences in the invasive blue crab, *Callinectes sapidus*: potential effects in marine and freshwater ecosystems. Estuar. Coast. Shelf Sci. 245, 106997. <https://doi.org/10.1016/j.ecss.2020.106997>.
- Prager, M.H., McConaughy, J.R., Jones, C.M., Geer, P.J., 1990. Fecundity of blue crab, *Callinectes sapidus*, in Chesapeake Bay: Biological, statistical and management considerations. Bull. Mar. Sci. 46, 170–179.
- Pranovi, F., Franceschini, G., Casale, M., Zucchetta, M., Torricelli, P., Giovanardi, O., 2006. An ecological imbalance induced by a non-native species: the Manila clam in the Venice Lagoon. Biol. Invasions 8, 595–609. <https://doi.org/10.1007/s10530-005-1602-5>.
- Presidenza del Consiglio dei Ministri, 2024. Piano di intervento per contenere e contrastare il fenomeno della diffusione e della proliferazione della specie granchio blu (*Callinectes sapidus*). Commissario straordinario del Governo per l'adozione di interventi urgenti connessi al fenomeno della diffusione e proliferazione della specie granchio blu, Roma, Italy, 35pp.
- Riedl, R., 1983. Fauna und Flora des Mittelmeeres. Paul Parey, Berlin and Hamburg, p. 836.
- Saputra, H.A., Andreas, 2025. Chitosan and its biomedical applications: a review. Next Mater. 9, 101270. <https://doi.org/10.1016/j.nxmte.2025.101270>.
- Schott, E., Brailo Šćepanović, M., Maršić-Lučić, J., Pares, O., Zhao, M., Hrabar, J., Glamuzina, L., Pećarević, M., Grdan, S., Da Silva, Pedro, Encarnação, J., Morais, P., Pešić, A., Četković, I., Glamuzina, B., 2025. The prevalence of two known pathogens of Atlantic Blue Crab *Callinectes sapidus* (Rathbun, 1896) in coastal Adriatic, Aegean Sea, and Atlantic Iberian coast. Mediterr. Mar. Sci. 26, 930–940. <https://doi.org/10.12681/mms.39256>.
- Schubart, C.D., Deli, T., Mancinelli, G., Cilenti, L., Gil Fernández, A., Falco, S., Berger, S., 2023. Phylogeography of the Atlantic blue crab *Callinectes sapidus* (Brachyura: Portunidae) in the Americas versus the Mediterranean Sea: determining origins and genetic connectivity of a large-scale invasion. Biology 12, 35. <https://doi.org/10.3390/biology12010035>.
- Sharov, A.F., Vølstad, J.H., Davis, G.R., Davis, B.K., Lipcius, R.N., Montane, M.M., 2003. Abundance and exploitation rate of the blue crab (*Callinectes sapidus*) in Chesapeake Bay. Bull. Mar. Sci. 72, 543–565.
- Shauer, M., Zangaro, F., Specchia, V., Pinna, M., 2025. Investigating invasion patterns of *Callinectes sapidus* and the relation with research effort and climate change in the Mediterranean Sea. Sci. Rep. 15, 34967. <https://doi.org/10.1038/s41598-025-18982-z>.
- Siddiolo, C., Palumbo, V., Milisenda, G., Pipitone, C., Rosso, A., Chemello, R., 2025. Assessing habitat suitability and distribution patterns of the invasive brachyuran crabs *Callinectes sapidus* and *Portunus segnis* in the Mediterranean basin. Mediterr. Mar. Sci. 26, 428–439.
- Sorokin, Y.I., Sorokin, P.Y., Giovanardi, O., 1996. Structure and functioning of the anthropogenically transformed Comacchio lagoonal ecosystem (Ferrara, Italy). Mar. Ecol. Prog. Ser. 133, 57–71. <https://doi.org/10.3354/meps133057>.
- Sorokin, Y.I., Sorokin, P.Y., Zakuskina, O.Y., Ravagnan, G., 1999. A survey on a persistent greenish bloom in the Comacchio lagoons (Ferrara, Italy). Bot. Mar. 42, 531–539. <https://doi.org/10.1515/BOT.1999.060>.
- Streftaris, N., Zenetos, A., 2006. Alien Marine Species in the Mediterranean - the 100 'Worst Invasives' and their Impact. Mediterr. Mar. Sci. 7, 27–38.
- Streftaris, N., Zenetos, A., Papanthassiou, E., 2006. Globalisation in marine ecosystems: the story of non-indigenous marine species across European seas. Oceanogr. Mar. Biol. Annu. Rev. 44, 419–453.
- Suaria, G., Pierucci, A., Zanello, P.P., Fanelli, E., Chiesa, S., Azzurro, E., 2017. *Percnon gibbsii* (H. Milne Edwards, 1853) and *Callinectes sapidus* (Rathbun, 1896) in the Ligurian Sea: two additional invasive species detections made in collaboration with local fishermen. Bioinvasions Rec. 6, 147–151.
- Tamburini, E., 2024. The blue treasure: comprehensive biorefinery of blue crab (*Callinectes sapidus*). Foods 13, 2018. <https://doi.org/10.3390/foods13132018>.
- Tapia, A., Peña, R., Zambrano, H., Paredes, V., 2025. Extraction and characterization of chitosan obtained from shells of crab (*Callinectes bocourti* and *Callinectes sapidus*). Int. J. Biol. Macromol. 320, 145963. <https://doi.org/10.1016/j.ijbiomac.2025.145963>.
- Tiralongo, F., Villani, G., Arciprete, R., Mancini, E., 2021. Filling the gap on Italian records of an invasive species: first records of the Blue Crab, *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae), in Latium and Campania (Tyrrhenian Sea). Acta Adriat. 62, 99–104. <https://doi.org/10.32582/aa.62.1.8>.
- Tiralongo, F., Nota, A., Di Pasquale, C., Muccio, E., Felici, A., 2024. Trophic interactions of *Callinectes sapidus* (Blue Crab) in Vendicari Nature Reserve (Central Mediterranean, Ionian Sea) and first record of *Penaus aztecus* (Brown Shrimp). Diversity 16, 724.
- Tiralongo, F., Mancini, E., Gattelli, R., di Pasquale, C., Rossetti, E., Martellucci, R., Felici, A., Mancinelli, G., Mulder, C., 2025. The devastating economic impact of *Callinectes sapidus* on clam fishing in the Po Delta (Italy): striking evidence from novel field data. arXiv:2501.01234. Available online: <https://arxiv.org/abs/2501.01234>. (Accessed 28 December 2025).
- UNEP/MAP-SPA/RAC, 2025. Best practices and management measures of the blue crabs in the Mediterranean by Guillaume, Marchessaux. Ed. SPA/RAC, Tunis, p. 23.
- Vincenzi, S., Caramori, G., Rossi, R., De Leo, G., 2006. Estimating clam yield potential in the Sacca di Goro lagoon (Italy) by using a two-part conditional model. Aquaculture 261, 1281–1291.
- Vivas, M., García-Rodríguez, E., Muñoz-Vera, A., Barcala, E., Guisjarro-García, E., 2025. Effect of the invasive blue crab (*Callinectes sapidus* Rathbun, 1896) in a protected coastal lagoon. Estuar. Coasts 48, 9. <https://doi.org/10.1007/s12237-024-01436-6>.
- Webster, C., Onokpise, O., Abazinge, M., Muchovej, J., Johnson, E., Louime, C., 2014. Turning waste into usable products: a case study of extracting chitosan from blue crab. Am. J. Environ. Sci. 10, 357–362. <https://doi.org/10.3844/ajessp.2014.357.362>.
- Xu, R., Chaudhary, K., Altemimi, A.B., Khalid, S., Ansar, S., Abid, N., Abdi, G., Aadil, R. M., 2025. Ultrasound-assisted extraction with deep eutectic solvents for valorization of agro-food waste: a sustainable and eco-friendly approach. Ultrason. Sonochem. 120, 107500. <https://doi.org/10.1016/j.ultsonch.2025.107500>.
- Younes, I., Rinaudo, M., 2015. Chitin and chitosan preparation from marine sources. Structure, properties and applications. Marine Drugs 13, 1133–1174. <https://doi.org/10.3390/md13031133>.
- Yu, D., Puhar, J., Mukherjee, S., Ošlovnik, T., Dutta, J., Vujanović, A., Ye, F., 2026. Sustainable extraction of chitosan from blue crabs (*Callinectes sapidus*) by green solvents. Bioresour. Technol. 441, 133595. <https://doi.org/10.1016/j.biortech.2025.133595>.
- Zenetos, A., Gofas, S., Morri, C., Rosso, A., Violanti, D., García Raso, J.E., Çinar, M.E., Almogi-Labin, A., Ates, A.S., Azzurro, E., Ballesteros, E., Bianchi, C.N., Bilecenoglu, M., Gambi, M.C., Giangrande, A., Gravili, C., Hyams-Kaplan, O., Karachle, P.K., Katsanevakis, S., Lipej, L., Mastrototaro, F., Mineur, F., Pancucci-Papadopoulou, M.A., Ramos Esplá, A., Salas, C., San Martín, G., Sfriso, A., Streftaris, N., Verlaque, M., 2012. Alien species in the Mediterranean Sea by 2012. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part 2. Introduction trends and pathways. Mediterr. Mar. Sci. 13, 328–352. <https://doi.org/10.12681/mms.327>.
- Zohar, Y., Hines, A.H., Zmora, O., Johnson, E.G., Lipcius, R.N., Seitz, R.D., et al., 2008. The Chesapeake Bay blue crab (*Callinectes sapidus*): a multidisciplinary approach to responsible stock replenishment. Rev. Fish. Sci. 16, 24–34. <https://doi.org/10.1080/10641260701681623>.