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Trophic Interactions of *Callinectes sapidus* (Blue Crab) in Vendicari Nature Reserve (Central Mediterranean, Ionian Sea) and First Record of *Penaeus aztecus* (Brown Shrimp)

Francesco Tiralongo [1,2,3,*], Alessandro Nota [2,4,*], Costanza Di Pasquale [2], Eliana Muccio [2] and Alberto Felici [5]

[1] Department of Biological, Geological and Environmental Sciences, University of Catania, 95124 Catania, Italy
[2] Ente Fauna Marina Mediterranea-Scientific Organization for Research and Conservation of Marine Biodiversity, 96012 Avola, Italy; costanzadip937@gmail.com (C.D.P.); elianamuccio@outlook.it (E.M.)
[3] Institute for Biological Resources and Marine Biotechnologies, National Research Council, 60125 Ancona, Italy
[4] Department of Biology and Biotechnology "Lazzaro Spallanzani", University of Pavia, 27100 Pavia, Italy
[5] School of Biosciences and Veterinary Medicine, University of Camerino, 62024 Matelica, Italy; alberto.felici@unicam.it
* Correspondence: francesco.tiralongo@unict.it (F.T.); alessandro.nota@conted.ox.ac.uk (A.N.)

Abstract: Invasive alien species pose severe threats to global biodiversity, ecosystem functions, and socio-economic values, particularly in coastal and marine ecosystems. This study aimed to investigate the trophic interactions between alien species and native fauna in a Mediterranean coastal ecosystem. Notably, our research focused on the presence and ecological roles of the invasive Atlantic blue crab (*Callinectes sapidus*) and the brown shrimp (*Penaeus aztecus*) within the Vendicari Nature Reserve (VNR), a protected area on the southeastern coast of Sicily, Italy. Field observations, specimen collection, and interviews with local fishermen were conducted to assess the presence, distribution, and feeding habits of these species. The results revealed significant temporal shifts in the diet of *C. sapidus*, with a clear decrease in predation on the alien *Penaeus aztecus* (first observed in the VNR) over the study months. The presence of *C. sapidus* in the fishing area around the reserve has been detected for many years, while *P. aztecus* appears to have recently colonized the area. Additionally, photographic evidence documented the predation of *C. sapidus* by *Octopus vulgaris*, highlighting a potential adaptive feeding behavior by the common octopus in response to the abundance of this invasive crab. The integration of scientific research, local ecological knowledge, and community participation is essential for mitigating the impacts of biological invasions and preserving the biodiversity and ecological integrity of natural ecosystems.

Keywords: invasive alien species; protected area; LEK (local ecological knowledge); coastal environments; feeding habits

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1. Introduction

Invasive alien species pose severe threats to global biodiversity, ecosystem services, and socio-economic values [1]. Their introduction and establishment in new environments often lead to deep ecological changes, including alterations in species composition, food web dynamics, and predator–prey relationships, as well as introductions of new pathogens [2–6]. Invasive species can disrupt these dynamics through both direct and indirect pressure on native species. This can include not only competition for space and resources, but also, for example, an increase in predation on native competitors by the attraction of native predators [7]. This competition can intensify predation on vulnerable native species, highlighting the need to consider both direct competition and indirect effects when evaluating the ecological impacts of invasive species. Coastal and marine ecosystems are particularly susceptible to such invasions due to increased globalization, shipping activities, and climate change [8–10]. The effective management of invasive species requires

comprehensive knowledge of their biology, ecology, and interactions with native counterparts. This includes understanding their reproductive cycles, dispersal mechanisms, habitat preferences, and feeding behaviors. Such information is critical for developing targeted monitoring efforts and control measures, such as physical removal, the encouragement of commercial use of the invader, and environmental rehabilitation [11]. These strategies aim to prevent further introductions and mitigate the impacts of existing invasions.

The Vendicari Nature Reserve, located on the southeastern coast of Sicily (Italy), is a protected area of high ecological value, encompassing a variety of habitats such as wetlands, salt pans, sand dunes, and coastal marine environments. The reserve is well-known for its rich biodiversity, serving as a stopover for migratory birds and hosting many native and endemic species of flora and fauna. The arrival and establishment of *C. sapidus* within this reserve raise several concerns due to its potential impacts on native communities [12].

The Atlantic blue crab (*Callinectes sapidus*), native to the western Atlantic coast from Nova Scotia to Argentina, has become a major invader of European waters over recent decades. Its first records in the Mediterranean Sea date back to the early 20th century, but its populations have been expanding notably in recent years [13]. *C. sapidus* exhibits a high degree of metabolic plasticity that allows it to thrive across variable environments, such as shallow marine and brackish waters, all of which are increasingly experiencing warmer temperatures due to climate change. Thermal Habitat Suitability models predict that these rising temperatures will enhance the suitability of Mediterranean habitats for *C. sapidus*, particularly in northern areas that were previously cooler and less favorable [14]. Indeed, the northward expansion of *C. sapidus* in the Atlantic has been linked to the warming ocean temperatures [15]. The blue crab is characterized by a high reproductive potential, broad environmental tolerance, aggressive behavior, and omnivorous diet, traits that enable it to establish stable populations in new habitats and outcompete native species [12,16]. The omnivorous feeding habits of *C. sapidus* allow it to exploit a wide range of food resources, including mollusks, crustaceans, fish, and plant material. This dietary flexibility not only facilitates its survival in diverse environments, but also poses a threat to native species through both predation and competition for resources. Previous studies have documented the negative impacts of *C. sapidus* on benthic organisms, leading to alterations in community structure and ecosystem functioning [16–19]. The crab is well-established in the reserve.

Another invasive species native to the western Atlantic, the brown shrimp (*Penaeus aztecus*), is establishing populations in various non-native areas of the Mediterranean, including Turkey [20], Greece [21], Egypt [22], Spain [23], and Italy. In Italy, the species is now present in both the Tyrrhenian Sea and the Adriatic, as well as around the two major islands (Sicily and Sardinia) [24]. The arrival of *P. aztecus* introduces an additional layer of complexity to the ecological interactions within the reserve, as the species may compete with native shrimps and other benthic organisms for habitat and food resources.

Similarly to *C. sapidus*, *P. aztecus* demonstrates a high thermal tolerance, with its thermal maxima increasing substantially when acclimated to warmer temperatures, underscoring its adaptability to thermally fluctuating environments [25]. In the context of seawater warming, these adaptive capacities underscore the potential for both the blue crab and the brown shrimp to further establish and impact the Mediterranean ecosystem.

Invasive species can interact in complex ways, potentially leading to phenomena such as invasional meltdown, where mutual facilitation among invaders accelerates their establishment and impact on native ecosystems [26]. Alternatively, negative interactions like predation between invaders could suppress the abundance of one species, potentially mitigating some ecological impact.

The main aim of this study was to investigate the trophic interactions and ecological roles of the invasive Atlantic blue crab (*C. sapidus*) within the Vendicari Nature Reserve (VNR) in Sicily, Italy. The Vendicari Nature Reserve provides an ideal setting for studying these interactions due to its protected status and relatively undisturbed habitats. The outcomes of this research will enhance our understanding of invasion biology in marine

ecosystems and support the development of effective management and conservation strategies to protect the biodiversity and ecological integrity of nature reserves.

Fieldwork and interviews were conducted to assess the presence, distribution, and feeding habits of these two invasive species. Key findings revealed temporal shifts in the blue crab's diet and in the predation on *P. aztecus*. Additionally, the study documented the predation of *C. sapidus* by the common octopus (*Octopus vulgaris*), highlighting an adaptive response that could help to regulate the invasive crab population. These findings emphasize the complex dynamics between invasive species and the importance of ongoing monitoring and management efforts in protected ecosystems.

2. Materials and Methods

2.1. Study Area

The research was conducted within the Vendicari Nature Reserve, located on the southeastern coast of Sicily, Italy (Ionian Sea) (Figure 1). The reserve encompasses a variety of habitats, including wetlands, lagoons, sand dunes, and coastal marine environments. Specifically, the study focused on the following two main areas within the reserve: the channel connecting one Vendicari lagoon (Pantano Grande) to the sea, and the estuarine area of the Tellaro River. Both the former and the latter are transitional habitats, characterized by a mix of freshwater and marine influences which support a diverse assemblage of aquatic species. This area provides important feeding and breeding grounds for various aquatic organisms.

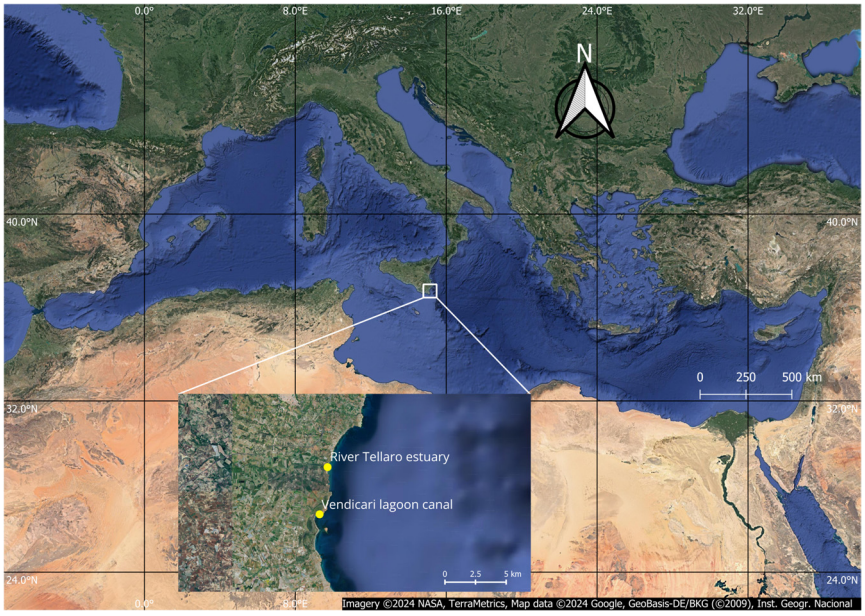


Figure 1. The study area located in the central Mediterranean Sea (Sicily, Ionian Sea).

2.2. Field Observations

Fieldwork was conducted over five months, from May to September 2024, during which, a total of 12 surveys were carried out on 12 and 30 May, 10, 15 24, and 28 June, 5, 11 and 24 July, 7 and 21 August, and 26 September. This timeframe was selected to encompass the warmer months when *C. sapidus* is most present [27] and to coincide with the peaks of biological activity in the ecosystem [28]. Visual censuses were performed during daylight hours, walking with boots up to a depth of 50 cm and systematically surveying the designated study areas. All observations of *C. sapidus* feeding individuals were recorded, and prey items were identified to the lowest possible taxonomic level. The water temperature was recorded on each sampling day. The macrofauna observed and associated with the presence of *C. sapidus* during the samplings was identified to the finest

taxonomic level possible and reported in order to provide additional information on the ecological context.

2.3. Specimens Collection

Three specimens of *P. aztecus* were captured by hand on the three following distinct dates: 20th May, 6 June, and 18 June 2024, within the channel connecting the Vendicari lagoon to the sea (see Figure 1). The captured specimens were preserved in 80% ethanol for the subsequent laboratory analysis. Identification was conducted using morphological characteristics based on established taxonomic keys [24,29], examining features such as the presence and number of teeth on the ventral margin of the rostrum, the lack of teeth on the lateral margins of the telson, the dorsolateral sulcus on the last abdominal somite, and the coloration patterns.

2.4. Fishermen Interviews—LEK (Local Ecological Knowledge)

To supplement field observations and gather information on the broader distribution of the two alien species, semi-structured interviews were conducted with local fishermen (N = 9) operating with gillnets in the marine areas immediately adjacent to the reserve. Participation was voluntary, and all respondents provided informed consent. The interviews were conducted face-to-face, using a semi-structured questionnaire format designed to gather insights into the following aspects:

1. The time since the fisherman started observing the alien species *C. sapidus* and *P. aztecus* among their catches. (Q1)
2. The number of individuals of *C. sapidus* and *P. aztecus* that the fisherman has caught over the last year (2023). (Q2)
3. The typical depths at which the fisherman catches the alien species. (Q3)
4. The types of habitats where the alien species are most commonly found by the fisherman. (Q4)
5. The native species commonly associated with the alien species in the fisherman's catches. (Q5)
6. The presence of other alien invertebrate species among the fisherman's catches. (Q6)

Responses were recorded during the interviews, and additional qualitative comments provided by the fishermen were annotated to further capture any relevant observations or insights.

2.5. Local Expert Interview

As part of a study on the trophic relationships of alien species present in the Vendicari Oasis nature reserve, interviews were conducted with naturalist experts who regularly frequent the area. The main objective was to collect qualitative information and photographic documentation on any type of predatory interactions involving *C. sapidus*. During these interviews, a particularly interesting case emerged regarding the predation of *C. sapidus* by *Octopus vulgaris*. The data were further corroborated by photographs taken by one of the experts in the field, dating back to July 2023. These images were analyzed and used to document the presence of blue crab remains near the dens of octopuses located close to the lagoons where the blue crab is abundant.

2.6. Data Analysis

The feeding events of *C. sapidus* were quantified to determine the frequency of their predation on different prey types. Prey species were identified and categorized to assess dietary preferences and potential impacts on the native fauna and on *P. aztecus*, grouping the first six surveys (first sampling season) and the last six ones (second sampling season). The association between the three main prey categories (algae, invertebrates, and fishes) and the two sampling seasons was tested with a Chi-square contingency test, since less than 20% of the expected frequencies were below 5. Given the high predation on *P. aztecus* during the first season, the test was also repeated when excluding this species. Descriptive statistics

were used to summarize the observation data and interview responses. Qualitative data from the interviews were evaluated to identify common patterns and perceptions among the fishermen. Statistical analyses were performed in R 4.3.2 with the R studio interface (RStudio Team, Boston, MA, USA).

3. Results

The grouped absolute frequencies of the three main prey categories in the two sampling seasons are represented in Table 1. *P. aztecus* was the most common prey for *C. sapidus*; despite not being captured during the second season, the shrimp was captured 13 times during the first one.

Table 1. Frequencies of the three main prey categories over the two sampling seasons.

	Algae	Invertebrates	Fishes
First season	2	22	5
Second season	11	4	5

The Chi-squared test on the values in Table 1 gave $\chi^2 = 17.634$ with $p < 0.001$, indicating a highly significant association between prey types and the two main sampling seasons (Figure 2). In the second test (excluding the 13 predations of *P. aztecus*), this association was still significant with $\chi^2 = 7.8058$ and $p = 0.020$.

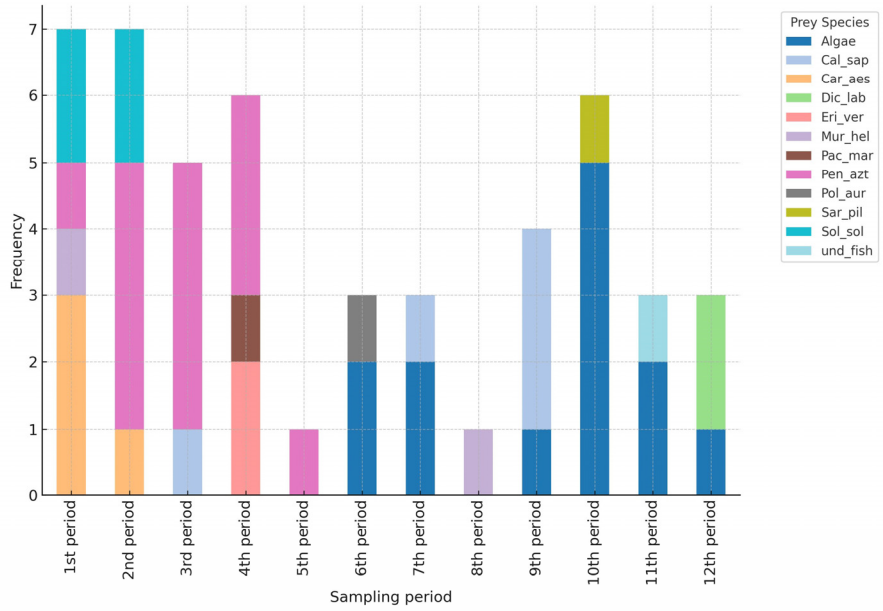


Figure 2. Species' frequency distribution along the 12 sampling periods. Cal_sap = *Callinectes sapidus*; Car_aes = *Carcinus aestuarii*; Dic_lab = *Dicentrarchus labrax*; Eri_ver = *Eriphia verrucosa*; Mur_hel = *Muraena helena*; Pac_mar = *Pachygrapsus marmoratus*; Pen_azt = *Penaeus aztecus*; Pol_aur = *Polititapes aureus*; Sar_pil = *Sardina pilchardus*; Sol_sol = *Solea solea*; and und_fish = unidentified fish (damaged).

Regarding the response to Q1, an average value of 14.66 years was recorded as the time since *C. sapidus* was first observed in the area, with a standard deviation of 6.20 and a range (min–max) of 5–25 years. Regarding the response to Q2, an average value of 7.22 individuals caught in the last year (2023) was recorded, with a standard deviation of 6.51 and a range (min–max) of 1–20 individuals. Regarding the response to Q3, an average depth of 13.33 m was reported for typically catching these species, with a standard deviation of 6.61 and a range (min–max) of 5–25 m. Of the nine fishermen interviewed, six stated that they usually caught *C. sapidus* on sandy bottoms (66.67%), while three indicated mixed bottoms (sand and rock) (33.33%) (Q4). Only one fisherman (11.11%) communicated

the capture of similar species in the area, i.e., *Portunus hastatus*, another crab from the Portunidae family, while all the others (88.89%) reported no catches of species similar to *C. sapidus* (Q5). The fishermen confirmed catching other alien species, including *Erugosquilla massavensis* (seven fishermen, 77.78%) and *Portunus segnis* (two fishermen, 22.22%) (Q6).

Regarding the response to Q1, an average value of 4.33 years was recorded as the time since *P. aztecus* was first observed in the area, with a standard deviation of 1.66 and a range (min–max) of 2–7 years. Regarding the response to Q2, an average value of 11.44 individuals caught in the last year (2023) was recorded, with a standard deviation of 10.58 and a range (min–max) of 1–30 individuals. Regarding the response to Q3, an average depth of 23.88 m was reported for typically catching these species, with a standard deviation of 7.82 and a range (min–max) of 10–35 m. Of the nine fishermen interviewed, eight stated that they usually caught *P. aztecus* on sandy bottoms (88.89%), while one indicated mixed bottoms (sand and rock) (11.11%) (Q4). All fishermen agreed that the only similar species caught in the area was *Penaeus kerathurus* (Q5). The fishermen confirmed catching other alien species, including *Erugosquilla massavensis* (88.89%) and *Portunus segnis* (11.11%). In absolute terms, eight fishermen reported catching *E. massavensis*, while one reported catching *P. segnis* (Q6).

The collected specimens of *P. aztecus* (Figure 3) were identified using the keys provided in the works of Farfante (1988) and Froglia (2023) [24,29]. The median sulcus is long and deep along its entire length, while the dorsolateral sulcus is broad, with a ratio of keel height to sulcus width less than three. The thelycum features relatively broad anterior and posterior processes.



Figure 3. Two of the three collected *P. aztecus* specimens, after thawing.

The photographs taken by the expert clearly show, in July 2023, the remains of *C. sapidus* deposited in front of the dens of several *O. vulgaris* individuals (Figure 4). These dens were located in the immediate proximity of the reserve's lagoons, areas where a high density of blue crabs has been documented. These observations provide indirect evidence of the predation of *C. sapidus* by *O. vulgaris.*

Species observed during field observations and sampling are reported in Table 2. A total of 21 taxa were identified (10 fishes, 10 crustaceans, and 1 mollusk), belonging to 18 families and 3 phyla. Only two species, the ones studied (*C. sapidus* and *P. aztecus*), are alien.

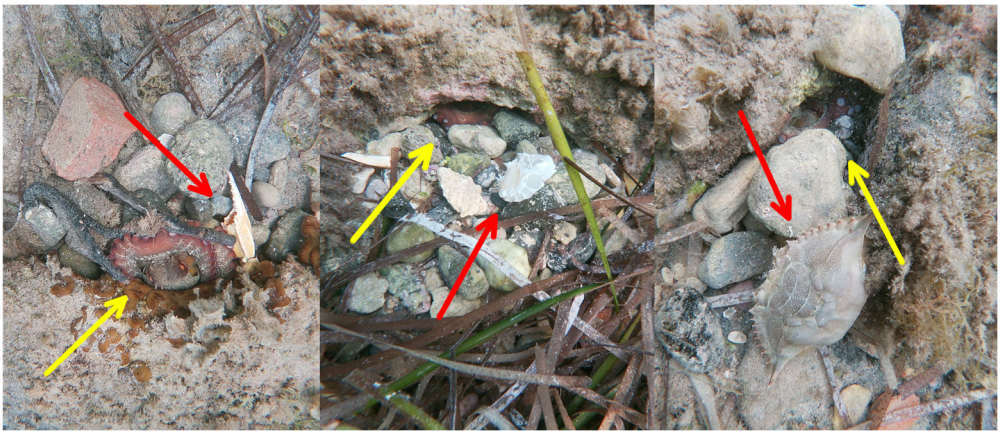


Figure 4. Photos demonstrating the presence of remains of *C. sapidus* (red arrows) close to octopus (yellow arrow) dens.

Table 2. List of species observed/collected during the study area.

Species	Family	Phylum	Origin
Anguilla anguilla	Anguillidae	Chordata	Native
Aphanius fasciatus	Cyprinodontidae	Chordata	Native
Callinectes sapidus	Portunidae	Arthropoda	Alien
Carcinus aestuarii	Carcinidae	Arthropoda	Native
Dicentrarchus labrax	Moronidae	Chordata	Native
Eriphia verrucosa	Eriphiidae	Arthropoda	Native
Gammarus insensibilis	Gammaridae	Arthropoda	Native
Gobius cobitis	Gobiidae	Chordata	Native
Gobius paganellus	Gobiidae	Chordata	Native
Idothea sp.	Idoteidae	Arthropoda	//
Mugil cephalus	Mugilidae	Chordata	Native
Muraena helena	Muraenidae	Chordata	Native
Pachygrapsus marmoratus	Grapsidae	Arthropoda	Native
Pachygrapsus transversus	Grapsidae	Arthropoda	Native
Palaemon elegans	Palaemonidae	Arthropoda	Native
Penaeus aztecus	Penaeidae	Arthropoda	Alien
Polititapes aureus	Veneridae	Mollusca	Native
Pomatoschistus sp.	Gobiidae	Chordata	Native
Solea solea	Soleidae	Chordata	Native
Sparus aurata	Sparidae	Chordata	Native
Upogebia sp.	Upogebiidae	Arthropoda	//

4. Discussion

The trophic interactions of alien species in colonized ecosystems pose a major threat to biodiversity, especially in protected, rich, and diversified areas like Vendicari [30]. Here, the presence of the blue crab, *Callinectes sapidus*, can have severe effects on the local community, altering ecological dynamics and disrupting food web structures [31]. The feeding habits observed in the Vendicari area show similarities with those documented in other regions. For instance, here, *C. sapidus* largely bases its diet on medium-sized crustaceans, similar to what occurs in the Mar Menor lagoon (Spain), where the alien crab mainly preys on *Penaeus kerathurus* and *Palaemon* spp., but also on teleosts and brachyurans, these latter mainly represented by *Carcinus aestuarii* [30].

The results of the Chi-Square tests revealed significant temporal shifts in the diet of *C. sapidus* within the study area, suggesting changes in prey composition over time, likely driven by fluctuations in prey availability. In the first sampling season, as expected, *C. sapidus* predominantly fed on other invertebrates and fish, with algal material generally

representing a small proportion of its diet [25]. However, during the second season, algae became the primary food source, likely due to a decrease in the abundance of invertebrate prey. This dietary shift underscores the crab's opportunistic feeding behavior and its ability to adapt its diet in response to changes in prey availability. On the other hand, the abundance of fish prey remained stable between the two sampling seasons (Table 1), suggesting that the predation of *C. sapidus* on fishes may occur mainly on damaged or weakened individuals, i.e., regardless of the season involved. Interestingly, these significant changes in prey composition over time remained significant, even when excluding *Penaeus aztecus* from the test, indicating a general trend that does not depend on any specific prey species. While *P. aztecus* seems to be expanding on a Mediterranean scale [23], the lack of predation events it suffered during the second sampling season probably suggests a cyclic presence of the shrimp in the invaded areas, likely driven by specific environmental changes or human-driven alterations. *Penaeus aztecus* is known to exhibit seasonal abundance patterns, likely influenced by naturally fluctuating environments [22]. Additionally, the periodic regulation of water flow in the canal by the reserve managers contributes to shaping the local environment. This artificial manipulation of the hydrological conditions can influence key environmental factors, which, in turn, can affect the presence and abundance of various species within the canal, including *P. aztecus*. Cycles in the consumption of plant or animal material throughout the year are common among crabs, and are usually attributed to changes in prey availability [32–34]. Similar seasonal shifts in the diet of the blue crab have already been observed by other authors in southeastern Italy, where this species generally shows lower trophic levels in winter than in summer, likely resulting from a greater amount of available dead seagrass during colder months [32]. However, a larger surveying effort will be required to elucidate how the diet of the blue crab changes throughout the four seasons within the Vendicari Nature Reserve.

The omnivorous and opportunistic diet of the blue crab [16–19] makes it potentially able to prey on a wide range of native and non-native species. The predations reported here further demonstrate the adaptability of the blue crab in exploiting new food resources. On the other hand, the study's findings suggest that *C. sapidus* may exert a form of biological control over *P. aztecus* populations, potentially mitigating some of the negative impacts of this newer invader. However, this does not reduce the overall threats posed by *C. sapidus*, whose feeding habits are known to impact native invertebrate communities [16,17,19]. In addition, as suggested by other authors [35], the replacement of an alien predator with another one in a specific habitat type will not change the impacts of the first in other habitats.

It is crucial to promote targeted fishing efforts toward the two crustaceans and to implement continuous monitoring measures to prevent further introductions and mitigate the negative impacts of these invaders in protected areas.

The interviews conducted with local fishermen operating in nearby areas provide insights into the presence and catch patterns of the two aliens. The results evidenced different arrival times and abundances for the two species, highlighting that the spread of *P. aztecus* is a more recent phenomenon. According to the data, *C. sapidus* has been present in the area for an average of 14.66 years, with a considerable range from 5 to 25 years. This suggests the presence of a well-established population that has likely adapted to the local conditions. The catch per fisherman in the last year was relatively low, with an average of 7.22 individuals, suggesting that the species is not particularly abundant in marine waters, unlike in the Vendicari lagoon areas. The report of another portunid species, *Portunus hastatus*, native and smaller in size compared to the blue crab, raises concerns about the conservation of the native counterparts of the blue crab.

Similarly, the massive reports of *E. massavensis* (77.78%) by the fishermen raise concerns about the conservation of native stomathopods. Indeed, the fishermen reported that *E. massavensis* is becoming increasingly common among catches of the native *Squilla mantis*, with which it probably competes for the same resources and space [36]. The competition between *E. massavensis* and *S. mantis* could lead to several potential ecological consequences. Beyond the potential displacement of the native mantis shrimp, this interaction might also

jeopardize the presence of other invertebrates that are closely related to the native shrimp, such as the caridean shrimp *Athanas amazon*, strictly associated with *S. mantis*' burrows [37]. However, further research is necessary to evaluate the competitive interactions between these species and the potential long-term impacts on native communities.

This, together with further reports of another alien, *P. segnis*, suggests that the presence of *C. sapidus* might be part of a broader trend of alien species establishment in the area, potentially facilitated by water warming, human disturbance, or other conditions that favor the colonization of alien species [38,39]. The presence of *P. aztecus* appears to be a more recent phenomenon, with an average of only 4.33 years since its first observation in the area. Despite its more recent introduction, the average number of individuals caught per year was higher, at 11.44, suggesting a high reproductive rate and a rapid colonization strategy. The preferred habitat for *P. aztecus* differs from *C. sapidus*, with an average depth of 23.88 m, indicating a preference for deeper waters in the nearby marine area to the Nature Reserve of Vendicari. Most fishermen (88.89%) reported catching *P. aztecus* on sandy bottoms, with only one reporting mixed substrates. This strong preference of *P. aztecus* for sandy bottoms and for generally higher depths compared to *C. sapidus* indicates some different habitat requirements, and could imply potential competition with the native *P. kerathurus*, which typically inhabits similar habitats [40]. Sandy bottoms within the natural reserve of Vendicari (estuary and lagoon with its channel) provide an ideal substrate for *C. sapidus* and *P. aztecus* to burrow and seek shelter, likely aiding in predator avoidance and temperature regulation, as well as providing abundant benthic invertebrates and detritus, which are primary food sources for both species.

All fishermen identified *P. kerathurus* as the only similar species caught in the area, indicating their ability to distinguish between these two species. This awareness could be beneficial for monitoring efforts, as fishermen are likely to report sightings or catches of *P. aztecus* accurately. The data collected from fishermen already provide critical information on the presence and distribution of many alien or thermophilic species in Mediterranean waters. For example, fishermen have been trained during recent years to identify and report sightings of invaders through the AlienFish project [41,42]. The reliance on local knowledge through fishermen's reports can serve as a valuable tool for the early detection and tracking of these two crustaceans and other potential alien species in the future. Their involvement not only enhances data collection, but also promotes a sense of shared responsibility and supervision over the local ecosystem.

The photographic documentation of the predation of *C. sapidus* by *O. vulgaris* agrees with the previous literature indicating that the blue crab is predated by the congeneric *Octopus maya*. Octopuses have a typical behavior of bringing back prey to their den, a refuge usually located among rocks or marine crevices. After feeding, they leave the uneaten remains, such as mollusk shells and crustacean or fish parts, near the entrance of the den. This interaction represents a perfect example of biotic resistance against invasions. By hosting rich native communities [43], natural ecosystems can often withstand the pressure exerted by NIS and resist, or at least mitigate, invasions. For instance, Rueskin et al. [44] demonstrated that the expansion of an alien bivalve can be impeded by the presence of predators that reduce its survival. Similarly, in the Mediterranean, it was proposed that the expansion of the alien *Siganus rivulatus* might be partially mitigated due to the predation by native predators [45]. This documented predation could indicate adaptive behavior by *O. vulgaris*, and is in line with the well-known diet plasticity of the octopus [46,47]. However, it remains to be assessed whether this phenomenon is widespread and relevant to a population and Mediterranean scale or limited to a few individuals. An interesting aspect to investigate further is the potential impact that this new food source could have on the biology and ecology of the common octopus. The abundance of *C. sapidus* could influence the distribution, foraging strategies, and even the population growth of *O. vulgaris* in the area. Moreover, these observations raise questions about whether other local predators might adapt to exploit the blue crab as a food source, leading to further changes in local food webs. Evidence suggests that larger fish species, such as stingrays, skates, and

especially benthic and bentho-pelagic sharks, might be other potential predators of the blue crab [48]. Among these, the dusky grouper (*Epinephelus marginatus*), very common in the Mediterranean, is well-known to predate portunids [49]. Additionally, other coastal cephalopod species (e.g., *Sepia officinalis*) present in the region might also incorporate *C. sapidus* into their diets, particularly if the crab's presence continues to increase. Therefore, further research is needed to evaluate whether these interactions might be extended to other species and to a wider spatial scale. Moreover, habitat restoration efforts should be considered, as they play a crucial role in ecosystem resilience by enhancing the ability of native species to thrive and reducing the likelihood of invasive species establishing themselves, making the ecosystem more stable and self-sustaining.

5. Conclusions

An integrated approach involving scientific research, environmental management, and community participation will be crucial to preserving biodiversity and ensuring the sustainability of the coastal ecosystem of the Vendicari Nature Reserve. Scientific research provides the necessary understanding of the biology, ecology, and potential control methods for alien species. This knowledge is vital for developing effective management strategies. In light of this evidence, it is crucial to implement monitoring programs and management measures to prevent further introductions and mitigate their negative effects on protected areas like the Vendicari Nature Reserve. These management measures should include stringent regulations on activities that facilitate the spread of alien species and the implementation of biosecurity protocols, such as regular inspections and the targeted removal of aliens. Additionally, habitat restoration efforts can strengthen the resilience of native species, making the ecosystem less susceptible to invasion.

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