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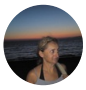

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Occurrence of the Invasive Crab Species *Callinectes sapidus* Rathbun, 1896 in NW Greece.

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Running title

The invasive potential of blue crab in NW Greece

Abstract

The present work aims to review and describe the current status of the invasive species *Callinectes sapidus* Rathbun, 1896, along the Ionian coastal zone of Greece and to assess its invasive potential. Blue crab has a long invasion history in the Mediterranean Sea but the available data on the species occurrence in the Ionian sub-region are scarce and fragmented. The proximity of most of the estuaries and lagoons to local ports and to the shipping routes, as well as the swimming/dispersal ability of the adults, indicate that range expansion will likely continue. The invasiveness risk of the species in the region was estimated with the use of a decision support tool (Marine Invertebrate Invasiveness Screening Kit, version 1.19). The observed impacts are discussed along with urgent mitigation priorities. Measures to limit the expansion of this invasive species may include the effective management of ballast waters and the targeted increase of fishing pressure on *C. sapidus* populations.. The importance of ballast water management is further highlighted by the existence of numerous ports with the capacity to serve ships with ballast tanks in close proximity to the recipient ecosystems. Moreover, the Ionian Sea which connects the Adriatic Sea to the rest of the Mediterraneanis a significant shipping route for the local, regional and international seaborne trade..

Keywords: Invasive species, ecological threats, marine pollution

Introduction

The blue crab *Callinectes sapidus* Rathbun, 1896 (Brachyura: Portuniidae), native to the western Atlantic coast, invaded at least since the beginning of the 20th century the European waters in multiple independent introductions via ballast water. Invasion history and success in a Pan-European level were recently reviewed for the Atlantic Ocean coasts, North, Baltic, Mediterranean, Black and Azov Seas by Nehring [1]. Concerning the Mediterranean Sea, the species has been recorded and positively established populations in 12 countries. This exceptionally high establishment rate in this region as well as the reported negative impacts towards the coastal invaded ecosystems and the related fishing activities, justified its ranking among the worst 100 invasive species in the Mediterranean [2].

Early records (the earliest dating back to 1948) from Greece refer exclusively to the Aegean Sea [3,4,5], particularly to the northern coasts were the species is currently abundant [6,7]. Contrary to this, limited data were available in the scientific literature until recently on the presence of the species in the Ionian coasts, although its occurrence was documented since 1949 in Italy [8-12], 2004 in Croatia [13,14], and 2008 in Albania near the border with Montenegro [15]. Despite the low number of alien marine species in the Ionian coasts compared to the Aegean Sea [16], the former sub-region has a very rich variety of estuaries, lagoons and transitional waters providing open ecological niches and favorable climatic conditions (i.e. the lowest, highest and annual mean water temperatures during 2013 in the north-western Ionian coast of Greece were 13.8 °C, 27.1 °C and 19.6 °C, respectively; Perdikaris, unpub. data). These conditions match with the biological requirements of *C. sapidus* as the reproductive cycle is related to the access to brackish water and first developmental stages need temperatures above 20°C [17].

Within the above context, the initial step of any management intervention has to rely on the earliest possible detection of the introduced species. This should be followed by the determination of the risk level it poses to the recipient water bodies, including socio-economic considerations [18]. Therefore, given the scarcity of zoogeographical data on *C. sapidus* in the Ionian coasts of Greece, the aim of the present work was to: a) review and depict the occurrence of the species in this particular sub-region; b) assess its invasiveness risk, and c) discuss any observed negative impacts to biodiversity and fisheries in order to suggest adequate mitigation measures.

Materials and methods

During 2012-2013, data were retrieved from peer reviewed published papers in the scientific literature, private communications and direct contacts with ichthyologists (in Regional Fisheries Departments), fishermen and members of fishermen's associations and estuary/lagoon co-operatives along the entire length of the Ionian coasts (including the Islands of Corfu and Lefkas). Data on species occurrence were subsequently inserted in a GIS software (ArcMap 10.1, Esri, USA) to generate a distribution map, including all major and minor ports in the sub-region with the minimum infrastructure to harbor ships with ballast tanks (i.e. above 300 gross registered tonnage - GRT). . Finally, the invasive potential of the species was preliminarily assessed by one of us (CP), using the Marine Invertebrate Invasiveness Screening Kit (MI-ISK v1.19) (available in http://www.cefas.defra.gov.uk/our-science/ecosystems-and-biodiversity/non-native-species/decision-support-tools.aspx). The final score was based on the responses to 49 questions related to topics such as domestication/cultivation, climate and distribution, invasiveness in non-native range, undesirable traits, feeding guild, reproduction, dispersal mechanisms and persistence attributes. Based on the responses, a numerical score was calculated according to the following thresholds: accept (score<0=low risk), evaluate (score 1-6= medium risk) or reject (>6= high risk). The scoring was provisional, given that the tool is not calibrated yet.

Results and discussion

Callinectes sapidus occurs in nine regional units (former prefectures) along the Ionian coasts of Greece (including the islands of Corfu and Lefkas) and in the majority of the estuaries/lagoons of the sub-region (Figure 1, Table 1). The earliest records date back to the late 1990s and in most cases the species has been detected during the 2000s..

The following key biological features and ecological traits of *C. sapidus* are exceptionally suitable for further range expansion in the Ionian sub-region. The enormous reproductive potential, e.g. the number of extruded eggs that was recently calculated at 1.96×10^6 [19] the early maturity and fast growth reported for the northern Aegean Sea [6,7] suggests that the species has been successfully established in Greece and efficiently exploits the available resources in brackish waters, transitional and coastal marine environments. This adaptation and the on-going invasion process is further assisted by its ability (at least in the native range) to move from shallow vegetated estuaries (juveniles) () to deep and no vegetated estuaries (adults) () during the development and the recruitment process at a spatial scales of 10^4 m to 10^5 m [20]. The above swimming ability suggests that further invasion to new areas from the initial establishment sites should be expected not only through passive dispersal (i.e. transportation of larvae in ballast waters), but also by energetic swimming (>1 m sec^{-1}) [21]. Subsequently, when established, the effective competition for space and resources, aided by the large size, the armored exoskeleton, its hardiness and the polytrophic feeding habits [17] are crucial attributes for dominance in the trophic webs. Finally, large juveniles (i.e. >75 mm) and adults are vulnerable to predators (piscivorous fish and birds) mainly during moulting (i.e. soft-sell stage) [22].

The application of the MI-ISK risk identification tool, although non-calibrated yet, suggested a high risk of invasiveness (i.e. total score of 28), as the species was rejected for introduction/translocation in the risk assessment area. Concerning score partitioning, the scores for biogeography, undesirable attributes and biology/ecology were 10, 9 and 9, respectively. This is the first attempt to assess the invasiveness potential of *C. sapidus*, following the assessment of freshwater crayfish species in Italy and Greece [23, 24] and of Chinese mitten crab *Eriocheir sinensis* Milne-Edwards, 1853 in the Serbian section of River Danube [25].

Albeit the scarcity of documented impacts in the Mediterranean region, the species is likely being in competition with other crabs [9]. This invasive species could compete with other crab species, increasing for example the natural mortality, distribution and dynamics of indigenous crabs [26]. In fact a species may be important for the economy of a region in which it is indigenous, but its expansion-invasion in other ecosystems-regions may result in considerable economic and ecological damages [27,28]. Observed impacts are related to severe damages in fishing nets when *C. sapidus* are trying to feed on fish caught on them [29] . The species has been also suggested as possible bio-accumulator of toxins and carrier of strains of the human cholera [1]. In this work, impacts were reported in three ecosystems (Table 1). In these ecosystems, blue crabs cause problems to fishing by tearing nets and to the fish harvesting when the crabs aggregate in the fixed harvesting installations in the lagoon mouth. However, there is no solid evidence to support negative impacts either to biodiversity (e.g. direct predation, displacement or growth suppression of other invertebrates such as native crabs or sea cucumber populations) or to local mussel farms in the Gulf of Amvrakikos in West Greece. Nevertheless,

The trade of the species may result in some economic benefits. Currently, the exploitation of the species is very limited and localized compared for instance to northern Greece (annual landings of 50-80 tons during 2010-2011 in the auction market of Thessaloniki; [7]) or to the trap fishery in Turkey [30]. The species is used in the local cooking in Corfu [31] where it is sold mainly in street markets at retail prices of €3-5 per kg and, although it is sporadically seen in fishmonger stores in many cities (e.g. in Patra, Igoumenitsa, Arta, Lefkada), it is rather unknown by the consumers in the continental part of the Ionian sub-region. This could be due to the recent invasion history of the species and the lack of a crab-eating tradition.

If a marine invasive species is not detected shortly after arrival and become widely distributed, there are no proven techniques to eradicate it [32]. This is exactly the case for *C. sapidus* in Greece and further range expansion in all suitable transitional ecosystems in the Ionian Sea is likely inevitable, given that established populations are already numerous and widespread. However, mitigation (i.e. control of the species so that the provision of essential ecosystem services are continued in its presence) would be a sound option. For *C. sapidus*, which has few year classes spawning, effects of overfishing could have a serious effect on population recruitment [33]. Constant pressure on these populations by crabbing (similarly to certain overexploited US populations [e.g. 34]) could be an effective method to maintain local abundance as low as possible. Moreover, the possibility of employing *C. sapidus* as fish feed additive to improve color enhancement and as flavor attractants should be experimentally assessed. For example, natural astaxanthin production utilizes by-products of Antarctic krill, crab, crayfish and shrimp meals and the content of carotenoids in crab meals from selected sources may reach 1300 mg/kg [35],

The importance of ballast water management and the use of filters in ships is highlighted by a) the existence of numerous (23) ports with the capacity to serve ships with ballast tanks in close proximity to the recipient ecosystems (Figure 1) and b) the significance of the Ionian shipping route (i.e. in terms of increased traffic volume) to the local, regional and international seaborne trade, connecting the Adriatic Sea to the rest of the Mediterranean. Accordingly, the implementation of the Ballast Water Management Convention (BWMC) [36] by all countries in the Adriatic-Ionian region is an urgent priority, in order to control the passive pathway of new introductions (e.g. all ships should implement a ballast water management plan, carry a ballast water record book and carry out ballast water management procedures to a given standard). Within the above context, the installation of filters could be a practical and cost-effective option compared to other methods such as heat treatment, chemical treatment and ultraviolet light which are expensive and with certain drawbacks. Currently, the most common treatment method applied is ballast water exchange at sea but with unknown efficacy. The volume of ballast tank is pumped three times through the tank. By this, it is expected to lead to 95% exchange of the original ballast water, replacing it with oceanic ballast that poses little threat to coastal ecosystems [32].

Conclusions

The data of the present work suggest that *C. sapidus* has invaded in a significant amount of estuaries, lagoons and transitional waters along the entire coastal zone of the Ionian Sea in Greece. This range expansion will likely continue due to active (swimming) spread and passive (ballast water) transportation. Concerning the negative effects, these are mainly related to damages in fishing nets and fish harvesting difficulties in lagoons. Given its high invasiveness risk, mitigation measures, may include the increase of fishing pressure targeting the species, the effective management of ballast waters and the utilization as an additive for animal feeds.

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Table 1 Occurrence, abundance and estimated date of first presence of blue crab *Callinectes sapidus* Rathbun, 1896, in the Ionian coast in Greece.

Regional Unit	Ecosystem	Estimated date of first presence	Observed or likely impacts (negative/positive)	Source
Corfu	Antinioti lagoon	Late 2000's	Small population commercially exploited	Fisheries Department in Corfu; [31]
	Chalkiopoulou lagoon	Late 2000's	Unknown	Fisheries Department in Corfu
Thesprotia	Voda estuary/mouth of River Kalamas	Late 1990's	Consuming netted fish and cutting gill nets	[19] [37]
	Richo/Vatatsa lagoon complex	Late 2000's	Unknown	Lagoon co-operative
	Bay of Igoumenitsa	Late 2000's	Consuming netted fish and cutting gill nets	Fishermen; Local Fishermen Association
Preveza/Arta	Lagoons complex of Rodia, Tsoukalio and Logarou in the northern part of the Amvrakikos Gulf	Early 2000's	Unknown	Fisheries Department in Preveza; Amvrakikos Wetlands Management Body
Lefkas	Lefkas lagoon and in nearby coastal zone	2000's	Unknown	Fishermen; Fishmongers
Etoloakarnania	Tholi lagoon and sporadically in most lagoons and estuaries of the Mesolongi complex	Early 2000's	Unknown	Fisheries Department in Mesolongi
	Mpouka lagoon/mouth of River Acheloos	Early 2000's	Unknown	Fisheries Department in Mesolongi
Achaia	Pappas lagoon	Unknown	Unknown	Fisheries Department in Patra
Ilia	Kotychi lagoon	Late 1990's	Consuming fish and cutting gill nets; harvesting difficulties of fish in the fixed structures of the lagoons due to the presence of high number of crabs	Fishermen; Lagoon co-operative
Messinia	Mouth of River Pamisos	2010's?	Unknown	[38]

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Figure 1 Map of occurrence of *Callinectes sapidus* in the Ionian coasts of Greece. Black and open circles with dots indicate major and minor ports, respectively. Invaded coastal ecosystems are shaded in black. 1: Antinioti lagoon; 2: Chalkiopoulou lagoon; 3: Voda estuary/mouth of River Kalamas; 4: Vatatsa lagoon; 5: Richo lagoon; 6: Bay of Igoumenitsa; 7: Logarou lagoon; 8: Tsoukalio lagoon; 9: Rodia lagoon; 10: Lefkas lagoon and nearby coast; 11: Mpouka lagoon/mouth of iver Acheloos; 12: Tholi lagoon and lagoons and estuaries of the Mesolongi complex; 13: Pappas lagoon; 14: Kotychi lagoon; 15: Mouth of River Pamisos