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Rapid Communication

A swallow doesn't make a summer: the case of *Charybdis* (*Charybdis*) *feriata* (Linnaeus, 1758) in the western Mediterranean Sea

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Abstract

An individual crucifix crab *Charybdis* (*Charybdis*) *feriata* was recorded in the northern Ligurian Sea (Genova, Italy) in February 2022. This non-native species was observed previously twice off the coast of Catalunia (Spain) and once in the southern Ligurian Sea (Livorno, Italy). As the species was "credited at least two reliable records, distinct in time and/or space" in the Mediterranean Sea , it is now considered as "established" following the Commission Internationale pour l'Exploration Scientifique de la Méditerranée (CIESM) classification. The potential invasiveness of *C.* (*C.*) *feriata* in the Ligurian Sea and the broader western Mediterranean Sea was evaluated through the screening tool Aquatic Species Invasiveness Screening Kit (AS-ISK) v.2.2. Results highlighted that the potential of the species being invasive in the screened area is in the lower range of the "medium risk" and environmental parameters are the main limiting factors for the reproduction of the crucifix crab, suggesting that the western Mediterranean Sea is not a suitable environment for the settlement of *C.* (*C.*) *feriata*. Through the application of the quantitative risk screening tool AS-ISK, this study shows that *C.* (*C.*) *feriata* should not be considered as an "established" non-native species as suggested by the CIESM classification. Future work should focus on integrating quantitative evaluations of invasiveness through risk screening tools such as AS-ISK also in the CIESM classification process, being the main reference for non-native species classification in the Mediterranean Sea.

Key words: AS-ISK, crucifix crab, invasive species, Ligurian Sea, non-native species

Introduction

Invasive species belonging to the crustacean Family Portunidae are represented increasingly in the Mediterranean Sea, entering through three possible ways: migration through the Suez Canal (Galil 2008) (Lessepsian species), migration through the Gibraltar Strait (Ben Rais Lasram et al. 2008), and ship transport through ballast waters (Abelló and Hispano 2006). Portunids, specifically, are more prone to be transported having long lasting larval stages, facilitating their long distance dispersal by both, natural and human vectors (Brockerhoff and McLay 2011).

Charybdis (*Charybdis*) *feriata* is a portunid crab widely distributed in its native range within the Indo-West Pacific area, from eastern and southern Africa and the western Pacific Ocean, from Japan to Australia (Stephenson 1972; Apel and Spiridonov 1998). It occurs on sandy, muddy and rocky bottoms and on coral reefs as well, at depths between 10 and 100 m (Dai and Yang 1991; Apel and Spiridonov 1998; Abelló and Hispano 2006; Kumar et al. 2019). This species has a high commercial value across Asia, as it is extensively exploited in India by bottom trawls; it moved from being a by-catch species of shrimp and demersal fisheries (Dineshbabu 2011; Dash et al. 2014) to be an established fishery in the last few years (Kumar et al. 2019).

Charybdis (*C.*) *feriata* was observed for the first time in the Mediterranean Sea in December 2004 off Barcelona (Catalan coast of Spain) (Abelló and Hispano 2006); a second individual was caught in December 2015 in the waters off the harbor of Livorno (southern Ligurian Sea) (Karachle et al. 2016) and a third individual was caught again off the Catalan coast (Tarragona) in November 2017 (Colmenero et al. 2021) (see Supplementary material Table S1 for geo-references records). *C.* (*C.*) *feriata* is now "presumed established on the basis of at least two reliable records distinct in time and/or space" following the classification of the Commission Internationale pour l'Exploration Scientifique de la Méditerranée (CIESM) (CIESM does not specify the unit of time and distance that should be used to consider records "distinct") (Galil et al. 2002). This study reports the capture of a fourth individual of *C.* (*C.*) *feriata*, in the northern Ligurian Sea (off the harbor of Genova) and aims at quantifying the invasiveness potential of this species and its ability to establish viable populations in the Mediterranean Sea basin as other portunids (e.g. *Callinectes sapidus, Charybdis longicollis*) have done before (Ozcan et al. 2005; Mancinelli et al. 2017), using the Aquatic Species Invasiveness Screening Kit (AS-ISK) (Copp et al. 2016, 2021).

Materials and methods

A specimen of *C.* (*C.*) *feriata* was captured with a trammel net on 3rd of February 2022 in the north-western Mediterranean Sea, on the fishing grounds off Genova (Liguria, Italy) (44,38893°N; 8,90838°E), at 50 m depth on rocky bottoms. The specimen was identified as a female of *C.* (*C.*) *feriata* (Figure 1), following the description by Apel and Spiridonov (1998). The coloration corresponded to the one described by Stephenson (1972), a brownish-red background with five cream coloured longitudinal bands in the midline. Morphometric measurements were taken with a caliper with 0.1 mm precision level, following Colmenero et al. (2019) to make the records comparable. The specimen was completely clean from macroepibionts. The specimen is now part of the collection of the Zoological Museum of DISTAV with number: IZUG - 16111.

Figure 1. Specimen of *C.* (*C.*) *feriata* caught off the harbor of Genova.

Table 1. Results from the pre-screening to evaluate if *C.* (*C.*) *feriata* is considered as invasive.

	Sea Life Base	IUCN-GISD	CABI	CIESM
Invasive				X
Non-invasive	X *(Harmless)*	X	X	

Risk screening

An *a priori* categorization of the status as invasive species of *C.* (*C.*) *feriata* was done following Vilizzi et al. (2022) through a series of websites, namely SeaLifeBase (Palomares and Pauly 2022), Global Invasive Species Database (Invasive Species Specialist Group, ISSG 2015), Centre for Agriculture and Bioscience International Invasive Species Compendium (CABI 2022) and CIESM Atlas of Exotic Crustaceans in the Mediterranean Sea (CIESM 2020), in order to have a comparison of the evaluation in the Mediterranean Sea with other areas (Table 1). Additional searches at continent and country level on governmental and international organizations websites (North America, South America, North-East Atlantic, Japan, New Zealand, Australia, South Africa, Africa) did not show records of *C.* (*C.*) *feriata* as non-native species in those areas.

Following Stasolla et al. (2021) and Vilizzi et al. (2021) the Aquatic Species Invasiveness Screening Kit (AS-ISK) v.2.2, which is available for free download at https://www.cefas.co.uk/nns/tools (Copp et al. 2016, 2021), was used to carry out the evaluation of potential invasiveness of *C.* (*C.*) *feriata* in the northern Ligurian Sea (western Mediterranean Sea) (Figure 2). The AS-ISK tool consists of two main sets of questions: one Basic Risk Assessment (BRA) score examining the biogeographical and biological aspects of the species screened (49 questions), and one Climate Change Assessment (CCA) score exploring the potential of future climatic conditions to affect the BRA score (BRA+CCA). Scores < 1 indicate a "low risk" for the species of becoming invasive (Pheloung et al. 1999), while higher scores indicate a "medium" or a "high" risk, depending on the threshold value set

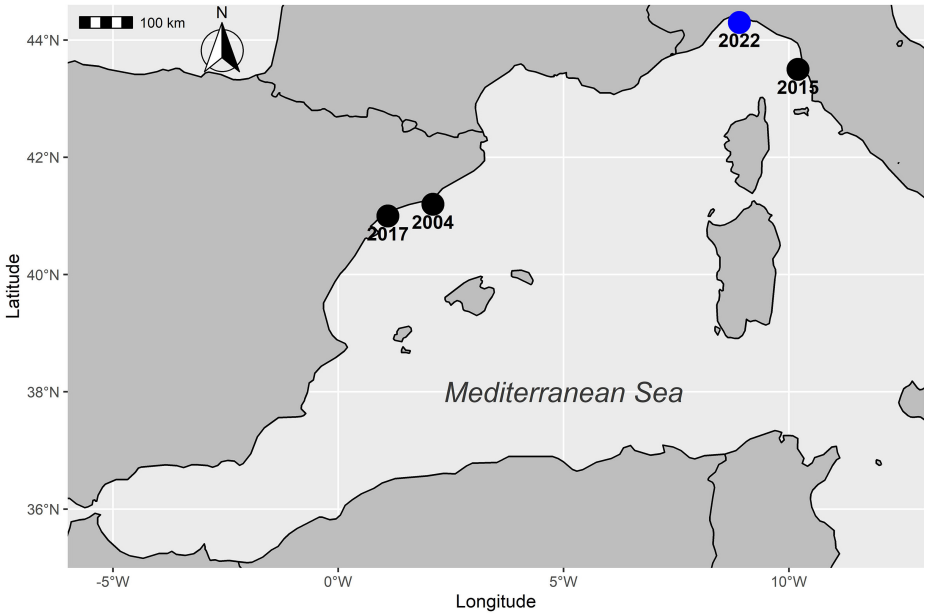

Figure 2. Distribution of sightings of *C.* (*C.*) *feriata* across years in the western Mediterranean Sea.

in the evaluation process. In this study the threshold to obtain the level of potential invasiveness of the screened species was set to 15.1 (marine invertebrates) and to 35.75 (tropical marine invertebrates), in a second screening, for both BRA and BRA+CCA scores following Vilizzi et al. (2021) (Table 2). A confidence level is applied to each answer (1 = low; 2 = medium; 3 = high; 4 = very high) depending on the available information on the topic (Copp et al. 2016). For details on the AS-ISK screening tool see (Vilizzi et al. 2022). The first author, who collected information through a bibliographic review, carried out the screening. Replicated screenings from other assessors were not possible in the present study due to logistic constraints.

Results

The specimen of *C.* (*C.*) *feriata* was a non-gravid (no egg mass) adult female; measurements are reported underneath:

- long carapace length (LCL) – 85 mm (from tip of the frontal teeth to the posterior end of the carapace);
- short carapace length (SCL) – 79 mm (from rostral notch to the posterior end of the carapace);
- carapace width (CW) – 130 mm (from tip to tip of the last anterolateral teeth);
- right propodus cheliped length (RCL) – 105 mm (from tip of the propodus to the posterior ventral end of the propodus);
- right propodus cheliped height (RCH) – 33 mm (from dorsal anterior and ; excluding dorsal spine, perpendicularly to ventral propodus side).

The live specimen weighed 410 g.

Table 2. Summary of AS-ISK risk assessment scores and confidence levels. Vilizzi et al. (2021).

Resulting scores	
BRA	6
Evaluation BRA	Medium
BRA+CCA	10
Evaluation BRA+CCA	Medium
Confidence levels	
BRA	0.50
CCA	0.33
BRA+CCA	0.48
Threshold	
Marine invertebrates	15.1
Tropical marine invertebrates	35.75

Risk screening

This species was recorded outside of its native distribution range only in the Mediterranean Sea, based on four records, including the present one. Following the classification of CIESM it should now be presumed as "established". The *a priori* categorization of *C.* (*C.*) *feriata* is reported in Table 1; the species was than considered as "invasive" in the Mediterranean Sea, before the AS-ISK evaluation.

Using AS-ISK v.2.2 the potential invasiveness of the study species was evaluated as "medium risk" for both thresholds applied. The resulting scores are in the lower half of the "medium range", compared to the thresholds applied, specifically when considering that the species is a tropical marine invertebrate (Table 2). It should be noted that the confidence levels associated to the BRA+CCA, BRA and CCA scores are in the low range (Table 2). The confidence levels assigned to the Biogeography/Historical section had the highest confidence scores (see Table S2) while the Biology/Ecology section and the Climate Change section has low confidence levels as information on the dispersal ability in other areas and tolerance of different environmental parameters from the ones in the area of origin are lacking.

Discussion

The Indo-Pacific crucifix crab *C.* (*C.*) *feriata,* evaluated through the AS-ISK tool, has a "medium risk" level of becoming invasive in the Ligurian Sea and more broadly in the western Mediterranean Sea in general. This species, therefore, is not to be considered "invasive" at present, contrary to what resulted from the pre-screening due to the CIESM classification, which reported it as "established" in the Mediterranean Sea. *Charybdis* (*C.*) *feriata*, which was previously recorded in the Catalan Sea twice and once in the southern Ligurian Sea, was recorded in the northern Ligurian Sea for the first time in February 2022. All records were of single specimens and three out of four individuals observed in the western Mediterranean Sea were adults not in reproductive phase. The single individual reported as a juvenile, was suggested to have arrived in the area through ballast waters

Table 3. List of species belonging to the Family Portunidae recorded in the Mediterranean Sea (WA = Western Atlantic, IP = Indo Pacific, WIO = Western Indian Ocean).

Species	Origin	First record
Callinectes danae	WA	2002
Callinectes sapidus	WA	2002
Charybdis feriata	IP	2004
Charybdis helleri	IP	2002
Charybdis longicollis	IP	1954
Portunus pelagicus	IP	2002
Thalamita gloriensis	IP	2002
Thalamita indistincta	IP	2008
Thalamita poissonii	IP	2002
Carupa tenuipes	IP	2003
Charybdis (Charybdis) lucifera	IP	2006
Gonioinfradens paucidentatus	WIO-IP	2010
Charybdis (Charybdis) natator	IP	2021
Portunus segnis	WIO	1898
Charybdis japonica	IP	2006

(Karachle et al. 2016). The two records in the Catalan Sea were 13 years apart, while the ones in the southern and northern Ligurian Sea were 7 years apart. As this species occupies depths between 10–100 m on a variety of seabed types (Dai and Yang 1991; Apel and Spirinidov 1998; Abello and Hispano 2006; Kumar et al. 2019), it can be caught by both, passive and active gears, which act at different depths and on different kind of seabeds. Therefore, it cannot be considered a cryptic species that would escape observation if settled and viable populations had developed from previous introductions in the Mediterranean Sea. Individuals recorded have most likely arrived independently through ballast waters or ship transport, remaining isolated from potential reproductive partners or finding environmental conditions not favorable for reproduction, as seawater temperatures of the western Mediterranean and, more specifically, of the northern Ligurian Sea, are lower than in the Indo-Pacific area.

Up to now, 15 alien portunid species have been recorded in the Mediterranean Sea (Table 3), with the earliest record in 1898 (*Portunus segnis* (Fox, 1924 in Rabaoui et al. 2015)), followed by new records only in 1954 and then in the early 2000s, while the latest record was in 2021 (*C.* (*C.*) *natator* (Orfanidis et al. 2021)). Except for the genus *Callinectes*, which is native of the Western Atlantic Ocean (WA), all other species are native of the Western Indian Ocean (WIO) and/or the Indo Pacific (IP) area (Table 3). Among portunid crabs recorded in the Mediterranean Sea only *Callinectes sapidus, P. segnis* and *P. pelagicus* have established viable populations, which are rapidly expanding (Shaiek et al. 2021) and have become, in some cases, a fishery resource (Ayas 2013; Mancinelli et al. 2017). Stasolla et al. (2021) evaluated that species belonging to the genus *Charybdi*s have a "high risk" of invasiveness in the Mediterranean Sea, due to their ecological characteristics (tolerance of a wide range of temperatures and salinities) and their history of known invasiveness in

other regions (Gust and Inglis 2006). It should be noted, though, that within the genus *Charybdis,* only *C. longicollis* has developed a stable and reproductive population within the Mediterranean Sea (Ozcan et al. 2005), while encounters with other species of the same genus have remained occasional. Additionally, all these species developed a stable population starting from the eastern basin of the Mediterranean Sea, which has warmer sea surface temperatures and higher levels of salinity than the western one.

Although portunid crabs have adapted to survive in a range of different habitats, both in marine and brackish waters, they are considered reproductively conservative, specifically bounded by the level of temperatures and salinity (brackish water species larvae are still released to sea waters to find suitable salinities to develop (Soundarapandian et al. 2013b)), which influence moulting, reproduction and larval survival (Norse 1977; Soundarapandian et al. 2013b). *Charybdis* (*C.*) *feriata* is considered a eurythermic species that can tolerate seawater temperatures between 13 °C and 26 °C (Hewitt et al. 2018). It needs, however, temperatures between 26–33 °C to trigger reproduction when kept in captivity in aquarium tanks (Soundarapandian et al. 2013c), with ideal reproductive conditions being temperature of ~ 27 °C, salinity of ~ 35% and pH of ~ 8.2 (Soundarapandian et al. 2013a).

In the Ligurian Sea, Bianchi et al. (2019a) reported a linear increase of native southerners (warm water species native of the southern basin of the Mediterranean Sea whose distribution was limited by the February 14 °C isotherm (Bianchi et al. 2012)) and an exponential increase of non-indigenous species since 2009 (already started in the 1950s) corresponding with the gradual increase of sea surface temperatures recorded since the 1980s. In the last 33 years (1985–2018) the Ligurian Sea has shown an average increase of 0.8 °C at the surface reaching average temperatures of 18.5 °C (Bianchi et al. 2019b), an increase which has been related to changes in species composition and communities structure, both in the pelagic and demersal environment (Bianchi et al. 2019a). Despite the observed increase of sea surface temperatures, when matching data from weather stations in Liguria with weather stations in Australia (ABARES 2020) through the Climatch 2.0 algorithm, the climatic similarity of the northern Ligurian Sea, matches the area of the S-SW Australia (ABARES 2020) where *C.* (*C.*) *feriata* is not present. The natural environment of the crucifix crab, instead, includes the northern waters of Australia (Atlas of Living Australia 2022), suggesting that this species is limited to tropical environments such as its native range, the Indo Pacific Ocean. Climatic similarity (based on climate data from weather stations elaborated through the Climatch 2.0 algorithm) with the northern part of Australia is found only within the south-eastern waters of the Mediterranean Sea (ABARES

2020). This could potentially suggest that if *C.* (*C.*) *feriata* was to develop a stable and reproductive population within the Mediterranean Sea this would most likely happen in areas characterized by higher air and surface seawater temperatures than the ones recorded in the western Mediterranean Sea. Average yearly temperatures have kept increasing in the last three years in the whole Mediterranean Sea reaching an overall ~ 20.5 °C at the surface (CEAM 2021) and non-native species could potentially find more and more prone conditions to develop and settle across the basin. Therefore, the evaluation of invasiveness of non-native species should be regularly updated using tools such as AS-ISK in order to be able to predict when environmental conditions, or adaptability of the species, are changing to a point that could allow reproduction in areas outside of their native range.

The *a priori* categorization defined the species as "invasive", following the CIESM evaluation that would declare a crustacean species as "established" after "at least two reliable records distinct in time and/or space". Results from the AS-ISK evaluation suggest that this kind of classification might be misleading, as it would characterize as "established" a non-native species which is not actually able to produce a settled and viable population. This study, contrary to what was proposed by Colmenero et al. (2019), suggests that *C.* (*C.*) *feriata* has not established a viable population in the Mediterranean Sea as gravid females or multiple juveniles have not been recorded. The screening through the AS-ISK tool showed that this species has a "medium to low risk" to become invasive in the northern Ligurian Sea (and more broadly the western Mediterranean Sea in general) due to sea water temperature and salinity being limiting factors to its reproduction. Additionally, the spawning season of the crucifix crab is characterized by two peaks (a major and a minor), which vary depending on the region (Josileen et al. 2021), being generally related to the monsoon season and variation of the rainfall patterns (Nieves et al. 2015), a climate event which does not occur in the Mediterranean Sea area. Therefore, the use of risk screening tools such as AS-ISK to review the classification of non-native crustacean species in contexts such as the CIESM one should be encouraged, in order to avoid biased evaluations of a species establishment in a new area. The CIESM classification of crustacean should also include the wording already used for the classification of exotic fishes: "established species may also be identified on the basis of strong evidence of local, self-maintaining populations" (Golani et al. 2021) to highlight the importance of these factors in the definition of an "established" species. The use of risk screening tools reduces the potential of obtaining contrasting results due to individual interpretation during the evaluation of the potential invasiveness of non-native species, as it produces comparable and standardized quantities.

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Authors' contribution

CP and FG research conceptualization; CP methodology; LL, GRV, EO, NR data collection; CP data analysis and interpretation; CP writing; FG and LL review and editing.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Geo-referenced information of records of crucifix crab in the Mediterranean Sea.

Table S2. Results of risk screening of crucifix crab with AS-ISK v.2.2 tool.

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