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The Atlantic blue crab *Callinectes sapidus* in southern European coastal waters: distribution, impact and prospective invasion management strategies

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ABSTRACT

The native distribution of the blue crab Callinectes sapidus in the western Atlantic extends from Nova Scotia to Argentina. Introduced to Europe at the beginning of the 20th century, it is currently recorded almost ubiquitously in the Mediterranean and in the Black Sea. An overview of the occurrence, abundance, and ecological impact of the species in southern European waters is provided; additionally, we present a pragmatic assessment of its management scenarios, explicitly considering the dual nature of C. sapidus as both an invasive species and a fishery resource. We emphasise that the ongoing expansion of C. sapidus in the region may represent a stimulating challenge for the identification and implementation of future strategies in the management of invasive crustaceans. The impact of the invader could be converted into an enhancement of the services delivered by southern European coastal ecosystems, while mitigation costs could be transformed into profits for local populations.

Keywords: *Callinectes sapidus*; Mediterranean and Black Seas; invasive species; control management; Marine Strategy Framework Directive; EU regulation 1143/2014

Contents

1. Introduction

In the last few decades, the Mediterranean Sea and southern European waters (SEW hereafter) in general have experienced a dramatic increase in non-indigenous flora and fauna (Coll et al., 2010; Chainho et al., 2015). Crustaceans are emblematic of this ongoing process: in 2008, the CIESM Atlas of Exotic Species listed 70 non-indigenous crustaceans in the Mediterranean Sea, while in subsequent years, 106 and 242 species were respectively listed by Galil (2011) and Nunes et al. (2014). Among other taxa, brachyurans made up a large part of these, with 44 species listed in 2011 (Brockerhoff and McLay, 2011). To date, 58 species have been recorded (Fig. 1).

Interestingly, the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Brachyura: Portunidae) occurs in seven of the nine South-European Marine Ecoregions (Fig. 1). Native to the western Atlantic Ocean, the blue crab was recorded in Europe for the first time in 1901 on the Atlantic coast of France. In the Mediterranean Sea it was recorded in 1949 (but probably as early as 1935: Enzenroß et al., 1997), and along the Portuguese coasts in 1978 (Castejón and Guerao, 2013; Ribeiro and Veríssimo, 2014). Ballast waters are considered the most probable introduction vector (Nehring, 2011).

In the eastern United States, *C. sapidus* is known to play a key role in the structure and function of coastal benthic food webs, either as a keystone species or by inducing trophic cascades (Baird and Ulanowicz, 1989; Silliman and Bertness, 2002; Hines, 2007; O'Connor et al., 2008; see also Boudreau and Worm, 2012 for a recent review). In the Mediterranean, the blue crab is currently considered an invasive alien species (IAS hereafter; Zenetos et al., 2005; Katsanevakis et al., 2014). However, the negative effects of the blue crab on invaded benthic communities and on ecosystems functioning and delivery of goods and services are only assumed (but see below for recent counterexamples), and a general lack of ecological information actually occurs. Intriguingly, in the United States the blue crab is considered a valuable seafood and supports an important fishery (Sharov et al., 2003; Perry, 2015). In the last decade, several investigations have emphasised the high nutritional qualities of Mediterranean blue crab meat (among others, Küçükgülmez and Çelik, 2008; Zotti et al., 2016a), and small *C. sapidus* fisheries are currently located in Turkey (Ayas and Ozogul, 2011) and northern Greece (Kevrekidis et al., 2013).

In 2011, Nehring argued that "*...comprehensive analyses about the economic benefits and disadvantages of C. sapidus in its introduced range are not done so far*", emphasising the need for an immediate effort to establish the framework for effective control and management policies for this species. The aim of the present overview is to acknowledge this still unanswered challenge and to achieve two specific, interconnected objectives.

The first is to identify the limitations currently limiting a robust assessment of the ecological impact of *Callinectes sapidus* in invaded SEW. To this end, we provide a state-of-art review of the expansion of the species in the region, from the Mediterranean Sea and Black Sea to the Atlantic coasts of the Iberian Peninsula, complemented by an evaluation of the abundance and other demographic parameters of established populations, and an assessment of the investigations performed to estimate their effects on invaded ecosystems.

The conceptual approach adopted here explicitly follows that of Parker et al. (1999), for which the overall impact of a non-indigenous species depends upon its distribution, abundance and *per-capita* ecological effect. Given the generally huge spectrum of biotic interactions involving an invader (including competition and predation as well as facilitation and mutualism) *per-capita* effects are hard to quantify and subject to practical limitations regarding their estimation (Ricciardi et al., 2013). Indeed, using the abundance and distribution of a species alone as surrogate impact estimators, although widely accepted (e.g.

EC, 2008a), actually confounds the distinction between the concepts of invasiveness and impact (see Ricciardi et al., 2013 and literature cited therein for definitions).

Thus, we reviewed the most recent attempts to assess the ecological effect of *C. sapidus* on invaded ecosystems. An effort was made to include aspects related to genetics and diseases, widely investigated in native habitats yet to date completely unexplored in SEW.

The second aim of the paper is to provide an appraisal of future blue crab management scenarios, setting out the challenges entailed in a robust, integrated management of the blue crab as both an invasive species and a fishery resource is performed. A concise analysis is presented, that may serve to identify the key issues, gaps in knowledge, and challenges to be addressed on the national and trans-national scale. The ultimate aim is to achieve a virtuous synthesis between the need to control an invasive species and mitigate its ecological impact, and the concrete opportunity to value it as a fishery resource.

2. Distribution and abundance

Figure 1 already indicates the almost ubiquitous distribution of *Callinectes sapidus* across south European waters. A more detailed overview of its occurrence was provided by Nehring in 2011. However, in the last few years the number of records in SEW has increased considerably.

Table A (online supplementary information) and Figure 2 summarise the studies published in the last 20 years, together with recent unpublished records from Greece, Italy and Spain. The literature search was performed using the online databases ISI Web of Science, Scopus, BioAbstracts, PubMed, and JSTOR in May 2016. A multiple search criterion was adopted, using combinations of the keywords "*Callinectes sapidus*" or "blue crab" and "Mediterranean Sea" or "Black Sea". Additional studies were found by checking the references of collected papers, performing general searches on the world wide web, and contacting authors for additional suggestions. Data on blue crab populations in Portuguese waters were directly provided by two of the authors (P.C. and F. R.). The search produced 54 references were collected; the 43 studies included in Table A and Figure 1 were selected in a three steps approach using a title/abstract/full text screening procedure (see Mangano and Sarà 2017 for details).

Three main issues are worth highlighting: i) an expansion of the species towards the western Mediterranean Sea and Portuguese Atlantic waters. Specifically, unpublished data on the occurrence of the species along the Spanish Valencian coast in 2014-2015, combined with the number of captured individuals, indicate that in this area the species is established and is currently expanding its range; ii) the widespread distribution of the blue crab in Greece and, in general, in the Ionian - Adriatic area. In the Aegean and Levantine basins the blue crab is to date almost ubiquitous, being recorded even in freshwaters (Lake Volvi: Kapiris et al., 2014). The species has also become common in western Greece along the Ionian coasts (Fig. 1; see also notes in Tab. A). Accordingly, records have increased considerably in the eastern Ionian (see insert in Fig. 1) and throughout the Adriatic Sea, with repeated observations in Italy, Croatia, Montenegro, and Albania; and iii) the species is also expanding in the Black Sea: in addition to a number of relatively old records from the northern area of the basin, there have been several recent observations along the south-eastern coasts.

From Table A it is apparent that most of the records are from coastal habitats close to freshwater inputs. This is not surprising, as blue crabs use all salinity regimes in order to complete their life cycle, and low-salinity environments are used for mating and as nursery habitats (Hines, 2007). Identifying the causes of the current expansion of the species in SEW is beyond the scope of this review. However, climate change may play a role. Warming of coastal waters is argued to have promoted the recruitment of the crab to the Gulf of Maine

100 Km north of its historical range (Johnson, 2015). Hines et al. (2010) analysed latitudinal patterns of reproduction and other life cycle parameters, highlighting the importance of seasonal temperature variations (see also Colton et al., 2014 for a more general appraisal). In environments characterised by winter water temperatures below 10°C, blue crabs become inactive, with negative effects on both survival and reproduction rates. The current increase in the surface temperature of south Atlantic and Mediterranean waters, with even more evident warming effects in the Adriatic/Ionian area and in the Black Sea (Ulbrich et al., 2013), is reducing the severity of winters. This may have positively affected the survival rate of overwintering populations (see Bauer and Miller, 2010a, 2010b for examples in the United States) as well as their maturation rates and brood production, ultimately increasing their fitness and promoting their expansion.

In order to corroborate this hypothesis, more demographic data are needed for blue crab populations in SEW. Table A shows that most information consists of sporadic records of single individuals. With the noticeable exception of Turkey (Atar and Seçer, 2003; Türeli et al., 2016), there is a relatively low number of studies providing quantitative data on the abundance and other demographic parameters of established populations, e.g. monthly or at least seasonally-resolved catch data, the capture of juveniles and ovigerous females, length-weight relationships, etc. (but see Carrozzo et al., 2014 and Mancinelli et al., 2013a for Italy), thus limiting any comparison within SEW and, more importantly, between SEW and Atlantic populations. Additionally, while the connectivity of blue crab populations in native Atlantic habitats has been widely investigated by molecular approaches (Yednock and Neigel, 2014; Lacerda et al., 2016), no studies are to date available for *C. sapidus* populations in SEW. These knowledge gaps hinder any assessment of the actual ecological impact of the blue crab (see next section), and represent one of the first issues that must be dealt with in future control and mitigation actions. In addition, they hamper a comprehensive evaluation of the role of niche conservation mechanisms and niche variation phenomena (Wiens et al., 2010; Guisan et al., 2014) in the ongoing expansion of the species. Lastly, it makes it harder to predict the impact of climate change, as recently investigated in other invasive marine brachyurans (e.g. *Carcinus maenas*: Compton et al., 2010).

3. Ecological impact

Callinectes sapidus has long been considered an IAS (Zenetos et al., 2005), with negative impacts on human activities. However, reports of negative effects on fishing, by e.g. mutilating fish caught in traps and tearing nets (Nehring, 2011 and literature cited therein; Perdikaris et al., 2016), have mainly been anecdotal. A quantitative assessment of the impact on Ionian and Aegean fisheries in Greece was recently conducted (July - October 2015) by means of questionnaires, the results indicating that where blue crab populations have reached high abundances in the last decade (i.e., Vistonida lagoon in the North Aegean Sea), considerable negative effects on fishing activities have been perceived by local populations (Katselis, unpublished data).

Besides a presumed high degree of competition with native brachyurans (Gennaio et al., 2006; Mancinelli et al., 2013a), and a *post facto* confirmation of its high invasive potential in Greek waters by means of the Marine Invertebrate Invasiveness Scoring Kit (MI-ISK by CEFAS: https://www.cefas.co.uk/services/research-advice-and-consultancy/invasive-and-non-native-species/; Perdikaris et al., 2016), little information is available on the functional role of the species in Europe. Invertebrate and vertebrate predators of *C. sapidus* in SEW are to date unidentified, as well as its parasites and pathogens (see Nagle et al., 2009 for native habitats; but see Mancinelli et al., 2013b for an unconfirmed claim of parasitic dynoflagellates of the genus *Hematodinium* in SE Italy) In addition, the trophic ecology of the species is virtually unexplored, the only exception being recent stable isotopes investigations (Mancinelli et al., 2013a; Carrozzo et al., 2014; Mancinelli et al., 2016a, 2017). A high size- and site-related variability in trophic position has been shown, implying that the blue crab has the potential to impact benthic communities at multiple trophic levels. These studies indicate that analysis of carbon and nitrogen stable isotopes (SIA hereafter) may represent a valuable approach to understand the overall ecological impact of the species. Bodey et al. (2011) reviewed the advantages and limitations of this method for assessing the impact of IASs, while Mancinelli and Vizzini, (2015) further emphasised the possibility of using recent community-scale isotopic metrics to provide a quantitative assessment of the overall impact of a species on an invaded community. Some recent investigations of marine food webs provide support for this approach (Fanelli et al., 2015; Fry and Davis, 2015) and indicate that SIA-based, community-scale studies may overcome most of the limitations affecting the estimation of *per-capita* ecological effects. Furthermore, SIA may also provide sound methodological support for the analysis of pollutant transfer routes in invaded food webs (e.g. Thomas et al., 2016 for a freshwater example). Atlantic blue crab populations have long been used as pollution indicators (e.g. heavy metals: Weinstein et al., 1992; Adams and Engel, 2014). In SEW, a considerable quantity of information is available for the Levantine sector (Türkmen et al., 2008; Mutlu et al., 2011). However, outside this area only Zotti et al. (2016b) have provided data on heavy metal concentrations in blue crabs from SE Italy.

4. To manage or not to manage?

It is apparent that more than sixty years after its official introduction, the blue crab has established itself in the Mediterranean Sea and neighbouring waters; most importantly, it is currently expanding its range towards the western sectors of the basin, the Adriatic Sea and the Black Sea. Given these premises, three alternative future scenarios are possible.

The first is simply a “no action” scenario. Overfishing, pollution, human-induced changes in oceanographic conditions or natural buffering due to intra- or inter-specific density-dependent controls within benthic communities may ultimately limit or even reverse the crab’s expansion. Such an approach clearly runs counter to the efforts currently being made by the European Union to implement regulatory guidelines concerning the control of IASs such as the Strategy on Invasive Species (EC, 2008b), the Marine Strategy Framework Directive (MSFD; EC, 2008a), the Biodiversity Strategy (EC, 2011) and the Regulation on the Prevention and Management of the Introduction and Spread of Invasive Alien Species (EU, 2014).

The second option is to develop a policy of species control. In principle, eradication remains the primary approach. However, the requirements in terms of time and monetary resources for completing successful eradication campaigns, particularly for aquatic invaders, are acknowledged to be huge (Lampert et al., 2014). Similarly, post-establishment control measures, whether they are aimed at reducing the presence of the invader or limiting its further spread, both require considerable investment in terms of time and money (Simberloff et al., 2013). In addition, when little or no knowledge is available on the connectivity of invasive populations (see previous paragraph), eradication attempts become increasingly difficult and often result in a strategy of long-term commitment to local control (Hulme, 2006).

In our opinion, the current distribution of the blue crab in SEW is so vast that eradication would be not only costly, but actually unfeasible. We thus identify a third approach, involving advanced management of the species as a high-value fishery resource to be implemented as a mitigation strategy.

The proposed approach requires an estimation of the services and disservices (*sensu* Mulder et al., 2015) provided by the species to coastal areas, and the implementation of a management scenario aimed at minimising the control and mitigation costs of the blue crab as an invasive species by exploiting it as a shellfish product.

The state-of-the-art knowledge on the blue crab in SEW includes information on its distribution and data on its nutraceutical value (e.g. Türeli et al., 2000; Küçükgülmez and Çelik, 2008) and contamination by heavy metals and other pollutants (e.g. Ayas and Ozogul, 2011; Genc and Yilmaz, 2015), primarily in Levantine populations. Additional, preliminary assessments of the functional role of the species within invaded food webs are limited to Italian and Croatian populations. Coupled with the huge body of information on blue crab populations in native habitats regarding their ecological role, pathogens, and connectivity, they could provide a robust basis for the future development of ecological and demographic investigations standardised across southern European countries. The results need to be integrated with data on the crab's effects on fishing activities collected by means of questionnaires given to fishermen and other stakeholders and specifically tailored to local fishing strategies and traditions (Sharp et al., 2011).These efforts will help to fill in the knowledge gaps regarding the ecological and economic disservices caused by the blue crab. In addition, they will provide an opportunity to implement and intercalibrate control procedures and impact assessment protocols – useful for the blue crab as well as for other marine invaders – that are consistent with the legislative and regulatory framework provided by the MSFD and other EU directives on invasive species (e.g. EU, 2014). Most importantly, besides facilitating an assessment of the blue crab's ecological impact by classical approaches (Parker et al., 1999) and helping to target crucial life stages for control management (Nuñez et al., 2012), quantitative demographic information will allow a large-scale assessment of blue crab stocks in SEW. As more crustacean species of increasing socio-economic importance are harvested worldwide (Anderson et al., 2011), Europe is witnessing increased market interest in decapod and brachyuran species (Molfese et al., 2014; see also ICES, 2015). The blue crab is already a valuable shellfish resource in Aegean and Levantine waters, and the development of a fishing sector focusing on the exploitation of the numerically most abundant (and potentially most ecologically impacting) populations may represent an effective mitigation strategy, supporting at the same time the diversification of European shellfish product markets and providing the food industry with a valuable product. A huge body of literature on stock assessment approaches is available for Atlantic populations, together with information on the effectiveness of different fishing methods and approaches (e.g. crab pots, dredging nets, etc.). Although some methods are inappropriate for Europe (e.g. aquaculture), there is a robust knowledge base that can be used for designing effective stock assessments. The limited efforts made to date to verify the occurrence of pollutants and pathogens, require the implementation of standardised procedures for quality control and traceability of the product. Multi-elemental fingerprinting, to date limited to mussels and other bivalves (Ricardo et al., 2015; but see Zotti et al., 2016b), complemented by other "foodomic" techniques (e.g. metabolomic profiling: Zotti et al., 2016a and literature cited therein) may provide effective, standardised procedures for shellfish quality profiling and traceability.

The risk in this scenario is that the blue crab may no longer be seen as an invasive species, achieving a sort of unofficial legitimisation of the risk it represents. In addition, the development of an economically important blue crab fishery may prompt illegal efforts to set up profitable businesses, ultimately promoting invasion (Nuñez et al., 2012). The negative effects of *C. sapidus* on invaded habitats must be made explicit; obviously, the nature and extent of these negative effects must be demonstrated and publicised, and not merely assumed. Thus, a thorough quantitative assessment of the ecological impact of the blue crab is an obligatory step in its management as a fishery resource.

5. Conclusions

This review shows that despite the growing number of records testifying to its ongoing expansion, there are still considerable gaps in our knowledge of the demographic and ecological features of *Callinectes sapidus* in invaded south European waters. It suggests, however, that the blue crab has the potential to be turned into a valuable resource, once its impact on ecosystem services and disservices have been thoroughly assessed. It is worth noting, with regard to the general implications of topics related to *Callinectes sapidus*, that the Mediterranean Sea is currently invaded by a number of portunid species, including the blue swimming crab *Portunus segnis* (Rabaoui et al., 2015), a species actively consumed in its native habitats (Giraldes et al., 2016) and locally important in Levantine fish markets (Özcan, 2012). The ongoing invasion by the blue crab and other portunids provides an opportunity to combine the development of successful mitigation and control policies with the exploitation and marketing of shellfish products whose economic value is already acknowledged outside Europe. Thus, management and control costs in invaded habitats may ultimately yield profits for local populations, while the effects of the invader may be greatly reduced, even enhancing the ecosystem goods and services provided by coastal habitats.

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Figure captions

Figure 1. Occurrence of 58 non-indigenous brachyuran species across 9 South European Marine Ecoregions (South European Atlantic Shelf, Alboran Sea, Western Mediterranean, Adriatic Sea, Ionian Sea, Tunisian Plateau/Gulf of Sidra, Aegean Sea, Levantine Sea, and Black Sea) as of June 1st, 2016. Data on species occurrence and distribution were collated using information from Brockerhoff and McLay, (2011), Moussa et al. (2016) and the online catalogue of the European Alien Species Information Network (EASIN; http://easin.jrc.ec.europa.eu). Additional records for *Callinectes sapidus* in the Black Sea were integrated in the data set using references included in Table A, while information on the occurrence of *Portunus segnis* in the Tunisian Plateau/Gulf of Sidra region were based on Rabaoui et al. (2015).

Figure 2. Records of the Atlantic blue crab *Callinectes sapidus* in South European waters in the last 20 years. Numbers refer to location ID# reported in Table A in the online supplementary information. For the sake of completeness, the record reported in Gijon by Cabal et al. (2006) (location ID# 80) is included.
In general, empty circles refer to locations reported in Table A; in the SEW map, full circles refer to records cited in Nehring, (2011), while in the sub-map of Greece they refer to records reported by the Hellenic Network on Aquatic Invasive Species – ELNAIS (http://elnais.hcmr.gr/); squares in the sub-maps of Greece and Spain are unpublished records made available by Kostas Kapiris and George Katselis (Greece) and Silvia Falco (Spain).

Figure 1.
Mancinelli et al.
Blue crabs in SEW

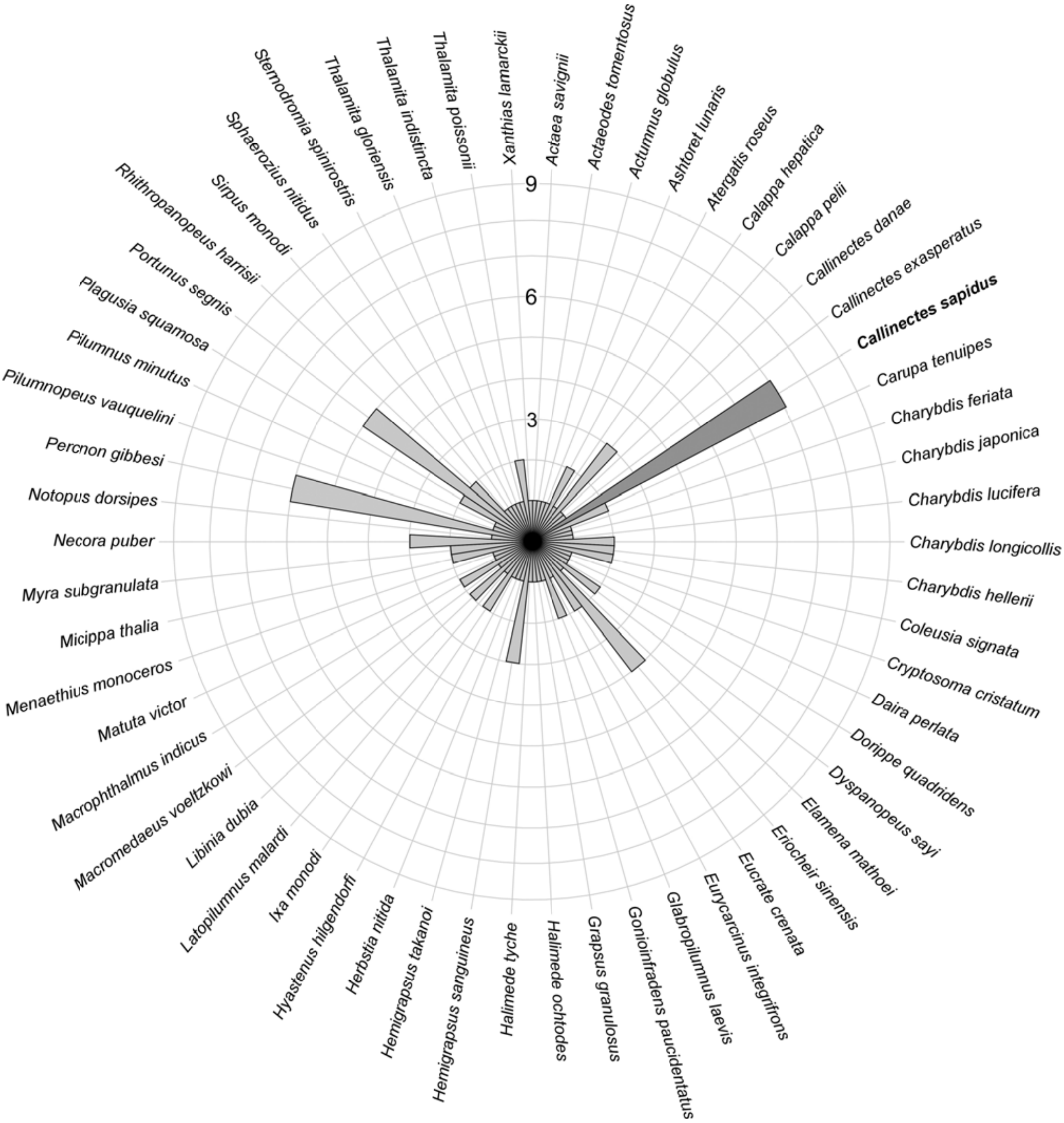
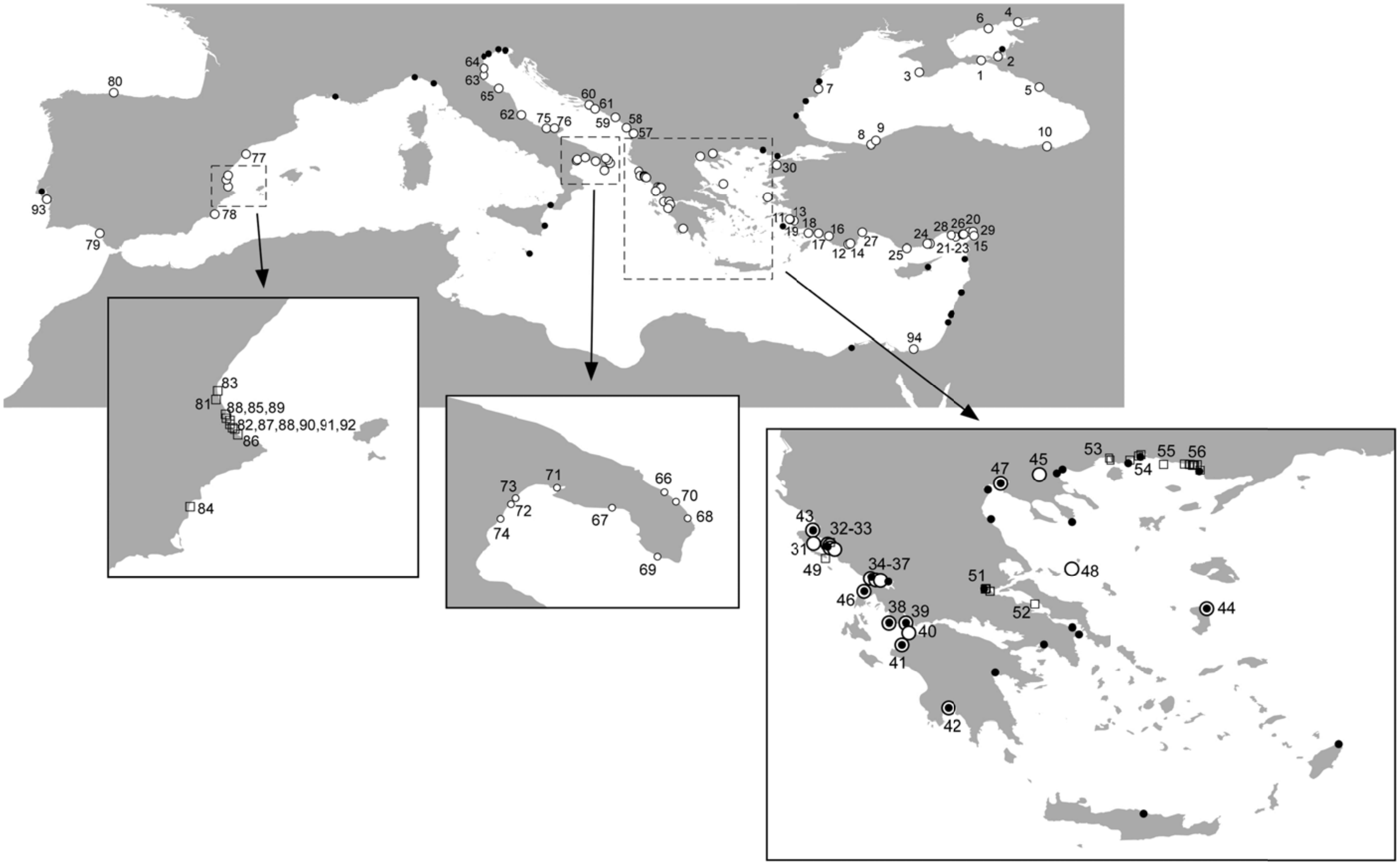


Figure 2.
Mancinelli et al.
Blue crabs in SEW



Online supplementary information

Table A. Records of the Atlantic blue crab *Callinectes sapidus* in South European waters in the last 20 years. LME (Large Marine Ecosystems): BS = Black Sea, MS = Mediterranean Sea; Loc ID# = location code as shown in Figure 1 anticlockwise from the Black Sea; Month: months coded as January = 1, February = 2 etc; mode: fishing gear used for capture (when available); N. = total number of captured specimens; when qualitative data are provided, the capture frequency is defined as low (*), frequent (**) and high (***).

References corresponding to ID# used in the table are: 1: Zaitsev, 1998; 2: Diripasko et al., 2009; 3: Khvorov, 2010; 4: Pashkov et al., 2012; 5: Gomoiu and Skolka, 1998; 6: Petrescu et al., 2000; 7: Yağlıoğlu et al., 2014; 8: Ak et al., 2015; 9: Enzenroß et al., 1997; 10: Başusta et al., 2002; 11: Tureli Bilen et al., 2011; 12: Atar and Seçer, 2003; 13: Çekiç et al., 2005; 14: Gökoðlu and Yerlikaya, 2003; 15: Çelik et al., 2004; 16: Küçükgülmez et al., 2006; 17: Özcan and Akyurt, 2006; 18: Gökçe et al., 2006; 19: Mutlu et al., 2011; 20: Küçükgülmez and Çelik, 2008; 21: Tuncer and Bilgin, 2008; 22: Sumer et al., 2013; 23: Özdemir et al., 2015; 24: Perdikaris et al., 2015; 25: Bilecenoglu et al., 2013; 26: Katsanevakis et al., 2014; 27: Kapiris et al., 2014; 28: Thessalou-Legaki et al., 2012; 29: Kevrekidis et al., 2013; 30: Zenetos et al., 2013; 31: Beqiraj and Kashta, 2010; 32: Dulčić et al., 2011; 33: Dulčić et al., 2010; 34: Onofri et al., 2008; 35: Castriota et al., 2012; 36: Scaravelli and Mordenti, 2007; 37: Manfrin et al., 2015; 38: Mancinelli et al., 2013; 39: Mancinelli et al., 2016c; 40: Mancinelli et al., 2016a; 41: Gennaio et al., 2006; 42: Cecere et al., 2015; 43: Stasolla and Innocenti, 2014; 44: Florio et al., 2008; 45: Cilenti et al., 2015; 46: Castejón and Guerao, 2013; 47: Cabal et al., 2006; 48: Ribeiro and Veríssimo, 2014; 49: Abdel Razek et al., 2016; §§: Kapiris, unpublished data; §§§: Falco, unpublished data

Ref ID#	LME	Country	Location	Loc ID#	Year	Month	mode	ecosystem type	N.	notes
1	BS	Russia	Kerch	1	1975	8		Open coast	2	
2	BS	Russia	Kerch	2	2007			Open coast	1	
3	BS	Russia	Sevastopol	3	2007		net	Open coast	1	
2	BS	Russia	Sedovo	4	2008			Open coast	1	
4	BS	Russia	Lazarevskoye	5	2010	11	gill net	Open coast	1	
2	BS	Ukraina	Berdyansk	6	2006			Open coast	1	
5	BS	Romania	Mangalia	7	1998	8	net	Open coast	1	
6	BS	Romania	Mangalia	7	1999		net	Open coast	1	
7	BS	Turkey	Duzce	8	2013	9	gillnet	Open coast	1	
7	BS	Turkey	Zonguldak	9	2013	11	gillnet	Open coast	1	
8	BS	Turkey	Trabzon	10	2015	5	gillnet	Open coast	1	
9	MS	Turkey	Akköy	11	1988		net	Lagoon	*	
9	MS	Turkey	Finike	12	1989		net	Estuary	*	
9	MS	Turkey	Akbük	13	1989		net	Bay	*	
9	MS	Turkey	Beymelek	14	1990		net	Lagoon	***	Massive, established population
9	MS	Turkey	Iskenderun	15	1991		net	Bay	*	
9	MS	Turkey	Fethiye	16	1994		net	Bay	**	
9	MS	Turkey	Dalyandere	17	1994		net	Lagoon	**	
9	MS	Turkey	Hisarönü	18	1994		net	Bay	**	
9	MS	Turkey	Menderes	19	1994		net	Estuary	**	
9	MS	Turkey	Burnaz	20	1995	4	net	Bay	**	
9	MS	Turkey	Deveciuşaği	21	1995	4	net	Bay	***	Massive, established population
9	MS	Turkey	Akyatan	22	1995	4	net	Lagoon	***	Massive, established population
9	MS	Turkey	Tuzla	23	1995	4	net	Lagoon	**	

9	MS	Turkey	Silifke	24	1995	4	net	Bay	**	
9	MS	Turkey	Anamur	25	1995	4	net	Estuary	*	
10	MS	Turkey	Iskenderun	15	1996-1997	5 to 4	trawl	Bay	2069	
11	MS	Turkey	Yumurtalik	26	1997-1998	2 to 1	trawl	Lagoon	410	Juveniles and ovigerous females observed
12	MS	Turkey	Beymelek	14	2000	6	net	Lagoon	1027	Juveniles and ovigerous females observed
13	MS	Turkey	Iskenderun	15	2001	7 to 11	trap	Bay	51	
14	MS	Turkey	Antalya	27	2001	7	dip net	Open coast		
15-16	MS	Turkey	Akyatan	22	2002	12		Lagoon		
17	MS	Turkey	Iskenderun	15	2002-2003	6 to 7	trawl	Bay	139	
18	MS	Turkey	Çamlik	28	2005	8	seine net	Lagoon	743	Juveniles and ovigerous females observed
19	MS	Turkey	Dörtyol	29	2006-2007	9 to 5	landing net	Lagoon	15	
19	MS	Turkey	Akyatan	22	2006-2007	9 to 5	landing net	Lagoon	15	
19	MS	Turkey	Paradeniz	24	2006-2007	9-5	landing net	Lagoon	10	
19	MS	Turkey	Çamlik	28	2006-2007	9-5	landing net	Lagoon	10	
20	MS	Turkey	Akyatan	22	2008			Lagoon		
21	MS	Turkey	Canakkale	30	2008	11	gillnet	Open coast	1	
22	MS	Turkey	Beymelek	14	2009-2010	7-9	fyke net/trap	Lagoon	2211	Juveniles and ovigerous females observed
23	MS	Turkey	Çamlik	28	2013?		trap	Lagoon	1051	
24	MS	Greece	Chalkiopoulou	31	2012-2013		net	Lagoon	**	
24	MS	Greece	Richo/Vatatsa	32	2012-2013		net	Lagoon	*	
24	MS	Greece	Igoumenitsa	33	2012-2013		net	Bay	**	
24	MS	Greece	Rodia	34	2012-2013		net	Lagoon	*	
24	MS	Greece	Tsoukalio	35	2012-2013		net	Lagoon	*	
24	MS	Greece	Logarou	36	2012-2013		net	Lagoon	*	
24	MS	Greece	Lefkas	37	2012-2013		net	Lagoon	*	Frequent captures between July and October 2015 (Katselis, unpublished data)
24	MS	Greece	Tholi/Mesolonghi	38	2012-2013		net	Lagoon	*	
24	MS	Greece	Mpouka/Acheloos	39	2012-2013		net	Lagoon/Estuary	*	

24	MS	Greece	Pappas	40	2012-2013		net	Lagoon	*	
24	MS	Greece	Kotychi	41	2012-2013		net	Lagoon	***	
24	MS	Greece	Pamisos	42	2012-2013		net	Estuary	*	See also the note by Kapiris et al. in Eleftheriou et al. (2011)
25	MS	Greece	Antinioti	43	2013	10	hand brailer	Lagoon	13	
26	MS	Greece	Marmaro	44	2013	8		Estuary	12	
27	MS	Greece	Volvi	45	2012	11	gillnet	Lake	1	
28	MS	Greece	Voda	46	2012	4	gillnet	Estuary	2	One ovigerous female observed
29	MS	Greece	Thermaikos	47	2011-2012	3,5,7,9,11,1		Bay		Massive established population
30	MS	Greece	Peristera	48	2012	7		Open coast	1	
§§	MS	Greece	Sparterá	49	2014	8		Open coast	1	
§§	MS	Greece	Sagiada	50	2014	9		Bay	1	
§§	MS	Greece	Malian Gulf	51	2014	4-7, 9-12		Bay	189	
§§	MS	Greece	North Euboean Gulf	52	2014	8		Bay	3	
§§	MS	Greece	Kavala	53	2014	4		Bay	66	
§§	MS	Greece	Porto Lagos	54	2014	5		Bay	14	Massive established population (Katselis, unpublished data)
§§	MS	Greece	Platanitis	55	2014	7		Bay	1	
§§	MS	Greece	Alexandroupoli	56	2014	7-9		Bay	63	
31	MS	Albania	Patok Lagoon	57	2009	10	gillnet	Lagoon	12	Juveniles and ovigerous females observed
27	MS	Montenegro	Port Milena	58	2012			Open coast		
27	MS	Montenegro	Boka Kotorska	59	2013	12	gillnet	Open coast	2	
32	MS	Croatia	Neretva	60	2010	8-9	gillnet/trap	Estuary	52	Juveniles and ovigerous females observed in 2010; juveniles observed in summer 2015 (Mancinelli et al., 2016b)
33	MS	Croatia	Neretva	60	2009	11		Estuary	1	
34	MS	Croatia	Neretva	60	2004-2006	10-12	gillnet/trap	Estuary	2	
34	MS	Croatia	Ston	61	2004	10		Lagoon	4	
35	MS	Italy	Silvi Marina	62	2011	5	gillnet	Estuary	1	
35	MS	Italy	Metauro	65	1972		net	Estuary	1	
36	MS	Italy	Ravenna	63	2007	3	gillnet	Open coast	1	

37	MS	Italy	Sacca di Goro	64	2014	4	angling	Lagoon	1	
38	MS	Italy	Acquatina	66	2012	2, 5, 8, 11	trap	Lagoon	10	Juveniles and ovigerous females observed
39	MS	Italy	Acquatina	66	2012-2013	2-1	trap	Lagoon	28	
38	MS	Italy	Torre Colimena	67	2012	2, 5, 8, 11	trap	Lagoon	29	Juveniles and ovigerous females observed
39	MS	Italy	Torre Colimena	67	2012-2013	2-1	trap	Lagoon	80	
40	MS	Italy	Alimini	68	2014	7	trap	Lagoon	7	
41	MS	Italy	Ugento	69	2004	7-8, 10	trap	Lagoon	5	Massive established population observed since 2012 (Mancinelli unpublished data)
40	MS	Italy	Ugento	69	2014	1, 7	trap	Lagoon	16	
40	MS	Italy	Cesine	70	2013	6	hand net	Lagoon	2	
40	MS	Italy	Taranto	71	2014	1, 7	trap	Lagoon	13	
42	MS	Italy	Taranto	71	2004			Lagoon		
43	MS	Italy	Basento	72	2013	8		Estuary	50	
43	MS	Italy	Bradano	73	2013	8		Estuary	20	
43	MS	Italy	Policoro	74	1999			Open coast	1	
44	MS	Italy	Lesina	75	2007	6-7, 10	net	Lagoon	5	
44	MS	Italy	Varano	76	2007	6-7, 10	net	Lagoon		
45	MS	Italy	Lesina	75	2013-2014	10-7	gillnet/trap	Lagoon	8	Ovigerous females observed
45	MS	Italy	Varano	76	2013-2014	10-7	gillnet/trap	Lagoon	11	Ovigerous females observed
46	MS	Spain	Tancada	77	2012-2013	11, 1		Lagoon	2	
46	MS	Spain	Mar Menor	78				Lagoon		Anecdotal reports
46	MS	Spain	Guadalquivir	79				Estuary		Anecdotal reports
47	MS	Spain	Gijon	80	2004	9		Open coast	1	
§§§	MS	Spain	Albufera de Valencia	81	2014, 2015	10, 3		Lagoon	5, 3	
§§§	MS	Spain	Serpis	82	2015	2		Estuary	1	
§§§	MS	Spain	Valencia	83	2015	7		Estuary	1	
§§§	MS	Spain	Segura	84	2014	12		Estuary	1	See also González-Wangüemert and Pujol, (2016)
§§§	MS	Spain	Estany de Cullera	85	2015	7		Open coast	1	

§§§	MS	Spain	Oliva	86	2015	7-8, 10		Estuary	7, 1	
§§§	MS	Spain	Tabernes	87	2015	8-9		Open coast	2	
§§§	MS	Spain	Cullera	88	2015	8-9	trammel net	Estuary	5	See also Karachle et al., (2016) for additional information
§§§	MS	Spain	Brosquil de Cullera	89	2015	8		Open coast	1	
§§§	MS	Spain	Miramar	90	2015	8		Open coast	1	
§§§	MS	Spain	Gandia	91	2015	10	trammel net	Open coast	2	See also Karachle et al., (2016) for additional information
§§§	MS	Spain	Bellreguart	92	2015	10		Open coast	1	
48	MS	Portugal	Sado	93	2009	4	gillnet	Estuary	1	
49	MS	Egypt	Bardawil	94	2016	5-12	trammel net	Lagoon	140	Established population

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