On the Atlantic blue crab (*Callinectes sapidus* Rathbun 1896) in southern European coastal waters: time to turn a threat into a resource?

Mancinelli G.[1*], Chainho P.[2], Cilenti L.[3], Falco S.[4], Kapiris K.[5], Katselis G.[6], Ribeiro F.[2]

[1] Department of Biological and Environmental Sciences and Technologies, University of Salento, Sp. Lecce-Monteroni, 73100, Lecce, Italy

[2] Marine and Environmental Sciences Centre, Faculdade de Ciencias, Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal

[3] Institute of Marine Science (ISMAR) – National Research Council (CNR), Via Pola 4,71010, Lesina (FG), Italy.

[4] Institut d'Investigació per a la Gestió Integrada de zones Costaneres, Universitat Politècnica València, C/ Paranimf, 1, 46730, Grau de Gandia, Spain

[5] Institute of Marine Biological Resources and Inland Waters - HCMR - Sounio ave. km 46.7, 19013, Anavissos, Athens, Greece

[6] Technological Educational Institute of Western Greece, Department of Aquaculture and Fisheries, Nea ktiria 30200, Messolonghi, Greece

[*]corresponding author: Giorgio Mancinelli (giorgio.mancinelli@unisalento.it)

Abstract

The blue crab *Callinectes sapidus* is native to the coastal waters of the western Atlantic Ocean, and along the US coasts the species supports an important fishery. The crab has been introduced to Europe at the beginning of the 20th century. To date the species is considered invasive and is extensively recorded in southern European waters (SEW), where it is starting to penetrate the shellfish market. Here, an integrated management strategy is proposed for the blue crab in SEW, including the Mediterranean and Black Sea and the eastern Atlantic coasts of the Iberian Peninsula. Taking as introductory examples two case studies represented by the red king crab *Paralithodes camtschaticus* and the green crab *Carcinus maenas*, a framework of key issues is reviewed considering the double nature of the species as invaders and shellfish products. A SWOT analysis is eventually presented for *C. sapidus*, in order to perform a state-of-the-art synthesis of the proposed scenario, highlighting the potential opportunities as well as the weaknesses related with the limited knowledge of the ecological and economic impact of the species in invaded habitats. The review is concluded by an appraisal of the current trends in global and European crustacean fisheries. The on-going expansion of *C. sapidus* might represent a useful management case study, where the need to control an invasive species and mitigate its ecological impact can be harmonized with the opportunity to value it as a fishery resource.

Keywords: *Callinectes sapidus*; biological invasions; crab fishery; integrated management; mitigation

1. Introduction

Food webs of marine coastal habitats support crucial ecosystem services, and are currently experiencing a diversified spectrum of human pressures worldwide. Besides habitat loss and overfishing, the introduction of non-indigenous species is among the most pervasive stressors affecting coastal areas at every latitude, from polar to temperate and tropical regions (Molnar et al., 2008). In the last decades, the Mediterranean Sea and, in general, southern European waters (SEW hereafter) have experienced a dramatic increase in the frequency of introduction and rate of expansion of non-indigenous crustaceans (Nunes et al., 2014; Chainho et al., 2015). Several examples (e.g., see Katsanevakis et al., 2014 for a recent review) are available regarding the effects of some of these species on the delivery of goods and services (*sensu* Liquete et al., 2013) by invaded ecosystems; in general, however, the ecological and economic impacts of crustaceans introduced in south European coastal systems have been scarcely investigated.

An illustrative example of this knowledge void is provided by the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896 (Brachyura: Portunidae). Native to the western coasts of the Atlantic Ocean, this species inhabits estuaries, lagoons and other coastal habitats, is euryhaline and eurythermal, and is characterized by a high fecundity and aggressive behaviour (Millikin and Williams, 1984). In native habitats, *C. sapidus* has long been recognized as an important functional component of coastal benthic food webs (Baird and Ulanowicz, 1989; Hines, 2007). In addition, it supports important fisheries in Northern and Central America (Fig. 1A and 1B; FAO, 2014; see also Fogarty and Miller, 2004; Kennedy et al., 2007; Bunnell et al., 2010 for the U.S.A.), with a capture production estimated in 2013 only in the United States in 74,495 tons, corresponding with a commercial and recreational asset valued at approximately US$185 million (NOAA, 2014).

The blue crab has been introduced in 1900 in northern Europe by ballast waters; subsequently, its distribution range has progressively extended throughout the Mediterranean Sea and neighboring waters (Nehring, 2011; Cilenti et al., 2015; González-Wangüemert and Pujol, 2016) and to date it is considered an Invasive Alien Species (IAS hereafter; Streftaris and Zenetos, 2006). Adverse interactions with other native crustacean species have been repeatedly suggested (Gennaio et al., 2006; Mancinelli et al., 2013a) and some negative effects on artisanal fishing activities have been episodically reported (Nehring, 2011); besides these scarce information, the impact of the species on non-native coastal ecosystems is poorly known. No general capture regulations or managing strategies have been identified to date; in addition, the actual perception of fishermen and stakeholders of the impact of the species on human activities in coastal habitats is virtually unexplored.

Here, the overarching scope is to outline an integrated management strategy of the blue crab in invaded habitats, highlighting its potential as a shellfish product in European markets for alimentary and non-alimentary purposes. The core of the study is an analysis of the strengths, weaknesses, opportunities, and threats (SWOT) related with a commercial exploitation of the blue crab that may simultaneously translate in an effective strategy of control and mitigation of its impacts as an invasive species. Two case studies - i.e., the red king crab *Paralithodes camtschaticus* and the green crab *Carcinus maenas* - are used to identify a spectrum of key issues directly associated with an integrated management of invasive brachyurans as shellfish products. An analysis of current and future developments of crustacean fisheries at a global and European scale is also provided, indicating how a current ecological threat may paradoxically foster in the next decade crab fisheries in SEW.

2. The red king crab and the green crab: two illustrative case studies

In 2011, Brockerhoff and McLay recorded 73 species of alien marine and brackish brachyurans worldwide; to date the number is likely to be even higher, as of 2014 Klaoudatos and Kapiris listed 40 species only in the Mediterranean Sea. Among others, here we focus on the red king crab *Paralithodes camtschaticus* Tilesius, 1815 and the green crab *Carcinus maenas* Linnaeus, 1758. Even though contrasting in terms of biology, invasion history, native habitats, and ecological characteristics (Tab. A in the online information and references cited therein), they provide two highly illustrative examples of the general convergence of strategies implemented to integrate the management of a fishery resource with effective actions of control and mitigation of an invader and *vice versa*. In Table A, three key points are worth being highlighted:

1) *P. camtschaticus* has been voluntarily introduced from native north-western Pacific waters with the explicit aim of developing a targeted fishery. Management and exploitation of established

populations have started almost immediately, and only in a second moment their invasive nature has been acknowledged. This recognition has been based on information provided by a number of field and laboratory investigations, in turn motivated by a research plan funded by the Norwegian government, allowing a quantitative assessment of the ecological and economic impact of the species, and of its overall effects on the services delivered by invaded coastal habitats. Methodological approaches originally developed to manage the populations in Norwegian waters such as the identification of free fishing zones, or three-S (size, season, sex) procedures of stock selection, are now acknowledged as effective tools of control and mitigation (Ojaveer et al., 2015);

2) *C. maenas* has been unintentionally introduced in North America by ballast waters, and its invasive nature has been recognized as early as 1998. A thorough assessment of the negative ecological and economic impacts on invaded coastal systems has been paralleled by various attempts of control and eradication, only temporarily successful. Interestingly, the huge body of information collected on the ecology of green crab populations in invaded habitats constituted a potentially useful basis for starting a fishery. Indeed, some unsuccessful attempts have been made in the past decade in the USA to develop a hard-shell fishery; more recently, the Department of Fisheries and Oceans in Canada is currently experimenting with a commercial green crab fishery whose marketing features as an alimentary asset (e.g. break-even prices) are currently under evaluation (Poirier et al., 2016; St-Hilaire et al., 2016);

3) regardless of the species and the sequence of events characterizing its recognition by governments and stakeholders as an invader or a fishery resource, Table A emphasizes that any action of integrated management of a marine invasive crab must necessarily rely on i) detailed information on the occurrence and abundance of populations, ii) data on their connectivity, as well as on iii) robust estimations of the ecological and economic impacts on ecosystem services, both as a nuisance for other traditional fisheries, and as a positive element as a fishery resource. This latter aspect also requires the identification of the actual value of the invader as an alimentary product and the most rewarding strategy to market it. For the red king crab this aspect was explicit ever since its

introduction; for the green crab previous efforts have clearly indicated that a classical hard-shell, meat-yield fishery may result impractical and high-priced; alternatively, soft-shell products have been proposed, on the model of the congeneric *C. aestuarii* in Italy (Cilenti et al., 2014 and literature cited; see also Glamuzina et al., 2017) or, noticeably, of *Callinectes sapidus* in the southern USA (Poirier et al., 2016; St-Hilaire, 2016).

3. Pros and cons of a blue crab management strategy: a SWOT analysis

Taking the issues highlighted for the red king crab and the green crab as guidelines (Tab. AO, an integrated management strategy of *Callinectes sapidus* in SEW as both a shellfish product and an invasive species is proposed. Its strengths, weaknesses, opportunities, and threats (SWOT) are summarized in Table 1. In recent years, SWOT analyses have been repeatedly applied to marine fisheries (e.g., Panigrahi and Mohanty, 2012; Glass et al., 2015); criticisms have been raised since no implementation procedures are generally identified (Helms and Nixon, 2010; Clardy, 2013). Here, an effort is made to go beyond the analysis itself and propose, as long as possible, effective follow-up approaches and methodologies.

In general, the notion that, by eating invasive species humans can effectively control their abundance and mitigate their impacts, has only recently gained popularity (Clark et al., 2009; Nuñez et al., 2012). However, the assumption that the commercial exploitation of the blue crab may ultimately help in the control of its distribution and abundance - the concept at the core of the proposed strategy - has been virtually already demonstrated: human activities have strongly impacted Atlantic populations, as the considerable decline in catch observed in the period 1995-1999 (Fig. 1B) has been ascribed to overfishing (Sharov et al., 2003; Hewitt et al., 2007; Huang et al., 2015). Similarly, the reduction in the abundance of commercial stocks of the red king crab in the Barents Sea has been related with overharvesting (Tab. A).

A number of strengths and opportunities characterizing the proposed strategy are listed in Table 1; though, we first focus on the most unwanted, threatening consequence that may derive from starting a *Callinectes sapidus* fishery. Once accepted in south European fish markets, the crab may no longer be considered an invasive species threatening the biodiversity and stability of invaded ecosystems. The occurrence of the species may be legitimized, and the risk it represents overlooked or even ignored (Pasko and Goldberg, 2014). Furthermore, the establishment of an economically important blue crab fishery may motivate illegal efforts to set up an uncontrolled export of live specimens at a national and international scale, ultimately promoting invasion (Nuñez et al., 2012). Unfortunately, this is a major threat already present, since Greek blue crabs are currently being exported alive and sold on Italian and Portuguese fish markets (Ribeiro and Veríssimo, 2014; Mancinelli, personal observation). Thus, even though recognized as invasive by European environmental regulations (e,g, EU, 2014), the blue crab is not subjected to any control, as it is not included in the list of species of Union concern (EU, 2016). As pointed out by Nuñez et al., (2012; see also Conde and Domínguez, 2015 for an example on the freshwater crayfish *Procambarus clarkii*), the effectiveness of a strategy avoiding the cultural incorporation of an IAS may depend on how the species is presented. An explicit reminder to entrepreneurs and consumers that the goal is to control the spread of an invasive species may be the key to avoiding negative consequences. To date, such an approach has been totally neglected; on the other hand, the implementation within south European countries of an integrated management plan may provide the opportunity for the identification and standardization of marketing and export strategies for the blue crab, including, in addition, common quality control and traceability procedures.

Of the strong points listed in In Table 1, the most significant is related with the alimentary value of the species. As a shellfish product, the blue crab has long been valued in native areas (among others, Farragut, 1965; Thompson and Farragut, 1982), and its high alimentary quality is, to date, also acknowledged in SEW (e.g., Küçükgülmez and Çelik, 2008; Zotti et al., 2016a, 2016b). A potential weakness for the European hard-shell market may be the species total meat yield (14-16%: Mancinelli, unpublished data; Desrosier and Tressler, 1977), lower than that characterizing other crab species of economic interest such as *Paralithodes camtschaticus* (Tab. A, online information) or *Cancer pagurus* (25-30%: Barrento et al., 2009). A soft-shell blue crab fishery may be alternatively developed (see previous paragraph); however, it may be economically unrewarding to start a blue crab market chain - either hard-shell or soft-shell - centred on alimentary uses only. In addition, the local extinction of the species - a positive event from a conservation point of view - may represent a threat for the sustainability of the market demand (Tab. 1). The extraction of chitosan and astaxanthin from crabs' shells may represent an opportunity to i) support the on-going global shellfish market shift (see further in the last paragraph); ii) increase the efficiency of waste management in agreement with current European regulations (EC, 2008b) and with global trends (Ravindran and Jaiswal, 2016); iii) reduce the species-specificity of the market chain (i.e., other crustacean species of economic interest may support the demand) and iv) produce valuable compounds with wide applications in pharmaceutical, biomedical, cosmetic, agricultural, and biotechnological fields (Ambati et al., 2014; see also Demir et al., 2016, Baron et al., 2017 for recent examples on *C. sapidus*).

In SEW, the number of records of *C. sapidus* have boosted in the past few years (Mancinelli et al., 2017b), testifying its range expansion but also a growing interest of the scientific community and the general public. In general, these information provide an advanced resolution of the current distribution of the species, constituting a preliminary, yet essential support to the implementation of a blue crab fishery. A huge body of studies from native habitats are available on the species regarding methodological approaches, field protocols, and procedures of catch data analysis for stock assessment and management, as well as on its functional role and ecology. An exhaustive analysis of these information is beyond the scopes of this paper; the book by Kennedy and Cronin, (2007) represents an outstanding example of the vast literature dedicated to the species. This knowledge basis may constitute, given the appropriate adjustments and complemented with the necessary biological and ecological information, a robust support for starting management actions of blue crab stocks in SEW, as well for integrating these efforts within a wider, environmental framework fully consistent with current EU legislations on invasive species (e.g., EC, 2008a; EU, 2014).

It is worth noting that a considerable number of quantitative studies have been already carried out on populations from Turkish waters and other invaded habitats of the Aegean and Ionian Sea (Atar et al., 2002; Atar and Seçer, 2003; Gökçe et al., 2007; Gökçe et al., 2006; Sumer et al., 2013; Türeli et al., 2016; Özdemir et al., 2015; Katselis and Koutsikopoulos, 2016) providing useful information for stock management as well as on fishing gears efficiency, tailored for reducing by-catch and other negative impacts on local traditional fisheries. Indeed, small-scale, local blue crab fisheries are currently located only in these areas; for example, annual landings of 17-77 tons of blue crabs have been recorded in Turkey in 2008 and 2009, respectively (Ayas and Ozogul, 2011) while 50-80 tons have been landed in 2010 and 2011 in northern Greece (Kevrekidis et al., 2013).

The challenge for an effective management of the blue crab in SEW as a shellfish product is to build on these experience, expanding them at a whole-basin scale, with a strong co-operation of Mediterranean countries (as that started between Norway and Russia for the management of the red king crab) in a perspective of standardization of methods and approaches, as implemented in the past years for the EU Water Framework Directive (EC, 2000).

Of the weak points reported in Table 1, the most relevant regards the paucity of biological and ecological data on blue crab populations. Indeed, with the exception of the Mediterranean Levantine sector, a low number of studies is available providing quantitative data on the abundance and biology of established populations. In addition, only scant attempts have been made to implement practices and approaches such as high efficiency fishing gears, or capture strategies tailored in space and time on the biological cycle of the species (e.g., selective for females: Cilenti et al., 2016).

Specifically, while data on maturity and fecundity are diverse (e.g., see Dulčić et al., 2011 for Croatia, Cilenti et al., 2015 for SE Italy), other crucial biological information on populations necessary for stock assessment, as abundance or natural mortality are lacking (but see Mancinelli et al., 2013a and Carrozzo et al., 2014 for studies providing quantitative information on seasonal abundance patterns).

These knowledge voids currently hinder the development of selective capture procedures (e.g., 3-S strategies), as well as the identification of areas characterized by specific capture regimes that may respond to the market demand and, as already tested with the red king crab (Tab. A), contribute in reducing the spread of the species.

The scarcity of biological data is echoed by a paucity of quantitative information on the ecological and economic impacts on the goods and services of invaded ecosystems. Table A clearly suggests that for both the red king crab and green crab a wealth of biological and ecological data have been collected on invasive populations in order to identify and refine effective management (as shellfish products) and control (as invasive species) actions. No similar information are available for the blue crab in SEW. Only recently, an estimation of its invasion potential based on decision support tools provided a posthumous assessment of a high risk of invasiveness (Perdikaris et al., 2016), while stable isotopes studies have only indirectly suggested a significant impact on the trophic structure of invaded benthic communities (Mancinelli et al., 2013a, 2016, 2017a).

In addition, preliminary information (period July - October 2015) on the impact on fisheries perceived by Ionian and Aegean Greek fishermen has been assessed by means of a questionnaire, indicating that where blue crab populations have reached maximum abundances in the last decade (i.e., Vistonida lagoon in North Aegean Sea), considerable negative effects on fishing activities are recognized by local populations (Katselis, unpublished data).

Independently from whether the blue crab is considered a product or an invader, a further weakness is represented by the lack of information on connections among populations. The spatial and genetic structure of blue crab populations in native Atlantic habitats has been widely investigated (McMillen-Jackson and Bert, 2004; Yednock and Neigel, 2014; Lacerda et al., 2016), indicating a generally low inter-population gene flow and high variability in genetic composition at extremely small spatial and temporal scales. However, these issues have been completely overlooked in SEW.

A further unexplored aspect regards parasites and pathogens. Infectious disease agents can magnify or buffer the impact of an IAS depending on their relative effects on its fitness and on that of indigenous competitors (Dunn and Hatcher, 2015; Goedknegt et al., 2015). In the USA the green crab has been demonstrated to experience reduced parasite diversity and prevalence in its invasive range, and the greater biomass density seen in invasive populations has been attributed to an "enemy-release" effect (Torchin et al., 2001; see also references in Tab. A). In fact, given its economic value, great attention has been given to the identification of pathogens in the blue crab in the USA (Messick, 1998; Nagle et al., 2009; Flowers et al., 2015). In SEW information is scant, being mostly limited to epiparasites (i.e., cirripedia: Zenetos et al., 2005), while there have been unconfirmed claims regarding the occurrence of parasitic dynoflagellates of the genus *Hematodinium* in blue crabs from the Ionian Sea (Mancinelli et al., 2013b). Future research is needed to specifically address the analysis of epi- and endoparasites and pathogens in SEW blue crabs, and to clarify the potential for transmission to native crustacean species.

4. Opportunities and future prospects in crab fisheries

The opportunities listed in Table 1 indicate that the implementation of a management plan of the blue crab in invaded habitats may provide an unprecedented support to the integration and coordination of common policies focused on both fisheries and IAS management among south European countries.

In 2011, the European Union adopted a new strategy to halt the loss of biodiversity and degradation of ecosystem services by 2020, to restore them as far as possible, and to contribute to averting global biodiversity loss (EC, 2011). Among the six main targets of the strategy, target 4 commits the EC to reform the Common Fisheries Policy (CFP) so that ecological impacts are reduced, including impacts on marine ecosystems, while target 5 commits the EC to combat invasive alien species through preventing their establishment and through control and eradication. Regarding target 4 it is worth noting that in the CFP the management of alien species is addressed only for aquaculture (EU, 2011; see also EU, 2013) and no other related issues are considered further. As outlined in Table 1, the implementation of the management strategy herein proposed may constitute an outstanding opportunity to i) widen the aims and the spectrum of practical policy actions of the CFP in terms of alien species, and to ii) provide a bridging framework of methodologies, procedures, and protocols with other EU environmental legislations focused on invasive alien species (e.g., Regulation 1143/2014, EU, 2014).

The most unique opportunity, however, may be related with the current and future shifts in European and global shellfish markets. The exploitation of crustacean fisheries has gained a growing relevance worldwide (Fig. 2; FAO, 2014; see also Anderson et al., 2011). It is worth noting that the exploitation of European crustacean fisheries has not varied accordingly: in the Mediterranean Sea, for example, total captures almost doubled in the period from 1970 through 1990; subsequently, however, negligible increases occurred (Fig. 2). Cultural reasons, local dietary habits, and market strategies have contributed to maintain finfish species as favoured seafood when compared to shellfish (Vasilakopoulos and Maravelias, 2015). Additional limitations are represented by the lack of attractive and valuable large-sized species, in particular for brachyurans: among the species considered in Green et al., (2014) the edible crab *Cancer pagurus* is the only valuable species found in European fish markets. Future developments of the Mediterranean demersal and coastal fisheries are nonetheless expected to mirror the shifts already observed at an European scale; given the current critical conditions of most of the stocks of crustacean species of commercial interest (Vasilakopoulos and Maravelias, 2015), new fishing grounds are needed and new species are to be exploited.

The current invasion of the blue crab offers the possibility of identifying successful policies of exploitation and marketing for a shellfish product whose economic value has been already recognized outside Europe. The management and control costs in invaded habitats may ultimately be reverted into profits for local populations, while the ecological impact of the invader may be greatly reduced, and partially converted into an enhancement of the ecosystem goods and services provided by coastal habitats.

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Table 1. Strengths, weaknesses, opportunities, and threats (SWOT) of the management of the blue crab *Callinectes sapidus* in south European waters as a shellfish resource and as an invasive species. MSFD: Marine Strategy Framework Directive (EC 2008).

	Strengths	Weaknesses	Opportunities	Threats
Shellfish product	• high alimentary value recognized in both native and invaded habitats; quality control and traceability procedures defined; • alternative product market chains (hard-shell, soft-shell) identified in native habitats; • the species distribution in SEW is known; the high awareness of the scientific community and the general public provides updated records almost in real time; • adjustable procedures and protocols standardized in native habitats for the assessment and management of stocks; • high-efficiency fishing gears identified in both native and invaded habitats (e.g., Turkey);	• low meat yields compared with competing shellfish products; • lack of quantitative information on impacts on fishing activities and other fish and invertebrate species of economic interest; • lack of regulations: the blue crab is already exported across south European countries without control; •	• new fisheries and diversification of European shellfish product markets; • development of eco-sustainable fishing practices (e.g., high efficiency, selective fishing gears, control of by-catch and discards, development of targeted fishing strategies); • development of standardized stock assessment procedures for crustaceans according to ICES, (2015); • support to alimentary commercial sectors; • support to non-alimentary commercial sectors and shellfish waste management; • opportunity to capitalize on positive media coverage associated with environmental protection from IAS;	• by-catch of other fish and invertebrate species of economic interest; • blue crab populations drawn to extinction by overfishing and unregulated harvesting; shellfish alimentary product characterized by a relatively short commercial life;
Invasive species	• reference information on the functional role available for native habitats and, to a lesser extent, for SEW; • growing interest of the scientific community for the ecological and economic impact of the crab in invaded habitats; • non-indigenous species are included as one the descriptors of good ecological status in the MSFD;	• incomplete knowledge on the biology, ecology, and connectivity of blue crab populations in SEW; • incomplete quantitative information on their functional impacts on invaded ecosystems; • lack of information on their impacts on economic activities; • no coordination and standardization of monitoring or early detection tools and procedures; • no standardization of ecological impact assessment tools;	• evaluation of the impact of an IAS integrating both environmental and economic issues related with the public interest and perception of stakeholders; • rise of media interest on IAS control, management, and mitigation; • support to the integration and coordination among south European countries on IAS management;	• once accepted as a product in fish markets, the species is no longer considered as an invasive species to be controlled, managed, and mitigated; • conversion of the blue crab to productive uses turns into perverse incentives that perpetuate and spread its distribution in SEW; • increased risk of ecological impact and economic damage to the fishery sector due to the diffusion of the blue crab;

Figure captions

Figure 1. Blue crab catch statistics in native areas: A) cumulative catches (in tons) of countries on the Western Atlantic in the decade 2003-2013; please note the logarithmic scale; B) temporal pattern of total catches in the same area in the period 1950-2013. Source: FAO (http://www.fao.org/fishery/statistics/global-capture-production/en, accessed 10/06/206).

Figure 2. Temporal patterns of variations in crustacean fishery catches: data on global wild catches (continuous line), global aquaculture (dashed line) and total catches in south European waters (including Portugal, and the Mediterranean and Black Sea: grey line) are reported. Please note the different scales on y-axes. Data cover the period 1950 - 2013. Source: FAO (http://www.fao.org/fishery/statistics/global-capture-production/en, accessed 10/06/206).

Figure 1
Mancinelli et al
Blue crabs in southern European waters

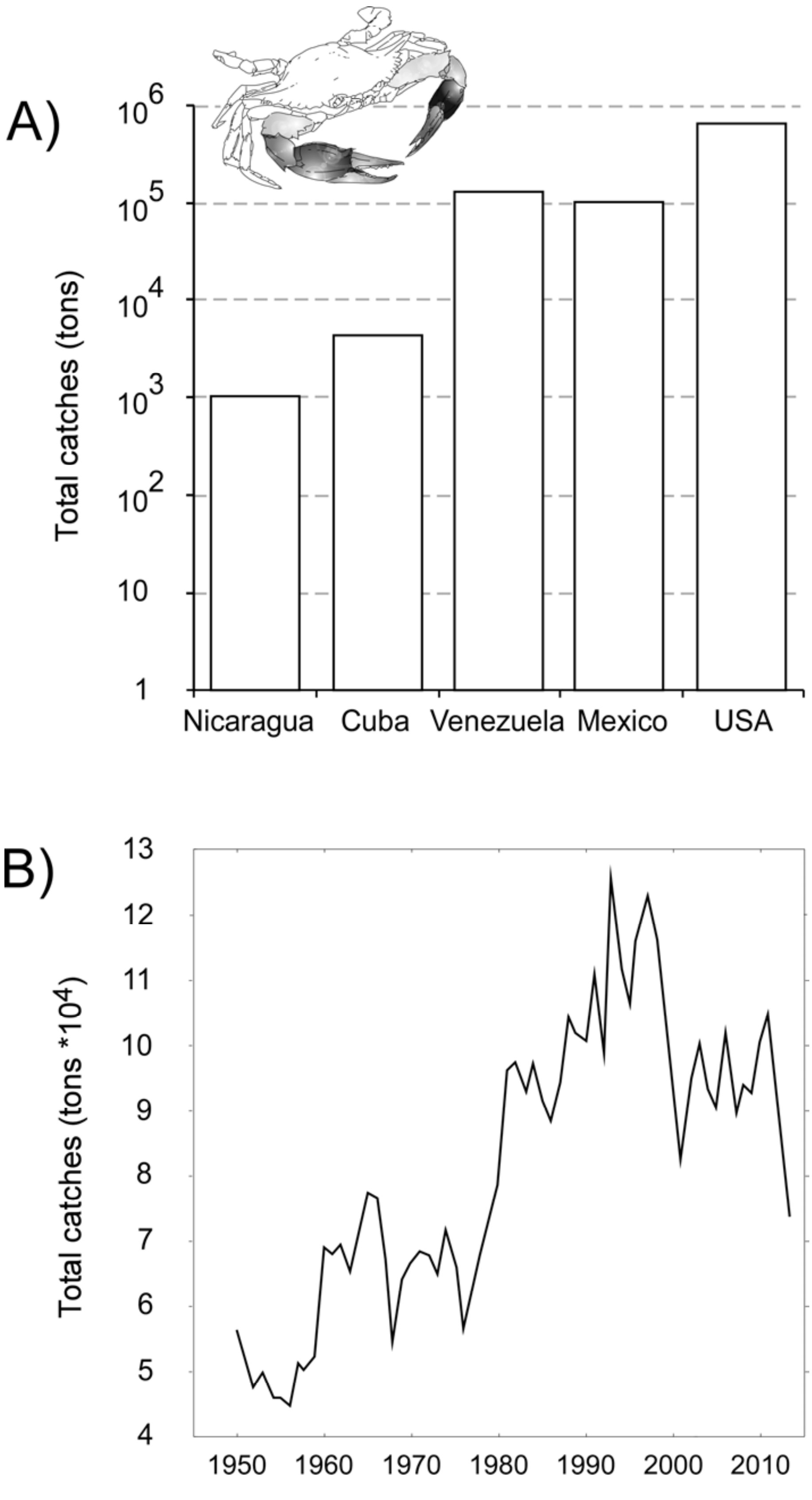
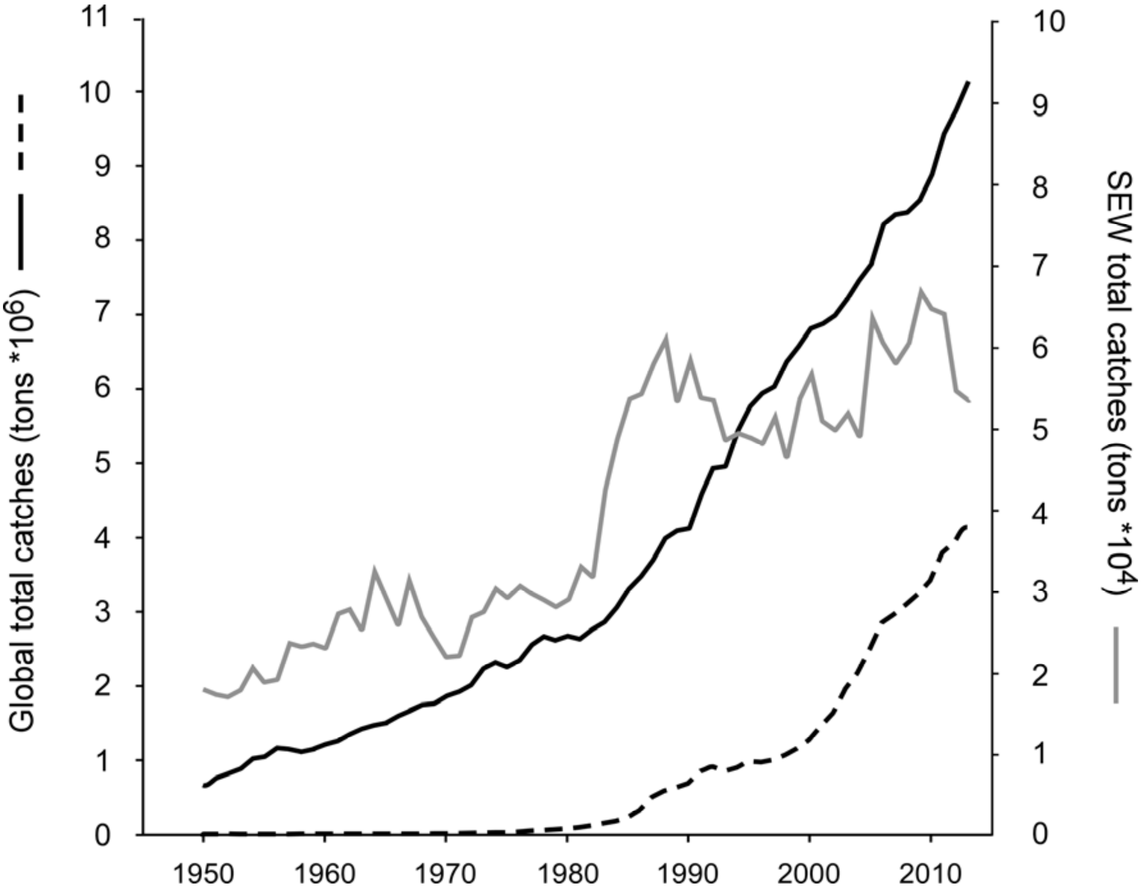


Figure 2
Mancinelli et al
Blue crabs in southern European waters



Supplementary online information

Table A. Summary of management actions and strategies developed for two invasive crab species: the red king crab *Paralithodes camtschaticus* Tilesius, 1815 and the green crab *Carcinus maenas* Linnaeus, 1758. Besides the references explicitly cited in the table, Stevens, (2014) and Leignel et al., (2014) are used as general references for *P. camtschaticus* and *C. maenas*, respectively.

	Paralithodes camtschaticus	*Carcinus maenas*
Shellfish product		
Economic value	• high, up to 500 NOK kg^{-1} (€56 kg^{-1}) given the high meat yield and size of edible parts (i.e., periopods: approximately 40%: James et al., 2013; Siikavuopio and James, 2015);	• low; the small size and the low yield of edible parts (23-28%: Naczk et al., 2004) make a traditional meat yield, hard-shell crab fishery impractical. The current market in Canada is as lobster bait, with a value ranging between \$0.30 and \$0.90 lb^{-1} (McNiven et al., 2013; St-Hilaire et al., 2016); • recently, an alternative soft-shell fishery has been proposed, similar to that established in the Venice Lagoon (Northern Italy) on the congeneric *Carcinus aestuarii* Nardo, 1847. During 2014 the average and maximum price were €51 kg^{-1} and €80 kg^{-1} respectively (Cataudella et al., 2015);
Fishery management	• A Russian-Norwegian research fishery was established in 1994; annual quotas were determined by a Mixed Fishery Commission. The management was based upon a 3-S regime (Size, Sex and Season), and depth limitations. Joint regulations for fishing grounds, periods, gears, and bycatch control were implemented (Sundet, 2014; Sundet and Hoel, 2016); • In 2007, the Commission agreed on a separate national management. In Norway two regimes have been adopted: in quota-regulated areas, fisheries are subjected to a 3-S capture regulation; outside them, a free-fishing zone has been created. Fishermen experiencing bycatch problems in stationary fisheries (gillnet, long line etc.) are allowed annual catch quotas;	• in the past decade, several unsuccessful attempts have been made to create a hard-shell green crab fishery in the United States (Hollenkamp, 2016 and literature cited); • In 2012, the Canadian Department of Fisheries and Oceans (DFO) approved commercial fishing in Nova Scotia, issuing experimental fishing licenses. Licenses currently have no limits on quantity, size, or sex of animals, while the method of capture is regulated. In Prince Edward Island, by-catch permits have been issued allowing the sale of crabs captured while fishing eels or other fish species (Poirier et al., 2016; St-Hilaire et al., 2016);
Threats	• None currently identified; in native habitats (southeastern Bering Sea and Gulf of Alaska) fisheries have declined owing to overharvesting and climate regime shifts;	• None currently identified; in native habitats (Greek Mediterranean Sea) the population of the congener *C. aestuarii* declined due to overfishing (Tsikliras et al., 2013);
Invasive species		
Native habitats	• Bering Sea, Okhotsk and Japan Sea, and North Pacific Ocean	• northeast Atlantic
Invasion history	• Intentionally introduced in Kola Bay in the waters of the Soviet Union on several occasions during the 1960s and 1970s (Orlov and Ivanov, 1978); • Since the first observation in Norwegian waters in the early 90s, the species has expanded westwards; in addition, the species has been recorded eastwards of the introduction area in the White Sea (Dvoretsky and Dvoretsky, 2013);	• First observed on the east coast of North America in Massachusetts in 1817, and now occurring from Newfoundland to Virginia; in Canadian waters was recorded in 1950 at the Bay of Fundy; to date it is observed in the five Atlantic Canadian provinces; • recorded in 1989 - 1990 on the Pacific coast of the USA. To date the range extends from California to British Columbia;

	• dispersal of larval stages and, to a lesser extent, migration of adults are considered the main determinants of the current range expansion;	• established populations recorded in South Africa, Japan, and Australia; • unintentional introduction by shipping on the east coast of North America; incidental introduction of adults on the west coast with commercial fishery and bait products and dispersal of larval stages; range expansion by dispersal of larval stages (Carlton and Cohen, 2003);
Distribution, abundance and connectivity of populations	• The management of the fishery involves a continuous monitoring of the distribution and abundance of populations in the quota-regulated area and, most importantly, in the a free-fishing zone; • connectivity and isolation by distance among populations assessed using molecular approaches (Jørstad et al., 2007; Zelenina et al., 2008; Grant et al., 2014);	• the monitoring of the distribution and abundance of populations are key actions of the Green Crab Management Plan (see further); • connectivity assessed using molecular approaches for both Atlantic and Pacific populations (Roman, 2006; Darling et al., 2008; Tepolt et al., 2009);
Ecological impact	• currently included in the highest risk category of invasive species by the Norwegian biodiversity authority (Gederaas et al., 2012); • in 2002, Norway started a comprehensive research programme on the ecosystem impacts of the species in co-operation with Russia (Jørgensen and Nilssen, 2011); • destabilizing impacts have been demonstrated on the structure and functioning of benthic assemblages related with the generalist feeding habits of the species and its trophic shifts during ontogeny (Oug et al., 2011; Falk-Petersen et al., 2011; Fuhrmann et al., 2015; but see Britayev et al., 2010 for a counterexample); • indirect negative impacts have been suggested as vector of fish pathogens (e.g. trypanosome blood parasites by hosting the leech *Johanssonia arctica*: Hemmingsen et al., 2005, 2010);	• designated as an aquatic nuisance species in the USA by the Aquatic Nuisance Species Task Force (ANSTF) since 1998; • in 2002 the ANSTF implemented a Green Crab Management Plan to assess the impacts and prevent, eradicate, and control the species; • negative impacts have been demonstrated on a number of benthic invertebrate taxa, including bivalves and other crustaceans (Floyd and Williams, 2004; Grosholz et al., 2000; Pickering and Quijón, 2011; Gehrels et al., 2016); • indirect negative effects have been suggested on physical characteristics of benthic habitats through bioturbation (Schratzberger and M. Warwick, 1999; Neira et al., 2006; Malyshev and Quijón, 2011; Lutz-Collins et al., 2016); • no parasite-related indirect effects have been emphasized to date; however, it has been suggested that the species may have a lower susceptibility to pathogens than other decapod crustaceans (e.g. *Hematodinium* infections:Hamilton et al., 2010);
Economic Impact	• negative effects have been indicated on the recruitment of valuable finfish species by feeding on egg-clutches (Mikkelsen and Pedersen, 2012; but see Dvoretsky and Dvoretsky, 2015 and Mikkelsen and Pedersen, 2017); • non-univocal effects have been highlighted on the abundance of finfish and crustacean species of economic interest (Falk-Petersen et al., 2011; Jørgensen and Spiridonov, 2013; Dvoretsky and Dvoretsky, 2015);	• negative impacts have been indicated on juvenile stages of fish and crustacean species of economic interest (Taylor, 2005; Rossong et al., 2006); • considerable economic impacts have been long acknowledged on native shellfish products; for example, in 2005 the Oregon Dungeness Crab Commission estimated the potential impact on the west coast dungeness crab (*Metacarcinus magister* Dana, 1852) fishery in $50 million, while Lovell et al. (2007) showed that the estimated average annual losses to east coast

	• severe interference of bycatch with traditional fishing methods, as crabs feed on captured commercial species, and damage fishing gears; bycatch impels the abandon of historically important coastal fishing grounds (Godøy et al., 2003; Furevik et al., 2008; Falk-Petersen and Armstrong, 2013);	shellfisheries were $22.6 million; in the Gulf of St. Lawrence The impact on fisheries and aquaculture was estimated between $42 and $109 million (Colautti et al. 2006); • bioeconomic analyses of the impacts on commercial shellfisheries along the West Coast of the United States have been performed (Grosholz et al., 2011);
Risk control measures	• identification of potential native competitors and predators (Petersen Falk-Petersen et al., 2011); screening of parasites and pathogens (Jansen et al., 1998; Bakay and Karasev, 2008); • the current management of the fishery is expected to effectively control the rate of expansion by the adoption of open-access, high-take zone in western Barents Sea (Sundet and Hoel, 2016); • ban on release after unintentional capture in the open-access zone (Sundet, 2014); • research is carried out to develop fishing gear that reduces by-catches of crab in gillnets (Furevik et al., 2008).	• a number of studies have been carried out to assess the influence of native predators, other invasive species, and parasites on *C. maenas* abundance and distribution (e.g. for parasites see Thresher et al., 2000; Zetlmeisl et al., 2011; Torchin et al., 2001; Blakeslee et al., 2015) • actions of prevention have been implemented, together with active control efforts including harvesting, fencing, trapping, and poisoning; noticeably, short-term, small-scale experimental harvests in Canada and the USA have been only temporarily successful (St-Hilaire et al., 2016).

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