ScienceDirect

Marine Pollution Bulletin

Volume 206, September 2024, 116715

Opportunistic omnivory impairs the use of the Atlantic blue crab *Callinectes sapidus* as a trace metal biomonitor in invaded Mediterranean coastal waters

Raffaele De Giorgi [a b 1], Roberta Bardelli [c 1], Lucrezia Cilenti [d], Silvia Falco [e], Francesco Paolo Fanizzi [a b], Maria Teresa Guerra [a], George Katselis [f], Kosmas Kevrekidis [g], Francesco Mancini [h], Lorenzo Doria [a], Agnese Marchini [i], Danilo Migoni [a b], Paride Papadia [a b], Salvatrice Vizzini [c j], Giorgio Mancinelli [a b j]

Show more

Outline | Share Cite

https://doi.org/10.1016/j.marpolbul.2024.116715 ↗

Get rights and content ↗

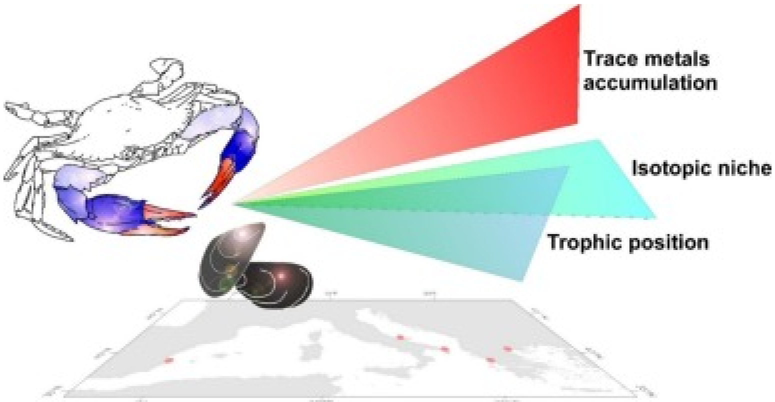
Highlights

- *Callinectes sapidus* is invasive in the Mediterranean Sea.
- Metals content was analyzed in five populations from Italy, Greece, and Spain.
- Variations in trophic position reflected on metals trophic transfer.
- Omnivory may hamper the use of a species for biomonitoring.
- Stable isotope analysis may provide clarifying information.

Abstract

The contribution of non-indigenous species to the transfer of contaminants in invaded food webs represents an active research area. Here we measured trace metals and CN stable isotopes in five populations of the invasive Atlantic blue crab *Callinectes sapidus* and in baseline bivalve species from Spain, Italy and Greece. They were used to estimate trophic transfer effects and the trophic position and isotopic niche of *C. sapidus*. Maximum trophic transfer effects occurred where the crab showed the largest isotopic niches and highest trophic positions; furthermore, the consistency of trace metal profiles between bivalves and crabs co-varied with the trophic position of the latters. Omnivory may influence the success of an invasive species, but also limit its effectiveness for biomonitoring. However, our results indicated that stable isotopes analysis provides a clarifying background where to cast patterns of contamination of the blue crab as well as of other omnivorous biomonitor species.

Graphical abstract



Keywords

Invasive species; Trace metals; Biomonitoring; Trophic plasticity; Isotopic niche; $\delta^{13}C$; $\delta^{15}N$

1. Introduction

Natural ecosystems are seldom jeopardized by single perturbations; conversely, the superimposition of multiple biotic and abiotic stressors is almost the norm, with synergistic and only rarely additive responses from the biota (Galic et al., 2018; Pirotta et al., 2022). Chemical pollution and biological invasions are among the anthropogenic threats (listed in e.g., Salafsky et al., 2008; Gelcich et al., 2014) involved in the alteration of the functionality of coastal marine ecosystems (Johnston et al., 2015). Bioinvaders can affect biogeochemical pools and fluxes of energy and materials (including pollutants), and thereby alter the structure and functions of ecosystems (Ehrenfeld, 2010; Corrales et al., 2020). Contaminants such as trace metals can cause impairment of biological functions even at low concentrations, reducing the abundance of the most sensitive species while facilitating opportunistic or tolerant taxa (Johnston and Roberts, 2009; Mayer-Pinto et al., 2010). In addition, persistent pollutants and xenobiotics can bioaccumulate (i.e. when their uptake rate by an organism from the environment and/or from the diet exceeds excretion or elimination rates) or biomagnify (i.e., when their prey-to-consumer transfer rate exceed the excretion or elimination rates of the consumer) along food chains up to top predators, including economically valuable species (Gray, 2002; Romero-Romero et al., 2017).

Noticeably, the interaction between bioinvaders and chemical contaminants in aquatic environments has been primarily addressed focusing on the use of invasive species for biomonitoring purposes (e.g., Annabi et al., 2018; Mancinelli et al., 2018; Tzafriri-Milo et al., 2019; Squadrone et al., 2020) and on the role of contaminants in facilitating invasions (McKenzie et al., 2012; Kenworthy et al., 2018; Osborne and Poynton, 2019). In contrast, lesser efforts have been made to elucidate the complex and non-univocal effects of invaders on the mobilization of contaminants in aquatic food webs (Eagles-Smith et al., 2018; Flood et al., 2020; see also Schiesari et al., 2018). This is particularly evident for marine and transitional environments (Boyd et al., 2018;

Ostrowski et al., 2021), while a number of freshwater investigations have provided contradictory evidence of how the re-wiring of food webs due to single- or multi-species invasions affects the transfer of contaminants across trophic levels (DeRoy and MacIsaac, 2020; Barst et al., 2020; Brown et al., 2022; Rennie et al., 2024 and literature cited).

In the present study, we focused on the Atlantic blue crab *Callinectes sapidus* Rathbun 1896 (blue crab hereafter), a portunid brachyuran originating from the western Atlantic coasts from the Gulf of Maine to Argentina (Millikin and Williams, 1984; Johnson, 2015; Cesar et al., 2003). The species was introduced in Europe in 1901 and appeared in 1947 in the Mediterranean Sea (but probably as early as 1935: Nehring, 2011). It is currently included in the list of the 100 most invasive species (Streftaris and Zenetos, 2006), and recognized as the cause of the consistent decline of several invertebrate and vertebrate species (Clavero et al., 2022).

During the last decade, the blue crab has spread almost ubiquitously in the Black Sea and in the eastern and central Mediterranean Sea, where it is currently expanding in the west and south of the basin (Mancinelli et al., 2017b, Mancinelli et al., 2021; Bardelli et al., 2023; Castriota et al., 2024) as well as in neighbouring freshwater habitats (Scalici et al., 2022). Blue crabs are benthic feeders (Hines, 2007) and their life history and behavior place them in direct contact with environmental contaminants via the water column, sediments, and prey (Reichmuth et al., 2010; Parmar et al., 2016). Additionally, laboratory studies have repeatedly demonstrated extensive accumulation of water- and food-borne xenobiotics (Hale, 1988; Mothershead II et al., 1991; Reichmuth et al., 2010; Evans et al., 2000), and several metal-binding metallothioneins have been identified in the tissue of blue crabs (Brouwer and Lee, 2007). Hence, the species has been proposed as a biomonitor species (i.e., a species that, by accumulating pollutants in its tissues, may be used to assess the bioavailability of the pollutants themselves in the surrounding habitat; Rainbow, 1995) in estuaries and other transitional habitats (Weinstein et al., 1992; Mutlu et al., 2011; Salvat-Leal et al., 2020).

Here we assessed the concentration of 13 trace metals (B, Ba, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, V, and Zn) in blue crabs from five coastal systems in Spain, Italy, and Greece. In invaded European waters, most of the information on trace metal contamination are available mainly for blue crab populations from the Levantine sector of the Mediterranean Sea, and for a limited set of trace metals (e.g., Türkmen et al., 2006; Mutlu et al., 2011; Genc and Yilmaz, 2015; but see Zotti et al., 2016; Salvat-Leal et al., 2020; El Qoraychy et al., 2023 for recent exceptions). To provide a first evaluation of the effectiveness of the species for large-scale biomonitoring in Mediterranean waters, we compared its trace metal contents with bivalves. Since the early 1970s, bivalves have been used to monitor coastal ecosystems, as they accumulate inorganic and organic pollutants and result more informative of environmental contamination conditions than other non-living matrices (Zuykov et al., 2013; Beyer et al., 2017). In both native and invaded benthic habitats, the blue crab is a voracious predator of mussels, clams, and other bivalves (Seed, 1980; Micheli, 1997; Seitz et al., 2001; Prado et al., 2020; Meira et al., 2024), a trophic preference recently testified by the dramatic effects observed in Italian lagoons (ARPAV-ISPRA, 2023). However, the diet of the species is far more diversified and omnivore, as it can opportunistically include a diverse set of vegetal and animal items such as plant material, crustaceans including conspecifics, gastropods, and fish (Hines, 2007; Mancinelli et al., 2017a; Rady et al., 2018; Kampouris et al., 2019; Prado et al., 2021).

Accordingly, in the present study we tested two alternative scenarios. The first assumed a direct trophic transfer of trace metals from bivalves to blue crabs, ultimately reflecting in bioaccumulation or even biomagnification phenomena in the latter. Alternatively, we hypothesized that the omnivory of the crab and thus its opportunistic consumption together with bivalves of multiple and differently-contaminated animal and vegetal resources would represent a confounding factor actually hampering its effectiveness as a biomonitor species.

To verify these hypotheses, along with the concentrations of trace metals we measured carbon and nitrogen stable isotopes in both *C. sapidus* and bivalves. Stable isotope analysis (SIA hereafter) has gained in the last decades a huge popularity for the study of invaded marine and coastal food webs (see Mancinelli and Vizzini, 2015 for a recent review) and, as it consents to relate contaminant concentrations in consumers to their trophic habits, it has long been acknowledged as a powerful tool to investigate accumulation and magnification phenomena along food chains (Jardine et al., 2006). In addition, SIA enables for robust, regional-scale analyses of species' dietary habits (e.g., Mancinelli, 2012a; Pethybridge et al., 2018; Figgener et al., 2019; Mancini et al., 2021, Mancini et al., 2022). Specifically, here $\delta^{13}C$ and $\delta^{15}N$ values of blue crabs were used to estimate their isotopic niche and, taking bivalves as baseline species, their trophic position, to verify the occurrence of variations in feeding habits across the five locations and whether they related with changes in trace metal profiles.

2. Materials and methods

2.1. Study sites

The study was performed in 2016 in five Mediterranean coastal systems located in Spain, Italy, and Greece and characterized by established *Callinectes sapidus* populations (see Fig. 1 and Table S1 in the online supplementary material for further details).

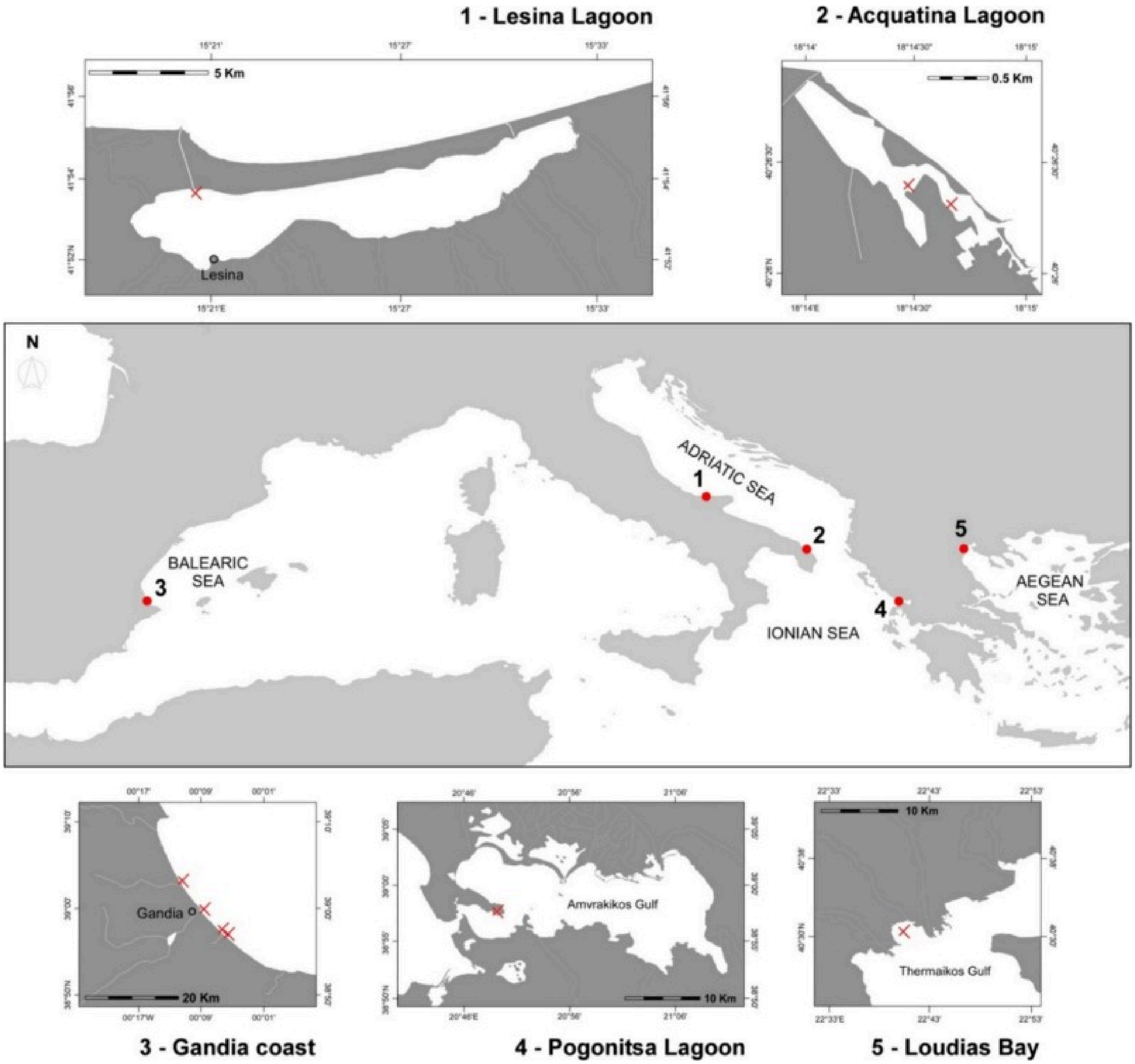


Fig. 1. The five coastal habitats included in the study. Red crosses in the inserts indicate the sampling locations where Callinectes sapidus and bivalves (i.e. *Arcuatula senhousia* for Lesina Lagoon and *Mytilus galloprovincialis* for the remaining locations; see text and Table 1 for further details) were collected. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In Italy, sampling operations were carried out in the Lesina and Acquatina lagoons (SE Italy, Fig. 1). The Lesina Lagoon is located on the northern coast of the Gargano Promontory (41°52′57.09”N, 15°26′34.71″E); it is approximately 22 km long and 3.5 to 1.5 km wide (52 km^2 total area), with depths ranging between 0.5 and 1.7 m (Mancinelli and Rossi, 2001; Spagnoli and Andresini, 2018). Two channels guarantee continuous water exchanges with the Adriatic Sea, while perennial and intermittent freshwater inputs occur in the south-eastern sector of the lagoon. The Acquatina Lagoon is located in the Salento Peninsula (40°26′34.50” N, 18°14′14.16″ E); The water body is approximately 1.9 km long with a surface area of 0.45 km^2; depths range between 0.5 and 1.7 m (1.2 m average depth; Mancinelli, 2012b; Pagliara and Mancinelli, 2018). Freshwater inputs are located in the northward sector of the basin, which is connected with the Adriatic Sea by a mouth (Fig. 1).

In Spain, samples were collected in a coastal area in the southern sector of the Valencia Gulf between the towns of Cullera (0°15′26.29“W, 39° 8’6.18”N) and Oliva (0° 4′41.29”W, 38°55′36.24”N; Fig. 1). The coastal environment is open to the Balearic Sea with a number of river mouths, and is generally low and sandy (Sospedra et al., 2018). In Greece, samples were collected in the Pogonitsa Lagoon (NW Greece, 38°57′53.04”N, 20°48′52.15″E) and in Loudias Bay (NE Greece, 40°30′7.36”N, 22°40′51.33″E; Fig. 1). The Pogonitsa Lagoon is located on the Ionian Sea in the south-western sector of the Amvrakikos Gulf. The lagoon has a surface of approximately 0.45 km^2, an average depth of 1.2 m, with sandy vegetated bottoms, and it is connected to the Amvrakikos Gulf by two channels (Katselis and Koutsikopoulos, 2017). Loudias Bay is situated in the inner Thermaikos Gulf (northern Aegean Sea). The bay is open to the sea (Fig. 1) has a surface of approximately 15 km^2 and depths up to 20 m, and receives freshwater inputs from Aliakmon, Axios, and Loudias rivers (Poulos et al., 2000; Catsiki and Florou, 2006).

2.2. Sample collection

At each of the five locations 15 to 24 blue crabs were captured using crab traps or other netting devices in summer 2016 (Table 1; see Table S1 for additional details). After collection, specimens were transferred alive to the laboratory in refrigerated containers (4 °C), where they were sexed and had the cephalothorax width (i.e., the distance between the two outermost lateral spines; CW hereafter) measured with a caliper to the nearest 1 mm. Subsequently, crabs were euthanized by thermal shock (−80 °C for 10 min) to avoid artefacts on elemental and isotopic determinations (Atwood, 2013). After crab collection, 6 to 10 individuals of locally dominant bivalve taxa were collected at each sampling location by hand (Table 1). *Mytilus galloprovincialis* was sampled at all the locations except Lesina Lagoon, where the non-indigenous Asian date mussel *Arcuatula senhousia* has recently outnumbered other native bivalves in the area (Scirocco and Urbano, 2018). Active predation of the selected species by the blue crab was confirmed by multiple evidences including repeated visual observations (all locations), analysis of stomach contents (Gandia; Gil Fernández, 2018), and collection of crushed specimens showing unequivocal signs of predation (Acquatina and Lesina; see Blundon and Kennedy, 1982 for examples on mytilids).

Table 1. Number of bivalve and *Callinectes sapidus* specimens collected at the five study locations. Taxonomic information on the bivalve species used as baseline for chemical analyses are included in parentheses.

Location	**Bivalves**	***Callinectes sapidus***
Lesina	10 (*Arcuatula senhousia*)	24
Acquatina	8 (*Mytilus galloprovincialis*)	20
Gandia	6 (*Mytilus galloprovincialis*)	19
Pogonitsa	6 (*Mytilus galloprovincialis*)	19
Loudias	6 (*Mytilus galloprovincialis*)	15

After collection, bivalves were transferred alive to the laboratory where they had their shell length measured in mm using a caliper before being euthanatized as already described.

2.3. Chemical analyses

Glassware and other equipment used to prepare samples for stable isotope and elemental analyses were preventively kept in diluted ultrapure HNO_3 65% for 24h, rinsed with Milli-Q water (Millipore Corp., Bedford, MA), and dried under a laminar flow hood.

For each crab, muscle tissues were removed from both claws using a ceramic scalpel, stored in falcon tubes, and randomly assigned to two groups. Samples were subsequently oven dried (40°C until constant weight) and powdered using a mortar and pestle. The first group of samples was used for carbon (C) and nitrogen (N) total content and stable isotope analyses. To this end, subsamples of known dry weight were pressed into Ultra-Pure tin capsules (Costech Analytical Technologies) and analyzed using an Elemental Analyser connected with an Isotope Ratio Mass Spectrometer (Thermo Scientific Flash EA 1112 and IRMS Delta Plus XP). Concentrations of total C and N were reported as g kg^{-1} tissue dry weight. Isotopic values were expressed in conventional δ notation (as ‰) in relation to international standards (PeeDee Belemnite and atmospheric N_2 for C and N, respectively) using the formula

$$\delta X = [(R_{\mathrm{sample}}/R_{\mathrm{standard}})-1]\times 10^3$$

where X is ^{13}C or ^{15}N and R is the corresponding $^{13}C/^{12}C$ or $^{15}N/^{14}N$ ratio. Analytical precision based on the standard deviation of replicates of internal standards (International Atomic Energy Agency IAEA-NO-3 for $\delta^{15}N$ and IAEA-CH-6 for $\delta^{13}C$) was 0.1‰ for both $\delta^{13}C$ and $\delta^{15}N$.

The total concentration of the trace metals boron, barium, cadmium, chromium, copper, iron, lithium, manganese, nickel, lead, strontium, vanadium, and zinc (for brevity all are subsequently referred to as “metals”) were determined on the second group of samples by wet digestion according to Raab et al. (2005). The procedure is described in detail elsewhere (Zotti et al., 2016); in brief, subsamples of known dry weight were mixed with 4 ml H_2O_2 and 6 ml HNO_3 at 180 °C for ten minutes using a microwave digestion system (Milestone START D). They were consequently cooled, diluted with ultrapure water to a final volume of 25 ml, filtered through Whatman No. 42 filter papers, and measured for metal contents using an inductively coupled plasma atomic emission spectrometer (ICP-AES; Thermo Scientific iCap 6000 Series). Results were expressed as mg kg^{-1} tissue dry weight; the minimum detection limit was 0.001 mg kg^{-1} for all metals.

For bivalves, the foot was dissected from each individual, dried, powdered, and analyzed for trace metals and stable isotopes adopting procedures identical to those described for *C. sapidus* tissues.

2.4. Data analysis

Values in the text are expressed as mean ± 1 SE if not otherwise specified. Morphometric and chemical data were preliminarily checked for normality (Shapiro-Wilk test) and homoscedasticity (Cochran's C-test); when necessary, they were square root- or log(x+1)-transformed to meet the required assumptions.

We used Non-metric Multidimensional scaling (nMDS) ordination to explore multivariate patterns of variation in the metal contents of bivalves and crabs across locations. nMDS plots were produced using similarity matrices based on Euclidean distances estimated on log(x+1)-transformed and *Z*-scaled concentration data. In general, a Type I (sequential sum of squares) permutational multivariate analysis of variance (PERMANOVA; Anderson, 2005) with 9999 unrestricted permutation of raw data was subsequently used to verify the effect on metal contents of the factor “location” (fixed, five levels), and the continuous covariate “size” as estimated by individual shell lengths in bivalves and individual cephalothorax widths in crabs. For the latter, the PERMANOVA design included the fixed factor “sex” to check for differences between males and females. *P* values for PERMANOVA tests were calculated using Monte Carlo permutations [*P*(MC) hereafter]. A Canonical Analysis of Principal Components (CAP) was further used to model changes in metal concentrations in individual crabs against their cephalothorax width across the five locations. Univariate comparisons were performed using Pearson product-moment correlation analyses and parametric ANOVAs followed by post-hoc Tukey's HSD tests. Statistical significance was evaluated at $\alpha=0.05$; when tests were reiterated, α values were always adjusted by performing sequential Benjamini-Hochberg corrections for multiple tests to reduce the risk of a type-I error (Benjamini and Hochberg, 1995).

Spearman rank correlation coefficients were eventually used to assess the congruence in metal contents between blue crabs and bivalves, as inter-specific comparisons performed using absolute metal concentrations may result biased by mechanistic, taxon-specific differences in the bioaccumulation of metals (Rainbow, 2018; McCue et al., 2020). Furthermore, to perform a general comparison of total metals content between bivalves and blue crabs at the different sampling locations we calculated the metal pollution index (MPI) according with the equation:

$$\mathrm{MPI} = (\mathrm{Cf}_1 \times \mathrm{Cf}_2 \ldots \times \mathrm{Cf}_\mathrm{k})^{1/\mathrm{k}}$$

(Usero et al., 1997) where Cf_k=concentration value of the k^{th} metal. When the measured contents were under the detection limits of the instrumentation (see previous paragraph), we assumed a concentration of 0.0005 mg kg^{-1}. Eventually, trophic transfer factors $\mathrm{TTF_i}$ were measured as the ratio of the concentration of each metal *i* in crabs to that in bivalves (DeForest et al., 2007). TTFi were not calculated when metals in bivalves or in crabs were under the detection limits.

Univariate and multivariate procedures identical to those described for metals were adopted to analyse isotopic data. Noticeably, the majority of crabs showed C:N ratios <3.5; conversely, bivalves from Lesina and Acquatina, and to a minor extent from Loudias, had ratios exceeding 3.5 (Table S2, online supplementary material). Lipids are depleted in ^{13}C compared to proteins and carbohydrates and can significantly bias δ^{13}C estimations when samples have a lipid content >5%, corresponding to a C:N ratio>3.5 (Post et al., 2007). Hence, here the δ^{13}C of individuals characterized by a C:N value >3.5 was normalized using the mathematical procedure proposed by Post et al. (2007).

We used individual δ^{13}C and δ^{15}N values of crabs from each location to measure in ‰^{2} their isotopic niche in terms of *standard ellipse area* (SEA; Jackson et al., 2011). Given the different number of specimens per location (Table 1) a sample size-corrected version of SEA was calculated (SEA_c hereafter), representing the core (40%) isotopic niche area and allowing for robust comparisons across samples of varying numerosity (Jackson et al., 2011). For the sake of completeness, we also estimated four additional metrics originally described by Layman et al. (2007), i.e., *nitrogen range* (NR) and *carbon range* (CR) as indicators of the total nitrogen and carbon range exploited by each population, the *mean distance to centroid* (CD) as a measure of population trophic diversity, the *standard deviation of nearest neighbour distance* (SDNND) as an index of population trophic evenness. SEA_c estimations were used for illustrative purposes; for statistical comparisons we calculated the Bayesian equivalent SEA_B of SEA_c (Jackson et al., 2011) using 100,000 posterior iterations of SEA_c to compute credible intervals. Pairwise comparisons were performed by calculating the probability that a population at location *i* had a SEA_B posterior estimate differing from that calculated at location *k* with a probability of at least 95% (Jackson et al., 2011). Since SEA estimations are independent from any inter-population difference in the isotopic baseline, we performed no correction for possible baseline shifts (e.g., Magioli et al., 2019).

The trophic position of crabs at the five locations (TP hereafter) was estimated implementing a Bayesian approach comparing the $\delta^{13}C$ and $\delta^{15}N$ values of the crabs themselves and those of bivalves, the latter adopted as isotopic baselines. This approach explicitly takes into consideration individual variability and propagation of sampling error (trophic enrichment factors, and measurements of baselines and consumers) in the modelling procedure and posterior estimates of parameters (Quezada-Romegialli et al., 2018). Specifically, here we used a single-baseline model with 5 parallel chains and 100,000 adaptive iterations. *M. galloprovincialis* and *A. senhousia* are filter feeders with diets mainly relying on phytoplankton and suspended particulate matter (Ezgeta-Balić et al., 2014); hence, a trophic position $\lambda=2$ was assumed for both taxa. Given the omnivorous trophic habits of the blue crab, calculations were carried out adopting trophic enrichment factors of 0.27 ± 2.44 for $\delta^{13}C$ and 2.57 ± 1.72 for $\delta^{15}N$ (mean±1SD, $n=27$ and 65, respectively). They were estimated as the average of published fractionation factors for aquatic crustaceans (including *C. sapidus*) feeding on both vegetal and animal items (Mancinelli and Bardelli, 2022; Mancinelli et al., 2022), and more consistent with other literature syntheses focused on crustaceans (Vanderklift and Ponsard, 2003; Mancinelli, 2012a; Carrozzo et al., 2014). Pairwise comparisons on posterior distributions of TP estimates were carried out as previously described for isotopic niche metrics.

All statistical procedures were implemented in the R package (R Development Core Team, 2023). Specifically, nMDS and PERMANOVA analyses were performed using the *metaMDS* and and *adonis* functions of the *vegan* library, respectively (

Wood and Scheipl, 2020); *C. sapidus* isotopic niche metrics were calculated using the package *SIBER* (Jackson and Parnell, 2023), while *tRophicPosition* (Quezada-Romegialli et al., 2022) was adopted to estimate trophic positions.

3. Results

3.1. Trace metals in bivalves

The mean shell lengths of bivalves collected at each sampling location varied between 22.9 and 33.4 mm (Table 2), with significant differences in size observed only between *Arcuatula senhousia* from Lesina and *Mytilus galloprovincialis* from Gandia (HSD test after 1-way ANOVA, *P*=0.01; *P*>0.05 for the remaining comparisons).

Table 2. Summary of information on the sex (F=females, M=males), number (in square brackets), and size (CW=mean carapace width, in mm; SE in round brackets, range in italics) of *Callinectes sapidus* specimens collected at the five study locations. Taxonomic information on the bivalve species used as baseline for chemical analyses are included (Mg=*Mytilus galloprovincialis*. As=*Arcuatula senhousia*), together with details on the size (SL=shell length, in mm; SE in round brackets, range in italics) of the specimens.

Location	**Bivalves**			***Callinectes sapidus***		
	Taxon	**SL (mm)**		**Sex**	**CW (mm)**	
Lesina	As	22.9 (1.5)	*18–32*	F [12]	152.2 (6.3)	*104–175*
				M [12]	131.7 (5.3)	*102–154*
				Total	141.9 (4.6)	
Acquatina	Mg	29.1 (3.1)	*18–39*	F [10]	153.6 (8.6)	*101–183*
				M [10]	170.2 (4.3)	*143–196*
				Total	161.9 (5.1)	
Gandia	Mg	33.4 (0.5)	*32–35*	F [12]	141.8 (9.2)	*99–186*
				M [7]	97.4 (6.9)	*70–128*
				Total	125.5 (8.1)	

Location	**Bivalves**			***Callinectes sapidus***		
	Taxon	**SL (mm)**		**Sex**	**CW (mm)**	
Pogonitsa	Mg	26.7 (1.1)	*23–30*	F [10]	136.4 (4.7)	*122–167*
				M [9]	172.3 (3.8)	*158–192*
				Total	153.4 (5.2)	
Loudias	Mg	29.9 (3.1)	*19–35*	F [7]	132.1 (7.9)	*99–153*
				M [8]	116.9 (9.5)	*81–152*
				Total	124.1 (6.4)	

Metal contents showed a marked pattern of spatial variation (Fig. 2; see Table S3 in the online supplementary material for mean concentrations ±1SE), and significant, size-independent differences were confirmed by PERMANOVA (factor “location”: Pseudo-$F_{4,31}$ = 16.5, $P(MC)=0.0001$; continuous covariate “size”, Pseudo-$F_{1,31}$ = 3.3, $P=0.08$). Pairwise comparisons testing for inter-site differences were likewise significant [maximum $P(MC)=0.03$ for the comparison Gandia vs. Loudias). Similarly remarkable among-location variations were observed in MPI indices (Fig. 3; 1-way ANOVA, $F_{4,31}$ = 15.9, $P<0.0001$). Lesina showed the highest index (10.8), significantly different from those characterizing the remaining locations with the exception of Pogonitsa (HSD test, $P=0.32$). Gandia, Pogonitsa, and Acquatina showed similar (HSD tests, $P>0.05$ for all bivariate comparisons) intermediate values ranging between 4.1 (Acquatina) and 7.7 (Pogonitsa), while the MPI estimated for Loudias (0.9±0.1) was significantly lower than those determined in other locations (Fig. 3; HSD tests, max $P=0.003$ for the comparison Loudias vs. Acquatina).

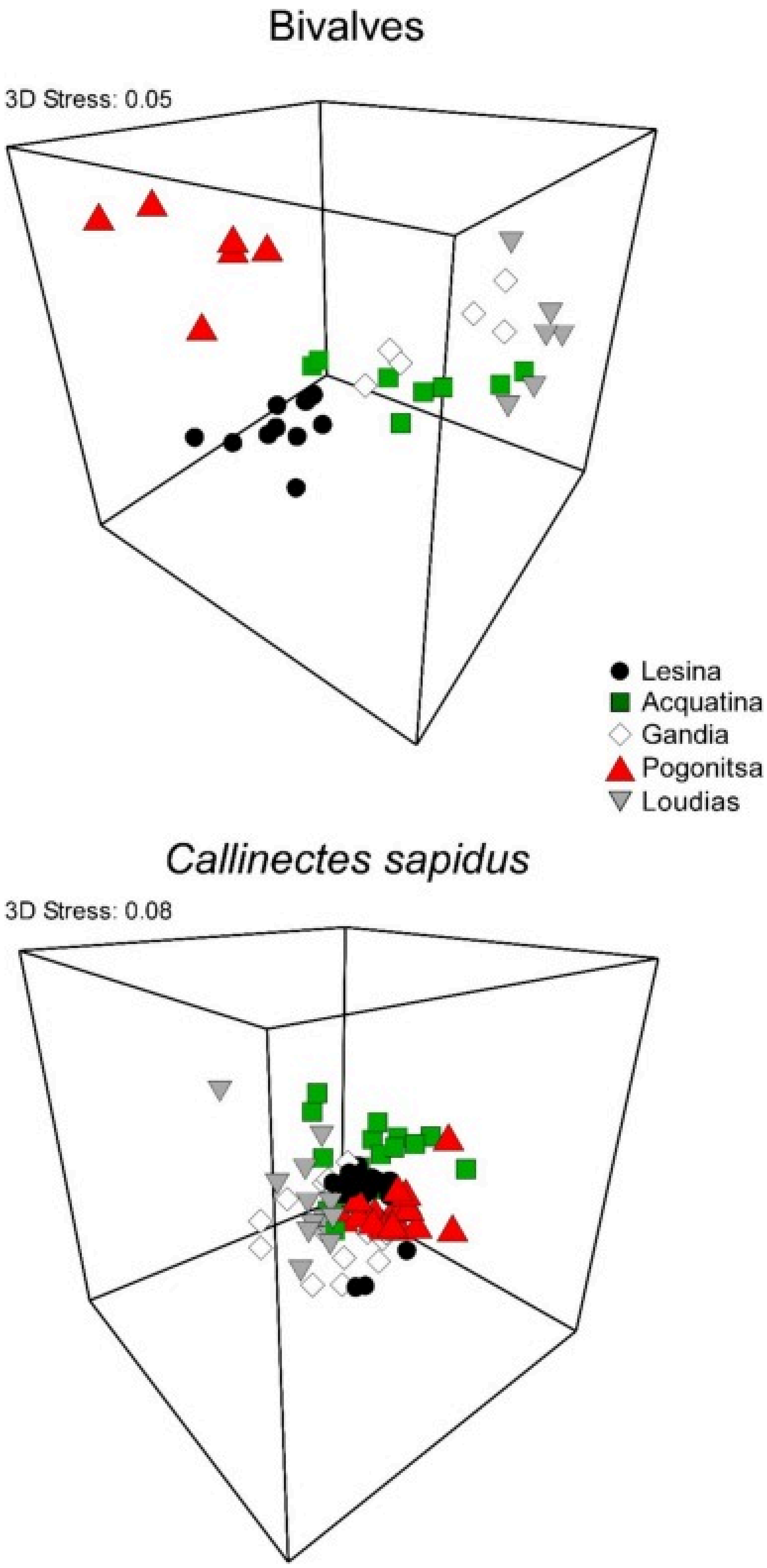
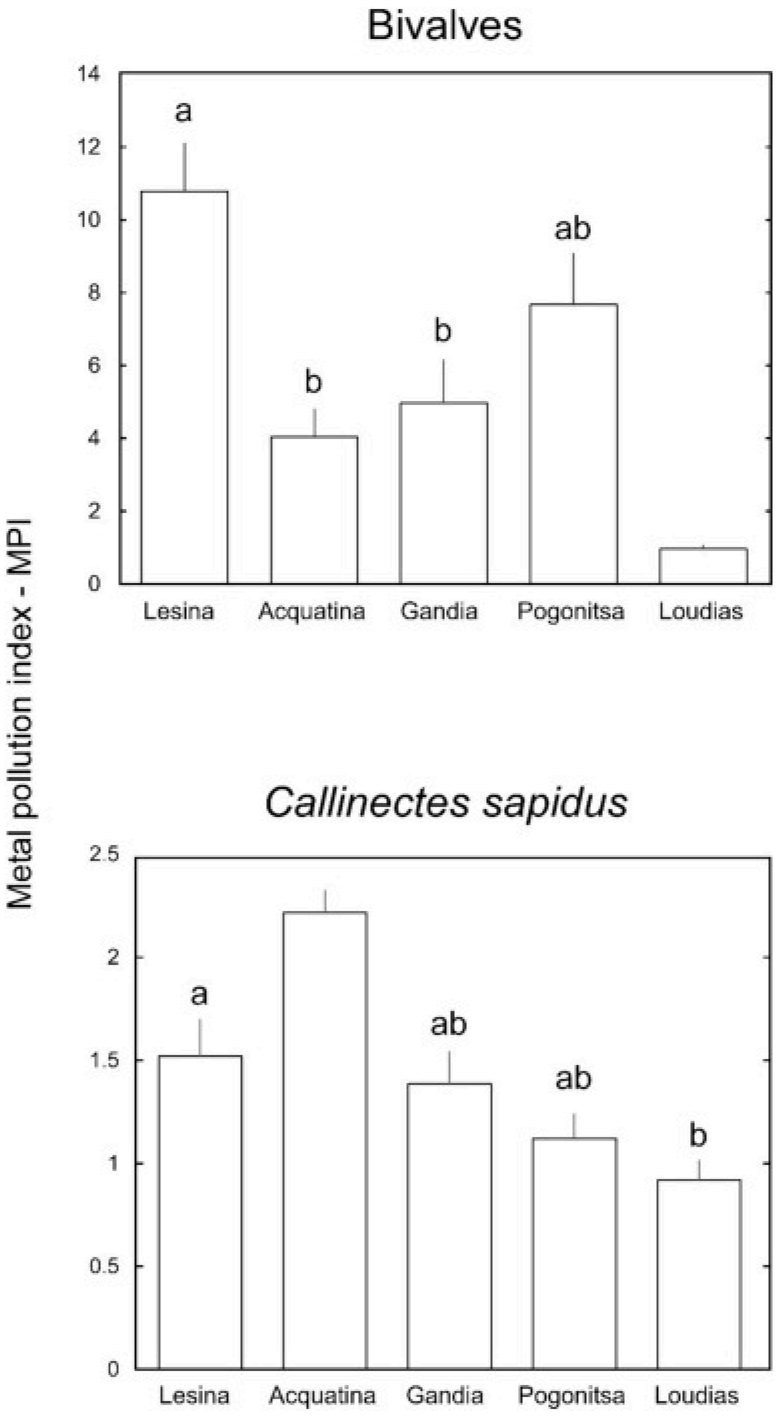


Fig. 2. 3d-nMDS plots based on Euclidean distance similarity matrices of trace metal concentrations in bivalves (top) and in *Callinectes sapidus* (bottom) from the five sampling locations.



Download: Download high-res image (171KB)
Download: Download full-size image

Fig. 3. Metal pollution indices (MPI) in bivalves (top) and in *Callinectes sapidus* (bottom) from the five sampling locations. The results of post-hoc bivariate comparisons (Tukey HSD tests) are included; locations showing identical letters do not differ at $P<0.05$. Please note the different scales in each plot.

At a single-metal level, significant differences were generally observed (1-way ANOVAs; P always <0.05); Cd, Fe, Li, Pb, V in *A. senhousia* from Lesina and Ba, Cr, Cu, Ni, Zn in *M.*

galloprovincialis from Pogonitsa showed significantly higher contents than the remaining locations (HSD tests, *P* always <0.05; see also Table S3, online supplementary material). *M. galloprovincialis* from Acquatina showed peak concentrations only for B and Sr, with Cd and Li contents comparable to the maximum values observed in *A. senhousia* from Lesina (HSD tests, $P>0.05$ for both comparisons). In contrast, Loudias generally showed the lowest metal contents with the exception of Cd, V, and Zn, followed by Gandia (HSD tests, *P* always <0.05); noticeably, Ni content was under the detection limits at both Loudias and Acquatina (Table S3).

3.2. Trace metals in blue crabs

A total of 97 adult crabs were analyzed, 51 females and 46 males (Table 2). Their carapace widths varied significantly among locations as well between sexes (2-way ANOVA, interaction factor "location×sex", $F_{4,87}=7.6$, $P<0.0001$). Males from Acquatina and Pogonitsa were significantly larger than those from the remaining locations (HSD tests, *P* always <0.05), while negligible differences were observed in the size of females (min $P=0.8$ for Lesina vs. Loudias). Furthermore, males from Gandia were significantly smaller than females ($P=0.001$), while negligible sex-related differences occurred for the remaining locations (min $P=0.09$ for Pogonitsa).

Metal contents in crabs varied significantly among locations [Fig. 2, Table 3; *P*(MC) always <0.05 for all pair-wise comparisons; see Table S4 in the online supplementary material for mean concentrations ±1SE]. Since males and females showed no significant differences, the factor "sex" was not considered further. Conversely, a significant effect for the interaction term "location×size" was observed (Table 3); a CAP analysis confirmed a substantial co-variation between crabs' size and metal contents for all the locations except Pogonitsa (Fig. S1, online supplementary material). Additional univariate analyses showed significant among-location differences for all metals (1-way ANOVAs: *P* always <0.05) with the exception of Sr ($F_{4,92}=1.6$, $P=0.18$); they were related with crabs' size only for a negligible number of location/metal combinations (8 out of 65; Table S5, online supplementary material).

Table 3. Summary of PERMANOVA results testing for the effects of sex and location as orthogonal fixed factors and size (carapace width, CW) as a continuous covariate on *Callinectes sapidus* trace metal contents and $\delta^{13}C$ and $\delta^{15}N$ values. Significant effects are reported in bold.

		Trace metals		**Stable isotopes**	
Source	**d.f.**	**Pseudo-F**	***P*(MC)**	**Pseudo-F**	***P*(MC)**
CW (1)	1	5.25	**<0.001**	1.2	0.09
Location (2)	4	9.22	**<0.001**	32.08	**0.001**
Sex (3)	1	1.59	0.14	1.92	0.15
1×2	4	1.82	**0.01**	0.88	0.54
1×3	1	0.74	0.61	2.77	0.09
2×3	4	1.21	0.21	1.61	0.14
1×2×3	4	0.87	0.63	0.51	0.86

Significant location-dependent differences in metal contents were observed between crabs and bivalves [two-way PERMANOVA with “location” and “taxon” as fixed factors: interaction factor “location×taxon”: Pseudo-$F_{4,131}$=20.8, *P*(MC)=0.001; bivariate inter-specific tests performed within each location: *P*(MC) always <0.001]. MPI values in crabs differed significantly among the five locations (1-way ANOVA, $F_{4,92}$=12.1, *P*<0.0001). With the exception of Loudias, their MPI values were generally one order of magnitude lower than bivalves (Fig. 3) and showed a significantly different pattern of among-location variation (Pearson *r*=0.13, *P*=0.82, d.f. = 3). Acquatina showed the highest index (2.2±0.1, mean±1SE; HSD tests, min *P*=0.004 for the comparison Lesina vs. Acquatina); Loudias was characterized by the lowest MPI (0.9±0.1), significantly different from that estimated for Lesina (Fig. 3B; HSD test, *P*=0.04) but not from those characterizing Gandia (1.4±0.2) and Pogonitsa (1.1±0.2; *P* always >0.05).

1-way ANOVAs performed at a single-metal level generally confirmed the lower metal concentrations in crabs as compared with bivalves, yet several exceptions were represented by Cd at Pogonitsa, Cu at Lesina, Acquatina, Gandia, and Loudias, Fe at Loudias, and Ni at Acquatina and Loudias (HSD tests, *P* always >0.05). Furthermore, while metal contents in crabs and bivalves from Pogonitsa showed a relatively low degree of correlation (Spearman ρ= 0.53, *P*=0.07, d.f. = 11), positive relationships with different levels of significance were observed for the remaining locations (Fig. S2, online supplementary material).

The trophic transfer indices estimated for crabs (Table 4) showed relatively low values (overall TTF: 1.39±0.38, mean±SE) and a pronounced variability, ranging between 0.002 (Mn at Pogonitsa) and 15.8 (Cu at Gandia) with the majority of the indices <1 (72%). In general, Cu and Zn were the metals showing the highest TTFs; values >1 were observed also for Cd, Sr, and V and, to a minor extent, for Ba, Fe, and Mn (Table 4).

Table 4. Trophic transfer factors (TTF) of metals in *Callinectes sapidus* calculated for each study location. Values >1 are reported in bold. For Acquatina, Gandia, and Loudias the TTF of Ni was not estimated as the metal content in bivalves or *C. sapidus* was under the detection limit of the instrumentation.

Metal/location	Lesina	Acquatina	Gandia	Pogonitsa	Loudias
B	0.08	0.02	0.26	0.09	0.13
Ba	0.06	0.46	1.03	0.01	**2.15**
Cd	0.35	0.27	0.74	**2.63**	**1.42**
Cr	0.02	0.08	0.83	0.01	0.47
Cu	**2.41**	**10.56**	**15.8**	0.92	**14.97**
Fe	0.01	0.13	0.07	0.02	**1.14**
Li	0.22	0.18	0.59	0.57	0.97
Mn	0.12	0.05	0.97	<0.01	**1.71**
Ni	0.03	**–**	–	0.05	**–**
Pb	0.03	0.23	0.2	0.08	0.33
Sr	0.8	0.31	**2.05**	0.39	**3.67**
V	0.3	0.7	**1.22**	**1.51**	0.6
Zn	**3.37**	**3.91**	**2.48**	0.52	0.66

3.3. Stable isotope analysis

A PERMANOVA performed on blue crabs δ^{13}C and δ^{15}N values (Table 5) with “sex” and “location” as orthogonal fixed factors and “body size” (CW) as a continuous covariate indicated a significant effect only for the factor “location” (Table 3). Thus, the effects of sex and body size were not considered in further isotopic analyses.

Table 5. Mean δ^{15}N and δ^{13}C values (SD in parentheses) of bivalves and *Callinectes sapidus* from the five study locations.

	Bivalves		***Callinectes sapidus***	
Lesina*	−20.68 (0.15)	11.55 (0.17)	−16.82 (0.84)	14.01 (0.54)
Acquatina	−23.01 (0.49)	7.33 (0.47)	−19.74 (2.27)	10.69 (0.87)
Gandia	−21.52 (0.39)	7.03 (0.27)	−22.73 (2.88)	11.68 (1.6)
Pogonitsa	−19.87 (0.44)	7.61 (0.39)	−17.88 (1.49)	9.51 (1.28)
Loudias	−23.15 (0.58)	7.89 (0.21)	−20.73 (1.83)	13.16 (2.26)

* Bivalve species=*Arcuatula senhousia*; *Mytilus galloprovincialis* for the remaining locations.

Bayesian estimations of standard ellipse areas (SEA_B) varied among the study locations independently from the number of analyzed crabs (Pearson r=− 0.68, P=0.2, d.f. = 3). SEA_B values ranged between maxima of 13.9 and 11.9‰^{2} determined at Gandia and Loudias, respectively, to a minimum value of 1.3‰^{2} determined for Lesina, with Pogonitsa and Acquatina showing intermediate areas ranging between 6.1 and 6.2‰^{2} (Table 6; see also Fig. S3, online supplementary material). Bivariate tests indicated negligible differences in SEA_B values between Gandia and Loudias, as well as between Pogonitsa and Acquatina (Table 6). With the exclusion of the carbon range CR, other Layman metrics showed a pattern of variation across the study locations similar to that verified for SEA_B (Table 6; minimum Pearson r=0.94, P=0.02, d.f. = 3 for NR; for CR: r=0.76, P=0.13, d.f. = 3).

Table 6. Posterior Bayesian estimations of standard ellipse areas SEA_B (A) and trophic positions (B) of *Callinectes sapidus* from the five study locations. SEA_B estimations are expressed in ‰^{2}. For both metrics, modal values and 95% confidence intervals are reported; identical letters in parentheses indicate that values do not differ with a probability of at least 95%. In (A), for the sake of completeness sample size-corrected standard ellipse areas (SEA_C; see also Fig. S3 in the supplementary material C), *nitrogen ranges* (NR), *carbon ranges* (CR), *mean distances to centroid* (CD), and *standard deviations of nearest neighbour distance* (SDNND) are included.

	Lesina	**Acquatina**	**Gandia**	**Pogonitsa**	**Loudias**
A) Isotopic niche					
SEA_B (mode)	1.28	6.22(a)	13.89(b)	6.11(a)	11.96(b)
SEA_B (95% CI)	0.88–2.01	3.83–8.53	8.75–18.33	3.63–9.33	8.54–19.03

	Lesina	**Acquatina**	**Gandia**	**Pogonitsa**	**Loudias**
SEA_c	1.4	6.52	15.14	6.32	12.17
NR	2.65	3.24	7.55	5.18	6.57
CR	3.31	8.63	9.22	4.78	6.97
CD	0.85	2.06	2.91	1.77	2.52
SDNND	0.25	0.4	0.78	0.51	0.83
B) Trophic position					
Mode	2.92(a)	3.36	3.78(b)	2.67(a)	4.16(b)
95% CI	2.75–3.21	3.09–3.7	3.41–4.32	2.44–3.09	3.79–4.78

The trophic position of *C. sapidus* estimated using the $\delta^{13}C$ and $\delta^{15}N$ values of bivalves as baselines (Table 6) showed a remarkable among-location variability, with mean values ranging between 2.7 (Pogonitsa), indicating omnivorous trophic habits including both animal and vegetal items, and 4.1 (Loudias), suggesting a diet completely based on animal prey. Bivariate tests indicated that Gandia and Loudias had modal TP estimations significantly different from Lesina, the latter in turn significantly higher than Acquatina and Pogonitsa (Table 6).

Noticeably, for most of the metals the variation of crabs' TTF values across locations was related with their trophic position; the only exceptions were Zn and Cd, the latter showing a negative co-variation with TP values (Fig. 4). Furthermore, a significant positive relationship was observed between TP estimations and the degree of rank-correlation ρ between the metals content of crabs and bivalves (Fig. 4; Pearson r=0.89, P=0.04, d.f. = 3).

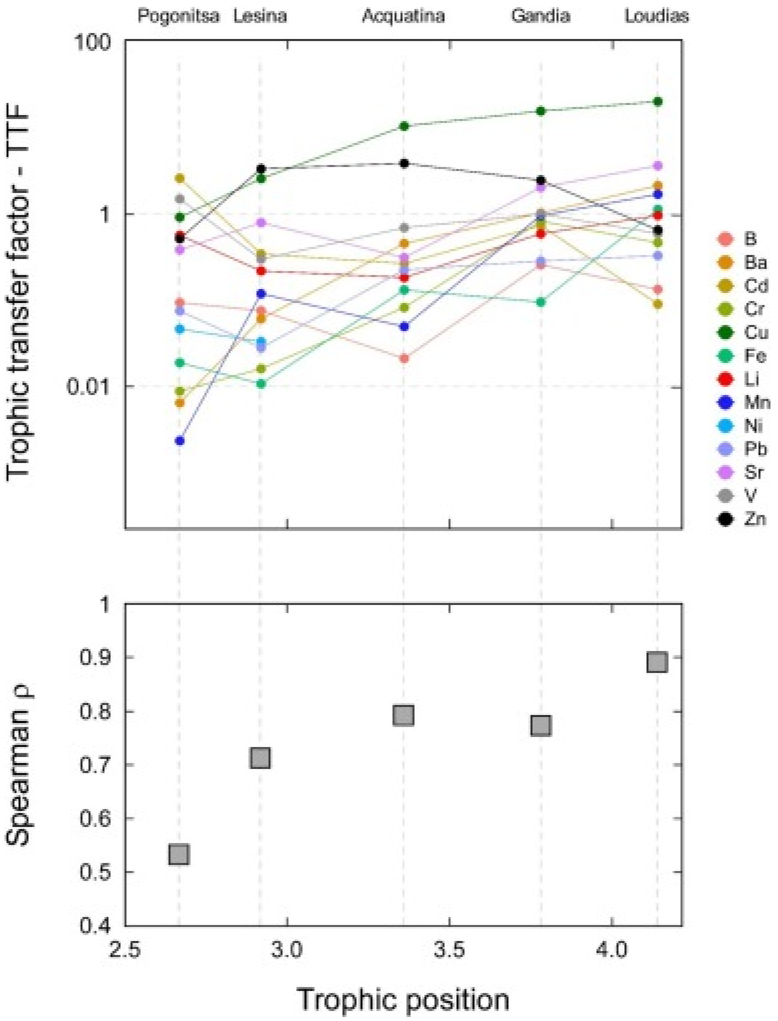


Fig. 4. Trophic position of *Callinectes sapidus* across the five study locations vs. metals trophic transfer factors (TTF; see Table 2 for means ±1SE; top) and Spearman rank correlation coefficients *ρ* estimating the consistency of metal profiles in bivalves and in *C. sapidus* (bottom). See text and Fig. S2 in the online supplementary material for details.

4. Discussion

4.1. Trace metals in bivalves

Independently from the sampling location, the mussel species included in the present study showed concentrations of hazardous metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) largely lower than the limits set by the European Union and the Food and Agriculture Organization (FAO, 1983; FAO/WHO, 1989; EC, 2006; see Table S6, online supplementary material). Accordingly, a low degree of metal contamination can be assumed for all the investigated systems. Furthermore, metal contents showed to vary significantly among locations independently from the size of the analyzed bivalves. Caution should be taken when considering these conclusions, as two methodological issues deserve to be explicitly considered. Firstly, a relatively low number of bivalve specimens (6 to 10, Table 1) were analyzed from each location. Indeed, this investigation was not specifically designed as a biomonitoring study exclusively focused on bivalves, thus requiring large sample sizes (Daskalakis, 1996; Saavedra et al., 2004a; Saavedra et al., 2009) and standardized approaches such as transplanting to cope with taxonomic differences (see further in this section; Cao et al., 2023). Since statistical analyses indicated for bivalves highly significant inter-location differences not related with size, we are confident of the robustness of our results within the specific context of the study; nevertheless, additional biomonitoring studies are necessarily required to confirm their generality. Secondly, we used *Mytilus galloprovincialis* across all the study locations with the exception of the Lesina Lagoon, where *Arcuatula senhousia* was analyzed.

Bivalves show significant inter-specific as well as intra-specific, size-related differences in the degree of metals accumulation (Saavedra et al., 2004b; Cai and Wang, 2019; but see Saavedra et al., 2004a). However, no single species of bivalve can be ubiquitously found, and in large-scale biomonitoring programs it is often necessary to collect multiple species; in this case, taxonomically-close species with similar life and trophic strategies should be chosen (Cao et al., 2023 and literature cited). We assumed *A. senhousia* as a surrogate of *M. galloprovincialis* since they belong to the same family (Mytilidae) and are epibenthic sessile filter-feeders (e.g., Inoue and Yamamuro, 2000); studies on coexisting populations of the two mussel species provided further evidence for the assumption, as negligible differences in C and N isotopic values (Feng et al., 2014) as well as in Hg, Cu, Pb, and Zn contents (Feng et al., 2016) have been observed. Finally, and most importantly, all the main conclusions of this study still holds if the data on Lesina Lagoon are not considered (see e.g., Fig. 4).

4.2. Trace metals in crabs

As for bivalves, metal contents in blue crabs were remarkably lower than international reference levels for human consumption (Table S6, online supplementary material). The blue crab represents an emergent target species as a shellfish product in invaded Mediterranean habitats (Mancinelli et al., 2017c; Kevrekidis and Antoniadou, 2018; Glamuzina et al., 2021; Kevrekidis et al., 2023). This is the first large-scale study providing a comparative assessment of metal contamination in *C. sapidus* in Mediterranean waters, and even though additional, year-long studies are necessary to corroborate our results, they nonetheless suggest a low ecotoxicological risk for the crab.

Noticeably, our findings indicated that metal contents in crabs varied significantly across the five locations independently from sex; yet, body size exerted a significant effect. The actual influence of sex and size on the accumulation of contaminants in blue crabs remains debated. Depending on the geographical location and the metals analyzed, past investigations have highlighted either significant or negligible sex- and size-related effects (Sastre et al., 1999; Adams and Engel, 2014; Taylor and Calabrese, 2018; Salvat-Leal et al., 2020). Furthermore, when significant relationships occurred between the size of crabs and their content of a specific metal, they varied from negative to positive depending on location (e.g., for Pb: Genç and Yilmaz, 2017; Salvat-Leal et al., 2020). Here we observed a similar ambiguity: while CAP analysis showed in a multivariate context a generalized co-variation between size and metals content with the exclusion of Pogonitsa, at a single-metal scale the effect of crabs' size was limited and showed inconsistent patterns of variation across locations (Table S5, online materials). The factors governing the variability in metals accumulation in blue crabs are multiple, including the complex interplay of external inputs with physicochemical and biogeochemical conditions influencing, in turn, metal mobilization at a local scale (Taylor and Calabrese, 2018). Furthermore, differences in the morphometry of the analyzed crabs (Table 2), may have reflected in location-specific dilution or accumulation effects (Salvat-Leal et al., 2020): molting frequency in blue crab is inversely related with body size (Millikin and Williams, 1984), and contaminants sequestration in the exoskeleton during molting is an important mechanism for eliminating trace metals in brachyurans (Engel and Brouwer, 1987; Bergey and Weis, 2007).

This study showed a remarkable inconsistency in metals content between bivalves and crabs across the five investigated locations, with most metals showing concentrations higher in bivalves than in crabs, ultimately reflecting in generally low trophic transfer indices. Noticeably, the trophic position of *C. sapidus* varied by approximately one level among locations, scaling positively with the degree of trophic transfer of most of metals as well as with the consistency of crabs' metal profiles with those of bivalves.

Two mutually non-exclusive scenarios can explain these results. The first assumes an influence of metal contamination on the feeding habits of the crab. Heavy metals can determine significant behavioral alterations in crustaceans (Perez and Wallace, 2004; Weis et al., 2011). In particular, increasing habitat contamination was related with blue crabs showing an impaired predatory behavior, a lower trophic position, and bioaccumulation patterns more representative of low-level resources (e.g., aquatic plants or leaf detritus: Reichmuth et al., 2009, Reichmuth et al., 2010). Here, a behaviorally-mediated trophic effect cannot be excluded, as Reichmuth et al. (2010) found concentrations of Cr, Cu, and Pb (i.e., 1.1, 15.4, and 0.37 $\mathrm{mg\,kg^{-1}}$, respectively) similar to or lower than those observed in this study (Table S4, online supplementary material). However, a pivotal yet improbable implication of this scenario is that the five locations investigated here, notwithstanding their considerable environmental differences (Table S1), offered to the crab similar trophic conditions in terms of e.g., resource diversity and availability, and that its trophic position was uniquely determined by behavioral mechanisms mediated by local contamination levels. A second hypothesis hinges on omnivory of the crab and how it opportunistically varies in response to local resource availability. Noticeably, at Acquatina, Lesina, and Pogonitsa crabs had TP values significantly lower than those determined at Gandia and Loudias. The first three locations are confined lagoons characterized by the occurrence of submerged vegetation represented by macroalgae or seagrasses, while Gandia and Loudias are open-sea habitats characterized by benthic environments with low or negligible vegetation cover (Table S1). Bivalves represent a major component of the crab's diet, yet conventional gut content analyses and stable isotope studies clearly confirmed that it feeds on multiple trophic levels, and that trophic positions may vary substantially depending on season, location, and ontogenetic stage (Hines, 2007; Mancinelli et al., 2013, Mancinelli et al., 2016, Mancinelli et al., 2017d; Rady et al., 2018; Prado et al., 2021). The occurrence of living and non-living plant material in the lagoons, together with their associated assemblages of primary consumers, implies that in these environments the blue crab may opportunistically feed on low-trophic level benthic resources characterized by contamination patterns differing from that of bivalves (among others, see Ghosn et al., 2020 for an example from a Mediterranean coastal area), ultimately obscuring any transfer effect. Conversely, in less-vegetated systems under open sea conditions the lack of primary producers and associated fauna may induce the blue crab, besides preying on bivalves, to focus on other animal prey from higher trophic levels and characterized by higher metal burdens. The generally higher TTF values, coupled with the higher trophic positions observed in blue crabs from Gandia and Loudias indirectly support this hypothesis, further confirmed by isotopic niche analyses. Indeed, compared with the remaining locations, crabs from Gandia and Loudias showed the largest isotopic niches ($\mathrm{SEA_B}$), total nitrogen and carbon ranges (NR and CR) trophic diversity (CD) and evenness (SDNND), ultimately indicating a higher intra-specific heterogeneity in trophic habits. Resource-related differences in ingestion and assimilation rates, coupled with variations in uptake and excretion kinetics of contaminants cannot be excluded, as they may have further determined the observed differences (Jardine et al., 2006).

5. Conclusions

Regardless from the underlying causative mechanisms, our findings indicated that the opportunistic omnivory of the blue crab might hinder its use as a bioindicator, as locations-specific differences in trophic habits might ultimately reflect on metals content. Noticeably, besides *C. sapidus* a number of omnivorous crustaceans have been recommended for biomonitoring purposes, including other portunids (e.g., *Callinectes danae*: Bordon et al., 2016; *Portunus segnis*: Annabi et al., 2018) the green crab *Carcinus maenas* (Ben-Khedher et al., 2014) and the Louisiana crayfish *Procambarus clarkii* (Suárez-Serrano et al., 2010; Henriques et al., 2014). Our results emphasize the urgent need to identify biomonitor animal species - in marine as well as in other environments - after a thorough scrutiny of their trophic habits, as originally suggested by Rainbow (1995).

In conclusion, invasive omnivores are recognized to exert significant, hard-to-be predicted threats on ecosystem functions because of their ability to directly and indirectly impact multiple trophic levels (Shea and Chesson, 2002; Romanuk et al., 2009; Jackson and Britton, 2014; Pettitt-Wade et al., 2015; see also Médoc et al., 2018). Our study suggested that they might represent an open issue also in ecotoxicology. However, we indicated that an advanced assessment of their trophic habits by stable isotope analysis could help in explaining the patterns of variation in contamination levels and, ultimately, provide more robust information for e.g., biomonitoring purposes.

Ethical statement

No ethical issues related with the use of animals in the performed analyses were involved.

CRediT authorship contribution statement

Raffaele De Giorgi: Investigation. **Roberta Bardelli:** Data curation. **Lucrezia Cilenti:** Writing – original draft. **Silvia Falco:** Investigation, Conceptualization. **Maria Teresa Guerra:** Data curation. **George Katselis:** Writing – original draft, Investigation, Data curation. **Kosmas Kevrekidis:** Writing – original draft, Investigation, Conceptualization. **Francesco Mancini:** Methodology, Investigation. **Lorenzo Doria:** Writing – original draft, Methodology. **Agnese Marchini:** Writing – original draft, Supervision. **Danilo Migoni:** Methodology. **Paride Papadia:** Writing – original draft, Methodology. **Salvatrice Vizzini:** Writing – original draft, Methodology, Investigation, Conceptualization. **Giorgio Mancinelli:** Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Financial support was provided to R.D.G. by the European Union - NextGenerationEU [National Biodiversity Future Centre (NBFC) Program, Italian Ministry of University and Research, PNRR, Missione 4 Componente 2 Investimento 1.4, Project CN00000033] and to L.C, A.M., S.V., and G.M. by the Progetto di Ricerca di Rilevante Interesse Nazionale (PRIN) 2022PKSCNT "TROPHYC" (The TROphic geograPHY of marine bioinvaders: the Atlantic blue crab *Callinectes sapidus* in the Mediterranean Sea as a model species). The authors wish to thank two anonymous reviewers whose valuable comments improved a first version of the manuscript, and are grateful to fishers from Gandia, Lesina, Loudias, and Pogonitsa for the support provided during sampling operations in the field.

Appendix A. Supplementary data

Download: Download Word document (579KB)

Supplementary material

Recommended articles

Data availability

Data will be made available on request.

References

Adams and Engel, 2014 D.H. Adams, M.E. Engel

Mercury, lead, and cadmium in blue crabs, *Callinectes sapidus*, from the Atlantic coast of Florida, USA: a multipredator approach

Ecotoxicol. Environ. Saf., 102 (2014), pp. 196-201, 10.1016/j.ecoenv.2013.11.029 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Anderson, 2005 M.J. Anderson

PERMANOVA. Permutational multivariate analysis of variance

Department of Statistics, University of Auckland, Auckland (2005)

Google Scholar ↗

Annabi et al., 2018 A. Annabi, R. Bardelli, S. Vizzini, G. Mancinelli

Baseline assessment of heavy metals content and trophic position of the invasive blue swimming crab *Portunus segnis* (Forskål, 1775) in the Gulf of Gabès (Tunisia)

Mar. Pollut. Bull., 136 (2018), pp. 454-463, 10.1016/j.marpolbul.2018.09.037 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

ARPAV-ISPRA, 2023 ARPAV-ISPRA

Relazione Tecnica Congiunta ARPAV e ISPRA Relativa alla Presenza della Specie *Callinectes sapidus* (Rathbun 1896) nelle Lagune del Canarin e Scardovari. Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto - ARPAV; Istituto Superiore per la Protezione dell'Ambiente - ISPRA

Accessed on 20/02/2024 at https://www.arpa.veneto.it/granchio-blu/relazione-intervento-arpav_ispra.pdf/@@download/file ↗ (2023), pp. 1-34

Google Scholar ↗

Atwood, 2013 M.A. Atwood

Effects of euthanasia method on stable-carbon and stable-nitrogen isotope analysis for an ectothermic vertebrate

Rapid Commun. Mass Spectrom., 27 (2013), pp. 909-913, 10.1002/rcm.6525 ↗

View in Scopus ↗ Google Scholar ↗

Bardelli et al., 2023 R. Bardelli, G. Mancinelli, A. Mazzola, S. Vizzini

The Atlantic blue crab *Callinectes sapidus* spreading in the Tyrrhenian Sea: evidence of an established population in the Stagnone di Marsala (Sicily, southern Italy)

Nase More, 70 (2023), pp. 177-183, 10.17818/NM/2023/SI6 ↗

View in Scopus ↗ Google Scholar ↗

Barst et al., 2020 B.D. Barst, K. Hudelson, G.L. Lescord, A. Santa-Rios, N. Basu, A. Crémazy, *et al.*

Effects of non-native fish on lacustrine food web structure and mercury biomagnification along a dissolved organic carbon gradient

Environ. Toxicol. Chem., 39 (2020), pp. 2196-2207, 10.1002/etc.4831 ↗

View in Scopus ↗ Google Scholar ↗

Benjamini and Hochberg, 1995 Y. Benjamini, Y. Hochberg
Controlling the false discovery rate: a practical and powerful approach to multiple testing
J. Roy. Stat. Soc. Ser. B. (Stat. Method.), 57 (1995), pp. 289-300, 10.1111/j.2517-6161.1995.tb02031.x ↗
Google Scholar ↗

Ben-Khedher et al., 2014 S. Ben-Khedher, J. Jebali, Z. Houas, H. Nawéli, A. Jrad, M. Banni, *et al.*
Metals bioaccumulation and histopathological biomarkers in *Carcinus maenas* crab from Bizerta lagoon, Tunisia
Environ. Sci. Pollut. Res., 21 (2014), pp. 4343-4357, 10.1007/s11356-013-2399-x ↗
View in Scopus ↗ Google Scholar ↗

Bergey and Weis, 2007 L.L. Bergey, J.S. Weis
Molting as a mechanism of depuration of metals in the fiddler crab, *Uca pugnax*
Mar. Environ. Res., 64 (2007), pp. 556-562, 10.1016/j.marenvres.2007.04.009 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Beyer et al., 2017 J. Beyer, N.W. Green, S. Brooks, I.J. Allan, A. Ruus, T. Gomes, *et al.*
Blue mussels (*Mytilus edulis* spp.) as sentinel organisms in coastal pollution monitoring: a review
Mar. Environ. Res., 130 (2017), pp. 338-365, 10.1016/j.marenvres.2017.07.024 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Blundon and Kennedy, 1982 J.A. Blundon, V.S. Kennedy
Mechanical and behavioral aspects of blue crab, *Callinectes sapidus* (Rathbun), predation on Chesapeake Bay bivalves
J. Exp. Mar. Biol. Ecol., 65 (1982), pp. 47-65, 10.1016/0022-0981(82)90175-7 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Bordon et al., 2016 I.C.A.C. Bordon, J.E.S. Sarkis, N.P. Andrade, M.A. Hortellani, D.I.T. Favaro, M.H. Kakazu, *et al.*
An environmental forensic approach for tropical estuaries based on metal bioaccumulation in tissues of *Callinectes danae*
Ecotoxicology, 25 (2016), pp. 91-104, 10.1007/s10646-015-1570-1 ↗
View in Scopus ↗ Google Scholar ↗

Boyd et al., 2018 P.W. Boyd, S. Collins, S. Dupont, K. Fabricius, J.-P. Gattuso, J. Havenhand, *et al.*
Experimental strategies to assess the biological ramifications of multiple drivers of global ocean change - a review
Glob. Chang. Biol., 24 (2018), pp. 2239-2261, 10.1111/gcb.14102 ↗
View in Scopus ↗ Google Scholar ↗

Brouwer and Lee, 2007 M. Brouwer, R.F. Lee
Responses to toxic Chemicals at the Molecular, cellular, tissue, and organismal level
V.S. Kennedy, L.E. Cronin (Eds.), The Blue Crab: *Callinectes sapidus*, Maryland Sea Grant College Program, College Park (2007), pp. 485-512
Google Scholar ↗

Brown et al., 2022 M.E. Brown, K.L. Buffington, L.B. Cleckner, N.R. Razavi
Elevated methylmercury concentration and trophic position of the non-native bloody red shrimp (*Hemimysis anomala*) increase biomagnification risk in nearshore food webs
J. Great Lakes Res., 48 (2022), pp. 252-259, 10.1016/j.jglr.2021.11.010 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Cai and Wang, 2019 C. Cai, W.-X. Wang
Inter-species difference of copper accumulation in three species of marine mussels: implication for biomonitoring
Sci. Total Environ., 692 (2019), pp. 1029-1036, 10.1016/j.scitotenv.2019.07.298 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Cao et al., 2023 X. Cao, G. Zhong, K. Pan, J. Qian, M. Xie, R. Chen, *et al.*
Interspecies calibration for biomonitoring metal contamination in coastal waters using oysters and mussels
Sci. Total Environ., 883 (2023), Article 163703, 10.1016/j.scitotenv.2023.163703 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Carrozzo et al., 2014 L. Carrozzo, L. Potenza, P. Carlino, M.L. Costantini, L. Rossi, G. Mancinelli
Seasonal abundance and trophic position of the Atlantic blue crab *Callinectes sapidus* Rathbun 1896 in a Mediterranean coastal habitat
Rend. Lincei Sci. Fis. Nat., 25 (2014), pp. 201-208, 10.1007/s12210-014-0297-x ↗
View in Scopus ↗ Google Scholar ↗

Castriota et al., 2024 L. Castriota, M. Falautano, P. Perzia

When nature requires a resource to be used - the case of *Callinectes sapidus*: distribution, aggregation patterns, and spatial structure in Northwest Europe, the Mediterranean Sea, and adjacent waters

Biology, 13 (2024), p. 279, 10.3390/biology13040279 ↗

View in Scopus ↗ Google Scholar ↗

Catsiki and Florou, 2006 V.A. Catsiki, H. Florou

Study on the behavior of the heavy metals Cu, Cr, Ni, Zn, Fe, Mn and ^{137}Cs in an estuarine ecosystem using *Mytilus galloprovincialis* as a bioindicator species: the case of Thermaikos gulf, Greece

J. Environ. Radioact., 86 (2006), pp. 31-44, 10.1016/j.jenvrad.2005.07.005 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Cesar et al., 2003 I.I. Cesar, L.C. Armendáriz, N. Olalla, A. Tablado

The blue crab, *Callinectes sapidus* Rathbun, 1896 (Decapoda, Portunidae) in the Río de la Plata, Argentina

Crustaceana, 76 (2003), pp. 377-384, 10.2307/20105573 ↗

View in Scopus ↗ Google Scholar ↗

Clavero et al., 2022 M. Clavero, N. Franch, R. Bernardo-Madrid, V. López, P. Abelló, J.M. Queral, *et al.*

Severe, rapid and widespread impacts of an Atlantic blue crab invasion

Mar. Pollut. Bull., 176 (2022), Article 113479, 10.1016/j.marpolbul.2022.113479 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Corrales et al., 2020 X. Corrales, S. Katsanevakis, M. Coll, J.J. Heymans, C. Piroddi, E. Ofir, *et al.*

Advances and challenges in modelling the impacts of invasive alien species on aquatic ecosystems

Biol. Invasions, 22 (2020), pp. 907-934, 10.1007/s10530-019-02160-0 ↗

View in Scopus ↗ Google Scholar ↗

Daskalakis, 1996 K.D. Daskalakis

Variability of metal concentrations in oyster tissue and implications to biomonitoring

Mar. Pollut. Bull., 32 (1996), pp. 794-801, 10.1016/S0025-326X(96)00042-2 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

DeForest et al., 2007 D.K. DeForest, K.V. Brix, W.J. Adams

Assessing metal bioaccumulation in aquatic environments: the inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration

Aquat. Toxicol., 84 (2007), pp. 236-246, 10.1016/j.aquatox.2007.02.022 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

DeRoy and MacIsaac, 2020 E.M. DeRoy, H.J. MacIsaac

Impacts of invasive species in the Laurentian Great Lakes

J. Crossman, C. Weisener (Eds.), Contaminants of the Great Lakes, Springer International Publishing, Cham (2020), pp. 135-156

Crossref ↗ View in Scopus ↗ Google Scholar ↗

Eagles-Smith et al., 2018 C.A. Eagles-Smith, E.K. Silbergeld, N. Basu, P. Bustamante, F. Diaz-Barriga, W.A. Hopkins, *et al.*

Modulators of mercury risk to wildlife and humans in the context of rapid global change

Ambio, 47 (2018), pp. 170-197, 10.1007/s13280-017-1011-x ↗

View in Scopus ↗ Google Scholar ↗

EC, 2006 EC

Commission regulation (EC) no 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs

Off. J. Eur. Union (2006), pp. 5-24

Google Scholar ↗

Ehrenfeld, 2010 J.G. Ehrenfeld

Ecosystem consequences of biological invasions

Annu. Rev. Ecol. Evol. Syst., 41 (2010), pp. 59-80, 10.1146/annurev-ecolsys-102209-144650 ↗

View in Scopus ↗ Google Scholar ↗

El Qoraychy et al., 2023 I. El Qoraychy, H. Rharrhour, O. Hammani, F. Wariaghli, F. Touhami, H. Jaziri

Heavy metal accumulation in blue crabs (*Callinectes Sapidus*) in Gharb region, Morocco

Egypt. J. Aquat. Biol. Fish., 27 (2023), pp. 695-705, 10.21608/ejabf.2023.312157 ↗

Google Scholar ↗

Engel and Brouwer, 1987 D.W. Engel, M. Brouwer

Metal regulation and molting in the blue crab, *Callinectes sapidus*: metallothionein function in metal metabolism

Biol. Bull., 173 (1987), pp. 239-251, 10.2307/1541876 ↗

Google Scholar ↗

Evans et al., 2000 D.W. Evans, R.D. Kathman, W.W. Walker

Trophic accumulation and depuration of mercury by blue crabs (*Callinectes sapidus*) and pink shrimp (*Penaeus duorarum*)

Mar. Environ. Res., 49 (2000), pp. 419-434, 10.1016/S0141-1136(99)00083-5 ↗

View PDF View article Google Scholar ↗

Ezgeta-Balić et al., 2014 D. Ezgeta-Balić, S. Lojen, T. Dolenec, P. Žvab Rožič, M. Dolenec, M. Najdek, *et al.*

Seasonal differences of stable isotope composition and lipid content in four bivalve species from the Adriatic Sea

Mar. Biol. Res., 10 (2014), pp. 625-634, 10.1080/17451000.2013.833338 ↗

View in Scopus ↗ Google Scholar ↗

FAO, 1983 FAO (Ed.), Compilation of Legal Limits for Hazardous Substances in Fish and Fishery Products. FAO Fisheries Circular (FAO). no. 764. In: FAO, editor, Rome (1983)

Google Scholar ↗

FAO/WHO, 1989 FAO/WHO

Evaluation of certain food additives and the contaminants mercury, lead and cadmium

WHO Tech. Rep. Ser, 505 (1989)

Google Scholar ↗

Feng et al., 2014 J.-X. Feng, Q.-F. Gao, S.-L. Dong, Z.-L. Sun, K. Zhang

Trophic relationships in a polyculture pond based on carbon and nitrogen stable isotope analyses: a case study in Jinghai Bay, China

Aquaculture, 428-429 (2014), pp. 258-264, 10.1016/j.aquaculture.2014.03.008 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Feng et al., 2016 J.-X. Feng, Q.-F. Gao, S.-L. Dong, Z.-L. Sun

Transference of heavy metals (Hg, Cu, Pb and Zn) with the trophic structure in a polyculture pond: evidence from nitrogen stable isotope

Aquac. Res., 47 (2016), pp. 1996-2003, 10.1111/are.12655 ↗

View in Scopus ↗ Google Scholar ↗

Figgener et al., 2019 C. Figgener, J. Bernardo, P.T. Plotkin

Beyond trophic morphology: stable isotopes reveal ubiquitous versatility in marine turtle trophic ecology

Biol. Rev., 94 (2019), pp. 1947-1973, 10.1111/brv.12543 ↗

View in Scopus ↗ Google Scholar ↗

Flood et al., 2020 P.J. Flood, A. Duran, M. Barton, A.E. Mercado-Molina, J.C. Trexler
Invasion impacts on functions and services of aquatic ecosystems
Hydrobiologia, 847 (2020), pp. 1571-1586, 10.1007/s10750-020-04211-3 ↗
View in Scopus ↗ Google Scholar ↗

Galic et al., 2018 N. Galic, L.L. Sullivan, V. Grimm, V.E. Forbes
When things don't add up: quantifying impacts of multiple stressors from individual metabolism to ecosystem processing
Ecol. Lett., 21 (2018), pp. 568-577, 10.1111/ele.12923 ↗
View in Scopus ↗ Google Scholar ↗

Gelcich et al., 2014 S. Gelcich, P. Buckley, J.K. Pinnegar, J. Chilvers, I. Lorenzoni, G. Terry, *et al.*
Public awareness, concerns, and priorities about anthropogenic impacts on marine environments
Proc. Natl. Acad. Sci. USA, 111 (2014), pp. 15042-15047, 10.1073/pnas.1417344111 ↗
View in Scopus ↗ Google Scholar ↗

Genc and Yilmaz, 2015 T.O. Genc, F. Yilmaz
Bioaccumulation indexes of metals in blue crab inhabiting specially protected area Koycegiz lagoon (Turkey)
Indian J. Anim. Sci., 85 (2015), pp. 94-99
View in Scopus ↗ Google Scholar ↗

Genç and Yilmaz, 2017 T.O. Genç, F. Yilmaz
Metal accumulations in water, sediment, crab (*Callinectes sapidus*) and two fish species (*Mugil cephalus* and *Anguilla anguilla*) from the Köyceğiz lagoon system-Turkey: an index analysis approach
Bull. Environ. Contam. Toxicol., 99 (2017), pp. 173-181, 10.1007/s00128-017-2121-7 ↗
View in Scopus ↗ Google Scholar ↗

Ghosn et al., 2020 M. Ghosn, C. Mahfouz, R. Chekri, B. Ouddane, G. Khalaf, T. Guérin, *et al.*
Assessment of trace element contamination and bioaccumulation in algae (*Ulva lactuca*), bivalves (*Spondylus spinosus*) and shrimps (*Marsupenaeus japonicus*) from the Lebanese coast
Reg. Stud. Mar. Sci., 39 (2020), Article 101478, 10.1016/j.rsma.2020.101478 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Gil Fernández, 2018 A. Gil Fernández

Análisis de la Dieta de *Callinectes Sapidus* (Rathbun, 1896) en Ambientes Recientemente Invadidos del Golfo de Valencia

M.Sc. Universitat Politècnica de València, Gandia (2018), p. 36

Google Scholar ↗

Glamuzina et al., 2021 L. Glamuzina, A. Conides, G. Mancinelli, B. Glamuzina

A comparison of traditional and locally novel fishing gear for the exploitation of the invasive Atlantic blue crab in the eastern Adriatic Sea

J. Mar. Sci. Eng., 9 (2021), p. 1019, 10.3390/jmse9091019 ↗

View in Scopus ↗ Google Scholar ↗

Gray, 2002 J.S. Gray

Biomagnification in marine systems: the perspective of an ecologist

Mar. Pollut. Bull., 45 (2002), pp. 46-52, 10.1016/S0025-326X(01)00323-X ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Hale, 1988 R.C. Hale

Disposition of polycyclic aromatic compounds in blue crabs, *Callinectes sapidus*, from the southern Chesapeake Bay

Estuaries, 11 (1988), pp. 255-263, 10.2307/1352012 ↗

Google Scholar ↗

Henriques et al., 2014 J.F. Henriques, P.C. Tavares, M.M. Correia-dos-Santos, M.A. Trancoso, M. Santos-Reis, C. Branquinho

Monitoring hg and cd contamination using red swamp crayfish (*Procambarus clarkii*): implications for wetland food chain contamination

Water Air Soil Pollut., 225 (2014), p. 2210, 10.1007/s11270-014-2210-8 ↗

View in Scopus ↗ Google Scholar ↗

Hines, 2007 A.H. Hines

Ecology of juvenile and adult blue crabs

V.S. Kennedy, L.E. Cronin (Eds.), The Blue Crab: *Callinectes sapidus*, Maryland Sea Grant College, College Park, Maryland (2007), pp. 565-654

Google Scholar ↗

Inoue and Yamamuro, 2000 T. Inoue, M. Yamamuro

Respiration and ingestion rates of the filter-feeding bivalve Musculista senhousia: implications for water-quality control

J. Mar. Syst., 26 (2000), pp. 183-192, 10.1016/S0924-7963(00)00053-1 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Jackson and Parnell, 2023 A.L. Jackson, A.C. Parnell

SIBER: Stable Isotope Bayesian Ellipses in R. R package version 2.1.7

URL:

http://cran.r-project.org/web/packages/SIBER ↗ (2023)

Google Scholar ↗

Jackson et al., 2011 A.L. Jackson, R. Inger, A.C. Parnell, S. Bearhop

Comparing isotopic niche widths among and within communities: SIBER – stable isotope Bayesian ellipses in R

J. Anim. Ecol., 80 (2011), pp. 595-602, 10.1111/j.1365-2656.2011.01806.x ↗

View in Scopus ↗ Google Scholar ↗

Jackson and Britton, 2014 M.C. Jackson, J.R. Britton

Divergence in the trophic niche of sympatric freshwater invaders

Biol. Invasions, 16 (2014), pp. 1095-1103

Crossref ↗ View in Scopus ↗ Google Scholar ↗

Jardine et al., 2006 T.D. Jardine, K.A. Kidd, A.T. Fisk

Applications, considerations, and sources of uncertainty when using stable isotope analysis in ecotoxicology

Environ. Sci. Technol., 40 (2006), pp. 7501-7511, 10.1021/es061263h ↗

View in Scopus ↗ Google Scholar ↗

Johnson, 2015 D.S. Johnson

The savory swimmer swims north: a northern range extension of the blue crab *Callinectes sapidus*?

J. Crustac. Biol., 35 (2015), pp. 105-110, 10.1163/1937240X-00002293 ↗

View in Scopus ↗ Google Scholar ↗

Johnston and Roberts, 2009 E.L. Johnston, D.A. Roberts

Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis

Environ. Pollut., 157 (2009), pp. 1745-1752, 10.1016/j.envpol.2009.02.017 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Johnston et al., 2015 E.L. Johnston, M. Mayer-Pinto, T.P. Crowe

Chemical contaminant effects on marine ecosystem functioning

J. Appl. Ecol., 52 (2015), pp. 140-149, 10.1111/1365-2664.12355 ↗

View in Scopus ↗ Google Scholar ↗

Kampouris et al., 2019 T.E. Kampouris, J.S. Porter, W.G. Sanderson

Callinectes sapidus Rathbun, 1896 (Brachyura: Portunidae): an assessment on its diet and foraging behaviour, Thermaikos gulf, NW Aegean Sea, Greece: evidence for ecological and economic impacts

Crustac. Res., 48 (2019), pp. 23-37

Crossref ↗ Google Scholar ↗

Katselis and Koutsikopoulos, 2017 G.N. Katselis, C. Koutsikopoulos

The establishment of blue crab *Callinectes sapidus* Rathbun, 1896 in the lagoon Pogonitsa (Amvrakikos gulf, Western Greece)

P. Berillis (Ed.), Trends in Fisheries and Aquatic Animal Health, Bentham Science Publishers, Sharjah, United Arab Emirates (2017), pp. 299-306

Google Scholar ↗

Kenworthy et al., 2018 J.M. Kenworthy, G. Rolland, S. Samadi, C. Lejeusne

Local variation within marinas: fffects of pollutants and implications for invasive species

Mar. Pollut. Bull., 133 (2018), pp. 96-106, 10.1016/j.marpolbul.2018.05.001 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Kevrekidis and Antoniadou, 2018 K. Kevrekidis, C. Antoniadou

Abundance and population structure of the blue crab (Decapoda, Portunidae) in Thermaikos gulf (Methoni Bay), northern Aegean Sea

Crustaceana, 91 (2018), pp. 641-657, 10.1163/15685403-00003795 ↗

View in Scopus ↗ Google Scholar ↗

Kevrekidis et al., 2023 K. Kevrekidis, T. Kevrekidis, A. Mogias, T. Boubonari, F. Kantaridou, N. Kaisari, *et al.*

Fisheries biology and basic life-cycle characteristics of the invasive blue crab *Callinectes sapidus* Rathbun in the estuarine area of the Evros River (Northeast Aegean Sea, eastern Mediterranean)

J. Mar. Sci. Eng., 11 (2023), p. 462, 10.3390/jmse11030462 ↗

View in Scopus ↗ Google Scholar ↗

Layman et al., 2007 C.A. Layman, D.A. Arrington, C.G. Montaña, D.M. Post

Can stable isotope ratios provide for community-wide measures of trophic structure?

Ecology, 88 (2007), pp. 42-48

View in Scopus ↗ Google Scholar ↗

Magioli et al., 2019 M. Magioli, M.Z. Moreira, R.C.B. Fonseca, M.C. Ribeiro, M.G. Rodrigues, K.M.P.M.d.B. Ferraz
Human-modified landscapes alter mammal resource and habitat use and trophic structure
Proc. Natl. Acad. Sci. USA, 116 (2019), pp. 18466-18472, 10.1073/pnas.1904384116 ↗
View in Scopus ↗ Google Scholar ↗

Mancinelli, 2012a G. Mancinelli
On the trophic ecology of Gammaridea (Crustacea: Amphipoda) in coastal waters: a European-scale analysis of stable isotopes data
Estuar. Coast. Shelf Sci., 114 (2012), pp. 130-139
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli, 2012b G. Mancinelli
To bite, or not to bite? A quantitative comparison of foraging strategies among three brackish crustaceans feeding on leaf litters
Estuar. Coast. Shelf Sci., 110 (2012), pp. 125-133
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli and Bardelli, 2022 G. Mancinelli, R. Bardelli
An updated dataset of published carbon and nitrogen trophic enrichment factors (Δ^{13}C and Δ^{15}N) for aquatic crustacean taxa
Figshare dataset (2022), 10.6084/m9.figshare.21206663.v1 ↗
Google Scholar ↗

Mancinelli and Rossi, 2001 G. Mancinelli, L. Rossi
Indirect, size-dependent effects of crustacean mesograzers on the Rhodophyta *Gracilaria verrucosa* (Hudson) Papenfuss: evidence from a short-term study in the Lesina lagoon (Italy)
Mar. Biol., 138 (2001), pp. 1163-1173
View in Scopus ↗ Google Scholar ↗

Mancinelli and Vizzini, 2015 G. Mancinelli, S. Vizzini
Assessing anthropogenic pressures on coastal marine ecosystems using stable CNS isotopes: state of the art, knowledge gaps, and community-scale perspectives
Estuar. Coast. Shelf Sci., 156 (2015), pp. 195-204, 10.1016/j.ecss.2014.11.030 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2013 G. Mancinelli, L. Carrozzo, G. Marini, M.L. Costantini, L. Rossi, M. Pinna
Occurrence of the Atlantic blue crab *Callinectes sapidus* (Decapoda, Brachyura, Portunidae) in two Mediterranean coastal habitats: temporary visitor or permanent resident?
Estuar. Coast. Shelf Sci., 135 (2013), pp. 46-56, 10.1016/j.ecss.2013.04.004 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2016 G. Mancinelli, B. Glamuzina, M. Petrić, L. Carrozzo, L. Glamuzina, M. Zotti, *et al.*
The trophic position of the Atlantic blue crab *Callinectes sapidus* Rathbun 1896 in the food web of Parila lagoon (south eastern Adriatic, Croatia): a first assessment using stable isotopes
Mediterr. Mar. Sci., 17 (2016), pp. 634-643, 10.12681/mms.1724 ↗
View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2017a G. Mancinelli, K. Alujević, M.T. Guerra, D. Raho, M. Zotti, S. Vizzini
Spatial and seasonal trophic flexibility of the Atlantic blue crab *Callinectes sapidus* in invaded coastal systems of the Apulia region (SE Italy): a stable isotope analysis
Estuar. Coast. Shelf Sci., 198 (2017), pp. 421-431, 10.1016/j.ecss.2017.03.013 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2017b G. Mancinelli, P. Chainho, L. Cilenti, S. Falco, K. Kapiris, G. Katselis, *et al.*
The Atlantic blue crab *Callinectes sapidus* in southern European coastal waters: distribution, impact and prospective invasion management strategies
Mar. Pollut. Bull., 119 (2017), pp. 5-11, 10.1016/j.marpolbul.2017.02.050 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2017c G. Mancinelli, P. Chainho, L. Cilenti, S. Falco, K. Kapiris, G. Katselis, *et al.*
On the Atlantic blue crab (*Callinectes sapidus* Rathbun 1896) in southern European coastal waters: time to turn a threat into a resource?
Fish. Res., 194 (2017), pp. 1-8, 10.1016/j.fishres.2017.05.002 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2017d G. Mancinelli, M.T. Guerra, K. Alujević, D. Raho, M. Zotti, S. Vizzini
Trophic flexibility of the Atlantic blue crab *Callinectes sapidus* in invaded coastal systems of the Apulia region (SE Italy): a stable isotope analysis
Estuar. Coast. Shelf Sci., 198 (2017), pp. 421-431, 10.1016/j.ecss.2017.03.013 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2018 G. Mancinelli, P. Papadia, A. Ludovisi, D. Migoni, R. Bardelli, F.P. Fanizzi, *et al.*
Beyond the mean: a comparison of trace- and macroelement correlation profiles of two lacustrine populations of the crayfish *Procambarus clarkii*
Sci. Total Environ., 624 (2018), pp. 1455-1466, 10.1016/j.scitotenv.2017.12.106 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2021 G. Mancinelli, R. Bardelli, A. Zenetos
A global occurrence database of the Atlantic blue crab *Callinectes sapidus*
Sci. Data, 8 (2021), pp. 1-10, 10.1038/s41597-021-00888-w ↗

View in Scopus ↗ Google Scholar ↗

Mancinelli et al., 2022 G. Mancinelli, T. Dailianis, C. Dounas, P. Kasapidis, P. Koulouri, G. Skouradakis, *et al.*
Isotopic niche and trophic position of the invasive portunid *Portunus segnis* Forskål (1775) in Elounda Bay (Crete Island, eastern Mediterranean)
Sustainability, 14 (2022), Article 15202, 10.3390/su142215202 ↗

View in Scopus ↗ Google Scholar ↗

Mancini et al., 2021 F. Mancini, R. De Giorgi, A. Ludovisi, S. Vizzini, G. Mancinelli
Ontogenetic shift in the trophic role of the invasive killer shrimp *Dikerogammarus villosus*: a stable isotope study
Biol. Invasions, 23 (2021), pp. 1-15, 10.1007/s10530-021-02472-0 ↗

View in Scopus ↗ Google Scholar ↗

Mancini et al., 2022 F. Mancini, A.O. Lillo, R. Bardelli, S. Vizzini, G. Mancinelli
Variation in the stable isotope trophic position of the bluefish *Pomatomus saltatrix* (Linnaeus, 1766) from two Mediterranean sites: insights from a global meta-analysis
Mediterr. Mar. Sci., 23 (2022), pp. 850-863, 10.12681/mms.29325 ↗

View in Scopus ↗ Google Scholar ↗

Mayer-Pinto et al., 2010 M. Mayer-Pinto, A.J. Underwood, T. Tolhurst, R.A. Coleman
Effects of metals on aquatic assemblages: what do we really know?
J. Exp. Mar. Biol. Ecol., 391 (2010), pp. 1-9, 10.1016/j.jembe.2010.06.013 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

McCue et al., 2020 M.D. McCue, M. Javal, S. Clusella-Trullas, J.J. Le Roux, M.C. Jackson, A.G. Ellis, *et al.*

Using stable isotope analysis to answer fundamental questions in invasion ecology: progress and prospects
Methods Ecol. Evol., 11 (2020), pp. 196-214, 10.1111/2041-210X.13327 ↗
View in Scopus ↗ Google Scholar ↗

McKenzie et al., 2012 L.A. McKenzie, R.C. Brooks, E.L. Johnston
A widespread contaminant enhances invasion success of a marine invader
J. Appl. Ecol., 49 (2012), pp. 767-773, 10.1111/j.1365-2664.2012.02158.x ↗
View in Scopus ↗ Google Scholar ↗

Médoc et al., 2018 V. Médoc, L. Thuillier, T. Spataro
Opportunistic omnivory impairs our ability to predict invasive species impacts from functional response comparisons
Biol. Invasions, 20 (2018), pp. 1307-1319, 10.1007/s10530-017-1628-5 ↗
View in Scopus ↗ Google Scholar ↗

Meira et al., 2024 A. Meira, J.E. Byers, R. Sousa
A global synthesis of predation on bivalves
Biol. Rev. (2024), pp. 1-43, 10.1111/brv.13057 ↗
in press
Google Scholar ↗

Micheli, 1997 F. Micheli
Effects of predator foraging behavior on patterns of prey mortality in marine soft bottoms
Ecol. Monogr., 67 (1997), pp. 203-224, 10.1890/0012-9615(1997)067[0203:EOPFBO]2.0.CO;2 ↗
View in Scopus ↗ Google Scholar ↗

Millikin and Williams, 1984 M.R. Millikin, A.B. Williams
Synopsis of biological data on blue crab, *Callinectes sapidus* Rathbun
FAO Fish. Synop., 38 (1984)
Google Scholar ↗

Mothershead II et al., 1991 R.F. Mothershead II, R.C. Hale, J. Greaves
Xenobiotic compounds in blue crabs from a highly contaminated urban subestuary
Environ. Toxicol. Chem., 10 (1991), pp. 1341-1349, 10.1002/etc.5620101013 ↗
View in Scopus ↗ Google Scholar ↗

Mutlu et al., 2011 C. Mutlu, M. Turkmen, A. Turkmen, Y. Tepe

Comparison of metal concentrations in tissues of blue crab, *Callinectes sapidus* from Mediterranean lagoons

Bull. Environ. Contam. Toxicol., 87 (2011), pp. 282-286, 10.1007/s00128-011-0363-3 ↗

View in Scopus ↗ Google Scholar ↗

Nehring, 2011 S. Nehring

Invasion history and success of the American blue crab *Callinectes sapidus* in European and adjacent waters

B.S. Galil, P.F. Clark, J.T. Carlton (Eds.), In the Wrong Place - Alien Marine Crustaceans: Distribution, Biology and Impacts, vol. 6, Springer, Netherlands (2011), pp. 607-624

Crossref ↗ Google Scholar ↗

Osborne and Poynton, 2019 K.L. Osborne, H.C. Poynton

Copper pollution enhances the competitive advantage of invasive ascidians

Manag. Biol. Invasion, 10 (2019), pp. 641-656, 10.3391/mbi.2019.10.4.05 ↗

View in Scopus ↗ Google Scholar ↗

Ostrowski et al., 2021 A. Ostrowski, R.M. Connolly, M. Sievers

Evaluating multiple stressor research in coastal wetlands: a systematic review

Mar. Environ. Res., 164 (2021), Article 105239, 10.1016/j.marenvres.2020.105239 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Pagliara and Mancinelli, 2018 P. Pagliara, G. Mancinelli

Parasites affect hemocyte functionality in the hemolymph of the invasive Atlantic blue crab *Callinectes sapidus* from a coastal habitat of the Salento peninsula (SE Italy)

Mediterr. Mar. Sci., 19 (2018), pp. 193-200, 10.12681/mms.13886 ↗

Google Scholar ↗

Parmar et al., 2016 T.K. Parmar, D. Rawtani, Y.K. Agrawal

Bioindicators: the natural indicator of environmental pollution

Front. Life Sci., 9 (2016), pp. 110-118, 10.1080/21553769.2016.1162753 ↗

View in Scopus ↗ Google Scholar ↗

Perez and Wallace, 2004 M.H. Perez, W.G. Wallace

Differences in prey capture in grass shrimp, *Palaemonetes pugio*, collected along an environmental impact gradient

Arch. Environ. Contam. Toxicol., 46 (2004), pp. 81-89, 10.1007/s00244-002-0249-9 ↗

View in Scopus ↗ Google Scholar ↗

Pethybridge et al., 2018 H. Pethybridge, C.A. Choy, J.M. Logan, V. Allain, A. Lorrain, N. Bodin, *et al.*
A global meta-analysis of marine predator nitrogen stable isotopes: relationships between trophic structure and environmental conditions
Glob. Ecol. Biogeogr., 27 (2018), pp. 1043-1055, 10.1111/geb.12763 ↗
View in Scopus ↗ Google Scholar ↗

Pettitt-Wade et al., 2015 H. Pettitt-Wade, K.W. Wellband, D.D. Heath, A.T. Fisk
Niche plasticity in invasive fishes in the Great Lakes
Biol. Invasions, 17 (2015), pp. 2565-2580, 10.1007/s10530-015-0894-3 ↗
View in Scopus ↗ Google Scholar ↗

Pirotta et al., 2022 E. Pirotta, L. Thomas, D.P. Costa, A.J. Hall, C.M. Harris, J. Harwood, *et al.*
Understanding the combined effects of multiple stressors: a new perspective on a longstanding challenge
Sci. Total Environ., 821 (2022), Article 153322, 10.1016/j.scitotenv.2022.153322 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Post et al., 2007 D.M. Post, C.A. Layman, D.A. Arrington, G. Takimoto, J. Quattrochi, C.G. Montana
Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses
Oecologia, 152 (2007), pp. 179-189
Crossref ↗ View in Scopus ↗ Google Scholar ↗

Poulos et al., 2000 S.E. Poulos, G.T. Chronis, M.B. Collins, V. Lykousis
Thermaikos gulf coastal system, NW Aegean Sea: an overview of water/sediment fluxes in relation to air–land–ocean interactions and human activities
J. Mar. Syst., 25 (2000), pp. 47-76, 10.1016/S0924-7963(00)00008-7 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Prado et al., 2020 P. Prado, A. Peñas, C. Ibáñez, P. Cabanes, L. Jornet, N. Álvarez, *et al.*
Prey size and species preferences in the invasive blue crab, *Callinectes sapidus*: potential effects in marine and freshwater ecosystems
Estuar. Coast. Shelf Sci., 245 (2020), Article 106997, 10.1016/j.ecss.2020.106997 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Prado et al., 2021 P. Prado, C. Ibáñez, L. Chen, N. Caiola
Feeding habits and short-term mobility patterns of blue crab, *Callinectes sapidus*, across invaded habitats of the Ebro Delta subjected to contrasting

salinity
Estuar. Coasts, 45 (2021), pp. 839-855, 10.1007/s12237-021-01004-2 ↗
Google Scholar ↗

Quezada-Romegialli et al., 2018 C. Quezada-Romegialli, A.L. Jackson, B. Hayden, K.K. Kahilainen, C. Lopes, C. Harrod
tRophicPosition, an r package for the Bayesian estimation of trophic position from consumer stable isotope ratios
Methods Ecol. Evol., 9 (2018), pp. 1592-1599, 10.1111/2041-210X.13009 ↗
View in Scopus ↗ Google Scholar ↗

Quezada-Romegialli et al., 2022 C. Quezada-Romegialli, A.L. Jackson, C. Harrod
tRophicPosition: Bayesian Trophic Position Calculation with Stable Isotopes. R package version 0.8.0
http://cran.r-project.org/web/packages/tRophicPosition ↗ (2022)
Google Scholar ↗

R Development Core Team, 2023 R Development Core Team
R: A Language and Environment for Statistical Computing
R Foundation for Statistical Computing, Vienna, Austria (2023)
http://www.R-project.org/ ↗
Google Scholar ↗

Raab et al., 2005 A. Raab, H. Schat, A.A. Meharg, J. Feldmann
Uptake, translocation and transformation of arsenate and arsenite in sunflower (*Helianthus annuus*): formation of arsenic-phytochelatin complexes during exposure to high arsenic concentrations
New Phytol., 168 (2005), pp. 551-558
Crossref ↗ View in Scopus ↗ Google Scholar ↗

Rady et al., 2018 A. Rady, W.S. Sallam, N.E.I. Abdou, A.A.M. El-Sayed
Food and feeding habits of the blue crab, *Callinectes sapidus* (Crustacea: Decapoda: Portunidae) with special reference to the gastric mill structure
Egypt. J. Aquat. Biol. Fish., 22 (2018), pp. 417-431, 10.21608/ejabf.2018.23925 ↗
View in Scopus ↗ Google Scholar ↗

Rainbow, 1995 P.S. Rainbow
Biomonitoring of heavy metal availability in the marine environment
Mar. Pollut. Bull., 31 (1995), pp. 183-192, 10.1016/0025-326X(95)00116-5 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Rainbow, 2018 P.S. Rainbow
Trace Metals in the Environment and Living Organisms: The British Isles as a Case Study
Cambridge University Press, Cambridge (2018)
Google Scholar ↗

Reichmuth et al., 2009 J.M. Reichmuth, R. Roudez, T. Glover, J.S. Weis
Differences in prey capture behavior in populations of blue crab (*Callinectes sapidus* Rathbun) from contaminated and clean estuaries in New Jersey
Estuar. Coasts, 32 (2009), pp. 298-308, 10.1007/s12237-008-9130-z ↗
View in Scopus ↗ Google Scholar ↗

Reichmuth et al., 2010 J.M. Reichmuth, P. Weis, J.S. Weis
Bioaccumulation and depuration of metals in blue crabs (*Callinectes sapidus* Rathbun) from a contaminated and clean estuary
Environ. Pollut., 158 (2010), pp. 361-368, 10.1016/j.envpol.2009.09.009 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Rennie et al., 2024 M.D. Rennie, L.A.H. James, S.E. Arnott, J.M. Casselman, D.O. Evans, W.G. Sprules
Spiny water flea invasion alters fish mercury bioaccumulation rates
Biol. Invasions in press (2024), pp. 1-19, 10.1007/s10530-023-03238-6 ↗
Google Scholar ↗

Romanuk et al., 2009 T.N. Romanuk, Y. Zhou, U. Brose, E.L. Berlow, R.J. Williams, N.D. Martinez
Predicting invasion success in complex ecological networks
Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci., 364 (2009), pp. 1743-1754
Crossref ↗ View in Scopus ↗ Google Scholar ↗

Romero-Romero et al., 2017 S. Romero-Romero, L. Herrero, M. Fernández, B. Gómara, J.L. Acuña
Biomagnification of persistent organic pollutants in a deep-sea, temperate food web
Sci. Total Environ., 605-606 (2017), pp. 589-597, 10.1016/j.scitotenv.2017.06.148 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Saavedra et al., 2004a Y. Saavedra, A. González, P. Fernández, J. Blanco
The effect of size on trace metal levels in raft cultivated mussels (*Mytilus galloprovincialis*)
Sci. Total Environ., 318 (2004), pp. 115-124, 10.1016/S0048-9697(03)00402-9 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Saavedra et al., 2004b Y. Saavedra, A. González, P. Fernández, J. Blanco
Interspecific variation of metal concentrations in three bivalve mollusks from Galicia
Arch. Environ. Contam. Toxicol., 47 (2004), pp. 341-351, 10.1007/s00244-004-3021-5 ↗
View in Scopus ↗ Google Scholar ↗

Saavedra et al., 2009 Y. Saavedra, A. González, J. Blanco
Inter-individual distribution of metal concentrations in four marine bioindicator organisms and its use for optimal sampling design of a monitoring system
Int. J. Environ. Anal. Chem., 89 (2009), pp. 559-568, 10.1080/03067310802553146 ↗
View in Scopus ↗ Google Scholar ↗

Salafsky et al., 2008 N. Salafsky, D. Salzer, A.J. Stattersfield, C. Hilton-Taylor, R. Neugarten, S.H. Butchart, B. Collen, N. Cox, L. Master, S. O'connor, D. Wilkie
A standard lexicon for biodiversity conservation: unified classifications of threats and actions
Conserv. Biol., 22 (2008), pp. 897-911, 10.1111/j.1523-1739.2008.00937.x ↗
View in Scopus ↗ Google Scholar ↗

Salvat-Leal et al., 2020 I. Salvat-Leal, D. Verdiell, P. Parrondo, E. Barcala, D. Romero
Assessing lead and cadmium pollution at the mouth of the river Segura (SE Spain) using the invasive blue crab (*Callinectes sapidus* Rathbun, 1896, Crustacea, Decapoda, Portunidae) as a bioindicator organism
Reg. Stud. Mar. Sci., 40 (2020), Article 101521, 10.1016/j.rsma.2020.101521 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Sastre et al., 1999 M.P. Sastre, P. Reyes, H. Ramos, R. Romero, J. Rivera
Heavy metal bioaccumulation in Puerto Rican blue crabs (*Callinectes* spp.)
Bull. Mar. Sci., 64 (1999), pp. 209-217
View in Scopus ↗ Google Scholar ↗

Scalici et al., 2022 M. Scalici, S. Chiesa, G. Mancinelli, P.M. Rontani, A. Voccia, F. Nonnis Marzano
Euryhaline aliens invading Italian inland waters: the case of the Atlantic blue crab *Callinectes sapidus* Rathbun, 1896
Appl. Sci., 12 (2022), p. 4666, 10.3390/app12094666 ↗
View in Scopus ↗ Google Scholar ↗

Schiesari et al., 2018 L. Schiesari, M.A. Leibold, G.A. Burton

Metacommunities, metaecosystems and the environmental fate of chemical contaminants

J. Appl. Ecol., 55 (2018), pp. 1553-1563, 10.1111/1365-2664.13054 ↗

View in Scopus ↗ Google Scholar ↗

Scirocco and Urbano, 2018 T. Scirocco, F. Urbano

The population of the non-indigenous bivalve *Arcuatula senhousia* of the Varano lagoon (Adriatic Sea, Italy)

J. Environ. Sci. Eng., 7 (2018), pp. 345-353, 10.17265/2162-5298/2018.09.001 ↗

View in Scopus ↗ Google Scholar ↗

Seed, 1980 R. Seed

Predator-prey relationships between the mud crab Panopeus herbstii, the blue crab, *Callinectes sapidus* and the Atlantic ribbed mussel *Geukensia* (=*Modiolus*) *demissa*

Estuar. Coast. Shelf Sci., 11 (1980), pp. 445-458, 10.1016/S0302-3524(80)80067-3 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Seitz et al., 2001 R.D. Seitz, R.N. Lipcius, A.H. Hines, D.B. Eggleston

Density-dependent predation, habitat variation, and the persistence of marine bivalve prey

Ecology, 82 (2001), pp. 2435-2451, 10.1890/0012-9658(2001)082[2435:DDPHVA]2.0.CO;2 ↗

View in Scopus ↗ Google Scholar ↗

Shea and Chesson, 2002 K. Shea, P. Chesson

Community ecology theory as a framework for biological invasions

Trends Ecol. Evol., 17 (2002), pp. 170-176, 10.1016/S0169-5347(02)02495-3 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Sospedra et al., 2018 J. Sospedra, L.F.H. Niencheski, S. Falco, C.F.F. Andrade, K.K. Attisano, M. Rodilla

Identifying the main sources of silicate in coastal waters of the southern gulf of Valencia (Western Mediterranean Sea)

Oceanologia, 60 (2018), pp. 52-64, 10.1016/j.oceano.2017.07.004 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Spagnoli and Andresini, 2018 F. Spagnoli, A. Andresini

Biogeochemistry and sedimentology of Lago di Lesina (Italy)

Sci. Total Environ., 643 (2018), pp. 868-883, 10.1016/j.scitotenv.2018.06.165 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Squadrone et al., 2020 S. Squadrone, P. Brizio, C. Stella, M. Mantia, L. Favaro, B. Biancani, *et al.*
Differential bioaccumulation of trace elements and rare earth elements in the muscle, kidneys, and liver of the invasive indo-Pacific lionfish (*Pterois* spp.) from Cuba
Biol. Trace Elem. Res., 196 (2020), pp. 262-271, 10.1007/s12011-019-01918-w ↗
View in Scopus ↗ Google Scholar ↗

Streftaris and Zenetos, 2006 N. Streftaris, A. Zenetos
Alien marine species in the Mediterranean - the 100 'Worst Invasives' and their impact
Mediterr. Mar. Sci., 7 (2006), pp. 87-117, 10.12681/mms.180 ↗
Google Scholar ↗

Suárez-Serrano et al., 2010 A. Suárez-Serrano, C. Alcaraz, C. Ibáñez, R. Trobajo, C. Barata
Procambarus clarkii as a bioindicator of heavy metal pollution sources in the lower Ebro River and Delta
Ecotoxicol. Environ. Saf., 73 (2010), pp. 280-286, 10.1016/j.ecoenv.2009.11.001 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Taylor and Calabrese, 2018 D.L. Taylor, N.M. Calabrese
Mercury content of blue crabs (*Callinectes sapidus*) from southern New England coastal habitats: contamination in an emergent fishery and risks to human consumers
Mar. Pollut. Bull., 126 (2018), pp. 166-178, 10.1016/j.marpolbul.2017.10.089 ↗
View PDF View article View in Scopus ↗ Google Scholar ↗

Türkmen et al., 2006 A. Türkmen, M. Türkmen, Y. Tepe, Y. Mazlum, S. Oymael
Metal concentrations in blue crab (*Callinectes sapidus*) and mullet (*Mugil cephalus*) in Iskenderun Bay, northern East Mediterranean, Turkey
Bull. Environ. Contam. Toxicol., 77 (2006), pp. 186-193, 10.1007/s00128-006-1049-0 ↗
View in Scopus ↗ Google Scholar ↗

Tzafriri-Milo et al., 2019 R. Tzafriri-Milo, T. Benaltabet, A. Torfstein, N. Shenkar
The potential use of invasive ascidians for biomonitoring heavy metal pollution
Front. Mar. Sci., 6 (2019), 10.3389/fmars.2019.00611 ↗
Google Scholar ↗

Usero et al., 1997 J. Usero, E. González-Regalado, I. Gracia

Trace metals in the bivalve molluscs *Ruditapes decussatus* and *Ruditapes philippinarum* from the Atlantic coast of southern Spain

Environ. Int., 23 (1997), pp. 291-298, 10.1016/S0160-4120(97)00030-5 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Vanderklift and Ponsard, 2003 M. Vanderklift, S. Ponsard

Sources of variation in consumer-diet δ^{15}N enrichment: a meta-analysis

Oecologia, 136 (2003), pp. 169-182

View in Scopus ↗ Google Scholar ↗

Weinstein et al., 1992 J.E. Weinstein, T.L. West, J.T. Bray

Shell disease and metal content of blue crabs, *Callinectes sapidus*, from the Albemarle-Pamlico estuarine system, North Carolina

Arch. Environ. Contam. Toxicol., 23 (1992), pp. 355-362, 10.1007/bf00216245 ↗

View in Scopus ↗ Google Scholar ↗

Weis et al., 2011 J.S. Weis, L. Bergey, J. Reichmuth, A. Candelmo

Living in a contaminated estuary: behavioral changes and ecological consequences for five species

Bioscience, 61 (2011), pp. 375-385, 10.1525/bio.2011.61.5.6 ↗

View in Scopus ↗ Google Scholar ↗

Wood and Scheipl, 2020 S. Wood, F. Scheipl

gamm4: Generalized Additive Mixed Models using 'mgcv' and 'lme4'. R package version 0.2-6

http://cran.r-project.org/web/packages/gamm4 ↗ (2020)

Google Scholar ↗

Zotti et al., 2016 M. Zotti, L. Del Coco, S.A. De Pascali, D. Migoni, S. Vizzini, G. Mancinelli, *et al.*

Comparative analysis of the proximate and elemental composition of the blue crab *Callinectes sapidus*, the warty crab *Eriphia verrucosa*, and the edible crab *Cancer pagurus*

Heliyon, 2 (2016), 10.1016/j.heliyon.2016.e00075 ↗

1–15

Google Scholar ↗

Zuykov et al., 2013 M. Zuykov, E. Pelletier, D.A.T. Harper

Bivalve mollusks in metal pollution studies: from bioaccumulation to biomonitoring

Chemosphere, 93 (2013), pp. 201-208, 10.1016/j.chemosphere.2013.05.001 ↗

View PDF View article View in Scopus ↗ Google Scholar ↗

Cited by (0)

[1] Equal contributions as first author.