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Evaluation and comparison of fishing gears for the capture, management, and control of the invasive blue crab in a Mediterranean coastal area

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ABSTRACT

Following the unprecedented blue crab (*Callinectes sapidus* Rathbun, 1896) outbreak in the Northern Adriatic during 2023 and the local lack of knowledge on its fishery, this study tested different types of fishing gears to compare their effectiveness in catching the species. The tested gears included the traditional fyke nets, locally called "*tresse con bertovelli*" and four types of crab pots, with either single or double chamber, some produced locally specifically for blue crab capture. Efficiency (defined as the probability of catching blue crabs when present), yield (catch per unit effort), species selectivity, size selectivity and sex selectivity (assessed as the proportion of each category over total catches) were evaluated. Results indicated that both the double chamber pot (inspired by North American designs) and the local fyke nets were the most effective gears overall in terms of efficiency and yield. However, the double chamber pot demonstrated significantly higher species selectivity in the capture of the blue crab, with lower bycatch of the native green crab (*Carcinus aestuarii* Nardo, 1847), and a greater size selectivity, targeting larger, adult specimens of blue crab. Conversely, fyke nets and smaller pots showed lower blue crab selectivity and a higher catch of green crabs and juvenile blue crabs. We conclude that the double chamber pot is the most suitable gear for managing or commercially exploiting the invasive blue crab population, offering high yield and species and size selectivity, thereby minimizing potential bycatch impacts on traditional fisheries. The results of this study could be helpful for managing the species, reducing its negative impacts and potentially exploiting it more effectively.

1. Introduction

The Atlantic blue crab *Callinectes sapidus* Rathbun (1896) is a decapod crustacean of the Portunidae family (Hill et al., 1989), included among the 100 worst invasive species in the Mediterranean (Streftaris and Zenetos, 2006). Native to the western Atlantic coast, from Nova Scotia to Argentina, *C. sapidus* has now spread all over the Mediterranean Sea (Mancinelli et al., 2017a), lately establishing also in the Northern Adriatic Sea, where its presence started to rapidly increase during summer of 2023, with an unprecedented outbreak (Azzurro et al., 2024; Chiesa et al., 2025). The biology of the blue crab has been deeply investigated in its native range (e.g. Hill et al., 1989; Hines, 2007; Epifanio, 2019) and, more recently, across newly colonized regions (e.g. Prado et al., 2022; Kevrekidis et al., 2023; 2024). Its life cycle is closely linked to salinity gradients, spanning estuaries, lagoons, and coastal waters (Van Engel, 1958; Epifanio, 2019). Males generally exhibit a preference for lower-salinity environments, whereas females require higher salinity levels to complete eggs development and larval release (Epifanio, 2019). Mating typically occurs in estuaries where males are more abundant, and subsequently females undertake a migration toward coastal waters to spawn, before returning to brackish environments and estuaries (Hines, 2007; Epifanio, 2019). Larval development occurs at sea through successive zoea and megalopa stages (Hill et al., 1989; Epifanio, 2019). The post-larval juveniles then settle in nursery habitats, such as seagrass meadows, macroalgal beds, or salt marshes, and eventually migrate upstream into estuaries after reaching a size of 20–30 mm (Hines, 2007; Epifanio, 2019).

C. sapidus is a keystone species in coastal ecosystems and a versatile

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omnivorous predator, feeding on a wide range of prey, with a preference for bivalve molluscs and crustaceans (Hines, 2007; Rady et al., 2018; Prado et al., 2022). Consequently, the blue crab outbreak in the Northern Adriatic is raising concerns about potential impacts on local ecosystems and the fishing industry, as the invasive species preys on or competes with native fauna for resources. Indeed, the blue crab can compromise the survival of native species, such as the Mediterranean green crab *Carcinus aestuarii* Nardo (1847), as observed in countries like Greece and Spain (Kampouris et al., 2019; Clavero et al., 2022). Furthermore, the blue crab significantly impacts the Manila clam, *Ruditapes philippinarum* (Adams and Reeve, 1850; Boschiero et al., 2025; Chiesa et al., 2025), a major economically important farmed bivalve in the EU, with Italy supplying approximately 94% of the EU's production in 2022 (Eurostat, 2025). In addition to its impact on the green crab and Manila clam, the blue crab can also negatively impact other commercial fish species (e.g. through food competition, direct predation or damage to the catch inside the fishing gear), leading to substantial economic losses (Kampouris et al., 2019; Clavero et al., 2022; Cannarozzi et al., 2023; Marchessaux et al., 2023).While complete eradication of the blue crab is unlikely due to its high adaptability and mobility (Garrido and De Basquiat, 2023), targeted capture strategies could be effective for population control and containment. These strategies include spatially and temporally tailored actions aligned with the biological cycle of the species, such as capturing females during their migration to the sea for egg hatching (Cilenti et al., 2016; Kevrekidis et al., 2024) in order to reduce the reproductive output of the species. Additionally, capturing specimens for human consumption (Perdikaris et al., 2016; Mancinelli et al., 2017b; Khamassi et al., 2022) or for other applications, such as in biomedicine, aquaculture pellet production, and biodegradable film production (Bölgen et al., 2016; Perdikaris et al., 2016; Baron et al., 2017; Kampouris et al., 2019), could also contribute to control the species abundance. Determining the optimal fishing gear for blue crab population management necessitates a comparative assessment of different capture methods. Few studies conducted in the Mediterranean Sea, however, have addressed this topic. Atar et al. (2002) tested two types of collapsible traps and a traditional hoop net, demonstrating that the hoop net was more efficient in capturing blue crabs. Glamuzina et al. (2021) compared a local adaptation of the crab wire trap adopted for the commercial capture of the blue crab in its native area (patented by Lewis in 1938; n. US2731761A) with traditional fyke nets, finding the former significantly more efficient.

As the blue crab has massively invaded the Northern Adriatic only recently, and due to the absence of native species with comparable size and behaviour, local fishers did not possess specific gear or long-term experience for its catch. Therefore, the aim of this study was to test different types of fishing gear to evaluate their efficiency, yield, and selectivity in catching the blue crab in the Northern Adriatic area. The gear tested included four types of crab pots, three of which were produced locally specifically for blue crab capture, as well as the traditional fyke nets, locally called "*tresse con bertovelli*" and normally used to catch various target species, including the green crab, *Carcinus aestuarii* (Granzotto et al., 2001; Zucchetta et al., 2016). We focused primarily on coated wire pots, as harvesting of the species in its native range have historically shifted towards this kind of gear, first introduced in the Chesapeake Bay region in 1927 (Guillory and Prejean, 1997; Steele and Bert, 1998). The adoption of wire traps allowed the blue crab fishing to expand due to their superior efficiency and ease of deployment compared to trotlines; furthermore, they are associated with fewer environmental impacts compared to trawl fisheries (Steele and Bert, 1998). Additionally, we assessed traditional fyke nets due to their well-established use in the study area, where they are extensively employed for lagoon fishery (Pellizzato, 2011; Zucchetta et al., 2016). The selectivity of the various types of gear was assessed in terms of size selectivity, species selectivity (between blue crab and green crab), and sex selectivity.

2. Materials and methods

2.1. Study area

The Venice lagoon, located in the northwestern Adriatic Sea, is Italy's largest lagoon and one of the largest in the Mediterranean basin, covering an area of about 550 km^2 (Solidoro et al., 2010). The lagoon is a shallow coastal water body, with an average depth of tidal flats and subtidal platforms of about 1.5 m (Roner et al., 2017). Three large navigable inlets (Lido, Malamocco, and Chioggia) connect the lagoon to the Adriatic Sea, facilitating water exchange between the sea and the lagoon (Molinaroli et al., 2007). A network of natural and artificial channels rooted at the three inlets facilitates navigation and water exchange (Solidoro et al., 2010), with water residence times ranging from values of less than 1 day close to the inlets, to over 30 days in the inner areas (Cucco and Umgiesser, 2006). Given its morphological complexity and multiple inlets connected to the sea, the Venice lagoon can be considered a "system of lagoons" (Tagliapietra and Ghirardini, 2006) and it can be divided into three main sub-basins: Northern, Central, and Southern, which are connected to the sea via Lido, Malamocco, and Chioggia inlets, respectively (Solidoro et al., 2010). The southern sub-basin, approximately 111 km^2, hosts the city of Chioggia and comprises 13 km^2 of channels, 13 km^2 of salt marshes and 85 km^2 of shallow bottoms (Molinaroli et al., 2009). Lagoon structure is an outcome of both natural hydrodynamic processes and centuries of human engineering, with fishing and human activities deeply rooted in these complex environments. (Solidoro et al., 2010). These areas have indeed been exploited by small-scale fishing activities using traditional methods to seasonally target a large variety of species for long time (Granzotto et al., 2001; Pranovi et al., 2013; Scapin et al., 2022). However, the recent massive spread of Invasive Alien Species (IAS), such as the ctenophore *Mnemiopsis leidyi* Agassiz (1865), is already having a negative impact on the Chioggia's small-scale artisanal fisheries (Piccardi et al., 2024).

The present study was conducted at four sampling stations near Chioggia (Fig. 1). The stations were selected to represent distinct environmental characteristics and include: two stations within the lagoon, CHN (northern Chioggia, 45°13'58.06" N 12°13'11.35" E) and CHS (southern Chioggia, 45°13'21.15" N 12°14'21.25" E); a coastal marine station located just outside Chioggia inlet, PELL (Pellestrina, 45°14'13.00" N 12°18'32.21" E) and a station at the mouth of the Brenta River, BR (Brenta, 45°10'33.90" N 12°17'27.15" E).

2.2. Gear description

The small pot (Fig. 2A) is a small, box-shaped trap locally constructed to be tested in the present study. The pot is made of a rectangular, plastic-coated, 3 × 1.5 cm wire mesh (2 mm thick). It is a single chamber pot, with dimensions 38 × 44 x 21 cm. The pot has two small funnel entrances (15 ×7 cm) for the crabs and no escape rings. The bait cage is a 4 × 4 x 16 cm parallelepiped with 3 × 1.5 cm rectangular mesh.

The type 1 pot (Fig. 2B) is a folding, box-shaped crab trap with a collapsible design for easy transport, typically used for recreational crab fishing. The pot is made with a corrosion-resistant, plastic-coated, 4 × 4 cm square wire mesh (4 mm thick). It is a single chamber pot, and its dimensions are 52.5 × 42.5 × 22.5 cm. The pot has 4 hinged doors (24 ×11 cm) that open to let crabs in and then close to prevent them from escaping, with 3 circular escape rings (6 cm diameter) for smaller specimens and non-target species to escape.

The type 2 pot (Fig. 2C) is a single chamber, box-shaped trap similar to the pots used for the crab fishery in the Chioggia area locally constructed to be tested in the present study. The pot is made of a plastic-coated, 5 × 5 cm square wire mesh (3 mm thick), with dimensions 60 × 60 x 25 cm. It has four funnel entrances (20 ×10 cm) for the crabs and no escape rings. The bait cage is a 25 cm long galvanized mesh cylinder of 5 cm diameter and 1 × 2.5 cm mesh.

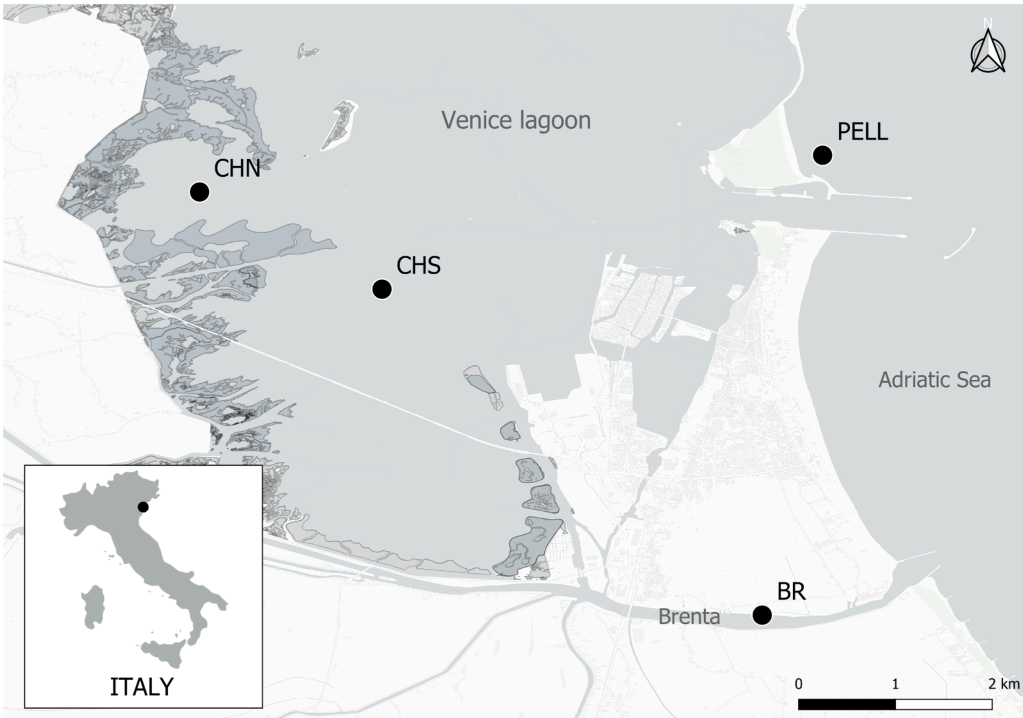

Fig. 1. Map of sampling sites near Chioggia: CHN and CHS (Venice Lagoon), PELL (Adriatic coast), and BR (Brenta River mouth).

The double chamber pot (Fig. 2D) is a double chamber, box-shaped trap of local construction for the blue crab fishery in the Po delta area (North Adriatic). Its design is inspired by the pots typically used for the commercial fishing of the species in the Chesapeake Bay (USA). The pot is made of a plastic-coated, 5 × 5 cm square wire mesh (3 mm thick), with dimensions 40 × 61 x 40 cm. The pot has four funnel entrances (20 ×15 cm) for the crabs and no escape holes. This trap is divided into two sections by an internal panel, inverted V shaped, connected by two internal funnels: a lower unit, the "bait chamber", and an upper unit, the "trap chamber". The bait cage is a 4 × 4 x 16 cm parallelepiped with 2 × 1 cm rectangular mesh located in the bait chamber. After entering the bait chamber, crabs pass through the internal funnels and enter the trap chamber, where escape possibility is minimal (Van Engel, 1962; Sturdivant and Clark, 2011; Carrozzo et al., 2014). A size comparison among the four types of wire crab pots is shown in Fig. 2E.

The fyke nets (Fig. 2F, G) used in this study, locally known as "*tresse con bertovelli*" (Pellizzato, 2011) are traditional fish traps and consist of 6 mm mesh size net barriers with a height of 90 cm, held in place by wooden poles driven into the lagoon bed approximately 1.5 m from each other, collecting fish in bags. Each net barrier (*tressa*), with a length of had 5 bags (*bertovelli)* along its 50–60 m length, consisting of two or three cylindrical or cone-shaped netting bags with a mesh size of 0.6 cm, mounted on 35 cm diameter plastic rings. The presence of wings or leaders guide the fish towards the entrance of the bags and convey the fish towards the terminal, closed cod end of the device through funnel-shaped nets (Pellizzato, 2011; Zucchetta et al., 2016).

2.3. Sampling and laboratory methods

Sampling activities using wire crab pots were carried out from June 2023 to June 2024 in order to collect a full year of observations covering all the seasons. A total of 14 sampling events were carried out at each of the four sampling stations (9 in 2023 and 5 in 2024), with each event treated as an independent replicate for the analysis. Three types of wire pots were tested during the 2023 sampling events: "small", "type 1"and "double chamber". In 2024, the "small" wire pot was replaced with the "type 2" pot due to its observed lower effectiveness. During each sampling event, nine wire pots (three of each type) were deployed through randomly scattered method at each station and retrieved 24 h later. The wire pots were baited with low-value fish species, primarily mullets and sardines. One sampling event in 2023 was not conducted at the PELL station due to adverse weather conditions. Sampling using fyke nets "*tresse con bertovelli*" was conducted from August 2023 to November 2023 and resumed from March 2024 to June 2024, for a total of 8 sampling events. The nets were positioned within the lagoon, in the area between stations CHN and CHS, and retrieved 24 h later. During each sampling event 20 "bertovelli" were inspected. Sampling dates for both wire pots and fyke nets are provided in Table S1.

All the crabs sampled with pots and crabs collected with fyke nets in 2024 were culled using a two-step ethical protocol as described in de Souza Valente (2022) and analysed in the laboratory. Each specimen was identified to species level and sexed based on Rathbun (1930), weighed to the nearest 0.01 g with an electronic precision balance (Bel Engineering S123, Italy, precision 0.001 g) and measured to the nearest 0.01 mm using a standard Vernier calliper according to the method in Fazhan et al. (2021) adapted for blue crab. Measurements of blue crab's carapace taken include Total Carapace Width (TCW), Carapace Width at the basis of spines (CW) and Carapace Length (CL). A total of 937 blue crabs collected with pots and 234 blue crabs collected with fyke nets were measured for this study. Blue crabs captured with fyke nets during 2023 were only counted.

2.4. Gear comparison

To compare the performance of different fishing gears across stations and seasons, we applied a stepwise modelling framework by means of generalized linear mixed models using the glmmTMB package (Brooks et al., 2017) for R (v 4.2.0; R Core Team, 2025) within RStudio (v 2024.12.1; Posit team, 2025). Efficiency, yield, and selectivity were used as response variables in the regression-based models.

For each response variable, we first explored candidate distribution families and error structures by fitting a semi-saturated model including

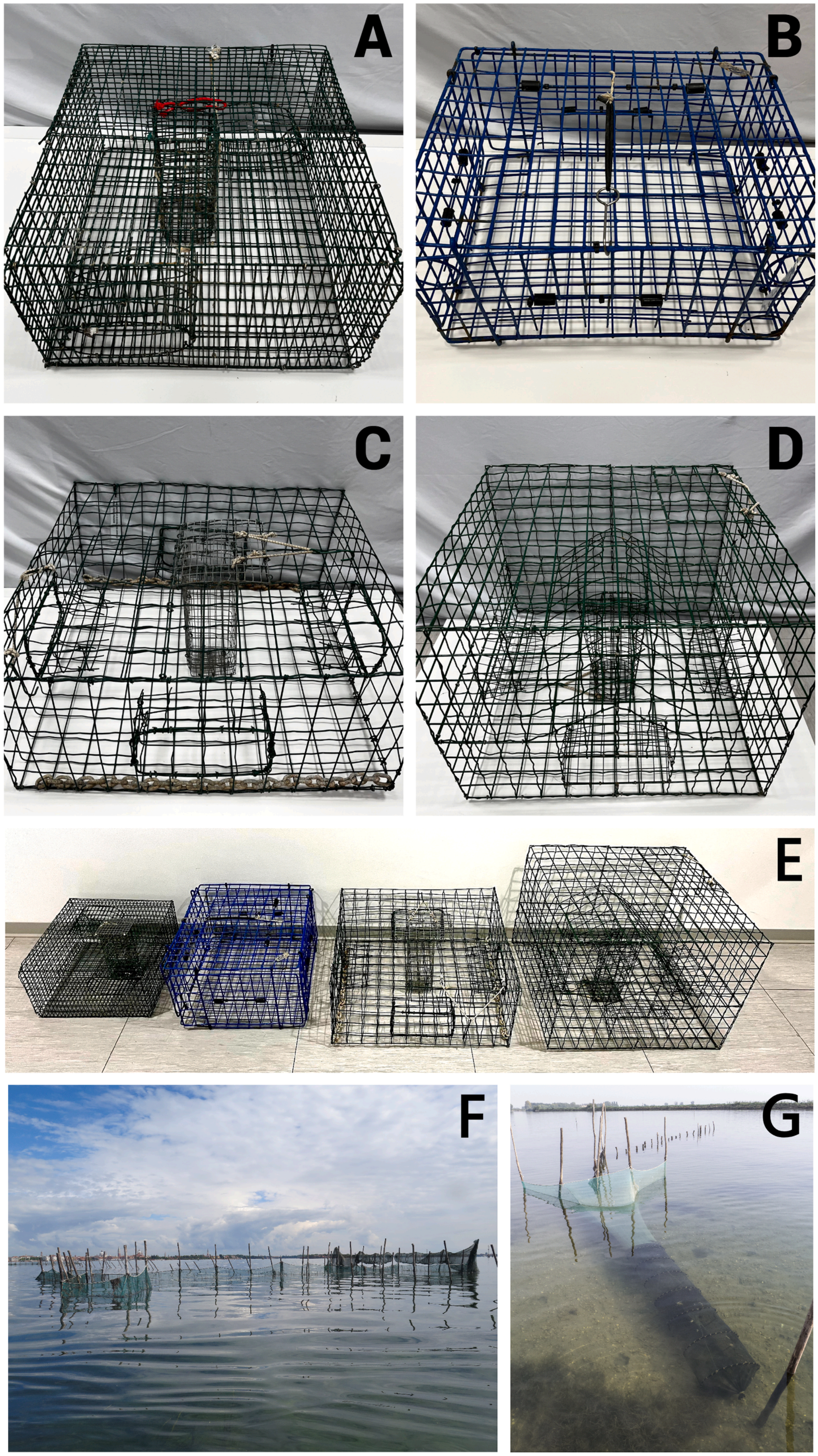

Fig. 2. The types of gears tested: pots tested: small wire crab pot (A), type 1 wire crab pot (B); type 2 wire crab pot (C); double chamber wire crab pot (D); wire crab pots size comparison (E); fyke nets locally known as "tresse con bertovelli": whole net (F) and detail of a single "bertovello" (G).

the interaction between gear and season and assessed residual diagnostics with the DHARMa package (v 0.4.7; Hartig, 2024). When residual heterogeneity was detected, we evaluated the inclusion of random terms (e.g., sampling station) or alternative dispersion structures. After identifying an appropriate family and random structure, we fitted the full model (including the two-way interaction between season and gear) and tested the significance of main effects and interactions using Type II Wald χ^2 tests ($\alpha = 0.05$). Non-significant terms were progressively removed, and the final model was validated through residual checks. Post hoc comparisons of gears, stations, and seasons were carried out with the package emmeans (Lenth and Piaskowski, 2025), applying Holm corrections for multiple testing ($\alpha = 0.05$). Comparisons were carried out only for double chamber and type 1 pots for the full period, and then separately for double chamber pots, type 1, and small pots for the first period (summer and autumn 2023) and for type 1, type 2, and double chamber pots for the second period (winter and spring 2024; Fig. 3). The same scheme was followed also including fyke nets data for the lagoon stations (CHN and CHS) for the variables and periods that were assessed (i.e., when the fyke nets were deployed). To ensure coherence between statistical inference and graphical representation, results are visualized using plots that display: (i) the empirical distribution of observations (univariate scatterplots), (ii) observed means (and medians for continuous variables), and (iii) model-based marginal estimates with 95% confidence intervals (for the terms included in the models).

2.4.1. Efficiency

We defined the efficiency of the gears as the capability of catching blue crabs provided that the species is present in a specific station in a given season (Zhou et al., 2014; Glamuzina et al., 2021). We estimated the differences among the different gear by comparing the probability of catch of each gear for the sampling occasion during which at least one of the gears collected at least one blue crab specimen. The comparisons were performed fitting binomial gl(m)ms.

2.4.2. Yield

We assessed the yields of the different gear by comparing the catch for unit effort (CPUE) in biomass (g/trap/day) for each gear. The comparisons were performed fitting tweedie gl(m)ms.

2.4.3. Selectivity

We defined selectivity as the proportion of each catch variable considered among the fishing gear (McClanahan and Cinner, 2008; Humphries et al., 2019). The gear selectivity was quantified considering three different variables: (i) the size of blue crabs (TWC), assuming that less selective gears would retain both adult and juvenile individuals (lower mean size), whereas more selective gears would mainly target adult specimens (size selectivity); (ii) the proportion of females (N) among total caught blue crabs (sex selectivity); and (iii) the proportion of green crabs among the total abundance of blue and green crabs (species selectivity). Comparisons involving fyke nets during the first and full sampling period were only performed for species selectivity, whereas all selectivity variables were assessed during the second period. Only TCW was used as measure for size comparisons due to the strong correlation detected with the other measure variables (CW and CL; Table S2). The comparisons were performed fitting gaussian gl(m)ms (size selectivity), binomial with zero inflation gl(m)ms (sex selectivity) and betabinomial gl(m)ms (crab species selectivity). The mean was deemed an appropriate measure of central tendency for size (TCW), as supported by the residual diagnostics of the Gaussian gl(m)ms.

3. Results

A total of 935 blue crabs were sampled with wire pots for a total biomass of 189.43 kg. Of which, 179 crabs were captured with type 1 pot (38.01 kg) and 616 with double chamber pot (127.90 kg) during the full sampling period, while 64 crabs were captured with small pot (7.73 kg) during the first period and 77 with type 2 pot (15.79 kg) during the second. Bycatch with wire pots comprised overall 162 specimens of *Carcinus aestuarii*, 15 of *Maja squinado*, 16 of *Eriphia verrucosa*, 5 of *Liocarcinus* sp., 2 of *Zosterisessor ophiocephalus*, 1 of *Hippocampus guttulatus*, 1 of *Sepia officinalis*, 92 of *Hexaplex trunculus*, 65 of *Nassarius* sp. and 1 of *Mnemiopsis leidyi*. Mean captures per pot ($\pm$ SE) of the most frequently caught taxa are summarized in Table 1.

A total of 463 blue crabs were sampled with fyke nets for a total biomass of 124.08 kg and a catch rate of 3.03 specimens per bag (153 bags checked). Additional 40 species were caught during the sampling period, including fishery targets such as *C. aestuarii* (40.50 kg), *Atherina boyeri* (16.32 kg), *Z. ophiocephalus* (3.32 kg), *Chelon auratus* (1.81 kg), *Sprattus sprattus* (1.76 kg) and *S. officinalis* (3.20 kg). The invasive ctenophore *M. leydyi* was also frequently caught, eventually registering the highest biomass among all the species (185.53 kg).

3.1. Efficiency

Overall, fyke nets and double chamber pots were the most efficient gear and the small pots the least efficient, with some seasonal effects detected.

Across the full sampling period, the double chamber pot consistently showed higher efficiency than type 1 ($p < 0.05$), with seasonal effects

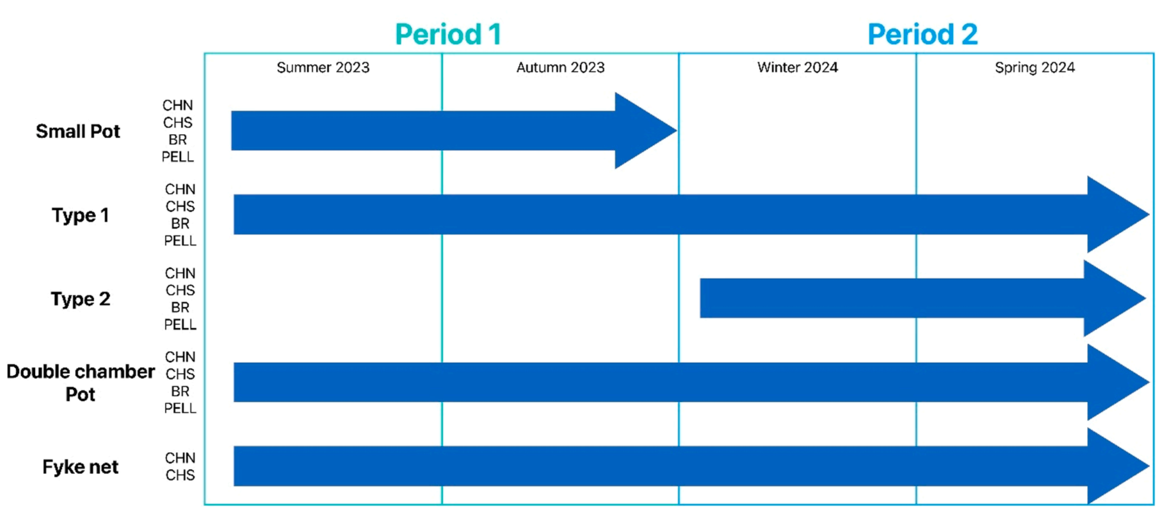

Fig. 3. Spatial (sites) and temporal scheme of the sampling activity.

Table 1
Mean captures per pot (N of individuals ± SE) of the most frequently caught taxa for each type of wire pot (N of deployed pots are also reported for each type).

	C. sapidus	*C. aestuarii*	*M. squinado*	*E. verrucosa*	*H. trunculus*	Nassarius sp.	N. samples
Small	0.60 ± 0.12	0.46 ± 0.17	0.07 ± 0.03	0.02 ± 0.02	0.26 ± 0.14	0.26 ± 0.15	105
Type 1	1.08 ± 0.11	0.37 ± 0.12	0.04 ± 0.02	0.02 ± 0.01	0.30 ± 0.12	0.00	165
Type 2	1.28 ± 0.24	0.52 ± 0.16	0.00	0.00	0.18 ± 0.09	0.47 ± 0.33	60
Double	3.73 ± 0.32	0.13 ± 0.04	0.01 ± 0.01	0.06 ± 0.03	0.02 ± 0.01	0.06 ± 0.03	165
TOT	1.89 ± 0.13	0.33 ± 0.06	0.03 ± 0.01	0.03 ± 0.01	0.19 ± 0.05	0.13 ± 0.05	495

indicating higher efficiency only in spring compared to winter ($p < 0.05$) (Table 2, Fig. 4). In 2023, both double chamber pot and type 1 outperformed the small pot, whereas in 2024 the double chamber pot was more efficient than both type 1 and type 2, with higher efficiency observed in spring than in winter ($p < 0.05$). In the lagoon stations, across the full period fyke nets and double chamber pots were more efficient than type 1 ($p < 0.05$) (Table 2, Figure S1). In both 2023 and 2024 fyke nets ranked highest when included in the comparison, resulting significantly more efficient than all the crab pots ($p < 0.05$) except for double chamber pots, which were also more efficient than small pots in 2023 and type 1 and type 2 in 2024 ($p < 0.05$).

3.2. Yield

Yield (CPUE in biomass) was also the highest with double chamber pots and fyke nets, and the lowest with small pots, with some seasonal effects, with yield higher in spring and lower in winter.

Mean yield of type 1 pots was 230.4 ± 23.6 g (median = 69.9 g; IQR: 0–382.4 g); of type 2 pots 263.2 ± 46.1 g (median = 0 g; IQR: 0–509.3 g); of small pots 73.7 ± 15.0 g (median = 0 g; IQR: 0–77.5 g); of double chamber pots 775.1 ± 62.5 g (median = 513.4 g; IQR: 142.4–1248.0 g) and of fyke nets 811.0 ± 71.8 g (median = 550.0 g; IQR: 20.0–1200.0 g) per bag. Over the full period, double chamber pots yielded more than type 1 ($p < 0.05$), with yields highest in spring and lowest in winter. In 2023, yields followed the order double chamber pot > type 1 > small pot ($p < 0.05$) (Table 3, Fig. 5), while in 2024 the double chamber pot yielded more than both type 1 and type 2 ($p < 0.05$). In the lagoon stations, across the full period fyke nets and double chamber pots yielded more than type 1 ($p < 0.05$), again with higher yield in spring and lower in winter ($p < 0.05$) (Table 3, Figure S2). Moreover, both in 2023 and in 2024 fyke nets and double chamber pots yielded more than all the other pot types ($p < 0.05$).

3.3. Selectivity

Overall, double chamber pots are the most selective in capturing blue crabs rather than green crabs. Moreover, they are more selective in the capture of larger-sized crabs. In contrast, fyke nets and small pots capture smaller sizes and are less selective for blue crabs, having the highest percentage of green crabs captured. No sex selectivity differences were detected amongst all gear types.

Mean crab sizes (TCW) ranged from 11.73 ± 3.54 cm of small pots (min = 3.94 cm; max = 18.30 cm) to 15.02 ± 1.63 cm of double chamber pots (min = 6.21 cm; max = 20.40 cm). Type 1 pots registered a mean crab size of 14.79 ± 2.12 cm (min = 8.99 cm; max = 19.20 cm), type 2 post of 14.80 ± 1.53 cm (min = 11.37 cm; max = 18.50 cm) and fyke nets of 14.76 ± 3.53 (min = 2.47 cm; max = 19.50 cm). In 2023, small pots captured smaller crabs than double chamber and type 1 pots, but only during summer ($p < 0.05$, interaction of season with gear) (Table 4, Fig. 6), while in 2024 fyke nets captured smaller crabs than double chamber pots in the lagoon stations ($p < 0.05$) (Table 4, Figure S3). Crabs captured with small pots and with fyke nets did indeed show a wider size distribution, with juveniles also present in the catch. All the other wire pots mainly captured adult crabs. Many seasonal effects and relevant spatial differences that do not seem to depend on gear were detected, with overall smaller crabs being captured in summer compared to all the other seasons. Moreover, in 2023, crabs captured in autumn were bigger than crabs captured in summer ($p < 0.05$), while in 2024, crabs captured in spring were bigger than crabs captured in winter ($p < 0.05$).

The proportion of females also varied seasonally, with lower values in autumn ($p < 0.05$). A spatial pattern also seems to be present, but with no relevant differences among gear in sex selectivity detected (Table 4, Fig. 7, Figure S4), with total female component ranging from 30.51% in type 1 pots to 51.95% in type 2 pots (small pots = 36.36%; double chamber pots = 39,87%; fyke nets = 38.08%).

For blue vs green crab selectivity, across the full sampling period type 1 caught more green crabs (25.63%) than double chamber pots (3.44%) ($p < 0.05$), in 2023 small pot caught more green crabs (42.11%) than type 1 and double chamber pot ($p < 0.05$), and in 2024 a global difference was detected ($p < 0.05$) but without any significant post hoc (green crabs captured with type 2 pots = 28.70%) (Table 4, Fig. 8). Including fyke nets across the full period (green crabs captured = 93.60%) in the lagoon stations, the green crab proportion followed the order fyke nets > double chamber pot > type 1, with small pots capturing less green crabs than fyke nets in 2023 ($p < 0.05$), but more than type 1 and double chamber pot ($p < 0.05$), and type 2 capturing similar percentage of green crab as type 1 in 2024 (Table 4, Figure S5). Seasonal significant differences were also detected, with overall larger capture proportion of green crabs during winter ($p < 0.05$).

4. Discussion

Both the local gear of the artisanal fishery (fyke nets) and the traps derived from the blue crab fishery in North America (double chamber pot) are effective gears for catching blue crabs, exhibiting similar yield (CPUE) levels, significantly higher than those of all the other gears. These results partially contrast with the findings of Glamuzina et al.

Table 2
Summary of the results of the statistical analyses performed to test the efficiency differences among gear (FN = fyke nets; DC = double chamber pot; T1 = type 1 pot; T2 = type 2 pot; S = small pot).

Model Distr. family	Gear (n. observations)	Period	Stations	Statistically significant differences		Correction for spatial effect
				Gear	Seasons	
Binomial	DC (156); T1 (156)	Full	All	DC > T1	Spring > Winter	-
	DC (102); T1 (102); S (102)	First		DC > T1 > S	-	Random
	DC (54); T1 (54); T2 (54)	Second		DC > T1, T2	Spring > Winter	Overdispersion
	DC (81); T1 (81); FN (135)	Full	Lagoon	FN, DC > T1	Spring > Autumn	-
	DC (54); T1 (54); FN (76); S (54)	First		DC > S; FN > T1 > S	-	
	DC (27); T1 (27); FN (59); T2 (27)	Second		FN, DC > T1, T2	Spring > Winter	

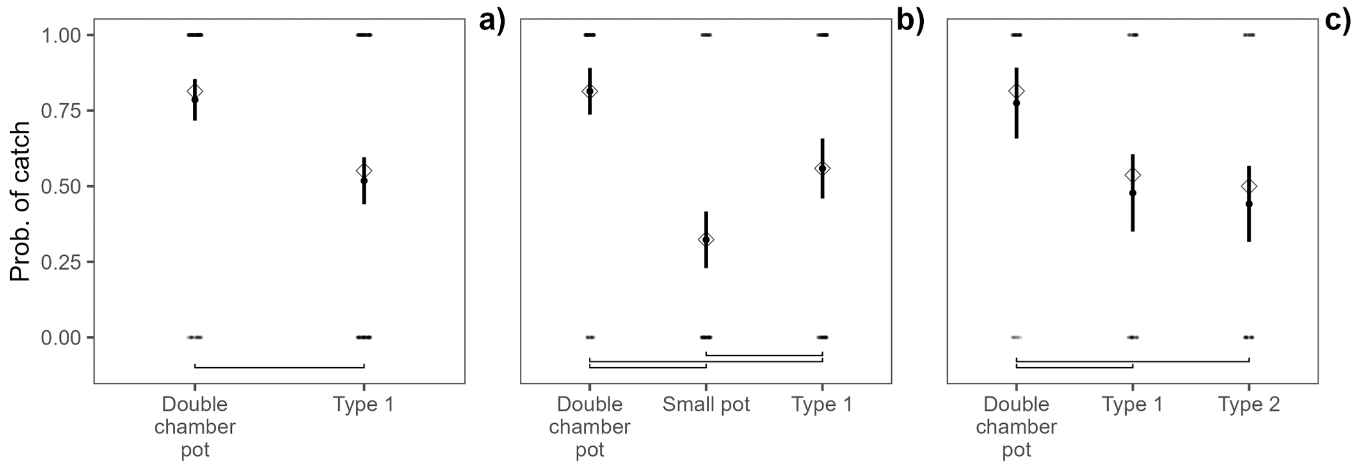

Fig. 4. Efficiency comparison between double chamber pot and type 1 pot in the two periods of the study (a); between double chamber pot, type 1 pot, and small pot in the first period (2023; b); between double chamber pot, type 1 pot, and type 2 pot in the second period (2024; c). The grey dots represent the observations; Diamonds indicate observed means. Black points and vertical bars denote estimated marginal means and 95% confidence intervals derived from the GLMM (population-level predictions). Horizontal lines at the bottom of the plots represent significant differences among gears after post-hoc comparisons.

Table 3
Summary of the results of the statistical analyses performed to test the yield differences among gear (FN = fyke nets; DC = double chamber pot; T1 = type 1 pot; T2 = type 2 pot; S = small pot).

Model Distr. family	Gear (n. observations)	Period	Stations	Statistically significant differences		Correction for spatial effect
				Gear	Seasons	
Tweedie	DC (165); T1 (165)	Full	All	DC > T1	Spring > Summer, Autumn > Winter Overdispersion (Season)	-
	DC (105); T1 (105); S (105)	First		DC > T1 > S	-	
	DC (60); T1 (60); T2 (60);	Second		DC > T1, T2	Spring > Winter	
	DC (84); T1 (84); FN (135)	Full	Lagoon	DC, FN > T1	Spring > Winter	
	DC (54); T1 (54); FN (76); S (54)	First		DC, FN > T1 > S	-	-
	DC (30); T1 (30); T2 (30); FN (59)	Second		DC, FN > T1, T2	Spring > Winter	-

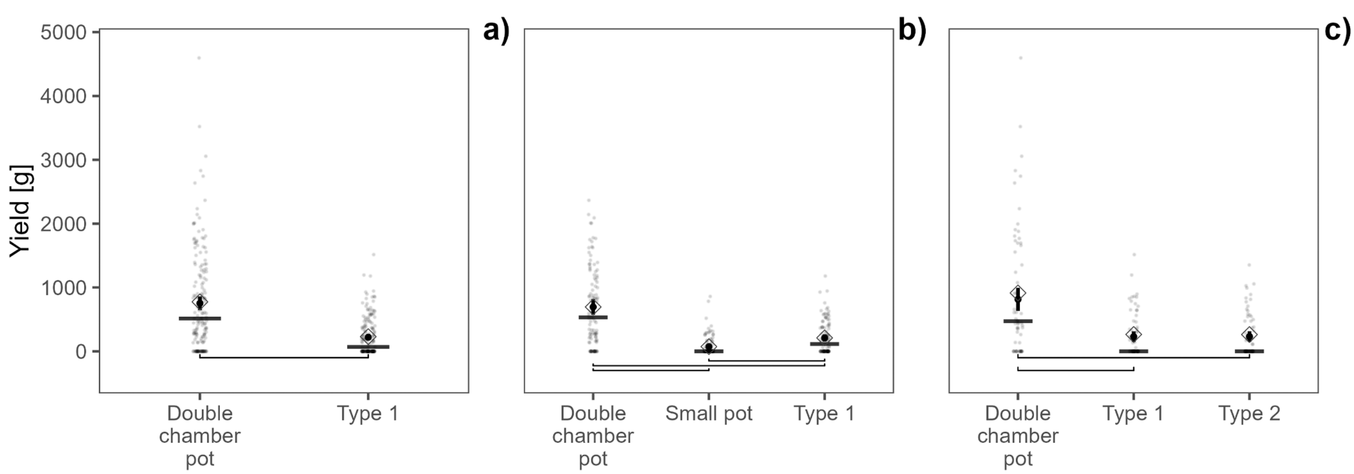

Fig. 5. Yield comparison between double chamber pot and type 1 pot in the two periods of the study (a); between double chamber pot, type 1 pot, and small pot in the first period (2023; b); between double chamber pot, type 1 pot, and type 2 pot in the second period (2024; c). The grey dots represent the observations; Diamonds indicate observed means and horizontal bars show medians. Black points and vertical bars denote estimated marginal means and 95% confidence intervals derived from the GLMM. Horizontal lines at the bottom of the plots represent significant differences among gears after post-hoc comparisons.

(2021), where wire traps were found to be significantly more profitable than fyke nets. Despite the fact that the lack of sampling with fyke nets in July and from December to February might have influenced annual descriptive statistics, our study recorded an overall mean catch of 3.03 crabs/fyke net. This yield is higher than those reported in other Mediterranean regions in the past: 2.17 crabs/fyke net in Methoni Bay (Greece) between 2011 and 2012 (Kevrekidis and Antoniadou, 2018); 1.41 crabs/fyke net in the Evros River Estuary (Greece) between 2020 and 2021 (Kevrekidis et al., 2023); and 0.25 crabs/fyke net in the Parila Lagoon (Croatia) between 2017 and 2018 (Glamuzina et al., 2021). The higher yields observed in our study area could be attributed to the exponential growth phase of the species' colonization, combined with the great primary production and consequently the high availability of resources, particularly clams, that are widely harvested locally (Pranovi

Table 4
Summary of the results of the statistical analyses performed to test the size, sex and species selectivity differences among gear (FN = fyke nets; DC = double chamber pot; T1 = type 1 pot; T2 = type 2 pot; S = small pot.

Response variable	Model Distr. family	Gear (n. observations)	Period	Stations	Statistically significant differences		Correction for spatial effect
					Gear	Seasons	
Size selectivity	Gaussian	DC; T1	Full	All	-	Winter, Spring, Autumn > Summer	Fixed + overdispersion
		DC (349); T1 (102); S (63)	First		DC, T1 > S in Summer only [interaction with season]	Autumn > Summer	
		DC (349); T1 (102); S (63)	Second		-	Spring > Winter	
		DC (91); T1 (31); T2 (13); FN (182)		Lagoon	DC > FN	Global difference (not significant post hoc)	-
Sex selectivity	Binomial + Zero inflaction	DC (165); T1 (165)	Full	All	-	Winter, Summer, Spring > Autumn	Fixed
		DC (105); S (105); T1 (105)	First			Summer > Autumn	Random
		DC (60); T1 (60); T2 (60);	Second			-	Fixed
		DC (30); T1 (30); T2 (30); FN (56)		Lagoon			-
Species selectivity	Betabinomial	DC (165); T1 (165)	Full	All	T1 > DC	Winter > Autumn, Spring, Summer	-
		DC (105); T1 (105); S (105)	First		S > DC, T1	Summer > Autumn	
		DC (60); T1 (60); T2 (60);	Second		Global difference (not significant post hoc)	Winter > Spring	Overdispersion
		DC (84); T1 (84); FN (117)	Full	Lagoon	FN > DC, T1	Winter > Spring, Summer, Autumn + Overdispersion (season)	-
		DC (54); T1 (54); FN (64); S (54)	First		FN > S > DC, T1	-	
		DC (30); T1 (30); FN (53); T2 (30)	Second		FN > T1, T2 > DC	Winter > Spring	

et al., 2006; Gavioli et al., 2025a). In our study, albeit fyke nets demonstrated yield and efficiency (defined as the probability of catching blue crabs when present) comparable to those of double chamber pots, they showed the lowest species selectivity, with the lowest proportion of blue crabs relative to green crabs, and captured a large number of other species. Thus, the use of fyke nets might represent an effective gear for blue crab control but might be incompatible with the traditional fishing of other species. Notably, the blue crab is an aggressive and voracious species (Hill et al., 1989; Epifanio, 2019), potentially causing direct damage to the other caught species or even directly feeding on them (Cannarozzi et al., 2023; Marchessaux et al., 2023). Fyke nets caught indeed a wide range of fish species of economic interest, which is why they have been employed for local fishing activities for centuries (Pranovi et al., 2013; Scapin et al., 2022). Relative to fyke nets, double chamber pots captured significantly larger blue crabs, which are more valuable for the market (Frem et al., 2024); conversely, by also capturing smaller individuals, fyke nets can contribute to limiting population growth through the removal of juveniles. While coated wire pots do have a cost to be employed, as they require baits to attract crabs, they are generally more resistant to cuts from crab claws compared to mesh nets, requiring less maintenance costs and time (Glamuzina et al., 2021). Indeed, mesh nets are more vulnerable to damages inflicted by blue crabs, primarily shredding (Öndes and Gökçe, 2021). Moreover, wire pots can be deployed in all aquatic habitats, while fyke nets are generally restricted to only lagoon areas and inland waters (Granzotto et al., 2001; Pellizzato, 2011), also representing a constraint in our study, as they could not be deployed at the marine and riverine stations. Therefore, we suggest that the double chamber pot represents the preferred gear for catching blue crabs. While type 1 and type 2 pots generally showed intermediate results among the compared gear, small pots were shown to be the overall worst gear for blue crab capture for all response variables in the current study. Small pots not only had the lowest yield and efficiency, but they also had a large proportion of green crabs captured. Even so, small pots may still be useful for specific purposes, such as sampling juveniles or conducting population structure studies, as they capture a wide range of crab sizes.

Lower catch efficiency and yield were recorded during the winter, in line with the drop of water temperatures and consistently with findings of studies from both the native range and other invaded Mediterranean regions (Sharov et al., 2003; Kevrekidis and Antoniadou, 2018; Kevrekidis et al., 2023). Conversely, the peak efficiency and yield observed during Spring 2024 surpassed those of the previous summer, suggesting that the population abundance was still substantially increasing. While gear selectivity exhibited less seasonal consistency, the higher capture of females during summer likely reflects the peak spawning period, but a more comprehensive analysis of the species spatio-temporal dynamics in this area is provided by Boschiero et al. (2026). Focusing on species selectivity, and thus considering bycatch of wire pots, double chamber pots did only occasionally capture specimens of other species, including the lowest proportion of green crabs among all the gears and some specimens of large crab species, such as *M. squinado* and *E. verrucosa*. The double chamber structure represents indeed the standard also for the wire pots employed in the native area of *C. sapidus* to optimize the targeted commercial capture of this species (Guillory and Prejean, 1997; Steele and Bert, 1998). All the other wire post were instead less selective, not only with green crabs, but also with gastropod bivalves such as *H. trunculus* and *Nassarius* sp., which were frequently part of the bycatch. Fyke nets are the least selective gear, having captured the highest proportion of green crabs but also more than 40 different species during the sampling period. The invasive *M. leidy* and *C. sapidus* represent the two highest biomasses. *M. leidy* impacts the fishery activities by filling the net bags and therefore preventing target species from entering the nets and forcing fishermen to open or cut the nets while retrieving them due to the excessive weight of the trapped ctenophores, leading to the loss of the catch (Piccardi et al., 2024). The ongoing invasion of *C. sapidus* might instead impact green crab populations, as already observed in other Mediterranean areas, such as Greece and Spain (Kampouris et al., 2019; Clavero et al., 2022). The larger proportion of green crabs was

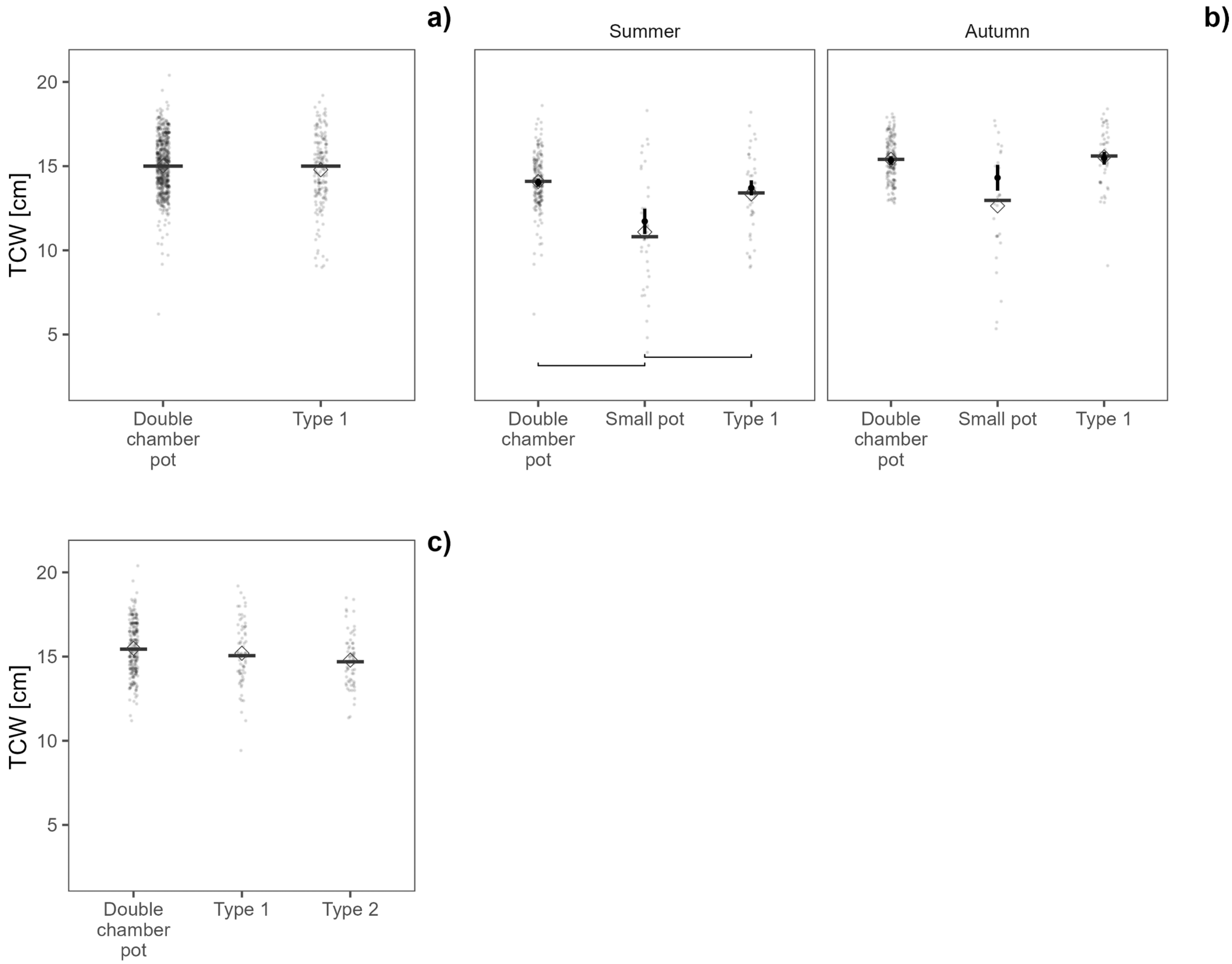

Fig. 6. Total carapace width (TWC) comparison between double chamber pot and type 1 pot in the two periods of the study (a); between double chamber pot, type 1 pot, and small pot in the first period (2023; b); between double chamber pot, type 1 pot, and type 2 pot in the second period (2024; c). The grey dots represent the observations; Diamonds indicate observed means and horizontal bars show medians. Black points and vertical bars denote estimated marginal means and 95% confidence intervals derived from the GLMM. Horizontal lines at the bottom of the plots represent significant differences among gears after post-hoc comparisons.

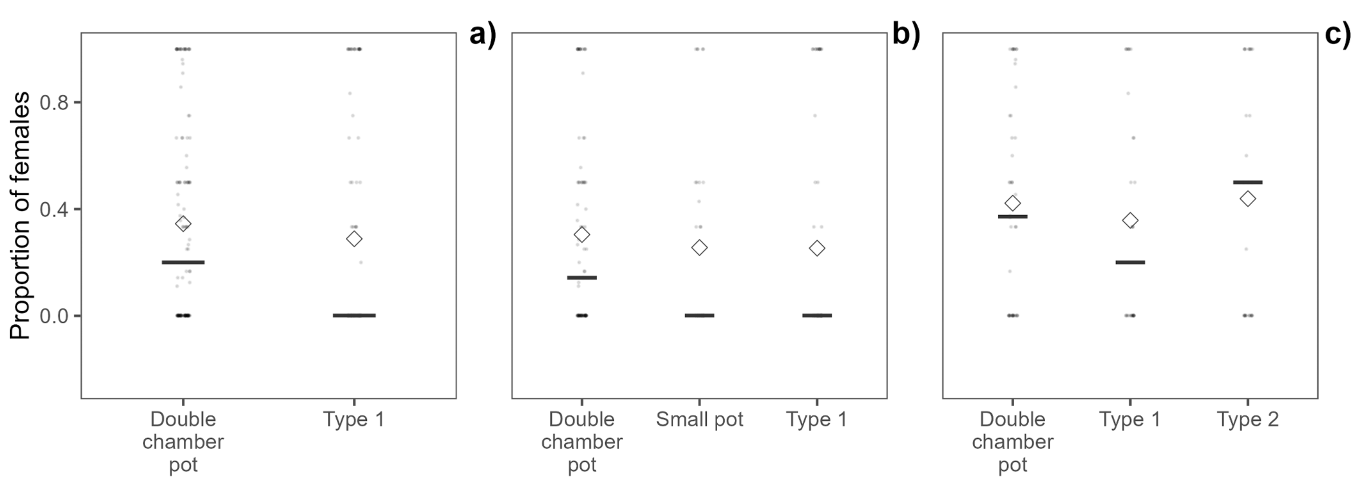

Fig. 7. Comparison of the proportion of females between double chamber pot and type 1 pot in the two periods of the study (a); between double chamber pot, type 1 pot, and small pot in the first period (2023; b); between double chamber pot, type 1 pot, and type 2 pot in the second period (2024; c). The grey dots represent the observations; Diamonds indicate observed means and horizontal bars show medians.

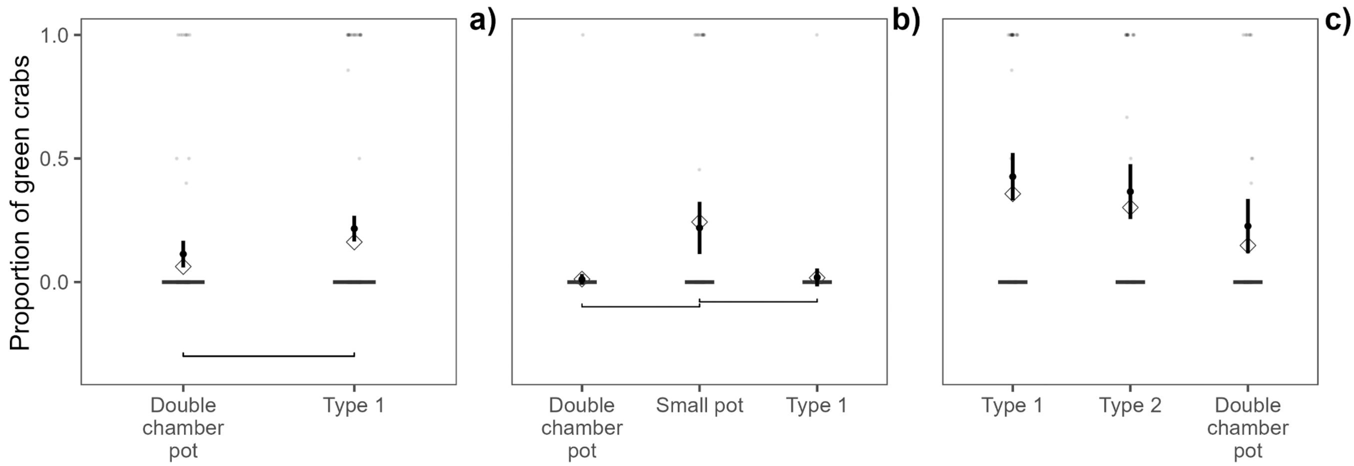

Fig. 8. Comparison of the proportion of green crab between double chamber pot and type 1 pot in the two periods of the study (a); between double chamber pot, type 1 pot, and small pot in the first period (2023; b); between double chamber pot, type 1 pot, and type 2 pot in the second period (2024; c). The grey dots represent the observations; Diamonds indicate observed means and horizontal bars show medians. Black points and vertical bars denote estimated marginal means and 95% confidence intervals derived from the GLMM (population-level predictions). Horizontal lines at the bottom of the plots represent significant differences among gears after post-hoc comparisons.

detected in winter, when the blue crab is generally less active due to lower temperatures (Hines, 2007; Epifanio, 2019, Boschiero et al., 2026), suggesting that *C. sapidus* exerts significant pressure on the native green crab during the rest of the year. Moreover, additional negative impacts on other species and on fishing activity have been detected in several invaded areas in the Mediterranean Sea, including the Adriatic Sea (Mancinelli et al., 2017b; Gavioli et al., 2025b). Blue crab may feed directly on target species such as the Manila clam *R. philippinarum* (Boschiero et al., 2025, Chiesa et al., 2025) but may also damage target catch, non-target bycatch and fishing gear (Glamuzina et al., 2021; Clavero et al., 2022).

Integrating the analysis of the blue crab spatial and temporal distribution with key life-history traits, such as mating and spawning patterns observed locally or in other invaded Mediterranean areas (Kevrekidis et al., 2024; Boschiero et al., 2026), is essential for implementing profitable catch strategies during its ongoing invasion. For instance, other researchers have suggested to intensify harvesting efforts during the peak abundance of ovigerous females, targeting the preferred areas and depth where spawning occurs (Cilenti et al., 2016; Kevrekidis et al., 2024). Therefore, additionally adopting the use of a high efficiency fishing gear, such as the double chamber pots, could be crucial for a more successful control of the species, but also for capturing the blue crab as an exploitable resource, leading to the development of a fishery (Mancinelli et al., 2017b, Cilenti et al., 2024). In some Mediterranean countries, such as Turkey, Greece, and Spain, blue crabs are already fished for food (Ayas and Ozogul, 2011; Kevrekidis and Antoniadou, 2018; Box et al., 2020). The blue crab has a high nutritional value (Tufan, 2023), and in Tunisia, for example, an industry has developed around the capture and commercialization of this species along with the other invasive crab, *Portunus segnis*, leading to economic benefits and new jobs for the local population (Khamassi et al., 2022). This model could be replicated in other areas of the Mediterranean, even though local diets and traditions may be resistant to the consumption of blue crabs (Mancinelli et al., 2017b). Therefore, in the short term, exporting blue crabs might represent a more profitable solution. Additionally, the blue crab could be utilized for purposes beyond dietary uses. For example, the shells can be employed to extract valuable substances like astaxanthin, a potent antioxidant used in feed and supplements (Ambati et al., 2014; Kampouris et al., 2019). Also, the chitin in shells can be processed into chitosan, a versatile biopolymer for applications in biomedicine and food packaging, offering a sustainable use for this byproduct (Bölgen et al., 2016). Therefore, managing the blue crab as a multi-purpose resource could mitigate its negative economic impacts on fishing activities and bivalve harvesting, while providing new employment opportunities and revenue streams. Simultaneously, this approach would contribute to the control of the population.

In conclusion, for management purposes such as population containment or commercial fishing, double chamber pots represent the best choice among the gear types investigated. Although the extent to which our findings can be generalized to all geographical regions or habitat types remains to be determined, the results were consistent across all the diverse environments assessed in this study (lagoon, marine and riverine) and across other studies (e.g. Steele and Bert, 1998; Glamuzina et al., 2021). Moreover, a longer sampling period, especially employing fyke nets, could have reinforced the results. Further investigations could be conducted in other areas, across different habitats or on gear with additional modifications, such as gear colour, that could influence blue crab yield or selectivity, as reported for other crab species (Tran et al., 2020; Susanto et al., 2025). Although none of the tested gears in the present and in other studies exhibited sex selectivity (e.g. Kevrekidis and Antoniadou, 2018), implementing gear modifications focusing on sex selectivity could help targeting ovigerous females for control purposes or optimizing the catch of males to meet market demands. Nevertheless, it is crucial for resource managers to weigh the benefits and risks of exploiting this highly invasive marine species. While commercial fishing could help containing the blue crab abundance, it may simultaneously promote a management approach aimed at sustaining exploitable stocks, and hence preserve the population of the blue crab, rather than minimizing or eradicating the species. This shift could generate a conflict between ecological and economic interests.

CRediT authorship contribution statement

Matteo Zucchetta: Writing – original draft, Formal analysis. **Marco Boschiero:** Writing – original draft, Investigation. **Chiara Facca:** Writing – review & editing, Methodology. **Federico Riccato:** Writing – review & editing, Investigation. **Piero Franzoi:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Google Gemini in order to improve the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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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.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rsma.2026.105025.

Data Availability

Data will be made available on request.

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