Mediterranean Marine Science

Vol 24, No 2 (2023)

VOL 24, No 2 (2023)

The use of an unmanned aerial vehicle to investigate habitat use and behavior of invasive blue crab in Mediterranean microhabitats

GUILLAUME MARCHESSAUX, SERGIO BIZZARRI, NICOLETTA MARSIGLIA, NICOLO PONZÈ, GIANLUCA SARÀ

doi: 10.12681/mms.31332

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
www.hcmr.gr
DOI: http://doi.org/10.12681/mms.31332

The use of an unmanned aerial vehicle to investigate habitat use and behavior of invasive blue crab in Mediterranean microhabitats

Guillaume MARCHESSAUX[1,2], Sergio BIZZARRI[1], Nicoletta MARSIGLIA[1,2], Nicolo PONZÈ[3] and Gianluca SARÀ[1,2]

[1] Laboratory of Ecology, Department of Earth and Marine Science (DiSTeM), University of Palermo, Palermo, Italy
[2] NBFC, National Biodiversity Future Center, 90133 Palermo, Italy
[3] Bio&Tec, via Marinella, 33, 91100 Trapani, Italy

Corresponding author: Guillaume MARCHESSAUX; guillaume.gmarchessaux@gmail.com

Contributing Editor: Giorgio MANCINELLI

Received: 7 September 2022; Accepted: 23 April 2023; Published online: 16 May 2023

Abstract

The blue crab *Callinectes sapidus* has shown an immense capacity to adapt to new habitats in the Mediterranean Sea. Following the numerous reports of its proliferation along western Sicily, an investigation was conducted to identify any existing populations. In August 2021, a population of blue crabs was found in the natural reserve of Trapani which includes a large area of restored saltmarshes. In this study, by developing a tracking system using Unmanned Aerial Vehicles (UAV), we studied (i) the behavior of blue crabs on an hourly scale, and (ii) the weekly position of blue crabs in the saltmarshes to determine substrate preference. This study provides a new approach to better understand *C. sapidus'* habitat use and their potential impact on local biodiversity. Blue crab activity was found to increase with temperature and tidal height, with a peak in activity observed at high tide and at maximum temperatures: the mean speed (m h^{-1}) was higher (12.1 ± 8.7 m h^{-1}) at T > 28 °C than at T = 23.7 °C (2.0 ± 3.2 m h^{-1}). Considering habitat use, in 49 ± 13 % of the cases, blue crabs were observed on the sand, while 21 ± 14 % in the *Cymodocea* meadows, and 30 ± 15 % in the *Ruppia* meadows. These microhabitats provide a refuge for *C. sapidus* and should be prioritized and studied before management plans are designed and implemented to manage this important invasive species.

Keywords: UAV; Saltmarshes; Microhabitats; Invasive Alien Species; *Callinectes sapidus*.

Introduction

Collecting spatially continuous and multi-temporal datasets on invasive species occurrence patterns are an integral part of building a database to better understand invasion patterns and dynamics (Müllerová *et al.*, 2017). The use of aerial surveys is a common tool to monitor wild populations, however until recently the costs were high, and the use restricted to large data collection surveys. The increased availability of inexpensive Unmanned Aerial Vehicles (UAVs) have offered an alternative method to investigate which factors are the most important when addressing colonization. UAVs can assist scientists in gathering useful data that better informs the design of effective conservation measures - from invasive species eradication to societal control (Colefax *et al.*, 2018; Dale *et al.*, 2020; Gonzalez *et al.*, 2016; Hodgson *et al.*, 2017; Kako *et al.*, 2020; Koyama *et al.*, 2020). Easy to manipulate, UAVs offer a new low-cost operational technology with a very high spatial resolution, especially in microhabitats (Kattenborn *et al.*, 2019), producing textural (2D) and structural (3D) metrics to characterize habitats (Colefax *et al.*, 2018; Kattenborn *et al.*, 2019). Several studies have already shown the potential of UAVs for mapping invasive species in terrestrial environments (Alvarez & Solís, 2018; Kattenborn *et al.*, 2019). In marine environments, UAVs are limited to the detection of megafauna (e.g., whales and dolphins, Fettermann *et al.*, 2019; Fiori *et al.*, 2020) or to mapping habitat structure (Doughty & Cavanaugh, 2019; Ventura *et al.*, 2017). For smaller organisms this technology is not currently used, due mainly to issues with detecting these small organisms. Mapping the habitat use and behavior of marine invasive species is important to increase our understanding and to provide critical information that can guide more appropriate management measures. In the absence of new technology, data that is useful for building management frameworks, that considers crucial variables such as habitat use of new colonizers is severely limited. This is because direct field observations are often restricted to a small portion of a much larger habitat. Yet, to develop conservation plans that help preserve biodiversity in habitats with high naturalistic value, it is necessary to enlarge the observational scale and to include essential ecological variables such as those related to habitat structure in the presence of habitat modulators (e.g., aggressive NIS). Integrating traditional data collection methods with new cheap technological devices may facilitate the efforts of conservationists, practitioners, and decision makers.

Callinectes sapidus Rathbun, 1896 is a blue crab native to the western Atlantic that is now prolific throughout the Mediterranean (Marchessaux *et al.*, 2022). Its characteristics lend itself to the use of UAVs to monitor its daily habitat use and behavior which improves our understanding of how to limit its incredible capacity to colonize and adapt to new habitats (Mancinelli *et al.*, 2021). *Callinectes sapidus* is known to live in the oligo-saline waters of estuaries, lagoons and also microhabitats, for the life stages from juveniles to adults (Mancinelli *et al.*, 2017), yet its pattern of habitat use in the Mediterranean Sea is poorly understood. To investigate the potential of UAV technology to improve data collection, we carried out a study on the aggressive alien species *C. sapidus* found in the heart of the Natural Reserve of Trapani ("Saline di Trapani e Paceco") and Stagnone di Marsala, which includes a large salt works and series of marsh ponds (Bellino *et al.*, 2019; Messina *et al.*, 2012; Sarà *et al.*, 1999, 2000). The ponds are microhabitats that range between highly anthropized areas and highly naturalistic sites. They are a key ecological corridor representing an essential stop-over in the Mediterranean for avifauna transiting from Northern Europe to Southern Africa providing a preserved trophic pabulum and possibility to recover during the long migration route. The presence of *C. sapidus* is a serious threat for local and migrating biodiversity due to its ability to disturb the ponds' sediments and alter the trophic structure of these habitats (Johnston & Caretti, 2017; Marchessaux *et al.*, 2023; Perkins-Visser *et al.*, 1996; Posey *et al.*, 2005; Ruas *et al.*, 2014). Tracking the blue crabs' behavior in the field using integrated tracking methods and UAVs is needed to provide insight into population dynamics (e.g., female migrations) and habitat use. Different methods have been applied to track crustacean movements, such as, ultrasonic tracking systems used in Chesapeake Bay, USA (Dittel *et al.*, 1995; Guerra-Castro *et al.*, 2011; Hines *et al.*, 1987; Ruiz *et al.*, 1993; Wolcott & Hines, 1989; Wrona, 2004) and capture/recapture techniques for blue crabs marked with a tag (Fouilland & Fossati, 1996; Jugovic *et al.*, 2015; Lambert *et al.*, 2006). However, these studies are limited to providing long-term data acquisition that misses the small-scale nuanced behavior of organisms.

This current study presents a new non-invasive approach for the *in-situ* study of (i) the behavior of blue crabs during day-time hours and (ii) substrate preference, by developing a tracking system using UAV. This present study will also provide original data on the blue crab behavior in Mediterranean microhabitats.

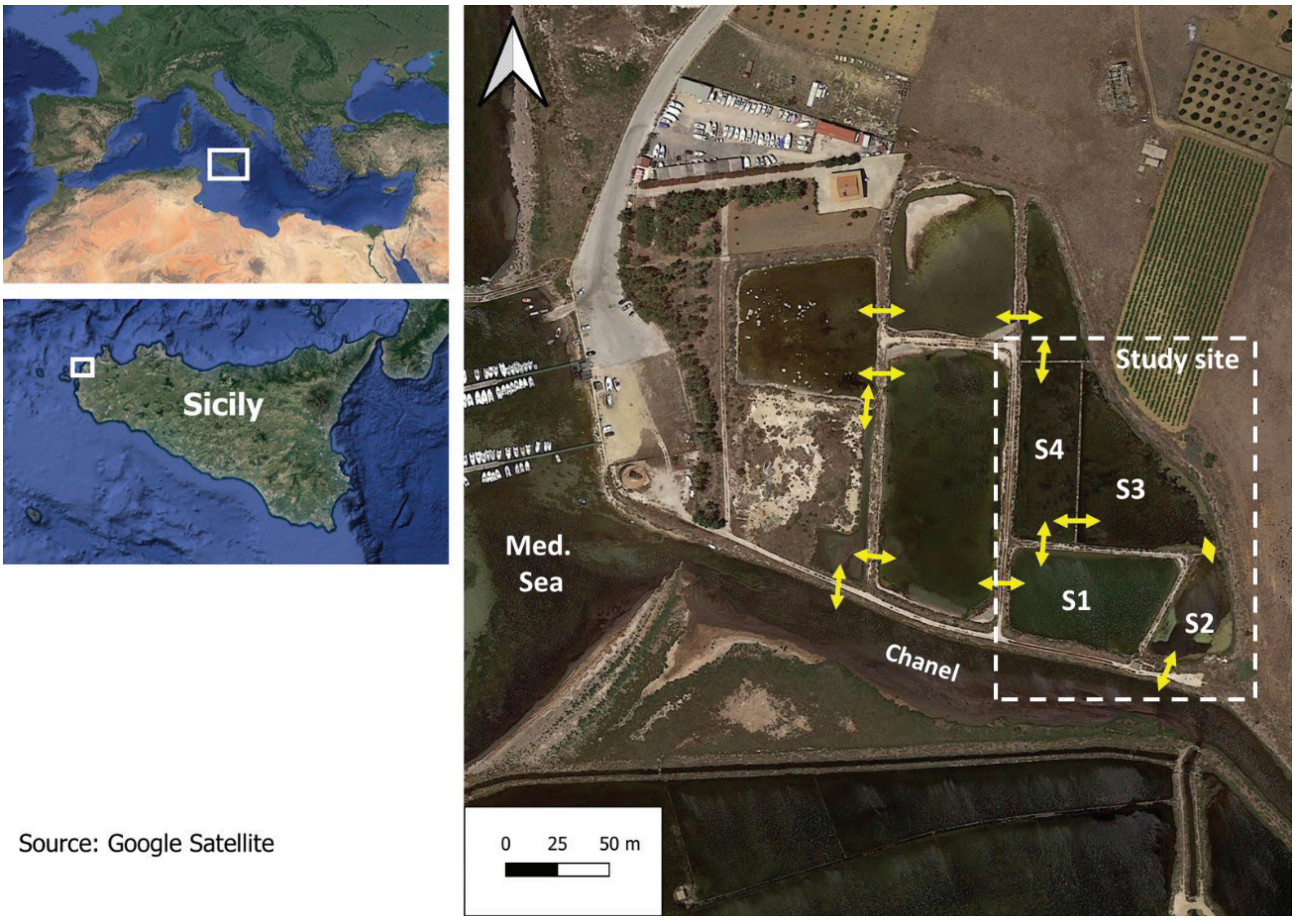

Fig. 1: Map of the study site in the Natural Reserve of Trapani. Yellow arrows represent the connections between the saltmarshes. Med. Sea: Mediterranean Sea.

Materials and Methods

Study site

The study site (named "Salina Grande"; latitude: 37.9538056, longitude: 12.4975833) is in the "Saline di Trapani e Paceco" Nature Reserve (SIC, ITA01007), Sicily (Italy). The reserve (covering 960 ha) consists of a plain characterized by a sandy coast and a large wetland (80 % of the area). The remainder is divided between areas of intense human activity (10 %), wooded and shrubby areas (5 %), and agricultural areas (5 %). Wetlands are represented by the following categories: reed thickets, ponds (30 ha), and salt marshes (750 ha). It is an important wetland used as a resting place by thousands of migratory birds and characterized by a purely halophilic environment of great naturalistic value. The vast wetland has different habitats such as natural mudflats, salt marshes, and canals that are home to over 200 species of birds.

The study site encompasses four connected saltmarshes (max depth; 40 cm) (Fig. 1). As no data was available in the literature for this site, a UAV was used to provide imaging of the entire site. We identified 3 substrate/landscape types from aerial photographs that provide diverse habitats for blue crabs: sandy-muddy substrate only, sandy-muddy and *Cymodocea nodosa* patches, and *Ruppia maritima* patches (Mannino & Sarà, 2006). Using QGIS software (version 3.16.3), and ground truthing from in situ field habitat identification, the site was mapped to calculate the total study area, and the area of different habitats (sand, *Ruppia maritima, Cymodocea nodosa*) (Table 1). The four saltmarshes presented diverse habitats (Table 1). Saltmarshes 1 (S1) and 4 (S4) were found to have important *Ruppia maritima* meadows representing more than 50 % of their total area. Saltmarsh 2 (S2) was found to be a sandy-muddy habitat and S3 was found to have both sandy-muddy and *Cymodocea nodosa* habitats.

Sampling and processing

The first blue crab was observed on the 6th of August 2021 in the "Salina Grande". Following this, monitoring was carried out between the 6th of August to the 30th of November 2021. Using traps and hand nets, blue crabs were sampled and frozen. In the laboratory the specimens' sex was determined, and the carapace width (distance between the two dorsal spines) and wet weight were measured for each sampling date.

To determine habitat use and blue crab movements in the saltmarshes, a new approach was designed using a UAV. Ten crabs were caught in the saltmarsh S3 with a hand net and placed in a basin containing saltmarsh water. After making sure they were in good health (complete organisms with the full number of legs and claws), a wire (1 mm diameter) was attached to the carapace and fixed between the two dorsal spines (Lambert *et al.*, 2006) (Fig. 2). Another ~50 cm length wire, with a buoy (mean mass: 30 ± 0.8 g) with a unique symbol was attached then to the one on the carapace (Fig. 2A, B). The wire was light and yet stiff enough to prevent crabs from getting stuck in the seagrasses. Crabs were gently released ~1 m from the wall of the saltmarsh at different locations for each. The size of the blue crabs studied was between 12.4 and 18.4 cm and the weight between 126 and 405 g (Table 2). The mass of the wire system alone averaged 3 ± 1 % of the blue crabs' total body mass (with the buoy being at the surface, its mass was negligible). This system was tested in a laboratory setting over a 10-day period, in which crabs were placed in a 500 L tank (60 cm depths, 180 cm length) to identify any effects on blue crab well-being and movements. After validation in the laboratory (no effect of buoy and wire system on blue crabs' movements), the system was approved for use in the field.

Experimental observations were carried out on 3 days (September 28th and 29th, 2021 and on October 6th, 2021). Before starting observations, a period of 2 hours was provided to allow the crabs to get used to the system. After this period, photos of the crabs' position were taken using a UAV (DJI Mavic Pro) every hour until sunset at ~19:00 (Fig. 2C): one high attitude (~ 50 m) picture was taken each hour to cover the whole basin and pictures were taken following each individual organism (at 5-6 m altitude). Simultaneously, an observer, hidden from the crabs (behind a mobile structure) to avoid possible researcher interference, recorded the positions of the crabs on an aerial photo of the saltmarsh taken on a previous occasion with the UAV (Fig. 2C). Between each flight, the observer reported the positions of the buoys on the maps to more precisely detect the trajectories. At the end of the first day,

Table 1. Habitat characteristics of Trapani's saltmarshes.

	Saltmarsh 1 (S1)	Saltmarsh 2 (S2)	Saltmarsh 3 (S3)	Saltmarsh 4 (S4)
Total area (m^2)	3 229	1 386	3 412	2 449
Area sand (m^2)	1 575	1 386	2 370	1 005
Area *Ruppia maritima* (m^2)	1 654	-	-	1 444
Area *Cymodocea nodosa* (m^2)	-	-	1 042	-

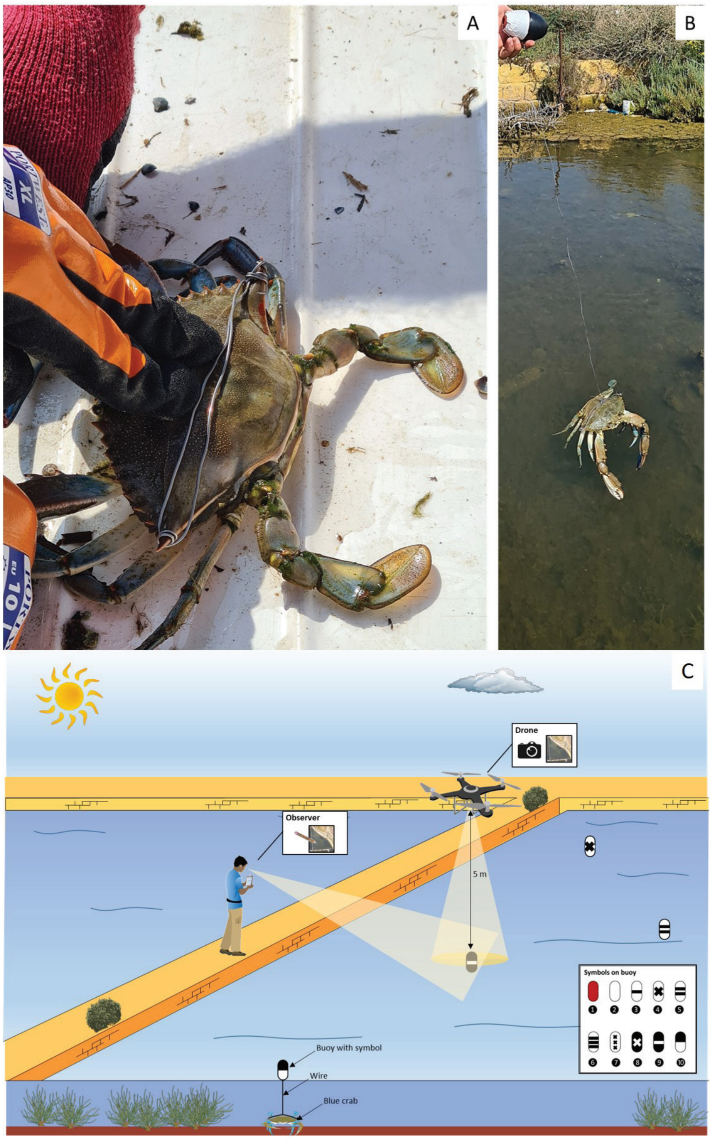

Fig. 2: (A-B) Pictures of the buoy system to track hourly movements of blue crab; (C) diagram presenting the method for tracking the movements of blue crabs in the saltmarshes of Trapani (Italy).

Table 2. Biometric measurements of the blue crabs used for the tracking experiment.

ID crab	Sex	Size (cm)	Weight (g)
1	Male	18.4	405
2	Male	14.9	273
3	Male	17.1	395
4	Male	16.3	357
5	Male	14.4	213
6	Male	14.1	220
7	Male	14.7	243
8	Male	13.5	147
9	Male	12.4	126
10	Male	15.7	303

the crabs with the buoys were left in the saltmarsh to track their weekly position over a month (28th September - 27th October 2021) preceding the crabs' hibernation period in the late fall (Milori *et al.*, 2017; Shields *et al.*, 2015).

Temperature was continuously recorded every hour throughout the recording period using HOBO Pendant® loggers (mod. MX2201, ± 0.5 °C accuracy). Data on tidal height (m) dynamics were extracted from the ISPRA database (Istituto Superiore per la Protezione e la Ricerca Ambientale, https://www.mareografico.it). Temperature and tidal height are known to be the main environmental factors influencing blue crab movements (Wrona, 2004).

Data analysis

All the spatial analyses were performed using QGIS software (version 3.16.3). Pictures taken with the UAV were compiled and georeferenced: each point was recorded along with the crab ID, date, and time. Hourly trajectories of blue crabs were traced between each position for each day and each hour using QGIS software (version 3.16.3). The distances covered by the blue crabs were also calculated using QGIS software. The substrate type for each point was extracted for the hourly and monthly records. For the hourly study, the percentage of time spent by the blue crabs as a function of substrate type was calculated. For the monthly study, the percentage of frequency was calculated as a function of habitat type. To determine the relationship between carapace width and crab mass, linear regressions were performed using Sigmaplot 12.5 software.

To test the importance of environmental variables (i.e., temperature, sea level) on blue crab activity, a linear multiple regression was performed. Differences in blue crab movement speed and sighting frequency as a function of substrate, were tested using nonparametric Kruskal–Wallis ANOVA, followed by post-hoc Dunn tests (Sigmaplot 12.5).

Results

The analyses of the activity and habitat use varied from one crab to another in the saltmarshes of Trapani (Supplementary Fig. S1). The crabs' hourly activity showed the same trends (Fig. 3A, B, C): a short distance covered before 15:00, 5.2 ± 7.7 m h^{-1} (T = 28.2 ± 0.6 °C, September 28th), 8.8 ± 12.4 m h^{-1} (T = 27.2 ± 1.1°C, September 29th), and 0.9 ± 1.1 m h^{-1} (T = 23.0 ± 0.8 °C, October 6th) respectively; increasing to reach a maximum at 16:00-17:00 (14.5 ± 13.6 m h^{-1}; on September 28th: 32.2 ± 26.4 m h^{-1}; on September 29th) and between 16:00 and 18:00 on October 6th (3.4 ± 2.0 m h^{-1}); related to the daily maximum temperature and tidal height measured at the same time. The multiple linear regression showed that the blue crab activity was significantly ($p < 0.001$) correlated with temperature and not tidal height (Table 3A; Fig. 3D).

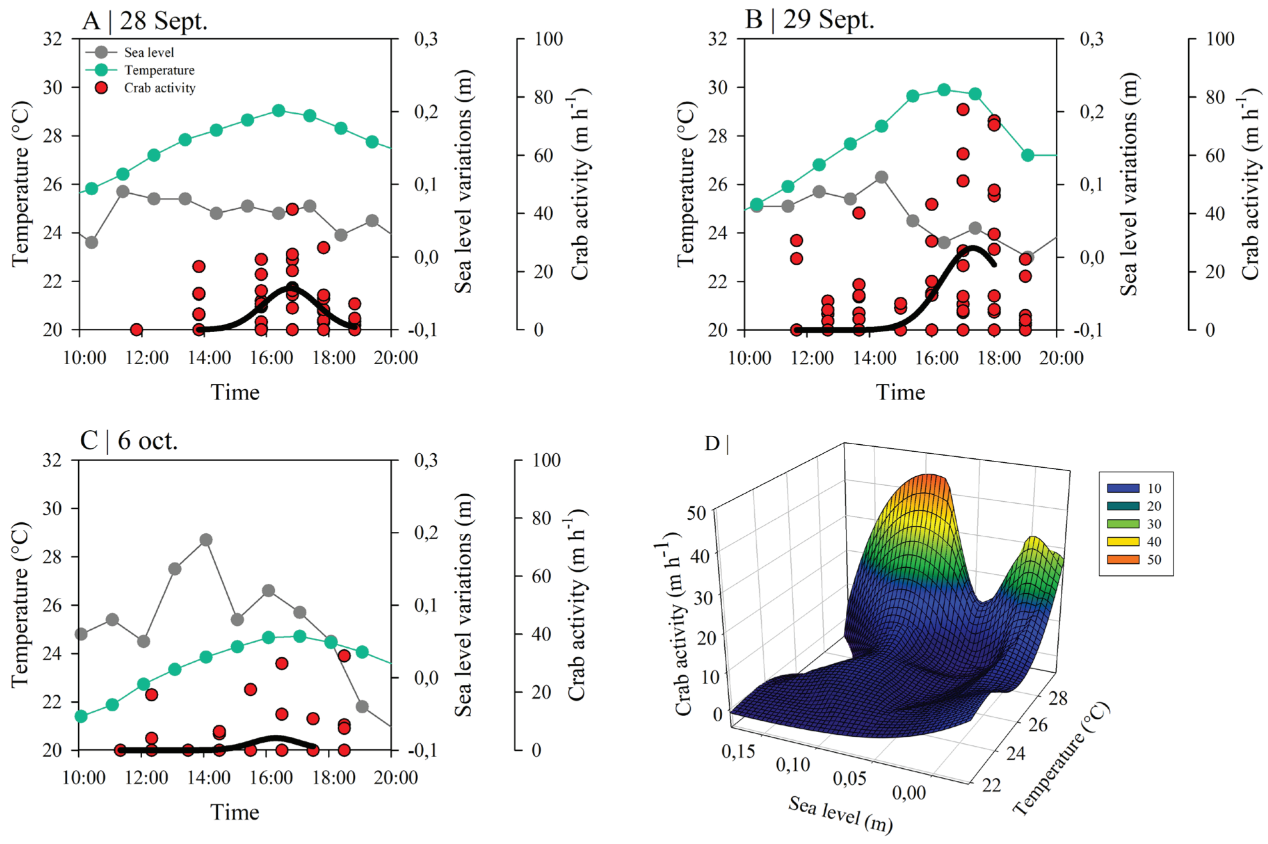

Fig. 3: Blue crab activity (speed, m h^{-1}), temperature (°C) and tidal height (m) for (A) 28th September 2021, (B) 29th September 2021, and (C) 6th October 2021, (D) 3-dimensional representation of the blue crab activity as a function of temperature and tidal height variations. The black lines on the graphs A, B, C represent the regressions based on the crab activity. Midday is at 12:00 h.

Table 3. (A) Linear multiple regression model on blue crab activity (n = 209 observations), and (B) results of the ANOVA performed on the frequency of blue crab observations as a function of substrate type over one month.

A

Environmental parameters	Coefficients	Standard error	t	*p* value
Temperature	1.939	0.441	4.400	< 0.001**
Tidal height	-38.845	20.286	-1.915	0.057 ^{NS}

**p < 0.01: significant difference; NS: non-significant difference

B

Comparison	Diff of Means	t	*p* value
Sand vs. *Cymodocea*	28.466	4.901	< 0.001**
Sand vs. *Ruppia*	18.965	3.265	0.008*
Ruppia vs. *Cymodocea*	9.501	1.636	0.334 ^{NS}

** p < 0,01: significant difference; NS: non-significant difference

The percentage of time spent in the substrate was significantly higher (ANOVA, Kruskal-Wallis, $H = 6.84$, $p < 0.05$) in the seagrasses (80 ± 42 %) than in the sand (20 ± 42 %) at 23.7 °C (6 Oct.) (Fig. 4A, B). For a higher temperature (28.3°C; 28 & 29 Sept.), there was no difference in the percentage of time spent in the different substrates (seagrasses: 50 ± 40 %, sand: 51 ± 39 %). The long-term distribution of blue crabs (September 28th and October 27th, 2021) (Supplementary Fig. S2) showed that in 49 ± 13 % of the cases, blue crabs were observed on the sand while 21 ± 14 % in the *Cymodocea* meadows, and 30 ± 15 % in the *Ruppia* meadows (Fig. 4C and D) and the differences were significantly higher (Table 3B).

Discussion

The temporal and spatial analysis presented in this study indicates that saltmarshes provide a favorable habitat for invasive blue crabs. The use of micro-habitats by *Callinectes sapidus* is known to be key to maintaining sustainable blue crab populations (Ramach *et al.*, 2009). The average speed data for blue crabs' movement obtained in this study was consistent with data available in the literature: 12 m h^{-1} in the shallow coastal waters (~1 m) of the Chesapeake Bay, USA (Clark *et al.*, 1999; Dittel *et al.*, 1995; Wolcott & Hines, 1989) and 28 m h^{-1} in the saltmarshes in Georgia, USA (Wrona, 2004). This would indicate that our approach to track their movement causes little or no disturbance to individuals, and this semi-rigid system prevented the wire from getting stuck in the seagrasses. The blue crabs were also very active during the day in our study site and more with the tide changes as observed in its native area (Clark *et al.*, 1999). The low-cost system tested allowed the position of individuals to be followed in shallow (~ 1 m) and semi-closed systems over a minimum period of one month. Tracking the movement of blue crabs is important for understanding population dynamics (e.g., female migrations, juveniles' recruitment) and habitat use. Other methods have been used to track crustacean movements, such as, ultrasonic tracking systems used in the Chesapeake Bay, USA (Dittel *et al.*, 1995; Guerra-Castro *et al.*, 2011; Hines *et al.*, 1987; Ruiz *et al.*, 1993; Wolcott & Hines, 1989; Wrona, 2004) and capture/recapture methods for blue crabs marked with a tag (Fouilland & Fossati, 1996; Jugovic *et al.*, 2015; Lambert *et al.*, 2006). These methods are certainly more suitable for monitoring well-established blue crab populations over the long term, but the buoy system presented in our study is well suited to hourly studies, providing a more nuanced understanding of behavior patterns. Also, this study needs to be exclusively applied in microhabitats with shallow water (< 1 m) where *Callinectes sapidus* does not need to swim due to the low depth.

When studying the life history or population dynamics of any organism understanding habitat use is fundamental as habitats provide the food and shelter needed for survival (Johnson & Eggleston, 2010; Ros *et al.*, 2021). Kenward (1987) identified important questions when studying the relationship between habitat and organisms such as: 1) what habitats are available to the organism? and 2) what is the preference and degree of habitat use? In this study, it was shown that the Trapani saltmarshes were used by both juvenile and adult blue crabs as are the saltmarshes in their native areas, which has been demonstrated in numerous studies (Fitz & Wiegert, 1991; Heck *et al.*, 1995; Hovel & Lipcius, 2002; Jivoff & Able, 2003; Orth & van Montfrans, 2002; Posey *et al.*, 2005; Rudershausen *et al.*, 2021).

Vegetated saltmarsh habitats are generally used as nursery areas by small (< 30 mm) juvenile blue crabs (Fitz & Wiegert, 1991; King *et al.*, 2005; Lipcius *et al.*, 2005; Posey *et al.*, 2005; Thomas *et al.*, 1990). Larger cohorts have also been observed in these areas (Fitz & Wiegert, 1991; Johnson & Eggleston, 2010; Lipcius *et al.*, 2005)

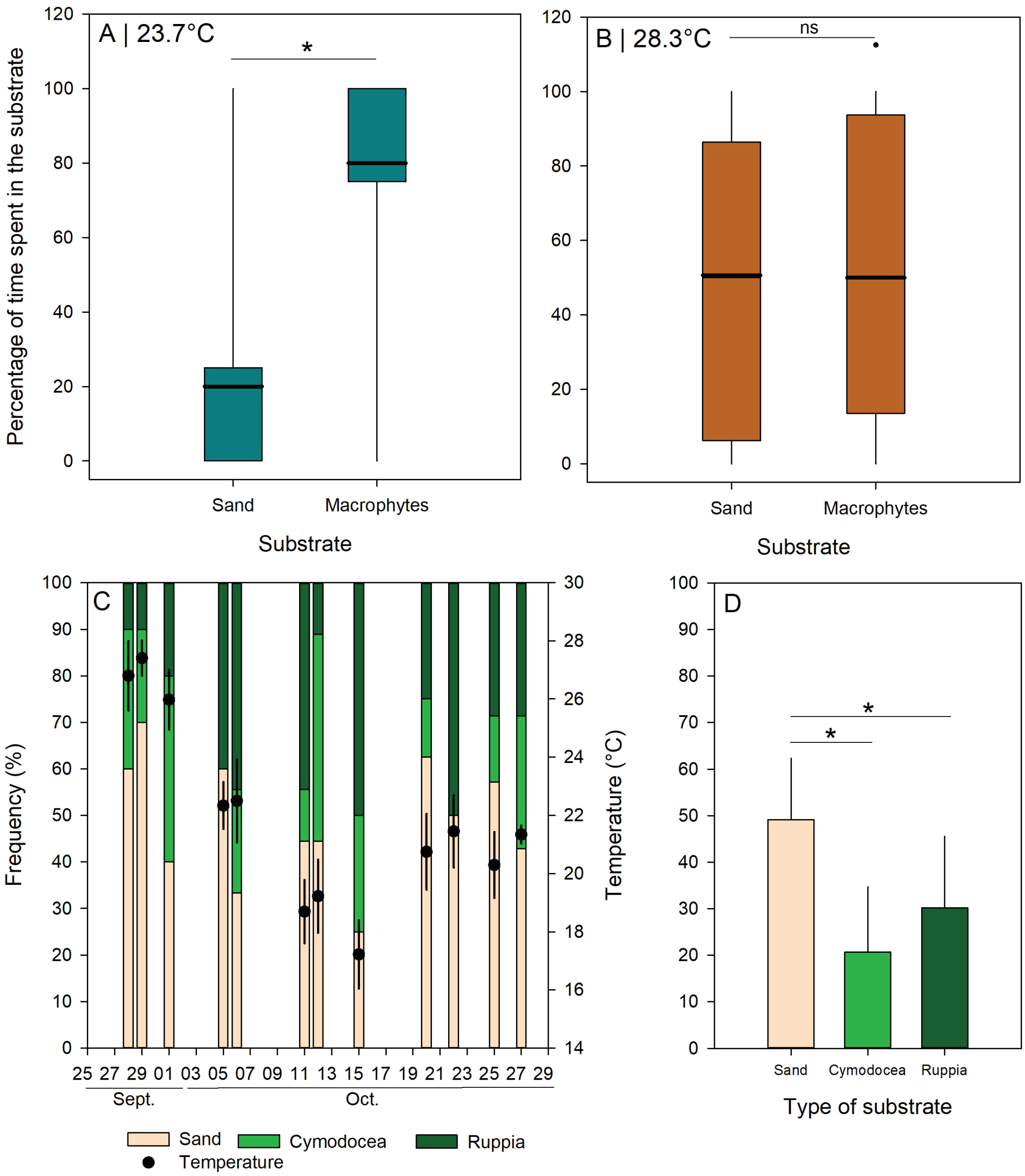

Fig. 4: Percentage of time spent as a function of substrate type at (A) 23.7 °C mean temperature (6th Oct.) and (B) 28.3 °C mean temperature (28th-29th Sept.), (C) monthly frequencies of observations and (D) mean monthly frequencies of observations as a function of substrate type. *: significant difference, Kruskal-Wallis, $p < 0.05$. NS: non-significant difference.

and was confirmed by our study. Shallow (~1 m), marshy, vegetated habitats are suitable for maintaining blue crab populations (Fitz & Wiegert, 1991; Hines *et al.*, 1987; Johnson & Eggleston, 2010), as these microhabitats are very important for ovigerous crabs (Ramach *et al.*, 2009). The females remain in these habitats until larval release (Hench *et al.*, 2004; Mense & Wenner, 1989).

Blue crabs were found to use the entire saltmarsh, alternating between sandy-muddy substrates and seagrasses, showing a preference for sandy-muddy substrate, as has been reported in the literature (Table 4). This study was the first to report the presence of a sustained population of *Callinectes sapidus* in Mediterranean saltmarshes. The complexity of the saltmarsh habitat investigated, offering both sandy-muddy and seagrasses substrates with high fragmentation, allows specimens to move over bare sediments (without vegetation) and be protected in the meadows in case of danger (Johnston & Caretti, 2017; Perkins-Visser *et al.*, 1996; Posey *et al.*, 2005; Ruas *et al.*, 2014) or to avoid cannibalism or fighting (Perkins-Visser *et al.*, 1996; Reichmuth *et al.*, 2011). The habitat variation and fragmentation pattern observed within the saltmarsh probably explained the small distances traveled in our study, which supports the data from the literature. We also found that blue crabs' activity was directly influenced by temperature, with a peak in activity observed for daily maximum temperatures (> 28 °C) and for the highest tidal heights. This pattern was also observed in saltmarshes in the USA during high tides (Fitz & Wiegert, 1991). Previous studies reported higher blue crab growth and

Table 4. Habitat descriptions reported in the literature for *Callinectes sapidus* in the Mediterranean Sea: ecosystem and substrate types, and depth.

Country	Location name	Ecosystem type	Substrate type	Depth (m)	Temperature ranges (°C)	Reference
Algeria	Mellh lagoon	Lagoon	Muddy	2.5	10-30.2	(Kara & Chaoui, 2021)
Croatia	Neretva	Estuary	Muddy	4	No data	(Dulcic & Dragicevic, 2010)
Croatia	Neretva	Estuary	Sandy-muddy and muddy	-	9.2-26.7	(Jakov & Glamuzina, 2011)
Croatia	Neretva	Estuary	Muddy	5-7	10.2-22.7	(Onofri *et al.,* 2008)
Croatia	Ston	Lagoon	Sandy-muddy	0.5	10.2-22.7	(Onofri *et al.,* 2008)
Egypt	Bardawil	Lagoon	Seagrasses	-	13.7-27.0	(Abdel Razek *et al.,* 2016)
Greece	Marmaro	Estuary	Muddy	0.4	No data	(Katsanevakis *et al.*, 2014)
Italy	Silvi Marina	Estuary	Rocks - sand	10	No data	(Castriota *et al.,* 2012)
Italy	Metauro	Estuary	Rocks - sand	10	No data	(Castriota *et al.,* 2012)
Italy	Ugento	Lagoon	Sandy	-	Max = 27	(Gennaio *et al.,* 2006)
Italy	Sacca di Goro	Lagoon	Sandy	0.6-2	No data	(Manfrin *et al.,* 2015)
Italy	Trapani	Salt marsh	Sandy-muddy, *Cymodocea, Ruppia*	0.5	7.0-30.5	This study
Morocco		Estuary	Sandy-muddy	-	No data	((Taybi & Mabro
Russia	Varna bay	Open coast	Sandy	5-6	3-35	(Pashkov *et al.,* 2012)
Russia	Cape Bolshoi Utrish	Open coast	Sandy	20	No data	(Monin, 1984)
Russia	Crimean coast	Open coast	Sandy	30	3-35	(Pashkov *et al.,* 2012)
Spain	Tancada	Lagoon	Muddy	1-5	10-30	(Castejón & Guerao, 2013)
Turkey	Trabzon	Open coast	Sandy-muddy	8-12	No data	(Orhan *et al.,* 2015)
Turkey	Yumurtalik	Lagoon	Muddy	5	No data	(Bilen *et al.,* 2011)

density in vegetated habitats compared to non-vegetated habitats (Lipcius *et al.*, 2005; Perkins-Visser *et al.*, 1996; Thomas *et al.*, 1990) with an increase in survival rates in closely fragmented environments (Mizerek *et al.*, 2011). In New England's tidal rivers an average temperature of 23 °C and a maximum of 29 °C closely match the conditions under which blue crab growth is maximized (23-27 °C; Cadman & Weinstein 1988), meaning that shallow waters provided an optimal thermal regime during the summer growing season (Taylor & Fehon, 2021). These structured habitats provided more food (Harrod, 1964; Heck Jr & Wetstone, 1977; Taylor & Fehon, 2021) and protection than bare sediment habitats (Canion & Heck, 2009; Heck & Thoman, 1984).

The high density of seagrasses in the Trapani saltmarsh probably explains the high abundance and biomass of mature adults found confirming the findings of previous studies (Dittel *et al.*, 2006, 2000; Orth & van Montfrans, 1990; van Montfrans *et al.*, 2003). The substrate type where crabs were found to aggregate in this study suggests that crab movements were most likely dependent on foraging activity. In previous studies, high abundances of blue crabs were observed in the Rhode River estuary where large quantities of clams were present (Seitz *et al.*, 2005; Wolcott & Hines, 1989). It has been observed that once on a patch, they remained there consuming multiple prey items (Seitz *et al.*, 2005; Wolcott & Hines, 1989). Saltmarsh habitat has been shown to be a refuge for blue crabs, but also a source of abundant food with large quantities of protein and amino acids in the sediments (Dittel *et al.*, 2006; Fantle *et al.*, 1999) and in the prey (e.g., infauna and epifauna; Calabretta & Oviatt 2008; Cordero & Seitz 2014). In fact, in the York River, a Chesapeake Bay tributary, blue crab growth rates were greatest where densities of clams were highest in both seagrasses and non-vegetated soft-substrate environments (Seitz *et al.*, 2005).

We conclude that the use of a low-cost system for hourly monitoring of a blue crab population was effective and the results were consistent with data available in the literature. Yet this type of method is limited and cannot be applied to all habitats. Even if this system is inexpensive, it demands time and human presence during the whole study (for many hours) but performed at high frequency the cost/benefit could be negligible. Additionally, the use of UAV is limited to daylight hours, shallow depths and in periods without strong winds. However, within shallow microhabitats (max 1 m depth) this method seems to be conclusive and would allow us to know more about the ecology of *Callinectes sapidus*. In future studies using this method, more individuals and information on insolation or light intensity needs to be used to understand whether (high or low insolation, clouds) may affect the blue crab's activity in different seasons.

The presence of the blue crab *C. sapidus* in microhabitats such as saltmarshes constitutes a new challenge in understanding the ecology of this species. Known as an aggressive and voracious predator, the presence of blue crabs in the Trapani natural reserve poses a significant threat to the preservation of the biodiversity of the site, especially on the native green crab which is decreasing with the presence of blue crabs due to the predation/competition pressure (unpublished pers. data). On a more global scale, it is important to consider these microhabitats in future studies on the invasion of *C. sapidus*. Indeed, these microhabitats constitute a refuge for *C. sapidus* populations and should be prioritized and well-studied before the design and implementation of management plans that deal with this problematic invasive species.

Acknowledgements

This study is part of the BLEU-ADAPT project supported by Interreg Italy-Tunisia Program 2014-2020, Ref. n° IS_3.1_021. We would like to thank Kate Hogg, a native English speaker, for proof-reading the text.

References

Abdel Razek, F.A.A., Ismaiel, M., Ameran, M.A.A., 2016. Occurrence of the blue crab *Callinectes sapidus*, Rathbun, 1896, and its fisheries biology in Bardawil Lagoon, Sinai Peninsula, Egypt. *Egyptian Journal Aquatic Research*, 42, 223-229.

Alvarez, S., Solís, D., 2018. Rapid Response Lowers Eradication Costs of Invasive Species. *Choices*, 33, 1-9.

Bellino, A., Mangano, M.C., Baldantoni, D., Russell, B.D., Mannino, A.M. *et al.*, 2019. Seasonal patterns of biodiversity in Mediterranean coastal lagoons. *Diversity and Distribution*, 25, 1512-1526.

Bilen, C.T., Kokcu, P., Ibrikci, T., 2011. Application of artificial neural networks (ANNs) for weight predictions of blue crabs (*Callinectes sapidus* Rathbun, 1896) using predictor variables. *Mediterranean Marine Science*, 12, 439-446.

Cadman, L.R., Weinstein, M.P., 1988. Effects of temperature and salinity on the growth of laboratory-reared juvenile blue crabs *Callinectes sapidus* Rathbun. *Journal of Experimental Marine Biology and Ecology*, 121, 193-207.

Calabretta, C.J., Oviatt, C.A., 2008. The response of benthic macrofauna to anthropogenic stress in Narragansett Bay, Rhode Island: a review of human stressors and assessment of community conditions. *Marine Pollution Bulletin*, 56, 1680-1695.

Canion, C.R., Heck, K.L., 2009. Effect of habitat complexity on predation success: re-evaluating the current paradigm in seagrass beds. *Marine Ecology Progress Series*, 393, 37-46.

Castejón, D., Guerao, G., 2013. A new record of the American blue crab, *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae), from the Mediterranean coast of the Iberian Peninsula. *BioInvasions Records*, 2, 141-143.

Castriota, L., Andaloro, F., Costantini, R., De Ascentiis, A., 2012. First record of the Atlantic crab *Callinectes sapidus* Rathbun, 1896 (Crustacea: Brachyura: Portunidae) in Abruzzi waters, central Adriatic Sea. *Acta Adriatica: International Journal of Marine Sciences*, 53, 467-470.

Clark, M.E., Wolcott, T.G., Wolcott, D.L., Hines, A.H., 1999. Foraging and agonistic activity co-occur in free-ranging blue crabs (*Callinectes sapidus*): observation of animals by

ultrasonic telemetry. *Journal of Experimental Marine Biology and Ecology,* 233, 143-160.
Colefax, A.P., Butcher, P.A., Kelaher, B.P., 2018. The potential for unmanned aerial vehicles (UAVs) to conduct marine fauna surveys in place of manned aircraft. *ICES Journal of Marine Science*, 75, 1-8.
Cordero, A.L.H., Seitz, R.D., 2014. Structured habitat provides a refuge from blue crab, Callinectes sapidus, predation for the bay scallop, *Argopecten irradians concentricus* (Say 1822). *Journal of Experimental Marine Biology and Ecology,* 460, 100-108.
Dale, J., Burnside, N.G., Hill-Butler, C., Berg, M.J., Strong, C.J. *et al.,* 2020. The use of unmanned aerial vehicles to determine differences in vegetation cover: A tool for monitoring coastal wetland restoration schemes. *Remote Sensing*, 12, 4022.
Dittel, A.I., Epifanio, C.E., Fogel, M.L., 2006. Trophic relationships of juvenile blue crabs (*Callinectes sapidus*) in estuarine habitats. *Hydrobiologia*, 568, 379-390.
Dittel, A.I., Epifanio, C.E., Schwalm, S.M., Fantle, M.S., Fogel, M.L., 2000. Carbon and nitrogen sources for juvenile blue crabs *Callinectes sapidus* in coastal wetlands. *Marine Ecology Progress Series*, 194, 103-112.
Dittel, A.I., Hines, A.H., Ruiz, G.M., Ruffin, K.K., 1995. Effects of shallow water refuge on behavior and density-dependent mortality of juvenile blue crabs in Chesapeake Bay. *Bulletin of Marine Science*, 57, 902-916.
Doughty, C.L., Cavanaugh, K.C., 2019. Mapping coastal wetland biomass from high resolution unmanned aerial vehicle (UAV) imagery. *Remote Sensing*, 11, 540.
Dulcic, J., Dragicevic, B., 2010. New record of the blue crab, *Callinectes sapidus* Rathbun, 1896,(Decapoda: Brachyura) in the Adriatic Sea, in: Annales: Series Historia Naturalis. *Scientific and Research Center of the Republic of Slovenia*, p. 23.
Fantle, M.S., Dittel, A.I., Schwalm, S.M., Epifanio, C.E., Fogel, M.L., 1999. A food web analysis of the juvenile blue crab, *Callinectes sapidus*, using stable isotopes in whole animals and individual amino acids. *Oecologia,* 120, 416-426.
Fettermann, T., Fiori, L., Bader, M., Doshi, A., Breen, D. *et al.*, 2019. Behaviour reactions of bottlenose dolphins (Tursiops truncatus) to multirotor Unmanned Aerial Vehicles (UAVs). *Scientific Reports*, 9, 1-9.
Fiori, L., Martinez, E., Bader, M.K.-F., Orams, M.B., Bollard, B., 2020. Insights into the use of an unmanned aerial vehicle (UAV) to investigate the behavior of humpback whales (Megaptera novaeangliae) in Vava'u, Kingdom of Tonga. *Marine Mammal Science*, 36, 209-223.
Fitz, H.C., Wiegert, R.G., 1991. Utilization of the intertidal zone of a salt marsh by the blue crab *Callinectes sapidus*: density, return frequency, and feeding habits. *Marine Ecology Progress Series*, 249-260.
Fouilland, E., Fossati, O., 1996. Trapping efficiency of plastic bottle "wickertraps" for population assessment of river Macrobrachium (Crustacea: Decapoda). *Fisheries Research*, 28, 343-351.
Gennaio, R., Scordella, G., Pastore, M., 2006. Occurrence of blue crab *Callinectes sapidus* (Rathbun, 1986, Crustacea, Brachyura), in the Ugento ponds area (Lecce, Italy). *Thalassia Salentina*, 29, 29-39.
Gonzalez, L.F., Montes, G.A., Puig, E., Johnson, S., Mengersen, K. *et al.,* 2016. Unmanned aerial vehicles (UAVs) and artificial intelligence revolutionizing wildlife monitoring and conservation. *Sensors,* 16, 97.
Guerra-Castro, E., Carmona-Suárez, C., Conde, J.E., 2011. Biotelemetry of crustacean decapods: sampling design, statistical analysis, and interpretation of data. *Hydrobiologia,* 678, 1-15.
Harrod, J.J., 1964. The distribution of invertebrates on submerged aquatic plants in a chalk stream. *Journal of Animal Ecology*, 335-348.
Heck, J., Coen, L.D., Kenneth, L., 1995. Predation and the abundance of juvenile blue crabs: a comparison of selected east and gulf coast (USA) studies. *Bulletin* of *Marine Science,* 57, 877-883.
Heck Jr, K.L., Wetstone, G.S., 1977. Habitat complexity and invertebrate species richness and abundance in tropical seagrass meadows. J. *Biogeography*, 135-142.
Heck, K.L., Thoman, T.A., 1984. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. *Estuaries,* 7, 70-92.
Hench, J.L., Forward Jr, R.B., Carr, S.D., Rittschof, D., Luettich Jr, R.A., 2004. Testing a selective tidal-stream transport model: Observations of female blue crab (*Callinectes sapidus*) vertical migration during the spawning season. *Limnology and Oceanography*, 49, 1857-1870.
Hines, A.H., Lipcius, R.N., Haddon, A.M., 1987. Population dynamics and habitat partitioning by size, sex, and molt stage of blue crabs *Callinectes sapidus* in a subestuary of central Chesapeake Bay. *Marine Ecology Progress Series*, 36, 55-64.
Hodgson, A., Peel, D., Kelly, N., 2017. Unmanned aerial vehicles for surveying marine fauna: assessing detection probability. *Ecological Applications*, 27, 1253-1267.
Hovel, K.A., Lipcius, R.N., 2002. Effects of seagrass habitat fragmentation on juvenile blue crab survival and abundance. *Journal* of *Experimental Marine Biology* and *Ecology,* 271, 75-98.
Jakov, D., Glamuzina, B., 2011. Six years from first record to population establishment: the case of the blue crab, *Callinectes sapidus* Rathbun, 1896 (Brachyura, Portunidae) in the Neretva River delta (South-eastern Adriatic Sea, Croatia). *Crustaceana* 84, 1211-1220.
Jivoff, P.R., Able, K.W., 2003. Evaluating salt marsh restoration in Delaware Bay: the response of blue crabs, *Callinectes sapidus*, at former salt hay farms. *Estuaries,* 26, 709-719.
Johnson, E.G., Eggleston, D.B., 2010. Population density, survival and movement of blue crabs in estuarine salt marsh nurseries. *Marine Ecology Progress Series*, 407, 135-147.
Johnston, C.A., Caretti, O.N., 2017. Mangrove expansion into temperate marshes alters habitat quality for recruiting *Callinectes* spp. *Marine Ecology Progress Series*, 573, 1-14.
Jugovic, J., Praprotnik, E., Buzan, E.V., Lužnik, M., 2015. Estimating population size of the cave shrimp *Troglocaris anophthalmus* (Crustacea, Decapoda, Caridea) using mark–release–recapture data. *Animal Biodiversity and Conservation*, 38, 77-86.
Kako, S., Morita, S., Taneda, T., 2020. Estimation of plastic marine debris volumes on beaches using unmanned aerial vehicles and image processing based on deep learning. *Ma-*

rine Pollution Bulletin, 155, 111127.

Kara, M.H., Chaoui, L., 2021. Strong invasion of Mellah lagoon (South-Western Mediterranean) by the American blue crab Callinectes sapidus Rathbun, 1896. *Marine Pollution Bulletin,* 164, 112089.

Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppäkoski, E., Çinar, M.E. *et al.*, 2014. Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. *Aquatic Invasions*, 9, 391-423.

Kattenborn, T., Lopatin, J., Förster, M., Braun, A.C., Fassnacht, F.E., 2019. UAV data as alternative to field sampling to map woody invasive species based on combined Sentinel-1 and Sentinel-2 data. *Remote Sensing* of *Environment,* 227, 61-73.

Kenward, R., 1987. Wildlife radio tagging. *Academic Press*, London. 222 pp. ISBN 0-12-4042406.

King, R.S., Hines, A.H., Craige, F.D., Grap, S., 2005. Regional, watershed and local correlates of blue crab and bivalve abundances in subestuaries of Chesapeake Bay, USA. *Journal* of *Experimental Marine Biology* and *Ecology,* 319, 101-116.

Koyama, A., Hirata, T., Kawahara, Y., Iyooka, H., Kubozono, H. *et al.*, 2020. Habitat suitability maps for juvenile tri-spine horseshoe crabs in Japanese intertidal zones: A model approach using unmanned aerial vehicles and the Structure from Motion technique. *PloS One*, 15, e0244494.

Lambert, D.M., Lipcius, R.N., Hoenig, J.M., 2006. Assessing effectiveness of the blue crab spawning stock sanctuary in Chesapeake Bay using tag-return methodology. *Marine Ecology Progress Series*, 321, 215-225.

Lipcius, R.N., Seitz, R.D., Seebo, M.S., Colón-Carrión, D., 2005. Density, abundance and survival of the blue crab in seagrass and unstructured salt marsh nurseries of Chesapeake Bay. *Journal* of *Experimental Marine Biology* and *Ecology*, 319, 69-80.

Mancinelli, G., Bardelli, R., Zenetos, A., 2021. A global occurrence database of the Atlantic blue crab *Callinectes sapidus. Scientific Data*, 8, 1-10.

Mancinelli, G., Chainho, P., Cilenti, L., Falco, S., Kapiris, K. *et al.*, 2017. On the Atlantic blue crab (*Callinectes sapidus* Rathbun 1896) in southern European coastal waters: Time to turn a threat into a resource? *Fisheries Research*, 194, 1-8.

Manfrin, C., Chung, J., Turolla, E., Giulianini, P., 2015. First occurrence of *Callinectes sapidus* (Rathbun, 1896) within the Sacca di Goro (Italy) and surroundings. *Check List*, 11, 1.

Mannino, A.M., Sarà, G., 2006. The effect of *Ruppia cirrhosa* features on macroalgae and suspended matter in a Mediterranean shallow system. *Marine Ecology*, 27, 350-360.

Marchessaux, G., Bosch-Belmar, M., Cilenti, L., Lago, N., Mangano, M.C. *et al.*, 2022. The invasive blue crab *Callinectes sapidus* thermal response: Predicting metabolic suitability maps under future warming Mediterranean scenarios. *Frontiers in Marine Science*, 9, 1055404.

Marchessaux, G., Mangano, M.C., Bizzarri, S., M'Rabet, C., Principato, E. *et al.*, 2023. Invasive blue crabs and small-scale fisheries in the Mediterranean sea: Local ecological knowledge, impacts and future management. *Marine Policy,* 148, 105461.

Mense, D.J., Wenner, E.L., 1989. Distribution and abundance of early life history stages of the blue crab, *Callinectes sapidus*, in tidal marsh creeks near Charleston, South Carolina. *Estuaries,* 12, 157-168.

Messina, G., Pezzino, E., Montesanto, G., Caruso, D., Lombardo, B.M., 2012. The diversity of terrestrial isopods in the natural reserve "Saline di Trapani e Paceco"(Crustacea, Isopoda, Oniscidea) in northwestern Sicily. *ZooKeys,* 215.

Milori, E., Qorri, L., Ibrahimi, E., Beqiraj, S., 2017. Data on the distribution, population structure and establishment of the invasive blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda, Brachyura, Portunidae) in the Lagoon of Viluni (South-East Adriatic Sea, Albania). *Albanian Journal of Agricultural* Sciences, 485-492.

Mizerek, T., Regan, H.M., Hovel, K.A., 2011. Seagrass habitat loss and fragmentation influence management strategies for a blue crab *Callinectes sapidus* fishery. *Marine Ecology Progress Series*, 427, 247-257.

Monin, V.L., 1984. New Find of the Blue Crab *Callinectes sapidus* (Decapoda, Brachyura) in the Black Sea. Zoologicheskii *Zhurnal*, 63 (7), 1100-1101.

Müllerová, J., Brůna, J., Bartaloš, T., Dvořák, P., Vítková, M. *et al.*, 2017. Timing is important: Unmanned aircraft vs. satellite imagery in plant invasion monitoring. *Frontiers in Plant Science,* 8, 887.

Onofri, V., Dulčić, J., Conides, A., Matić-Skoko, S., Glamuzina, B., 2008. The occurrence of the blue crab, Callinectes sapidus Rathbun, 1896 (Decapoda, Brachyura, Portunidae) in the eastern Adriatic (Croatian coast). *Crustaceana,* 403-409.

Orhan, A.K., Haşimoğlu, A., Bayram, K., 2015. Southeastward expansion of the blue crab Callinectes sapidus (Rathbun, 1896) in the Black Sea. *Cahiers de Biologie Marine*, 56, 397-399.

Orth, R.J., van Montfrans, J., 2002. Habitat quality and prey size as determinants of survival in post-larval and early juvenile instars of the blue crab *Callinectes sapidus*. *Marine Ecology Progress Series,* 231, 205-213.

Orth, R.J., van Montfrans, J., 1990. Utilization of marsh and seagrass habitats by early stages of Callinectes sapidus: a latitudinal perspective. *Bulletin* of *Marine Science*, 46, 126-144.

Pashkov, A.N., Reshetnikov, S.I., Bondarev, K.B., 2012. The capture of the blue crab (*Callinectes sapidus*, decapoda, crustacea) in the Russian sector of the Black Sea. *Russian Journal of Biological Invasions*, 3, 22-28.

Perkins-Visser, E., Wolcott, T.G., Wolcott, D.L., 1996. Nursery role of seagrass beds: enhanced growth of juvenile blue crabs (*Callinectes sapidus* Rathbun). *Journal* of *Experimental Marine Biology* and *Ecology,* 198, 155-173.

Posey, M.H., Alphin, T.D., Harwell, H., Allen, B., 2005. Importance of low salinity areas for juvenile blue crabs, *Callinectes sapidus* Rathbun, in river-dominated estuaries of southeastern United States. *Journal* of *Experimental Marine Biology* and *Ecology,* 319, 81-100.

Ramach, S., Darnell, M.Z., Avissar, N., Rittschof, D., 2009. Habitat use and population dynamics of blue crabs, *Callinectes sapidus*, in a high-salinity embayment. *Journal* of *Shellfish Research,* 28, 635-640.

Reichmuth, J.M., MacDonald, J., Ramirez, J., Weis, J.S., 2011. Fight or flight: an investigation of aggressive behavior and predator avoidance in two populations of blue crabs (*Cal-*

linectes sapidus Rathbun) in New Jersey. *Hydrobiologia,* 658, 173-182.

Ros, M., Guerra-García, J.M., Lignot, J.-H., Rivera-Ingraham, G.A., 2021. Environmental stress responses in sympatric congeneric crustaceans: Explaining and predicting the context-dependencies of invader impacts. *Marine Pollution Bulletin,* 170, 112621.

Ruas, V.M., Rodrigues, M.A., Dumont, L.F.C., D'Incao, F., 2014. Habitat selection of the pink shrimp *Farfantepenaeus paulensis* and the blue crab *Callinectes sapidus* in an estuary in southern Brazil: influence of salinity and submerged seagrass meadows. *Nauplius,* 22, 113-125.

Rudershausen, P.J., Merrell, J.H., Buckel, J.A., 2021. Factors Influencing Colonization and Survival of Juvenile Blue Crabs *Callinectes sapidus* in Southeastern US Tidal Creeks. *Diversity,* 13, 491.

Ruiz, G.M., Hines, A.H., Posey, M.H., 1993. Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. *Marine Ecology Progress Series*, 1-16.

Sarà, G., Leonardi, M., Mazzola, A., 1999. Spatial and temporal changes of suspended matter in relation to wind and vegetation cover in a Mediterranean shallow coastal environment. *Chemical Ecology*, 16, 151-173.

Sarà, G., Romano, C., Caruso, M., Mazzola, A., 2000. The new Lessepsian entry *Brachidontes pharaonis* (Fischer P., 1870) (Bivalvia, Mytilidae) in the western Mediterranean: a physiological analysis under varying natural conditions. *Journal of Shellfish Research*, 19 (2), 967-977.

Seitz, R.D., Lipcius, R.N., Seebo, M.S., 2005. Food availability and growth of the blue crab in seagrass and unvegetated nurseries of Chesapeake Bay. *Journal* of *Experimental Marine Biology* and *Ecology*, 319, 57-68.

Shields, J.D., Sullivan, S.E., Small, H.J., 2015. Overwintering of the parasitic dinoflagellate Hematodinium perezi in dredged blue crabs (*Callinectes sapidus*) from Wachapreague Creek, Virginia. *Journal of Invertebrate Pathology,* 130, 124-132.

Taybi, A.F., Mabrouki, Y., 2020. The American blue crab *Callinectes sapidus* Rathbun, 1896 (Crustacea: Decapoda: Portunidae) is rapidly expanding through the Mediterranean coast of Morocco. *Thalassas An International Journal of Marine Sciences,* 36, 267-271.

Taylor, D.L., Fehon, M.M., 2021. Blue Crab (*Callinectes sapidus*) Population Structure in Southern New England Tidal Rivers: Patterns of Shallow-Water, Unvegetated Habitat Use and Quality. *Estuaries and Coasts,* 44, 1320-1343.

Thomas, J.L., Zimmerman, R.J., Minello, T.J., 1990. Abundance patterns of juvenile blue crabs (*Callinectes sapidus*) in nursery habitats of two Texas bays. *Bulletin* of *Marine Science,* 46, 115-125.

van Montfrans, J., Ryer, C.H., Orth, R.J., 2003. Substrate selection by blue crab *Callinectes sapidus* megalopae and first juvenile instars. *Marine Ecology Progress Series,* 260, 209-217.

Ventura, D., Bonifazi, A., Gravina, M.F., Ardizzone, G.D., 2017. Unmanned aerial systems (UASs) for environmental monitoring: A review with applications in coastal habitats. *Aerial Robots: Aerodynamics, Control and Application*, 165-184.

Wolcott, T.G., Hines, A.H., 1989. Ultrasonic biotelemetry of muscle activity from free-ranging marine animals: a new method for studying foraging by blue crabs (*Callinectes sapidus*). *Biology Bulletin*, 176, 50-56.

Wrona, A.B., 2004. Determining movement patterns and habitat use of blue crabs (*Callinectes sapidus* Rathbun) in a Georgia saltmarsh estuary with the use of ultrasonic telemetry and a geographic information system (GIS) (PhD Thesis). University of Georgia, USA.

Supplementary Data

The following supplementary information is available online for the article:

Fig. S1: Positions and hourly trajectories of the 10 crabs studied in the saltmarshes and substrate type.

Fig. S2: Positions and trajectories of blue crabs measured between September 28 and October 27, 2021.