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Occurrence data of the Atlantic Blue Crab (*Callinectes sapidus*, Rathbun, 1896) Indicates that a New Indwelled is Settling in the Black Sea

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Abstract

It is remarkable that blue crabs have been encountered frequently in recent years, especially on the southern coast of the Black Sea, after it was first reported in 1968**.** Reporting of three new records for blue crabs was tried to identify suitable areas for possible blue crab distribution in the Black Sea based on environmental variables, and past occurrence records. Ecological niche modeling was applied for this and the most contributing environmental variables were determined as maximum bathymetry, maximum mean salinity, and nitrate. It turned out that especially shallow areas on the coast of the Black Sea can be suitable habitats for blue crabs.

Introduction

The settlement of non-native aquatic species in new marine areas is realized by sea transportation. Species that migrate to new areas are called invasive, depending on the damage they cause to the environment or other living organisms (Skolka & Preda, 2010). The blue crab *Callinectes sapidus* (Rathbun, 1896) is known to be a species of western Atlantic origin but was also detected on the eastern side of the Atlantic in the early 20th century (Hines, 2007; Mancinelli *et al*., 2017). The records of blue crabs are found in the Mediterranean, Aegean, and Black Seas later (Bulgurkov, 1967; EnzenroB *et al*., 1997; Nehring, 2011). It is understood that the blue crab has spread over a wide area in the world after being introduced on the west coast of Africa, in the Pacific, Indian Ocean, and Australia (URL-1; URL-2). Blue Crab, which is defined as an invasive to the Mediterranean, spread to very large areas in the world because of being euryhaline (Guerin & Stickle, 1992; Zenetos *et al*., 2005). It is understood that the blue crab has a total of 18 reported locations in the Black Sea and it has been found especially on the Turkish coasts recently (Ceylan, 2020; Gül *et al*., 2021; Snigirev et al., 2020). In addition, it was reported that a gravid female individual was caught on the southern coast of the Black Sea (Gül *et al*., 2021). Many researchers have recently reported that the temperature of the Black Sea has increased, and accordingly, it has become more suitable for species of different origins, and its ecosystem has changed with the introduction and adaptation of new species (Sağlam *et al.,* 2011; Shefer *et al.,* 2004; Şahin *et al.,* 2009; Turan *et al.,* 2016). This situation supports that the Black Sea may be more suitable for the adaptation of the blue crab in terms of temperature day by day. Due to the changes in environmental conditions due to increasing sea water temperature and activities such as maritime transport, the Black Sea is turning into a very suitable area for the introduction of species of different origins, and records of many alien species have been reported recently (Sağlam *et al.,* 2011; Şahin *et al.,* 2009; Turan *et al.,* 2016). In this study, it was aimed to report new locations in addition to the increasing blue crab records, especially in the southern coasts of the Black Sea, and to model whether the basin is suitable for the life cycle of the blue crab.

Material and Method

Occurrence Data and New Records

Occurrence data were collected based on literature (8 records) throughout the Black Sea (Ak *et al,* 2015; Ceylan, 2020; Diripasko, 2020; Pashkov *et al.,* 2011; Shaverdashvili, & Ninua, 1975; Yağlıoğlu, 2013), and 3 new records were added to the occurrence data; thus, a total of 11 records were used for the analyses, and there were also no duplicated records in these data (Figure 1). Three new location information for the southern coasts of the Black Sea;

1) On 17 October 2023, a male blue crab was caught coast of Çayeli/Rize as a bycatch in a gillnet operation. The depth was 35 m and the coordinates were 40.7380560° N- 41.1213890° E.

2) On 22 August 2023, also a man blue crab was caught coast of Rize, as bycatch in the trammel net fishery. The depth was 21 m and the coordinates were 40.4919440° N- 41.0461110° E.

3) on 28 February 2023, a male blue crab was caught coast of Cide/ Kastamonu as bycatch, in the gill net operation. The depth was 18 m and the coordinates were 42.876° N-32.872°E

Samples were examined for use in different research at the Recep Tayyip Erdoğan University, Faculty of Fisheries.

Environmental Variables

12 global geophysical, biotic, and climate layers were examined, and a total of 36 layers at 5 arcmins spatial resolution as max, mean, and min were downloaded as a tiff raster file from Bio-ORACLE v.2.2 (Assis *et al.,* 2018; Tyberghein *et al.,* 2012;). These layers were selected considering the geographic position and depth of cells in the benthic average depth. Then, they were changed to ASCII format in ArcGIS® (Esri® software available www.esri.com). In addition, the bathymetry dataset that includes variables describing the depth, slope, aspect, and curvature of the seafloor, as well as distance to the nearest shoreline were downloaded at 1 km resolution (Sbrocco & Barber, 2013). Then, it was changed to a common spatial resolution with a resample in ArcGIS®. Thus, all environmental changes were kept at a spatial resolution of 5 arcmin (Table 1). The highly correlated environmental variables were removed based on Pearson's correlation coefficient at 0.85 using the SDMToolbox v2.2 (Brown *et al.* 2017; Carlos *et al.* 2015; Ceylan & Gül, 2022). Thus, thirteen environmental variables were used for all analyses (Table 1).

Model Selection and Niche Modeling

Wallace (v2.0.3) which is a flexible application for reproducible ecological modeling was used for the calibration and the best model selection (Kass *et al.,*

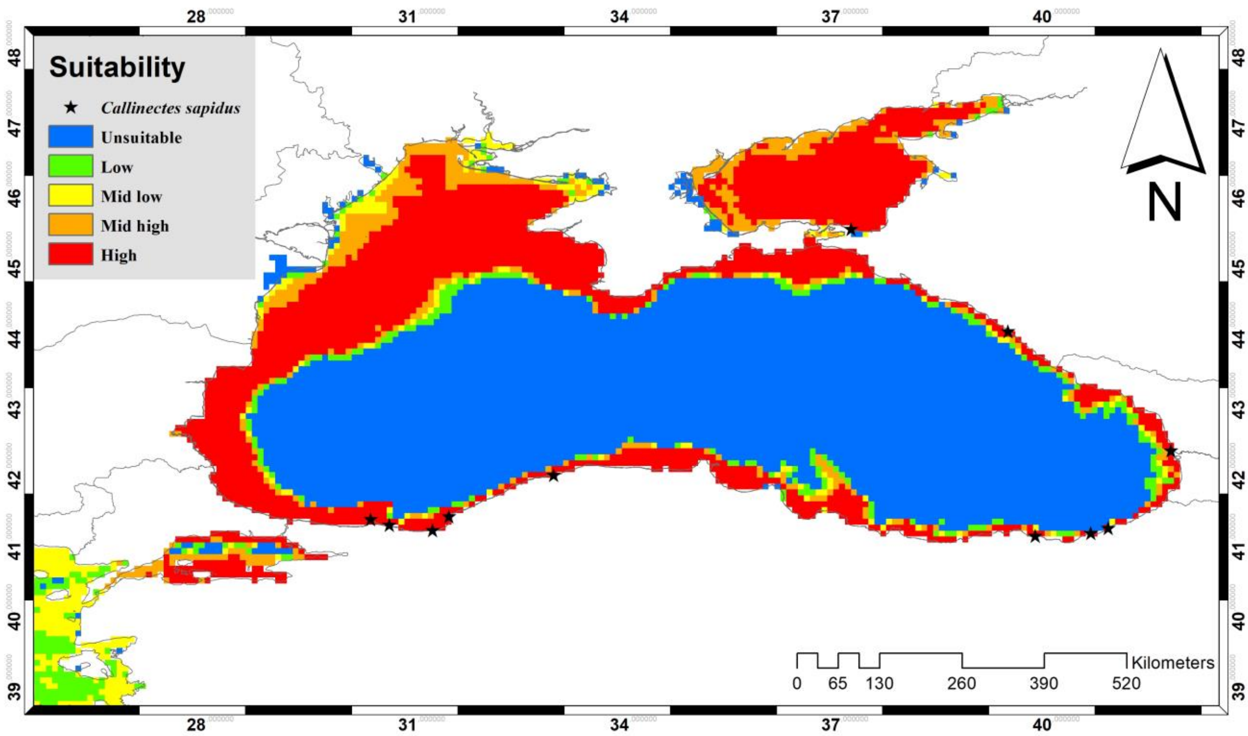

Figure 1. The present distribution pattern of *C. sapidus* based on ecological niche modeling

2018, 2023). To select a study region, minimum convex polygon buffered by 4.5 degrees was preferred and this determined the spatial extent for model building. Thus, environmental data were masked within this region and random background points sampled out of 8100 total points were created. For occurrence data, non-spatial partition module with jackknife (k = n) was used because the jackknife procedure which is appropriate for small sample sizes is each occurrence record is put into a unique group (k equals the number of localities; technically an n - 1 jackknife) (Shcheglovitova & Anderson, 2013; Pearson *et al.,* 2007). To build and to evaluate the niche model, Maxent which is the presence-background algorithm was used (Phillips *et al.,* 2006). To increase or decrease the potential for model complexity, feature classes as L (linear), LQ (linear, quadratic), H (hinge), LQH (linear, quadratic, hinge), and LQHP (linear, quadratic, hinge, product) and the regularization multiplier of 0.5–10 were selected as two key factors. Thus, 100 candidate models were generated. The model with the lowest AIC (Akaike Information Criterion) between these models was selected as the best model (Table 2). Then, Maxent v.3.4.3 was run according to model parameters selected with 500 iterations, 50 replicates, and cloglog output (Phillips *et al.,* 2017).

Results

The distribution of *C. sapidus* in the present period was created using maximum entropy modeling. The prediction of the model was high and consistent with its real distribution. The average test AUC for the replicate runs of the model was 0.996, and the standard deviation was 0.005. This indicated that the model had good predictive ability. Mean_Salinity_Max, bathymetry, and Mean_Nitrate_Max as the environmental variables used in the Maxent model provided the most effective contributions. The percent contribution of these variables are 41, 38.8, and 14.9, respectively. Other variables contributed for less than 5% of the total contribution. In addition, mean response curves gained in the results of the analyses show the effect of each environmental variable on the prediction of the model (Figure 2).

Inland areas of the Black Sea are the most unsuitable habitats for this species, while the coastal areas are the most suitable habitats. This suitability is most pronounced in the northern and western parts of the Black Sea and is also observed in the Sea of Azov (Figure 1).

Discussion

The adaptation of an organism to a new ecosystem depends on its biology and the similarity of an ecosystem to its natural distribution area. The first record of blue crab in the Black Sea was reported off the coast of Bulgaria in 1968, and in the past 55 years, especially recent records on the southern coast, are noteworthy. When the occurrence points are examined, it is seen that there are ports or regions with heavy ship traffic. Therefore, scientists defended the view that it entered this region both through ballast waters or natural ways from the Mediterranean because it was a very good swimmer (Aydın, 2017; Ceylan, 2020; Pashkov *et al.,* 2012; Stefanov, 2021). Transportation of marine organisms by ballast water may be solely responsible for invasions in the past, but recently there have been important regulations regarding ballast water around the world, as well as countries implementing regulations locally. In addition, it is mandatory to have ballast

Table 1. The variables for niche modeling. Bold color shows the variables used in analyses in result of the correlation

Layer	Unit	Max	Mean	Min
Temperature	°C	✓	✓	✓
Salinity	PSS	✓	✓	✓
Currents velocity	m^{-1}	✓	✓	✓
Nitrate	$mol.m^{-3}$	✓	✓	✓
Phosphate	$mol.m^{-3}$	✓	✓	✓
Silicate	$mol.m^{-3}$	✓	✓	✓
Dissolved molecular oxygen	$mol.m^{-3}$	✓	✓	✓
Iron	$umol.m^{-3}$	✓	✓	✓
Chlorophyll	$mg.m^{-3}$	✓	✓	✓
Phytoplankton	$umol.m^{-3}$	✓	✓	✓
Primary productivity	$g.m^{-3}.day^{-1}$	✓	✓	✓
Light at bottom	-	✓	✓	✓
Bathymetry	meter			

Table 2. The best model parameters selected for ecological niche modeling

Feature Class	Regularization Multiplier	AICc	Delta AICc
L	3.5	104.180819825881	0

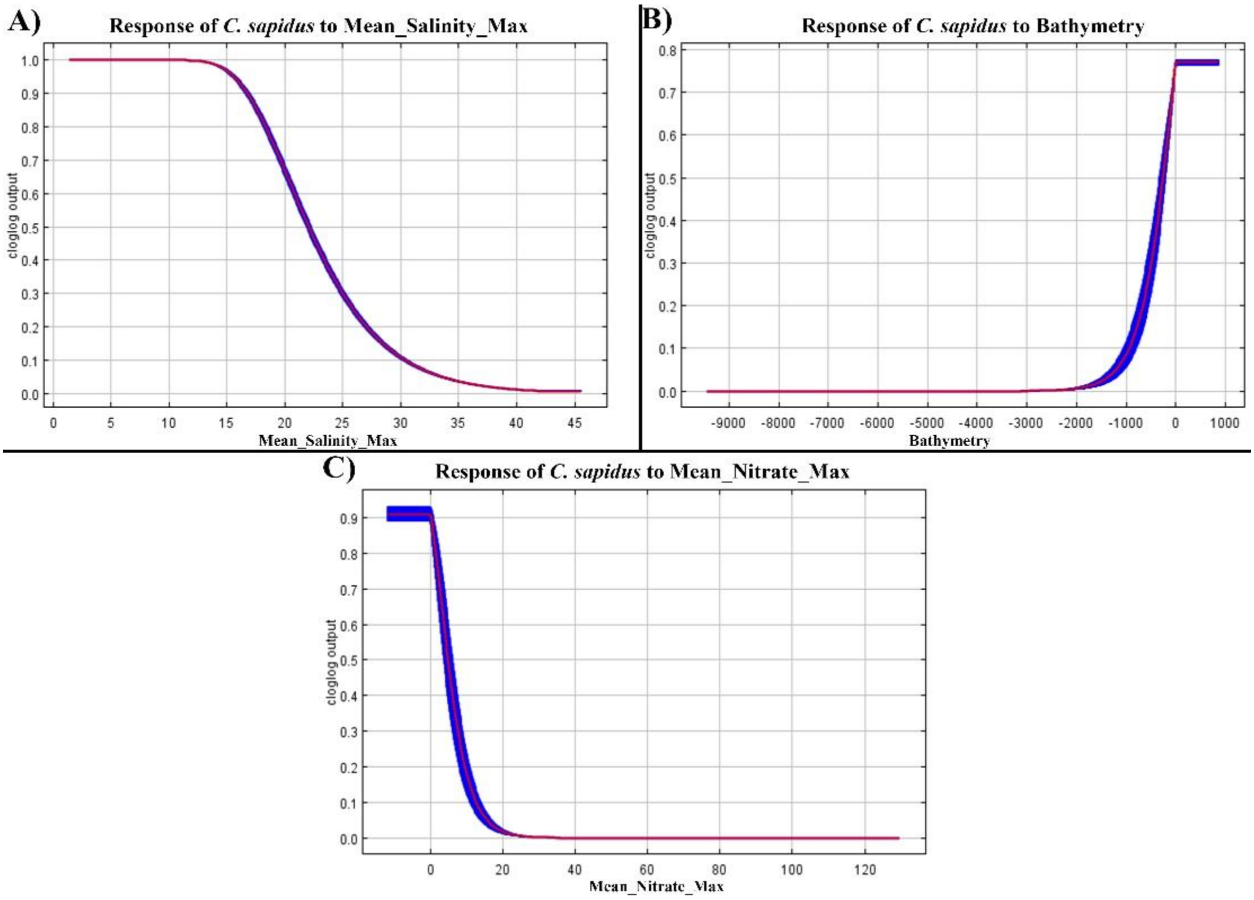

Figure. 2. The most important response curves for three variables A) Mean_Salinity_Max, B) Bathymetry, C) Mean_Nitrate_Max.

treatment systems on ships that carry out ballast water operations (Anwar & Churcher 2015; Bax *et al.,* 2003). Evidence that this idea needs to change emerged for the Black Sea in 2021 when a gravid female with eyed eggs was caught off the coast of Türkiye (Gül *et al.,* 2021). Recently, new records especially from the southern coasts and Bulgaria moreover, a single gravid female may indicate that the blue crab adaptation process is about to take place in the Black Sea. Every occurrence for the Black Sea shouldn't be connected to external entrances.

Furthermore, model results revealed that all of the Black Sea and Azov contain highly suitable habitats for blue crabs. One of the environmental variables used in the Maxent model and providing the most effective contribution was bathymetry. However, due to the special situation of the Black Sea, not every depth is suitable for blue crabs. Especially, the entire coastal ecosystem except for the anoxic area (depth < 100 m) appears as a suitable habitat for it (Zaitsev & Mamaev 1997). The blue crab has a very high tolerance to temperature and salinity, which is why it has spread over a wide area around the world. Due to these features, it becomes easier to adapt to new habitats. The most important features that facilitates its spread to new habitats are that blue crab is an euryhaline organism and it can inhabit a wide range of temperatures from 3 to 35°C (Pashkov *et al.,* 2012). One of the environmental variables that contribute most to determining suitable areas is salinity in modeling. Since the salinity value varies between 14-19 ‰ on the surface, the entire Black Sea can be a suitable habitat for euryhaline blue crabs in general (Leonov, 2005; Schmittmann, 2017; Zavialov *et al.,* 2020). Long-term surface water temperature data show that the average surface temperature of the Black Sea during the winter is reported to be approximately 8°C degrees (Oguz, 2007). Under the circumstances, similar to the model results, the Black Sea can be considered a suitable habitat for the blue crab in terms of temperature and salinity. This may be an indication that the low-temperature-related unsuccess of the blue crab's adaptation to the Black Sea, claimed by some researchers, has now changed (Nehring, 2011). Because average seawater temperatures are increasing as a reflection of global warming on the seas.

Nitrogen is in a cycle in aquatic environments. In experimental studies, it has been reported that blue or other crabs are sensitive to nitrogenous compounds, especially nitrate, during molting, and that the pH value that moves parallel to the increase in nitrate in the environment will pose a risk of death. Besides, it has been expressed that water quality affects the hardening time of the exoskeleton. (Hungaria *et al.,* 2021; Manthe *et al.,* 1983). It can be thought that the strong correlation of the model with nitrate is due to these situations.

Juvenile, adult, and egg-laying female blue crab individuals choose areas with different salinity levels.

While adult males are generally likely to prefer estuaries with lower salinity, it can be expected that egg-bearing females in the reproductive period and juveniles will prefer saltier areas (Carr *et al.,* 2004). The Black Sea does not have large lagoons, estuaries, and tidal areas due to its geographical location and characteristics. However, it is possible to find such some areas on the coasts of Bulgaria, Romania, Ukraine, and Crimea. Furthermore, areas where large freshwater ecosystems flow into the Black Sea can be expected to be important for the low salinity preferences of blue crab individuals. Considering the previous locations of the blue crab in the Mediterranean and Black Seas, its proximity to freshwater input is noteworthy (Mancinelli *et al.,* 2017). Accordingly, male and female blue crabs are expected to prefer areas with different salinity, especially during reproductive periods. However, studies reported a new location in the Black Sea, it is seen that male individuals are caught in the sea (no occurrence of blue crabs in the outfall of rivers yet) (Ak *et al.,* 2015; Aydın, 2017; Bilgin, 2019; Ceylan, 2020; Stefanov, 2021). In this case, it can be predicted that male and female individuals will share the same environment in the marine, and there will be no reproductive migration of females from low salinity areas to high salinity areas.

Blue crabs are opportunistic feeders and are generally known to feed on polychaete, small crustaceans and detritus, etc. while especially adults have developed different techniques to feed on invertebrates such as mussels, oysters, and winkles (Seitz *et al.,* 2011; Hamilton, 1976). It can be thought that the blue crab can find sufficient feeding opportunities in the Black Sea. Invasive or alien species are recognized as important factors in the composition and structure of habitats, ecosystems, resource utilization, and environmental change (Simberloff *et al.,* 2013). They may cause changes in ecosystem structure as a result of feeding and competition. When the predator-prey relationship of blue crab is examined, the blue crab's menu can composed especially *Rapana venosa*, as well bivalves such as *Mytilus galloprovincialis, Chamelea gallina,* and smaller crustaceans such as *Liocarcinus navigator, Clibanarius erythropus* (Lin, 1991; Harding, 2003; Seitz *et. al.,* 2011). Thus, while the emergence of a new predator for the Black Sea may have negative effects on some species, it can initially be thought that it will contribute to the control of *R. venosa*, an invasive species. Considering the life cycle and habitat preferences of the blue crab it is thought that these two species share the same environment. As a matter of fact, our model results also support this view because life in the Black Sea is already in a narrow area with oxygen the depth is below 100 m. It is also necessary to think about competition with other crabs. Scientists and authorities need to anticipate possible impacts, both in terms of competition and their place in the food chain, and consider the consequences of previous invasions of blue crabs and precautions.

Conclusion

The Black Sea ecosystem is changing due to reasons such as maritime transportation, pollutants, and climate change (Aytan *et al*., 2022; Bat *et al*., 2007; Sağlam *et al*., 2011). In addition, the introduction of alien species poses a risk to native species. Blue crab is known for its widespread distribution and high adaptability to new ecosystems. The study results revealed that the Black Sea is a suitable habitat for the blue crab. Therefore, interaction with native species in the Black Sea should be predicted and, if possible, measures to prevent future invasion should be considered in advance. Considering the model results, the fact that temperature is not included in the most contributing environmental factors. This suggests that temperature is not a limiting factor in determining suitable habitats for blue crabs in the Black Sea. Therefore, the claim previously expressed by some scientists that the Black Sea is a cold sea for the adaptation of the blue crab is invalid.

Ethical Statement

Not applicable.

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Author Contribution

The study was designed, prepared and submitted by Yusuf Ceylan.

Conflict of Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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