Journal of Geography, Environment and Earth Science International

Volume 28, Issue 6, Page 93-111, 2024; Article no.JGEESI.119010
ISSN: 2454-7352

Population, Distribution Structure, and Fishery Potential of the Golden Deep-Sea Crab, *Chaceon somaliensis* in the Kenyan Coast in East Africa

Richard Mzungu [a,b]*, Godfrey Makokha [a], Esther Fondo [c], Mika Siljander [d], Elizabeth Mueni [b] and Benedict Kiilu [b,e]

[a] School of Science and Informatics, Taita Taveta University, PO Box 635, 80300 Voi, Kenya.
[b] Kenya Fisheries Service-PO Box 90423 – 80100, Mombasa, Kenya.
[c] Kenya Marine and Fisheries Research Institute - PO Box 81651 – 80100 Mombasa, Kenya.
[d] Department of Geosciences and Geography, Helsinki Laboratory of Interdisciplinary Conservation Science, University of Helsinki, PO Box 64, 00014 Helsinki, Finland.
[e] Coastal Oceans Research and Development in the Indian Ocean (CORDIO), Kenya.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jgeesi/2024/v28i6784

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/119010

Original Research Article

Received: 15/04/2024
Accepted: 17/06/2024
Published: 20/06/2024

ABSTRACT

Aim: This study focused on *Chaceon somaliensis*, a species in the Geryonid family, which is commonly found in the Horn of Africa. The species has global commercial value, yet little is known about it. The study adds to our understanding of the species by identifying its distribution, population structure, and fisheries potential in the Kenyan Coast.
Methodology: Maxent modeling assessed the appropriate environmental variables and predicted potential species distribution and hotspot locations. Regression was used to explain *C. somaliensis* distribution and some aspects of the population structure.

Corresponding author: E-mail: mutuamzungu@gmail.com;

Cite as: Mzungu , Richard, Godfrey Makokha, Esther Fondo, Mika Siljander, Elizabeth Mueni, and Benedict Kiilu. 2024. "Population, Distribution Structure, and Fishery Potential of the Golden Deep-Sea Crab, Chaceon Somaliensis in the Kenyan Coast in East Africa". Journal of Geography, Environment and Earth Science International 28 (6):93-111. https://doi.org/10.9734/jgeesi/2024/v28i6784.

Study Design: Analytical study.

Results: Stratification by depth was observed with large male crabs (carapace width>150 mm, weight=1100 g) found in shallower depths (depth<501 m), while females, smaller in size (carapace width =92 mm, weight=316 g), seemed to prefer higher depths of >500 m. The Males were dominant (0.94), and females and juveniles comprised only 0.06 of the population. The population was found to be skewed towards males of large size (carapace width > 140 mm, weight 1100 g). Bathymetry and environmental variables associated with feeding and nutrients, such as phytoplankton, iron, and silicate, were the best predictors of species presence. Potential sites and hotspot areas occurred on a ridge at gentle slopes (0.98°– 4.31), with the hotspot areas being spatially about 3,230 km^2 of 61,694 km^2.

Conclusion: The fishery was considered productive and suitable for maintaining marine biodiversity (catch> 94% adults). The male population should be monitored as it is the key indicator of the status of the fishery.

Keywords: Geryonid; chaceon somaliensis; species distribution; maxent; habitat modelling, Kenya.

1. INTRODUCTION

The brachyuran family Geryonidae, characterized by its five anterolateral carapace teeth [1,2], is globally distributed in the continental slopes of the world's oceans [3] at depths 200–1500 m. Geryonidae are a source of food and supports numerous world commercial fisheries [4-9]. The family comprises of four genera and twenty-four species [5]. Those which have attracted scientific research include *Chaceon fenneri, Chaceon affinis, Chaceon macphersoni, Chaceon maritae, Chaceon quinquedens, Chaceon chilensis, Chaceon gordonae, Chaceon albus* and *Chaceon notialis* of the South West Atlantic Ocean [2,10–16]. The *Chaceon* genus attains medium to large size, from 118 mm to 170 mm carapace width, and is a source of food, livelihood, and revenue, supports industrial fisheries and has ecological value. The crabs form part of the benthic community [4,5,12].

Chaceon somaliensis [17], a Geryonid crab found and exploited in the Coast of Kenya is the interest of this research. The name *C. somaliensis* was derived from the locality as it was originally discovered, off-Somalia Coast, in the Horn of Africa [17]. The crabs are large in size, with males generally being larger than the females [2,10]. *C. somaliensis* crabs in Kenya are commercially harvested yet, little is known about it. This lack of information hindered conservation efforts [18]. For instance, in Kenya, the reported export revenue of *C. somaliensis* was (USD $4,840, 26,400 and 37,100) for the years 2018, 2019 and 2020, whereas the exported quantities were (1,210, 6,600, and 6,100 kg) respectively. The reported live sea crabs' total catches were 55,065 and 109,746 kg for 2019 and 2020 (GoK, unpublished statistical reports), yet little was known about the fishery.

Previous studies of Geryonid crabs point to different factors that influenced the crab's distribution and population structure. These include; ocean depth [19–21], indicators of food, such as chlorophyll-a [22,23], temperature, infaunal biomass [22], dissolved oxygen [24], ontogenetic shift, and species interaction activities such as competition [23]. Geryonid crabs also exhibited bathymetric migration of the females during the reproduction cycle [5]. Stratification by depth was observed with depths of 400–500 m having higher biomass density, and abundance of the crabs and large-sized than in deeper regions of >600 m [2,19,20]. Depth-sex stratification was also present, with males being larger and heavier than females and found in shallow places (optimum depth of 400–500 m). Females preferred deeper áreas >600 m [2,10]. Geryonid crabs' weight also decreased with the increasing depth [5,19]. This was attributed to large-scale ontogenetic migration, and that breeding population was restricted to the upper layers of the bathymetry range [19]. This upscale migration of deep-sea crabs segregated by sex was observed for *Chaceon quinquedens* and *Geryon maritae* [25–27]. Distribution and abundance were found to be highest in areas of canyons and slopes [19].

Geryonid crabs and other marine crab species studies have mostly focused on population data and ecological descriptions [15,16,19,20]. Surprisingly, as compared to terrestrial environment, there are relatively few species distribution modelling (SDM) studies in marine ecosystems [24,28,29]. Species distribution models characterize the relationship between species occurrence and environmental variables [30,31]. Three main types of Species distribution models exist; mechanistic, process-oriented and correlative models [13]. Correlative Species distribution models uses a self-learning algorithm without prior knowledge of the species to characterize its distribution [13,32,33]. They are better suited at predicting species distribution in marine environments [23]. The Maxent algorithm is an ideal correlative Species distribution model algorithm [32,34]. It produces areas with similar environmental conditions to the species prevalence areas, delineating potentially suitable sites [32,34–36]. In earlier studies, Maxent outperformed other algorithms, such as the Genetic Algorithm for Rule Set Production (GARP) [37]. It worked well with only presence data, and produced easily interpretable outputs [29,38]. Thus, species distribution models (SDM) were vital in informing ecosystems [18].

To the best of our knowledge, this is the first comprehensive study of *C. somaliensis* in the Kenyan Coast, and it provides new insights into population structure and species spatial distribution, environmental correlates, and fishery. This study takes a holistic approach employing regression analysis for population structure and species distribution modelling to characterize the spatial distribution and environmental correlates of *C. somaliensis* in the marine environment. The research findings can help policymakers and fishery authorities implement efficient benthic species management methods, hence enhancing conservation efforts for the *Chaceon somaliensis* species. The analysis methods presented here could be used to investigate and provide information to improve management and control distribution, population structure, and fishery potential of other deep-sea crab species in other parts of the world.

2. MATERIALS AND METHODS

2.1 Site Description

The Kenyan Coast study area elongates from the South Coast in Kwale County to the North Coast in Lamu County. It extends from (-1.68°E, 41.97°S and -4.82°E and 39.36°), and it approximates 63,094 km^2. The Area experiences two primary seasons in a year caused by the monsoon wind: The North East Monsoon (NEM) winds from November to March and the South East Monsoon (SEM) winds starting from April to October [12,39]. The region encompasses the North Kenya Banks, a region with rich fishery potential [40].

2.2 Species Sampling and Analysis

The 2021/2022 occurrence data on *Chaceon somaliensis* was collected onboard a longline trap fishing vessel of over 25.56 m and a gross tonnage of 79 tons. The fishing equipment consisted of cylindrical pots/traps that had a diameter of 90 cm and a height of 40 cm and were particularly effective for catching benthic crabs [41]. The trap frames were metallic and were covered with a fishing net of 6 cm mesh size and had three openings made by use of mesh having different colors from the rest of the trap and were located at the mid-height of the trap. The trap-longlines', referred to as sets had an average length of 8,300 m and an average number of traps (337 traps), with each trap being placed at 20 m equidistance from the other. The longline-trap vessel fished for live crabs. The live captured crabs were stored in oxygenated water chambers with a temperature range of between 8.4°C to 12°C. Active data collection for morphometrical details took place onboard the fishing vessel from August 31, 2021, to January 16, 2022. A total of 44 out of 161 sets were sampled, with 1363 individuals of the deep-sea crab measured, one specimen in each pot translating to 1363 pots sampled for the deep-sea crab out of a total of 15,751 pots. The live crabs were first identified visually using crustacea standard indicators [12] to be *Chaceon somaliensis* and checked if all appendages were intact [2,42]; the crabs were then placed on a flat measurement table ready for measurements. Immediately after being measured, the crabs were released into the oxygenated chambers. Random sampling method was used as it best captured the spatial and population variability of the fishery. The sets, traps and the crab in each trap were selected randomly. The place or fishing grounds to be sampled were limited to where the vessel fished. However, this did not affect the accuracy of the results when tested for sampling biases**.**

Measurements sizes of carapace width (CW) and carapace length (CL) were taken to the nearest 0.1 mm [19,21] and weight to the nearest 1 g using a vernier calliper, 0.01 mm accuracy [2] and an electronic balance (1 g accuracy), respectively. Carapace width was measured between most exterior carapace spines; carapace length measurements were between the rostrum and the abdomen [43]. Sex identification was made by mode of observation. The male sex was identified by its narrow, straight, and T-like and the female by its broad-roundish abdomens [21,44].

Chaceon somaliensis historical data for 2019 and 2020, was sourced from the Kenya Fisheries Service (KEFS) and Kenya Marine and Fisheries Research Institute (KMFRI). The data was mainly catch and was used to calculate catch trends, fishing effort, and seasonality with the 2021 presence record.

2.3 Data Analysis and Modelling

Regression and descriptive statistics were used to compute seasonal catches, vessel catch trends and catch per unit effort (CPUE) to describe the species population. The catch rate (CPUE) was calculated as total catch (kg)/the number of traps [5,45] for the three years (2019, 2020, and 2021). Average catch details for 2019, 2020, and 2021 were calculated per set (total catch in kilograms/total number of sets). This was because using a total number of sets standardized the effects of hauling disruptions, vessel breakdowns, and lost traps compared to the use of time. Catch for the respective months during active data collection in 2021 was also analyzed. It should be noted that the fishing effort, weighted catch per unit effort (WCPUE), was introduced for the year 2021 (only when analyzing the 2021 catch in isolation) and was computed as:

$$WCPUE = \frac{t}{T} * CPUE \quad (1)$$

$$CPUE = \frac{rc}{ast} \quad (2)$$

Where t represents the number of traps (in this case, t= 300), T represents the total number of traps, rc represents retained catch (kg), and ast represents averaged soak time (hrs.)

Weighted catch per unit effort was important to reduce the effect of the number of pots/traps on the total catch and catch per unit effort in general. The Weighted catch per unit effort formula formulated by this research assumed 300 traps as the standard number of traps in a set. The 300 number of pots/traps was informed by the average number of pots being 334, the minimum number of pots being 186, and the maximum of 480 pots. Catch per unit effort was calculated using processed catch [5]. Weighted catch per unit effort was able to be calculated for the year 2021 because three parameters: catch weight, number of traps, and soak time were collected. Weighted catch per unit effort was a standardized fishing effort taking into account both the number of traps and soak time, hence a best-suited measure of fishing effort. Weighted catch per unit effort and catch per unit effort were positively correlated.

Depth analysis was computed using a depth stratum of 100 m [19–21,41]. The relationship between depth and catch, fishing effort, distance to the shore, sex, size, and seasonality was computed using Excel 2016 [46] and Statistica 12 [47] see (Fig. 1).

2.4 Environmental Variables Selection

Benthic environmental variables of averaged depth for the present period (2000–2014) were obtained from the Bio-ORACLE data portal https://bio-oracle.org/faq.php [48,49]. As climate is a long-term measure of daily climatic conditions, it was less likely that the predictors had since changed to significantly affect this research. The variables were the monthly averaged conditions. The bathymetric data layer was acquired from the GEBCO's gridded bathymetric data set https://www.gebco.net [50]. Altogether, sixty-nine raster layers were obtained for this study.

Twelve environmental variables were used, each with six distinct categories (maximum, mean, minimum, LT. maximum, Lt. Minimum, and range). *Lt.max and Lt.min were the averages of the maximum or minimum records per year* [48,49]. The bathymetric grid layer of 2022 [50], with a resolution of 15 arcseconds, formed the second data set.

2.5 Preprocessing

Spatial data (bathymetry, environmental variables) was processed using ArcGIS 10.7 [51], with Excel spreadsheet software and Statistica 12 used for statistical work. The raster dataset's pixel size, spatial resolution, and projection were set to 0.833, 9.2 km, the same as the environmental variable from Bio-Oracle [48,49], and UTM projection zone 37S to match and for further processing in Maxent. The layers were then converted to the necessary ASCII format and used as the predictor environmental variable. At the same time, occurrence data from the statistical analysis (Fig. 1) was used as input occurrence points. Species distribution modeling was conducted using Maxent [37,38]. Variable percentage contribution was used to select high-weight environmental variables in influencing the *Chaceon somaliensis* species distribution. Once the environmental variables were established, they were further modeled to visualize the species' ecological hotspots.

2.6 Model Calibration

Maxent version 3.44 was used to compute species distribution models, also known as ecological niche modeling [34,52–54]. Maxent was set to random sampling and used 70% of the data for training and 30% for the test. The output was set to logistic output, the threshold rule was set to minimum training presence, and other settings were left at default. Iterative modeling was done to identify suitable environmental predictors, with percentage contribution (%C) used to eliminate variables with 0% contribution. Six rigorous runs were done. When all variables had percentage contributions greater than 0 (Percentage contribution >0), the process ended. The resulting predictors were picked as the most suitable for *Chaceon somaliensis* distribution. The first run involved all 69 predictors. Potentially suitable sites were then modeled using the established environmental variables and the occurrence points with the Maxent setting set to 10 replicates and replicate types to cross-validate. This was to produce an average model out of the ten replicas, increasing model predicting accuracy.

2.7 Model Evaluation

The accuracy of the model was assessed using the receiver operating characteristics curve (ROC) and the Area Under the Curve (AUC) [24,34,53]. Area Under the Curve values > 0.9 signify excellent accuracy, Area Under the Curve values 0.7–0.9 signifies moderate accuracy, and Area Under the Curve values < 0.7 signify poor accuracy [33]. The maximum Area Under the Curve value achievable is 1, and an Area Under the Curve value above 0.5 in a model was considered to have performed better than in a random model [32]. In evaluating the most important predictors influencing *Chaceon somaliensis* occurrence, the percentage contribution column was used to select the most important predictors (Fig. 1, Percentage contribution >0).

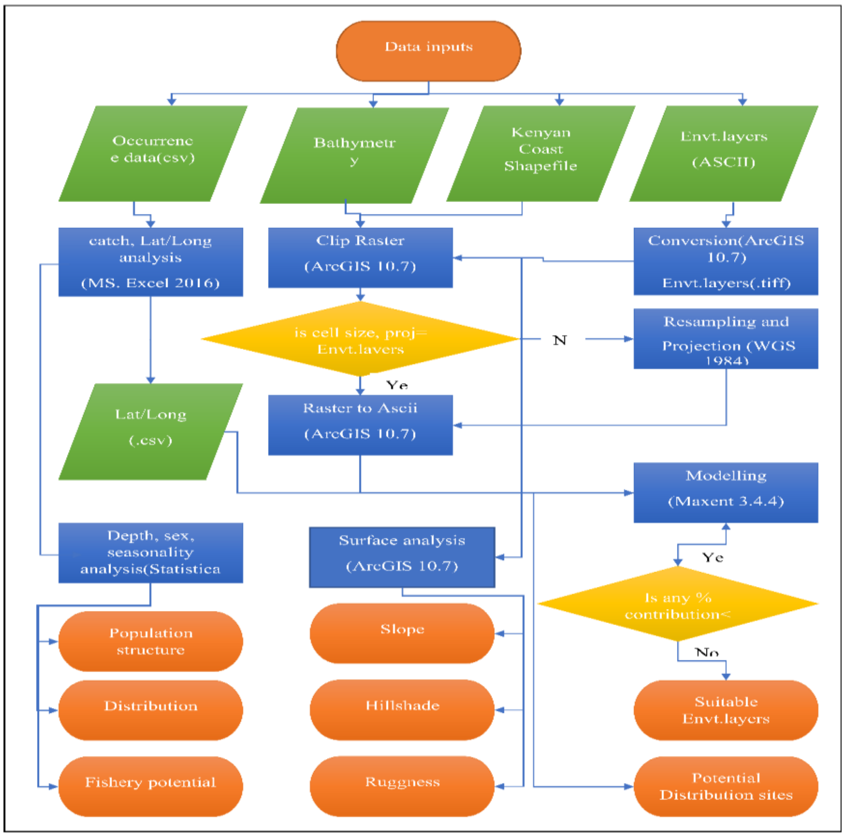

Fig. 1. The methodology of determining the population structure and species distribution modelling

2.8 Model Outputs

Maxent outputs included weighted environmental predictors ranked, showing each predictor's percentage contribution to the model's overall performance [55]. With the jackknife setting activated, Maxent weighed each variable contribution to the model's gain. The other outputs included response plots which were used to describe the tolerance limits of *C. somaliensis* to each variable. The plots showed each variable effect on the species being plotted and a final potential distribution model [56].

3. RESULTS

3.1 Population Structure and Size Distribution

Generally, *Chaceon somaliensis* catch decreased for the period of data collection, September to January 2022 (Fig. 2A); the decline and slight increase were attributed to the change in Weighted catch per unit effort during that period. Fishing effort (Weighted catch per unit effort) was positively correlated with the catch ($R^2 = 0.94$, P=0.02) for 2021 and $R^2 = 0.83$, $P=1.96^{-98}$ (catch per unit effort) for the three years, 2019, 2020 and 2021. Fishing effort Weighted catch per unit effort calculated for 2021 was correlated with catch per unit effort ($R^2 = 0.92$). The population was skewed towards the males (0.94:0.05:0.01) for male, female, and immature crabs, respectively. The males were large and heavier compared to the females (Fig. 2B, mean carapace width = 143.94 ± 18.30 mm SD, mean carapace width = 92.1 ± 19.02 mm SD and 1077.05 ± 316.59 g SD) and (258.73 ± 323.18 g SD for male and female respectively) and with a mean (mean carapace width = 143.94 ± 18.30 mm SD) for the whole population depicting that only large crabs were caught by the traps. The relationship between carapace width and weight was significant ($R^2 = 0.9$, $P = 0.00$). An exponential relationship curve was observed (Fig. 2C), and a normal weight distribution curve with two peaks (1000 and 1200 g) was observed (Fig. 2D). The mean soak time was 78 hours.

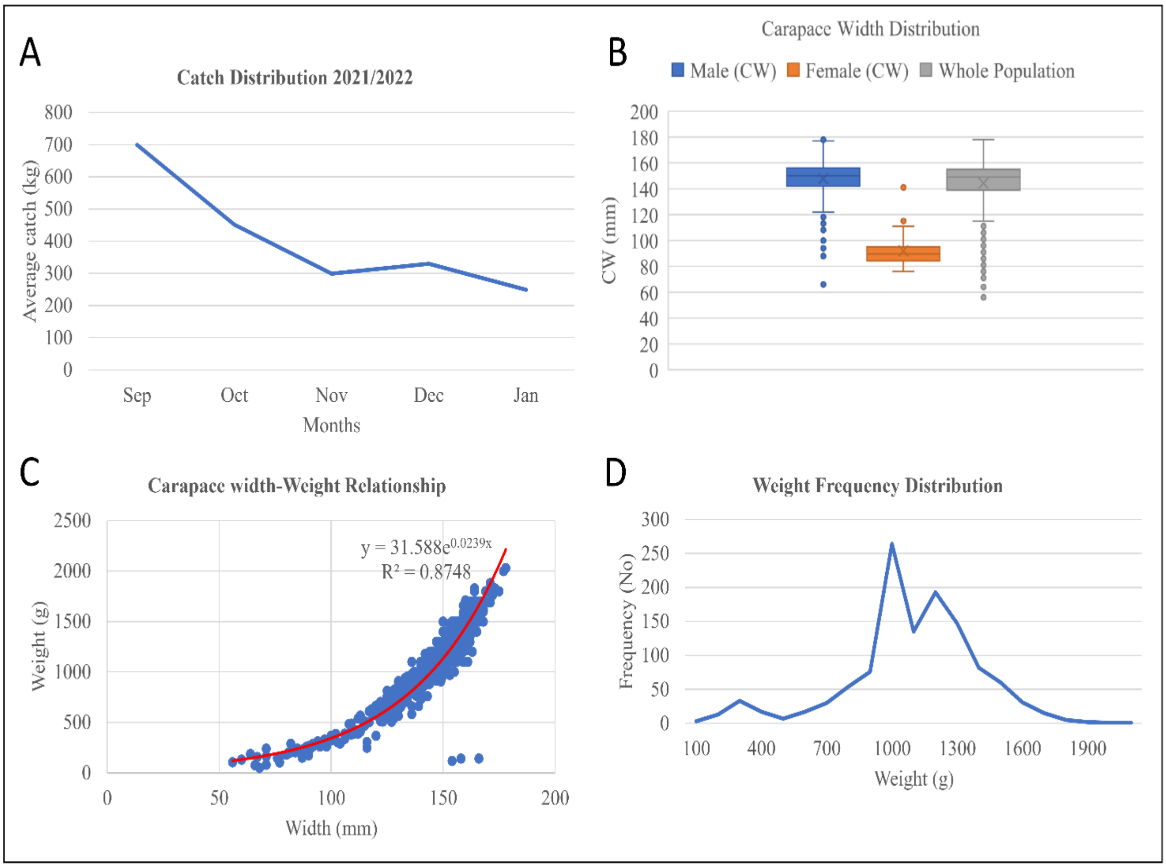

Fig. 2. Catch distribution 2021/2022 (A), carapace width distribution (B), carapace width-weight relationship (C), and weight frequency distribution (D)

3.2 Depth-Distribution, and Population Structure

Generally, *Chaceon somaliensis* catch and fishing effort decreased with an increasing depth in all the plotted 100 m depth horizons except for the depth 701–800, where the catch and fishing effort was higher than the depth range of 601–700 m (Fig. 3A). The depth was subdivided into 100 m (15), and the catch was analyzed using those depth horizons (fishing depth range was from 395–759 m. Fishing distance from the shore increased with the increasing depth except for the same depth strata 701–800 m (Fig. 3B). For depth size (Fig. 3C and D), size generally decreased across the increasing depth profile except for the depth range 401–500 m, where the largest crab size of approximately 1.1 kg and carapace width of 151 mm were caught, polynomial relationship curve was observed. For the sex-depth distribution, the male and female abundance in relationship to depth was extremely opposite of each other (Fig. 3E AND F). The male sex crab followed the depth size distribution described above, with the depth (401–500) m having the highest abundance (see Fig. 3E). The females' abundances increased with the increasing depth, except for depth (401–500) m, where there was a zero abundance (see Fig.3F).

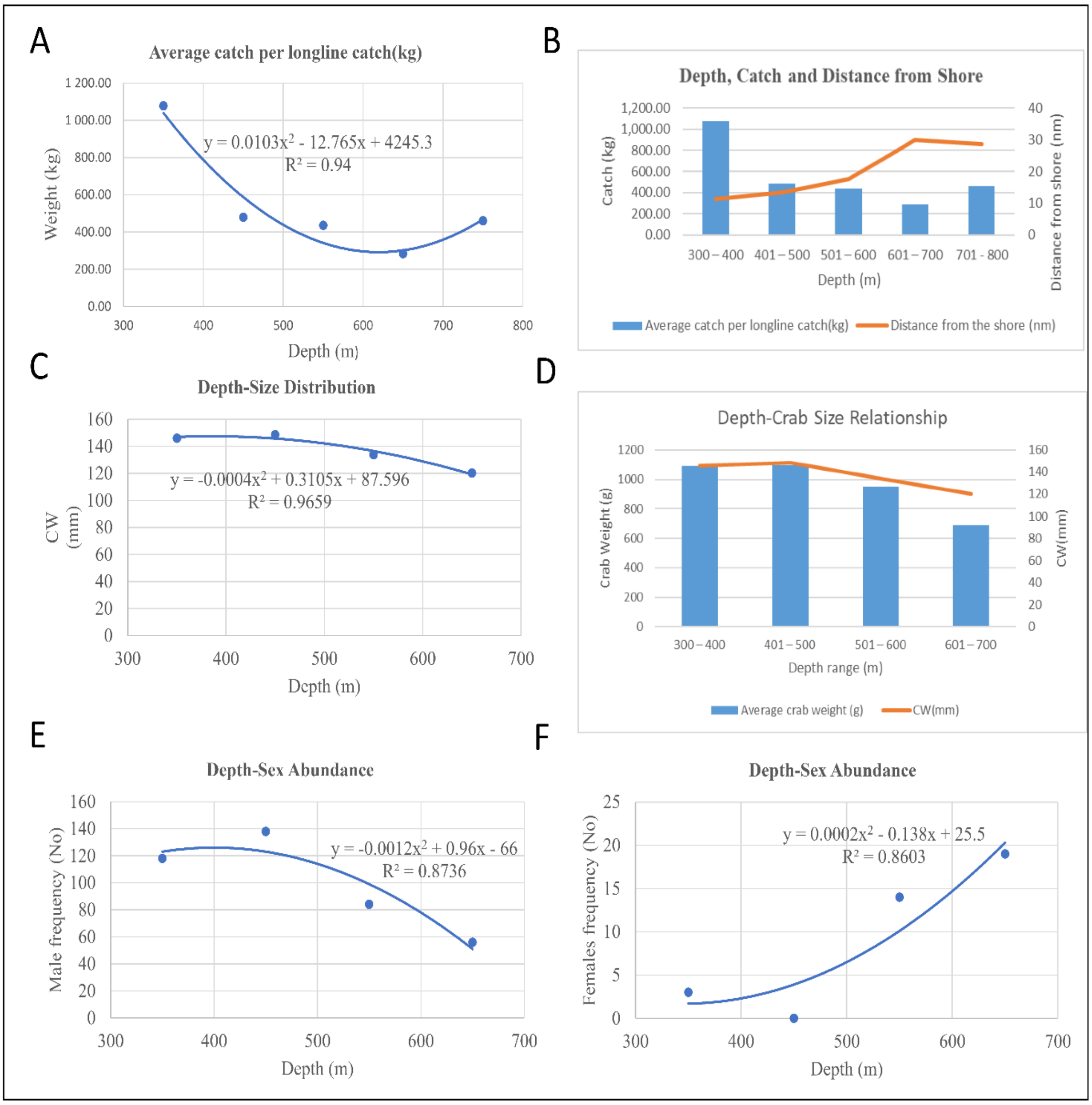

Fig. 3. Average catch per longline (A), relationship between depth, catch and distance from shore (Fig. B), depth size distribution (Fig. C and D) Depth -sex relationship (Fig. 3E and F)

3.3 Distribution and Seasonality

The fishing effort and the catch were high in the North East Monsoon compared to the South East Monsoon season, with only an exception in 2021 (Figs. 4A and 4B). There was a decline in the fishing effort and catch and an increase in the fishing depth in the North East Monsoon season across the years (Figs. 4B, 4A, and 4C). Higher catches in the South East Monsoon season in 2021 can be attributed to the increased fishing effort, shallower fishing depth, and fishing closer to the shore (Figs. 4A, 4B, 4C, and 4D). Catch per unit effort, in this case, was calculated as catch (kg) / No of traps for comparison across the three years.

3.4 SDM in the Environmental Variable Evaluation

The predictors were rigorously modelled in Maxent to evaluate environmental variables influencing *Chaceon somaliensis* distribution on the Kenyan Coast. A set of 6 runs were done, with the first run having all the predictors, 69 in total. The selection of the most suitable variable was based on percentage contribution. Any variable whose percentage contribution was zero was eliminated, and the modeling process was redone till all variable contributions were more significant than 0%. In the fifth run (Table 1), all the remaining environmental variables had a percentage contribution of greater than 0%.

All variables had a percentage contribution greater than zero in the fifth run. All variables measuring the same elements were eliminated to avoid overfitting, except the variable with the highest percentage contribution. Thus, silicate mean, iron minimum, currents velocity minimum, and silicate maximum were eliminated. The remaining seven variables were then rerun in the Maxent model. The model's outcome produced the environmental variables approximating the necessary conditions for *Chaceon somaliensis* occurrence, distribution, and population (Table 2).

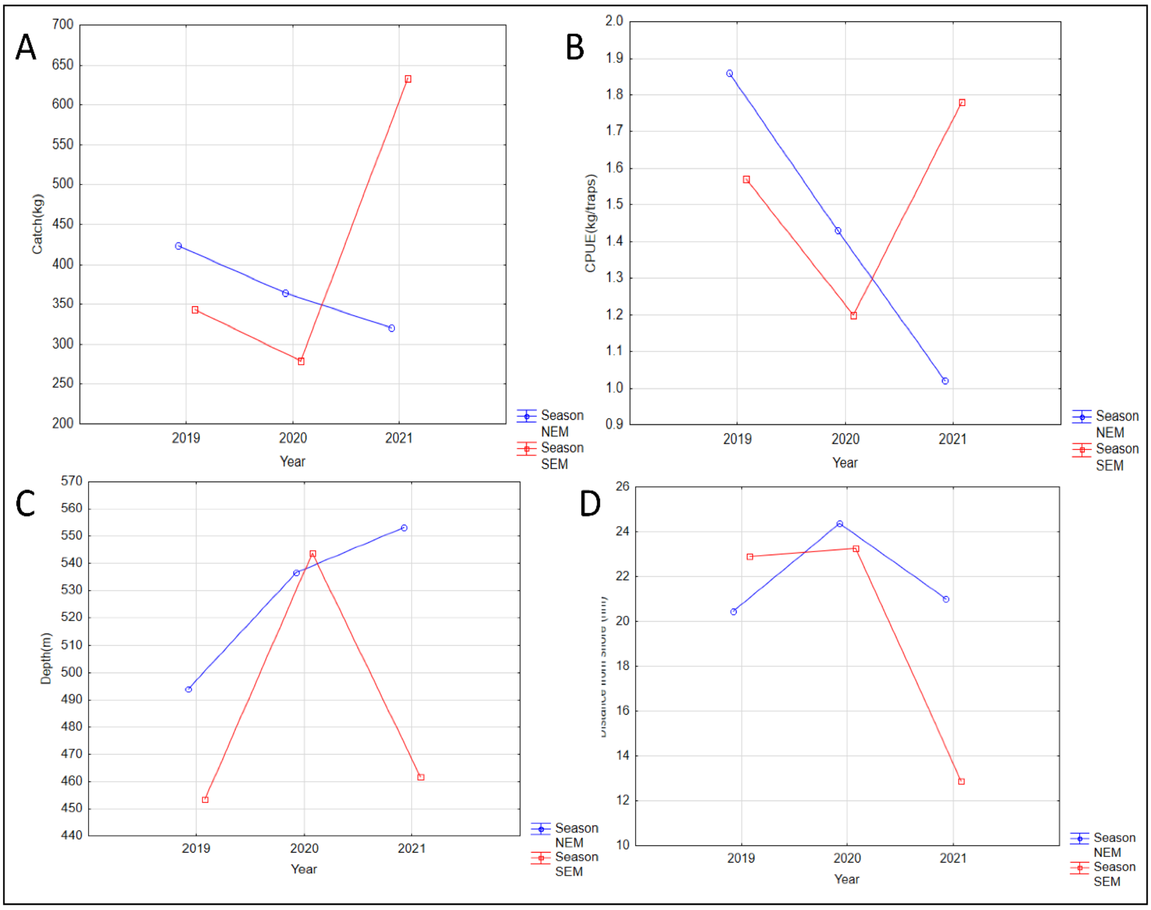

Fig. 4. Seasonality and catch per line (kg) (Fig. 4A), seasonality and CPUE (Fig. 4B), seasonality and fishing depth (Fig. 4C), seasonality and fishing distance (Fig. 4D)

Table 1. Results of the *Chaceon somaliensis* species' fifth run of Maxent modeling

Variable (Fifth run results)	Percentage contribution	Permutation importance
Mean phytoplankton	46.3	0.1
Silicate range	26.2	1
Mean primary productivity	5.6	0.1
Range of dissolved oxygen	5.3	4.1
Minimum LT currents speed	4.5	5.3
Maximum LT chlorophyl	4.4	2.4
Iron range	4	11.5
Bathymetry	1.6	61.6
Mean silicate	1	11.7
Minimum iron	0.8	1.8
Maximum silicate	0.3	0
Minimum currents speed	0.2	0.3

Table 2. Environmental variables affecting the species distribution on the Kenyan Coast

Variable	Percentage contribution	Permutation importance
Mean phytoplankton	47.5	0.8
Silicate range	25.7	2
Range of dissolved oxygen	5.6	4.7
Mean primary productivity	5.4	0.2
Maximum LT chlorophyl	5.1	3
Minimum LT currents speed	4.5	6.3
Iron range	4.1	6.3
Bathymetry	2	76.6

The seven environmental variables and the 1-bathymetry layer were the most suitable.

Fig. 5 shows the jackknife measure of variable importance when a variable is run in isolation and other variables omitted. Iron range had the highest gain showing that it had the most useful information. The variable that decreased the gain most when omitted was currents LT minimum, meaning it had very important information that the other variables did not.

3.5 Variable Optimum and Tolerance Limits

Suitable bathymetric depth ranged from approximately 100–500 m, with the peak of suitability to *C. somaliensis* occurrence being at 400 m depth (Fig. 6A). Chlorophyll exhibited a drastic rise and a narrow optimum peak at 0.01 mg/m^3 (Fig. 6B). The suitability range of minimum currents LT velocity to *Chaceon somaliensis* was between 0.002–0.08 m/s (Fig. 6C). Dissolved molecular oxygen suitability ranged from 20 mol/m^3 to 57 mol/m3 (Fig. 6D), iron range to *Chaceon somaliensis* was from 0.4 umol/m^3 to 0.7 umol/m^3(Fig. 6E), mean phytoplankton suitability range was narrow, 0.02 umol/m^3 (Fig. 6F), suitability range of silicate range was between 8 mol/m^3 to 18.2 (Fig. 6H), mol/m^3 with 18 mol/m^3 representing the optimum conditions.

The eight variables selected (Table 2) were modeled in Maxent to produce the potential distribution areas. Maxent setting for this exercise was set to 10 iterations. The random test percentage was set to 0 to allow random partitioning between train and test data in each replica.

3.6 Potential Sites and Hotspot Areas

Potential sites for *Chaceon somaliensis* showed a latitudinal distribution from the Southwest Coast of Kenya to the Northeast direction. The distribution followed the North Kenya Banks ridge from the South Coast of Kenya towards the Northeast, with the depth of the ridge extending from 250 m to 1250 m (Figs. 7A and 7B). Hotspot areas of great abundance of the species coincided with the ridge (Fig. 8B). The hotspot zone was approximately 3,230 km^2 of 61,694 km^2 of the study area (Fig. 7B).

Overlaying the raster image of the potential sites with raster images of the slope, hill shade, and ruggedness showed that the hotspot areas occur at slopes [19,22] with an angle between 0.98° and 4.31° within a low hill shade and a low rugged terrain (Fig. 8A).

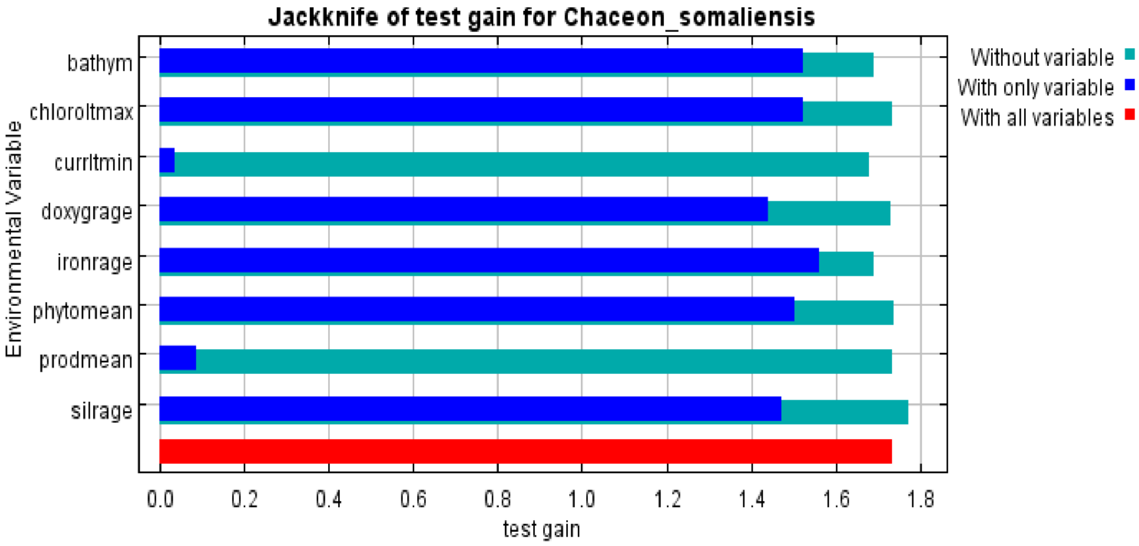

Fig. 5. Jackknife measure of variable importance

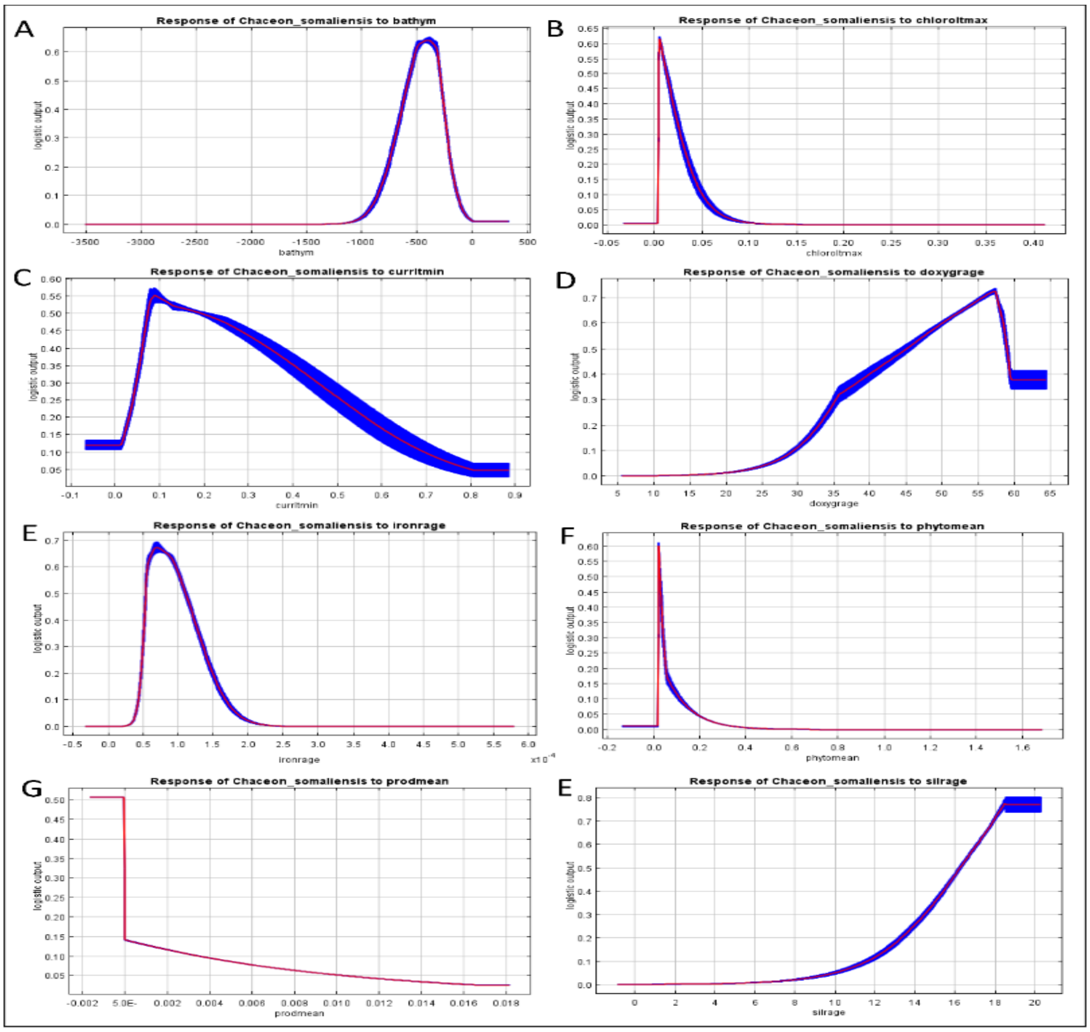

Fig. 6. The *Chaceon somaliensis* response curves for the environmental predictors

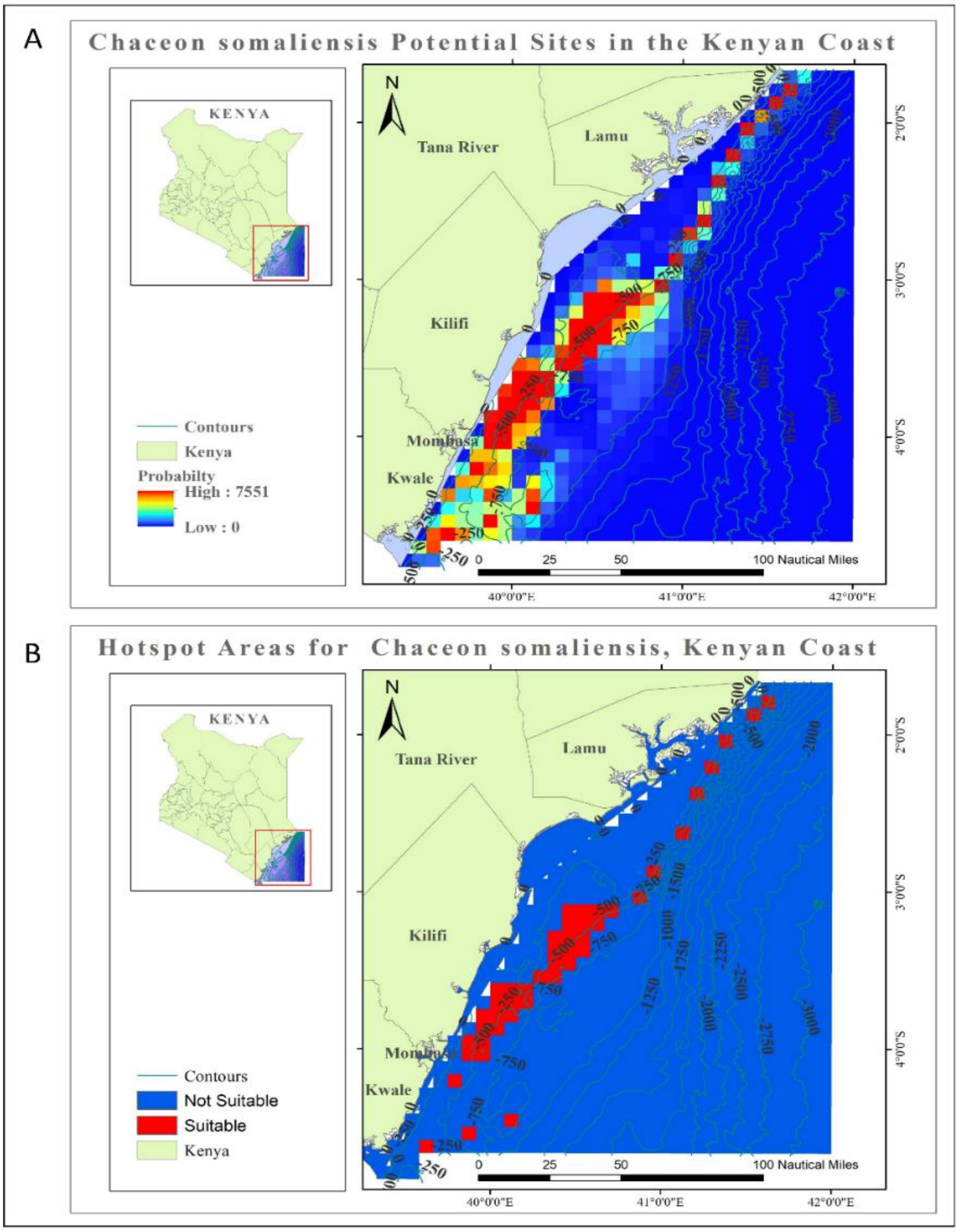

Fig. 7. (A) Potential sites, (B) hotspot areas, red colour show potentially suitable sites for *Chaceon somaliensis* occurrence, blue colour colors represent areas of low suitability

3.7 Accuracy of the Model

For the above model, the average AUC for the ten replicates was 0.938 ± 0.022 SD (Fig. 9A). Models for the respective three years using each year's occurrence data were developed to compare the effect of sampling on the model output over the overall potential site model above (Fig. 9B).

The output (Fig. 9B) shows there was a negligible effect of sampling on the overall performance of our model. The 3-year model, 2019, 2020, and 2021, can also be used to calibrate environmental variables to specific grounds of the Kenyan Coast as they showed that the percentage contribution and permuted importance of primary production was 0% for all the years showing that primary production was not an important predictor and could be left out when running future models. Maxent train area under the curve (AUC) and test AUC for the years 2019, 2020, and 2021 were 0.9, 0.964 and

0.975, 0.964 and 0.905, and 0.979 and 0.943, respectively, exhibiting high accuracy [33].

4. DISCUSSION

Chaceon somaliensis population abundance was found to be skewed towards large-sized male crabs. The population abundance was typical of Geryonid crabs [10]. This was also evidenced by the Geryonid *Chaceon chilensis* making up 97.9 of the sampled population in Robinson Island, Chile [10], *Chaceon gordonae* (1:0.82) for male: female in Brazil [2]. In contrast, female *Chaceon macphersoni* were dominant (1:0.29) in the KwaZulu–Natal Coast of South Africa [4]. Possible reasons for male dominancy were; the low mobility in the females which made it difficult for them to enter the traps, longer soak time which allowed the small female crabs to escape [57], sampling bias in that smaller crabs avoided entering the traps when larger crabs were present [58] and fishing method because, in the use of traps as fishing gear, ovigerous females tended to avoid traps when brooding [58].

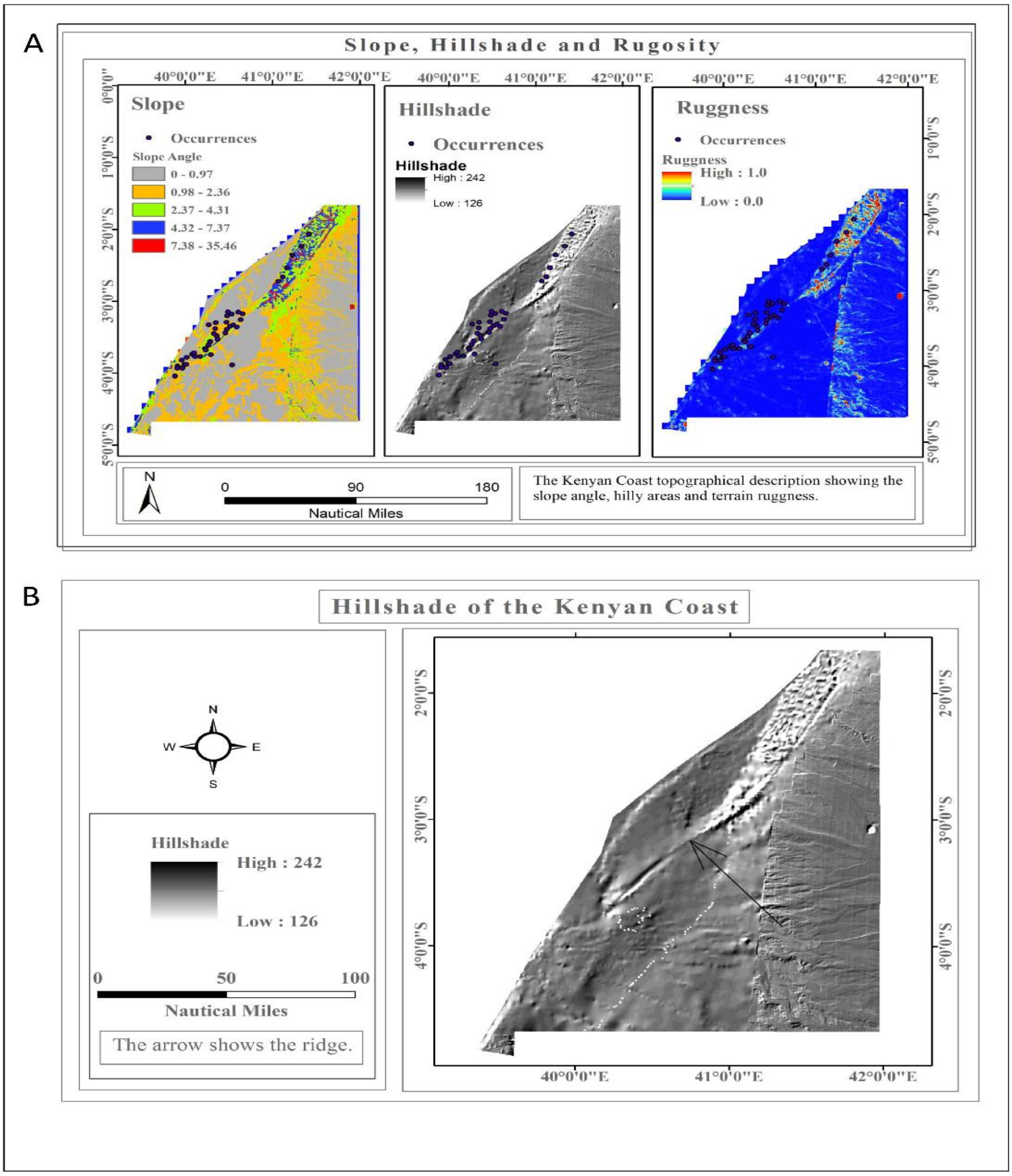

Fig. 8. (A) Hillshade and rugosity of *Chaceon somaliensis* potential distribution sites. (B) ridge-like depression running along the Kenyan Coast, Slope

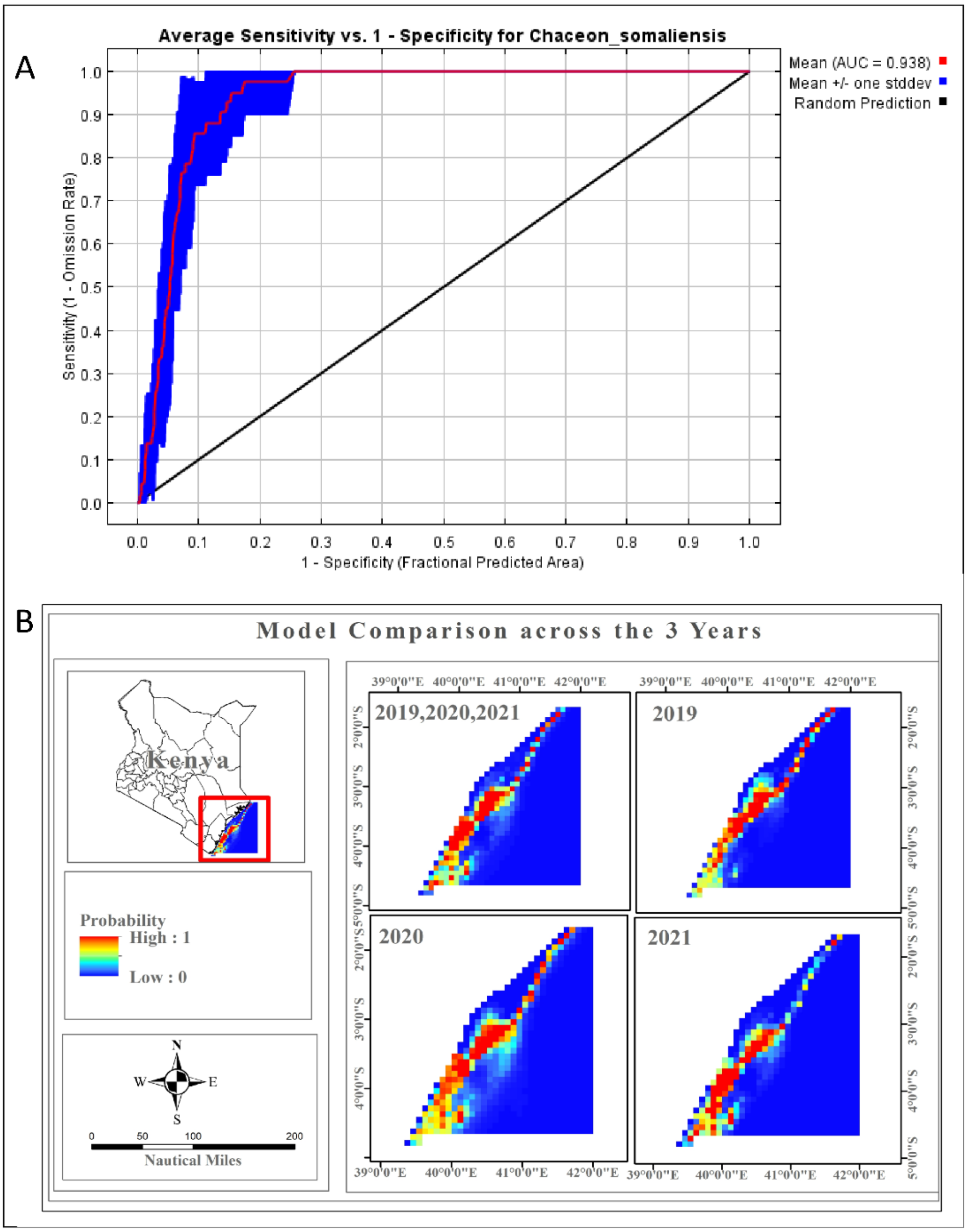

Fig. 9. AUC curve of *Chaceon somaliensis* (Fig. 9A) and comparison maps among models with the first model (2019, 2020, 2021) being the overall model, the same as (Fig. 9B)

Chaceon somaliensis males were larger and heavier than the females. This was common for Geryonid crabs [10]. For instance, *Chaceon gordonae* males were larger (mean carapace length = 110.81 ± 14.52 mm SD) and heavier (650.39 ± 236.26 g SD) than females (102.00 ± 16.55 mm SD and 387.42 ± 151.89 g SD) respectively (2). Also, the males of *Chaceon fenneri* [20,42], *Chaceon affinis* (3) and *C. macphersoni* (4) were larger than the females [59] in the study of *C. maritae* attributed this characteristic of the males being larger than the females to the difference in molting patterns between the sexes, the females experienced a shorter molting period in the immature stage and longer after maturity. Notably, *C. Somaliensis* in this study were comparatively larger than the other Geryonid, with the abundance of the species occurring above a carapace width of 140 mm and a bi-modal weight distribution curve observed (at 1000 and 1200 g, see Fig 2D). Thus, based on size, the traps mainly caught adult crabs. Therefore, the positive correlation between catch per unit effort and catch, and the tendency of the traps to mainly catch adult crabs made an 'ideal distribution' [45], shows that the Kenyan Coast Crab fishery was healthy.

Segregation by depth was observed for *C. somaliensis*, both depth-abundance and depth-sex stratification. The bathymetric layer from Maxent modelling (Fig. 6A and 3D) showed the depth stratification with an optimum depth range of 401–500 m. Depths <500 m had large-sized male crabs and numerical abundance. Females' abundance increased with depth, with the highest abundance at depths 601–700 m. This sex stratification was also observed for other Geryonid crabs; in the Atlantic; *Chaceon fenneri* males occurred in depths 274–549 m and females 733–823 m [60], *Chaceon affinis* in the Azores also exhibited similar patterns [61]. In other studies, the sex-stratification differed, and males predominated over deeper zones and females' shallower ones, *C. notialis* with the females being abundant in shallower regions 300–400 m [41], and *C. fenneri* in Brazil had females found in deeper zones compared to the males [5]. Segregation by sex was also observed for *C. gordonae* in Brazil [2]. The possible explanation for the depth-sex stratification was the difference in the reproduction cycle between males and females, biological conditions and environmental influences on the sexes [2,5]. Depth-abundance stratification was also evident for *C. gordonae* at depths 400–500 m (2), *C. macphersoni* abundance increased with increasing depths 200–499 m and declined thereafter (4), *Chaceon notialis* depths 400–700 m (37), *Geryon trispinosus*, occurred at depths 506 and 510 m (15). In contrast, (3) and (6) provided deeper depth strata as the regions of abundance, *C. affinis* abundance occurred at strata (600–799 m) and (800–899 m) and mean sizes decreased with depth for both sexes, *Chaceon chilensis* abundance was fund at depth of 750 m and the species was larger at deeper strata's compared to the shallow ones.

Distribution of *C. somaliensis* decreased with increasing distance from the shore. This was because as the distance to the shore increased, depth also increased, and as depth and *C. somaliensis* were inversely related, so was the distance to the shore. For seasonality during North East Monsoon (November to March), the distribution of fishing effort and the catch was higher than in the South East Monsoon (April to October) seasons for the two years (2019 and 2020). This compares with (4), who observed seasonality in the distribution of *Chaceon macphersoni,* with the highest catch in November and December and lowest in June and July for trawl catch, probability of good catch was higher in spring and lowest in winter. (37) also observed seasonality for *C. notialis* where abundance occurred in summer (December–February, in Argentinian-Uruguayan area). The possible reason for the change in seasonal catch (higher catch during South East Monsoon than in North East Monsoon) in the year 2021 for this research was due to the increased fishing effort (Fig. 4B), the vessel fished in shallower regions (Fig. 4C) and closer to the shore (Fig. 4D). Though, 3-year data might not have been adequate to conclude on seasonality.

In the evaluation of environmental predictors suitable for *Chaceon somaliensis* distribution, it was found that factors related to food (18,19) and nutrient minerals were the top predictors (Table 2). These include mean phytoplankton, range of silicate, maximum Lt chlorophyll, and mean primary productivity. Depth was observed to be an important variable in influencing the distribution of the species, with a permutation importance of 76.6 % (Table 2), meaning that depth by itself had useful information for the distribution of the *Chaceon somaliensis*, which other predictors did not have [37,38]. The tolerance limit of *Chaceon somaliensis* to each environmental variable differed, with the species having a wide niche breadth for bathymetry, dissolved molecular oxygen, and silicate. Other variables suitable for *Chaceon somaliensis* distribution included minimum LT current velocity, dissolved molecular oxygen, and iron range (Table 2). Though temperature and salinity were considered very important in the distribution of deep-sea crabs (15), this study found the most important input factors related to feeding, nutrients and bathymetry.

Hotspot areas and potential zones occurred in the North Kenya Bank ridge with a slope angle of between 0.98° and 4.31° and a low rugged terrain. This compares with other Geryonid crabs, *Chaceon gordonae* found on the ridge of Sierra Leone, off Western Africa and the Mid-Atlantic ridge in the Brazilian Archipelagos of

Saint Paul and Peter [2,62,20] explained the habitats of Geryonid crabs as varied, ranging from sloppy areas, valleys at depths of 200–900 m having and or soft sandy bottoms, rocky escarpments, sinkholes, boulder and slab areas, vertical escarpments and dense coral thickets. The need for species to migrate easily or the effect of sediment type on the habitat of the species [63] and the crab's ability to detect steep slopes and migrate to low slopes a behavior termed as negative geotaxis [19] were cited as the reasons for the Geryonid crabs' habitat choice.

The Maxent SDM confirmed most of the statistical results; the optimum depth for the species distribution (400–500 m) aligned with the statistical results. The model also tried to explain the observed distribution with food, nutrients and depth (topography) variables influencing the species population structure and its geographical distribution. The species distribution modelling also pointed out the optimum conditions under which the species thrived. Potential hotspot areas that only covered a small fraction of the study are (0.05), emphasizing the need for sustainable exploitation and conservation of the resources. The potential sites from the species distribution model should guide conservation and potential efforts towards Kenya's emerging *Chaceon somaliensis* fishery.

5. CONCLUSION

The study could not emphasize enough the importance of integrating statical analysis and species distribution models in the evaluation of species population structure and its distribution properties. It showed the complementary nature of the two methods, with both the species distribution model and statistics used to achieve the main objective. Regression analysis and species distribution model established that the *Chaceon Somaliensis* population structure followed a depth stratification, with shallow areas having both large and heavier crabs. Both the Maxent model and statistical analysis suggested that the optimal depth for the species was found at depths 400–500 m. The Maxent species distribution model further evaluated potential environmental variables found in the study area and their influence on the species distribution, migration and population. Eight environmental variables were suggested as of importance in influencing the distribution of the species in the study area. The model also produced the potential suitable areas and their topographic characteristics. The study agreed with [19] that the species was prone to gentle slopes and ridges (along the slopes of the North Kenya Banks). It also brought into focus the small size of the hot spot areas (3,230 km^2) a very important information in the conservation practices of the species. Annual catch limits for the species can be introduced as a conservation measure. For instance, in the sea off Eastern Florida, the annual catch limit for *C. fenneri* was set at 909,090 kg whole weight. The limit could be modified for the fishery after conducting a stock survey to help in the conservation of the deep-sea crab fishery in Kenya. *T*hough, fishery was considered productive *(*catch> 94% adults) effective monitoring practices that use population structure, depth, and predictive models as key system elements should be implemented [3,35]. For instance, in the study of *Chaceon ramosae* [64], advocated for prohibition of fishing in areas less than 500 m. The study agrees with previous studies [2,10] that the male population sustains the Geryonid fishery and should be factored in the management and conservation of the fishery.

Among other contributions of this study was in profiling the new *Chaceon somaliensis* fishery, providing its population structure and distribution and using species distribution model to evaluate environmental variables and model the potential suitable sites. This information can be used to conserve and manage the new fishery. The study also helped correctly identify and name the deep-sea crab as *Chaceon somaliensis*; previous unpublished data referred to the species as *Chaceon fenneri.* The newly introduced fishing effort (Weighted catch per unit effort) should be tested for its rigidity in future research of a similar nature. Though the study is essential, it did not cover the role of sediment size in influencing the distribution of the species*, Chaceon somaliensis* molting patterns, maturity, reproduction, life cycle, and biology and habitat types [2,4,20].

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ACKNOWLEDGEMENTS

The research was funded by the Western Indian Ocean Marine Science Association (WIOMSA) (project number is MARGI_2021_CO-13). The host institutions were Taita Taveta University, where the researcher was a postgraduate student. Kenya Fisheries Service, and Kenya Marine and Fisheries Research Institute (KMFRI), which helped in administration of the project. I also acknowledge the WIOFish for their help in identifying the deep sea crab. MS acknowledges personal financial support from the KONE Foundation (Grant #202101976). The funding sources had no involvement in the design, analysis of the research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Manning RB, Holthuis LB. Two New Genera and Nine New Species of Geryonid Crabs (Crustacea, Decapoda, Geryonidae). Proc Biol Soc Wash. 102(1).
2. Ferreira RCP, Nunes DM, Shinozaki Mendes RA, Pires AMA, Hazin FHV. First record and preliminary information on the biology of the deep sea African crab, Chaceon gordonae (Ingle, 1985) *(Brachyura: Geryonidae*) in Saint Peter and Saint Paul Archipelago, Brazil. Lat Am J Aquat Res. 2016;44(2):392–400.
3. Biscoito M, Freitas M, Pajuelo JG, Triay-Portella R, Santana JI, Costa AL, et al. Sex-structure, depth distribution, intermoult period and reproductive pattern of the deep-sea red crab Chaceon affinis (*Brachyura, Geryonidae*) in two populations in the north-eastern Atlantic. Deep Sea Res Part Oceanogr Res Pap. 2015;95:99–114.
4. Groeneveld JC, Everett BI, Fennessy ST, Kirkman SP, Santos J, Robertson WD. Spatial distribution patterns, abundance and population structure of deep-sea crab Chaceon macphersoni, based on complementary analyses of trap and trawl data. Mar Freshw Res. 2013;64(6):507–17.
5. Barros Carvalho T, De Oliveira Filho RR, Da Cruz Lotufo TM. Note on the fisheries and biology of the golden crab (*Chaceon fenneri*) off the northern coast of Brazil. Lat Am J Aquat Res. 2009 Nov 10;37(3):571–6.
6. Adawiyah, Dewi, Atikah Nurhayati, Ine Maulina, and Asep Agus Handaka. Analysis of the Economic Potential of the Fisheries Sector as a Basic Sector in Cianjur Regency West Java Province. Asian Journal of Fisheries and Aquatic Research. 2023;24(4):42-49. Available:https://doi.org/10.9734/ajfar/2023/v24i4641.
7. Aimerance, Kenfack Donhachi, Daniel Brice Nkontcheu Kenko, Zebaze Tagning Pegis Davy, Efole Ewoukem Thomas, and. Tchoumboue. Species Richness, Diversity and Distribution of Phytoplankton in Fertilised Ponds of the Western Highlands Agro-Ecological Zone of Cameroon. Asian Journal of Environment & Ecology. 2022;19(4):115-34. Available:https://doi.org/10.9734/ajee/2022/v19i4423.
8. Desai BN, Bhargava RM, Sarupria JS. Estimates of fishery potentials of the EEZ of India. Estuarine, Coastal and Shelf Science. 1990;30(6):635-9.
9. Karlsson R, Obst M, Berggren M. Analysis of potential distribution and impacts for two species of alien crabs in Northern Europe. Biological Invasions. 2019;21:3109-19.
10. Guerrero A, Arana P. Size structure and sexual maturity of the golden crab (*Chaceon chilensis*) exploited off Robinson Crusoe Island, Chile. Lat Am J Aquat Res. 2009;37(3):347–60.
11. Gutiérrez NL, Masello A, Uscudun G, Defeo O. Spatial distribution patterns in biomass and population structure of the deep sea red crab Chaceon notialis in the Southwestern Atlantic Ocean. Fish Res. 2011;110(1):59–66.
12. Everett BI, Groeneveld JC, Fennessy ST, Dias N, Filipe O, Zacarias L, et al. Composition and abundance of deep-water crustaceans in the Southwest Indian Ocean: Enough to support trawl fisheries? Ocean Coast Manag. 2015;111:50–61.
13. Melo-Merino SM, Reyes-Bonilla H, Lira-Noriega A. Ecological niche models and species distribution models in marine environments: A literature review and spatial analysis of evidence. Ecol Model. 2020 Jan 1;415.
14. Erdman RB, Blake NJ, Torres JJ. Oxygen consumption of the deep-sea crabs Chaceon fenneri and C. quinquedens (*Brachyura: Geryonidae*). Comp Biochem Physiol A Physiol. 1991;99(3):383–5.
15. Davie PJF, Ng PKL, Dawson EW. A new species of deep-sea crab of the genus Chaceon Manning & Holthuis, 1989 (Crustacea: Decapoda: Brachyura:

Geryonidae) from Western Australia. Zootaxa. 2007;1505(1):51–62.

16. Da Silva Cortinhas MC, Ortega I, De Souza Alves Teodoro S, Proietti M, Masello A, Kersanach R, et al. Defining deep-sea fishery stocks through multiple methods: The case of the red crab Chaceon notialis Manning & Holthuis, 1989 (Crustacea, Decapoda, Geryonidae) in the Southwestern Atlantic. Deep Sea Res Part Oceanogr Res Pap. 2022;179:103659.
17. Manning B. A New Deep-Sea Crab, Genus Chaceon, from the Arabian Sea (Crustacea, Decapoda, Geryonidae).
18. Grüss A, Drexler MD, Chancellor E, Ainsworth CH, Gleason JS, Tirpak JM, et al. Representing species distributions in spatially-explicit ecosystem models from presence-only data. Fish Res. 2019;210:89–105.
19. Attrill MJ, Hartnoll RG, Rice AL, Thurston MH. A depth-related distribution of the red crab, Geryon trispinosus (Herbst) [= G. tridens Krøyer]: indications of vertical migration. Prog Oceanogr. 1990;24(1–4).
20. Reed JK, Farrington S, Messing C, David A. Distribution and Habitat Use of the Golden Crab Chaceon fenneri off Eastern Florida Based on in situ Submersible and ROV Observations and Potential for Impacts to Deep Water Coral/Sponge Habitat. Gulf Caribb Res. 2017;28:1–14.
21. Capezzuto F, D'Onghia G, Carluccio A, Maiorano P. Distribution and life strategy of the deep-sea crab Paromola cuvieri (Risso, 1816) (Brachyura, Homolidae) in the central Mediterranean Sea over twenty-five years. Deep Sea Res Part Oceanogr Res Pap. 2023;196:104002.
22. Hardy SM, Lindgren M, Konakanchi H, Huettmann F. Predicting the distribution and ecological niche of unexploited snow crab (Chionoecetes opilio) Populations in alaskan waters: A first open-access ensemble model. In: Integrative and Comparative Biology. 2011;608–22.
23. Robinson LM, Elith J, Hobday AJ, Pearson RG, Kendall BE, Possingham HP, et al. Pushing the limits in marine species distribution modelling: Lessons from the land present challenges and opportunities. Glob Ecol Biogeogr. 2011; 20(6):789–802.
24. Georgian SE, Anderson OF, Rowden AA. Ensemble habitat suitability modeling of vulnerable marine ecosystem indicator taxa to inform deep-sea fisheries management in the South Pacific Ocean. Fish Res. 2019;211:256–74.
25. Melville-Smith R. Density distribution by depth of Geryon maritae on the northern crab grounds of South West Africa/Namibia determined by photography in 1983, with notes on the portunid crab Bathynectes piperitus. South Afr J Mar Sci. 1985;3(1):55–62.
26. Beyers C de B, Wilke CG. Quantitative stock survey and some biological and morphometric characteristics of the deep-sea red crab Geryon quinquedens off South West Africa. Fish Bull-Contrib Oceanogr Fish Biol-South Afr Dept Ind Sea Fish Branch; 1980.
27. Haefner Jr PA. Seasonal aspects of the biology, distribution and relative abundance of the deep-sea red crab Geryon quinquedens Smith, in the vicinity of the Norfolk Canyon, western North Atlantic.
Available:https://scholarworks.wm.edu/vimsarticles/1263
28. Ben Rais Lasram F, Hattab T, Nogues Q, Beaugrand G, Dauvin JC, Halouani G, et al. An open-source framework to model present and future marine species distributions at local scale. Ecol Inform. 2020;59.
29. Holmes M, Kotta J, Persson A, Sahlin U. Marine protected areas modulate habitat suitability of the invasive round goby (*Neogobius melanostomus*) in the Baltic Sea. Estuar Coast Shelf Sci. 2019; 229:106380.
30. Guisan A, Zimmermann NE. Predictive habitat distribution models in ecology Ecological Modelling. 2000;135:147–86.
Available:www.elsevier.com/locate/ecolmodel
31. Gábor L, Jetz W, Zarzo-Arias A, Winner K, Yanco S, Pinkert S, et al. Species distribution models affected by positional uncertainty in species occurrences can still be ecologically interpretable. Ecography. 2023;2023(6):e06358.
32. Pearson RG. Species' Distribution Modeling for Conservation Educators and Practitioners.
33. França S, Cabral HN. Predicting fish species distribution in estuaries: Influence of species' ecology in model accuracy. Estuar Coast Shelf Sci. 2016; 180:11–20.
34. Hallstan S. Species distribution models. Ecol Appl Manag Biodivers Fac Nat

Resour Agric Sci Dep Aquat Sci Assess Upps Swed; 2011.
[Accesson: 2024 Jun 6];
Available:http://pub.epsilon.slu.se/8131/1/hallstan_s_110519.pdf

35. Li M, Zhang C, Xu B, Xue Y, Ren Y. Evaluating the approaches of habitat suitability modelling for whitespotted conger (Conger myriaster). Fish Res. 2017;195:230–7.
36. Bittner RE, Roesler EL, Barnes MA. Using species distribution models to guide seagrass management. Estuar Coast Shelf Sci. 2020;240:106790.
37. Phillips SJ, Dudík M, Phillips SJ. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation.
38. Phillips SJ, Anderson RP, Schapire RE. Maximum entropy modeling of species geographic distributions. Ecol Model. 2006;190(3–4):231–59.
39. Jebri F, Jacobs ZL, Raitsos DE, Srokosz M, Painter SC, Kelly S, et al. Interannual monsoon wind variability as a key driver of East African small pelagic fisheries. Sci Rep. 2020;10(1):13247.
40. Jacobs ZL, Jebri F, Raitsos DE, Popova E, Srokosz M, Painter SC, et al. Shelf-Break Upwelling and Productivity Over the North Kenya Banks: The Importance of Large-Scale Ocean Dynamics. J Geophys Res Oceans. 2020;125(1).
41. Defeo O, Little V, Barea L. Stock assessment of the deep-sea red crab Chaceon notialis in the Argentinian-Uruguayan Common Fishing Zone. Fisheries Research. 1991;11:25–39.
42. Trigg C, Perry H. Size and Weight Relationships for the Golden Crab, Chaceon fenneri, and the Red Crab, Chaceon quinquedens, from the Eastern Gulf of Mexico. Gulf Res Rep. 1997;9.
[Accesson: 2023 Jul 11];
Available:http://aquila.usm.edu/gcr/vol9/iss4/11
43. Anam R, Mostarda E. Field Identification Guide to the Living Marine Resources of Kenya.
44. Fernández-Vergaz V, Abellán LL, Balguerías E. Morphometric, functional and sexual maturity of the deep-sea red crab Chaceon affinis inhabiting Canary Island waters: chronology of maturation. Mar Ecol Prog Ser. 2000;204:169–78.
45. Swain DP, Wade EJ. Spatial distribution of catch and effort in a fishery for snow crab (Chionoecetes opilio): Tests of predictions of the ideal free distribution. Can J Fish Aquat Sci. 2003;60(8):897–909.
46. Microsoft Corporation. Microsoft Excel; 2016.
Available:https://office.microsoft.com/excel
47. StatSoft Inc. Statistica (data analysis software system), version. 2014;12.
Available:http://www.statsoft.com
48. Tyberghein L, Verbruggen H, Pauly K, Troupin C, Mineur F, De Clerck O. Bio-ORACLE: a global environmental dataset for marine species distribution modelling: Bio-ORACLE marine environmental data rasters. Glob Ecol Biogeogr. 2012;21(2):272–81.
49. Assis J, Tyberghein L, Bosch S, Verbruggen H, Serrão EA, De Clerck O. Bio-ORACLE v2.0: Extending marine data layers for bioclimatic modelling. Glob Ecol Biogeogr. 2018;27(3).
50. GEBCO Compilation Group. GEBCO 2022 Grid. 2022.
51. ESRI. ArcGIS Desktop: Release 10.7. Redlands, CA: Environmental Systems Research Institute; 2011.
52. Aguirre-Gutiérrez J, Carvalheiro LG, Polce C, van Loon EE, Raes N, Reemer M, et al. Fit-for-Purpose: Species Distribution Model Performance Depends on Evaluation Criteria - Dutch Hoverflies as a Case Study. PLoS ONE. 2013;8(5).
53. SDMtoolbox JB. A python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. 2014;5.
DOI: Httpsdoi Org1011112041-210X. 12200:694–700.
54. Guillera-Arroita G, Lahoz-Monfort JJ, Elith J, Gordon A, Kujala H, Lentini PE, et al. Is my species distribution model fit for purpose? Matching data and models to applications. Glob Ecol Biogeogr. 2015;24(3):276–92.
55. Nor W, Zainol Z, Abdullah @. Habitat Mapping and Species Distribution Modelling of the Endangered Bulloak Jewel Butterfly A thesis submitted by; 2016.
56. Obunga G, Siljander M, Maghenda M, Pellikka PKE. Habitat suitability modelling to improve conservation status of two critically endangered endemic Afromontane forest bird species in Taita Hills, Kenya. J Nat Conserv. 2022;65.
57. Barea L, Defeo O. Aspectos de la pesquería del cangrejo rojo (Geryon

quinquedens) en la zona común de pesca argentino-uruguaya. Publ Com Téc Mix Fr Mar. 1986;1(1):38–46.

58. Taggart SJ, O'Clair CE, Shirley TC, Mondragon J. Estimating Dungeness crab (Cancer magister) abundance: crab pots and dive transects compared; 2004. [Accesson: 2024 Jun 7]; Available:https://aquadocs.org/handle/1834/30926
59. Melville-Smith R. A growth model for the deep-sea red crab (*Geryon maritae*) off South West Africa/ Namibia (*Decapoda, Brachyura*). Crustaceana. 1989;279–92.
60. Lindberg WJ, Wenner EL. Geryonid crabs and associated continental slope fauna: a research workshop report. 1990 [Accesson: 2024 Jun 7]; Available:https://aquadocs.org/handle/1834/18134
61. Pinho MR, Gonçalves JM, Martins HR, Menezes GM. Some aspects of the biology of the deep-water crab, Chaceon affinis (Milne-Edwards and Bouvier, 1894) off the Azores. Fish Res. 2001;51(2–3):283–95.
62. Ingle RW. Geryon gordonae sp. nov. (*Decapoda Brachyura, Geryonidae*) from the northeastern Atlantic Ocean. Crustaceana. 1985;88–98.
63. Bluhm B, Iken K, Mincks Hardy S, Sirenko B, Holladay B. Community structure of epibenthic megafauna in the Chukchi Sea. Aquat Biol. 2009;7:269–93.
64. Boos H, Araujo PB, Boos H, Araujo PB. Abundance and distribution of the deep-sea crab Chaceon ramosae (*Decapoda: Geryonidae*) in southern Brazil: contribution to the fishing regulation. Lat Am J Aquat Res. 2018;46(5):1091–102.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119010