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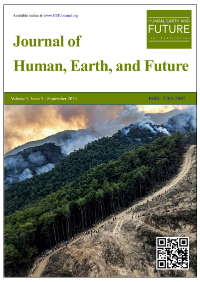

Nursery Habitat Requirements for the Blue Swimming Crab: Implications for Larval Development

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Abstract

Overfishing causes a significant decline in blue swimming crab (*Portunus pelagicus*) populations, an essential marine resource for Thailand. This research aimed to identify suitable nursery areas for this species throughout the four distinct monsoon seasons. This is the first comprehensive study of habitat characteristics: water temperature, pH, salinity, dissolved oxygen, marine sediment, seagrass beds, and suitability assessment of nursery areas, using a combined approach of Analytic Hierarchy Process and Geographic Information Systems. Our findings reveal that highly suitable nursery habitats comprise a small percentage of the total study area, varying with the monsoon season: 1.66% in the Northeast Monsoon (NEMS), 1.00% in the NEMS transition (NEMST), 1.11% in the Southwest Monsoon (SWMS), and 1.97% in the SWMS transition (SWMST). These areas are concentrated along the coastlines of Sed Island, Phum Riang, Takrob, Tha Thong, and Donsak. Sed Island was designated as a fishery refuge zone in 2022. The identified nursery areas coincide with existing crab banks, highlighting the model's accuracy. Conversely, unsuitable areas were predominantly in shellfish farming zones and low-salinity estuaries. By identifying suitable nursery grounds for the blue swimming crab, this study offers valuable information that can support Thailand's sustainable management and conservation efforts for this species.

Keywords: Nursery Ground; Bandon Bay; Geographic Information System; Blue Swimming Crab; Fisheries Refuges.

1. Introduction

The blue swimming crab (BSC), *Portunus pelagicus* (Linnaeus, 1758), is a commercially valued crustacean inhabiting the tropical coastal waters of the Indo-Pacific region [1]. In Thailand, the BSC is found along the coasts of the Andaman Sea and the Gulf of Thailand, and it has populations in 21 provinces. However, this economic boom is accompanied by a pressing environmental problem. Intensified fishing pressure driven by high domestic and international market demand has resulted in the overexploitation of BSC populations in the Gulf of Thailand, with estimated depletion exceeding 75.25% [2]. Bandon Bay, a vital nursery and feeding ground for BSC in the Gulf, is no exception [3, 4]. This multifunctional habitat is home to various shellfish species, including oysters, blood cockles, and green mussels, and serves as a spawning, nursery, and feeding ground [3]. In 2020, Thailand exported over 5,233 tons of frozen and canned BSC meat worth 879.62 billion baht to countries such as the United States, China, Taiwan, and Hong Kong [5]. The consequences of overfishing are apparent. Practices such as the removal of immature

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specimens and gravid (egg-bearing) females significantly reduce natural recruitment and hinder population replenishment [6]. Over the past two decades (1997-2021), BSC catches have fluctuated, dropping from 40,100 tons in 1997 to a low of 22,400 tons in 2015 before recovering to 36,245 tons by 2021 [7-11].

In response to the declining fishery resources, Thailand introduced the Crab Bank Program based on the Fisheries Strategy 2009-2012 [12]. Under this initiative, which was expanded by the Thai Cabinet in 2018, cages are placed in the sea or in hatcheries to house gravid BSC females [13]. Here, the females can safely spawn, and the resulting zoea larvae (first larval stage) and young crabs are then released back into the sea to replenish the wild populations. In Bandon Bay, there are 29 crabbing beds strategically distributed along the western and eastern coastline [14]. There is evidence of the program's effectiveness, as BSC catches increased to 36,245 metric tons by 2021 [2]. Interestingly, BSC females in Bandon Bay exhibit year-round spawning activity, with two distinct peaks observed from March to May and July to September [15]. A single female with a carapace size of 9.8-16.6 cm can produce a staggering 33,268 to 2,340,000 eggs, with an average of 1,186,634. However, only 1% of these eggs survive to become young crabs [16]. The crab bank program plays a crucial role in protecting these gravid females, allowing them to contribute to population replenishment through successful larval releases.

A comprehensive understanding of the environmental factors impacting the survival of BSC larvae is essential. The first stage of a BSC's life cycle (1-30 days) thrives under certain conditions: salinity between 23-30 ppt, pH between 6.5-8.5, and water temperature between 26-31°C [17-19]. Shallow (≤20 m) nearshore and estuarine ecosystems provide ideal habitats due to these factors, especially in benthic areas with sand, mud, or algae and seagrass beds [16, 20]. When BSC mature into megalopas and juveniles, they primarily inhabit coastal areas, especially those with seagrass beds which provide shelter and a rich food source [21-23]. Researchers have successfully used Geographic Information Systems (GIS) technology to identify several aquatic species' spawning and nursery areas, including those for Rose shrimp, Hilsa shad, sardine, and Walleye [24-27]. However, no previous study has used GIS to identify suitable nursery grounds for larval blue swimming crab (BSC). Therefore, this study is the first comprehensive investigation of the factors that make certain areas in Bandon Bay suitable nursery grounds for BSC larvae. Identifying these optimal locations will enable strategic release site selection for young crabs from the Crab Bank program, enhancing their post-release survival and contributing to the long-term sustainability of the BSC population in the area. The research focuses on the assessment of suitable BSC nursery areas during four different sub-seasons within a year: the Northeast Monsoon Season (NEMS), the Northeast Monsoon Season Transition (NEMST), the Southwest Monsoon Season (SWMS) and the Southwest Monsoon Season Transition (SWMST).

2. Material and Methods

2.1. Study Area

The study area is located in Bandon Bay, Thailand (9° 12' N-9° 26' N and 99° 12' E-99° 34' E), covering an area of 839.48 km^2 starting 10 km from the coast to sea (Figure 1-a, 1-b). Bandon Bay is a fertile estuary that receives freshwater and nutrients from two major rivers, the Tapi and Phum Duang, with 11 large and minor canals [28]. Bandon Bay has an average depth of 1 m, with water depth ranging between 1-5 m [29]. Bandon Bay comprises mud flats, mangroves, sandbars with seagrass beds, and seaweeds [30]. Seagrass beds in this area are 14.02 km^2 [31]. Bandon Bay experiences a distinct bimodal seasonal pattern characterized by a wet season extending from July to December and a dry season encompassing January to June. The temperature at Bandon Bay ranges between 23.2-32.9°C, with an annual mean temperature of 27.1°C. The yearly rainfall in Bandon Bay is 1,669.8 mm [32]. The average runoff of the Tapi and Phun Phin rivers is 5,048.78 and 4,022.93 million m^3/year, respectively (Royal Irrigation Department Thailand: *http://hydro-8.rid.go.th/*).

2.2. Data and Software

Ground suitability categorization was achieved in the nursery by integrating spatial data from diverse sources. These sources included existing Geographic Information System (GIS) data, administrative maps, topographical maps, and field-collected data. Suitable nursery grounds were delineated based on an assessment of water quality parameters- temperature, dissolved oxygen (DO), pH, and salinity [33]. In addition, the physical and biological factors, such as seagrass beds and marine sediment, are also used as analysis factors. Water quality data were collected from 32 stations (Figure 2-b), both from primary and secondary sources [34]. We collected seawater quality samples in the study area for the first time in January during NEMS; the second in May during NEMST; the third time in August represented SWMS, and the fourth time in November represented SWMST in 2019, 2020, and 2021. The data on marine sediments were obtained from maps of the Ministry of Mineral Resources and navigation charts of the Hydrographic Department of Thailand [29]. Seagrass resource data were sourced from the Department of Marine and Coastal Resources, Thailand [31]. We classified the Landsat 8 satellite images in 2021 by visual classification method and obtained the shoreline data. Spatial interpolation of all geospatial data and imagery was performed within ArcGIS (version 9.2) using the Spatial Analyst extension module. A Universal Transverse Mercator (UTM) projection with reference system WGS-84, zone 47N, was adopted for data consistency. The parameters were weighted and scored based on the importance of the nursery ground.

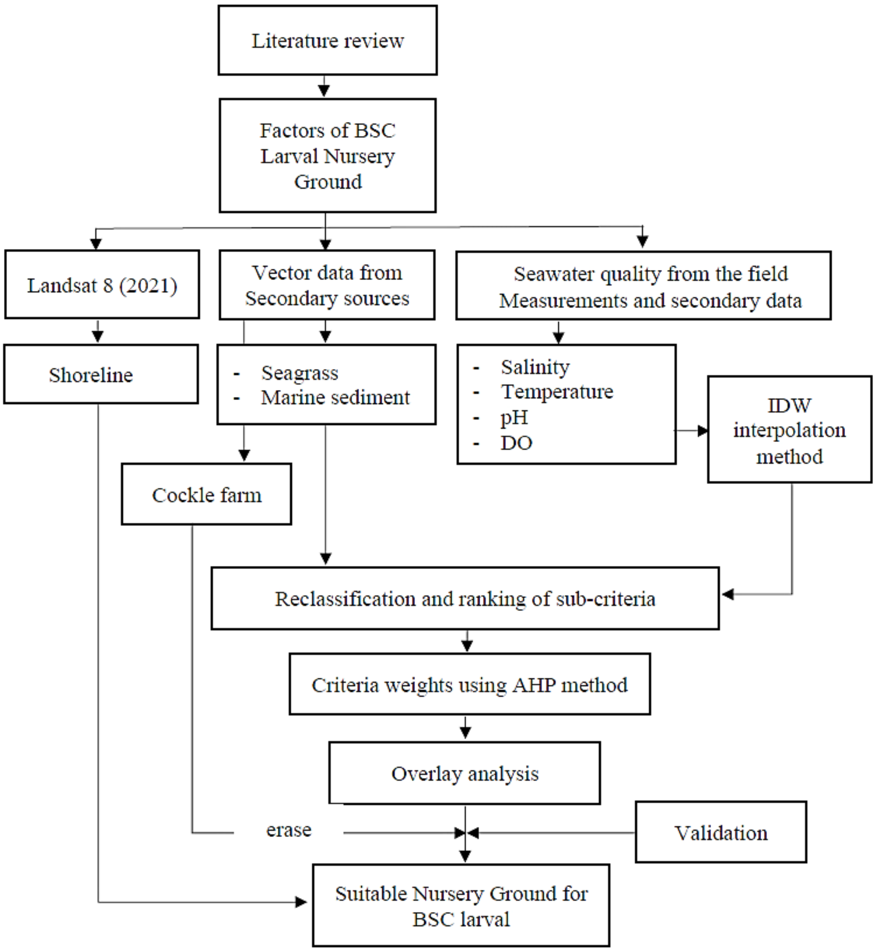
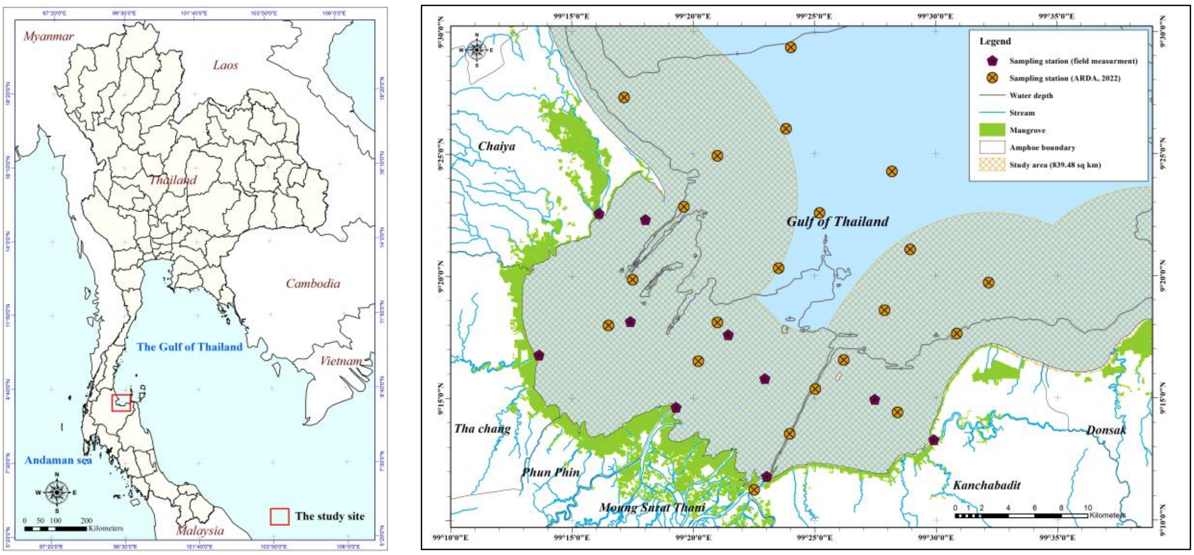


Figure 1. Research methodology schema



(a) (b)

Figure 2. Location of the study site within Thailand. (a) Map of Thailand highlighting Bandon Bay (red). (b) Map of the study area within Bandon Bay, Thailand, focusing on suitable nursery grounds for blue swimming crab (BSC).

2.3. Methods

This study employed a novel methodological framework (Figure 1) to assess the suitability of nursery grounds for BSC larvae in Bandon Bay, Thailand. This framework utilized multi-criteria decision analysis (MCDA) techniques, specifically the analytical hierarchy process (AHP) integrated with GIS as referenced in [35-41]. The AHP enabled pairwise comparisons to determine the relative importance of various environmental factors, reflecting its contribution to the overall suitability assessment. The AHP structured approach ensures a transparent and objective evaluation of the complex interplay between ecological variables, aiding in identifying optimal nursery grounds for BSC larvae.

The initial step involved determining the optimal conditions for developing BSC larvae. A literature review and consultations with experts determined that these conditions were influenced by two main criteria: environmental factors and habitat characteristics (Table 1). Environmental factors include salinity, dissolved oxygen, pH, and temperature. Habitat characteristics include the presence and quality of seagrass beds, water depth, and the type of bottom sediment (mud, sand, etc.).

Table 1. Nursery ground suitability index of BSC larvae

Criteria	Unit	Rating and score*						References
		5	4	3	2	1	0	
Seagrass beds		-	-	-	-	Yes	No	[21-23]
Marine sediments		Sand	Sandy mud	Muddy sand	Muddy	Clay	-	[16, 20]
Salinity	ppt	-	-	23-30	20-22, 30-35	<20, >35	-	[33]
Temperature	(°C)	-	28-32	25-27	21-24	<20	-	[19]
pH		-	8.0-8.5	>8.5	6.5-7.0	<6.5	-	[17 ,18]
DO	(mg/l)	-	5 -7	3-4	1-2	<1	-	[33]

* Rating and score: 5 Highly suitable, 4 Moderately suitable, 3 suitable, 2 Marginally suitable, 1 Not suitable

In the next step of the AHP process, we developed pairwise comparisons (Table 2). We compared each identified criterion influencing the suitability of the BSC nursery site to all other criteria. Experts familiar with BSC larval ecology used a Likert scale from one to five to assign scores within the matrix. Assigned scores (1-5) reflected the relative importance of each criterion for BSC larvae, with five being the most crucial. Next, the pairwise comparison matrix was subjected to eigenvector calculation to derive the weights for each criterion. These weights represented each factor's relative importance in determining a site's suitability as a nursery ground. Weight consistency was ensured by maintaining a Consistency Ratio (CR) below 0.1, as per [42].

Table 2. Pairwise Comparison Matrix for Nursery Ground Suitability Factors of BSC Larvae in Bandon Bay, Thailand. (Values represent the relative importance of the row factor compared to the column factor)

Criteria	Seagrass	Seafloor	Salinity	Temperature	pH	DO	Weight AHP
Seagrass beds	1	1/5	1/7	1/3	5	3	0.081
Marine sediments	5	1	1/3	3	9	7	0.260
Salinity	7	3	1	5	9	7	0.442
Temperature	3	1/3	1/5	1	7	5	0.146
pH	1/5	1/9	1/9	1/7	1	1/3	0.025
DO	1/3	1/7	1/7	1/5	3	1	0.046
Total							**1**
Consistency ratio (C.R.) = 0.090							

Next, in the Spatial Data and Scoring step, we assigned weights to each criterion's spatial data layers within a GIS. To create spatially continuous water quality maps, we employed inverse distance weighted (IDW) interpolation for key parameters: pH, temperature, dissolved oxygen (DO), and salinity. We chose the IDW interpolation method because it balances accuracy and computational efficiency. This method has provided satisfactory accuracy for various spatial interpolation tasks [43-45]. Then, we assigned the weightings and scores to the raster map for each criterion presented in Table 2 and Figure 3. Finally, we processed the spatial data by overlaying the six spatial data using union techniques in ArcGIS 9.2. We stratified BSC larval nursery suitability into four classes: high, moderate, marginal, and not suitable. We validated the model by comparing suitable areas with the recognized nursery ground for BSC larvae. Data from secondary sources, including the opinions of blue swimming crab experts, government officials and representatives of the Department of Fisheries, and fishermen with more than 20 years of experience in the fishery [25, 46], were used.

3. Results

3.1. Habitat Criteria and Sub-Criteria

3.1.1. Salinity

The salinity of seawater varied depending on the season. During the NEMS period, salinity measurements ranged from 23.0 to 30.0 ppt. Notably, the central study area near the river mouth, particularly along the Muang Surat Thani coast, exhibited lower salinity levels, ranging from 20.0-23.0 ppt (Figure 3A). During the NEMST period, salinity measurements showed a dominance of the 23.0-30.0 ppt range, followed by a range of 30.0-32.5 ppt observed along the Chaiya coast and in the open sea to the east (Figure 3B). During the SWMS period, salinity in the central and eastern parts was predominantly 23-30 ppt, while the coastline of the Chaiya district exhibited a higher range of 30 to 32.5 ppt (Figure 3C). Salinity values during the SWMST period were predominantly in the range of 23 to 29.7 ppt.

However, an exception was observed near the center area (the coastline of Muang Surat Thani), where salinity was measured in the ranges of 20.0-23.0 ppt, 10.0-20.0 ppt, and 1.0-10.0 ppt, respectively (Figure 3D). Based on previous studies summarized in Table 1, the most favorable salinity levels for BSC larval development are 23.0-30.0 ppt. Salinity levels between 20.0-22.0 ppt and 30.0-35.0 ppt were considered moderately suitable, while levels below 20.0 and above 35.0 ppt are unsuitable for BSC larvae survival.

3.1.2. Seawater Temperatures

The study results showed that seawater temperatures during the NEMS were mainly between 27.33-28.00°C, except in the nearshore areas of the Chaiya district, where temperatures ranged between 28.00-28.34°C (Figure 3E). During NEMST, temperatures ranged from 31.00-32.00°C in the study area (Figure 3F). During SWMS, temperatures were between 29.00-30.00°C in practically all parts of the study area (Figure 3G). Finally, during SWMST, seawater temperatures were mainly 30.00-31.00°C, except for the western side of the study area near the coastal region of Chaiya district, where temperatures were between 29.00-30.00°C (Figure 3H). According to previous studies summarized in Table 1, water temperature played a crucial role in successfully developing BSC larvae. The ideal temperature range for these larvae is between 28.00-32.00°C, providing the best conditions for survival. Moderately suitable temperatures are found in the 25.00-27.00°C range, whereas the 21.00-24.00°C range is considered less appropriate for BSC larvae. Temperatures below 20.00°C are considered particularly unsuitable.

3.1.3. pH

The pH value of the seawater analyzed in four periods corresponds to the Thai quality standards for seawater between 7.0-8.5. An analysis of the pH value of the seawater revealed seasonal fluctuations throughout the study area. During the NEMS period, pH values were predominantly between 8.0-8.1, except in the coastal regions of Tha Chang, Chaiya, and Don Sak districts, where values were slightly higher, between 8.1-8.2 (Figure 3I). During the NEMST period, pH was consistently in the range of 8.0-8.1 across most of the study area, except for the coastal region near the river mouth Mueang Surat Thani district (Figure 3J). During the SWMS, pH values were between 8.2-8.3, especially in the coastal areas of Tha Chang, Chaiya, and parts of Kanchanadit and Don Sak districts (Figure 3K). Finally, the SWMST period showed a spatial pattern with pH values between 8.0-8.1 in the western area (including Tha Chang and Chaiya districts) and the eastern area (including Don Sak and parts of Kanchanadit district adjacent to Don Sak). The central area of the study site, which includes the coastlines of Mueang Surat Thani and Kanchanadit districts, had lower pH values, ranging from 7.0-8.0 (Figure 3L). According to previous studies summarized in Table 1, pH plays a crucial role in successfully developing BSC larvae. The ideal pH range for these larvae is between 8.0-8.5, providing the best conditions for their survival. A moderately suitable pH value is above 8.5. pH values between 6.5-7.0 are considered less appropriate for BSC larvae. In particular, the pH value below 6.5 was classified as unsuitable.

3.1.4. Dissolved Oxygen (DO)

Except for the SWMST period, DO levels in seawater consistently surpassed the minimum requirement of 4.0 mg/l set by Thai seawater quality standards. During this period, DO levels below 4.0 mg/l were measured in some areas. During the NEMS, most of the measured values were 6.0-6.5 mg/l, with even higher values (above 6.5 mg/l) observed in the coastal areas of Tha Chang, Kanchanadit, and Don Sak districts. Lower DO levels (below 6.0 mg/l) were found near the coastline of Chaiya district (Figure 3M). During the NEMST, DO levels ranged from 6.0-6.5 mg/l in most study areas. However, higher values of 6.5-7.0 mg/l were measured in the coastal regions of Tha Chang, Kanchanadit, and Don Sak districts (Figure 3N). During the SWMS, DO levels remained in the range of 6.0-6.5 mg/l in the western study site, which includes the coasts of Phunphin, Tha Chang, and Chaiya districts. Similar levels were observed on the eastern side, including the coastal and offshore areas of Mueang Surat Thani, Kanchanadit, and Don Sak districts. The lowest DO concentrations (5.2-5.5 mg/l) were observed in some coastal regions of Kanchanadit district (Figure 3O). Finally, during the SWMST, DO levels in the western areas (Tha Chang and Chaiya districts) were mainly between 5.5-6.0 mg/l. In particular, the eastern areas near the coast of Mueang Surat Thani and Kanchanadit districts had significantly lower DO values compared to the other regions, ranging between 3.3-5.0 mg/l (Figure 3P). Previous studies (Table 1) have shown that DO is a crucial factor influencing the development of BSC larvae. The ideal DO range for these larvae is between 5.0-7.0 mg/l, providing the most favorable conditions for survival. Moderately suitable DO levels fall in the range of 3.0-4.0 mg/l. However, DO concentrations between 1.0-2.0 mg/l become ideal for BSC larvae. In particular, DO levels below 1.0 mg/l are considered entirely unsuitable.

3.1.5. Sea grass

Seagrass beds, identified as highly suitable habitats for BSC larvae (Table 1), were distributed across the coastal areas of Ban Don Bay [31], specifically within the districts of Chaiya, Tha Chang, Phun Phin, and Mueang Surat Thani (Figure 3Q).

3.1.6. Marine sediments

An examination of the data provided by the Department of Natural Resources and the Hydrographic Department revealed differences in the composition of marine sediments in Ban Don Bay. Outside the coast of the bay, the predominant sediment type is clay. Within the bay, closer to the coastline, the sediment changes to sandy mud in the coastal regions of Mueang Surat Thani, Kanchanadit, Don Sak, and Chaiya districts and parts of Tha Chang district. In

Phun Phin and the remaining areas of the Tha Chang district, the marine sediment is muddier, while in the Sed lands and on the coast of the Chaiya district, sand dominates the marine sediment (Figure 3R). The suitability of marine sediments for BSC larvae is highlighted in Table 1. Sandy bottoms are considered the ideal habitat, providing the most favorable conditions for larval development and survival. Sandy mud provides a moderately suitable environment, while muddier sand is always less suitable for BSC larvae. Clay, in particular, is classified as completely unsuitable for these larvae.

3.1.7. Shellfish Farm

The areas where shellfish cultivation was permitted in Ban Don Bay were primarily near the coast and on the shores of Tha Chang District, Phun Phin District, Mueang District, Kanchanadit District, and Don Sak District. The total area was about 174.75 km^2 (Figure 3S) [47, 48]. The shellfish farming area was considered a factor indicating that the area is not suitable for analyzing the appropriate map for BSC nursery ground.

3.2. Suitability Map

Suitability maps for the BSC larvae nursery ground in Bandon Bay were identified by weighting criteria with AHP and using the overlay technique in ArcGIS 9.2. The results of the AHP weighting criteria revealed that salinity was the most important criterion, followed by marine sediments, water temperature, seagrass beds, DO, and pH, respectively, with C. R. = 0.090. The results were shown for each of the four seasons: (1) NEMS, (2) NEMST, (3) SWMS, and (4) SWMST. Seasonal suitability maps were generated for BSC larval nursery grounds, classifying them into four categories (high, moderately, marginal, and not suitable) for each season (Table 3 and Figure 4). These maps were validated through expert consultation with local specialists and experienced personnel and secondary data verification.

Table 3. The suitable area for the BSC larvae nursery ground in Bandon Bay, Thailand

Season	A suitable area for the BSC larvae nursery ground									
	Highly suitable		Moderately suitable		Marginally suitable		not suitable		Total	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
The NEMS	13.93	1.66	14.83	1.77	523.36	62.34	287.36	34.23	839.48	100.00
The NEMST	8.36	1.00	20.71	2.47	571.30	68.05	239.11	28.48	839.48	100.00
The SWMS	9.35	1.11	23.06	2.75	567.97	67.66	239.10	28.48	839.48	100.00
The SWMST	16.53	1.97	15.63	1.86	568.22	67.69	239.10	28.48	839.48	100.00

3.2.1. NE Monsoon Season-NEMS

The study revealed the distribution of suitable regions for nursery grounds. The analysis found 13.93 km^2 to be highly suitable, 14.83 km^2 moderately suitable, 523.36 km^2 marginally suitable, and 287.36 km^2 unsuitable. Highly suitable regions were primarily concentrated in the western part of the bay, notably including the coastline of Sed Island, Phum Riang, and Takrob sub-districts. Moderately suitable areas were mainly in the Phum Riang, Thathong, and Donsak sub-district coastline.

3.2.2. NE Monsoon Season Transition-NEMST

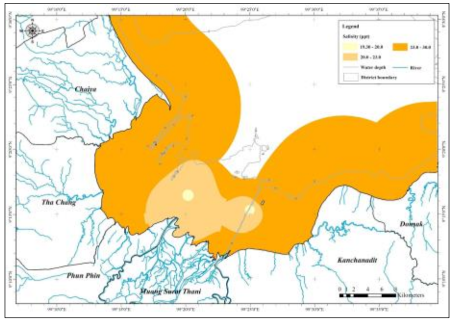
Our spatial analysis quantified the areas of various suitability classes for nursery grounds. Notably, 8.36 km^2 was identified as highly suitable, 20.71 km^2 as moderately suitable, 571.30 km^2 as marginally suitable, and 239.11 km^2 as unsuitable (Table 3). The most appropriate area was mostly in Sed Island. Moderately suitable areas were primarily concentrated along the coastlines of Phum Riang, Takrob, Thathong, and Donsak sub-districts.

3.2.3. SW Monsoon Season-SWMS

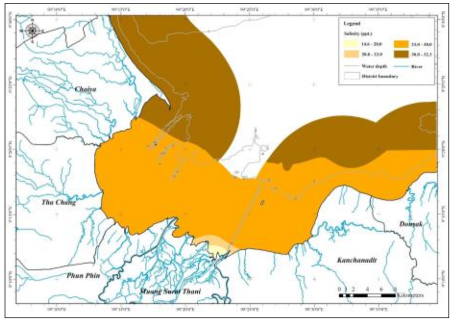
This season's analysis identified distinct suitability classes for nursery grounds (Table 3). The results revealed that 9.35 km^2 was highly suitable, 23.06 km^2 moderately suitable, 567.97 km^2 marginally suitable, and 239.10 km^2 unsuitable. Areas exhibited high suitability for nursery grounds along the eastern coastline of Bandon Bay, encompassing the sub-districts of Kadae, Thathong, and Donsak. The majority of areas on the west side of the bay seem to be moderately suitable, including Sed Island, Phum Riang, and Takrob sub-district coastline.

3.2.4. SW Monsoon Season Transition-SWMST

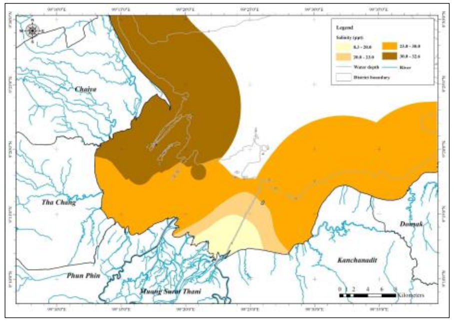
Spatial distribution analysis quantified the total areas of various suitability classes. The study identified a total of 937.48 km^2 across the Ban Don Bay, categorized into suitability classes: 16.53 km^2 (highly suitable), 13.63 km^2 (moderately suitable), 568.22 km^2 (marginally suitable), and 239.10 km^2 (unsuitable) (Table 3). Our analysis identified highly suitable areas concentrated along the western coastline of the bay, encompassing Sed Island and the coastlines of Phum Riang and Takrob sub-districts. Similarly, the most moderately suitable areas were also on the west side of the bay, such as the Phum Riang sub-district coastline. There were also moderately suitable areas east of the bay, such as the Kadae, Thathong, and Donsak sub-district coastline.



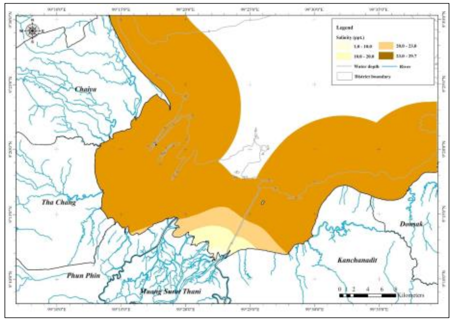
(A) Salinity in the NEMS



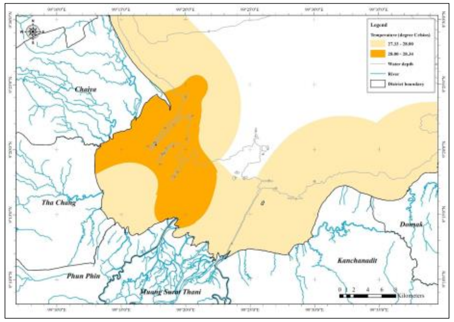
(B) Salinity in the NEMST



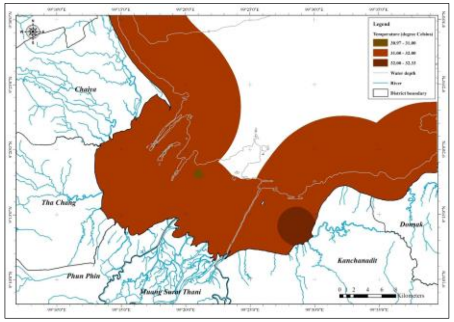
(C) Salinity in the SWMS



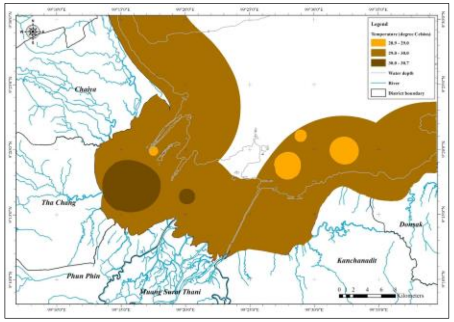
(D) Salinity in the SWMST



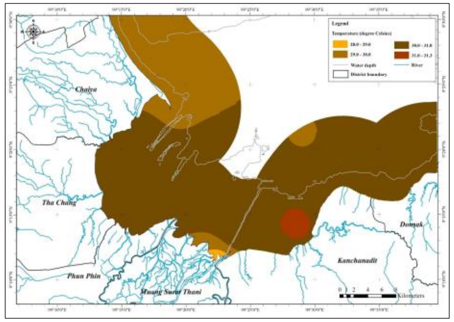
(E) Temperature in the NEMS



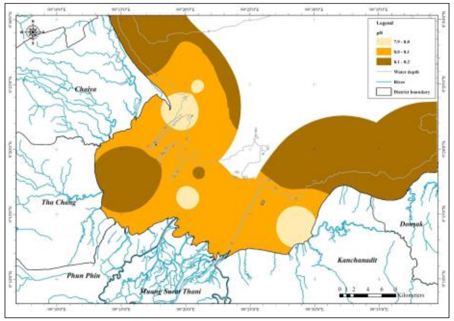
(F) Temperature in the NEMST



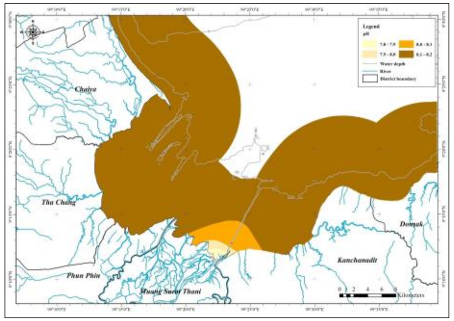
(G) Temperature in the SWMS



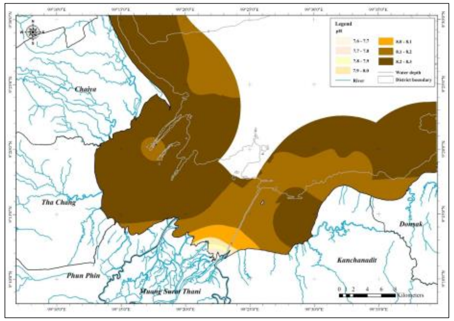
(H) Temperature in the SWMST



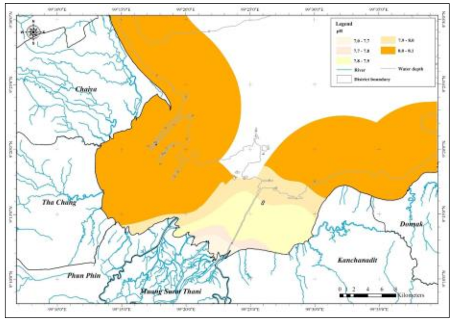
(I) pH in the NEMS



(J) pH in the NEMST

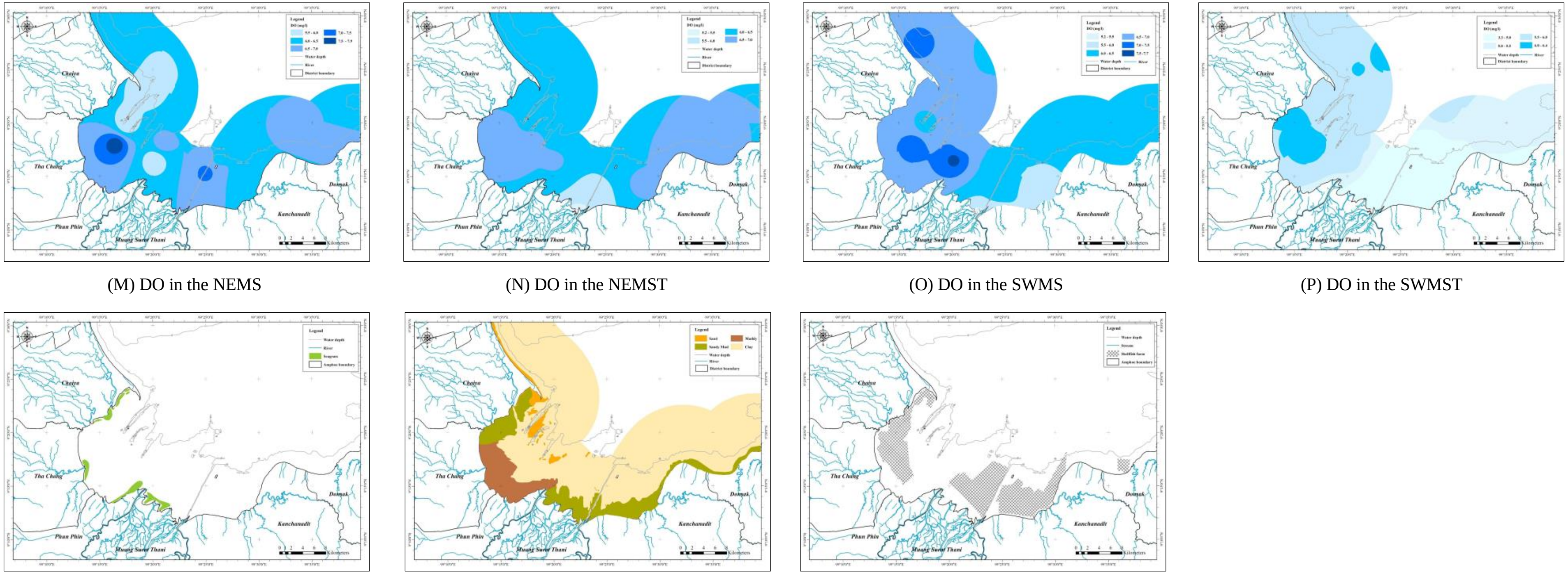


(K) pH in the SWMS



(L) pH in the SWMST

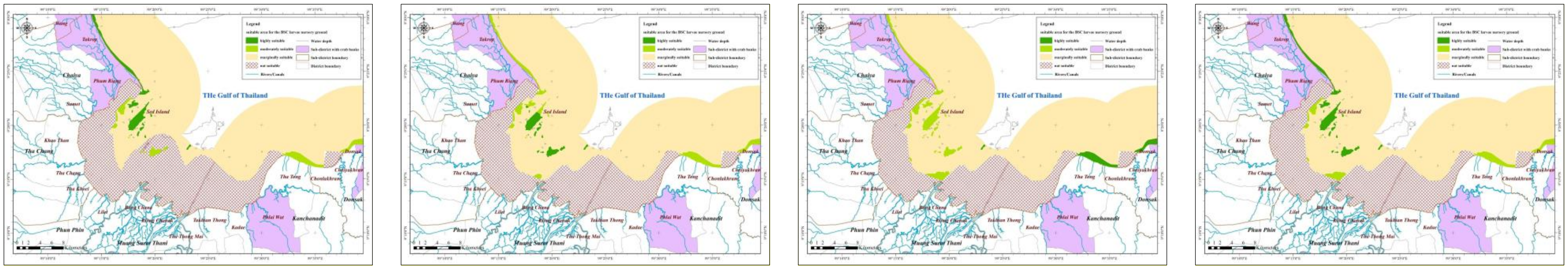
.



(M) DO in the NEMS (N) DO in the NEMST (O) DO in the SWMS (P) DO in the SWMST

(Q) Seagrass (R) Marine sediments (S) Shellfish farm

Figure 3. GIS-based criterion maps and environmental parameters of Bandon Bay province, Thailand, during four seasons



(A) The NEMS (B) The NEMST (C) The SWMS (D) The SWMST

Figure 4. Suitability maps at the different seasons for the BSC larvae nursery ground in Bandon Bay, Thailand

4. Discussion

This study presented the use of applied AHP integrated with the GIS to evaluate the suitability of the BSC larval nursery ground in Bandon Bay, Thailand, during the four seasons: (1) The NEMS, (2) The NEMST, (3) The SWMS, and (4) The SWMST. The results indicated that the suitable BSC nursery ground of Bandon Bay in all seasons was in the same areas based on the salinity level of the seawater [33]. During the NEMS, the current flowed northwest of the bay toward the Tha Chana district [34, 49, 50]. The higher salinity water outside the bay mixed with the bay water, resulting in an appropriate salinity level for BSC nursery of 23.0-30.0 ppt. During this season, the highly and moderately suitable nursery ground areas are situated on the western bayside. This coincides with the NEMST wind patterns, which cause water currents to flow eastward across the bay. Therefore, the highly suitable area was moved into the middle of the bay into a sandy area. During the SWMS, water flowed from the mouth of Bandon Bay to the east of the bay into the area of the Kanchanadit and Donsak districts [33, 49, 50]. Therefore, this area became a highly suitable BSC nursery area. In the SWMST, the water flowed less and moved towards Phun Phin district in the western part of the bay. Thus, this area has become highly and moderately suitable for BSC nursery areas.

The results showed that the Sed Island areas were highly and moderately suitable for BSC larvae nursery grounds in all seasons due to two possible reasons: (1) Sed Island is composed of 11 sandbars that reduce the current flow rate [28], and (2) seagrass beds provide a complex habitat as a refuge and foraging sites for BSC zoea [50-52]. Furthermore, Sed Island offers environmental conditions favorable for BSC reproduction, such as suitable seawater temperature, dissolved oxygen (DO), and salinity levels [28]. Thongkhao [51] surveyed sandbars and seagrass beds at Sed Island and found zoea and megalopa stages of BSC. Significantly, study results suggest consistency with Sed Island being declared an area of fisheries refuge under the “Establishment and Operation of a Regional System of Fisheries Refugia in the South China Sea and Gulf of Thailand project” [52].

The analysis revealed that areas with the highest and moderate suitability for nursery grounds coincided spatially with the proximity of existing crab bank operations. There are three crab banks in the Takrob sub-district: 16 in the Phum Riang sub-district, one in the Plaiwas sub-district, and two in the Donsak sub-district. In the Chaiya district, the community plans to set up a crab bank. An area within 500 m of the shoreline has been identified as a nursery and fisheries refuge for the community [14]. The suitable nursery in the coastal area of the Chaiya district obtained from the study was arranged in a highly appropriate and moderately suitable area consistent with current community-based activities.

Similarly, in the Takrob sub-district, the community designated an area 1,000 m offshore as a conservation area for aquatic animals. Mekdaeng & Chairattana [53] monitored the release of BSC larvae in the Takrob sub-district conservation area and found them distributed there. This study showed that the Phum Riang sub-district coastal line is highly and moderately suitable for all seasons. Seagrass beds provide refuge for BSC larvae [30, 51]. Moreover, sandy marine sediments make the area ideal as a nursery ground for BSC [16, 20].

The marginally suitable areas for BSC nurseries were found in most seasons. No seagrass beds were in the slightly suitable areas, and the sediments were clayey and not sandy. Most areas that should be more suitable were close to the coast where shellfish farming is practiced [54]. The cockle farming areas were located in extensive areas with soft sediments and low topography, making them suitable for extensive mechanical harvesting. Cockle harvesting, which occurs every 15 days, results in intensive and extensive physical disturbance of the substrate, making the areas unsuitable for BSC rearing [55]. According to the Sawasdee et al. [34] study, no BSC larvae were found in the areas where cockles are harvested. Additionally, several rivers, notably the Tapi River, contribute freshwater to Bandon Bay, particularly during the rainy season. The study found that the salinity of the Tapi River estuary in the SWMS and SWMST was below 20 ppt, resulting in unsuitable conditions for a rearing area for BSC larvae [56]. Finally, water current must be considered when releasing BSC larvae, especially at the zoea stage. The water current transports the BSC larvae to an area suitable for the nursery ground [34]. This study helps us to understand how we can determine fishery refuges and suitable areas for BSC nursery areas, increase BSC survival rates, and support future management of BSC.

5. Conclusion

This study investigated the environmental suitability factors for BSC larvae. Salinity was generally in a favorable range (23.0-30.0 ppt) throughout the year, except in areas near the river mouth during the SWMST season. Seawater temperatures were primarily suitable for BSC larvae across all seasons (27.33-32.00°C). DO concentrations met the minimum threshold (4.0 mg/l) except in some eastern areas during SWMST, indicating potential limitations. The pH values remained within the acceptable range for BSC larvae (7.0-8.5) throughout the study. Seagrass beds in the coastal areas and sandy bottoms near the coast provide ideal habitat characteristics for BSC larvae. In contrast, clayey sediments outside the bay and areas designated for shellfish aquaculture are unsuitable for BSC larvae which prefer sandy environments. These results suggest that Ban Don Bay has the potential to serve as a nursery area for BSC larvae, with conditions varying by location and season. The most favorable conditions for larval development and survival are in areas with salinity between 23-30 ppt, temperatures between 28-32°C, DO levels above 5.0 mg/l, and seagrass beds or sandy bottoms. Areas with significant freshwater influence or shellfish farming may be less suitable due to lower salinity or altered seabed characteristics.

This study applied the AHP and GIS combined approach to identify specific Bandon Bay area most suitable for BSC nursery areas. The results were validated by expert opinion and secondary data. Further research could include analyzing the distribution patterns of larvae within the bay to validate the suitability maps produced in this study. Spatial distribution analysis revealed that during the NEMS season, 1.8% of the total study area was highly suitable for nursery grounds, while 2.71% was moderately suitable. In contrast, during the NEMST season, these values were 1.01% and 3.98%, respectively. During the SWMS season, they showed the highest proportion of moderately suitable areas (4.21%), with 1.28% classified as highly suitable. SWMS season analysis pinpointed 2.11% of the study area as ideal for nursery grounds, while an additional 3.00% was classified as moderately suitable. Changes mainly influence seasonal variations in suitable areas in seawater salinity, seawater temperature, and other environmental factors. The suitable areas were primarily on the coastline of Sed Island, Phum Riang, Takrob, Tha Thong, and Donsak sub-districts. In addition, the results indicated that the suitable areas obtained from the study matched the locations of crab banks operating in the area. The areas were unsuitable, mainly in cockle farming areas and estuaries with low salinity levels. Overall, the results indicate that Bandon Bay has the potential to serve as a nursery area for BSC larvae, with some differences depending on location and season.

This study successfully identified factors such as salinity, temperature, marine sediment characteristics, and areas suitable for BSC larvae in Bandon Bay. These critical environmental factors are essential for BSC larvae in all regions, suggesting that the results may be transferable to other locations with similar crab species. However, the generalizability of the study may be limited. First, the study focuses on the specific environment of Bandon Bay, including factors such as currents and freshwater input, which could be different in other regions. Second, validating the suitability maps with data on the actual distribution of larvae in the bay would strengthen the applicability of these results in the other areas. Finally, the study's exclusive focus on BSC larvae restricts direct application to other crab species, which may exhibit distinct habitat preferences. While this study provides valuable insights into the suitability of BSC larval habitats in Bandon Bay, broader application would require consideration of regional environmental variation, larval distribution patterns, and possibly other crab species. Further research in other locations and considering these factors could lead to a more broadly applicable framework for BSC conservation efforts.

6. Declarations

6.1. Author Contributions

Conceptualization, J.R., M.J., K.J., and A.S.; methodology, J.R., M.J., K.J., and A.S.; formal analysis, J.R., K.J., M.J., and A.S.; investigation, J.R., K.J., M.J., and A.S.; data curation, J.R. and A.S.; writing—original draft preparation; J.R., K.J., M.J., and A.S.; writing—review and editing, E.B.S.; visualization, J.R. and A.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

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6.5. Institutional Review Board Statement

Not applicable.

6.6. Informed Consent Statement

Not applicable.

6.7. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

7. References

[1] Songrak, A. (2015). Co-management of blue swimming crab fishery for sustainable utilization. Rajamangala University of Technology Srivijaya (Trang campus), Trang, Thailand. (In Thai).

[2] No. Report 14/2022. (2022). Fisheries Statistics of Thailand 2021. Fisheries Development Policy and Planning Division, Bangkok, Thailand. Available online: http://www.seafdec.org/stat2021/ (accessed on May 2024).

[3] Jarernpornnipat, A., Pedersen, O., Jensen, K. R., Boromthanarat, S., Vongvisessomjai, S., & Choncheanchob, P. (2003). Sustainable management of shellfish resources in Bandon Bay, Gulf of Thailand. Journal of Coastal Conservation, 9(2), 135–146. doi:10.1652/1400-0350(2003)009[0135:SMOSRI]2.0.CO;2.

[4] Sawusdee, A. (2010). Fishing status and management proposal in Bandon Bay, Suratthani Province, Thailand. Walailak Journal of Science and Technology (WJST), 7(2), 89-101.

[5] Fisheries Development Policy and Strategy Division. (2021). Fishery Trade Statistic of Thailand. Fishery Department Ministry of Agriculture and Cooperatives, Bangkok, Thailand. Available online: http://www.seafdec.org/county-fisheries-trade-thailand/ (accessed on May 2024).

[6] Nitiratsuwan, T., Nitithamyong, C., Chiayvareesajja, S., & Somboonsuke, B. (2010). Distribution of blue swimming crab (*Portunus pelagicus* Linnaeus, 1758) in Trang Province. Songklanakarin Journal of Science and Technology, 32(3), 207-212.

[7] No. Report 5/2000. (2000). Fisheries Statistics of Thailand 1997. Fisheries Development Policy and Planning Division. Available online: https://data.worldbank.org/indicator/ER.FSH.PROD.MT?locations=TH (accessed on July 2024).

[8] No. Report 30/2004. (2004). Fisheries Statistics of Thailand 2002. Fisheries Development Policy and Planning Division. Available online: https://openknowledge.fao.org/server/api/core/bitstreams/2bd5cf38-ef62-47e8-aa93-28b28ceb1ad2/content (accessed on August 2024).

[9] No. Report 8/2008. (2008). Fisheries Statistics of Thailand 2006. Fisheries Development Policy and Planning Division. Available online: http://www.vliz.be/imisdocs/publications/343634.pdf (accessed on May 2024).

[10] No. Report 30/2013. (2013). (2013). Fisheries Statistics of Thailand 2011. Fisheries Development Policy and Planning Division. Available online: https://www.oecd-ilibrary.org/agriculture-and-food/oecd-review-of-fisheries-2011/thailand_rev_fish-2011-38-en (accessed on August 2024).

[11] No. Report 12/2018. (2018). Fisheries Statistics of Thailand 2016. Fisheries Development Policy and Planning Division. Available online: http://www.seafdec.org/fishstat2016/ (accessed on May 2024).

[12] Planning Division. (2008). The Fishery Strategy 2009-2012. Fisheries Department. Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

[13] Thiammueang, D., Chuenpagdee, R., & Juntarashote, K. (2012). The "crab bank" project: Lessons from the voluntary fishery conservation initiative in Phetchaburi Province, Thailand. Kasetsart Journal (Natural Science), 46(3), 427-439.

[14] Sawasdee, A., Jitpakdee, R., Tansakul, P., Chaisiya, K., & Sramolee, P. (2018). The distribution of knowledge from relevant researches to support crab bank project in order to enhance Blue swimming crab stock in Nakhon Si Thammarat and Surat Thani provinces (Research Report). Agricultural Research Development Agency (Public Organization), Thailand.

[15] Munprasit, R., Nootmorn, P., & Loychuen, K. (2020). Establishment and Operation of a Regional System of Fisheries Refugia in the South China Sea and Gulf of Thailand, Fisheries Refugia Profile for Thailand: Surat Thani, Southeast Asian Fisheries Development Center, Training Department, Samut Prakan, Thailand; FR/REP/TH31, 58 p.

[16] Tantikul, S. (1984). Fishery biology of blue swimming crab in the Gulf of Thailand. Fishery academic report, Fishery department, Bangkok, Thailand. (In Thai).

[17] Tanasomwang, V., & Vunzingzi, T. (2006). Effects of Water pH on the Survival Rates and Growth of Young Blue Swimming Crab (*Portunus pelagicus* Linnaeus, 1758) in Fiber Nursery Tanks. Technical Paper No. 38/2006. Samutsakhon Coastal Fisheries Research and Development Center. Thailand.

[18] Phinrub, W., Na Ranong, S., & Khamcharoen, K. (2019). Growth Performance of Blue Swimming Crab (*Portunus pelagicus* Linnaeus, 1758) in Difference Shelter. Rajamangala University of Technology Srivijaya.

[19] Soundarapa, P., & Dominic Ar, S. (2007). Fattening of the Blue Swimming Crab *Portunus pelagicus* (Linnaeus). Journal of Fisheries and Aquatic Science, 3(1), 97–101. doi:10.3923/jfas.2008.97.101.

[20] Johnston, D., Yeoh, D., Harris, D., & Fisher, E. (2020). Blue Swimmer Crab (*Portunus armatus*) and Mud Crab (*Scylla serrata* and *Scylla olivacea*) Resources in the North Coast and Gascoyne Coast Bioregions, Western Australia. Fisheries Research Report No. 306. Department of Primary Industries and Regional Development, Western Australia.

[21] Raungprataungsuk, K. (2009). Relationship between population dynamics of blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) and physical factors of seagrass bed, Kung Krabaen Bay, Chanthaburi Province. Master Thesis, Chulalongkorn University, Bangkok, Thailand.

[22] Jindalikit, J., Khongchai, T., Phuttharaksa, K., & Jaruthamsopon, B. (2011). Spawning season, fecundity and sex ratio of blue swimming crab in Thai water. Marine fisheries research and development bureau. Technical Paper No. 13/2011, Department of fisheries, Dhaka, Bangladesh. (In Thai).

[23] Kunsook, C., Gajaseni, N., & Paphavasit, N. (2014). The feeding ecology of the blue swimming crab, *Portunus pelagicus* (Linnaeus, 1758), at Kung Krabaen bay, Chanthaburi Province, Thailand. Tropical Life Sciences Research, 25(1), 13–27.

[24] Fortibuoni, T., Bahri, T., Camilleri, M., Garofalo, G., Gristina, M., & Fiorentino, F. (2010). Nursery and spawning areas of deep-water rose shrimp, *Parapenaeus longirostris* (Decapoda: Penaeidae), in the Strait of Sicily (Central Mediterranean Sea). Journal of Crustacean Biology, 30(2), 167–174. doi:10.1651/09-3167.1.

[25] Hossain, M. S., Sarker, S., Chowdhury, S. R., & Sharifuzzaman, S. M. (2014). Discovering spawning ground of Hilsa shad (*Tenualosa ilisha*) in the coastal waters of Bangladesh. Ecological Modelling, 282, 59–68. doi:10.1016/j.ecolmodel.2014.03.001.

[26] Szalaj, D., Wise, L., Rodríguez-Climent, S., Angélico, M. M., Marques, V., Chaves, C., Silva, A., & Cabral, H. (2018). A GIS-based framework for addressing conflicting objectives in the context of an ecosystem approach to fisheries management-a case study of the Portuguese sardine fishery. ICES Journal of Marine Science, 75(6), 2070–2087. doi:10.1093/icesjms/fsy094.

[27] Gillenwater, D., Granata, T., & Zika, U. (2006). GIS-based modeling of spawning habitat suitability for walleye in the Sandusky River, Ohio, and implications for dam removal and river restoration. Ecological Engineering, 28(3), 311–323. doi:10.1016/j.ecoleng.2006.08.003.

[28] Sustainable Development Foundation. (2020). Study Report on Area Context and Socio-Economic Conditions of Coastal Communities in Surat Thani Province: Fisheries Refugia Management for Blue Swimming Crab in Surat Thani Site, Thailand. Available online: https://www.fisheries-refugia.org/country-activities/thailand/list-activities/th-act-2020.html (accessed on July 2024).

[29] Thailand Hydrographic Department. (1990). Ao Ban Don (Map). Hydrographic Department, Bangkok, Thailand. Available online: https://asap-marine.com/en/map-227-ao-ban-don (accessed on August 2024).

[30] Nokket, C. (2005). A study on the distribution of seagrass beds in Surat Thani province. Academic report No 7/2005. Marine and Coastal Resources Research and Development Institute, Bangkok, Thailand.

[31] Department of Marine and Coastal Resources. (2021). Seagrass map 2021. Marine and Coastal Resources Research and Development Institute, Bangkok, Thailand.

[32] Meteorological Department. (2022). Climate of Surat Thani province. Available online: http://climate.tmd.go.th (accessed on August 2024).

[33] Tanasomwang, V., Singhong, S., & Thongbor, C. (2005). Effect of water salinities on the survival rate and growth of young blue swimming crab (*Portunus pelagicus* Linnaeus, 1758) reared in capture. Technical paper no.19/2005. Fishery department, Bangkok, Thailand. (In Thai).

[34] Sawasdee, A., Jutagate, T., Tanasomwang, V., Rattanarat, J., Pokavanich, T., Koolkalya, S., Songrak, A., & Nooseng, S., Keawrat, J. (2021). The research and development for the restoration and improvement of blue swimming crab fishery that links to international standards (Fishery improvement program: FIP) in Bandon Bay, Surat Thani province: phase II (Research Report). Agricultural Research Development Agency (Public Organization), Bangkok, Thailand.

[35] Azizan, N. H., Naharudin, N., Hashim, N., & Rusli, M. U. (2023). Site Suitability Analysis for Sea Turtle Nesting Area by using AHP and GIS. IOP Conference Series: Earth and Environmental Science, 1217(1), 12031. doi:10.1088/1755-1315/1217/1/012031.

[36] Wibowo, I. S., Mashar, A., Pratiwi, N. T. M., & Kurniawan, F. (2023). Marine Suitability Assessment for Mariculture: Combining GIS and AHP Technique in Dampier Strait Conservation Area, West Papua Province, Indonesia. Jurnal Ilmiah Perikanan Dan Kelautan, 15(2), 316–330. doi:10.20473/jipk.v15i2.40172.

[37] Pogoda, B., Hausen, T., Rothe, M., Bakker, F., Hauser, S., Colsoul, B., Dureuil, M., Krause, J., Heinicke, K., Pusch, C., Eisenbarth, S., Kreutle, A., Peter, C., & Pesch, R. (2023). Come, tell me how you live: Habitat suitability analysis for *Ostrea edulis* restoration. Aquatic Conservation: Marine and Freshwater Ecosystems, 33(7), 678–695. doi:10.1002/aqc.3928.

[38] Mao, Z., Ding, F., Yuan, L., Zhang, Y., Ni, Z., Li, Y., Wang, L., & Li, Y. (2023). The Classification of Riparian Habitats and Assessment of Fish-Spawning Habitat Suitability: A Case Study of the Three Gorges Reservoir, China. Sustainability (Switzerland), 15(17), 12773. doi:10.3390/su151712773.

[39] Miesner, A. K., Brune, S., Pieper, P., Koul, V., Baehr, J., & Schrum, C. (2022). Exploring the Potential of Forecasting Fish Distributions in the North East Atlantic With a Dynamic Earth System Model, Exemplified by the Suitable Spawning Habitat of Blue Whiting. Frontiers in Marine Science, 8, 777427. doi:10.3389/fmars.2021.777427.

[40] Akdeniz, H. B., Yalpir, S., & Inam, S. (2023). Assessment of suitable shrimp farming site selection using geographical information system based Analytical Hierarchy Process in Turkey. Ocean and Coastal Management, 235, 106468. doi:10.1016/j.ocecoaman.2022.106468.

[41] Zhang, Z., Wang, Z., Li, G., Zhao, M., & Li, W. (2024). The suitability assessment on site selection for bottom-seeding scallop culture based on analytic hierarchy process. Journal of Oceanology and Limnology, 42(2), 647–663. doi:10.1007/s00343-023-2389-x.

[42] Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3), 234–281. doi:10.1016/0022-2496(77)90033-5.

[43] Maleika, W. (2020). Inverse distance weighting method optimization in the process of digital terrain model creation based on data collected from a multibeam echosounder. Applied Geomatics, 12(4), 397–407. doi:10.1007/s12518-020-00307-6.

[44] Yang, W., Zhao, Y., Wang, D., Wu, H., Lin, A., & He, L. (2020). Using principal components analysis and IDW interpolation to determine spatial and temporal changes of Surfacewater quality of Xin'Anjiang river in huangshan, china. International Journal of Environmental Research and Public Health, 17(8), 2942. doi:10.3390/ijerph17082942.

[45] Khouni, I., Louhichi, G., & Ghrabi, A. (2021). Use of GIS based Inverse Distance Weighted interpolation to assess surface water quality: Case of Wadi El Bey, Tunisia. Environmental Technology & Innovation, 24, 101892. doi:10.1016/j.eti.2021.101892.

[46] Bergmann, M., Hinz, H., Blyth, R. E., Kaiser, M. J., Rogers, S. I., & Armstrong, M. (2004). Using knowledge from fishers and fisheries scientists to identify possible groundfish "Essential Fish Habitats." Fisheries Research, 66(2–3), 373–379. doi:10.1016/j.fishres.2003.07.007.

[47] Surat Thani Provincial Fisheries Committee. (2018). Announcement of the Surat Thani Provincial Fisheries Committee on the Designation of Aquaculture Zones for Controlled Aquaculture Activities, Category: Shellfish Aquaculture, B.E. 2560. Royal Gazette, 135(5), 32.

[48] Surat Thani Provincial Fisheries Committee. (2019). Announcement of the Surat Thani Provincial Fisheries Committee on the Designation of Aquaculture Zones for Controlled Aquaculture Activities, Category: Shellfish Aquaculture (No. 2), B.E. 2562. Royal Gazette, 136(312), 17.

[49] Lorpittayakorn, P. (2015). Circulation patterns in the Gulf of Thailand from Model. Science and Technology Journal, 23(3), 446-465.

[50] Lowwittayakorn, S. (1998). Analysis of sea surface temperature and salinity from oceanographic buoys with circulation patterns in the Gulf of Thailand from mathematical model. Master Thesis, Chulalongkorn University, Bangkok, Thailand.

[51] Thongkhao, S. (2020). Establishment and Operation of a Regional System of Fisheries Refugia in the South China Sea and Gulf of Thailand, Territory, Resources and Ecosystem in Sed Island, Ban Don Bay, Surat Thani Province. Southeast Asian Fisheries Development Center, Training Department, Samut Prakan, Thailand.

[52] Announcement of the Surat Thani Provincial Fisheries Committee. (2022). Prohibition of the use of certain types of fishing gear to fish for aquatic animals in coastal areas around Sed Island, Phum Riang sub-district, Chaiya district, Surat Thani province 2022. (2022, March 22). Government Gazette, 139, Special Section 97 D, 1-77.

[53] Mekdaeng, N., & Chairattana, C. (2021). Some biological aspects of blue swimming crab (Portunus pelagicus Linnaeus, 1758) in marine conservation zone Ban Phaipru, Trakrob sub-district, Chaiya district, Suratthani province. Journal of Fisheries Technology Research, 15(2), 32-45.

[54] Announcement of the Surat Thani Provincial Fisheries Committee. (2017). Designation of Aquaculture Areas for Aquaculture Activities under the Shellfish Culture 2017 Category. Government Gazette, 134, Special Section 219 D, 1-13.

[55] Ruangpanupan, N., Ussawarujikulchai, A., Prapagdee, B., & Chavanich, S. (2023). Seasonal variation in the abundance of microplastics in three commercial bivalves from Bandon Bay, Gulf of Thailand. Marine Pollution Bulletin, 197, 115600. doi:10.1016/j.marpolbul.2023.115600.

[56] Tanasomwang, V., Thongrod, S., & Rueangpan, L. (2005). Breeding and aquaculture of Blue Swimming Crab in commercial (Portunus pelagicus Linnaeus, 1758) (Research Report). Agricultural Research Development Agency (Public Organization), Thailand.