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Evaluation of suitable sites for mud crab farming in Ratnagiri District of Maharashtra, India

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Original Article

Abstract

The State of Maharashtra has vast stretches of estuaries, creeks and mangrove swamps, which offers great potential for aquaculture, particularly for mud crab farming. In view of the natural resources and market potential for mud crab, the Department of Forests, Government of Maharashtra plans to promote mud crab farming through a novel approach, which aims at providing livelihood support to the local communities utilizing the mangrove wetlands; thereby the local communities also shoulder the responsibility of conservation of mangroves. In this backdrop, a study was conducted to identify the suitable sites for sustainable mud crab culture, in GIS environment, based on various physical and environmental criteria including topography, soil types, land-use systems, vegetation, water quality, water availability, salinity, risks of flooding, infrastructure, seed resources and availability, market and support services. The brackishwater stretches of Anjarle, Kelshi, Aade, Velas and Ansure in the Ratnagiri district of Maharashtra were studied, and all study stations had patchy to thick mangrove vegetation. The major mangrove species encountered were: *Avicennia marina, Avicennia officinalis, Sonneratia caseolaris, Rhizophora mucronata* and *Acanthus ilicifolius*. The pH of water was near-neutral to alkaline, whereas dissolved oxygen levels were found to be within the ideal range. The salinity of the tidal creeks ranged from 7.24 ppt (Velas) to 35.9 ppt (Ansure) which generally varies with the tide. The ammonia levels which ranged from 0 (Aade and Ansure) to 0.5 ppm (Kelshi), falls within the safe levels for aquaculture. The sediment pH ranged from 6.2 to 8.32. The organic carbon levels in sediment ranged from 0.27 to 2.94% indicating medium to high productive nature of sediment. Samples of mud crab collected from the study areas were processed for screening for WSSV infection. All samples gave Negative results in primary as well as nested PCRs, indicating the absence of WSSV in the wild mud crab population. Integrating the analysis result along with supporting spatial data with the aid of GIS and Remote Sensing techniques, a total of 10.063 ha have been evaluated as suitable areas for mud crab farming along the brackishwater stretches of Anjarle (1.91 ha), Aade (2.069 ha), Kelshi (1.77 ha), Velas (0.538 ha) and Ansure (3.776 ha).

Keywords: *GIS, Maharashtra, mud crab farming, potential areas, Ratnagiri*

Introduction

The brackishwater mangrove swamps is one of the most biologically productive habitats of the coastal and marine ecosystem, and act as a buffer zone between land and the

sea (Hegazy, 2003; Wolf, 2012; Jusoff, 2013; Lee *et al.*, 2014, Vijaya Kumari Nunna, 2016). The mangroves act as a shield against the vagaries of storms, cyclones and other natural disasters and play a significant role as protectors of shorelines (Fritz and Blount, 2007; Latief and Hadi, 2007; Spalding *et al.*, 2014). They help to prevent erosion by stabilizing sediments with their tangled root systems (Prasetya, 2007; Lang'at *et al.*, 2009; Spalding *et al.*, 2014). They are also capable of filtering the pollutants and trapping sediments originating from land (Tam and Wong, 1995; Spalding *et al.*, 2014). The mangrove habitats are home to a variety of life forms like invertebrates, fish, amphibians, reptiles, birds and even mammals. They are also ecologically significant as they serve as breeding and nursery grounds for many of the commercially important fin and shell fishes (Alistar and Duke, 1987; Sasekumar *et al.*, 1992; Laegdsgaard and Johnson, 1995; Acosta and Butler IV, 1997; Abu El-Regal and Ibrahim, 2014). The mangrove trees are harvested for water-resistant wood for building houses, boats, furniture etc. Some mangrove trees are good source of charcoal and some of them serve as source of dyes which are extracted from the barks. Some mangroves are also known for their medicinal properties. The mangrove habitat is a rich source of commercially important fishes thereby providing income to scores of coastal communities. Therefore loss of mangroves would have direct economic repercussions on the coastal people.

There has been a continuous decline in mangrove forests caused by various factors: for example, conversion to agriculture, reclamation for aquaculture, urban development and tourism (Upadhyay *et al.*, 2002; Sahu *et al.*, 2013), and according to the Government of India (1987) report, India lost 40 per cent of its mangrove area in the last century. The reduction in mangrove area will increase the threats due to cyclones, erosion and flooding, besides affecting the coastal water quality and reduction in biodiversity. The decline in mangrove vegetation will also lead to release of large quantities of stored carbon, exacerbating the process of global warming and climate change. Considering the enormous ecosystem services provided by mangroves, there is an urgent need to conserve this valuable ecosystem. There are wide range of methods for conservation such as developing sanctuaries, community sacred groves and mangrove plantation programmes (Selvam *et al.*, 2003; Khan *et al.*, 2008; Bhatt and Vivekanandan, 2013; Upadhyay *et al.*, 2015; Vasudevan and Goenka, 2017). However, any conservation programme would be successful if only all the stakeholders including the local communities are involved in the conservation efforts. The mangrove cover in Maharashtra had remained constant at 186 sq. km. since 2005 till 2013; but showed a remarkable increase to 222 sq. km by 2015 and 304 sq. km by 2017 (FSI, 2017). Maharashtra has been proactive in conservation of mangroves and it has notified 15,087.6 hectares of mangroves across the state as reserved forest, and thus became the first state in the country to do so.

The State of Maharashtra has vast stretches of estuaries, creeks and mangrove swamps which would have great potential for farming of finfishes and shellfishes. The mud crab, *Scylla serrata* is one of the good candidate species, which has great demand in local markets as well as in the export markets.

The local communities play a vital role in the protection of mangroves as they share a symbiotic relationship with this ecosystem. Sustainable mangrove conservation by local communities can happen when they start deriving tangible benefits from protecting the mangrove ecosystem (Vasudevan and Goenka, 2017). Thus, the Department of Forests, Government of Maharashtra aims to promote mud crab farming in the mangrove ecosystems as a part of conservation of mangroves. This novel approach aims at providing livelihood support to the local communities utilizing the mangrove wetlands, and thereby the local communities also shoulder the responsibility of conservation of mangroves. In this backdrop, a study was conducted to evaluate the mud crab farming potential in some of the brackishwater areas of Ratnagiri District of Maharashtra, in GIS environment, based on various physical and environmental criteria including topography, soil types, land-use systems, vegetation, water quality, water availability, salinity, risks of flooding, infrastructure, seed resources and availability, market and support services.

Material and methods

The study was conducted in brackishwater stretches of Ansure, Anjarle, Aade, Kelshi and Velas in the Ratnagiri District of Maharashtra (Fig. 1).

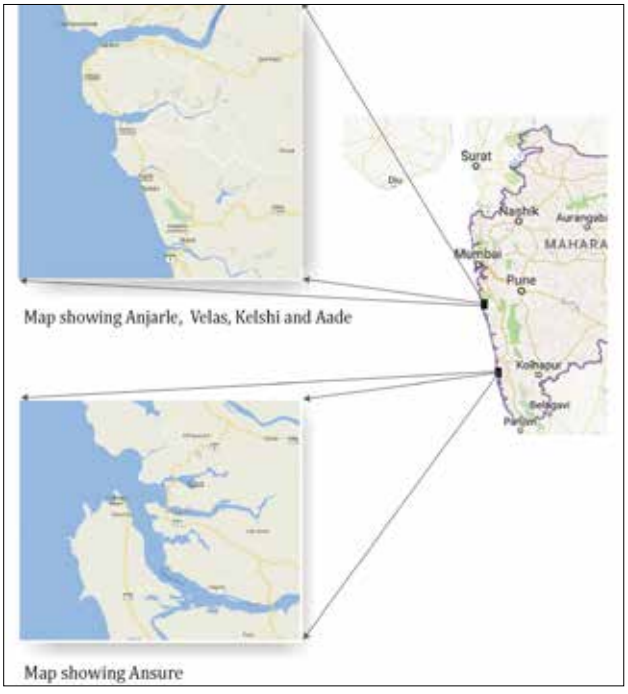

Fig. 1. Map showing the study locations in the Ratnagiri District of Maharashtra

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Collection and analysis of water and sediment

Field surveys were conducted in the study areas, along with the beneficiaries identified for mud crab farming by the Forest Department. During the field surveys, the mangrove species were identified and information on pollution, water retention etc. were gathered from the local people. The depth of the study stations were measured by suspending a weight from the boat. The geo-location of each of the sampling sites were recorded using GPS (GARMIN Montana 680). The surface water samples were collected in clean plastic bottles and were analysed for various physicochemical parameters like temperature, salinity, pH, dissolved oxygen, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), chlorophyll-*a*, primary productivity, ammonia, nutrients like nitrite, phosphate and silicate following the standard methods (APHA, 2012). The sediment samples were collected using a PVC corer. The sediment samples were analysed for pH using a table top pH meter. The organic carbon in sediment was estimated following the methods of Walkley and Black (1934), while the sediment texture was determined through pipette analysis method (Day, 1965).

Screening of wild collected mud crab for White Spot Syndrome Virus (WSSV) infection

Samples of *S. serrata* (medium-sized) were collected from the brackishwater areas of all the study stations *viz.*, Ansure, Anjarle, Aade, Kelshi and Velas. The animals were dissected and gill tissues were preserved in absolute alcohol. The samples were diagnosed for WSSV infection as per the OIE protocols with slight modifications. Briefly, DNA was extracted from the samples using HiPurA™ Multi-Sample DNA Purification kit as per the manufacturer's protocol. The extracted DNAs were stored at -20°C until used for PCR analysis. PCR was performed with EmeraldAmp GT PCR Master Mix (Takara) in a ProFlex™ PCR System (Applied Biosystems) as per the OIE recommended protocols. Briefly, 0.5 μl DNA was added to 10μl of 2x mastermix containing 200 μM each of forward (146F1, 5'-ACT-ACT-AAC-TTC-AGC-CTA-TCTAG-3') and reverse primers (146R1, 5'-TAA-TGC-GGG-TGT-AAT-GTT-CTT-ACG-A-3'). The PCR profile was 40 cycles of 98°C for 30 seconds, 55°C for 1 minute, and 72°C for 2 minutes, and a final 5-minute extension at 72°C. A nested PCR step was followed with 0.5 μl of the first-step PCR product to 19.5 μl of a PCR cocktail with the same composition as above except that it contains the second (inner) primer pair: 146F2 (5'-GTA-ACT-GCCCCT-TCC-ATC-TCC-A-3') and 146R2 (5'-TAC-GGC-AGC-TGC-TGC-ACC-TTG-T-3'). The WSSV-specific amplicon for the first step PCR was 1447 bp while that for the nested step was 941 bp. The PCR products were visualized on a 1.5 % agarose gel containing 0.5 μg ml - 1 ethidium bromide.

Preparation of GIS maps and evaluation of potential mud crab farming sites

Geo-referenced Google map having Universal Transverse of Mercator (UTM) Zone 43 N projection systems were used as base map for the study. The GPS locations of sampling sites were overlaid on the base map and boundaries were digitized using analysis tool in ArcGIS 10.3 software. Buffer analyses were performed using geo-processing Tool of Arc GIS 10.3 and demarcated the suitable sites for sustainable mud crab culture. Areas for each zone were calculated using statistical analysis of Arc GIS.

For categorizing the suitability of potential sites, the different parameters *viz.*, water temperature, salinity, pH, dissolved oxygen (D.O.), ammonia, nitrite, sediment pH, sediment organic carbon, water depth, distance from shore to the culture site and distance from the culture site to the market were given a weighted value, wherein the sum of all the weighted values is 1.0. The values obtained for different parameters were given a rating point in a scale of 10 to 1, based on the assumed range of parameters in which it falls. The weighted value (w) of each parameter was multiplied with the rated value (r) and the resultant value was categorized based on the weighted category as excellent, very good and good. Stakeholder consultation workshops were organized involving the project officials from the Forest Department, researchers and local communities. The inputs received during the workshops and interactions with local communities during the surveys were also considered while evaluating the suitability of farming sites.

Results and discussion

The results of the studies were integrated to identify the potential mud crab farming sites at Ansure, Anjarle, Aade, Kelshi and Velas in the Ratnagiri District of Maharashtra.

Potential mud crab farming sites at Anjarle

The brackishwater stretches of Anjarle has patchy to dense mangrove vegetations. Extending from the bar mouth, it is a large stretch of water body with many creeks meandering into the fringing mangroves making it highly suitable for aquaculture. The mangrove species observed in the study area were *Avicennia marina*, *Avicennia officinalis*, *Rhizophora mucronata* and *Sonneratia caseolaris*. The salinity ranged from 33.15 to 32.87 ppt and the pH was alkaline (8.10 to 8.24). The dissolved oxygen content in water was found to be optimum and ranged from 7.83 to 9.27 ppm. The Total Suspended Solids ranged from 0.0412 to 0.0256 mg/l (Table 1). The water quality parameters were found to be suitable for mud crab farming operations. The sediment pH was found to be alkaline and the organic carbon values were 1.23 and 1.56% indicating a good productivity. The analysis of sediment texture revealed

Table 1. Water quality characteristics of the study stations at Ratnagiri

Stations	Temperature (oC)	Salinity (ppt)	pH	Dissolved oxygen (ppm)	TDS (mg/l)	TSS (mg/l)	NH_4 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)	SiO_2 (mg/l)	Chl-*a* (mg/m^3)	NPP (mgC/l/hr)
Anjarle 1	31.0	32.87	8.24	7.83	45.33	0.0256	0.250	0.20	0.02	0.21	0.231	1.956
Anjarle 2	31.3	33.15	8.10	9.27	45.65	0.0412	0.025	0.15	0.02	0.37	0.247	2.445
Aade 1	31.9	33.28	8.17	8.73	46.13	0.0388	0.150	0.15	0.10	0.21	0.151	0.952
Aade 2	30.0	8.10	7.76	8.44	12.47	0.0048	0.025	0.15	0.15	0.53	0.020	0.772
Aade 3	30.7	21.76	8.18	9.08	31.21	0.0192	0.000	0.10	0.00	0.43	0.153	6.933
Aade 4	30.7	33.66	8.18	8.08	46.10	0.0212	0.000	0.15	0.00	0.25	0.056	3.250
Kelshi 1	29.8	34.12	8.13	8.14	46.77	0.0220	0.050	0.30	0.30	0.37	0.126	4.993
Kelshi 2	29.9	29.12	8.03	7.61	41.80	0.0080	0.500	0.30	0.30	0.43	0.185	2.883
Kelshi 3	30.4	34.54	8.23	7.36	47.27	0.0288	0.050	0.35	0.30	0.32	0.059	4.839
Velas 1	30.2	7.24	7.64	10.10	12.05	0.0112	0.050	0.10	0.25	0.53	0.270	1.873
Velas 2	30.6	17.20	7.64	7.59	26.31	0.0120	0.050	0.09	0.19	0.52	0.180	1.912
Ansure 1	27.9	35.90	7.66	7.83	48.60	0.0098	0.000	0.15	0.06	0.21	0.385	0.506
Ansure 2	29.1	35.74	7.75	8.80	48.94	0.0067	0.000	0.15	0.05	0.32	0.152	0.283
Ansure 3	28.7	35.55	7.72	8.17	48.45	0.0083	0.000	0.15	0.05	0.32	0.471	0.335
Ansure 4	29.5	35.22	7.75	8.03	48.22	0.0113	0.000	0.15	0.12	0.32	0.394	0.129
Ansure 5	30.7	35.15	7.68	7.93	47.82	0.0129	0.000	0.10	0.10	0.37	0.365	0.128
Ansure 6	30.1	34.19	7.68	7.64	47.29	0.0107	0.000	0.10	0.10	0.37	0.298	0.026
Ansure 7	30.3	33.86	7.55	7.91	46.54	0.0124	0.000	0.15	0.10	0.37	0.218	0.023

Table 2. Physical and chemical characteristics of sediment of the study stations at Ratnagiri

Stations	Chemical characteristics		Physical characteristics			
	pH	Organic Carbon (%)	Sand (%)	Silt (%)	Clay (%)	Loss in solution (%)
Anjarle 1	7.42	1.23	30.18	54.32	14.15	1.35
Anjarle 2	7.60	1.56	33.61	47.40	18.15	0.84
Aade 1	8.32	1.35	37.00	52.84	6.40	3.76
Aade 2	8.15	0.81	62.75	29.77	3.08	4.40
Aade 3	7.36	0.80	33.10	46.90	17.00	3.00
Aade 4	8.17	0.98	30.58	54.22	13.75	1.45
Kelshi 1	6.30	1.02	26.17	62.72	6.49	4.62
Kelshi 2	6.25	1.71	20.50	61.82	12.68	5.00
Kelshi 3	6.70	2.94	19.82	65.28	11.90	3.00
Velas 1	6.20	0.66	60.80	30.50	4.99	3.70
Velas 2	6.88	2.88	30.01	60.49	6.30	3.20
Ansure 1	7.32	0.27	61.05	31.75	3.45	3.75
Ansure 2	7.18	0.81	25.60	62.50	8.24	3.66
Ansure 3	7.04	2.04	35.30	55.32	6.68	2.70
Ansure 4	7.23	0.66	36.28	55.81	3.37	4.54
Ansure 5	6.80	1.83	33.30	46.20	16.50	4.00
Ansure 6	7.27	2.61	37.34	52.50	6.50	3.66
Ansure 7	7.03	1.11	73.75	13.86	8.24	4.15

predominance of silt fraction when compared to sand and clay (Table 2).

The area along Anjarle estuary was spatially analysed to understand the existing water use and found that the northern border of the estuary is being used for many industrial, domestic and transportation activities. This area has a dense human population which depends on water for multiple uses. The main stretch of the water body is used by fishermen of different villages to reach the sea. However, the marginal areas and the creeks do not have much human interference. Site suitability studies have shown that the northern and southern banks of the main creek are suitable for mud crab farming. Besides, some of the smaller creeks that ramify into the fringing mangroves are also suitable. The potential areas have an easy access from the boat jetty present closer to the bar mouth. The mud crab is regularly caught by fishermen from the creeks of Anjarle. The availability of mud crab seed resources at Anjarle is an added advantage for the local people who are interested in mud crab fattening/farming. The suitable areas available for mud crab farming in Anjarle is shown in the digitized map (Fig. 2). Based on the topography, water quality, water availability, soil type and accessibility, a total of 1.91 ha has been identified as suitable for mud crab farming.

Potential mud crab farming sites at Aade

The brackishwater stretch along Aade village is a vast area and offers enormous potential for aquaculture. Patchy to dense mangrove vegetations were observed here. The mangrove species observed were *A. marina*, *S. caseolaris*, *R. mucronata*, *Kandelia candel* and *Acanthus ilicifolius*.

The salinity ranged from 8.10 to 33.66 ppt, while the

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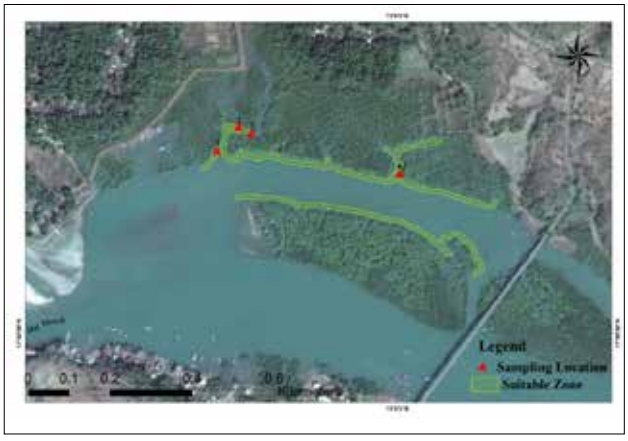

Fig. 2. Digitized map of Anjarle showing the suitable sites for mud crab farming

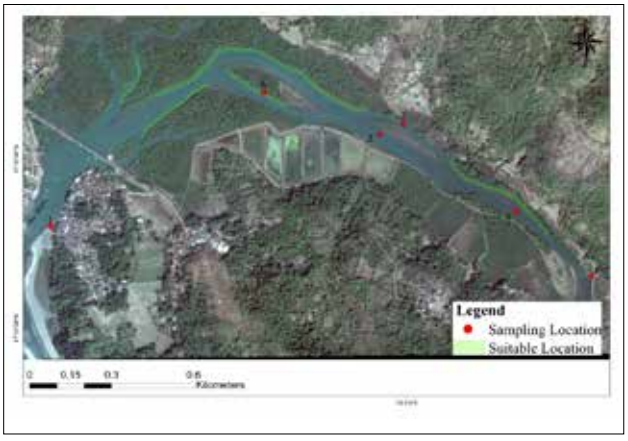

Fig. 3.Digitized map of Aade showing the suitable sites for mud crab farming

pH values were alkaline and ranged from 7.76 to 8.18. The dissolved oxygen values were found to be in the optimum range and ranged from 8.08 to 9.08 ppm (Table 1). The Total Dissolved Solids (TDS) ranged from 12.47 to 46.13 mg/l while the Total Suspended Solids (TSS) ranged from 0.0048 to 0.0388 mg/l. A higher sediment pH ranging from 7.36 to 8.32 was observed while the organic carbon values ranged from 0.80 to 1.35% indicating a reasonably good productivity (Table 2). The texture was predominantly silty in all the study stations except in station 2 which was predominantly sandy (62.75% sand). Station 2 was towards the upper reaches and considering all the criteria including accessibility, this area was not considered suitable for farming.

The potential sites for mud crab farming in Aade creek is shown in Fig. 3. Only few fishing boats ferry through the main creek to enter the sea for fishing as large number of boats are anchored close to the bar mouth itself. There are no industries nearby and thereby the creeks were found to be safe from any contaminants. Most of the suitable areas are found along the main creek itself and a total of 2.069 ha have been identified as most suitable for mud crab farming based on the topography, water quality, diurnal water retention, soil characteristics and other infrastructure facilities. The mud crabs are available in the creek and are regularly caught by fishermen using traps. The creek is also known to have mud crab seed resource. The access to the potential sites is from the landing centre close to the bar mouth. There are many human settlements close to the bar mouth, near the landing centre and hence the area nearer to the human settlements have been avoided while choosing the ideal farming sites.

Potential mud crab farming sites at Kelshi

Kelshi is a mangrove-rich area dominated by *Avicennia marina* and *Rhizophora mucronata* with *Acanthus ilicifolius* at the periphery. The mangroves were found to form a thick vegetation. The area is rich in fish resources, besides oysters and clams. The livelihood of many people living in Kelshi village is dependent on this mangrove stretch. Picking of clams and oysters and catching shrimps and finfishes is an important occupation and source of income of many people living in the coastal hamlets at Kelshi.

The pH of water ranged from 8.03 to 8.23, while the salinity at Kelshi ranged from 29.12 to 34.54 ppt during the field survey, indicating the suitability of this area for aquaculture. The dissolved oxygen values ranged from 7.36 to 8.14 ppm which was found to be within the ideal range for mud crab farming (Table 1). The sediment pH ranged from 6.25 to 6.70 while the organic carbon values ranged from 1.02 to 2.94% indicating high productivity. The textural analysis of sediment indicated a high silt fraction ranging from 61.82 to 65.28% (Table 2).

In Kelshi, the southern part is found to have a multi-user scenario for water with comparatively high domestic settlement. To make the proposal socially acceptable and eco-friendly, the water bodies which are being used for various uses by the local population was avoided to reduce conflicts and also to avoid pollution. The mangrove area has criss-cross of streams which are narrow and wide. Most of the creeks meandering into the thick mangrove vegetations have also been found suitable for aquaculture. This region has very good water exchange, and the mangroves all around ensure very good protection for crab pens even in the case of heavy water flow in estuaries. Based on the topography, soil characteristics, water quality, tidal amplitude, water retention and infrastructure facilities, a total of 1.769 ha have been identified as suitable for mud crab farming (Fig. 4). The access to the potential sites is from the village hamlet, where some of the villagers own a boat for fishing and navigational purposes.

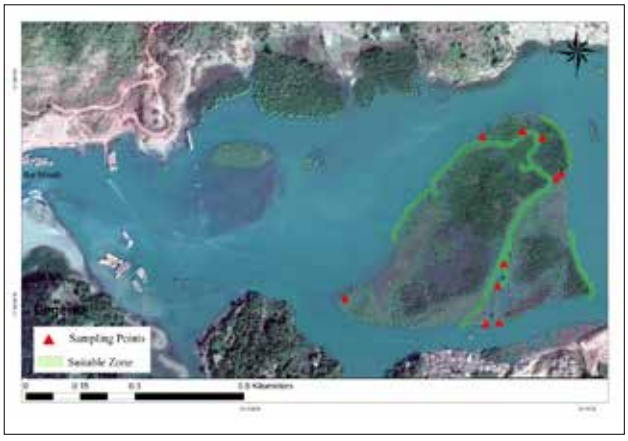

Fig. 4.Digitized map of Kelshi showing the suitable sites for mud crab farming

Potential mud crab farming sites at Velas

The brackishwater available at Velas for mud crab farming is a small stretch, with no much human inhabitations around. The dominant mangrove species is *A. marina*. The other mangrove species present are *R. mucronata*, *S. caseolaris* and *A. ilicifolius*.

Fig. 5. Digitized map of Velas showing the suitable sites for mud crab farming

During survey, the salinity ranged from 7.24 to 17.2 ppt (low tide), while the pH was near neutral and was 7.64 at both the study stations. The dissolved oxygen values were 10.1 and 7.59 ppm at stations 1 and 2 respectively (Table 1). The sediment pH ranged from 6.20 to 6.88 while the organic carbon values ranged from 0.66 to 2.88% (Table 2). Station 1 which is towards the upper reaches is predominantly sandy (60.8% sand), while station 2 which falls in the suitable zone identified is predominantly with silt fraction (60.49% silt).

The area is free from any contaminants as there is no industrial outfall near to this region. The suitable sites identified is somewhat close to the bar mouth where there is a good tidal water exchange. There is no human settlement in the vicinity and the area is free from navigational use. Based on the topography, water quality, tidal amplitude, water exchange, soil characteristics, and accessibility, at total of 0.538 ha has been identified to be suitable for mud crab farming (Fig.5).

Potential mud crab farming sites at Ansure

The mangrove area at Ansure is an excellent stretch for mud crab farming. The mangrove species observed were *A. marina*, *A. officinalis*, *S. caseolaris* and small fringing patches of *A. ilicifolius*.

The salinity of water ranged from 33.86 to 35.9 ppt, while the pH ranged from 7.55 to 7.75. The dissolved oxygen content in water found to be ideal and ranged from 7.64 to 8.80 ppm while the Total Dissolved Solids (TDS) ranged from 46.54 to 48.94 mg/l. The Total Suspended Solids (TSS) were in the range of 0.0067 to 0.0129 mg/l while the chlorophyll-*a* values ranged from 0.152 to 0.471 mg/m3 (Table 1). The sediment pH ranged from 6.8 to 7.32 while the organic carbon values ranged from 0.27 to 2.61% (Table 2). The textural analysis of sediment revealed a higher silt fraction in all the stations, except for station 1 and station 7 which were predominantly sandy. Station 1 is close to the bar mouth and station 7 is towards the upper reaches.

Fig. 6 is the digitized map of Ansure showing the suitable areas for mud crab farming. The area very close to the bar mouth is avoided due to the frequent movement and berthing of fishing boats. A little beyond, towards the eastern side, the mangrove areas were found to be highly suitable for mud crab farming. The water body has access from more than one point and the village has good roads almost reaching close to the mangrove wetland. As the Ansure village lies in the northern side of the main creek, the potential zones along the northern belt is identified. Based on the topography, water quality, sediment characteristics, water availability and accessibility, a total of 3.776 ha has been identified to be suitable for mud crab farming. The creek is also known for its rich fish, shrimp, crab and edible oyster resources. Some of the villagers are dependent on the

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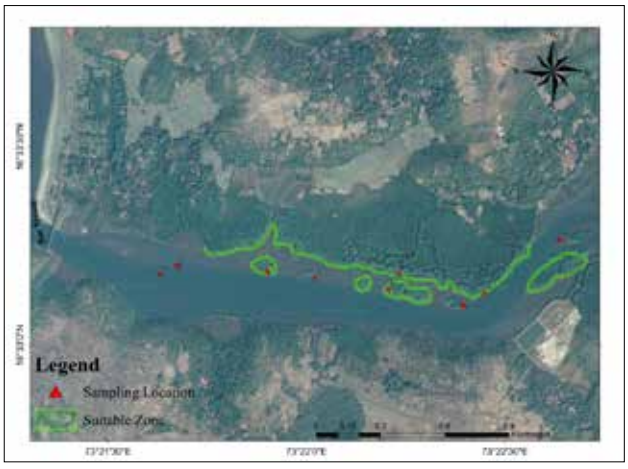

Fig. 6. Digitized map of Ansure showing the suitable sites for mud crab farming

creek for their livelihood by regularly harvesting the fish and shellfish resources.

Screening of wild collected mud crab for WSSV infection

The samples of *S. serrata* collected from all the study areas *viz.*, Ansure, Anjarle, Aade, Kelshi and Velas gave Negative results in primary as well as nested PCRs, indicating the absence of WSSV in the wild mud crab population of the study area. This indicated that the potential areas identified are safe at present for mud crab farming.

Categorisation of potential sites

The preferred habitat of mud crabs is mangrove forests and swamps with sheltered tropical to sub-tropical estuaries and embayments (Shelley and Lovatelli, 2011). The mangrove vegetation is important for mud crab as it provides suitable habitat, shelter and food. However, all the areas within the mangrove habitat may not be suitable for mud crab culture and therefore the area need to be categorized based on various parameters including water quality, soil characteristics, topography, water availability, risks of flooding, land-use type, infrastructure, seed availability, market and support services. Salam *et al.* (2012) identified potential mud crab farming sites in southwestern Bangladesh using multi-criteria evaluation module in GIS environment and categorized the sites into very suitable, moderate suitable, marginal suitable and currently not suitable.

In the present study, based on the weighted average values, the potential zone in each of the study areas were delineated into three categories namely, excellent, very good and good (Table 3 and 4). Two stations at Ansure and one station at Velas had a total score more than 8, and hence categorized as 'excellent' which can be taken up for mud crab farming on priority. All stations at Anjarle and Kelshi, two stations at Aade, one station at Velas and five stations at Ansure were rated as 'very good' (total score of 6.0 to 7.9) and therefore falls second in priority while taking up the farming activities. Shelly and Lovatelli (2011) suggested a salinity range of 10-25 ppt, dissolved oxygen value of $>$ 5 ppm, alkaline pH ranging from 7.5 to 9.0 and ammonia value less than 3 ppm for mud crab culture. All the mangrove areas surveyed in Ratnagiri district had ideal range of water quality characteristics (Table 1); however, being an estuarine zone, the parameters are subject to diurnal variations due to the tidal influx.

It is to mention here that all the marked areas in figures 2 to 6 are suitable for mud crab farming. Thus, integrating the analysis result along with supporting spatial data with the aid of GIS and Remote Sensing techniques, a total of 10.06 ha have been evaluated as suitable areas for mud crab farming along

Table 3. Assumptions of rating points for the range of parameters used for classifying the potential sites

Rating point	Parameters										
	Temperature (°C)	Salinity (ppt)	pH	D.O. (ppm)	Ammonia (mg/l)	Nitrite (mg/l)	Sediment pH	Sediment organic carbon (%)	Average depth (m)	Distance from shore to culture site (m)	Distance from culture site to market (m)
10	25–35	15–25	7.5–8.5	$>$ 5.0	$<$ 0.3	$<$ 5.0	6.0–7.5	2.0–5.0	1.0–1.5	$<$ 100	$<$ 500
9	24–36	14–26	7.4–8.6	4.5–5.0	0.3–0.32	5.0–5.1	5.9–7.6	1.9–2.0	0.9–1.6	100–200	500–750
8	23–37	13–27	7.3–8.7	4.0–4.5	0.32 -0.34	5.1–5.2	5.8–7.7	1.8–1.9	0.8–1.7	200–300	750–1000
7	22–38	12–28	7.2–8.8	3.5–4.0	0.34–0.36	5.2–5.3	5.7–7.8	1.7–1.8	0.7–1.8	300–400	1000–1250
6	21–39	11–29	7.1–8.9	3.0–3.5	0.36–0.38	5.3–5.4	5.6–7.9	1.6–1.7	0.6–1.9	400–500	1250–1500
5	20–40	10–30	7.0–9.0	2.5–3.0	0.38–0.40	5.4–5.5	5.5–8.0	1.5–1.6	0.5–2.0	500–600	1500–1750
4	19–41	08–31	6.9–9.1	2.0–2.5	0.40–0.42	5.5–5.6	5.4–8.1	1.4–1.5	0.4–2.1	600–700	1750–2000
3	18–42	06–32	6.8–9.2	1.5–2.0	0.42–0.44	5.6–5.7	5.3–8.2	1.3–1.4	0.3–2.2	700–800	2000–2250
2	17–43	04–33	6.7–9.3	1.0–1.5	0.44–0.46	5.7–5.8	5.2–8.3	1.2–1.3	0.2–2.3	800–900	2250–2500
1	15–45	00–35	6.5–9.5	0.0–1.0	0.46–0.50	5.8–6.0	5.0–8.5	0.0–1.2	0.1–2.5	$>$ 1000	2500–3000
Weighted value	0.1	0.1	0.1	0.1	0.1	0.03	0.1	0.1	0.1	0.07	0.07

Table 4. Score and weighted assessment of selected sites for mud crab farming in the Ratnagiri District of Maharashtra

Stations	Attributes											Total score	Weighted category*
	Temp	Salinity	pH	D.O.	NH_4^+	NO_2	Sediment pH	Sediment Org. C	Depth	Distance from site to shore	Distance from site to market		
Weighted (w)	0.1	0.1	0.1	0.1	0.1	0.06	0.1	0.1	0.1	0.07	0.07		
Anjarle 1	1.0	0.2	1.0	0.7	1.0	0.6	1.0	0.2	0.6	0.35	0.35	7.0	Very good
Anjarle 2	1.0	0.1	1.0	0.9	1.0	0.6	0.9	0.5	0.8	0.14	0.28	7.22	Very good
Aade 1	1.0	0.1	1.0	0.8	1.0	0.6	0.2	0.3	0.5	0.35	0.21	6.06	Very good
Aade 2	1.0	0.4	0.9	0.8	1.0	0.6	0.3	0.1	0.3	0.07	0.14	5.61	Good
Aade 3	1.0	1.0	1.0	0.8	1.0	0.6	1.0	0.1	0.8	0.07	0.07	7.44	Very good
Aade 4	1.0	0.1	1.0	0.7	1.0	0.6	0.3	0.1	0.3	0.07	0.07	5.24	Good
Kelshi 1	1.0	0.1	1.0	0.7	1.0	0.6	1.0	0.1	0.5	0.56	0.28	6.84	Very good
Kelshi 2	1.0	0.5	1.0	0.7	0.1	0.6	1.0	0.7	0.9	0.63	0.35	7.48	Very good
Kelshi 3	1.0	0.1	1.0	0.7	1.0	0.6	1.0	1.0	0.9	0.14	0.14	7.58	Very good
Velas 1	1.0	0.3	1.0	0.9	1.0	0.6	1.0	0.1	0.8	0.56	0.28	7.54	Very good
Velas 2	1.0	1.0	1.0	0.7	1.0	0.6	1.0	1.0	0.9	0.28	0.21	8.69	Excellent
Ansure 1	1.0	0.1	1.0	0.7	1.0	0.6	1.0	0.1	1.0	0.07	0.07	6.64	Very good
Ansure 2	1.0	0.1	1.0	0.8	1.0	0.6	1.0	0.1	1.0	0.14	0.14	6.88	Very good
Ansure 3	1.0	0.1	1.0	0.8	1.0	0.6	1.0	1.0	1.0	0.28	0.21	7.99	Very good
Ansure 4	1.0	0.1	1.0	0.7	1.0	0.6	1.0	0.1	1.0	0.49	0.28	7.27	Very good
Ansure 5	1.0	0.1	1.0	0.7	1.0	0.6	0.9	0.8	0.9	0.7	0.35	8.05	Excellent
Ansure 6	1.0	0.1	1.0	0.7	1.0	0.6	1.0	1.0	0.8	0.63	0.35	8.18	Excellent
Ansure 7	1.0	0.1	1.0	0.7	1.0	0.6	1.0	0.1	0.6	0.21	0.21	6.52	Very good

*4.0 – 5.9 Good; 6.0 – 7.9 Very good; 8.0 – 10.0 Excellent

the brackishwater stretches of Anjarle (1.91 ha), Aade (2.069 ha), Kelshi (1.77 ha), Velas (0.538 ha) and Ansure (3.776 ha).

Mud crab supports local fishery in coastal areas, estuaries and lagoons and there also exists enormous potential for farming of mud crabs in India (Marichamy, 1996). However, the major limitation is the shortage of hatcheries to supply quality seeds in required numbers. At present, Tamil Nadu is the only state in India that produces crablets and states like Maharashtra has been procuring the baby crabs from Tamil Nadu for fattening (Sengupta, 2017). This calls for an urgent need to develop mud crab hatcheries in Maharashtra to cope up with the increasing demand for seeds. The steady supply of mud crab seeds would encourage more coastal people of Maharashtra to take up farming in suitable mangrove wetlands, as a source of livelihood option.

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