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Mapping of Production and Marketing of Mud Crab Fishing Business (*Scylla Serrata*) in Bengkulu Province, Indonesia

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ABSTRACT
The mud crab (*Scylla serrata*) capture fisheries represent a strategic sector that supports food security and empowers coastal communities in Bengkulu Province. This study aimed to comprehensively map the production and marketing of mud crabs in the region using Geographic Information System (GIS) applications. The research locations include the mainland area and Enggano Island, representing mangrove ecosystems with distinct characteristics. Primary data were collected through field surveys, interviews, and geolocation data of production and marketing sites. These data were analyzed using Landsat 8 satellite imagery to identify the spatial patterns of production and distribution routes. The findings reveal that mud crab production is closely associated with well-preserved mangrove ecosystems, with key production sites spread across six administrative regions. Marketing routes are predominantly local shipments to Bengkulu City and exports to other provinces, such as Jakarta and Padang. This study underscores the importance of integrating mangrove ecosystem management with capture fisheries to ensure sustainable mud crab production. The resulting catch maps and marketing routes provide a foundation for formulating more efficient and sustainable fisheries resource management policies. Consequently, this research offers significant contributions to supporting the economic development of coastal communities while preserving the integrity of mangrove ecosystems.

INTRODUCTION

Capture fisheries are a strategic sector that supports food security, community empowerment, and poverty alleviation in coastal areas. Among the key commodities in mangrove-based capture fisheries is mud crab (*Scylla serrata*), which has significant economic value in both local and international markets. Mud crabs play a crucial role in the mangrove ecosystem as apex predators, maintaining ecological balance and supporting the sustainability of capture fisheries **(Suryani, 2007)**.

In Bengkulu Province, the abundant mangrove resources provide substantial potential for mud crab fisheries. Previous studies have explored the biological and ecological aspects of mud crabs in this region, including population dynamics, habitat

distribution **(Suryani, 2007; Cahyadinata *et al.*, 2021)**, community perceptions of mud crab fisheries management **(Cahyadinata *et al.*, 2019a)** and utilization rates **(Cahyadinata *et al.*, 2020)**. However, these studies have not specifically addressed the production and marketing dimensions of mud crab fisheries, leaving an information gap regarding the socio-economic aspects critical for comprehensive resource management.

The state of the art in mud crab research in Bengkulu indicates that technology-based approaches, such as the application of Geographic Information Systems (GIS), have rarely been implemented. GIS has significant potential for mapping production sites and distribution routes, aiding in understanding spatial patterns and identifying priority areas for management **(UMS, 2019; Hidayat *et al.*, 2023)**. Additionally, GIS can visualize the relationship between mangrove habitats and fisheries potential, which was previously analyzed descriptively without spatial data support **(Harahap, 2009; Rusdi *et al.*, 2020)**.

Mapping these aspects is particularly important because Bengkulu Province consists of both mainland areas and several small islands with distinct mangrove ecosystem characteristics. Mangroves on small islands tend to be more isolated and vulnerable to environmental pressures, while mainland mangroves are more extensive and serve as the primary support for mud crab fisheries **(Cahyadinata *et al.*, 2019a, 2019b)**. GIS enables detailed mapping of these spatial differences to identify production patterns in both regions. These data are invaluable for designing management strategies tailored to the local conditions of small islands and the mainland.

This study aimed to comprehensively map the production and marketing of mud crabs in Bengkulu Province using GIS applications. The analysis includes identifying key production locations, marketing routes, and challenges faced by fishers and entrepreneurs. This approach not only provides accurate empirical data but also offers innovative solutions for sustainable mud crab fisheries management.

By integrating GIS, this research is expected to make a tangible contribution to ecosystem-based management while simultaneously supporting the economic development of coastal communities. The study's findings also provide recommendations for local governments, academics, and other stakeholders to establish more efficient and sustainable governance of mud crab fisheries.

MATERIALS AND METHODS

Study area

The research location was selected purposefully, as described by **Nazir (2014)**. It includes regencies and cities situated along the west coast of Sumatera and Enggano Island. The mainland areas are represented by Kaur Regency, Seluma Regency, Central Bengkulu Regency, North Bengkulu Regency, Mukomuko Regency, and Bengkulu City, while Enggano Island represents the outermost small island (Fig. 1).

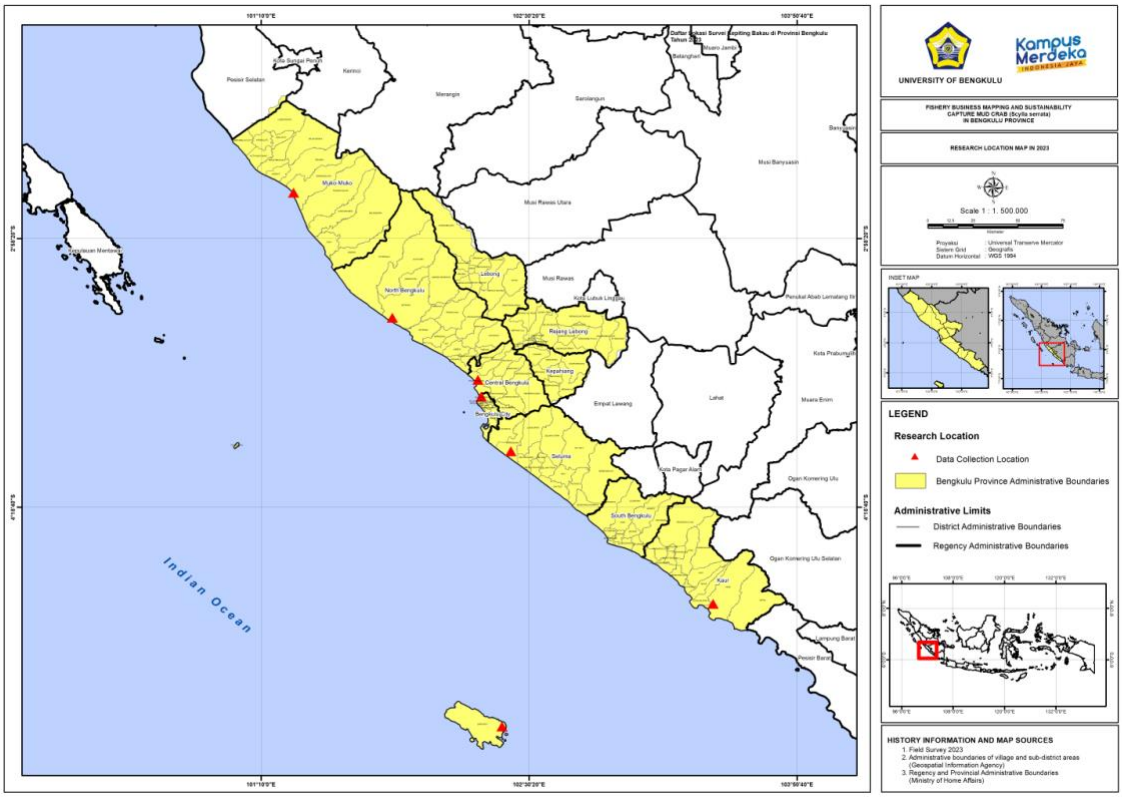

Fig. 1. Map of study sites

Data collection

The data in this study consist of primary data and secondary data. Secondary data were obtained from available literature (sourced from related institutions) and primary data were obtained directly in the field through interviews and surveys. The interview used instruments in the form of questionnaires and survey methods adjusted to the data needs needed from the field. The survey was carried out to collect data on the production and marketing location of mud crabs, including the form of coordinate points that will be input in the image map. Through this mapping, the distribution and distance of each fishing location and marketing location will be determined (the first research objective).

Data analysis

Procedure of map analysis processing

The map used was in the form of Landsat 8 OLI image data, by trimming the study area in the research location, then converting the digital number (DN) value on the image into a reflectance value through atmospheric correction. Images that have gone through the pre-processing stage were then given a combination of channel 8-11-4 to obtain visual information on the image **(Hendrawan *et al.*, 2018)**. Information about the object was used as a reference for the maximum likelihood classification process to obtain the distribution of mud crab fishing business. The data on the general state of the

research location used Landsat 8 (OLI) path/raw 122/65 image data from August 17, 2021, and administrative data of the research area (Table 1).

Table 1. Characteristics of Landsat 8 imagery bands

Channels	Lenght wave	Resolution (m)
Band 1 - Coastal aerosol	0.43 – 0.45	30
Band 2 - Blue	0.45 – 0.51	30
Band 3 - Green	0.53 – 0.59	30
Band 4 - Red	0.64 – 0.67	30
Band 5 - Near Infrared (NIR)	0.85 – 0.88	30
Band 6 - Shortwave Infrared (SWIR) 1	1.57 – 1.65	30
Band 7 - Shortwave Infrared (SWIR) 2	2.11 – 2.29	30
Band 8 - Panchromatic	0.50 – 0.68	15
Band 9 - Cirrus	1.36 – 1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6 – 11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.5 – 12.52	100

Source: **USGS (2014)**

Image pre-processing

Pre-processing of images is the first step in processing satellite images. Some of the steps in image pre-processing include data import, image merging, image coordinate transformation, image fusion, image data cutting and visual interpretation of the image.

1. **Data import**: The first step in image pre-processing is data import. The image used in this study is Landsat 8 (OLI) in TIFF format. This process involves converting the TIFF format into IMG format, performed using ENVI software version 5.2. Additionally, Sentinel-2A imagery with a spatial resolution of 10m × 10m was utilized in the study.
2. **Image merge (Layer stacking)**: Landsat 8 imagery comprises nine channels from the Operational Land Imager (OLI) and two channels from the Thermal Infrared Sensor (TIRS). Band combination is performed to obtain multispectral image data, including visible light bands, Near Infrared (NIR), Shortwave Infrared (SWIR), and Cirrus bands. The purpose of band merging is to create multispectral image data consisting of visible, NIR, and SWIR bands in the Landsat 8 imagery.
3. **Image coordinate transformation**: The image coordinate transformation stage aims to rectify or restore the image coordinates to align with geographic coordinates. This process registers the position of the image with other images or transforms the coordinate system of multispectral or multi-temporal images. It includes registering images to maps or transforming image coordinates into a specific map projection system. The coordinate system, projection, and datum used in this study align with the research location, which is in Universal

Transverse Mercator (UTM) zone 48S with the World Geodetic System 1984 (WGS 84) datum.

4. **Radiometric correction**: Radiometric correction is conducted to improve the visual quality of images, making it easier to identify features. This technique enhances or adjusts the contrast of the image by modifying the pixel values. In this study, an equalization histogram method was employed, setting the Digital Number (DN) values for each band within the range of 0 to 65,535.
5. **Cropping**: Cropping defines the research location clearly and ensures that the imagery corresponds to the study area. This step involves cutting the corrected image to match the research site boundaries, performed using ENVI software version 5.2.

Visual interpretation of imagery

Visual interpretation of imagery was conducted to obtain a general understanding of the research location and to preliminarily identify land cover types prior to conducting field ground checks. At this stage, visual image interpretation (digitization on-screen) was performed using key interpretation elements such as color, shape, size, pattern, and texture. This process was carried out using ArcGIS software version 10.4.

To enhance the analysis, visual classification was applied to optimize the spatial and spectral resolution of the Landsat 8 imagery. The classification utilized a band combination of 7-5-4, as suggested by **Latifah *et al.* (2018)**.

RESULTS AND DISCUSSION

Production mapping

Mud crab production in Bengkulu Province is found in one city and five regencies (Fig. 2), namely Bengkulu City, Central Bengkulu Regency, North Bengkulu Regency, Mukomuko Regency, Seluma Regency, and Kaur Regency. Specific production locations include Muara Bangkahulu District and Kampung Melayu District in Bengkulu City, Pondok Kelapa District in Central Bengkulu Regency, Ketahun and Enggano Districts in North Bengkulu Regency, Teramang Jaya District, Mukomuko City, and Fourteen Koto District in Mukomuko Regency, Air Periukan and Semidang Alas Maras Districts in Seluma Regency, and Meje District and South Kaur District in Kaur Regency. Management of mud crab production involves several related sectors such as the marine and fisheries services, both provincial and district/city, and the natural resource conservation agency.

Mud crab populations in these production areas are closely linked to the presence of well-preserved mangrove forests. Habitat loss in these ecosystems would have severe consequences for mud crab populations. For instance, Enggano District, located on one of Indonesia's outermost small islands, possesses a well-maintained mangrove ecosystem

(LIPI, 2017) and significant potential for mud crab production, making it a primary target for local fishermen.

The production mapping of mud crabs (*Scylla serrata*) in Bengkulu Province highlights the strong correlation between the preservation of mangrove ecosystems and the abundance of this fishery resource. Healthy mangroves serve as crucial habitats for the entire life cycle of mud crabs, providing shelter from natural predators and abundant food sources. Previous studies have shown that the degradation of mangrove habitats significantly reduces mud crab populations **(Siahainenia *et al.*, 2008)**. Therefore, integrated management strategies combining mangrove conservation and sustainable fisheries practices are essential to support the long-term viability of this resource.

Spatial analysis using Landsat 8 imagery illustrates the distribution of production locations across districts such as Muara Bangkahulu, Kampung Melayu, and Enggano. These areas exhibit unique ecosystem characteristics, with Enggano being particularly noteworthy for its biodiversity due to its relative isolation and minimal anthropogenic pressures **(LIPI, 2017)**. Furthermore, the mapping reveals spatially concentrated production patterns in areas with direct access to mangroves and adequate distribution infrastructure, emphasizing the critical role of logistics in supporting fishing activities.

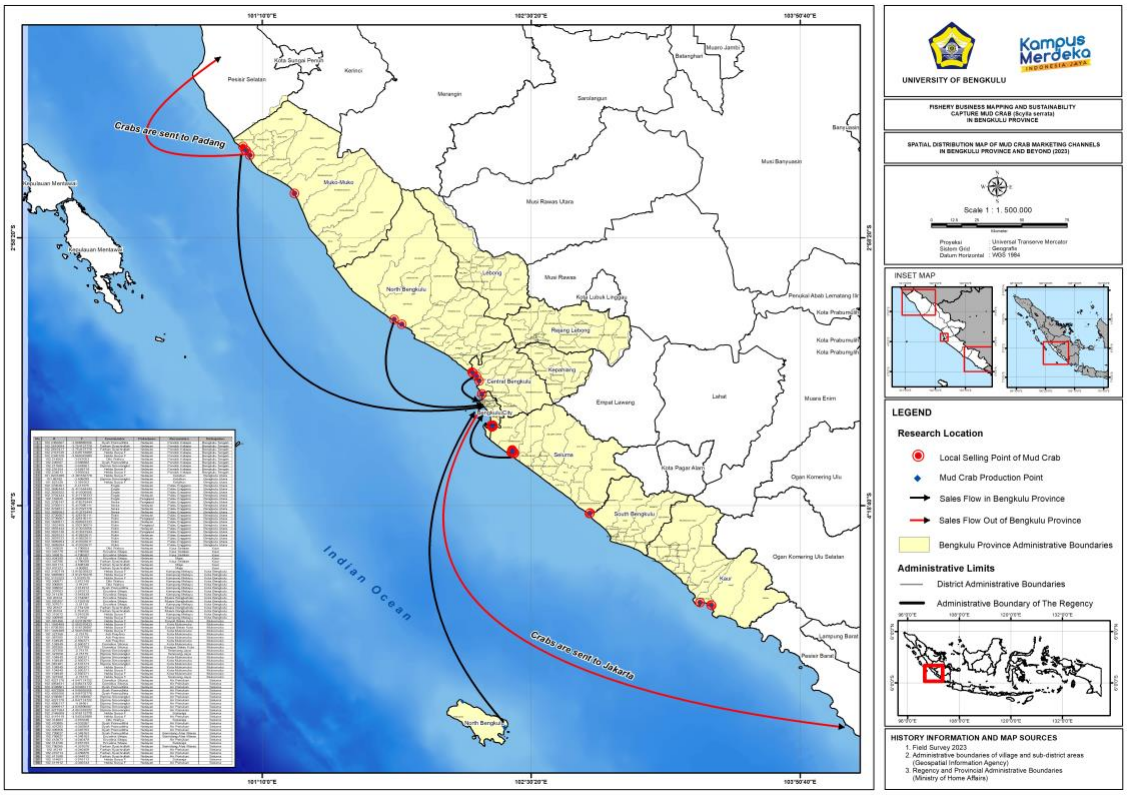

Fig. 2. Map of mud crab production and marketing in Bengkulu Province

Comparing this study with similar research conducted in other regions, such as Pannikiang Island, South Sulawesi, reveals some notable differences. In Pannikiang, the mud crab population is similarly dependent on healthy mangrove ecosystems, but the

habitat conditions there are influenced more by anthropogenic activities such as aquaculture and land conversion **(Rusdi *et al.*, 2020)**. Additionally, research from Sebatik Island, North Kalimantan, has emphasized the use of remote sensing to monitor mangrove cover changes and their impact on fishery resources, showing consistent findings that mangrove degradation leads to declining crab populations **(Hendrawan *et al.*, 2018)**. These studies underscore the universal importance of mangrove conservation but highlight regional differences in pressures and management approaches.

The application of GIS-based systems in this study provides not only accurate data but also opportunities for ecosystem-based management. Information on the most productive sites can guide stakeholders in developing management policies, such as establishing conservation zones or enhancing the capacity of local fishers. These findings align with previous research that emphasizes the critical role of spatial analysis in sustainable fisheries management **(Latifah *et al.*, 2018)**. Thus, this research significantly contributes to the economic development of coastal communities while ensuring the sustainability of natural resources.

Marketing mapping

Spatial analysis and field observations revealed that mud crab products in Bengkulu Province are sold to local communities and collectors, primarily in Bengkulu City. Specific locations, such as Kampung Melayu and Muara Bangkahulu Districts in Bengkulu City, Air Periukan District in Seluma Regency, and Pondok Kelapa District in Central Bengkulu Regency, serve as key hubs. Meanwhile, areas like Mukomuko Regency export mud crabs to other provinces, such as Padang and Jakarta, with distances exceeding 800km. This distribution pattern highlights the importance of logistics and infrastructure in connecting local producers to larger markets.

The mapping of the mud crab sales flow has additional information such as the distance traveled to the collection area in Bengkulu City (Table 2).

Table 2. Distance information to collectors in Bengkulu City

No	**District**	**Regency**	**Distance** (Km)
1	Air Periukan	Seluma	35
2	Pondok Kelapa	Bengkulu Tengah	11
3	Ketahun	Bengkulu Utara	90
4	Enggano	Bengkulu Utara	156
5	Mukomuko City	Mukomuko	264.7
6	Empat Belas Koto	Mukomuko	267

The results of mud crab fishing in Mukomuko Regency are sent inside and outside Bengkulu Province such as to Padang City. The distance from Mukomuko City to Padang City is about 285km, while the distance from Mukomuko City to collectors in Bengkulu City is about 264.7km. Mud crab fishery products from collectors in Bengkulu City are

then sent for purposes outside Bengkulu Province such as to Jakarta with 813km from Bengkulu City. Quality management of crab commodities in Bengkulu Province in the future will be able to compete with crab commodities from other provinces and will make it an attraction for importing countries to buy crabs from Bengkulu Province.

The marketing of mud crabs in Bengkulu Province is consistent with findings in other regions where middlemen dominate the marketing chain, reducing fishers' profits **(Harahab, 2009)**. For instance, in Pasuruan, East Java, local producers rely heavily on collectors to distribute their catches, resulting in limited bargaining power for fishers. Similar challenges are observed in the Buru and West Muna District, where crab producers are often constrained by logistical inefficiencies and price fluctuations in the export market **(Tetelepta *et al.*, 2019; Lopulalan *et al.*, 2024)**.

Mukomuko Regency, however, shows a different dynamic, with direct access to interprovincial markets allowing for broader market integration. This mirrors findings from research in Vietnam, where enhanced infrastructure and access to export networks significantly improved fishers' income and reduced dependence on intermediaries **(Nguyen & Hoang, 2024)**. These insights suggest that addressing logistical bottlenecks in Bengkulu Province could help maximize the potential of mud crab markets.

Quality management is another critical aspect highlighted in this study. The findings align with research in Bangladesh, where proper handling and processing practices were shown to increase the market value of mud crabs **(Kamal, 2020)**. Such practices could be implemented in Bengkulu Province to enhance the competitiveness of local products in national and international markets.

Furthermore, the use of GIS in marketing mapping offers a distinct advantage by providing spatially explicit insights into the distribution network, similar to findings in research conducted in the Sundarbans, India. GIS applications in that region helped identify inefficiencies in transportation routes and highlighted opportunities for streamlining supply chains **(Banerjee *et al.*, 2020)**. The study by **Jackson *et al.* (2020)** highlights how fish-processing activities in the Sundarbans Reserve Forest, Bangladesh, face not only ecological challenges but also social issues such as labor exploitation in the supply chain. This finding is relevant to Bengkulu Province, where the efficiency of marketing distribution must also align with improving the welfare of coastal communities. The use of technologies such as GIS, as demonstrated in their study, offers valuable insights into the relationship between ecosystem sustainability and market dynamics, a connection similarly critical in the context of mud crab fisheries in Bengkulu.

CONCLUSION

This study revealed that the production of mud crabs (*Scylla serrata*) in Bengkulu Province is concentrated in mangrove areas with relatively good ecosystem conditions, covering the mainland and small islands such as Enggano. Mapping using the Geographic

Information System (GIS) shows a structured spatial pattern of production and marketing, with the main distribution of catches to local markets in Bengkulu City and some out-of-province areas such as Jakarta and Padang.

The results of the analysis confirm the importance of ecosystem-based management in supporting the sustainability of mud crab fisheries. Mangrove habitat destruction has been proven to have a significant impact on mud crab populations and production, so the integration of mangrove conservation and fishery activities is a top priority. In addition, the study highlights the need to strengthen marketing governance, shorten distribution chains, and increase fishers' capacity to utilize modern technology to improve production efficiency and competitiveness in the market.

Overall, the study offers strategic guidance for sustainable capture fisheries management and contributes to the economic development of coastal communities. The application of GIS in spatial mapping is an effective method to support data-based decision-making in fisheries resource management and mangrove ecosystem conservation.

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