Precision Mapping: Harnessing Geographic Coordinates for Effective Identification of Aquaculture Ponds to Enhance Spatial Planning

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Ecological Importance of Mangroves:

Mangroves, thriving in the intertidal zones of tropical and subtropical shores, are among the most carbon-rich forests in the world[1]. They sequester carbon at rates much higher than other forests, and this process can continue for millions of years, making mangroves crucial in the fight against climate change[1]. The amount of carbon stored within the sediments of mangrove ecosystems varies widely, with a global median value of 2.2%[2]. However, when these blue carbon ecosystems are degraded or lost, they release stored carbon back into the atmosphere, contributing significantly to greenhouse gas emissions[2]. Protecting and restoring mangroves is thus a vital strategy for mitigating climate change and enhancing the resilience of coastal habitats[1].

Coastal aquaculture, particularly shrimp farming, has been heavily criticized for its environmental impacts, including the widespread devastation of mangrove forests[3]. This deforestation exacerbates various climatic variables, such as coastal flooding, cyclones, droughts, rainfall changes, salinity, sea-level rise, and sea surface temperature increases, all of which dramatically affect coastal aquaculture[3]. Shrimp ponds hold significantly lower ecosystem carbon stocks compared to intact mangroves, translating to higher carbon emissions[2]. For instance, converting mangroves to shrimp ponds results in an estimated 2250 kg CO_2-e emissions per kilogram of shrimp produced[2]. Additionally, the conversion of mangroves to aquaculture ponds increases nutrient export from land, negatively impacting adjacent ecosystems like seagrass meadows and coral reefs[4]. These persistent ecological and biogeochemical changes highlight the urgent need to protect and restore mangrove forests to ensure the sustainability of coastal and marine ecosystems[1].

Aquaculture impact on Land use and its Socioeconomic effects:

Agriculture remains the dominant land use in many areas, often utilized for both aquaculture and buildings. A major concern is the extensive clearing and conversion of natural habitats for shrimp farming and agriculture and, more recently, the shift from agriculture to aquaculture. This trend is driven by high global demand for aquaculture products and technological advancements, resulting in rapid and often unplanned coastal development [5]. These changes have sparked conflicts between agriculture and shrimp farming, leading to land and water degradation[6].

This growth of shrimp farming has led to a decline in land area devoted to rice farming, affecting traditional livelihoods and employment opportunities [7]. The labor requirements for shrimp farms are lower compared to paddy production, leading to "absolute desensitization", where many middle- and low-income residents have been displaced to pursue industrial labor in urban areas or become low-wage workers in aquaculture[8].

Environmental Challenges and Sustainable Practices:

Despite the high market demand for fish and shrimp and their importance for food security, the growth of aquaculture presents significant environmental challenges [9]. Sustainable aquaculture is limited by various environmental and ecological concerns, including land, water, feed, and energy use [9]. To ensure long-term growth, aquaculture must adopt environmentally sound practices and sustainable resource management [10]. The greening of aquaculture through Integrated Aquaculture-Agriculture (IAA) and Integrated Multi-Trophic Aquaculture (IMTA) could play a significant role in reversing the trend of blue carbon emissions and enhancing coastal ecosystems [9]. Ponds within IAA systems, which sequester more carbon per unit area than conventional fishponds, and moving shrimp culture offshore could reduce mangrove loss and increase blue carbon storage through mangrove restoration [9].

Aquaculture development has been the major reason for mangrove loss in many Asian countries[2]. With increasing recognition of the importance of mangroves, rehabilitating aquaculture ponds back to mangrove forests has gained popularity [2]. The thresholds for mangrove recruitment varied greatly across ponds and were correlated with elevation but not with distance to open water, salinity, or soil properties [11]. Natural recruitment is a cost-effective way to rehabilitate mangroves at fluvial sites with favorable soil properties, but planting can speed up rehabilitation and increase species diversity at less favorable oceanic sites [11]. Invasion of exotic species should be considered during pond rehabilitation [11].

Abandoned ponds could potentially be rehabilitated for shrimp and fish production after restorative treatments or targeted for mangrove restoration projects [2]. Revegetating abandoned aquaculture regions should be a priority for integrated coastal zone management (ICZM) [2]. A time series of very high spatial resolution optical satellite images from 2001 to 2015 revealed trends in the evolution of mangrove forests within aquaculture ponds[12]. The results showed that mangroves are expanding both inside and outside of ponds[12]. However, the yearly expansion rate varied significantly between replanted ponds[12]. Ground truthing revealed that only Rhizophora species had been planted, while natural mangroves consisted of Avicennia and Sonneratia species[12]. Dense Rhizophora plantations had low regeneration capabilities compared to natural mangroves[12]. Also, there is evidence that propagules of natural mangrove species can reach and colonize the understory of planted areas connected to water flow[12]. This suggests that with limited budgets, mangrove restoration plans could be more efficient by simply opening sluice gates or breaching pond dykes at strategic locations of unfilled ponds nearer to mangrove forests[12].

Ecological Importance of my research:

My research is valuable in several critical ways for marine spatial planning (MSP). By accurately identifying the latitude and longitude of aquaculture ponds, facilitating the creation of precise spatial maps, and ensuring that aquaculture activities are situated in suitable areas. This minimizes conflicts with other marine uses and protects sensitive habitats such as mangroves and coastal waters.

Tracking temporal changes in aquaculture ponds allows MSP to assess environmental impacts over time, which is crucial for evaluating the sustainability of aquaculture practices and their effects on ecosystems. Tracking temporal changes also helps in estimating of lifespan of aquaculture ponds. The lifespan of aquaculture ponds varied between 1 and 22 years, with most having productive lifespans of 10 to 13 years. This information is crucial for developing management plans for the delta or similar coastal ecosystems.

Furthermore, detailed spatial data aids in resolving conflicts between various marine activities, such as fishing, tourism, and conservation, enabling more efficient space allocation. This also supports Sustainable Development Goals (SDGs) by promoting sustainable aquaculture practices that balance economic growth with environmental protection, contributing to food security and economic development.

The data generated can inform policymakers and regulators, aiding in the development and enforcement of sustainable aquaculture policies. Monitoring spatial and temporal dynamics also offers insights into the impacts of climate change, helping MSPs develop adaptive strategies.

Additionally, my research enhances resource management by providing detailed information on the location and condition of aquaculture ponds, ensuring optimal and sustainable resource allocation.

Finding coordinates of Pond:

Accurate geographic coordinates are foundational to effective marine spatial planning (MSP). In the context of open pond aquaculture, knowing the precise location of aquaculture ponds is crucial for sustainable development, environmental protection, and conflict minimization. This methodology utilizes a top-left reference point of an image, which helps in the significant identification of ponds.[13]

Accurate geographic coordinates play a pivotal role in marine spatial planning for several reasons. Firstly, precise coordinates ensure that aquaculture ponds are located in optimal areas, minimizing overlap with other marine activities. This resource allocation is vital for maintaining the efficiency and sustainability of marine resources. Secondly, identifying exact locations helps in protecting sensitive habitats and biodiversity by avoiding ecologically critical zones. This is essential for environmental protection and the preservation of marine ecosystems. Thirdly, accurate mapping supports adherence to regulations and aids in monitoring and enforcement, ensuring regulatory compliance and facilitating governance. Fourthly, clear demarcation of aquaculture zones reduces conflicts between different marine stakeholders, such as fisheries, tourism, and conservation efforts. Lastly, efficient management of space leads to better resource utilization and higher productivity in aquaculture operations, enhancing both economic and operational efficiency.[14]

The method for identifying pond coordinates using a top-left reference point involves several key steps. The process begins with the acquisition of high-resolution satellite images of the target area. These images are then subjected to image processing and analysis using computer vision techniques to detect the boundaries of aquaculture ponds. Once the boundaries are identified, the centroid of each pond is selected as a reference point for coordinate extraction. The next step is georeferencing these extracted reference points using geographic or projected coordinate systems to obtain accurate latitude and longitude values.[15]

Geographic Coordinate System:

The Geographic Coordinate System (GCS) uses a three-dimensional spherical surface to define locations on the Earth. Latitude and longitude are the primary components of this system. Latitude measures the distance north or south of the equator, ranging from 0° at the equator to 90° at the poles. Longitude measures the distance east or west of the Prime Meridian, ranging from 0° at the Prime Meridian to 180° eastward and westward. These coordinates are expressed in degrees, minutes, and seconds or in decimal degrees for precision.[16][17]

Geographic coordinates are essential in mapping and spatial analysis for several reasons. They serve as a global standard, making them universally accepted and a reliable reference for mapping and navigation. The precision they offer allows for exact pinpointing of any location on Earth, which is crucial for detailed and accurate mapping. Their interoperability with various mapping tools and GIS software facilitates data sharing and integration, enhancing the efficiency of spatial data management. Furthermore, geographic coordinates are vital for conducting spatial analysis, such as distance measurements, area calculations, and pattern recognition, enabling comprehensive spatial understanding and planning.[18][19]

Universal Transverse Mercator (UTM) Coordinate System:

The UTM coordinate system is a global map projection that divides the world into a series of six-degree longitudinal zones. Each zone has its coordinate system, with a central meridian, false easting, and northing to avoid negative values. Coordinates in the UTM system are expressed in meters, providing high accuracy and ease of use in large-scale mapping.[16]

Compared to geographic coordinates, UTM coordinates offer several advantages. Unlike the GCS, which uses a spherical model, UTM is a planar projection, reducing distortions over small areas. This makes UTM coordinates more accurate for regional and local-scale mapping. Additionally, UTM coordinates **are easier to work with in calculations** and spatial analysis because they are in metric units, simplifying the process of distance and area computations. For applications requiring high precision and minimal distortion, such as regional planning and engineering projects, UTM is preferred over geographic coordinates.[20][21]

Conversion from Geographic to UTM Coordinates and vice-versa[22]:

To convert geographic coordinates to UTM coordinates, start by determining the UTM zone and band based on the given latitude and longitude. Calculate intermediate values such as the central meridian and constants for the WGS84 ellipsoid, including the radius of curvature, tangent and cosine terms, longitude difference, and the meridional arc. Then, use these values to compute the Easting and Northing coordinates. For identifying the pond's centroid, calculate the average x and y coordinates of the pond's boundary points. Adjust the UTM coordinates by adding horizontal and subtracting vertical distances from the reference point. To convert back to geographic coordinates, remove false easting and northing, compute the footprint latitude, use a series expansion for latitude, and calculate the longitude.

Given:

- Latitude (ϕ)
- Longitude (λ)

1. Determine the UTM Zone and Band

$$\text{Zone Number} = \lfloor \frac{\lambda + 180}{6} \rfloor + 1$$

Band Letter:

ϕ Range (degrees)	Band
-80 ≤ ϕ < -72	C
-72 ≤ ϕ < -64	D
-64 ≤ ϕ < -56	E
-56 ≤ ϕ < -48	F
-48 ≤ ϕ < -40	G
-40 ≤ ϕ < -32	H
-32 ≤ ϕ < -24	J

-24 ≤ ϕ < -16	K
-16 ≤ ϕ < -8	L
-8 ≤ ϕ < 0	M
0 ≤ ϕ < 8	N
8 ≤ ϕ < 16	P
16 ≤ ϕ < 24	Q
24 ≤ ϕ < 32	R
32 ≤ ϕ < 40	S
40 ≤ ϕ < 48	T
48 ≤ ϕ < 56	U
56 ≤ ϕ < 64	V
64 ≤ ϕ < 72	W
72 ≤ ϕ < 84	X

2. Calculate Intermediate Values

Central Meridian:

$$\lambda_0 = (\textit{Zone Number} - 1) \times 6 - 180 + 3$$

Constants for the WGS84 Ellipsoid:

$$a = 6378137.0 \textit{(semi-major axis)}$$

$$e^2 = 0.00669438 \textit{(square of eccentricity)}$$

Radius of Curvature in the Prime Vertical:

$$N = \frac{a}{\sqrt{1-e^2 \sin^2 \phi}}$$

Square of the Tangent of the Latitude:

$$T = \tan^2 \phi$$

Square of the Cosine of the Latitude Times the Second Eccentricity:

$$C = \frac{e^2}{1-e^2} cos^2 \phi$$

Difference in Longitude from the Central Meridian:

$$A = (\lambda - \lambda_0) cos\phi$$

Meridional Arc:

$$M = a \left[\left(1 - \frac{e^2}{4} - \frac{3e^4}{64} - \frac{5e^6}{256}\right)\phi - \left(\frac{3e^2}{8} + \frac{3e^4}{32} + \frac{45e^6}{1024}\right) sin(2\phi) + \left(\frac{15e^4}{256} + \frac{45e^6}{1024}\right) sin(4\phi) - \left(\frac{35e^6}{3072}\right) sin(6\phi)\right]$$

Scale Factor (k_0):

The standard value for k_0 in the UTM system is 0.9996. This means that the scale is slightly reduced to ensure that the distortion is minimized across the map projection. The scale factor ensures that the projection maintains accuracy across the entire zone. It adjusts for the fact that the projection surface (a cylinder) is not perfectly aligned with the Earth's surface.

3. Easting (E) and Northing (N)

$$Easting = 500000 + k_0 \cdot N(A + (1 - T + C) \cdot \frac{A^3}{6} + (5 - 18T + T^2 + 72C - 58e^2) \cdot \frac{A^5}{120})$$

$$Northing = k_0(M + N \cdot tan(\phi)(\frac{A^2}{2} + (5 - T + 9C + 4C^2) \cdot \frac{A^4}{24} + (61 - 58T + T^2 + 600C - 330e^2) \cdot \frac{A^6}{720}))$$

4. Identifying the Pond's Centroid

To find the centroid of the pond, calculate the average of the x and y coordinates of all the points defining the pond's boundary. The horizontal and vertical distances from the top-left reference point to the centroid are then measured.

5. Adjusting UTM coordinates to get pond coordinates

$$New\ Easting = Easting_{top\text{-}left} + Horizontal\ Distance$$

$$New\ Northing = Northing_{top\text{-}left} - Vertical\ Distance$$

6. Conversion from UTM to Geographic Coordinates

Remove False Easting and Northing:

E' = E - 500000

$N' = (\text{if in southern hemisphere}) N - 10000000$

Compute Footprint Latitude (μ):

$$\mu = \frac{N'}{k_0 a}$$

Series Expansion for Latitude:

$$\phi = \mu + \left(\frac{3e_1}{2} - \frac{27e_1^3}{32}\right) sin(2\mu) + \left(\frac{21e_1^2}{16} - \frac{55e_1^4}{32}\right) sin(4\mu) + \left(\frac{151e_1^3}{96}\right) sin(6\mu)$$

Where e1 is a constant:

$$e_1 = \frac{1-\sqrt{1-e^2}}{1+\sqrt{1-e^2}}$$

Calculate Longitude:

$$\lambda = \lambda_0 + \frac{E'}{Ncos\phi}\left(1 - \frac{T}{2}\frac{E'^2}{N^2} + \frac{5+3T+6C-6e^2}{24}\frac{E'^4}{N^4}\right)$$

These equations show robust methods for converting coordinates, identifying pond centroids, and applying these techniques in marine spatial planning. The process leverages mathematical transformations and spatial analysis to achieve precise and actionable geographic data.

Conclusion:

Identifying accurate pond coordinates involves satellite imagery analysis, computer vision techniques, and georeferencing using a top-left reference point. This process ensures the precision and reliability of spatial data critical for effective marine spatial planning. Innovations in geographic information systems, such as advanced satellite imagery analysis and precise coordinate extraction methods, significantly enhance the capabilities of marine spatial planning. These innovations lead to more sustainable and efficient management of marine resources, fostering balanced development and environmental stewardship.[18][23]

About Author:

Susank Chigilipalli is an undergraduate student from the Department of Civil Engineering at the Indian Institute of Technology Kharagpur. He interned at the Maritime Research Centre in Pune in the summer of 2024. Susank is skilled in Data Analytics and Computer Vision; combining his engineering knowledge with advanced computational techniques, he contributes to innovative projects to make impactful contributions to society.

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