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DYNAMIC CHANGE MONITORING OF MANGROVES IN QI'AO ISLAND AND ITS IMPACT ON CARBON SEQUESTRATION

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ABSTRACT

This study aims to realize the capacity of carbon storage and carbon sequestration by monitoring the temporal and spatial dynamics of mangrove wetlands for two decades, and discuss its impact on the ecological environment. Based on Remote Sensing (RS) images and Geographical Information System (GIS), this study used Object-Oriented Classification (OOC) to obtain the spatial distribution data of mangroves in Qi'ao Island, Zhuhai. The temporal and spatial dynamics and the correlation between mangrove area and carbon storage and sequestration capacity were analyzed by related formula. The results showed that the mangrove area increased significantly from 2000 to 2015, and gradually increased slightly from 2015 to 2020. In 2000, mangrove carbon sequestration was only 2077.928-3960.055 t and Carbon sequestration capacity was 386.705-690.195 t/a. Carbon sequestration in 2020is26446.35-50400.7t and Carbon sequestration capacity is 4921.7-8784.3t /a respectively. It is present that the carbon storage and carbon sequestration capacity of mangroves are linearly distributed with their area, and the increase of mangrove area in recent 20 years not only carbon sequestration and maintaining atmospheric carbon balance, but also bring good ecological benefits to Qi 'ao Island and even Zhuhai.

KEYWORDS: *Mangrove; Carbon Sequestration; Geographical Information System (GIS); Remote Sensing (RS); Qi'ao Island*

INTRODUCTION

Mangrove wetland is composed of mangrove plant community, bare beach outside the forest, tidal ditch and water area less than 6 m at low tide. It is a complex ecosystem with both Marine and terrestrial characteristics (Wang and Wang, 2007), and has significant ecological functions in wind-breaking, wave breaking, bank protection, offshore water purification and biodiversity protection, etc. (Li et al., 2017; Ding et al., 2016). At the same time, mangrove wetland soil has great carbon accumulation potential, known as "blue carbon", which plays an important role in maintaining the balance of global carbon cycle(Zhang et al., 2015)[15]. However, with the rapid development of coastal economy and the increasing intensity of human activities, coupled with the multiple impacts of climate change and invasive species such as Spartina Alterniflora Loisel. Mangrove wetlands have experienced ecological and environmental problems such as reduced area, biodiversity and carbon sequestration capacity (Dan et al., 2016). From the 1950s to the beginning of the 21st century, the overall area of mangrove wetlands in the world decreased by 1/3, and in some areas with poor ecological and environmental protection effects, the degradation of mangrove wetlands was more serious, even reduced to less than 10% of the original area (Alongi, 2002). In China, the area of mangrove wetland decreased from 487.50 km^2 in 1973 to 185.87 km^2 in 2000, with a decrease rate as high as 61.87%. In the 21st century, although the area of mangrove wetland has increased, it has only recovered to the level of 1980s (Jia, 2014). Therefore, effectively strengthening the protection and management of mangrove wetland resources has gradually become the focus of many governments and relevant scholars around the world.

The temporal and spatial dynamic characteristics of mangrove wetlands are the basis and prerequisite for the research, protection and management of mangrove wetlands. At the same time, mangroves are also an ecosystem with high primary productivity. On the one hand, it can store carbon dioxide through photosynthesis. On the other hand, the soil in which mangrove grows contains a large amount of organic carbon, becoming an important green belt and carbon sink in the distribution area, and playing an important role in the process of mitigating climate change. RS technology has several advantages and characteristics such as data update rapidly, wide coverage area, abundant spectral information, and flexible observation visiting time scale as well as space scope and strong comparability (Wang et al, 2021). Sentinel-2, as a high resolution multispectral image, has abundant spectral information and is one of the important data for mangrove extraction. At the same time, combined with the spatial analysis ability of Geographical Information System (GIS) technology, the two technologies have been widely used in the study of spatio-temporal dynamic monitoring and driving force analysis of mangrove wetland. This study aims to survey this region by means of Support Vector Machine (SVM), Artificial Neural Network (ANN) and Object-Oriented Classification (OOC). Therefore, this study is of great significance to the implementation of China's "dual carbon" strategy and the construction of land-sea integrated carbon sink pattern by monitoring the long-term temporal and spatial changes of mangrove wetland in Qi 'ao Island and analyzing the carbon sequestration capacity of mangroves.

STUDY AREAS AND DATA SOURCES

The Study Site

Qi’ao Island is a small little island with a total area of 1865hm^2 which is located 2 km northeast of Tangjia Town, Zhuhai city, Guangdong Province, China, with a permanent population of about 2000 people. Where locating in the Hengmen estuary of the pearl river system (113°36'40 "-113°39'15" E, 22°23'40 "-22°27'38" N) is the center of the "golden triangle" of Guangzhou, Hong Kong and Macao, the mid-north of the eight major outlets of the pearl river, and the throat of the four outlets of the west bank of the pearl river (shown as Figure 1). The coastline long is about 23.2km, including 4.9km reclaimed seawall, and the island area is about 23.8km^2, which is the largest island in Lingding yang Island group. Irregular semi-diurnal tides with an average high tide of 0.17 m. The average annual salinity of sea water is 1.82%, and the total salinity of topsoil (0-13 cm) is 2.08%8. It belongs to the south subtropical maritime climate, with an average annual temperature of 22.4 ℃, minimum monthly average temperature of 15.3 ℃ and annual precipitation of 1,964 mm (Qiu et al., 2019).

The study area is located in the northwest of Qi 'ao Island with a half-moon shape. The mangrove wetland covers an area of 394.6 hm^2 which is one of the few mangroves close to the urban center in China. In the Mangrove Nature Reserve of Qi 'ao Island, woodland and water were the main ecosystems, accounting for 62.1% and 30.2% of the area, respectively. In addition, irrigated land has only a few patches accounting for 0.85%. The remaining grassland, roads, docks, villages, scenic spots and special lands cover less than 6.8% of the total area. Meanwhile, there are more than 20 species of water birds in the mangrove wetland and its surrounding wetlands, and the main birds living there are 46 species of 20 families, including 38 species of resident birds and 8 species of migratory birds. The main families are Podicipedidae, Ardeidae, Hirundinidae, Parus major, Apodidae. There are 2 orders, 7 families, and 23 species of amphibians. Reptiles, 1 order, 3 families, 23 species; Mammals, 2 orders, 3 families, 8 species. In the mangrove wetland system of Qi 'ao Island, there are abundant marine resources such as fish, shrimp, crab and shellfish adapted to the brackish water environment in the region under and around the forest (Wang et al., 2005; Jiang et al., 2021).

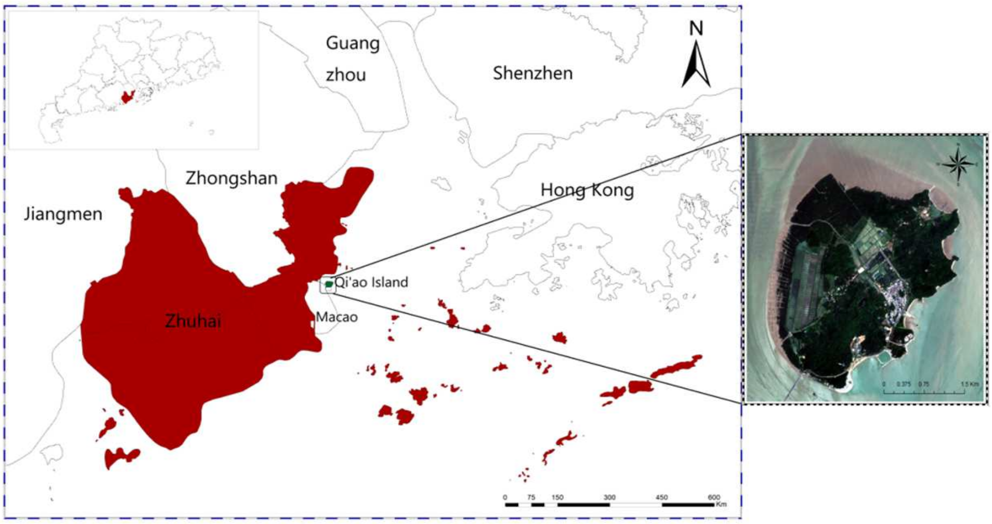

Figure 1: The Study Area of Qi 'ao Island.

The Data Source

Sentinel-2 RS Data

Sentinel-2 RS images are a product of the European Space Agency's (ESA) Copernican Earth Observation Mission, which provides RS services by observing the earth's surface. It has two matching satellites that provide high-resolution optical images, namely as Sentinel-2A and Sentinel-2B which carry multispectral instruments (MSI). They were successfully launched in June 2015 and March 2017 respectively, providing an important means to enhance earth observation capabilities. The satellites revisit the same site every two to five days. The MSI sensor has 13 spectral bands, 4 bands at 10 meters, 6 bands at 20 meters, and 3 bands at 60 meters spatial resolution (shown as Table 1), which has a wide range of earth observation applications.

Table 1: The Bands and Resolutions Parameters of Sentinel-2

Name	Description	Resolution(m)	Wavelength(nm)
B1	Coastal aerosol	60	443
B2	Blue	10	490
B3	Green	10	560
B4	Red	10	665
B5	Red Edge 1	20	705
B6	Red Edge 2	20	740
B7	Red Edge 3	20	783
B8	NIR	10	842
B8A	Red Edge 4	20	865
B9	Water vapor	60	945
B10	Cirrus	60	1380
B11	SWIR 1	20	1610
B12	SWIR 2	20	2190

Landsat-7 ETM +RS Data

Landsat-7 ETM+ RS imagery is the seventh satellite in the U.S. Landsat program. The satellite carries Enhanced Thematic Mapper (ETM+) sensors which have collected and transmitted data gaps resulting from scanline corrector (SLC) failures. Landsat-7 scans the same area every 16 days, and covers the world once every 16 days. Landsat ETM+ image data includes 8 bands. The spatial resolution of Band1-Band5 and Band7 is 30 meters, that of Band6 is 60 meters, and that of Band8 is 15 meters (show as Table 2). The north-south sweep is about 170km, and the east-west sweep is about 183km. The data used in this experiment (L7 SLC-ON) refers to the data products before the Landsat 7 SLC failure on May 31, 2003.

Table 2: The Bands and Resolutions Parameters of Landsat-7 (ETM+)

Name	Description	Resolution(m)	Wavelength(nm)
B1	Blue	30	450-520
B2	Green	30	520-600
B3	Red	30	630-690
B4	NIR	30	770-900
B5	SWIR1	30	1550-1750
B6	Thermal	60 *(30)	10400-12500
B7	SWIR2	30	2090-2350
B8	Panchromatic	15	520-900

METHODS

RS Data Processing

In this study, landsat-7 ETM+ RS images in 2000, L1 Sentinel-2 RS images in 2015 and 2020 were downloaded from USGS (shown as Table 3). The sentinel-2 images downloaded are pre-processed to achieve sub-pixel accuracy for geometric and radiometric correction. Atmospheric correction (converting atmospheric top reflectivity to canopy top reflectivity) was then performed using the Sen2Cor (version 02.10.01) tool, available in the Sentry Application Platform (SNA) toolbox. Open CMD, input simple code, and then generate the image of L2B after accurate atmospheric correction.

SNAP is a software tool which is used to select bands (B2, B3, B4, B8) and resample them to 10m*10m pixels. The Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI) were calculated by ENVI5.3 software, and the instantaneous water boundary line was extracted by Decision Tree Classification (DTC) method. Secondly, the 20-level Google image with a resolution of 0.5m was downloaded by SAS Planet software, and the Google image and RS image were superimposed, and the training samples were selected in ArcGis10.1 software. Finally, the training samples were imported into ENVI5.3 for classification by SVM, ANN and OOC methods. The sentinel-2 RS image has a high resolution, so it is preferentially processed. The spatial resolution of Landsat-7 ETM+ satellite images was 30m*30m. Radiometric calibration and atmospheric correction were carried out through ENVI5.3, and the specific operation was the same as above (shown as Figure 2).

Table 3: The Basic Information of RS Satellites

Serial Number	Satellite	Data Format	Number	Date
1	Landsat-7ETM+	ETM	122-45	2000-11-01
2	Sentinel-2	MSI	T49QGE	2015-10-23
3	Sentinel-2	MSI	T49QGE	2020-10-26

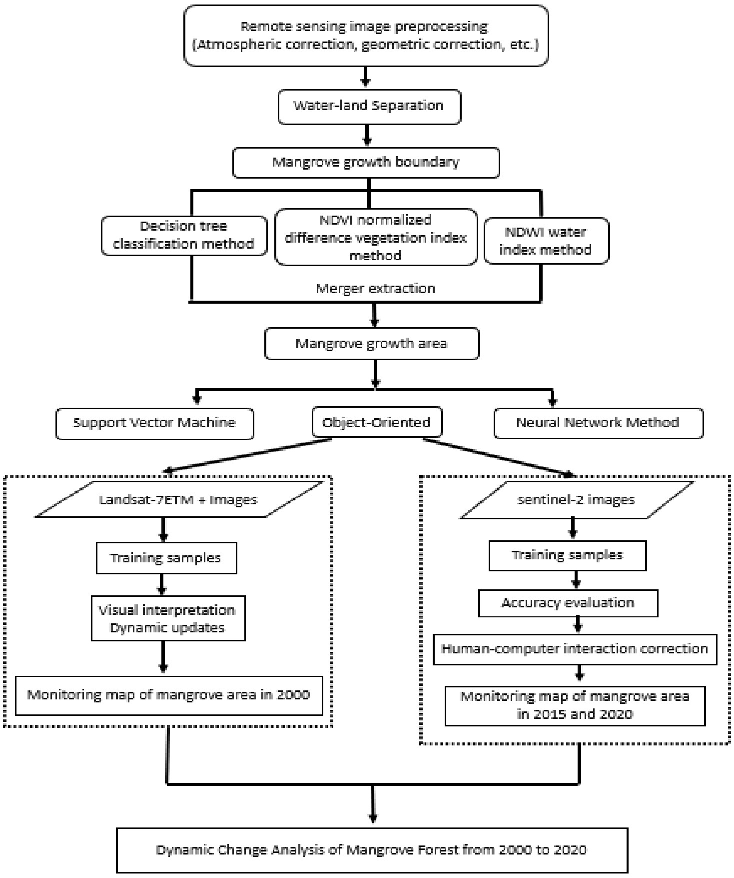

Figure 2: The Framework of the Study.

Estimation of Exponential Bands

NDVI and NDWI were calculated based on Sentinel-2 images. NDVI is a key variable to determine the classification threshold of mangrove greenness, canopy coverage and tidal inundation. NDWI has certain advantages in distinguishing mangroves from water bodies (Cárdenas et al., 2017; Chen et al., 2017), and the formula is as follows:

NDVI = (NIR-RED)/(NIR + RED) ……………. (1)

NDWI = (Green- NIR)/(Green + NIR) ………… (2)

Where NIR, Red and Green are the Near-Infrared band8, Red band4 and Green band3 of Sentinel-2 image respectively. NIR band 4, Red band 3 and Green band 2 of Landsat-7 image.

Calculation of Carbon Sequestration

This study is not only for the dynamic change monitoring of mangroves, but also for realize the situation of mangrove biomass, Net Primary Production(Poungparne et al.,2020), in order to calculate the carbon storage and carbon sequestration capacity. Thus, there are a few formulas induction as follows, and proposed a processing procedure such as Figure 3.

Calculation method of mangrove biomass: $P = Pi \times A$.. (3)

Where P is mangrove biomass (t), Pi is mangrove biomass per unit area (t / hm^2), A is mangrove area (hm^2).

Calculation method of mangrove carbon storage: $W = P \times \alpha$.. (4)

Where W is mangrove carbon storage (t), α is the coefficient of biomass conversion to carbon storage.

Calculation method of Net Primary Production of mangrove: $M = Q \times A$...................... (5)

Where M is the Net Primary Production f mangrove (t / a), Q is the Net Primary Productivity (NPP) of mangrove (t / hm2 a)

Calculation method of mangrove carbon sequestration capacity: $C = M \times \alpha$.................….(6)

Where C is the mangrove carbon sequestration capacity (t / a).

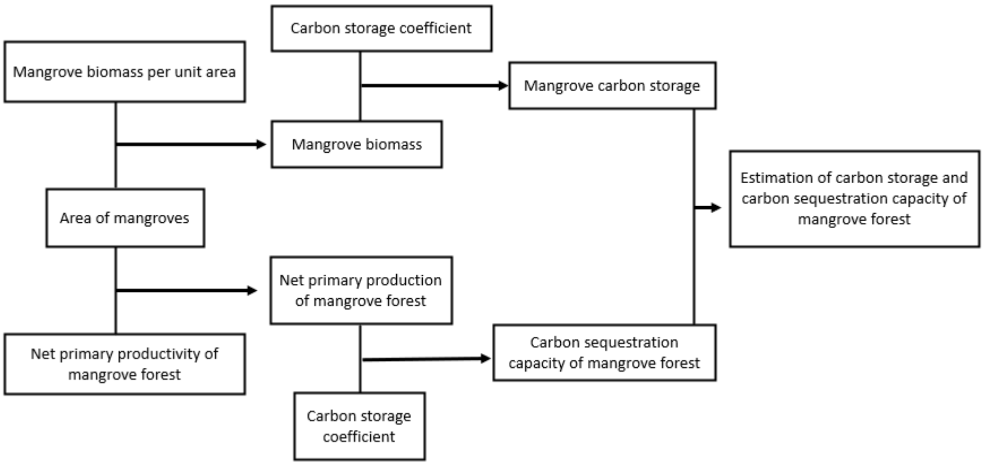

Figure 3: The Processing Procedure of Calculation of Carbon Storage and Carbon Sequestration Capacity.

According to Zhang et al. (1992) the biomass of mangrove communities ranged from 84.9 to 161.8 t / hm^2, with an average of 126.7 t / hm^2. For every 264 g CO_2 or (72 gC) and 108 gH_2O absorbed by photosynthesis, 180 g glucose (or 162 g dry matter) and 193 gO_2 can be produced, that is, 1.63 g CO_2 (or 0.445 gC) is needed for every 1 g dry matter produced by plants. Therefore, the coefficient a of mangrove biomass conversion to carbon storage can be calculated to be about 0.445. Similarly, according to the study of Zhang et al. (1992) the average NPP of mangrove plants was about 15.8 - 28.2 t / hm^2·a, with an average of 21.2 t / hm^2·a. Based on this, the mean and range values of carbon storage and carbon sequestration capacity of mangroves in Qi 'ao Island, Zhuhai City were obtained

STATISTICAL RESULTS

Classification Results and Precision

In this study, landsat-7 ETM+ images from November 1, 2000 and Sentinel-2 images from October 26, 2020 were taken as materials to carry out s SVM, ANN and OOC methods. The overall accuracy and Kappa coefficient were calculated based on the confusion matrix (error matrix) to measure the consistency between the land cover classification results and the real situation of the land surface in the mangrove distribution area. The confusion matrix is calculated by comparing the position of each real pixel on the surface with the corresponding position in the classified image. Total classification accuracy is equal to the total number of correctly classified pixels/total pixels. The Kappa coefficients use a multivariate technique to measure the degree of coincidence or accuracy by considering all factors of the error matrix. Generally, Kappa coefficient values between 0.61 and 0.80 indicate high consistency, while 0.81 and 1.00 indicate almost complete consistency.

The results shown as Table 4,the overall accuracy and Kappa coefficient of the OOC of Landsat-7 ETM+ images (as Figure. 4, Figure. 5, Figure. 6) and Sentinel-2 images (as Figure. 7, Figure. 8, Figure. 9) are higher than those of SVM and ANN classification. In summary, the OOC has a high degree of coincidence and good classification effect, which can meet the study needs. Compared to OOC method, the traditional classification method is a kind of pixels based of basic classification and processing unit, the process of OOC classification is based on multiple object for processing unit, composed of adjacent pixels, to segmentation of the image, and then calculate the object's spectrum, arithmetic, texture, geometry and other parameters, through the contrast analysis of each parameter selection for a proper threshold, and then complete classification. The classification results can avoid the phenomenon of "salt and pepper" and improve integrity. Thus, after this study’s experiment, all images adopted the OOC method to extract the mangrove area in this region. However, in statistical estimation of mangrove area, a pixel-based method is adopted. The product of forest pixels and image resolution squares are the area of mangrove.

Table 4: Classification Accuracy of Different Methods

Image	Classification Methods		Overall Accuracy	Kappa Coefficient
Landsat-7	Supervised Classification	SVM	82.1203%	0.8043
		ANN	80.1873%	0.7958
	OOC	SVM	84.1023%	0.8212
Sentinel-2	Supervised Classification	SVM	89.1304%	0.8546
		ANN	89.1892%	0.8558
	OOC	SVM	92.6522%	0.9110

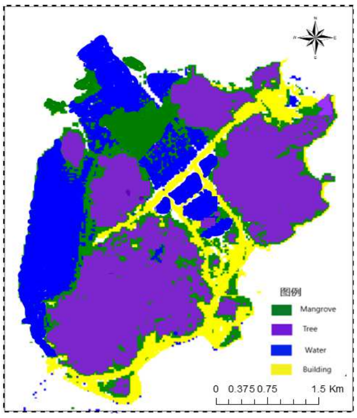

Figure 4: Landsat-7 (SVM).

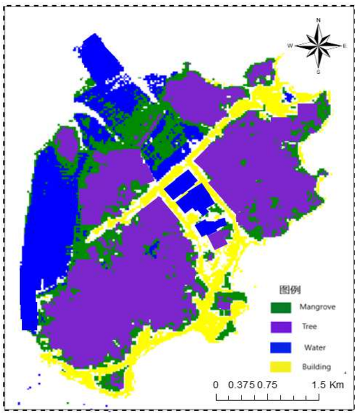

Figure 5: Landsat-7 (ANN).

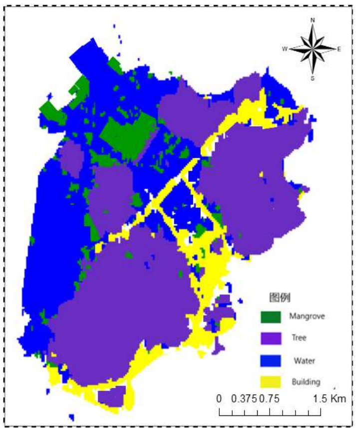

Figure 6: Landsat-7 (OOC).

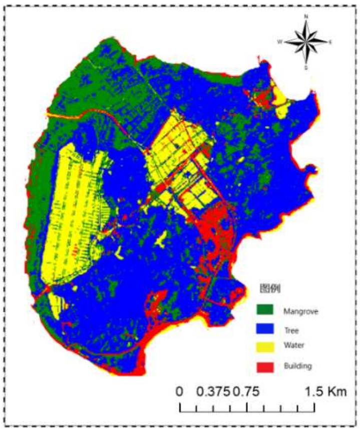

Figure 7: Sentinel-2 (SVM).

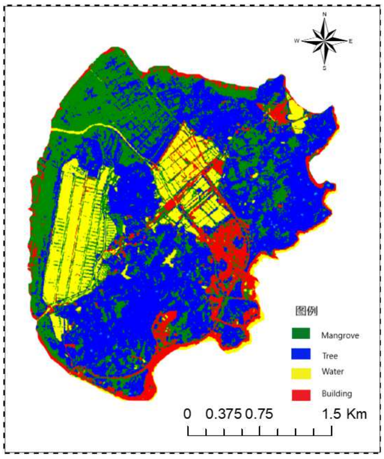

Figure 8: Sentinel-2 (ANN).

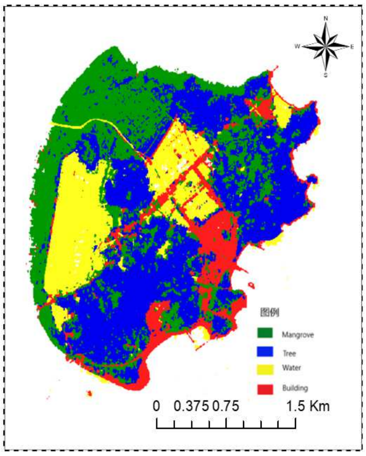

Figure 9: Sentinel-2 (OOC).

Comprehensive Analysis

In terms of time, in the early 1980s, Spartina alterniflora, originating from the Atlantic coast of North America, was introduced into China in order to protect beaches, improving soil, green beaches as well as the ecological environment of beaches. However, Spartina alterniflora rapidly flooded the coastal beaches in China, causing serious threats to the ecological environment and biodiversity of shallow sea transportation, aquaculture and beach coasts, and the vast beaches of Qi'ao Island were not spared. Biological invasion and occupation of mangrove living space directly led to only 32 hectares of primary mangrove in Qi'ao Island in 1998, which attracted the attention of relevant government departments and began to control in 1999. In 2000, the area of mangroves recovered to about 55 hectares. Subsequently, the area of Spartina alterniflora and mangrove protection and cultivation increased rapidly from 32 hectares to 600 hectares in 2015, followed by a slow and steady increase of about 700 hectares in 2020.

In terms of spatially, before 2000, the mangrove forest in Qi'ao Island was patchy and scattered in the north-central part of the island, with a large concentration area near the river. Through the management and protection, mangroves grow rapidly and the area expands unceasingly. In 2015, the mangrove area as a whole was crescent-shaped and concentrated in the western and northwestern regions. Combined with data and RS images, it was found that the overall mangrove area increased slowly in 2020, and continued to show indigenous growth along the western coast and sporadic increase in the northeast coast (shown as Figure 10).

Mangrove ecosystems are an important component of blue carbon in the oceans. Although mangroves cover only 0.1 percent of the earth's surface, they lock up 5 percent of the carbon in the atmosphere. Its carbon sequestration capacity is mainly affected by both natural and man-made factors. In nature, it is mainly affected by mangrove area and dense planting state, photo synthetically active radiation, biological invasion and mangrove species. The artificial aspect is mainly affected by industrial pollution, economic development, policy protection, public awareness and other factors. This paper mainly analyzes the correlation between the mangrove area and its carbon storage and carbon sequestration capacity. Formula 3-6 was used to calculate the mean value and range value of carbon storage and carbon sequestration capacity of mangrove on Qi'ao Island (as Table 5).

On the whole, with the increase of mangrove area from 2000 to 2020, its carbon storage and carbon sequestration capacity also increased accordingly (shown as Figure 11). And with the increasing area, the difference between carbon storage and carbon sequestration capacity becomes larger. Locally, the area of mangrove forest increased rapidly from 2000 to 2015, and its carbon storage and carbon sequestration capacity also increased significantly, and the increase of carbon sequestration capacity was greater than that of carbon storage. From 2015 to 2020, the area of mangrove increased slowly, so did its carbon storage and carbon sequestration capacity, and the carbon sequestration capacity was roughly parallel to the carbon storage. In conclusion, the mangrove area and carbon storage and carbon sequestration capacity conform to the characteristics of linear distribution, and the increase of mangrove area has different degrees of impact on carbon storage and carbon sequestration capacity.

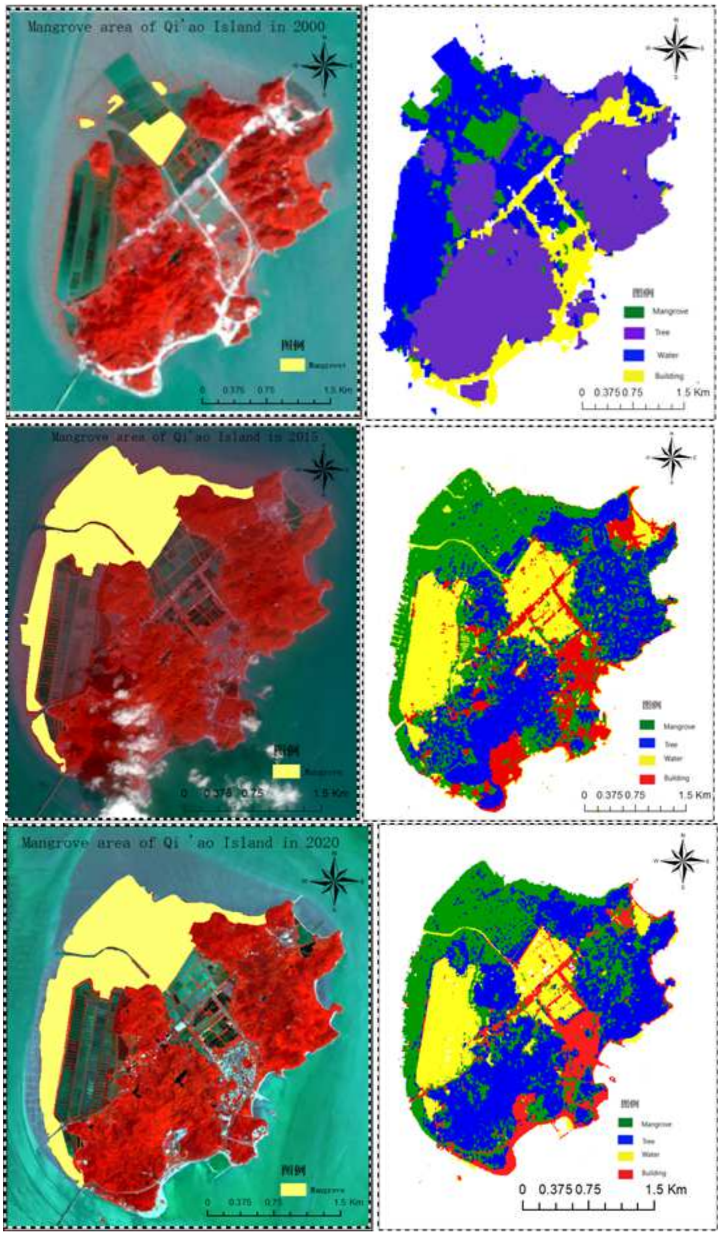

Figure 10: The Dynamic Changes of Mangrove Area from 2000, 2015 to 2020.

Table 5: Carbon Storage and Sequestration Capacity of Mangroves

Years	Area (hm^2)	Carbon Storage W(t)	Carbon Sequestration Capacity (t/a)
2000	55	2077.928~3960.055	386.705~690.195
2015	600	22668.3~43200.6	4218.6~7529.4
2020	700	26446.35~50400.7	4921.7~8784.3

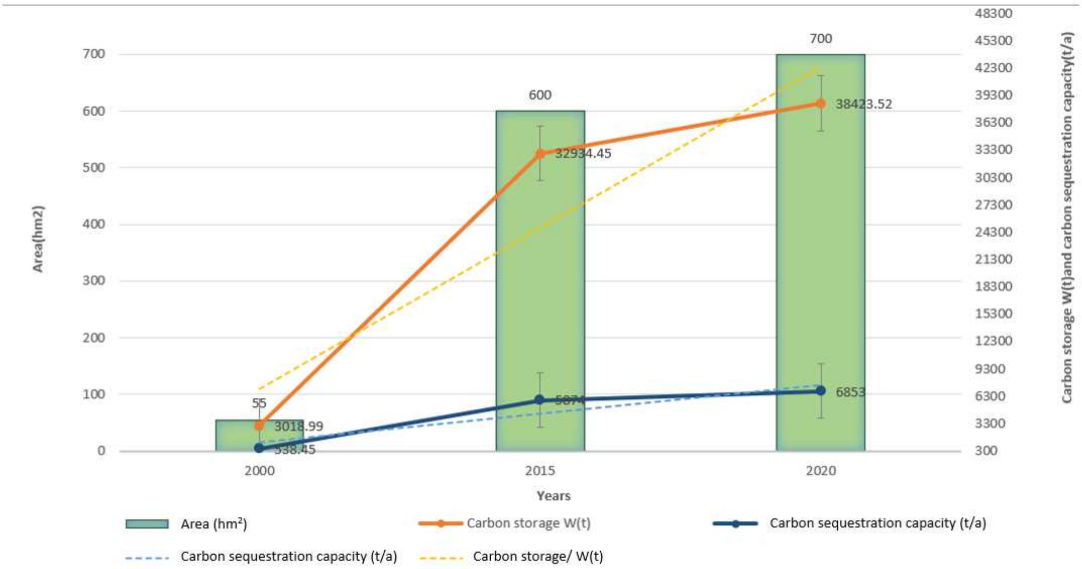

Figure 11: Correlation of Mangrove Area with Carbon Storage and Carbon Sequestration Capacity.

(Note: The solid line is the average value of carbon storage and carbon sequestration capacity range, and the dotted line is the corresponding linear forecast trend)

CONCLUSION

Through RS and GIS technology, this study conducted a comparative analysis of the changes of mangroves in Qi'ao Island in the past two decades, and calculated the carbon storage/ sequestration capacity through relevant formulas. The main analysis results are as follows: The growth area of mangrove in Qi'ao Island from 2000 to 2020 was about 645 hm^2, the total biomass increased 54760.5 ~ 104361t, the carbon storage increased 24368.4225 ~ 46440.645 t, the net primary production increased 10191 ~ 18189 t / a, and the total carbon sequestration capacity increased 4534.995 ~ 8094.105 t / a. It can be seen that in the past 20 years, the mangrove area in Qi'ao Island has continued to increase, the overall protection of mangrove ecosystems has improved, and the potential space for carbon sequestration has been significantly improved.

Obvious, it plays an important role in achieving carbon absorption, carbon sequestration and maintaining atmospheric carbon balance, and also plays an important role in maintaining biodiversity and wind and wave protection. The coastal mangrove wetland in Qi'ao Island not only enhanced the carbon sink of the blue carbon ecosystem, but also optimized the ecological environment around Qi'ao Island and even the whole of Zhuhai City. Therefore, the protection and management of existing mangroves and the restoration of damaged mangroves are essential to enhance the carbon sink capacity of mangrove ecosystems. Meanwhile, there are of great significance for the implementation of China's “dual carbon” strategy and the construction of an integrated land-sea carbon sink pattern.

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