

Article

Sea Reclamation Status of Countries around the South China Sea from 1975 to 2010

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Abstract: As a way of turning sea into land for living space for humans, the actions of sea reclamation bring about significant benefits. Nevertheless, it is also an under-recognized threat to the environment and the marine ecosystem. Based on images in two periods, sea reclamation information of countries around the South China Sea was extracted from 1975 to 2010. The spatial state and driven forces of sea reclamation are then discussed. Results show that the overall strength of sea reclamation in the South China Sea was great. New reclaimed land added up to 3264 km². Sea reclamation for fish farming was the main reclamation type and widely distributed in the whole area, especially on the coast from the Pearl River Delta to the Red River Delta, and the coast of Ca Mau Peninsula. Sea reclamation in China and Vietnam was rather significant, which occupies 80.6% of the total reclamation area. Singapore had the highest level of sea reclamation. New reclaimed land for fish farming holds a key role in China, Vietnam, and Indonesia, while new reclaimed land for construction and docks dominated in Malaysia, Singapore, and Brunei. Areas and use-type compositions of new reclaimed land in countries varied greatly due to the differences of economic factors, policy inclination, and landscapes in the respective countries.

Keywords: sea reclamation; South China Sea; land use; landscape

1. Introduction

Coastal zones are the most densely populated and economically developed areas. Almost one-third of the global human population currently lives along the seaboard of East and Southeast Asia [1]. Accompanied by migration to the coastal zone, the population and economics are consistently growing. It has greatly impacted land use patterns [2–5]. Nowadays, coastal zones are facing serious problems of land shortage. With the advantages of a low cost and ease of use, sea reclamation occurs more and more frequently. To a certain extent, it meets the needs of expanding living space for humans and economic development.

As the main method of utilizing the ocean, sea reclamation is prevailing in many countries, such as Holland, Japan, and Korea [6–8]. Countries around the South China Sea also have a long history of sea reclamation. Early land reclamations in Singapore date back to the 19th century and large scale land reclamation projects have taken place since its independence in the 1960s. Land reclamation works occur in most coasts of Singapore Island and the adjacent islands, including Ubin Island, Jurong Island, and Sentosa Island [9–11]. China has continuously reclaimed coastal sea areas from the 1950s and sea reclamation has tended to be more extensive, faster, and more large-scaled, especially in the last

two decades of 20th century. The land-use types of coastal reclaimed lands vary from agricultural land through to beach aquaculture land to construction and dock land [12–16]. Coastal reclamation works have been carried out in Malaysia since the 1950s and large-scale reclamation projects are concentrated along the coast of the Malacca Strait [17,18]. In Vietnam, Thailand, and Indonesia, large areas of mangrove forest have been filled into land for aquaculture [19–21].

Meanwhile, sea reclamation also causes severe environmental problems, such as a decline in fishery resources, sediment deposition, and wetland degradation [22]. The South China Sea is one of the primary mangrove distribution centers in the world and the mangrove area accounts for about 28% of the world's total mangrove area [23]. Additionally, the South China Sea has a favorable fishery environment and rich fishery resources. In 1998, the Asian region produced the largest amount (72%) of whole shrimp [24]. Large-scale disordered sea reclamation works may damage the abundant resources in the region. This study obtained new reclaimed land information in the coastal zone around the South China Sea from 1975 to 2010 and analyzed the total distribution, differences, and driven forces between countries. This research is of great significance to the works of land resource planning, development and protection of coastal zones, and global environment change research.

2. Materials and Methods

2.1. Study Area

The South China Sea is located in a tropical and semi-tropical region, between the latitudes of 4° S and 24° N and between longitudes 102° E and 123° E. In terms of geographical location, it is the crossroads between Asia and Oceania, connecting the Pacific and the Indian Oceans (Figure 1). As the world's third largest continental margin sea, the area of the South China Sea exceeds 3 million square kilometers. The South China mainland, Indochina, Malay peninsulas, and the Malay Archipelago surround the sea. There are nine countries around the South China Sea, including China, Vietnam, Cambodia, Thailand, Malaysia, Singapore, Indonesia, Brunei, and the Philippines.

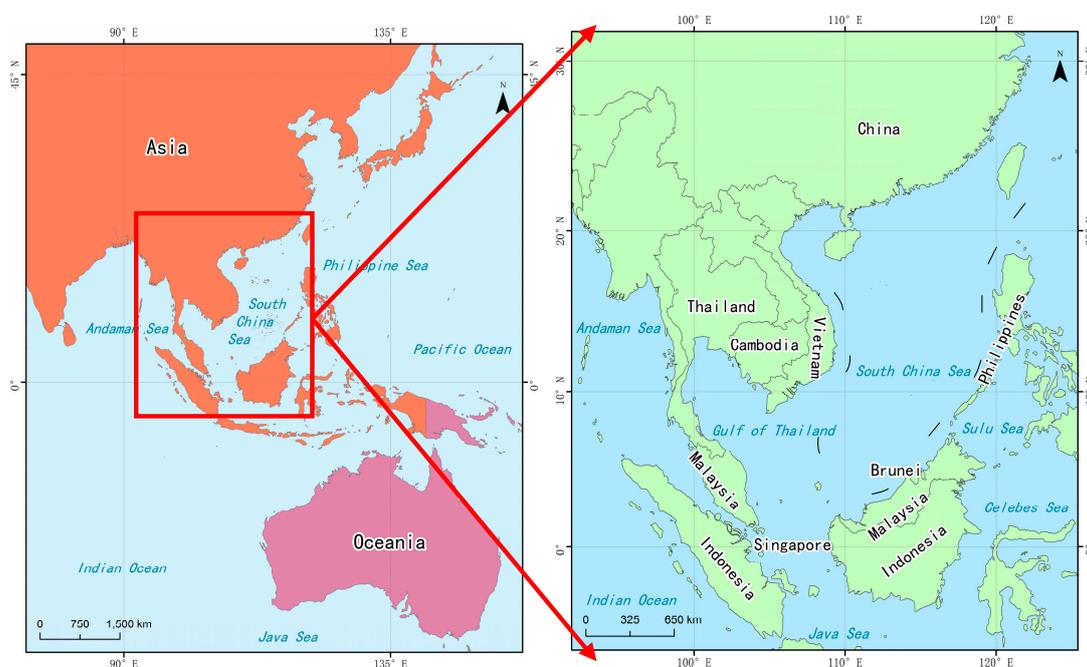


Figure 1. Cont.

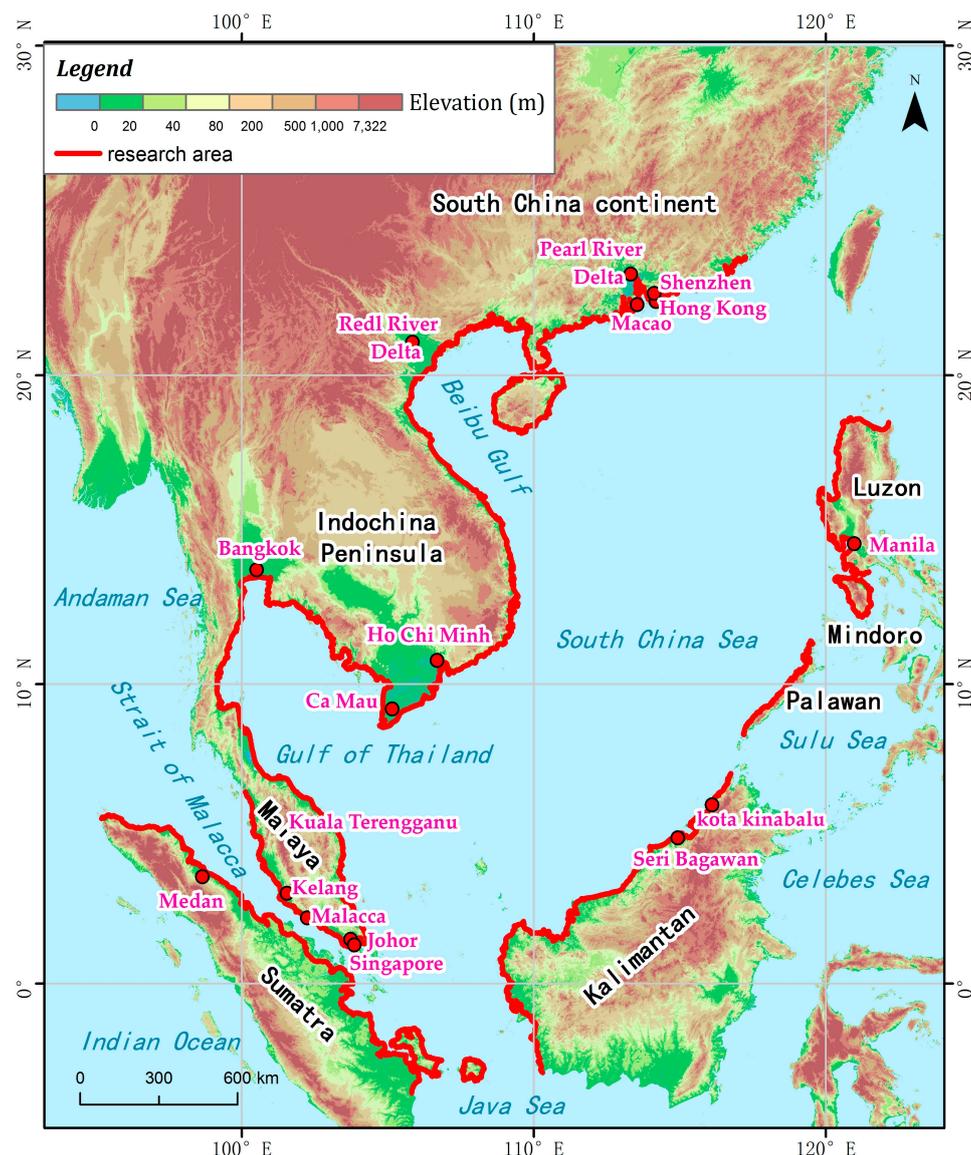


Figure 1. Location of the South China Sea.

Regarding the topography, the alternate distribution of vast plains and hills is the notable feature in the coastal zone of the South China Sea. Four important great rivers (the Pearl River, the Red River, the Mekong River, and the Chao Phraya River) cross over the region. There are two large bays (Beibu Gulf and the Gulf of Thailand) in the north. The Strait of Malacca, Sunda Strait, and Bashi Channel are famous channels, bringing flourishing trade to the ports. The South China Sea has abundant rainfall, perennially high temperatures, good hydrological conditions, plentiful marine fishery resources, and rich oil and gas resources. An abundant natural environment forged the densely-populated and rapidly-developed area.

The research area focused on the coasts of the South China Sea, Gulf of Thailand, and the Strait of Malacca. The total length of the coast is 29,022 km. In addition to continental coastline, only land-tied islands and very large islands (area > 3000 km²) were taken into consideration in this thesis. The lengths of the coastline in countries are shown in Table 1. In China, Guangdong Province, Guangxi Province, and Hainan Province were included in the statistics. In Thailand, the coast on the Gulf of Thailand was considered. For Indonesia, it included some coasts of Sumatra and Kalimantan. For the Philippines, it included the west coasts of Luzon, Mindoro, and Palawan.

Table 1. Length of coastline in research area.

Country	Coast Length in the Research Area	Total Coast Length	Proportion
China	6857	24,329	28%
Vietnam	4569	6761	68%
Cambodia	721	1008	72%
Thailand	2517	6077	41%
Malaysia	4326	7211	60%
Singapore	261	347	75%
Indonesia	5785	80,041	7%
Brunei	217	217	100%
Philippines	3769	26,560	14%
Total	29,022	152,550	19%

2.2. Data Sources

The data used in this study include Landsat Multi-Spectral Scanner (MSS) images taken around 1975, and Landsat 5 Thematic Mapper (TM) images and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images taken in 2010. Data preprocessing included geometric correction, radiometric calibration, gap filling, and image enhancement. The administrative map and DEM map were collected.

2.3. Sea Reclamation Extraction

There are three steps to extract sea reclamation information. Firstly, the coastlines of the two periods were extracted; secondly, sea reclamation information was extracted; and, finally, the attributes of the sea reclamation information were assigned.

2.3.1. Coastline Extraction

The extraction of the coastline is based on the manual interpretation method according to the features of different types of coastline shown in the images. Coastline can be divided into artificial coast and natural coast, and natural coastline can be subdivided into bedrock coast, sandy coast, silt coast, mangrove coast, and estuary coast. For artificial coast and bedrock coast, coastline is the boundary between water and land; for sandy coast, coastline is the upper limit of the beach ridge trace; for silt coast, coastline lies at the seaward vegetation line, while coastline lies to the landward vegetation line for mangrove coast. Estuary coast is located at the sudden narrowing of the river. When the coastlines of two periods were extracted, topological correction of the coastlines was performed.

2.3.2. Sea Reclamation Extraction

Sea reclamation extraction was achieved by the cut of two-phase coastlines. Firstly, the ends of the coastline were connected and the coastline data was used to generate the polygon shapefiles in ArcGIS (developed by ESRI Company in America). Secondly, the two polygon shapefiles were clipped and the new polygon shapefile was obtained, indicating the sea reclamation information. Finally, reclamation correction was conducted. According to the area of the polygon, small polygons which were less than 900 km² (3 × 3 pixels) were removed. The aspect ratio of the minimum bounding rectangle of the polygon was used to eliminate the long and narrow polygons caused by the error of the coastline extraction. After two rounds of screening, the remaining polygons were checked and corrected manually on the remote sensing images.

2.3.3. Attribute Assignment

Sea reclamation polygons were assigned from the TM/ETM+ images in 2010. Attributes were divided into five classes: fish farming, farmland, construction, docks, and airports. For the unused land (sea area which has been embanked but not yet used), a simple treatment was applied, as they

were few. The unused land was assigned on the basis of the recent images. The specific introduction is shown in the Table 2.

Table 2. Classification of sea reclamation and their meanings.

Type	Description
Fish farming	Construct embankments on coastal mudflat for fish farming
Farmland	Enclose the sea for agriculture land
Docks	Use earthworks etc. to fill the sea into land for docks
Airports	Fill the sea into land for airports
Construction	Fill the sea into land for residences, traffic, and industry, except docks and airports

3. Results

3.1. General Overview of Sea Reclamation

Statistics on the reclamation information of the South China Sea from 1975 to 2010 were calculated. The result showed that the total new area of sea reclamation reached 3264 km² in 35 years, almost four times the area of Singapore Island. The average annual growth rate was nearly 93 km². Among them, the area of sea reclamation in Vietnam reached 1586 km², almost half of the total area (Figure 2). Sea reclamation in China was also significant, at about 1044 km², which occupies one third of the total reclamation area. This indicated that the demand and size for sea use in Vietnam and China was great, largely outweighing the overall level. Newly-reclaimed land in Indonesia added up to 306 km², which was also notable. The results of sea reclamation area in Malaysia and Singapore were similar, about 120 km² or so. A noteworthy phenomenon was that although the area of sea reclamation in Singapore was not too large in all of the surrounding countries, it accounted for 15% of Singapore Island. This was a rather high proportion, even at a global level. The proportion of sea reclamation in the remaining countries (Cambodia, Thailand, and Brunei) was low, accounting for less than 2%.

From the land-use types, the size of sea reclamation structure was not balanced (Figure 3). Sea reclamation for fish farming was the major type in the whole sea from 1975 to 2010, and the area of which was 2493 km², taking up 76.4% of the total new area. Secondly, the amount of sea reclamation for construction and docks were also large. The proportion accounted for 11.6% and 7.8%, respectively, and the area were 380 and 253 km². By comparison, sea reclamation for farmland and airports occupied a low proportion, both less than 3%.

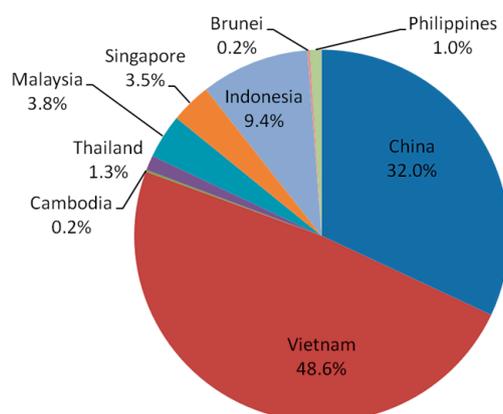


Figure 2. Sea reclamation in countries.

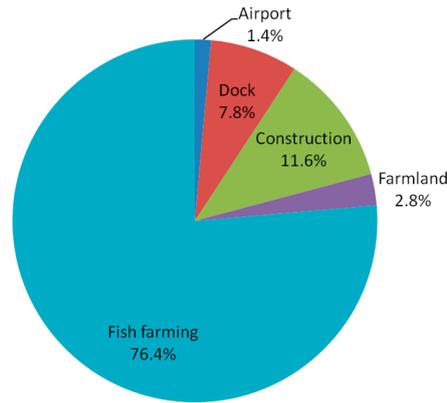


Figure 3. Sea reclamation of different land-use types.

Statistics on the reclamation information in each administrative area were calculated. From the spatial distribution, sea reclamation was quite different on the east and west sides of the South China Sea. Area in the west was notably higher than the east. New areas of sea reclamation were centered in the South China mainland, North Beibu Gulf, Ca Mau Peninsula, and the Strait of Malacca (Figure 4). From the administrative district, sea reclamation in different provinces (states) varied remarkably. Among them, sea reclamation area in Ca Mau, Vietnam was the largest, at about 1062 km², accounting for one third of the total area. Guangdong Province in China followed, with an area of 866.7 km². Sea reclamation in Aceh, Indonesia; Quang Ninh, Vietnam; Guangxi, China; and Singapore was relatively high, the areas of which were 145.6, 140.6, 114.3, and 112.8 km². In most provinces, sea reclamation area was very low.

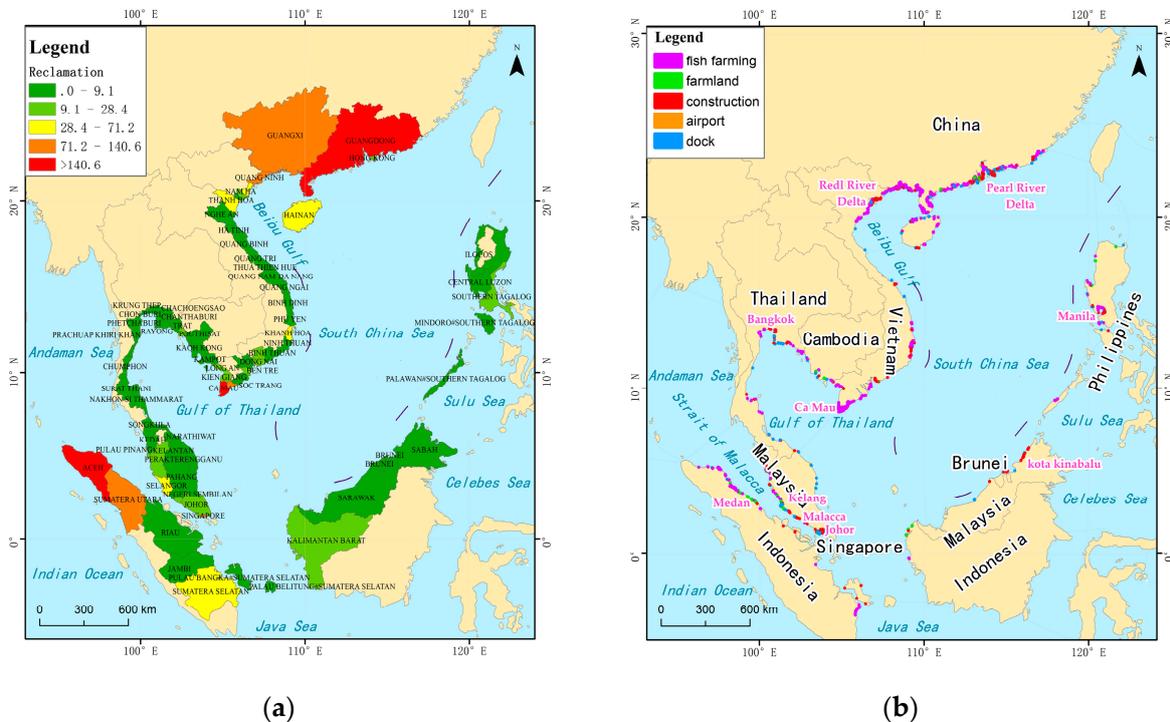


Figure 4. Distribution of sea reclamation in the South China Sea from 1975 to 2010. (a) Distribution by administrative district. (b) Distribution by reclamation types (Sea reclamation represents location, not area).

From the distribution of sea reclamation of different land-use types, sea reclamation for fish farming was widely distributed in the whole area. The most concentrated areas were located on two coasts. One stretched from the eastern boundary of Guangdong Province, China to the Red River Delta, Vietnam. The other one was in the Ca Mau Peninsula. The distributions of sea reclamation for construction and docks were similar, mainly in the Pearl River Delta, Beibu Gulf, and Singapore Island. Sea reclamation area for farmland was lower, centered in West Pearl River Delta and Sumatera Utara, Indonesia. Finally, there were five places of sea reclamation for airports, located in Shenzhen, Zhuhai, Macau, China; Kuala Terengganu, Malaysia; and Singapore. Among them, Macau Airport was almost entirely constructed by sea reclamation. Half of the area of Shenzhen Airport and Singapore Changi Airport were constructed through sea reclamation.

3.2. Sea Reclamation between Countries

From the land-use types, area, and type composition of sea reclamation in different countries varied greatly (Figure 5). According to the area of sea reclamation, areas for fish farming were located mostly in China, Vietnam, and Indonesia. Especially in China and Vietnam, sea reclamation for fish farming covered an area of 673 and 1511 km², respectively. Similarly, sea reclamation areas for construction were mainly distributed between China and Vietnam. The areas were 202 and 68 km², respectively. For sea reclamation for docks, China, Malaysia, and Singapore held a dominant role, and the areas were 128, 61 and 56 km². In Indonesia and China, sea reclamation areas for farmland were mainly distributed. According to the proportion of sea reclamation, sea reclamation for fish farming was the main type in China, Vietnam, and Indonesia. With respect to sea reclamation for construction, it prevailed in Brunei and the Philippines. In Malaysia and Singapore, the proportion of sea reclamation for docks was the largest. For farmland, it belonged to Cambodia.

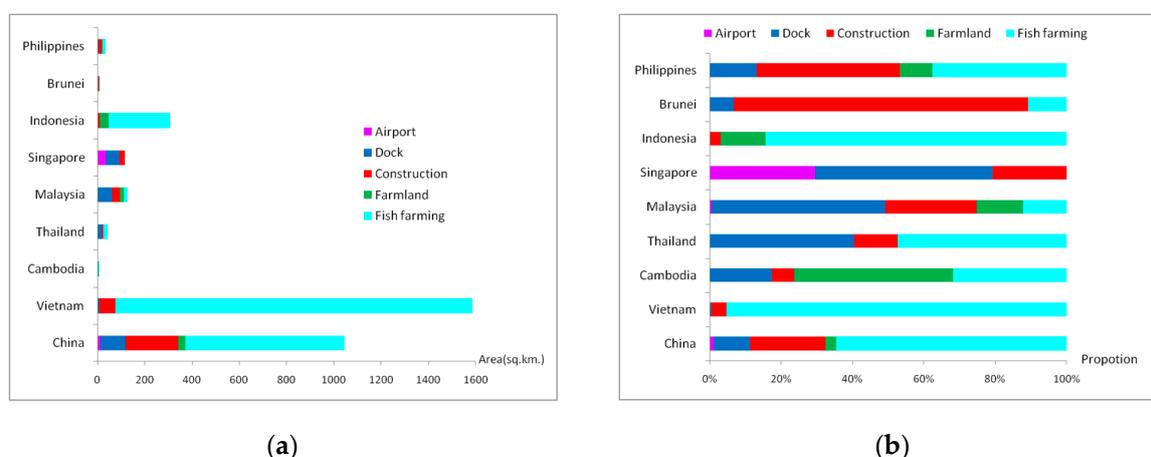


Figure 5. Sea reclamation of different types by country. (a) Area of sea reclamation. (b) Proportion of sea reclamation.

Distributions of sea reclamation are different between countries (Figure 4). In China, sea reclamation was widely distributed in the coastal zone, especially in Guangdong Province. Sea reclamation in Guangdong Province covered a total area of 867 km², over 80% of the total new area. Meanwhile, the patch area of sea reclamation was relatively large and it showed significantly banded distributions. In Guangxi and Hainan Province, sea reclamation patches were scattered and cracked. Sea reclamation for fish farming was the main type, followed by sea reclamation for construction and docks. The areas were 673, 272, and 128 km². In China, the coastline was sinuous and irregular, with numerous bays. Sea reclamation for fish farming was evenly distributed in the large and small bays. Among them, the west coast of the Pearl River Mouth and Lei Zhou Peninsula were the most distinctive ones. For construction, it was centered on the both sides of the Pearl River Mouth, covering more than 50%

of the total area. Sea reclamation areas for docks were mainly located in Daya Bay, Dapeng Bay, Pearly River Estuary, Huangmao Bay, Qinzhou Bay, and Fangcheng Bay. The distribution of sea reclamation for farming was relatively smaller, concentrated in Qingshui Bay, Zhongshan, and Huangmao Bay, and Jiangmen on the west coast of the Pearl River Mouth.

In Vietnam, sea reclamation was relatively concentrated in distribution. The Red River Delta and the North Highland, the southeast coast of Changshan Mountains, and the Ca Mau Peninsula were the dense distributions. Among them, sea reclamation in the Ca Mau Peninsula was the most dramatic, followed by the Red River Delta and the North Highland. The type composition of sea reclamation in Vietnam was simple. Sea reclamation for fish farming was the main type and the proportion exceeded 95%. The area was also very impressive, about 1511 km². Fish farming in Vietnam grew rapidly and this was achieved by expanding the area to increase the production. The locations for fish farming were located in estuarine delta regions and bays. Sea reclamation for construction was mainly located in Ha Long Bay and the Cam Pha area. Ha Long Bay was a beautiful and charming bay in Quang Ninh. Stimulated by the tourism industry, the demand of expanding for construction increased. Sea reclamation in Cam Pha was mainly stimulated by the coral industry. The areas of reclaimed land were 20 and 11 km².

Cambodia held fewer coast resources with a low degree of exploration. The area of sea reclamation was the smallest of all the surrounding countries, at just 5 km². Sea reclamation for farmland and fish farming were the main types and the areas of the two were close. In Thailand, sea reclamation was also not prevalent, with a total area of 42 km². The main distributions were in the Bangkok Bay and the east side. The southern coast had rare reclaimed land. Sea reclamation for fish farming and docks were the main types. Fish farming was developed in Thailand, but the new area of sea reclamation for fish farming was not significant. The area was 20 km², just one twentieth of the reclamation area for fish farming in Vietnam.

Sea reclamation was dramatic in Malaysia, and unlike the above countries, there was less sea reclamation area for fish farming. Sea reclamation for construction and docks were the main types. The distributions were scattered in the two peninsulas. Overall, sea reclamation in West Malaysia far outweighed sea reclamation in East Malaysia. In West Malaysia, sea reclamation on the west coast of the Malay Peninsula was more dramatic than the east coast. Sea reclamation in Selangor State was the most dramatic and newly-reclaimed land reached 64 km². Especially in Kelang, Kelang Port was wholly built on Pulau Indah (a mangrove island) wholly through sea reclamation. Perak State and Johor State followed. In East Malaysia, sea reclamation was mainly distributed in Kota Kinabalu, Sabah.

Singapore occupied the highest level of sea reclamation. The area of Singapore Island was increased by 114 km². In the southwest coast, southeast coast, and northeast coast, large-scale reclamation works took place. Sea reclamation for docks took up over 50% of the total new area and occurred mostly in the southwest coast.

In Indonesia, sea reclamation in Sumatra was more dramatic than Kalimantan. Sea reclamation for fish farming was the main type, followed by farmland. Newly-reclaimed land was concentrated in Aceh and Sumatera Utara, which is on the west coast of the Malacca Strait. In Brunei, sea reclamation for construction occupied an absolutely dominant position. The reclaimed land was distributed mainly in Bandar Seri Begawan and caused the loss of mangroves. In the Philippines, sea reclamation for fish farming and construction were the main types. The areas were densely distributed in the two largest bays of Luzon Island: Manila Bay and Lingayen Gulf.

3.3. Sea Reclamation in Typical Areas

3.3.1. Typical Estuarine Delta

The Pearl River Delta is located along the sea in the central part of Guangdong Province (Figure 6). As a large tropical estuarine delta, the Pearl River Delta has abundant bifurcate rivers, and many entrances and shallows, and is easy for sea reclamation. Meanwhile, vast land area, a convenient water

system, and the large trade port of Guangdong as the hinterland, leads the Pearl River Delta as the key area of China's economic development. Since the reform and opening up in the 1970s, as the gateway in the South China region opening to the Southeast Asia area, the economy of the Pearl River Delta has developed rapidly and the demand for the sea has increased as well. Sea reclamation in the region (Huangmao Sea to the west and east to Daya Bay) covered a total area of 558 km², more than 50% of the total reclamation area in China. From the land-use types, sea reclamation for fish farming dominated and the area reached 309 km². Sea reclamation for construction followed, covering 164 km². The areas of sea reclamation for docks and farmland were 44 and 30 km², respectively. From the distribution, the largest-scale works occurred in Zhuhai, followed by Shenzhen and Jiangmen. In Gaolan Island, Sanzao Island, and Hengqin Island, in Zhuhai, sea reclamation works filled in the sea which connected the continent and islands.

From the landform, the Pearl River Delta is a complex estuarine delta composed of the Xijiang River, the Beijiang River, and the Dongjiang River. Additionally, the Pearl River Estuary (Linding Sea) presents a landscape of the drowned harbor coast. The landforms at the two sides of the Pearl River Delta are quite different. Most entrances are concentrated on the west bank, including Yamen, Modaomen, and Jiaomen. Thus, most regions are alluvial plains and shoals, with few low hills in Zhuhai and Jiangmen. On the east bank, it is a complex landscape scheme in which hills and platform dominate with some piedmont alluvial plains. Only the Humen entrance lies in the east bank, yet most bays are located in the region, such as Shenzhen Bay, Dapeng Bay, and Daya Bay. Different landforms contribute to the spatial variation of sea reclamation. Overall, the area of sea reclamation on the west bank was higher than the east. Sea reclamation areas for fish farming occurred mainly on the west bank, such as Yamen, Modaomen, Jinxing Bay, Hongqimen, and Jiaomen. Meanwhile, the patch area of fish farming was relatively large. Large-scale reclamation misappropriated most waterways and affected shipping. Sea reclamation areas for docks occurred mainly in the bays of the east bank, such as Qianhai Bay, Dapeng Bay and Daya Bay. Sea reclamation areas for construction were scattered in distribution, mainly occurring on offshore islands, waterways, and bays. In Huangmao Bay, Maliuzhou Waterway, Dangzi Island, Qianhai Bay, and Shenzhen Bay represent several reclamation projects were conducted.

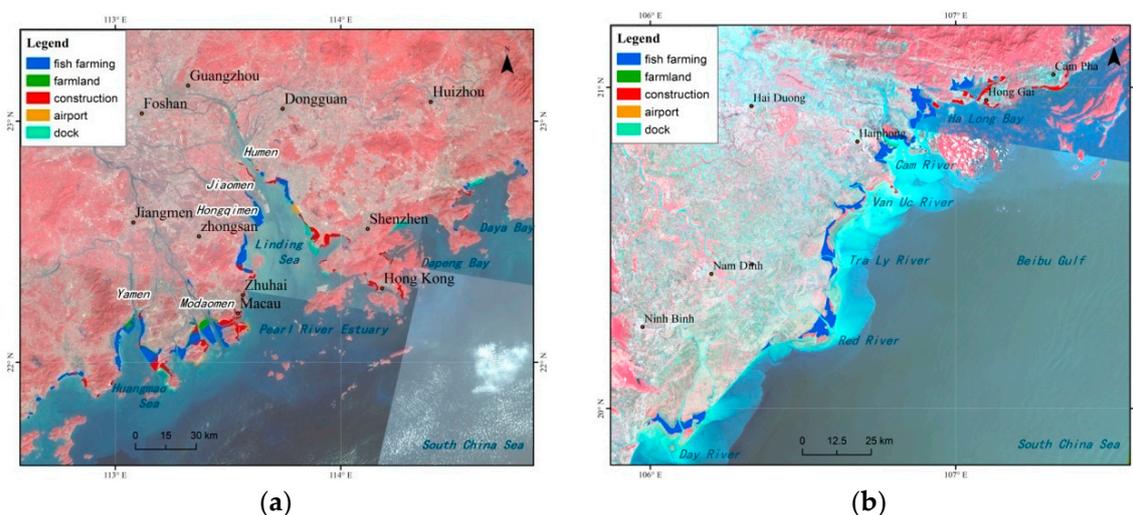


Figure 6. Sea reclamation in estuarine deltas. (a) Sea reclamation in the Pearl River Delta. (b) Sea reclamation in the Red River Delta.

The Red River Delta has been developed in Northern Vietnam, opening up to the Beibu Gulf. It is composed of the Red River and its streams. Alluvial plain is the major geomorphologic type. With dense river networks, the surrounding land in the Red River Delta is low with widespread shoals and tidal mangrove forests. The type of sea reclamation was simple. Newly-reclaimed land for fish farming was 221 km², over 95% of the total new area in the delta. In distribution, it occurred mainly in the river

mouths, including Da Bach River, Cam River, Van Uc River, Thai Binh River, Tra Ly River, Hong River, and Day River, from north to south. Additionally, the patch area of reclaimed land was relatively large. Due to sea reclamation for fish farming, mangroves in the Red River Delta had been severely damaged and the area was drastically reduced. Furthermore, newly-reclaimed land for docks was located in Hai Phong, which is the outport of Hanoi. It is an estuary harbor in the Cam River Mouth.

3.3.2. Typical Bays

Qinzhou Bay and adjacent bays are drowned bays in Beibu Gulf, China (Figure 7). The total area of reclaimed land added up to 74 km². Among them, Qinzhou Bay and Fangcheng Bay are mountain-drowned bays which are suitable for dock construction. Newly-reclaimed land was rather considerable, with about 13 and 20 km², respectively, reclaimed for Fangchenggang dock and Qinzhou dock. In the Maowei Sea and Dafengjiang River, where mangroves grew thickly, sea reclamation for fish farming occurred.

Bangkok Bay is the largest bay in Thailand, standing at the outlet of the Chao Phraya River. Reclaimed land in the bay (including Rayong) added up to 25 km². Sea reclamation for fish farming was located mostly on the west side of Bangkok Bay in a banded distribution. In contrast, sea reclamation for docks (Laem Chabang and Rayong) was located on the east side of Bangkok Bay. The reclaimed land areas for docks were 6 and 5 km², respectively. The natural environments of both sides of the bay are also different. On the west side, alluvial plain is the main geomorphologic type and silt-mangrove coast is the main coast type, which is suitable for fish farming. On the east side, the terrain is higher with bedrock—sandy bays—matching the conditions for dock construction.

Manila Bay is a large natural harbor on Luzon Island. The western and southern parts are surrounded by peninsulas. In the north, there is a large marsh delta for fish farming. New land for fish farming was small and the distribution was scattered. A relatively large reclamation project occurred on the west coast of Pasay City. A block of 8 km² was reclaimed for building construction. Sea reclamation for docks was also not notable as the demand for trade was limited. Several projects had been completed in the estuary of the Vitas River.

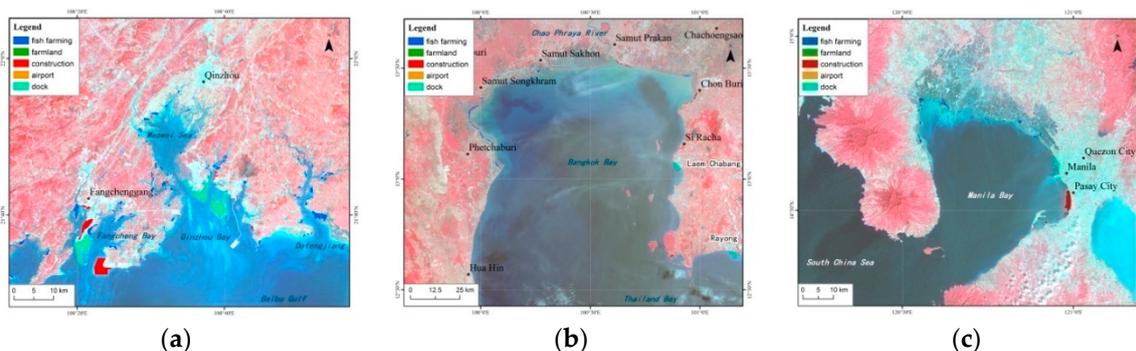


Figure 7. Sea reclamation in bays. (a) Qinzhou Bay; (b) Bangkok Bay; (c) Manila Bay.

3.3.3. Typical Offshore Islands

Macau lies on the west coast of the Pearl River, adjacent to Zhuhai (Figure 8). It is a famous international commercial center with a dense population and prosperous economy. Due to the lack of land surface area and its mountainous topography, Macau has a long history of sea reclamation. Influenced by the streams of the West Pearl River, sediment deposition of the coast in Macau is serious and brings about a large number of shallows. This reduces the costs of sea reclamation. From 1975 to 2010, reclamation of land from the sea in Macau covered a total area of 13.7 km², close to its original area. Most reclamation areas were used for construction; about 11.6 km². The north coast of the Macau Peninsula moved seaward by nearly one kilometer. Dangzai Island and Luhuan Island were connected by the large scale of land reclamation. On the east coast of Dangzai Island, an airport was built entirely

through sea reclamation. Again, due to the sediment deposition, no large docks occurred in the region. The only dock through reclamation lay on the north coast of Dangzai Island.

Singapore lies to the south of the Malay Peninsula, near the outlet of the Malacca Strait. As the fortress connecting the Indian Ocean and the Pacific Ocean, Singapore has an excellent geographical location. Since the area of Singapore Island is limited, sea reclamation projects have been carried out intensely since the independence of Singapore to meet the needs of economic development. The area of Singapore Island has increased from 629 to 743 km² from 1975 to 2010. Large-scale reclamation works occurred in the southwest, northeast, and southeast coasts. Sea reclamation for docks predominated. The main dock works were on the southwest coast and adjacent offshore islands. Seven small islands were reclaimed into one larger island—Jurong Island—for expanding the petrochemical industry. The whole port scale was rather large, covering a total area of 50 km². It was also the largest port in the South China Sea region. Sea reclamation for construction occurred on the northeast and southeast coasts. The continued sea reclamation project in the northeast caused the decrease in the water area of the Johor Strait and affected navigation. The largest airport—Singapore Changi Airport—was also constructed by reclamation on the east coast.

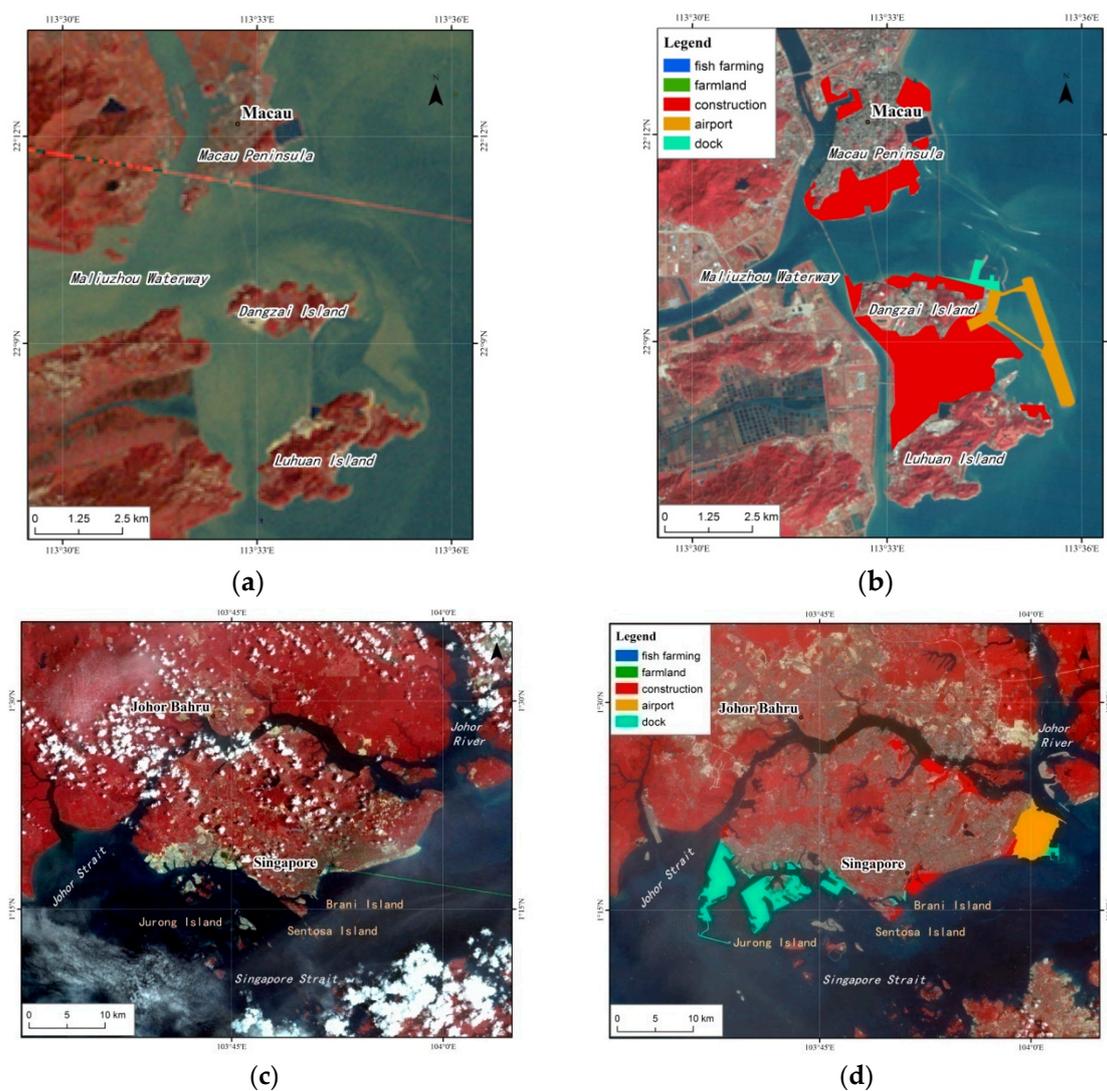


Figure 8. Sea reclamation of offshore islands. (a) Macau in 1975. (b) Macau in 2010. (c) Singapore in 1975. (d) Singapore in 2010.

4. Discussion

Economic policy and land supply factors contributed to sea reclamation. Since the 1970s, countries around the South China Sea have faced the acceleration of population and economic development. According to the statistics of the World Bank [25], the total population of the nine countries in the research area had increased by more 50% from 1975 to 2010. Meanwhile, the total GDP had increased by 30 times. As the key areas of economic development and population centers, turning the sea into land is unstoppable in coastal zones. Among the countries examined, sea reclamation in China, Vietnam, and Singapore was the most dramatic.

For Singapore, the increase of new reclaimed land was due to economic growth and land shortages. As an island country, the sea is a national resource upon which Singapore's well-being depends to a large extent on the country's limited sea space [10]. Reclamation for housing and industry was one of the main coastal development activities [26]. After Singapore separated from Malaysia in 1965, the economics of Singapore advanced rapidly. The GDP increased from 0.97 billion dollars in 1965 to 236 billion dollars in 2010. The growth speed was the largest of the nine countries examined. Large-scale and reclamation projects occurred to meet the urgent and growing needs of housing, commercial, industrial, infrastructure, and recreational development. The Tuas Reclamation Project, Jurong Industrial Estate Project, and Changi Airport Project were conducted in recent decades.

This is also the case for China. Since the result of reforms and the "opening up" policy in 1978, China's economic growth rate is accelerating. In 2010, the GDP of China (including Hong Kong and Macao) held 76.7% of the total GDP. In the 10th, 11th, and 12th Five-Year Plans of China from 2001 to 2011, the development of the marine economy has been put forward with emphasis "to thrive the city by relying on the port". At the forefront of opening up, the southeast coast faced a serious conflict between economic development and limited land [27], as there were large hills and less plain in the South China continent. At the same time, the corresponding laws and regulations were not perfect, causing the situation of large-scale disordered sea reclamation. Sea reclamation in China had the notable features of large scale, large area, and diversified utilization.

As a major power of sea reclamation, the increase of sea reclamation in Vietnam was stimulated mainly by fish farming. Compared with other countries, the ratio of agriculture GDP (together with forest and fishing) to total GDP was much higher [28]. In agriculture, fish (inland fish farming and marine catching) production value had increased rapidly. In 2010, aquaculture production in Vietnam rose to third, globally, (behind only China and India) [29]. The growth of fish farming was particularly fast; up to 2007, the production of fish farming was equal to that of marine catches. The increase of production was achieved by expanding the area for fish farming on shoals and mangroves to a great extent. In the two large estuarine deltas (the Red River Delta and the Mekong River Delta), especially the latter, new land for aquaculture had a significant impact.

In the remaining countries, sea reclamation was not notable. First, the growth of GDP in such countries was lower and land supply was relatively adequate compared to Singapore and China. Second, sea reclamation for fish farming was the main type in coasts around the South China Sea. However, in Thailand, Malaysia, Brunei, and the Philippines, aquatic products were mainly from marine fisheries and fish farming accounted for a small proportion [30,31]. The growth of fish farming was relatively low, which had little demand for new reclaimed land. Third, some main fish farming areas were not in the scope of the research area. In the Philippines, a significant number of culture ponds were distributed in the Visayas Islands and Mindanao [32]. In Indonesia, the main fish farming areas were located on Java Island.

Except for the above factors, landscapes influence sea reclamation significantly. Bays, estuaries, and offshore islands are primary choices. Most of new reclaimed land takes place in such areas. According to the type of sea reclamation, the distributions are different. Countries around the South China Sea own rich shoal and mangrove resources, which are suitable for fish farming. As the main reclamation type, new reclaimed land for fish farming was located mainly on the silt coast, in areas such as estuarine coasts and muddy bays. The west coast of the Pearl River Delta, the Red River Delta,

the Mekong River Delta, and the east coast of Sumatera Utara were the main areas. For construction, bays or offshore islands are good choices. In bays, such as Shenzhen Bay, Tseung Kwan, and Ha Long Bay, and offshore islands, such as Dangzai Island and Sentosa Island, new reclaimed land for construction occurred. For docks, new reclaimed land was distributed in bedrock bays, drowned bays, or estuaries owing to good conditions conducive to sheltering from the wind, such as Daya Bay, Qinzhou Bay, Cam River Mouth, Kelang River Mouth, and Pulai River Mouth.

Although sea reclamation brings about abundant economic profits, the impact of reclamation is felt in many ways, including mangrove loss, fishery decline, and shipping impact. Mangrove is one of the marine ecosystems with the highest productivity, contributing significantly to the maintenance of biodiversity and the improvement of the ecological environment. Mangrove is widely distributed in the South China Sea, especially in the vast area of the Mekong River and the Strait of Malacca. Due to sea reclamation for aquaculture ponds, the loss of mangrove is serious. In Aceh Province of Indonesia, the construction of ponds destroyed large areas of mangroves. With the loss of mangrove protection, the coastal zone is vulnerable to natural hazards, such the tsunami in 2004. In Ca Mau Province of Vietnam, new shrimp culture ponds added up to 1062 km². They were constructed absolutely in the mangrove area. The loss of mangrove exceeded 70% [33]. In Ha Long Bay of Vietnam, the extent of sea reclamation was great and newly-reclaimed land added up to 32 km². The consequential reduction in mangrove is amazing, at over two thirds of the original mangrove area. The same situation occurred in Hai Phong, Vietnam, and Pulau Indah, Malaysia. [34–36]. In Tieshangang Bay and Zhenzhugang Bay of China, the environments of the two famous pearl cultivation bases were seriously destroyed due to large-scale sea reclamation works for dock construction. Now it was no longer suitable for pearl cultivation [37]. Sea reclamation in the northeast coast of Singapore resulted in a narrowing of the Johor Channel between the two countries, impacting upon ships' entry to Johor's eastern port at Pasir Gudang. Additionally, it caused disputes of territorial sovereignty between Singapore and Malaysia [38].

5. Conclusions

With rapid population growth and economic development since the 1970s, countries around the South China Sea have steadily taken up large-scale sea reclamation activities. The total area of sea reclamation increased by 3264 km² from 1975 to 2010. Aquaculture was the dominant factor and the proportion of new reclaimed land used for fish farming exceeded 75%. Urban development (construction, docks, and airports) was the second dominant factor, while agriculture accounted for a slight proportion. Sea reclamation in China, Vietnam, and Singapore was significant owing to economic stimulation. China accounted for 32% of the total new reclaimed land and presented the features of large patch areas, large scale, and diversified utilization. Vietnam accounted for 48.6% of the total new reclaimed land and fish farming was the main land-use type. Approximately 15% of Singapore's area was acquired by sea reclamation for urban and industry development.

Moderate sea reclamation can give time for the marine environment to recover as it creates economic profits. However, sea reclamation at too fast a pace may cause serious damage to the environment. One important reason for the mangrove loss can be traced to cultural pond construction. It was especially prominent in Vietnam. Due to sea reclamation, mangrove degradation was particularly devastating in the Red River Delta and the Mekong River Delta, especially in the latter. The same problem exists on the southern coasts of China and the coasts of the Malacca Strait (Malaysia and Indonesia). Controlling the scale of reclamation and giving consideration to ecological protection should be considered.

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