


Article

Assessment of Quality of Fishery Resources in the Northeastern South China Sea

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Abstract: The quality of fishery resources and its assessment is critical and a key to the sustainable development and management of fisheries. In this paper, the quality of fishery resources in the northeastern South China Sea was assessed by analyzing the survey data of fishery resources obtained through bottom trawling in 1964–1965, 1997–1999, 2006–2007, and 2017. The results show that fishery resources in the study region have declined significantly. In 2017, the density of fishery resources in the region was only 19.53% of that in 1964–1965. Overall, the quality of fishery resources in the region showed a downward trend with a quality grade index ranging from 0.30 to 0.42. It was in a critical condition from 1997 to 2007, and in poor condition from 2007 to 2017. In the 53 years from 1964 to 2017, the quality index of fishery resources in the region has decreased by 0.70, with an average decline of 0.13 every 10 years. In the past 20 years, the decline rate of the quality of fishery resources in the northeastern South China Sea has slowed.

Keywords: bottom trawling; grade index; quality status; fisheries management



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1. Introduction

Located at the interface between the world's largest continent and the ocean, the north of the South China Sea is rich in marine resources. Meanwhile, the northeastern South China Sea is important for the production, consumption, and export of aquatic products, which play important roles in China [1]. According to the 2020 Guangdong Rural Statistical Yearbook, Guangdong, a province in the northeastern South China Sea, relies on marine fisheries, with a total of 943,000 fishermen and fisheries employees [2]. Fishery resources are the premise of fisheries production; the basic resources for the survival of people working in the fisheries industry; the food to ensure regional social stability; an important component of the marine ecosystem; and the material basis for sustainable marine development [3,4]. The quality and rational utilization of fishery resources have a direct impact on the sustainable development of the region's society, economy, and environment.

One of the keys to assessing the sustainable development and utilization of marine fishery resources is quality [5]. At present, scholars at home and abroad have carried out some research on the assessment of the quality of fishery resources [6–21]. Most of these evaluation index systems have higher or more requirements for data, and only a few are based on survey data. The sustainable utilization of fishery resources in northwest Pacific Ocean was evaluated based on catch statistics [22]. Based on the field investigation and research on fishery resources and the statistical data of fishery production in China, a quality evaluation index system of offshore fishery resources was constructed, and the quality of fishery resources in the Beibu Gulf was assessed [5]. However, there is no report on the assessment of the quality of marine fishery resources in the northeastern South

China Sea. Most simple evaluations based on fishery production statistics are insufficient to reflect the state of marine fishery resources and cannot provide an effective data support for the sustainable development of marine fisheries.

The main fishing method for marine fisheries in the northeastern South China Sea is bottom trawling [23], of which the fishes caught consist of a variety of species. In the past five years, bottom-trawled marine fisheries accounted for approximately 50% of the total marine fisheries of Guangdong, a province adjoining the northeastern South China Sea [2]. This study was based on the bottom trawling survey data of fishery resources in the region. Combined with the statistical data of the fishery production, this study used a proven and feasible fishery resources quality evaluation system to assess the quality of fishery resources in the study region in order to provide references for the scientific management, sustainable development, and utilization of fisheries.

2. Materials and Methods

2.1. Study Area and Fishery Data

The study area is located in the northern South China Sea, 107°–120° E, 17°–24° N. From 1964 to 1965, the study area of fishery resources in the northeastern South China Sea covered the coastal waters with a depth of less than 120-m in the 200-m exclusive economic zone of Guangdong, where 55 survey stations were arranged in a checkerboard manner (Figure 1).

From 1997 to 1999, the survey of fishery resources in the northeastern South China Sea covered the shallow waters below the 100-m isobath in the northern South China Sea, where 87 survey stations were arranged in a checkerboard manner (Figure 1).

From 2006 to 2007, the survey of fishery resources in the northeastern South China Sea covered the shallow waters below the 200-m isobath in the northern South China Sea, where five sections were arranged roughly orthogonal to the isobath with a total of 45 survey stations (Figure 1).

In 2017, the survey of fishery resources in the northeastern South China Sea covered the coastal waters with a depth of less than 100 m in the 200-M exclusive economic zone of Guangdong, where 45 survey stations were arranged in a checkerboard manner (Figure 1).

The data used in this assessment are mainly derived from the survey of the fishery resources obtained through bottom trawling in the northeastern South China Sea in 1964–1965, 1997–1999, 2006–2007, and 2017. In addition, the total output of marine fishing and the output and power of trawlers in Guangdong from 2007 to 2017 in the *Guangdong Rural Statistical Yearbook* were also used.

2.2. Evaluation Indicators

In this study, seven indicators [5] were selected concerning the quantity of fishery resources, structure of fishery resources, and development of fishery resources (Table 1). The indicator data were obtained mainly from the survey results of bottom trawling in the northeastern South China Sea and relevant data from the *Guangdong Rural Statistical Yearbook*. In view of the relative stability of the fishery ecosystem in the northern South China Sea in the 1960s and the decline in marine fishery resources [24,25], this study assumed that the index of fishery resources status was 1 at that time.

2.2.1. Total Resource Density Index (D)

This indicator reflects the total stock of fishery resources, which is calculated as follows:

$$D = \frac{D_k}{D_0} \quad (1)$$

where D_k represents the total average resource density in the k -th year, D_0 represents the total average resource density of fishery resources in the northeastern South China Sea from 1964 to 1965.

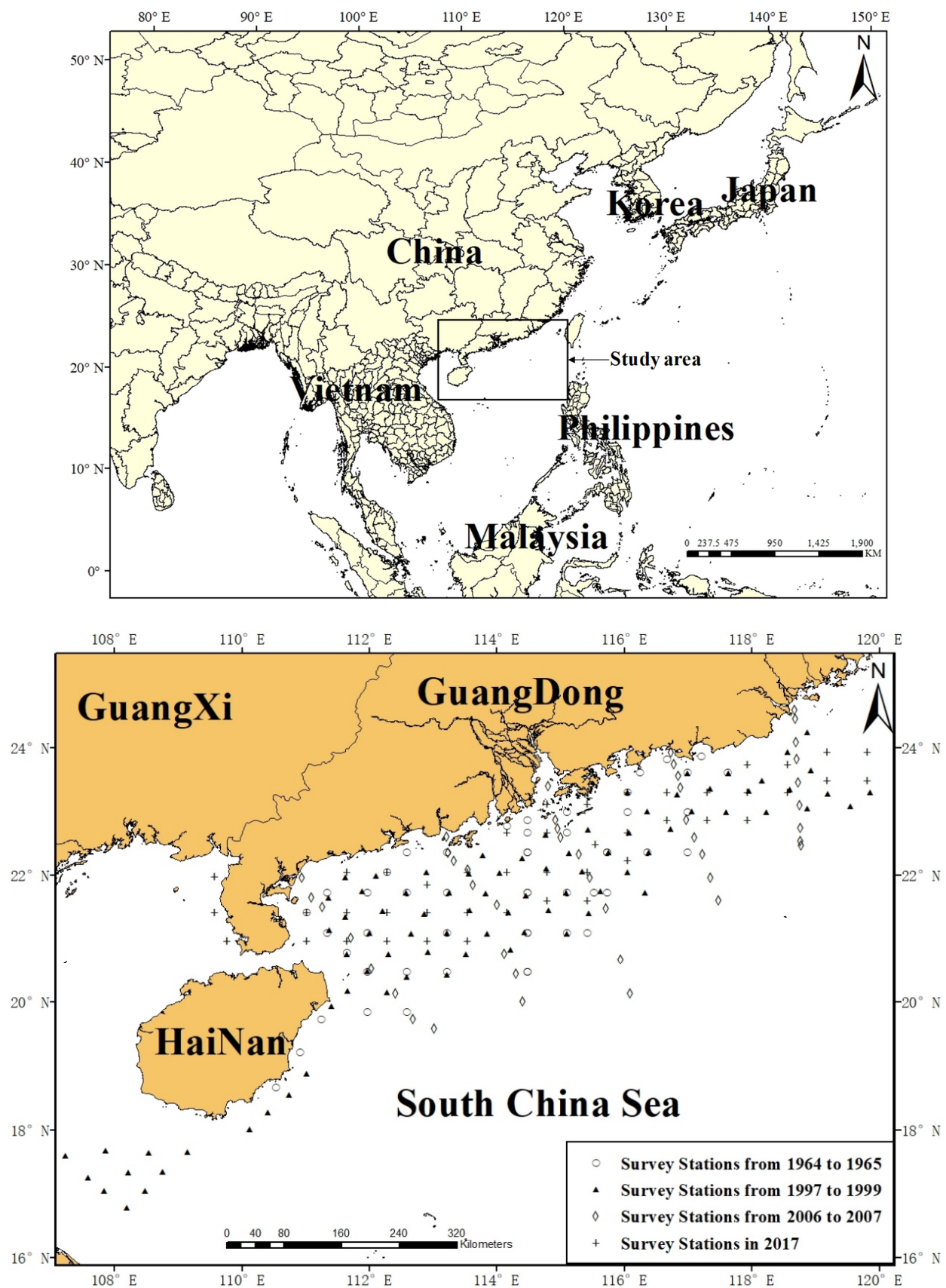


Figure 1. Survey stations in the northeastern South China Sea in different periods.

Table 1. Evaluation index system of marine fishery resources quality.

Objective	Criterion	Indicator
Grade index of marine fishery resources quality (<i>I</i>)	Quantity of fishery resources (C_1)	Total resource density (D) Resource density of 14 main economically important species (d)
	Structure of fishery resources (C_2)	Average body length of 14 main economically important species (L) Proportion of resources of 14 main economically important species (P) Ratio of fish resources to crustacean and cephalopod resources (R)
	Development status of fishery resources (C_3)	Ratio of total resources to total output (T) Catch per unit effort of trawler

2.2.2. Resource Density of Main Economically Important Species (d)

This indicator reflects the resources of economically important species, which is calculated as follows:

$$d = \frac{\sum_{i=0}^n \frac{d_i}{d_{i0}}}{n} \quad (2)$$

where d_i represents the resource density of the i -th species, d_{i0} represents the resource density of the i -th species from 1964 to 1965, and n represents the number of main economically important species, that is, 14.

We selected 14 species with large catches and high economic value over the years as the main economically important species in the northeastern South China Sea, including *Saurida tumbil*, *Saurida undosquamis*, *Muraenesox cinereus*, *Priacanthus macracanthus*, *Decapterus maruadsi*, *Parargyrops edita*, *Sparus latus*, *Nemipterus japonicus*, *Nemipterus bathybius*, *Therapon theraps*, *Upeneus sulphureus*, *Upeneus japonicus*, *Trichiurus lepturus*, and *Psenopsis anomala*.

2.2.3. Average Body Length of Main Economically Important Species (L)

This indicator reflects the measurement of main economically important species, which is calculated as follows:

$$L = \frac{\sum_{i=0}^n \frac{l_i}{l_{i0}}}{n} \quad (3)$$

where l_i represents the average body length or fork length or anal length of the i -th species, and l_{i0} represents the average body length or fork length or anal length of the i -th species from 1964 to 1965, and n represents the number of main economically important species, that is, 14.

2.2.4. Proportion of Resources of Main Economically Important Species (P)

This indicator is the proportion of total catch of the 14 main economically important species in the survey of total catch of the trawl, reflecting the quality of fishing catch species, which is calculated as follows:

$$P = \frac{d_k \cdot D_0}{D_k \cdot d_0} \quad (4)$$

where d_k represents the total average resource density of 14 main economically important species (groups) in the k -th year, D_k represents the total average resource density of fishery resources in the k -th year, d_0 represents the total average resource density of 14 main economically important species (groups) from 1964 to 1965, and D_0 represents the total average resource density of fishery resources from 1964 to 1965.

2.2.5. Ratio of Fish Resources to Crustacean and Cephalopod Resources (R)

Cephalopods and crustaceans have short life cycles, and the ratio of fish resources to their resources, to a certain extent, reflects the stability of fishery resource structure. The formula for calculation is as follows:

$$R = \frac{F_k \cdot C_0}{C_k \cdot F_0} \quad (5)$$

where F_k represents fish resources in the k -th year, F_0 represents fish resources from 1964 to 1965, C_k represents the total resources of cephalopods and crustaceans in the k -th year, and C_0 represents the total resources of cephalopods and crustaceans from 1964 to 1965.

2.2.6. Ratio of Total Resources to Total Output (T)

This indicator reflects the fishing intensity, which is calculated as follows:

$$T = \frac{TR_k \cdot TO_0}{TO_k \cdot TR_0} \quad (6)$$

where TR_k represents the total fishery resources in the northeastern South China Sea in the k -th year, TR_0 represents the total fishery resources in the northeastern South China Sea from 1964 to 1965, TO_k represents the total output of fishery resources in the northeastern South China Sea in the k -th year, and TO_0 represents the total output of fishery resources in the northeastern South China Sea from 1964 to 1965.

2.2.7. Catch per Unit Effort of Trawler (E)

Catch per unit effort of the trawler reflects the input and output of trawl fishery, which is calculated as follows:

$$E = \frac{TP_k \cdot TK_0}{TK_k \cdot TP_0} \quad (7)$$

where TP_k represents the total output of trawling fishery in the northeastern South China Sea in the k -th year, TP_0 represents the total output of trawling fishery in the northeastern South China Sea from 1964 to 1965, TK_k represents the total power of trawlers in the northeastern South China Sea in the k -th year, and TK_0 represents the total power of trawlers in the northeastern South China Sea from 1964 to 1965.

2.2.8. Grade Index

The grade index of fishery resources quality (I) is obtained according to the weighting of 7 indicators selected for the evaluation [5]. The weight of each indicator is determined by the expert assignment method, which is calculated as follows:

$$I = 0.214D + 0.179d + 0.130L + 0.117P + 0.104R + 0.131T + 0.125E \quad (8)$$

The grade index of fishery resources quality (I) has a value between 0 and 1; the higher the value, the better the quality of fishery resources. It can also be divided into 5 levels [5] (Table 2).

Table 2. Evaluation index system of marine fishery resources quality.

Range of Grade Index	Fishery Resources Quality
$0 \leq I \leq 0.19$	Very poor
$0.20 \leq I \leq 0.39$	Poor
$0.40 \leq I \leq 0.59$	Critical
$0.60 \leq I \leq 0.79$	Good
$0.80 \leq I \leq 1.00$	Very good

3. Results

3.1. Changes in Indicators of Fishery Resources Quality

3.1.1. Total Resource Density Index (*D*)

From March 1964 to May 1965, the South China Sea Fisheries Research Institute of the Chinese Academy of Fishery Sciences conducted monthly trawl surveys in the northeastern South China Sea; each station trawled for 2 h at a towing speed of 3 kn and with a 16-m sleeve net. According to the surveyed average catch, the coastal fishery resource density of Guangdong from March 1964 to May 1965 was calculated by the swept area method [26], and the total average resource density is 2156.30 kg/km², while that in 1997–1999, 2006–2007, and 2017 were 658.80 kg/km², 1084.39 kg/km², and 421.03 kg/km², respectively (Table 3). Therefore, the total resource density index (*D*) of fishery resources in the northeastern South China Sea in 1997–1999, 2006–2007, and 2017 were 0.33, 0.50, and 0.20, respectively.

Table 3. Estimation of fishery resource density in the northeastern South China Sea from March 1964 to May 1965.

Survey Time	Average Catch (kg/h)	Trawling Time (h)	Trawling Speed (kn)	Sleeve Net Length (m)	Fishery Resources Density (kg/km ²)
March 1964	58.98	2	3	16	1990.42
April 1964	65.95				2225.63
May 1964	69.00				2328.56
June 1964	53.39				1801.77
July 1964	81.03				2734.54
August 1964	72.89				2459.84
October 1964	56.30				1899.97
November 1964	49.00				1653.62
December 1964	62.00				2092.33
January 1965	58.36				1969.49
February 1965	75.95				2563.11

Notes: In September 1964, affected by the typhoon weather, the survey could not be conducted as scheduled.

3.1.2. Resource Density of Main Economically Important Species (*d*)

The resource density of 14 main economic types in the northeastern of the South China Sea from 1964 to 1965, 1997 to 1999, 2006 to 2007 and 2017 are listed in Table 4. The resource density index of main fishery economic categories in each period is 0.12, 0.13 and 0.06 respectively. Compared with 1964–1965, the resource density of main economic types in the northeastern of the South China Sea decreased seriously.

Table 4. Resource density of main economically important fish species in the northeastern South China Sea in different periods.

Species	Fishery Resources Density (kg/km ²)			
	1964–1965	1997–1999	2006–2007	2017
<i>Saurida tumbil</i>	100.48	18.26	8.25	8.23
<i>Saurida undosquamis</i>	46.23	18.37	7.92	8.16
<i>Muraenesox cinereus</i>	77.62	3.66	13.36	6.64
<i>Priacanthus macracanthus</i>	74.03	2.89	2.49	0.25
<i>Decapterus maruadsi</i>	40.83	7.19	4.56	3.32
<i>Parargyrops edita</i>	64.29	1.62	10.11	1.55
<i>Sparus latus</i>	66.48	0.10	4.09	4.72
<i>Nemipterus japonicus</i>	81.29	4.47	5.21	4.52
<i>Nemipterus bathybius</i>	302.50	2.16	25.01	8.86
<i>Therapon theraps</i>	48.93	0.12	/	0.46
<i>Upeneus sulphureus</i>	38.30	1.41	1.65	1.76
<i>Upeneus japonicus</i>	42.77	1.48	16.82	3.34
<i>Trichiurus lepturus</i>	53.87	32.66	6.95	3.89
<i>Psenopsis anomala</i>	50.96	1.07	11.51	0.83

Notes: No data on *Therapon theraps* was recorded in the trawling survey in 2006–2007.

3.1.3. Average Body Length of Main Economically Important Species (L)

The fishery resources surveys conducted in the northeastern South China Sea from 1964 to 1965 and 2017 only recorded the average body weight of fish. Therefore, the average body length or anal length of fish was estimated according to the power function of fish body weight and body length. Based on this calculation, the body length index (L) of main economically important fish species in the northeastern South China Sea from 1997 to 1999, 2006 to 2007, and 2017 are 1.11, 1.03, and 0.88, respectively (Table 5).

Table 5. Body length index of main economically important fish species in the northeastern South China Sea in different periods.

Species	Power Function of Body Weight and Body Length	Average Body Length (mm)			
		1964–1965	1997–1999	2006–2007	2017
<i>Saurida tumbil</i>	$W = 4.085 \times 10^{-6} \times L^{3.169}$ [27]	247.0	164	165	155.0
<i>Saurida undosquamis</i>	$W = 2.733 \times 10^{-5} \times L^{2.8103}$ [27]	178.4	149	134	130.2
<i>Muraenesox cinereus</i>	$W = 2.577 \times 10^{-3} \times L^{2.849}$ [28]	92.9	88.4	242.2	68.5
<i>Priacanthus macracanthus</i>	$W = 5.034 \times 10^{-5} \times L^{2.8524}$ [27]	197.3	151	105	135.2
<i>Decapterus maruadsi</i>	$W = 2.651 \times 10^{-5} \times L^{2.88995}$ [27]	125.8	165	145	161.0
<i>Parargyrops edita</i>	$W = 1.209 \times 10^{-5} \times L^{3.62}$ [27]	55.4	124	103	70.3
<i>Sparus latus</i>	$W = 3.3925 \times 10^{-5} \times L^{2.9862}$ [29]	140.7	71.3	203.1	217.5
<i>Nemipterus japonicus</i>	$W = 3.906 \times 10^{-5} \times L^{2.936}$ [30]	124.1	110	111	106.8
<i>Nemipterus bathybius</i>	$W = 2.016 \times 10^{-5} \times L^{3.0487}$ [27]	118.2	115	112	113.5
<i>Therapon theraps</i>	$W = 3.8891 \times 10^{-2} \times L^{2.8761}$ [31]	12.0	31.3	/	11.3
<i>Upeneus sulphureus</i>	$W = 6.119 \times 10^{-5} \times L^{2.816}$ [27]	112.2	121	95	115.8
<i>Upeneus japonicus</i>	$W = 2.2633 \times 10^{-5} \times L^{2.9905}$ [32]	100.5	100	92	100.0
<i>Trichiurus lepturus</i>	$W = 6.732 \times 10^{-5} \times L^{2.718}$ [30]	178.8	186	198	184.8
<i>Psenopsis anomala</i>	$W = 3.210 \times 10^{-6} \times L^{3.404}$ [27]	156.4	138	128	148.6

3.1.4. Proportion of Resources of Main Economically Important Species (P)

From 1964 to 1954, the total average resource density of fishery resources in the northeastern South China Sea was 2156.30 kg/km², and the average resource density of 14 main economically important species was 77.76 kg/km². In 1997–1999, 2006–2007, and 2017, the total average resource density of fishery resources in the northeastern South China Sea was 718.36 kg/km², 1084.39 kg/km², and 421.03 kg/km², respectively, while the average resource density of 14 main economically important species was 95.47 kg/km², 117.94 kg/km², and 56.52 kg/km², respectively. Therefore, the proportion of resources of main economically important species (P) in the northeastern South China Sea in 1997–1999, 2006–2007, and 2017 was 0.26, 0.23, and 0.27, respectively.

3.1.5. Ratio of Fish Resources to Crustacean and Cephalopod Resources (R)

The density of fish, crustaceans, and cephalopods resources in the northeastern South China Sea in 1964–1965, 1997–1999, 2006–2007, and 2017 are shown in Table 6. The ratio of fish resources to crustacean and cephalopod resources in each period was 0.75, 0.27, and 0.12, respectively.

3.1.6. Ratio of Total Resources to Total Output (T)

According to the 2018 Guangdong Rural Statistical Yearbook, the Investigation Report on Bottom Trawling Fish Resources in the Northern South China Sea (East of Hainan), and the statistics of fishery production in Guangdong, the marine capture in the northeastern South China Sea was calculated, as shown in Table 7. Based on this calculation and

fishery resources density of each period, the ratio of total resources to total output (T) in the northeastern South China Sea in 1997–1999, 2006–2007, and 2017 was 0.06, 0.11, and 0.04, respectively.

Table 6. Density of fishes, crustaceans, and cephalopods resources in the northeastern South China Sea in different periods.

Species	Fishery Resources Density (kg/km ²)			
	1964–1965	1997–1999	2006–2007	2017
Fishes	2019.95	658.80	870.09	272.939
Crustaceans	36.28	15.13	87.20	70.409
Cephalopods	100.07	44.44	127.10	77.642

Table 7. Marine capture and fishery resources density in the northeastern South China Sea in different periods.

Survey Time	Marine Capture ($\times 10^4$ t)	Fishery Resources Density (kg/km ²)
1965	33.23	2156.30
1997–1999	194.06	718.36
2006–2007	159.36	1084.39
2017	148.91	421.03

3.1.7. Catch per Unit Effort of Trawler (E)

According to the 2018 Guangdong Rural Statistical Yearbook, the Investigation Report on Bottom Trawling Fish Resources in the Northern South China Sea (East of Hainan), and the statistics of fishery production in Guangdong, the trawl output and the total power of trawlers in the northeastern South China Sea in each period were calculated, as shown in Table 8. Based on this calculation, the CPUE of trawl fishery in the northeastern South China Sea from 1997 to 1999, 2006 to 2007, and 2017 were 0.57, 0.50, and 0.56, respectively.

Table 8. Trawl output and total power of trawlers in the northeastern South China Sea in different periods.

Survey Time	Trawl Output ($\times 10^4$ t)	Total Power of Trawlers (kW)
1965	11.88	74,709.94
1997–1999	112.72	1,250,016.7
2006–2007	84.07	1,050,311
2017	73.69	831,901

3.1.8. Change Trend of Seven Indicators

Figure 2 shows the changes in the seven indicators of fishery resources quality grade index in the northeastern South China Sea. On the whole, the seven indicators show a downward trend, among which the total resource density index (D), resource density of 14 main economically important species (d), proportion of resources of 14 main economically important species (P), ratio of fish resources to crustacean and cephalopod resources (R), and ratio of total resources to total output (T) show a significant decline in 1997–1999, 2006–2007, and 2017. In contrast, the average body length of 14 main economically important species (L) increased first then decreased, and the catch per unit effort of trawler (E) decreased first then increased.

3.2. Quality of Fishery Resources in the Northeastern South China Sea

The evaluation index of fishery resources quality in the northeastern South China Sea for 1964–1965, 1997–1999, 2006–2007, and 2017 was 1.00, 0.42, 0.41, and 0.30, respectively, showing a downward trend, as shown in Figure 3. According to the grade index of

fishery resources quality evaluation index (Table 2), the quality of fishery resources in the northeastern South China Sea was in a critical condition from 1997 to 1999 and from 2006 to 2007, and in a poor condition in 2017. In the 53 years from 1964 to 2017, the quality status index of fishery resources in the northeastern South China Sea has decreased by 0.70, with an average decline of 0.13 every 10 years. The period from 1964 to 1997 saw the most significant decline, with a decrease of 0.58 in the evaluation level index and a decline rate of about 0.18 every 10 years. From 1997 to 2007, it decreased by 0.01, and the decline rate was 0.01 every 10 years, and from 2007 to 2017, it decreased by 0.11, with a decline rate of 0.11 every 10 years. It shows that the decline rate of fishery resources quality in the northeastern South China Sea has slowed in the past 20 years.

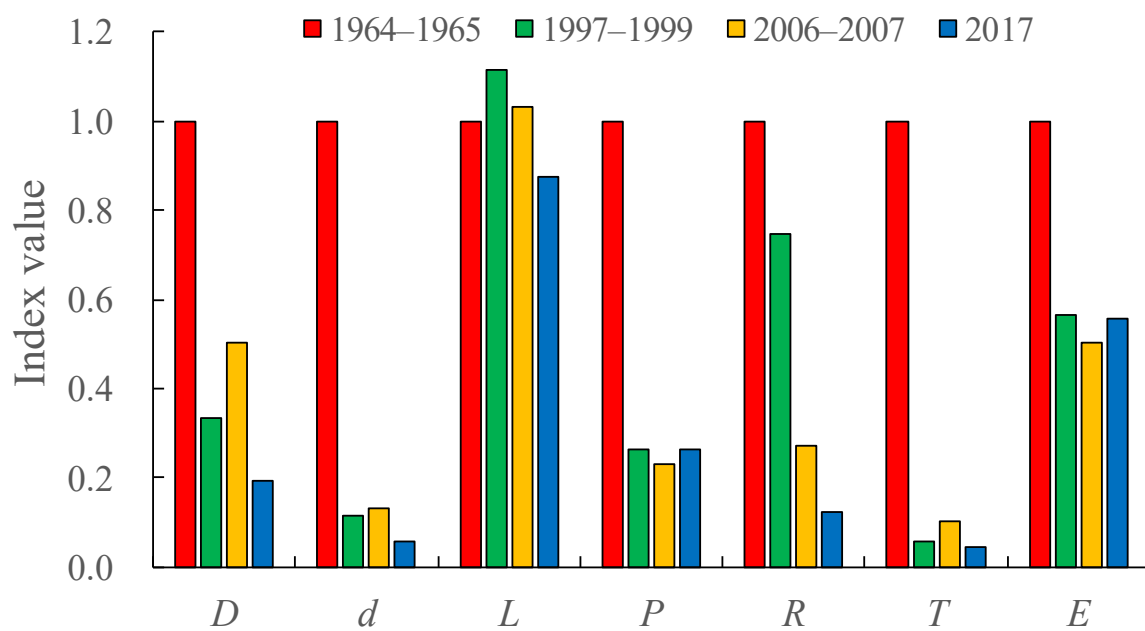


Figure 2. Trends of changes in indicators for the assessment of fishery resources quality in the northeastern South China Sea.

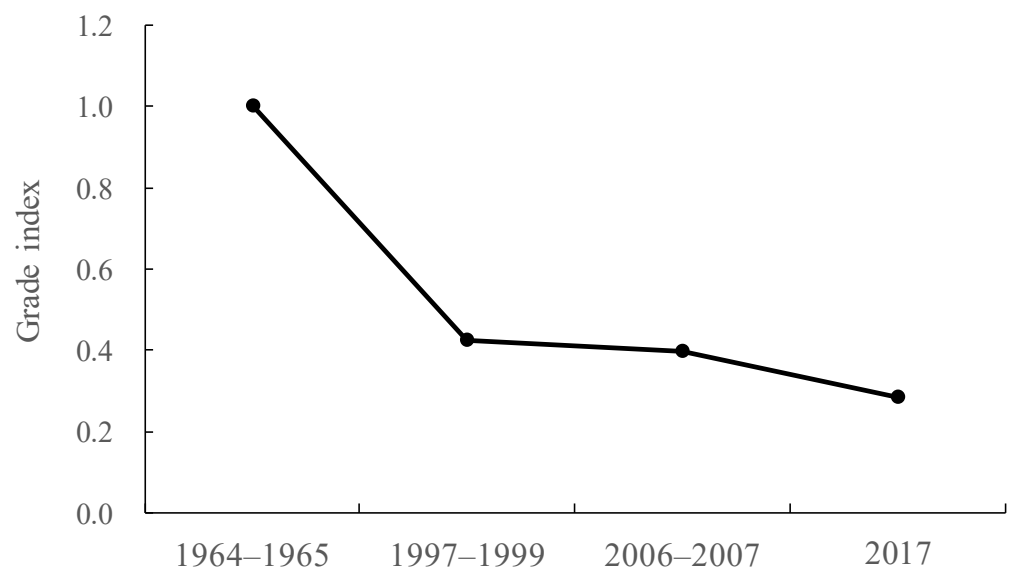


Figure 3. Trend of changes in the grade index of fishery resources quality in the northeastern South China Sea.

4. Discussion

At present, scholars and managers are paying more attention to the sustainable use of fishery resources [33–36], making it the essence and core of the sustainable development of fisheries, and one of the most important issues in China's fisheries management [37–39]. The evaluation index system of fishery resources quality based on survey data used in this study comprehensively considered the density, quality, and fishing pressure of fishery resources, which can reflect the usage and development potential of fishery resources. In this assessment, the northeastern South China Sea also includes the coastal waters of Guangdong, while the calculation of the output and power of trawlers mainly relies on data of the coastal waters of Guangdong.

The results show that in the past 53 years, the quality of fishery resources in the northeastern South China Sea has generally shown a downward trend, the quality of fishery resources is in a critical and poor condition, and the development quality of fishery resources is getting worse, which are consistent with the hierarchical grey comprehensive evaluation model applied by Chen Zuozhi to assess the sustainable use of fishery resources in Guangdong, which is located at the northeastern South China Sea from 1978 to 2007 [4], and the carrying capacity of marine fishery resources in Guangdong from 1991 to 2017 assessed by Feng Fei [3].

In 1999, the South China Sea began implementing the summer fishing moratorium policy [40]. From 2004 to 2007, Guangdong implemented the fishery resources multiplication project. From 2002 to 2011, Guangdong carried out large-scale artificial reef construction [41], and 50 ecotypes artificial reef area were built in the coastal waters of Guangdong. Through follow-up investigations and effect evaluation, the construction and proliferation and release of artificial reefs have a significant impact on resource conservation and proliferation [42–46]. We presume that through these fishery resource conservation measures, the downward trend of fishery resource quality in the northeastern South China Sea has been slowed down, with a decrease of 0.01 in the 10 years from 1997 to 2007 and 0.11 in the 10 years from 2007 to 2017. From 2007 to 2017, the decline rate of the quality of fishery resources in the northeastern South China Sea increased compared with that in 1997–2007, which was possibly due to the seemingly decreased but in reality, increased, number of marine fisheries workers [47]. This led to the emergence of large numbers of illegal fishing vessels and exacerbated the overexploitation of fishery resources, resulting in a continuous increase in the total fishing volume [48] exceeding the carrying capacity of natural resources.

Among the evaluation indicators, the body length structure index (L) of 14 main economically important species showed a trend of first rising and then falling. The average body length of *Saurida tumbil*, *Saurida undosquamis*, *Muraenesox cinereus*, *Priacanthus macracanthus*, *Nemipterus bathybius*, *Therapon theraps*, *Upeneus japonicus*, and *Psenopsis anomala* decreased compared with 1964–1965, indicating that these species had experienced miniaturization. These findings were consistent with the conclusion on the evolution of biological characteristics of *Nemipterus bathybius* and *Saurida undosquamis* in the Beibu Gulf of the South China Sea studied by Chen Zuozhi et al. [49,50].

The proportion of the 14 main economically important species (groups) in the total catch showed a downward trend, indicating that the decline of economically important species resources was more prominent during the decline in fishery resources in the northeastern South China Sea. There was a slight increase between 2006 and 2017, which was mainly due to the relative decrease of bottom fish resources and the relative increase of pelagic fish resources in the northern South China Sea. Wang Xuehui et al. [51] reported that after the 1970s, the proportion of pelagic fish resources in the Beibu Gulf of the South China Sea has increased significantly.

The research results show that the ratio of fish resources to crustacean and cephalopod resources showed a continuous downward trend, and the proportion of cephalopod resources and crustacean resources gradually increased. It can be seen that the decline of fish resources was faster than that of cephalopod and crustacean resources, the structure of

fishery resources had gradually changed, and the resources of cephalopods and crustaceans in fishery resources had relatively increased. Cephalopods and crustaceans have short life spans, can grow fast, and are more adaptable to environmental changes [52].

On the whole, the ratio of total resources to total output showed a downward trend, and slightly increased between 2006 and 2017. However, the CPUE of trawl fishery did not increase significantly, indicating that although the fishing effort of fishery resources increased, the fishery output did not significantly increase. This also indicates that the fishery resources in the northeastern South China Sea had declined. In 2017, the fishery resource density in the northeastern South China Sea was only 19.53% of that in 1964–1965.

The quality of fishery resources in the northeastern South China Sea has been in poor condition with a downward trend. This is mainly due to the decline in fishery resources, the proportion of fish, the reduction of resources of main economically important species, the miniaturization and short aging of fishery structure composition, and the increase of fishing pressure, where changes in the fishery structure in the northern South China Sea are mainly due to overfishing [53]. Through analysis, it can be concluded that relevant fishery management and conservation measures such as the summer fishing moratorium, artificial reef construction and proliferation and release, and “double reduction policy” have played a certain role in slowing down the decline of fishery resources, but they have not yet been able to reverse the continued decline. Many coastal countries in the world are actively seeking scientific sustainable fishery management measures [54–56]. Therefore it is suggested that the conservation measures of relevant fishery resources should continue to be strengthened, and fishery resources management strategies should be strictly implemented to slow down or even improve the quality of current fishery resources in the northeastern South China Sea [57–59].

5. Conclusions

This study evaluated for the first time the quality of fishery resources in the Northeastern South China Sea by evaluation indicators based on survey data. In the 53 years from 1964 to 2017, the quality index of fishery resources in the northeastern South China Sea has decreased by 0.70, with an average decline of 0.13 every 10 years. In 2017, the density of fishery resources in the northeastern South China Sea was only 19.53% of that in 1964–1965. The quality of fishery resources in the northeastern South China Sea was in poor condition in 2017. With the implementation of fishery conservation policies and measures in the South China Sea, such as the construction of artificial reefs, the fishery enhancement and the summer fishing moratorium policy, the decline of fishery resources in the South China Sea has been slowed down in the past 20 years. However, it still has not recovered to a good or very good state, the situation of low-quality fish and miniaturization is still relatively serious, and the fishing of economic species is still in an overfishing state – attention should be paid to this problem. Fisheries resource conservation policies and measures should be continuously implemented and managed, while raising the awareness of the population on resource conservation and protection.

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