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Environmental effects of mariculture in China: An overall study of nitrogen and phosphorus loads

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Abstract

Eutrophication in coastal area has become more and more serious and mariculture potential is a main cause. Although there are some quantitative research on nutrient loads in national and global perspective, the calculation method problems make the results controversial. In this paper, the farming activities are divided into fed culture types (include cage culture and pond culture) and extractive culture types (e.g. seaweed, filter-feeding shellfish culture). Based on the annual yield of China in 2019 and feed coefficient of fed culture types and carbon (C), nitrogen (N), and phosphorus (P) content of extractive culture types, the annual nutrient loads was estimated. The results showed that to coastal region of China (1) annual nutrient released by fed culture types were about 58 451 t of N, 9 081 t of P, and annual nutrient removed by harvest of extractive culture types were 109 245 t of N, 11 980 t of P and 1.86×10^6 t of C. Overall, the net amount of nutrient removed annually by mariculture industry were 50 794 t of N and 2 901 t of P. (2) The nutrient released from mariculture industry influenced nutrient stoichiometry. Pond farming and seaweed farming had the potential of increasing the molar concentration ratio of N and P (N:P), while cage farming and bivalve farming decreased the N:P. (3) Due to different mariculture types and layouts in the coastal regions in China, N and P loading were regional different. Among the coastal regions in China, net release of nutrient from mariculture occurred only in Hainan and Guangxi regions, while in the other regions, N and P were completely removed by harvest. We suggest decrease the amount of fed culture types and increase the amount of integrated culture with extractive culture types. This study will help to adjust mariculture structure and layout at the national level to reduce the environmental impact.

Key words: fed culture type, extractive culture type, nutrient loads, nitrogen, phosphorus

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1 Introduction

Eutrophication is a worldwide problem in coastal ecosystems that severely threatens environmental equilibrium (Nichols et al., 2019; Liu et al., 2020). Nutrient loads are very important drivers of eutrophication (Meier et al., 2019). Excessive nutrient enrichment causes alternated algal flourish and collapse cycles (Farmaki et al., 2014), which can influence food web and ecosystem.

Mariculture is one of the fastest-growing food-producing industries in the world with an annual production of over 63×10^6 t in 2018 (FAO, 2020). The potential effects of the mariculture industry on its surrounding environment have attracted a large interest from both marine scientists and policymakers (e.g., Bambaranda et al., 2019; Joesting et al., 2016; Bannister et al., 2016; Carballeira et al., 2018). Mariculture is dominated by extractive culture of aquatic plants, filter-feeding bivalves, and fed culture of marine finfish and crustacean. Most studies have illustrated that mariculture has remarkable effects on the environment (Holmer, 2010) mainly due to waste load, which promotes eutrophication of coastal waters (Boyd, 2003; Farmaki et al., 2014; Filgueira et al., 2017). Two generally accepted views are that fed culture (cages and pond) is the source of nitrogen (N) and phosphorus (P) (Wang et al., 2012; Bannister et al., 2016; Carballeira et al., 2018), and photosynthetic seaweed is the sink of nutrient (Xiao et al., 2017). Due to different estimation methods, the calculations of source-sink effect of bivalve are different. The major eco-physiological pathways in which bivalves interact with coastal nutrient cycling are filtration of sestons from water column, nutrient storage in tissue and shell (growth), excretion of inorganic metabolic waste, and production and mineralization of biodeposits (Newell, 2004). The calculation methods on N and P loading of bivalve mariculture include, taking account of biodeposition+excretion (Gallardi, 2014), growth–excretion–biodeposition (Bouwman et al., 2013), growth+biodeposition–excretion (Christensen et al., 2003) and growth+biodeposition–excretion–

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remineralization (Richard et al., 2007), which lead to significantly different results of bivalve being source or sink of nutrient.

Most of the previous studies on nutrient loads mainly focused on one specific species or on the region, such as a relatively short distance (i.e., hundreds meters) from the farms. However, the discharge of N and P could transport and distribute in large-scale area, and the spatial-temporal distribution and impact on the ecosystem depend on the ocean characteristics (current, water depth, temperature, etc.) and mariculture practices, such as culture density, species, etc. (Sarà et al., 2011; Filgueira et al., 2017; Oh et al., 2015; Wu, 1995). It is important to understand the interactions between mariculture and environment on ecosystem scale and provide management strategies in the ecosystem approach to aquaculture (Aguilar-Manjarrez et al., 2017). There were a few studies on national or global scale about nutrient loads of fed culture type of cage finfish culture (Bouwman et al., 2013; Cai and Sun, 2007; Islam, 2005), extractive culture types of shellfish and seaweed farming (Bouwman et al., 2013), and on both culture types (Wang et al., 2020; Bouwman et al., 2013).

China is one of the fastest-growing mariculture countries in the world. To protect and restore the marine ecological environment and to pursue a sustainable development of mariculture, China currently proposes a nationwide mariculture management strategy. Therefore, an improved understanding of the influence of mariculture on both province and national scale is crucial for appropriate regulation and management of mariculture operations at the ecosystem level. The potential environmental impact of mariculture and how to keep mariculture sustainable development are the issues of concern (Cao et al., 2007; Yang et al., 2017; Shen et al., 2018). In this paper, we aimed to (1) evaluate N and P released from 4 different typical culture systems in China; (2) quantify the amount of N and P loading from mariculture on province scale in China; (3) analyze the association between N and P loading and culture structures and provide strategic advice on mariculture.

2 Materials and methods

2.1 *Data sources*

Data of pollutant discharge coefficient (PDC) and pollutant producing coefficient (PPC) were obtained from the first national pollution survey of China (National Pollution Source Census, 2009). The national pollution source census was organized by the Chinese Academy of Fishery Sciences, and 42 scientific research units joined in the monitoring work. A total of 98 monitoring areas and 196 sampling stations had been set up across the country, covering most mariculture species (30 categories) and mariculture types in China. The annual yield of mariculture in 2019 was obtained from Zhang et al. (2020a). The dry/wet weight ratio, C, N, and P contents of extractive organisms were obtained from published papers (Yang and Fei, 2003; Tang et al., 2011; Chen et al., 2013).

2.2 *Estimates of N and P loads from mariculture entering the coastal area*

Mariculture systems in the coastal area are comprised of four typical types: fed culture types of pond culture and cage culture, and extractive culture types of seaweed and bivalve culture. The types of waste included dissolved inorganic, organic N and P and particle inorganic, organic N, P. In the paper, we chose not to consider the waste types and use N and P represent simply.

2.2.1 *Pond culture*

For pond culture, the wastes dissolved or suspended in the seawater were discharged into the coastal area, whereas most deposited wastes were not entered into the coastal area (Shen et al., 2018). So, N and P loads were estimated according to the PDCs, which were based on the water flux and the difference in N and P concentrations input and output of the pond (Zhang et al., 2004). In the paper, the N and P loading of 12 categories (including 4 types of shrimp, 2 types of fish, 2 types of crabs, sea cucumber, jellyfish and others) were estimated based on the following formula:

$$L_{\text{pond},i} = \text{PDC}_i \times W_{\text{pond},i} \times 10^{-3}, \tag{1}$$

where L_{pond} (unit: t) is the N or P loading from the type of main categories; PDC unit is g/kg; W_{pond} is the annual production (t); i is different categories (i=1, 2, ···, 12).

2.2.2 *Cage culture*

Marine cage culture is generally used for fish farming. The cages are set in coastal water and the wastes include uneaten feeds and fish-produced wastes (such as feces and excretion) are directly released into the ocean. Therefore, for cage culture, except for N and P removed by harvest, all the N and P in the feeds supplied to the cage are retained in the coastal ecosystem. Generally, N and P loads were estimated according to the PPCs, which are based on feed conversion ratio (Bouwman et al., 2013; Islam, 2005). In this paper, 7 categories were assessed based on the following formula:

$$L_{\text{cage},i} = \text{PPC}_i \times W_{\text{cage},i} \times 10^{-3}, \tag{2}$$

where L_{cage} (t) is the N or P loads from fish of different species; PPC unit is g/kg; W_{cage} is the annual production (t); i is different categories (i=1, 2, ···, 7).

2.2.3 *Bivalve and seaweed culture*

Seaweed, as a primary producer, can absorb N and P through photosynthesis. So, its N and P were negative loads, and were calculated according to N or P content of seaweed and their annual production:

$$L_{\text{seaweed},i} = C_{\text{seaweed},i} \times W_{\text{seaweed},i}/100, \tag{3}$$

where L_{seaweed} (t) is the N or P loads from seaweed; C_{seaweed} is N or P content (%) of seaweed; W_{seaweed} is the annual production of seaweed (dry weight, t); i is different categories (i=1, 2, ···, 5).

The role of bivalve mariculture in the ecosystem is complicated. We do not consider processes such as filtration, excretion, and biodepostion, and only consider the quantitative results in this paper. Bivalve mariculture does not result in additional nutrient loads, but rather, transfers suspended particles from water column to benthic sediments in biodeposits, rapids nutrient cycling when dissolved inorganic nutrient are released into the overlying water, and removes portion of those nutrient when bivalves are harvested (Dumbauld et al., 2009). Thus, the N and P were negative loads, and the simplified method was used according to N or P contents of bivalve individual (both in the shell and in soft tissue) and their annual production (Chen et al., 2016). The contents in the seed were ignored in this paper. The possible errors during calculation by this method were analyzed in the discussion. The C sink was calculated according to C content and annual production of bivalve and seaweed (Tang et al., 2011). The N and P loads of bivalve were estimated based on the following formula:

$$L_{\text{bivalve},i} = W_{\text{bivalve},i}\times r_i\times(t_i\times C_{\text{bivalve-m},i}+(1-t_i)\times C_{\text{bivalve-s},i})/100, \tag{4}$$

where L_{bivalve} (t) is the N or P loads from bivalve; W_{bivalve} is the annual production of bivalve (wet weight, t); r is the bivalve's dry and wet weight ratio; t is the ratio of dry tissue weight to total dry weight; $C_{\text{bivalve-m}}$ and $C_{\text{bivalve-s}}$ are N or P contents in dry tissue and shell respectively (%); i is different categories (i=1, 2, ···, 5).

3 Results

3.1 *The total annual N and P loads of mariculture in China*

The waste coefficient (PDC), yield, and nutrient release from the main species of the pond mariculture in China were shown in Table 1. The PDC varied greatly among different categories. The highest PDC (from *Takifugu* and *Portunus*) for N and P respectively were 15 times and 10 times of the lowest values. The waste coefficient (PPC), yield, and nutrient release from the main species of the cage mariculture in China were shown in Table 2. For cage culture, the PPC had relatively small differences among different categories. PPC was much higher than that of PDC.

The N, P, and C contents of soft tissue of bivalve and seaweed were shown in Tables 3 and 4. Since the N, P and C contents in the shell of different species of bivalves were relatively similar, we took the average value of 0.14, 0.029 and 0.11, respectively.

The proportion of yield in typical mariculture systems was shown in Fig. 1. Fed culture types and extractive culture types represented about 17% and 83%, respectively. Shanghai was not included in the paper, because its mariculture production was very low. Among the 10 coastal regions in China, the mariculture production in 8 regions was dominated by extractive culture types, and only the mariculture production in Tianjin and Hainan regions was dominated by fed culture types.

The N and P loads and its molar ratios from four typical mariculture systems in China were shown in Table 5. The estimated N and P loads and molar ratios were 10 330 t and 1 026 t and 22:1

Table 1. The waste coefficient of pollutant discharge coefficient, yield and nutrient release from the main species of the pond mariculture in China in 2019

Waste sources	Yield/(10^3 t)	Waste coefficient/ (g·kg^{-1})		N release/ (10^3 t)	P release/ (10^3 t)
		N	P		
Takifugu sp.	17.473	15.51	0.65	0.28	0.02
Sea bass	180.267	11.85	0.86	1.36	0.07
Penaeus vannamei	1 144.370	1.82	0.29	3.14	0.39
Penaeus monodon	84.066	2.04	0.32	0.25	0.03
Penaeus chinensis	38.583	1.41	0.25	0.05	0.01
Penaeus japonicus	50.968	1.67	0.31	0.07	0.01
Portunus sp.	113.810	2.22	0.96	0.27	0.12
Scylla sp.	160.616	2.65	0.11	0.45	0.02
Sea cucumber	171.700	4.37	0.1	0.43	0.01
Sea urchin	8.243	4.98	0.12	0.04	0.00
Jellyfish	89.576	3.31	0.36	0.29	0.03
Others	421.400	8.78	0.75	3.70	0.32
Total	2 481.027	–	–	10.33	1.03

Note: – represents no data.

Table 2. The waste coefficient of pollutant producing coefficient, yield and nutrient release from the main species of the cage mariculture of China in 2019

Species	Yield /(10^3 t)	Waste coefficient/(g·kg^{-1})		N release/ (10^3 t)	P release/(10^3 t)
		N	P		
Pseudosciaena crocea	225.55	72.02	12.07	16.24	2.72
Rachycentron canadum	42.22	76.47	12.77	3.23	0.54
Seriola sp.	30.00	76.47	12.77	2.29	0.38
Seabream	101.28	72.02	12.07	7.29	1.22
Sciaenops ocellatus	70.19	72.02	12.07	5.06	0.85
Epinephelus sp.	183.13	76.47	12.77	14.00	2.34
Total	652.37	–	–	48.11	8.05

Note: – represents no data.

Table 3. The contents of N, P and C, and N, P, C removed by harvest of the main species of seaweed of China in 2019

Species	Yield/ t	N content/%	P content/%	C content/%	N remove/t	P remove/t	C remove/ (10^3 t)
Kelp	1 461 058	1.63	0.379	31.20	23 815.25	5 537.41	506.69
Undaria	152 572	3.41	0.33	28.81	2 486.92	578.25	62.13
Laver	135 252	1.88	0.055	41.96	4 612.09	446.33	58.15
Gracilaria	293 179	1.63	0.379	24.50	5 511.77	161.25	98.86
Others	24 476	2.31	0.25	30.27	565.40	61.19	10.94
Total	2 066 537	–	–	–	36 991.43	6 784.43	736.77

Note: – represents no data.

Table 4. The contents of N, P and C contents, and N, P, C removed by harvest of the main species of bivalves of China in 2019

Item	Oyster	Scallop	Mussel	Clam	Others	Total/(10^3 t)
W/(10^6 t)	4.83	1.86	0.88	4.17	1.21	–
r	0.65	0.64	0.75	0.53	0.64	–
t	0.02	0.11	0.06	0.14	0.04	–
N $C_{\text{bivalve-m}}$/%	9.23	10.51	9.23	9.00	9.92	–
P $C_{\text{bivalve-m}}$/%	0.10	0.10	0.10	0.54	0.21	–
C $C_{\text{bivalve-m}}$/%	0.45	0.44	0.46	0.42	0.44	–
N $C_{\text{bivalve-s}}$/%	–	–	0.14	–	–	–
P $C_{\text{bivalve-s}}$/%	–	–	0.03	–	–	–
C $C_{\text{bivalve-s}}$/%	–	–	0.11	–	–	–
N remove/(10^3 t)	10.73	15.70	4.62	31.11	4.31	65.88
P remove/(10^3 t)	9.87	4.52	2.27	21.68	2.85	4.12
C remove/(10^3 t)	383.37	180.01	98.29	349.09	102.26	1 112.79

Note: – represents no data. W is the annual production; $C_{\text{bivalve-m}}$ and $C_{\text{bivalve-s}}$ are N or P contents in dry tissue and shell, respectively.

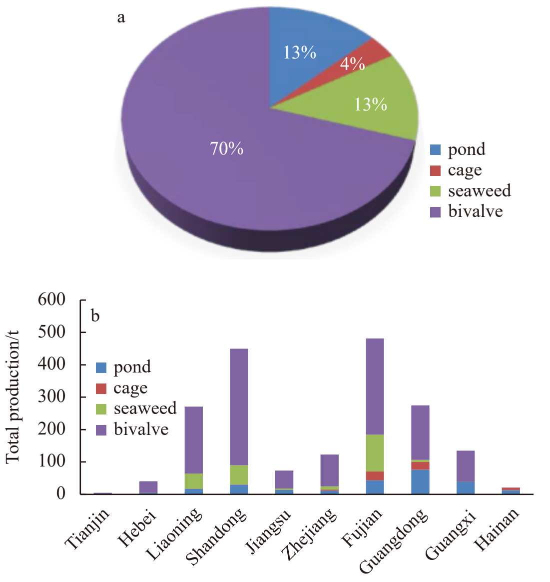

Fig. 1. Percentage of total production in typical mariculture systems (a), and the proportion of yield in typical mariculture systems in coastal provinces of China in 2019 (b) (Zhang et al., 2020a).

from the pond and 48 121 t and 8 053 t and 13:1 from the cage culture system, respectively. The estimated N and P loads and relatively molar ratio were –44 188 t and –7 883 t and 12:1 from seaweed and –65 057 t and –4 097 t and 35:1 from the bivalve culture system, respectively. In total, the annual net N and P loads of mariculture in China were –50 794 t and –2 901 t, respectively, and the total molar N: P ratio was 39:1. In comparison, N and P loads mainly came from cage culture, while seaweed and bivalve had the greatest ability to remove P and N from the Chinese coastal ecosystem, respectively. Seaweed and filter-feeding bivalve also had the potential of C sink, and it was estimated that about 1.78×10^6 t of C were removed by harvest (Table 5).

3.2 *The N and P loads from mariculture in coastal regions*

Along the coastal line of China, the N and P loads from the four typical mariculture systems of 10 regions were showed in Fig. 2. Regions exhibited higher net N and P loads on the southern coast than the northern coast. Among these 10 coastal regions, 7 regions had negative net N load, and 6 of these, bivalve mariculture played the biggest role, only in Fujian, seaweed farming played the key role. Three regions (Tianjin, Guangxi, and Hainan) had positive net N load, and relatively high N load were attributed by the cage culture. For the 10 regions, 6 regions had negative net P load, and seaweed culture played the key role in Liaoning, Shandong, and Fujian, bivalve culture played the key role in Hebei, Jiangsu, and Zhejiang. In Guangdong, the net P load was positive, the N load was negative.

3.3 *Role of mariculture N and P loads in pollutant flux into coastal China*

The amounts of N and P discharged in the Chinese coast from the river, sewage, and mari culture in 2019 were shown in Fig. 3. And among which, over 95% of the N and P loads were from the river. The amount of N and P loads from the pond and cage culture accounted up to 5.85×10^4 t and 9.1×10^3 t respectively, which were only 2.32% and 5.05% of river N and P loads, respectively. Considering the negative loads of seaweed and bivalve farming, mariculture as a whole acted as a “weak sink”, i.e. mariculture activities in China removed N and P from the ocean.

4 Discussion

From this research, we found that the N and P loads were negative from the national perspective in China, which indicates that through mariculture, a large amounts of N and P were re-

Table 5. The N and P loads and molar concentration ratios of N and P (N:P) from four typical mariculture systems and C sink from extractive mariculture system of China in 2019

Item	Bivalve	Seaweed	Pond	Cage	Total
Yield/(10^6 t)	13.16	2.41	2.48	0.65	18.71
N load/t	–65 057	–44 188	10 330	48 121	–50 794
P load/t	–4 097	–7 883	1 026	8 053	–2 901
N:P	35:1	12:1	22:1	13:1	39:1
C sink/t	1 127 735	736 770	–	–	1 864 505

Note: – represents no data.

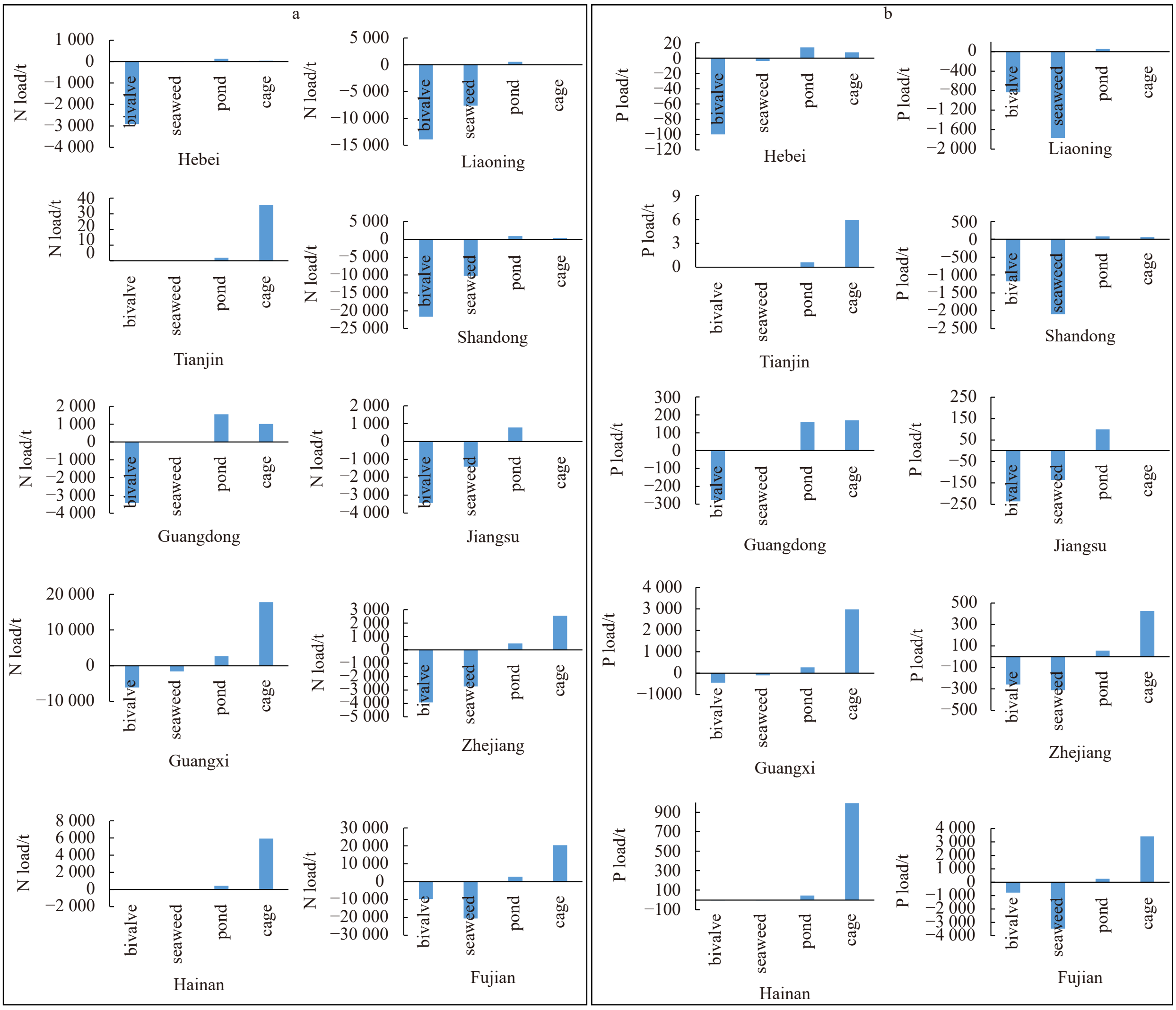

Fig. 2. The N loads (a) and P loads (b) from the four typical mariculture systems of 10 provinces along with coastal China.

moved from the coastal environments every year. One of the reasons was Chinese mariculture characteristics. In China, the maricultural species were mainly extractive low-trophic macroalgae and filter-feeding bivalves, and this culture structure was relatively stable over the past 30 a (Fig. 1). Compared with other countries in the world, China's mariculture had the characteristics of high production, large scale, rich diversity, low nutritional level, and high ecological efficiency (Tang et al., 2016). Fed culture types (e.g., cages and pond) brings bigger nutrient loads than the extractive culture types comparatively (Wang, et al., 2012; Bannister et al., 2016; Carballeira et al., 2018).

Ours results showed N and P loads from mariculture of 2019 were 5.08×10^4 t and 2.9×10^3 t respectively, which were remarkably lower compared with the 0.4×10^6 t/a (according to N) and 0.06×10^6 t /a (according to P) in 2017 and the 0.184×10^6 t/a (according to N) (Wang et al., 2020) and 0.022×10^6 t/a (according to P) in 2010 (Zhang et al., 2015), probably due to differences in the approaches used. The bivalves reared using raft and tidal flat systems (the yield in 2019 was 11×10^6 t, occupy nearly 90% of total mariculture yields of bivalves) were ignored in Zhang et al. (2015), only fish, shrimps, crabs, and mollusks in pond system were estimated, which would overestimate the nutrient loads. In addition, the fish production and waste coefficient were different comparing with Wang et al. (2020). In this paper, the yield of fish from re-circulating aquaculture system were ignored because the waste coefficient was low. For the fish cultured in pond, not all the pollution materials were released to coast; therefore, we calculated the nutrient loads based on PDC, which was lower than PPC. The above reasons led to the underestimation of the nutrient loads in this paper. Another main problem was the nutrient loads of bivalves. In this paper, we consider bivalve mariculture as a negative nutrient loads and subtract the N and P removed by bivalves from the total nutrient loads, while the calculation method was just opposite in Wang et al. (2020). As filter feeders, bivalves acquired their food (mostly, phytoplankton) directly from the water column, and part of them were released into water, which includes biodeposits (feces and pseudo-feces) and dissolved waste (such as ammonia); and part of ingestion food was utilized as growth, which was eventually harvested from the coast (Tang et al., 2011). The farming of bivalves begins with the seeding of spat and ends with harvesting. Therefore, nutrient extraction by bivalves represented a cumulative effect from bivalve feeding activity over the full growth cycle and could be readily quantified from harvest data (Petersen et al., 2016). Phytoplankton as the main food of bivalve has 2 sources, from primary production of local phytoplankton, and from transportation of out-

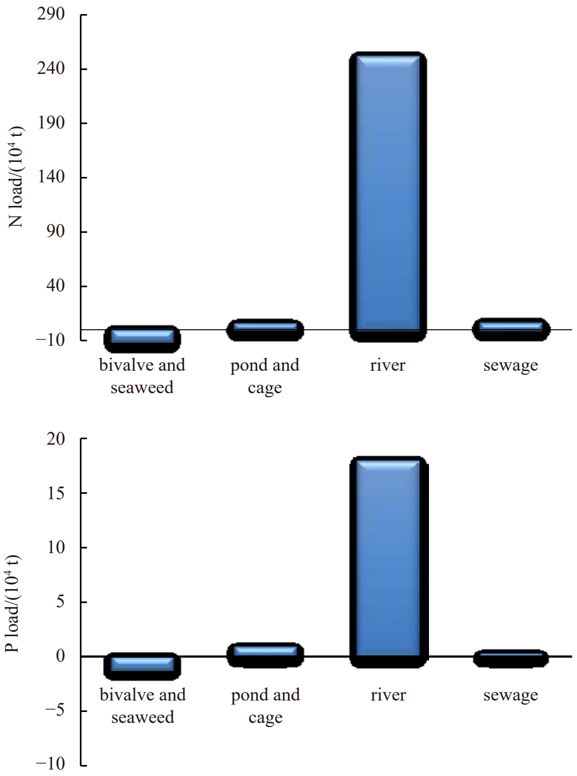

Fig. 3. N and P loads flux into the Chinese coast in 2019 (river and sewage's data from Ministry of Ecology and Environment of People's Republic of China (2020).

side phytoplankton (Sun et al., 2021). In area with relatively slow flow rate, phytoplankton mainly comes from local photosynthetic production. Bivalve cultivation sites are situated in nutrient-rich coastal areas mostly, thereby taking advantage of high primary production rates to achieve rapid growth. Under excessive nutrient availability, filtration of phytoplankton may help to prevent or overcome eutrophication problems (Brigolin et al., 2009; Ferreira et al., 2014). While the area with higher flow rate, usually in relatively open area, phytoplankton mainly comes from transportation outside the farming area. In such harsh areas, most of biodeposits from bivalve can be transported to outside and the amount that settled in the bottom bed of farming area is limited. According to current research reports, after more than 30 a of longline bivalves and seaweed culture in the Sanggou Bay, the organic pollution of the sedimentary environment is very light (Zhang et al., 2020b). Recently, Bivalve farming was widely considered to be an efficient means of nutrient removal in coastal areas affected by eutrophication as a result of the consumption of anthropogenic sources of N and P contained within phytoplankton and the sequestration of these excess nutrient into harvestable bivalve biomass (Petersen et al., 2016).The major eco-physiological pathways in bivalves interact with coastal nutrient cycling are filtration, growth, excretion and biodeposits. It is complex process that closed with local environment and culture density, the excretion and biodeposits regeneration of nutrient could stimulate the growth of phytoplankton (Ferreira et al., 2014). It will overestimate the nutrient loads of bivalve and even led to the opposite of positive and negative results, if only focus on excretion and biodeposition process. Therefore, we think it is better not to consider the process and just look at the result. Wang et al. (2020) estimated the nutrient loads of bivalves by the approach of "growth-excretion-biodeposition", which is one of the reasons that results are significantly higher than this article.

Water quality was a critical component of health and welfare for marine organisms. Nutrient concentration and ratio could affect the composition, structure, dominance, growth, and biomass of planktonic communities and in farther the food web dynamics in the ecosystem (Oh et al., 2015; Price et al., 2015; Dempster et al., 2011). These results demonstrated mariculture may lead to changing element ratios (Table 5). The effects of bivalve mariculture on nutrient fluxes were complex (Sarà et al., 2011). If only consider part of their physiology, the results were different. For example, bivalves consume P and N in phytoplankton, and sometimes these nutrient remain undigested and accumulate in the benthic environment as biodeposits (Newell, 2004). Contrarily, bivalves can accelerate the N cycle via ammonia excretion (Dame, 1996) and benthic remineralization (Grant et al., 1995). These results showed that bivalve and seaweed culture could remove N and P from the coast of China, and the removed N:P were 35:1 and 12:1 for bivalves and seaweed farming, respectively (Table 3). As a result, bivalves farming could decrease the N:P of the water body by harvest which is consistent with report (Nixon et al, 1996). In contrast, seaweed farming could increase the N: P of water. The N and P released into the water body could pass through a complex biogeochemical process, including transport and transformation process, dictated the distribution and final fate. In terms of the total N and P, mariculture not only affected the N and P concentration in the receiving system but also affected its molar ratio. Different farming types had different effects. These results demonstrated that integration of different types of culture species could help to regulate the amounts of N and P, and N/P ratio, and reduce the environmental impact of mariculture.

It was reported that causal linkages between farming and eutrophication at the bay scale had been difficult to establish (Price et al., 2015). In this study, we got the same results. From the perspective of each region, the N and P loads of mariculture were distributed in southern regions (including Hainan, Guangxi and Guangdong) (Fig. 2), where the water quality was in the state of first-class water quality (Ministry of Ecology and Environment of People's Republic of China, 2020). Rivers were the main source of N and P loads (Fig. 3), especially the Changjiang River and the Huanghe River Estuary were the severe eutrophication area in China, although mariculture in these areas was a negative discharge of N and P. We suggested increasing the amount of seaweed and bivalve farming in the areas of the river estuary.

The N and P loads of mariculture were negative from a national perspective, however, some regions such as Hainan and Guangxi had relatively large positive loads, and the N:P of some regions seriously deviated from the Redfield ratio (16:1) (e.g., in Zhejiang, the total N: P ratio was 81), which should be paid more attention. Through the large-scale concerns and understanding, it is recommended to control the N and P loads and N: P ratio through integrated farming of different trophic species. For Hainan and Guangxi, we suggested decreasing the amount of fed-type culture and appropriately increasing the extractive culture species. Generally, the development of China's mariculture was relatively sustainable, and the mode and structural characteristics might be a good reference for other countries.

5 Conclusions

Although China was the largest and one of the fastest-growing mariculture countries in the world, the N and P loads from mariculture in coastal regions were negative from the national perspective. On the province scale, the nutrient loads which came from fed culture types were detrimental in Hainan and Guangxi; but in Shandong, Liaoning and Fujian, mariculture could remove N, P and C via bivalve and seaweed farming. Balancing different types of culture species could help to regulate the amount of N, P, and N: P ratio and reduce the environmental impact of mariculture. This article calculated overall results about N and P emissions from mariculture, and further research on local area effects (i.e., mariculture leads to the local accumulation of nutrient in sediment, and bivalves culture accelerates the nutrient cycle, etc.) is needed in the future.

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