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Impacts of anthropogenic activities on the Changjiang (Yangtze) estuarine ecosystem (1998–2012)

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Abstract

Estuarine ecosystem has greatly changed in the recent decades due to anthropogenic perturbations in the Changjiang Estuary. Change patterns and impact factors were analyzed based on the continuous data in relation to the Changjiang estuarine ecosystem from 1998 to 2012. The results showed significant decreases in plankton species and annual output of *Coilia nasus*, *Coilia mystus*. Furthermore, species and biomass of benthos showed abrupt change in 2003, downward before that and upward after that. It was noted that, *Eriocheir sinensis*, a high value commercial fish, had an annual production increase of 97%. Reduction of riverine nutrients, especially dissolved silicate (DSI) loads into the estuary could contribute to the decline in *Bacillariophyta* species. Dredging and dumping works of the North Passage led to the decreases in regional plankton species. However, the species reproduction and releasing projects could restore the estuarine ecosystem through increasing the output of *E. sinensis*, as well as species and biomass of benthos.

Key words: ecosystem, anthropogenic activities, Changjiang (Yangtze) Estuary

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1 Introduction

Estuaries located at the interface between land and ocean, have been widely considered to be the most productive and valuable aquatic areas in the world (McHugh, 1967; Selleslagh et al., 2012). These estuaries are also known as variable ecosystems, changing continually in relation to the interactions of physical, geological, chemical, and biological factors (McLusky and Elliott, 2004; Cardoso et al., 2010; Dauvin and Pezy, 2013). However, due to the impacts of intense anthropogenic activities from catchments (e.g., dam construction) and estuarine regions (e.g., harbor construction and navigational channel dredging), eutrophication, habitat modification and decreased numbers of species are becoming the major threats to the ecological integrity of the estuarine biodiversity (Golubkov and Alimov, 2010; Korpinen et al., 2012; Dauvin and Pezy, 2013). Most estuarine ecosystems have experienced heavy degradation, with reduced resources being provided to these areas for sustainability (Selleslagh et al., 2012; Dauvin and Pezy, 2013). Great attention has been paid to understand the consequences of anthropogenic activities on estuarine ecosystems (Dauvin and Pezy, 2013; Dai et al., 2011).

The Changjiang River (Yangtze River) is 6 300 km long and the largest river in China. It has a discharge rate of 960×10^9 m^3/a and a suspended sediment discharge (SSD) rate of 0.42×10^9 t/a (Chen et al., 2001). The abundant fresh water and SSD of the Changjiang River transport high nutrient loads into the estuary and adjacent East China Sea (ECS), which plays an important role in the ecosystem of the Changjiang Estuary and ECS (Dai et al., 2011; Wang, 2006; Gao and Wang, 2008). There have been studies on the Changjiang Estuary with respect to ECS microphytoplankton changes (Liu et al., 2013), model-based ecosystem analysis (Cheng et al., 2009), spatio-temporal variability of demersal fish (Chang et al., 2012), diversity of planktonic archaea (Zeng et al., 2007), and environmental changes in the estuarine region and ECS by anthropogenic impacts (Li and Daler, 2004; Li et al., 2007; Dai et al., 2011). However, only few research has investigated how interventions of anthropogenic activities from upstream catchments and estuaries affect estuarine ecosystem in recent decades.

The Changjiang estuarine ecosystem is greatly impacted by the largest hydropower dam in the world, the Three Gorges Dam (TGD), and the largest estuarine hydraulic project in China, the North Passage (NP) Deep Water Channel Regulation Engineering (NPDWCRE). Due to the construction of TGD located far upstream in 2003 (Fig. 1a), river materials delivered into the estuary have changed considerably, including the rapidly decrease in SSD and loads of DSI (Dai et al., 2011). The NPDWCRE started in January 1998 and finished in 2011 (Fan and Gao, 2009), which was divided into three stages of continual dredging from a mean depth of less than 7 m to the present 12.5 m using trailing-suction hopper dredgers (Fan and Gao, 2009; Fan et al., 2012; Dai et al., 2013) (Fig. 1b). Apparent the Changjiang estuarine ecosystem is facing severe challenges due to substantial changes in riverine materials delivered into the estuary and large-scale dredging with dredged and dumped sediments over 80×10^6 t/a in the NP since 2010. With the newly available observation data, the objective of this paper is to investigate the ecosystem changes of

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*Corresponding author, E-mail: zjdai@sklec.ecnu.edu.cn the Changjiang Estuary during the years from 1998 to 2012 and to assess whether the influences of distal river catchments or the proximal local anthropogenic activities are affecting the ecosystem of the Changjiang Estuary. This study will be invaluable to the evaluation of the present Changjiang estuarine ecosystem and provide insights into the response of the ecosystem of the Changjiang Estuary and ECS to external anthropogenic activities.

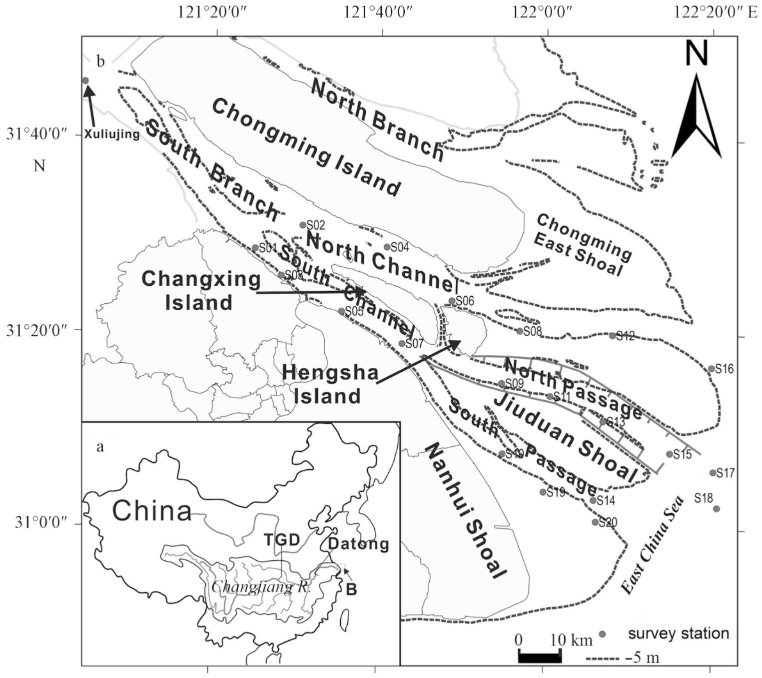

Fig. 1. The survey stations and study region.

2 Materials and methods

The environmental survey data of the Changjiang Estuary was implemented in the months of May or June, August or September from 1998 to 2012 (Fig. 1b). The two cruises were coincided with the normal river flow period and the flood season. Twenty survey stations were investigated for their environmental characteristics as well as planktonic and benthic communities. All records with occasionally missing data are obtained from the East China Sea Environment Monitoring Center (www.dhjczx.org/) and Shanghai Environmental Monitoring Center (SEMC) (www.semc.com.cn). Additionally, data on the mean annual catches of commercial fishes during 1998–2012 of the Changjiang Estuary including *Coilia nasus Temminck et Schlegel*, *Collia mystus Linnaeus*, *Eriocheir sinensis H. Milne-Edwards*, *and Anguilla japonica Temmincket schlegel* were collected from East China Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences (www.eastfishery.ac.cn/). The annual records of DSI and dissolved inorganic phosphate (DIP) at Xuliujing from 2002 to 2012 were also acquired from East China Sea Environment Monitoring Center, State Oceanic Administration (www.dhjczx.org/). The mean annual dredged volume amounts from 1999 to 2012 were from the Changjiang Estuary Waterway Administration Bureau (CJWAB), Ministry of Transportation (www.cjkhd.com).

Plankton samples were taken by vertically trawling from the seabed to the water surface at the speed of 0.5 to 0.8 m/s during the flood tidal periods. Phytoplankton samples were collected based on a shallow III type network (network length of 140 cm, net mouth diameter of 37 cm, network port area of 0.1 m^2, and silk screen model of JP80 or JF62). All phytoplankton samples were preserved with Lugol’s solution and analyzed by microscopy (SMM, 2007) in the laboratory. Zooplankton samples were collected with shallow I type net (net length 145 cm, net mouth diameter 50 cm, net mouth area 0.2 m^2, silk screen model JP12 or CQ14). Samples were fixed in 5% formalin solution and were taken back to the laboratory for mirror detection analysis (SMM, 2007). A box sampler was used to collect benthos samples four times per station. The average of four samples is considered to be the total biomass of benthos at each station. Benthos samples were further selected by a silk sieve and fixed in 5% formalin solution for species identification, weight analysis and count (SMM, 2007).

3 Results

3.1 *Changes in plankton*

The identified phytoplankton in the Changjiang Estuary from 1998 to 2012 is attributed to six divisions with 87 genera and 283 species (Table 1). Among these species, *Bacillariophyta* division had 198 species, which is the dominant division in the Changjiang Estuary. The identified phytoplankton species of each year from 1998 to 2012 showed the highest amount of 143 species in 1999 and the lowest amount of 36 in 2011 (Table 1). The structure of phytoplankton community is obviously simple, and had decreased by 60% from 126 species in 1998 to 50 in 2012. The species of the *Bacillariophyta* division decreased by 70% from 98 species in 1998 to 30 in 2012 (Table 1, Fig. 2a). However, the habitat density of phytoplankton fluctuated with a decrease from 12×10^3 units per m^3 in 1998 to 794 units per m^3 in 2005 and increase to 14×10^3 units per m^3 in 2012 (Fig. 2b). It seems that both species and density of phytoplankton had temporal and spatial differences, especially for the survey cruises in 2005 and 2012 which had relative high values in August and low values in May for phytoplankton elements (Tables 2 and 3). Phytoplankton elements showed high values in the seaward mouth (such as S17–S20) and bifurcated region of channels (S02–S04), and low values within the channels (S04, S06, S07).

Table 1. The annual changes in phytoplankton, zooplankton, and benthos between 1998–2012

Attributes		1998	1999	2000	2002	2003	2005	2007	2008	2009	2010	2011	2012
Phytoplankton	*Cyanophyta*	6	9	10	6	8	1	8	6	6	4	3	5
	Cryptophyta	–	1	2	0	0	0	0	0	0	0	0	1
	Bacillariophyta	98	101	41	40	37	65	56	51	36	40	26	30
	Chlorophyta	15	21	10	11	7	3	10	8	8	8	3	8
	Pyrrophyta	6	8	1	3	2	12	3	5	5	4	4	5
	Euglenophyta	1	3	2	0	0	0	2	0	1	1	0	1
Zooplankton	*Protozoa*	8	5	1	2	2	0	0	0	0	0	0	0
	Rotifera	6	18	14	17	12	0	2	7	6	10	3	0
	Pelagic Cladocera	7	2	6	11	16	1	2	11	6	10	9	6
	Copepoda	16	19	18	26	12	41	10	13	9	9	9	11
	Chaetognatha	3	4	6	1	2	3	3	2	2	1	1	2
	Decapoda	13	12	12	5	7	0	1	1	0	0	0	0
	the others1)	3	6	7	10	9	19	6	6	6	8	9	7
Benthos	*Pisces*	6	–	9	12	7	–	19	17	21	13	18	16
	Annelida	6	–	0	2	2	–	0	0	1	3	1	0
	Mollusca	2	–	1	6	3	–	8	16	11	10	10	9
	Crustacea	9	–	8	8	10	–	15	25	14	12	21	21
	Coelenterata	0	–	2	1	0	–	2	1	1	3	0	1
	Echinodermata	0	–	0	1	1	–	1	0	1	2	2	0
	the others1)	1	–	0	1	0	–	1	0	0	1	0	0

Note: 1) The identified species is less than 2.

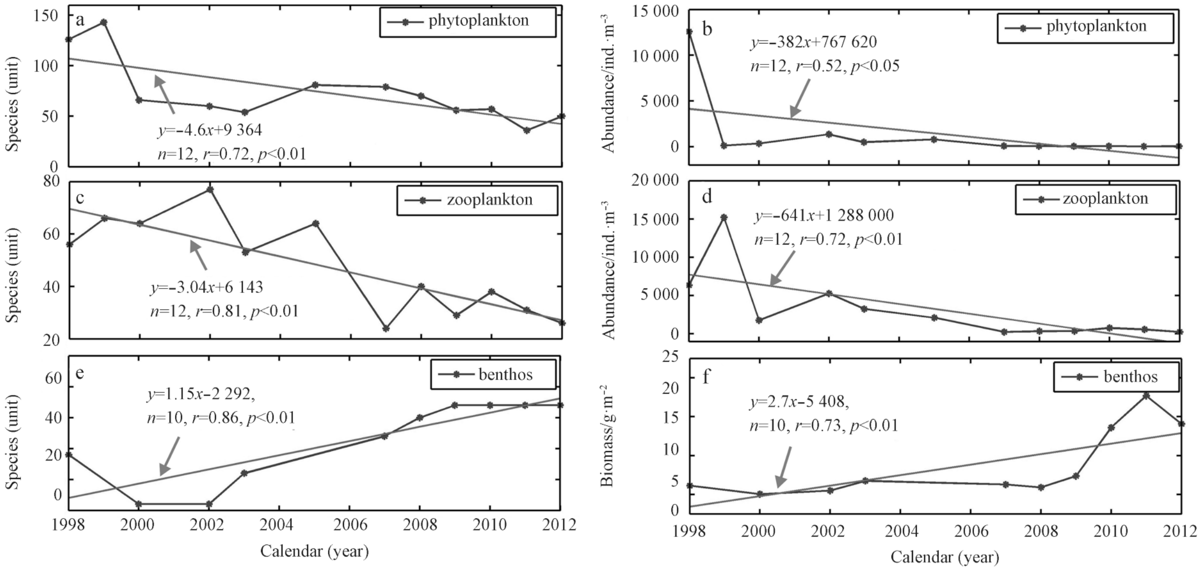

Fig. 2. Changes in phytoplankton species (a) and habitat densities (b), zooplankton species (c) and habitat densities (d), and benthos species (e) and biomass (f).

From 1998 to 2012, the identified zooplankton in the Changjiang Estuary had 16 divisions and 148 species (Table 1). The community structure of zooplankton showed significant changes in species abundance, which decreased by 54% from 56 in 1998 to 26 in 2012 (Table 1, Fig. 2c). Several species, including decapod and protozoan, had not been found since 2009. Additionally, there were obvious decreased trends in zooplankton habit density from 1998 to 2012, with the highest of 15 200 units per m^3 in 1999 and the lowest of 251 units per m^3 in 2012 (Fig. 2d). This indicates that zooplankton habitat density dropped dramatically by 85% from 1999 to 2012 (Fig. 2d). Meanwhile, in comparison with those of phytoplankton, changes in species and density of zooplankton presented seasonal differences with high values in normal condition and low values in flood season (Tables 2 and 3). The spatial variations of zooplankton in the Changjiang Estuary were similar to those of phytoplankton (Tables 2 and 3).

3.2 *Changes in benthos*

The identified benthos in the Changjiang Estuary during 1998–2012 can be divided into eight groups and 107 species, in which *Crustacea* is the dominant subphylum with 34 species identified (Table 1). Community structure of benthos in the observed years is mainly composed of *Pisces*, *Crustacea*, and *Mollusca*, which was relatively stable (Table 1). The occurrences of benthos for each year in the Changjiang Estuary ranged from 20 to 59, with the highest species count in 2009 and the lowest in 2000. Additionally, there is an obvious increasing trend for benthic species abundance from 2007 to 2012 compared to those from 1998 to 2005 (Table 1, Fig. 2e). It was also observed that benthic species abundance increased from 20 in 2000 to 47 in 2012 as a result of increases in species of *Pisces*, *Crustacea*, and *Mollusca* (Table 1).

Benthos biomass in the Changjiang Estuary was relatively low with averages of approximately 15 g/m^2 during the observed years (Fig. 2f). The annual benthos biomass during 1998–2008

Table 2. The observed basic elements for zooplankton, phytoplankton, and benthos in May, August, 2005

	Zooplankton				Phytoplankton			
	Species		Abundance/ind.·m^{-3}		Species		Abundance/ind.·m^{-3}	
	May	Aug.	May	Aug.	May	Aug.	May	Aug.
S01	12	2	143	9	13	4	103	3 612
S02	12	5	150	10	11	5	59	26
S03	4	4	178	6	14	4	46	32
S04	2	6	107	8	9	4	41	149
S05	4	7	204	11	12	5	59	352
S06	5	9	110	15	14	6	69	524
S07	4	6	22	12	14	2	49	353
S08	5	7	208	28	12	5	59	696
S09	6	9	46	9	16	4	93	686
S10	5	10	58	64	13	5	57	459
S11	7	8	308	73	12	5	61	713
S12	6	11	86	420	12	9	81	242
S13	8	6	93	65	11	6	83	913
S14	7	18	81	626	14	17	413	675
S15	11	9	158	281	4	8	4	1 006
S16	9	19	456	102	13	18	31	390
S17	10	9	270	94	23	25	287	1 036
S18	10	15	156	871	18	17	100	21 772
S19	8	6	296	562	16	12	166	864
S20	8	9	85	654	12	14	282	675

Table 3. The observed basic elements for zooplankton, phytoplankton, and benthos in May, August, 2012

	Zooplankton				Phytoplankton				Benthos			
	Species		Abundance/ind.·m^{-3}		Species		Abundance/ind.·m^{-3}		Species		Abundance/ind.·m^{-3}	
	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.
S01	4	2	192	2	3	13	2	229	3	2	7 632	156.44
S02	5	2	50	1	7	10	15	88	1	1	18.44	33.72
S03	4	1	43	0	6	10	14	17	2	1	22.8	5.68
S04	2	2	2	1	6	11	10	166	2	1	83.68	8.6
S05	6	1	113	1	10	11	247	257	1	1	8.6	7.12
S06	6	1	39	1	7	13	65	210	1	2	61.88	15.56
S07	4	3	36	9	6	10	13	982	1	1	21.92	41.36
S08	4	4	104	23	7	16	38	1 925	1	0	33.32	0
S09	5	2	44	2	10	12	148	74	2	2	92	49.16
S10	9	6	243	105	6	13	27	6 435	2	2	21	20.24
S11	7	2	110	2	5	10	140	338	1	1	11.4	49.48
S12	7	6	458	190	5	16	63	9 347	1	3	75	53.64
S13	7	5	2 242	96	7	10	104	575	2	2	68.88	40.44
S14	11	12	190	251	5	12	58	1 156	2	1	5.2	1.24
S15	8	6	472	192	9	9	59	264	3	1	52.2	33.32
S16	9	7	67	112	7	16	59	19 109	4	3	59.48	10.8
S17	6	5	72	426	5	10	47	656	1	2	11.56	34.44
S18	10	8	564	186	8	13	19	1 094	0	1	0	73.52
S19	10	4	112	70	6	14	208	2 287	1	1	61.72	6.08
S20	10	9	206	432	7	9	314	791	1	1	4 132	1.4

remained relatively stable with a range of 0.2 to 5.0 g/m^2. However, from 2008 to 2012, the annual benthic biomass showed a rapid increase from 3.64 g/m^2 in 2008 to 36 g/m^2 in 2012 (Fig. 2f). Moreover, both species and biomass of benthos were relatively higher in normal condition than flood season (Table 3).

3.3 *Changes in commercial fishes*

The most important commercial fish in the Changjiang Estuary consists of *Coilia nasus*, *Coilia mystus*, *Eriocheir sinensis*, and *Anguilla japonica*. However, these commercial fish have experienced great changes in recent decades due to impacts of the intensive anthropogenic activities in the Changjiang Estuary.

The annual output of *Coilia nasus* decreased from 208 t in 1998 to 7 t in 2012 (Fig. 3a). This trend indicates a reduction of 97% in the observed years. Although the annual output of *Coilia nasus* was 300 t in 2001, the average annual output was 182 t for the years 1998 to 2002 (Fig. 3a). In the subsequent years from 2003 to 2012, the annual output of *Coilia nasus* is decreased further to less than 60 t. The lowest output values of 10 and 7 t occurred in 2011 and 2012, respectively (Fig. 3a).

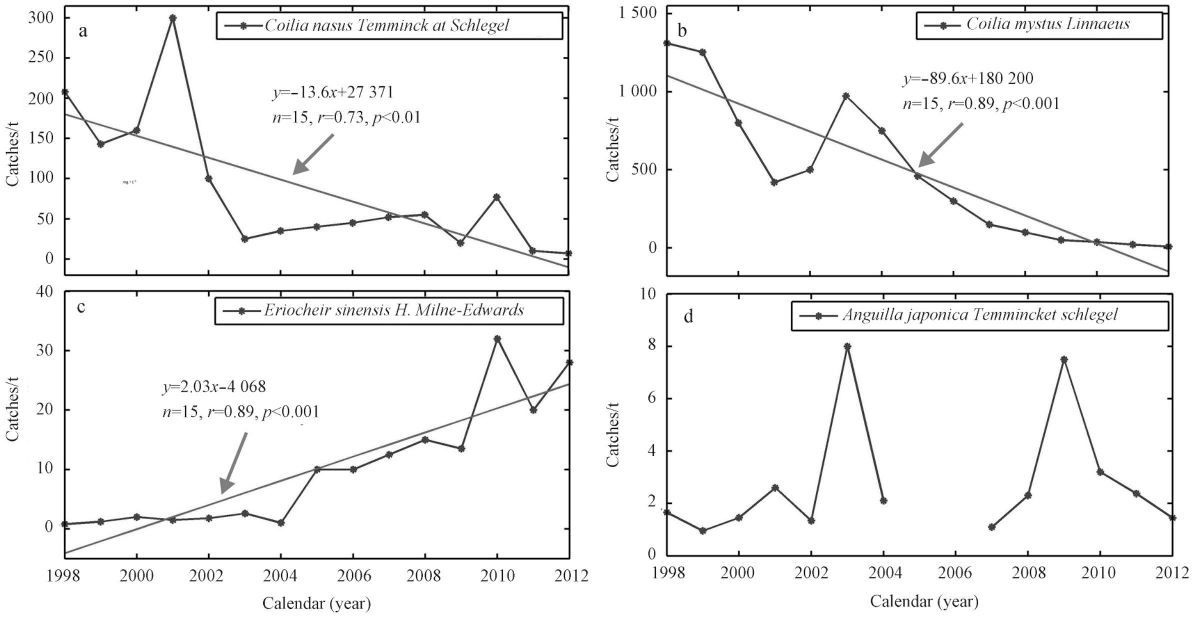

Fig. 3. Catches of commercial fishes in the Changjiang Estuary.

The output of *Coilia mystus* showed similar decrease in the observed years as those of *Coilia nasus*. From 1998 to 1999, the annual output of *Coilia mystus* was as low as 1 282 t. From 2000 to 2003, it further decreased by 50% compared to 1998–1999 (Fig. 3b). Additionally, a sharp reduction of the annual output of *Coilia mystus* occurred during the years 2003 to 2012 (Fig. 3b) with a low value of 8.2 t in 2012.

The annual output of *Eriocheir sinensis* increased 97%, with 0.8 t in 1998 and 28 t in 2012 (Fig. 3c). Between 1998 and 2004, the annual output of *Eriocheir sinensis* ranged from 0.8 to 2.6 t with an average of 1.56 t. Between 2005 and 2009, the annual output of *Eriocheir sinensis* increased by 12.2 t with a range of 10 to 15 t. Between 2010 and 2012, there was an obvious increase in the annual output of *Eriocheir sinensis*, with an amount of 27 t (Fig. 3c). Whereas, *Anguilla japonica* is evenly distributed over the Changjiang Estuary and had a relatively stable annual output with an average of 1.9 t from 1998 to 2012, except for two abnormal years that showed outputs of 8 t and 7.5 t in 2003 and 2009, respectively (Fig. 3d).

4 Discussion

4.1 *Impacts of nutrients from catchment into the estuary*

The riverine nutrient materials flowing into the Changjiang Estuary have great impacts on the Changjiang estuarine environment that include a shift of phytoplankton, decreases in siliceous alga and the minimum dissolved oxygen (Dai et al., 2011). The DSI concentration decreased by 15% from 3.17 mg/L in 2002 to 2.66 mg/L in 2012, which showed clearly downward trend between 2002–2012 (Fig. 4a). In contrast, DPI concentration increased by 20% from 2002 to 2012, showing a clearly upward trends during the observed period (Fig. 4b). Moreover, the previous study showed the same trends from 1990s to 2008 (Dai et al., 2011). Increased DPI and DIN indicated that riverine nutrient (DIN, DIP) materials were likely dominated by chemical fertilizer usage in the Changjiang River basin (Li et al., 2007; Dai et al., 2011). It indicated the effects of DIN and DIP increases on Changjiang aquatic eutrophication with shifted compositions of nutrients and phytoplankton (Li et al., 2007). Meanwhile, there was much more nonsiliceous algae growing in the Changjiang Estuary (Li et al., 2007).

With respect to the aquatic ecosystem, these changes have significant impact on the silicon cycle which, in turn, has affected the primary productivity of the estuarine phytoplankton and ecosystem structure (Smetacek, 1998; Li et al., 2007). Although studies had assessed the impact DSI loads on changes in algae in the Changjiang Estuary (Wang, 2006; Li et al., 2007; Dai et al., 2011), the collected data and time series on both DSI and siliceous alga species were relatively sparse and short.

Bacillariophyta is identified as one of the dominant species of phytoplankton in the Changjiang Estuary (Table 1). A linear regression analysis of relation between DSI loads and total species of *Bacillariophyta* shows that there is a close correlation with statistical significance (Fig. 5a). The sharp decreases in DSI from

Changjiang River basin have had serious impacts on the *Bacillariophyta* in the Changjiang Estuary, which is in agreement with the previously published results (Li et al., 2007; Dai et al., 2011). It can be expected that the community structure of phytoplankton in Changjiang Estuary could be further affected by a serious decrease of *Bacillariophyta* species in the coming decades due to decreasing DSI loads from the catchments. Moreover, when considering estuary water pollution, previous studies indicated that changes in estuarine nutrients caused by large scale fertilizer use of the Changjiang catchment should be determining factors in Changjiang estuarine ecosystem (Li and Daler, 2004; Wang, 2006; Li et al., 2007; Dai et al., 2011).

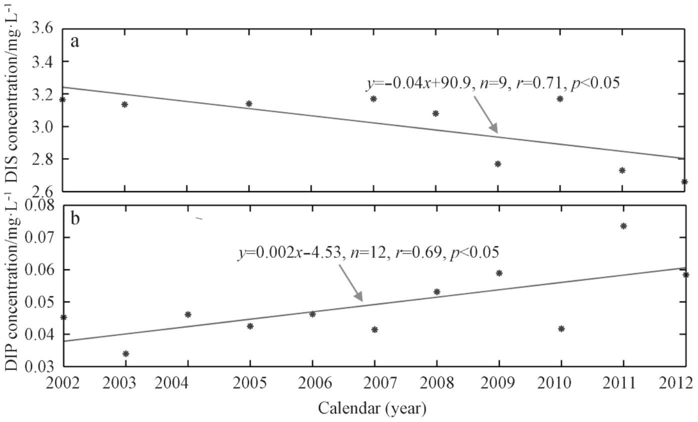

Fig. 4. Changes in DSI and DIP concentrations during 2002–2012.

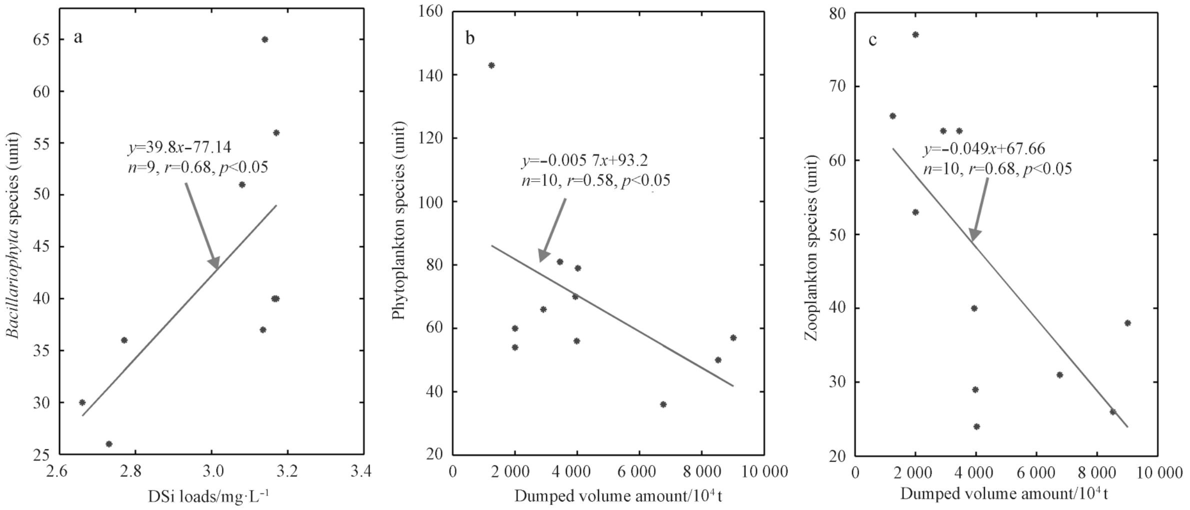

Fig. 5. Plots of *Bacillariophyta* species vs. DSI loads (a), phytoplankton species vs. dumped volume amount (b), and zooplankton species vs. dumped volume amount (c).

4.2 *Impacts of estuarine dredging and dumping works*

The NPDWCRE may cause further changes in the habitat environment of aquatic organism by channel dredging and dumping. The mean yearly dredging and dumping volumes of the NPDWCRE were 20×10^6 m^3 during 1999–2003, 34×10^6 m^3 during 2004–2006, and 81×10^6 m^3 during 2010–2012 (Table 4). It was obvious that dredging and dumping volumes from 1999 to 2012 showed upward changing trends (Table 4). A simple linear regression analysis revealed significant negative correlation between the yearly dredging and dumping volumes and phytoplankton species (Fig. 5b). The increasing dredging and dumping volumes in sediments will affect light penetration and nutrient release into the water that, in turn, influence species and amounts of plankton. The suspended sediment concentrations (SSC) of the water in the North Passage was largely increased by the operation of dredging and dumping work, which reduced transparency of the water and further impacted phytoplankton photosynthesis (Gardner, 1981; Jiang et al., 2010). Therefore, several species of phytoplankton could be inhibited due to increased SSC of the water. However, dredging and dumping work will also bring lots of nutrients and microelements into the surface water, which could promote the growth and reproduction of some phytoplankton species with corresponding increase in habitat density.

There is high negative correlation between dredging and dumping volumes and zooplankton species (Fig. 5c). Therefore, a decrease in zooplankton could likely be induced by large-scale dredging and dumping of the North Passage. Despite dredging and dumping, zooplankton species with selected foraging ability such as *Copepoda* could survive (Levine et al., 2005). However, even though the dumping may have a minor influence on zooplankton species with selected foraging ability, these species could be reduced by the long-term and large-scale dredging and dumping in the North Passage (Table 1). With respect to benthos, as they live on the ocean floor with limited movement, the dredging and dumping not only destroys the ocean floor environment but also the habitat they lived on, led to the dramatic decrease of benthos species in the Changjiang Estuary before 2003 (Table 1).

Table 4. Statistics of dumping in the North Passage of the Changjiang Estuary

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Dumped volume amount/10^4 m^3	1 247	2 914	1 990	2 000	2 000	3 800	3 444	3 003	4 022	3 937	3 980	9 008	6 762	8 521

4.3 *Eco-biological restoration works in the Changjiang Estuary*

While dredging and dumping work in the Changjiang Estuary have had serious impacts on the Changjiang estuarine ecosystem, a series of eco-biological restoration projects have been implemented during 2001–2008. Approximately 3×10^6 huge oysters were released in the Changjiang Estuary during 2003–2004. Nearly 260 hectares of artificial oyster reef systems have been constructed to provide a feeding habitat for different organism. There was an obvious increase in benthic species from 2007 to 2012 (Table 1, Fig. 2e). Additionally, fishery resource enhancement in the Changjiang Estuary were implemented in 2001, 2004 and 2008. There were 3 080 *Acipenser sinensis*, 25×10^3 *Eriocheir sinensis*, and 390×10^3 other fishes released to the Changjiang Estuary, resulted in the increases of *Eriocheir sinensis* after 2005. During 2010–2012, the yearly output of *Eriocheir sinensis* showed further increases of approximately 27 t. Therefore, eco-biological restorations through resource enhancement could somehow mitigate the damaged Changjiang estuarine ecosystem.

Although anthropogenic activities from catchment and estuary had great impacts on ecological environment, seasonal changes in water discharge of the Changjiang was one of the important factors affecting the species and density of plankton. The reproduction of plankton fluctuates with different nutrient amounts discharged into the Changjiang Estuary, i.e., high nutrients in flood season leads to high plankton reproduction (Mouny and Dauvin, 2002; Fernando et al., 2003; Kibirige and Perissinotto, 2003). In the bifurcated region and outer mouth, hydrotic condition is relatively mild compared with that in the channel (Yun et al., 2004), where more species and high density of the plankton and benthos possibly occur in the sluggish flow (Morgan et al., 1997; Lougee et al., 2002; Shen and Shi, 2002).

5 Conclusions

The Changjiang estuarine ecosystem has undergone substantial changes in recent decades due to intensive anthropogenic activities. In this study, changes in estuarine ecosystems in relation to plankton, benthos, and commercial fish from 1998 to 2012 were analyzed. The primary results can be summarized as follows:

(1) There was an obvious decrease in phytoplankton species. *Bacillariophyta* divisions, the dominant species of the Changjiang Estuary, had decreased by 70% and accounted for most of the decrease in phytoplankton species. However, phytoplankton habitat densities showed upward trends from 1998 to 2012.

(2) Both species and habitat densities of the zooplankton in the Changjiang Estuary show clear decreasing trends during 1998–2012. However, species and biomass of benthos showed fluctuations, with decreasing trends before 2003 and increasing trends from 2003 to 2012. Moreover, there was an accelerated decrease of over 50% in yearly output of *Coilia nasus*, *Coilia mystus* during 1998–2012, and an increase of 97% in yearly output of *Eriocheir sinensis*.

(3) DSI loads decreasing from catchment into the estuary could be responsible for decreased *Bacillariophyta* species. Dredging and dumping works of the NPDWCRE had substantial impact on the decrease of plankton species of the North Passage. However, projects of resource enhancement, i.e., species reproduction and releasing could enhance the output of *Eriocheir sinensis* and increased the species and biomass of benthic community.

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