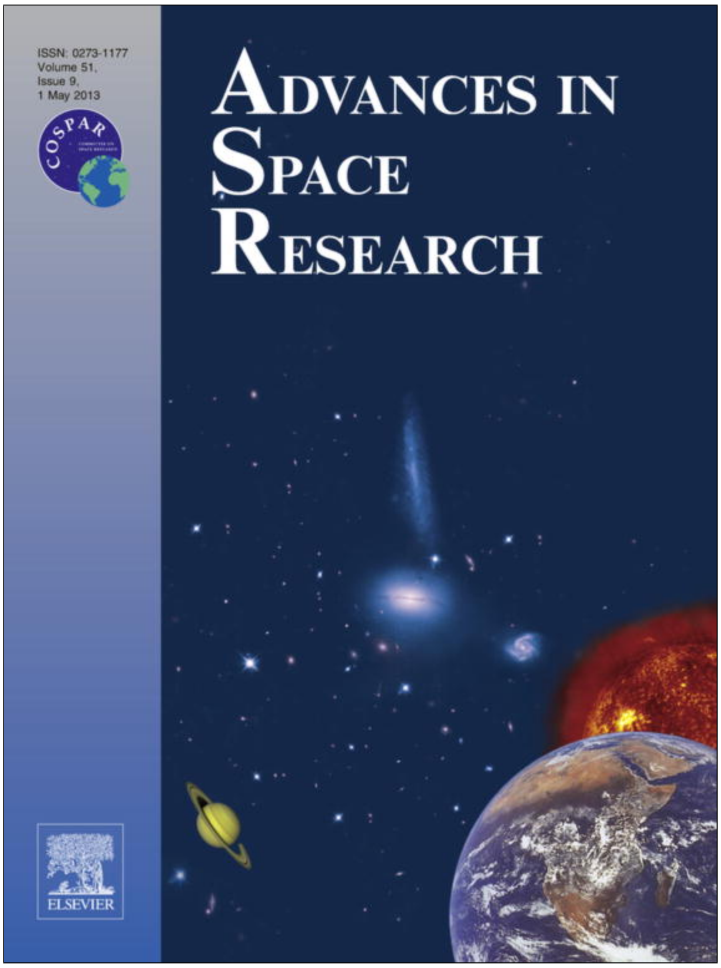
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Increase in fish abundance during two typhoons in the South China Sea

Jie Yu [a,b,c], Danling Tang [a,c,*], Yongzhen Li [b], Zirong Huang [b], Guobao Chen [b]

[a] Research Center for Remote Sensing of Marine Ecology and Environment, State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanography, Chinese Academy of Sciences, Guangzhou 510301, PR China

[b] Scientific Observing and Experimental Station of South China Sea Fishery Resources and Environments, Ministry of Agriculture, South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou 510300, PR China

[c] University of Chinese Academy of Sciences, Beijing 100049, PR China

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Abstract

A fish monitoring program was conducted in the northern region of the South China Sea from March 2009 to December 2010. During this period, two typhoons, GONI and Koppu, hit this region consecutively in August and September 2009. The fish and satellite data were analyzed to understand the influence of the typhoons on fish activities. The results showed that the fish species number (FSN) increased by approximately 14.29% and 14.81% after the two typhoons, GONI and Koppu, respectively. The five increased fish species included three estuarine species and two shallow sea species. However, one shallow sea species was also absent. In the nearshore (near the Pearl River Estuary) and offshore (along the typhoon's track) regions after GONI, the FSN increased by approximately 24% (nearshore) and 52.63% (offshore), with estuarine species accounting for 42.86% (nearshore) and 33.33% (offshore) of the fish species; after Koppu, the FSN increased by approximately 15.38% (nearshore) and 163.64% (offshore), with estuarine species accounting for 60% (nearshore) and 26.32% (offshore) of the fish species. In the increased records, small and medium-sized fish species were dominant nearshore, and small fish species were dominant offshore. The FSN increased to a maximum value between the 5th and the 10th days after the typhoon nearshore and between the 3rd and 8th days after the typhoon offshore. The results indicated that river discharge, triggered by the typhoon's nearshore rainfall, as well as offshore upwelling nutrients, also triggered by the typhoons, and may have played important roles in the variability of fish species. This research found that the increase in the FSN was associated with the typhoons in the northern South China Sea.

Keywords: Typhoon; Fish species number (FSN); South China Sea

1. Introduction

The marine environment can be disturbed by large-scale weather events, such as typhoons (Zheng and Tang, 2007; Yang and Tang, 2010), cyclones/hurricanes (Gautam et al., 2005; Hagy et al., 2006; Kundu et al., 2001; Lohrenz et al., 2008), earthquakes and tsunamis (Singh et al., 2001, 2007; Tang et al., 2004a; Tang et al., 2009; Yan and Tang, 2008). Changes in the habitat of aquatic animals are attributed to direct or indirect damage to the stability of the community (Andrews, 1973; Boesch et al., 1976; Jury et al., 1995; Locascio and Mann, 2005).

In estuaries, the strong winds and rainfall that are caused by typhoons result in increased freshwater inflow, low dissolved oxygen (Guo et al., 2000) and changes in the water quality and water temperature, all of which may affect the fish community. The immediate changes in the aquatic habitat, cause marine species to escape or perish and estuarine species to increase in number, can alter the fish community and composition (Greenwood et al., 2006; Switzer et al., 2006). Similar results

* Corresponding author at: Research Center for Remote Sensing of Marine Ecology and Environment, State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanography, Chinese Academy of Sciences, Guangzhou 510301, PR China. Tel./fax: +86 20 89023203.

E-mail address: lingzistdl@126.com (D. Tang).

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are also found near coral reefs (Kaufman, 1983; Adams, 2001). The broken coral reefs can cover some sedentary species, leaving some less visible fish exposed, changing the fish community and composition accordingly (Letourneur et al., 1993; Adams and Ebersole, 2004; Hernández et al., 2008).

Weak typhoons can also induce upwelling and bring nutrients to the surface waters from the bottom (Walker and Leben, 2005; Sun et al., 2010; Zhao et al., 2009). Our previous research also indicated that phytoplankton bloom after typhoons and enhance primary production (Chen and Tang, 2012; Zheng and Tang, 2007; Tang et al., 2004b; Zhao et al., 2009). It is still unclear whether typhoons can affect the Pearl River Estuary (PRE) and offshore, in the northern South China Sea (SCS). Specifically, it is still not known what effect typhoons may have on the FSN.

In this research, by taking advantage of a long-term monitoring program in the northern SCS, we not only analyzed the in situ monitoring data to investigate the impact of the typhoons on the fisheries but also analyzed the satellite data to understand the oceanic parameters for interpreting the mechanisms. Two typhoons (GONI and Koppu) triggered rainfall and upwelling nearshore (just on the mouth of the PRE) and offshore and were compatible with the extent of the fish monitoring program. These factors offer us a valuable opportunity to complete the research.

Typhoons GONI and Koppu, with different intensities, hit the SCS on August 3 and September 13, 2009 (Fig. 1(b)). Our research focuses on the changes in the FSN during these two typhoons.

2. Study area, data and methods

2.1. Study area

Covering an area of 3.5 million km^2, the SCS is located in the western Pacific Ocean. This area is not only a

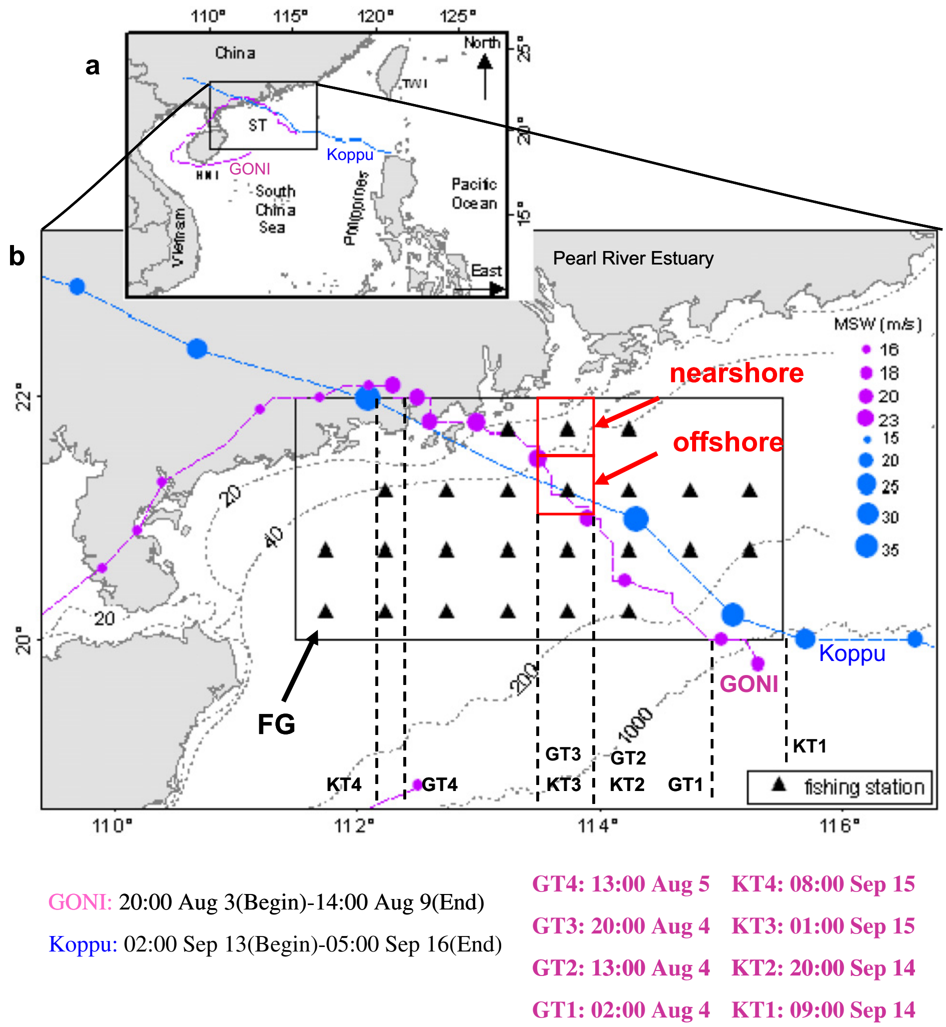

Fig. 1. (a) Location of study area (box ST) with two typhoons tracks. (b) Fishing stations and tracks of typhoons GONI and Koppu. HNI: Hainan Island; TWI: Taiwan Island; FG: Fishing Ground; Black triangles: fishing stations; Dashed lines: isobathic lines; MSW: maximum sustained wind (m/s); Purple disks and blue circles with the dashed line: typhoon paths; GT1 and KT1: the time typhoons GONI and Koppu arrived at FG; GT2 and KT2: the time typhoons GONI and Koppu arrived offshore; GT3 and KT3: the time typhoons GONI and Koppu left the offshore region; GT4 and KT4: the time typhoons GONI and Koppu left the FG. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

typhoon-dominated tropical sea with high primary productivity but also a crucial fishing region in China (Tang et al., 2008; Zhao et al., 2008; Zheng and Tang, 2007). According to its geological features and traditional fish distribution, the region is divided into the northern SCS continental-shelf fishing area, the northern SCS continental slope fishing area, the southern SCS continental shelf fishing area and the Xisha and Nansha islands fishing area (Ma et al., 2007). Our study area includes the coastal waters in the northeastern SCS and extends to both the northern SCS continental shelf and slope fishing areas, which are important traditional fishing grounds with water depths from 20 to 200 m (Fig. 1(a)). Our research mainly focuses on the western Guangdong Fishing Ground (Box FG, Fig. 1(b)), where we conducted a fisheries monitoring program from March 2009 to December 2010 (black triangle in Fig. 1(b)).

2.2. Data and methods

2.2.1. Analysis of fish data

We conducted a long-term tracking program (Oceanic Fishing Information Dynamical Collection, the work in the SCS was conducted by the South China Sea Fisheries Research Institute, SCSFRI) to evaluate the changes in fisheries resources from March 2009 to December 2010. To standardize the records for each net's production, we designed a special fishing log with the 43 most common commercial fish species in the SCS. Considering the differences in the scientific and popular names of the same fish, we used popular names in the log for the convenience of the fishermen and then converted these popular names into scientific names when they were entered into the database. The fishing logs were distributed to the fishermen at the beginning of 2009. An associated training was also conducted to help the fishermen learn how to fill in the fishing logs. The fishing data recorded in the logs and some auxiliary information such as date, trawling time and production value were entered into a network database at the beginning of each month. The original logs were then sent to SCSFRI by mail. To obtain the correct production data, fishing place and trawling time, all fishermen followed this fishing practice.

Fishing data from dual trawl boats (DTBs) in the study area were collected from March 2009 to December 2010, excluding the periods from the middle of May to the end of July in both 2009 and 2010 due to the Chinese fishing moratorium in the SCS. We used the central point of each small fishing region in an area of 0.25°∗0.25° to represent the fishing stations.

Initially, the FSN and Shannon Weiner index in box FG (Fig. 1(b)) were distributed by an average of three days to investigate the long-term variability. To understand how the FSN was affected by the typhoon, we analyzed the spatial distribution of the FSN before and after the typhoons. To understand the short-term effects of the typhoon, we compared the daily variation in the FSN nearshore and offshore before and after the typhoon.

Table 1
Information about DTBs.

No	Boat Name	Power(hr)	Fishing Period	Working Date(d)	Average Drawling time(h)
1	Y00040/00145	899	Apr 5 2009 to May 6 2009	12	5.21
2	Y00088/00812	721	Mar 2 2009 to May 13 2009	24	5.02
3	Y00572/00573	1368	Mar 2 2009 to May 11 2009	28	4.94
4	Y00813/00608	1244	Mar 16 2009 to May 9 2009	28	4.96
5	Y47148/47149	884	Apr 7 2009 to Nor 12 2010	71	11.06
6	Y04201/04202	1189	Mar 17 2009 to Aug 19 2010	75	4.89
7	Y04198/04199	1716	Mar 9 2009 to Apr 29 2010	80	4.58
8	Y00701/00702	779	Aug 1 2010 to Dec 23 2010	80	4.63
9	Y00595/00596	1354	Mar 4 2009 to Dec 22 2010	134	4.38
10	Y00008/00137	1058	Apr 1 2009 to Dec 20 2010	163	5.11
11	Y00413/00414	645	Mar 2 2009 to Dec 21 2010	199	4.19
12	Y42108/42109	1050	Mar 8 2009 to Dec 29 2010	219	6.28
13	Y47145/47146	426	Mar 5 2009 to Nor 25 2010	237	8.62

Fish species were divided into two groups: estuarine species (Li et al., 2000; Wang and Lin, 2006; Yang et al., 2005) and shallow sea species (Lei et al., 1981; Ji et al., 2007; Ou, 2009). Furthermore, we divided the catches into 3 size groups to evaluate the effect of typhoons on different length groups: fish with average body length (AVL) lower than 20 cm (S type), fish with 20 to 30 cm AVL (MS type) and fish with AVL larger than 30 cm (Table 3). The FSN was estimated for each size class.

2.2.2. Typhoon tracks and related environmental data

The typhoon data obtained from the Wenzhou Typhoon Delivery System (http://www.wztf121.com/) were used to represent the central position of the typhoons and the maximum sustained wind speeds.

The sea surface wind (SSW) data came from QuickScat and WindSat. QuickScat data from March 2nd to November 21st, 2009, and WindSat data from November 22nd to December 23rd, 2010, were obtained from JPL (http://podaac.jpl.nasa.gov/ and http://www.remss.com). To understand the temporal variation in wind, the time series of the SSW in the key region was evaluated every three days on average. The spatial and daily distribution of the SSW before and after the typhoons was used to indicate the typhoons' position and wind strength.

Rainfall data with a resolution of 0.25°∗0.25° were obtained from NASA (http://mirador.gsfc.nasa.gov/). The spatial and daily variation in rainfall before and after the typhoons was used to study the effect of the typhoons' precipitation.

The sea surface temperature (SST) data, with a resolution of 25 km, was merged from two microwave radiometers: Aqua AMSR-E, TRMM microwave imager (TMI), on board the Tropical Rainfall Measuring Mission (TRMM), and MODIS infrared (IR) data with a 9×9 km grid (http://www.remss.com). The three-day average SST over box FG (Fig. 1(b)) was calculated to illustrate the temporal change in SST from March 2009 to December 2010. The spatial and daily distribution of the SST was mapped to indicate the changes in water temperature affected by the two typhoons.

We obtained chlorophyll a (Chl-a) data from EESA (http://www.globcolour.info/). The resolution of this data is 4 km, merged from Meris, Modis, and SeaWiFs. The spatial distribution of Chl-a was measured to study daily variations during the two typhoons.

The sea surface current (SSC) data were obtained from NOAA (http://www.oscar.noaa.gov/). Satellite altimeter

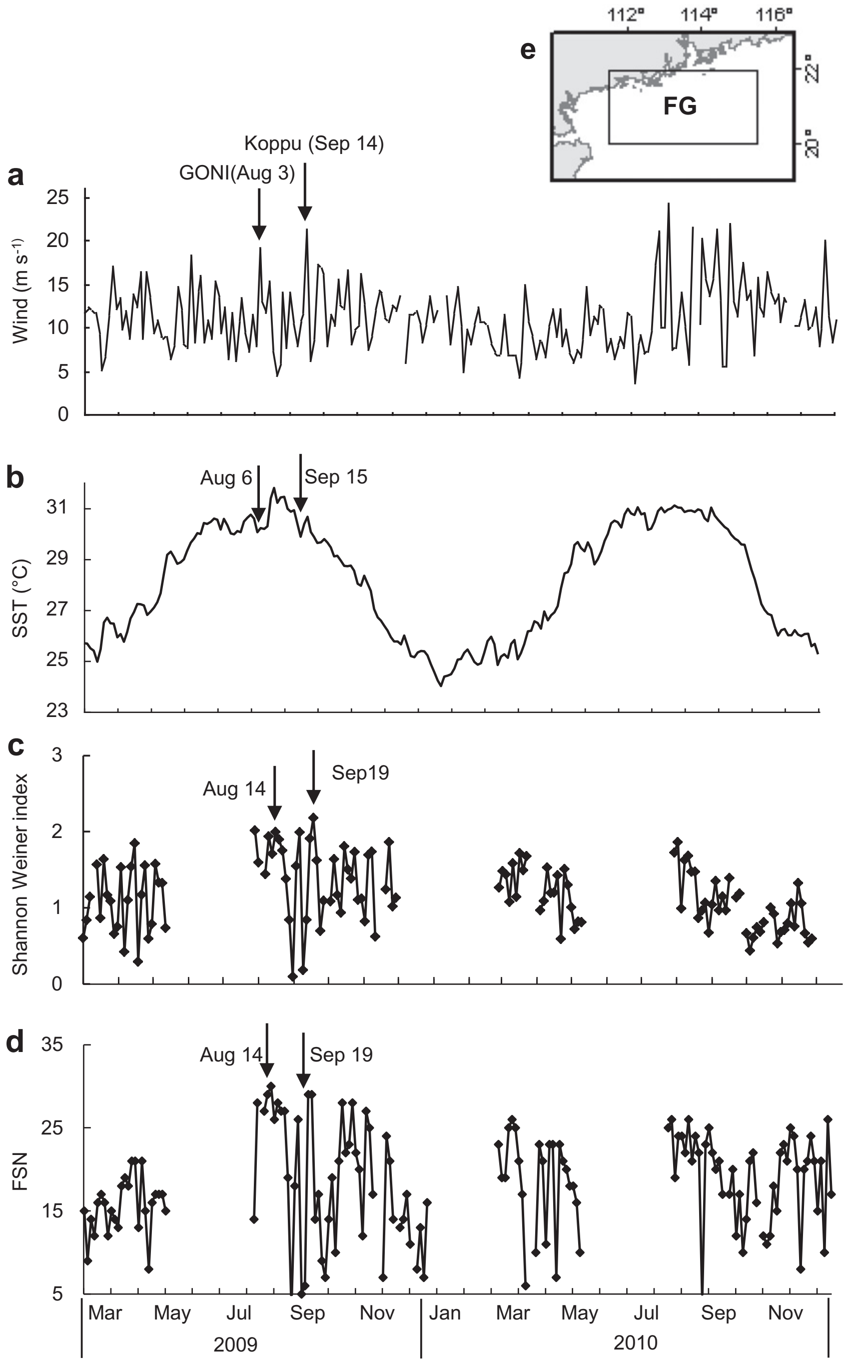

Fig. 2. Time series of three-day averaged FSN. (a) Wind speed (m s^{-1}), (b) SST (°C), (c) Shannon Weiner index, (d) FSN, (e) data averaged for the FG. Black arrows: the date of the two typhoons' occurrences (a), lowest SST (b) and maximum Shannon Weiner index (c) and FSN (d).

and scatterometer data provided by the OSCAR Project Office have a resolution of 100 km. The six-day average data were mapped to compare current conditions before and after the two typhoons.

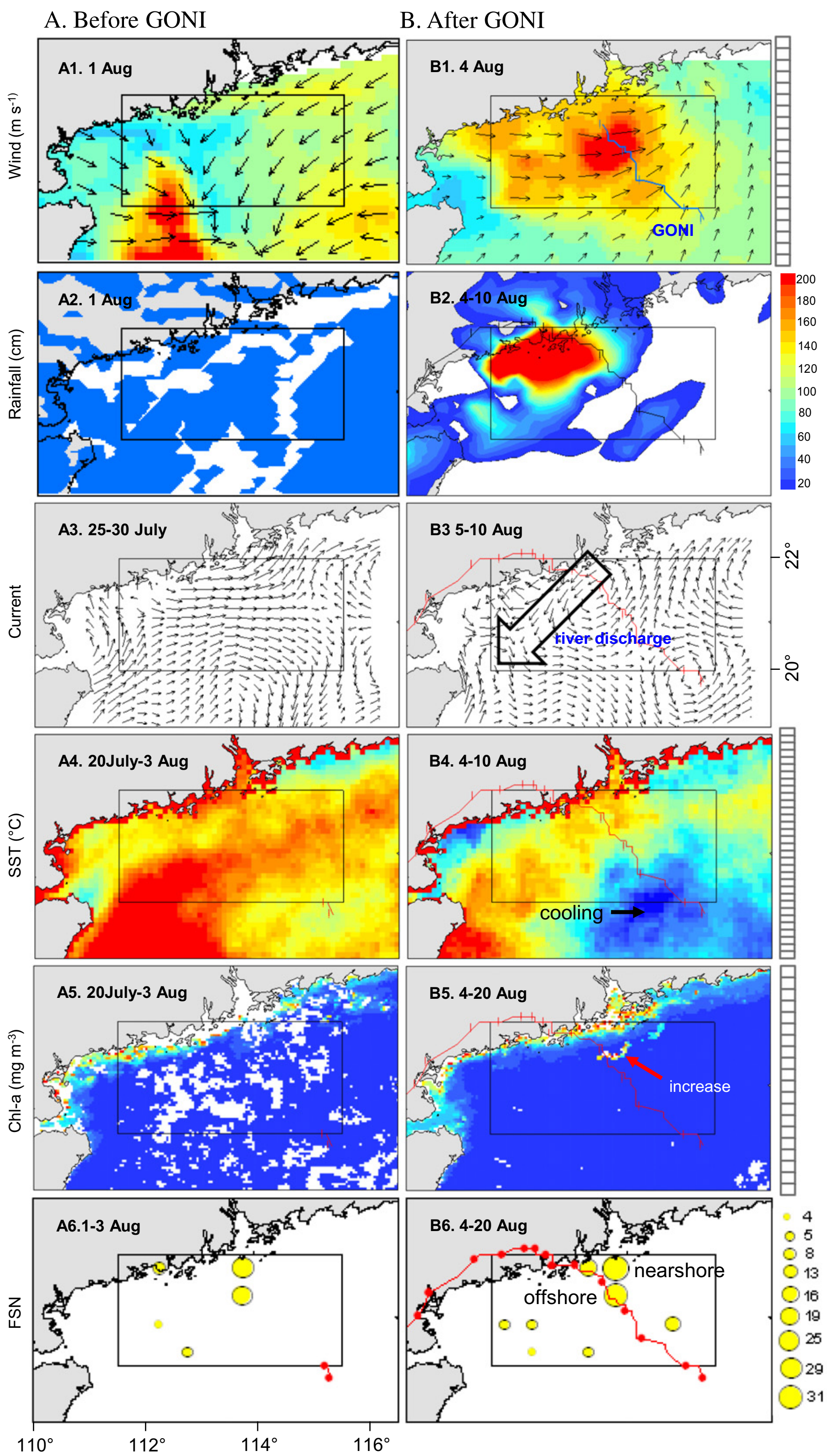

Fig. 3. Spatial distribution of wind (m s^{-1}), rainfall (cm), SSC, SST (°C), Chl-a (mg m^{-3}) and FSN. A are before typhoon GONI (A1, A2, A3, A4 and A5); B are after GONI (B1, B2, B3, B4 and B5).

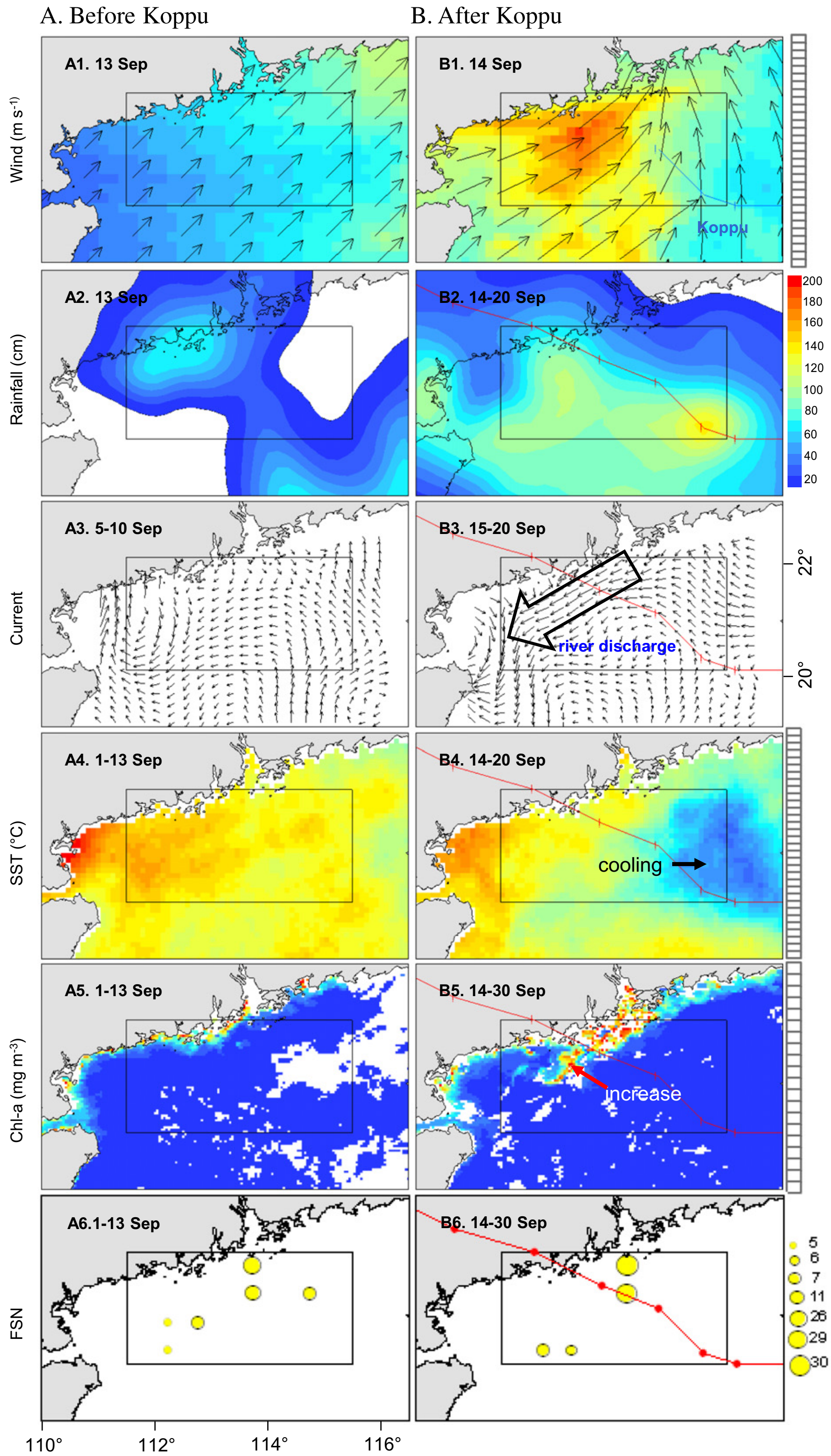

Fig. 4. Spatial distribution of wind (m s^{-1}), rainfall (cm), SSC, SST (°C), Chl-a (mg m^{-3}) and FSN before typhoon Koppu (A1, A2, A3, A4 and A5) and after typhoon Koppu (B1, B2, B3, B4 and B5).

3. Results

3.1. Boats and fishing stations

DTBs maintained stable fishing activity in our study area, FG. There were 13 DTBs participating in the research, with powers ranging from 426 to 1716 h (Table 1). All these boats with mesh size are about 40 mm and belong to the same province, they have similar gear selectivity (Yang et al., 2003). The length of fishing periods and the number of working days for each boat were unequal. Four DTBs (Y00040/00145, Y00088/00812, Y00572/00573 and Y00813/00608) provided data before the first typhoon, GONI, which helped us to accurately assess the fish species. The other nine DTBs provided data during the typhoon periods for 71 to 237 working days. The average drawl time (ADT) changed smoothly, except for boat Y47148/47149, which had an ADT of 11.06 h.

We had 24 fishing stations west of the Pearl River Estuary (PRE), uniformly distributed along isobathic lines from 20 to 200 m (Fig. 1(b)).

3.2. Two typhoons

GONI was a weak, Class-II typhoon and originated in the northern SCS (19.8 N, 115.3E) at 20:00 on August 3rd. It moved to the northwest with an initial maximum speed of 18 m/s. After following a half circle over China and the Beibu gulf, GONI ended over the southeastern HNI at 14:00 on August 9th (Fig. 1(a)).

Koppu began north of the Philippines and south of the Bashi Channel at 2:00 on September 13th. It was a Class-IV typhoon with an initial wind speed of 18 m/s. Koppu traveled northwest and was upgraded to a tropical storm between 10:00 and 16:00 on September 14th. It then became a typhoon, lasting until 9:00 on September 15th, and ending over the Chinese mainland at 5:00 on September 16th (Fig. 1 (a)).

The two typhoons, GONI and Koppu, passed box FG in Fig. 1(b) with speeds of 20–23 m/s from 13:00 to 20:00 on August 4th, 2009 and 33–38 m/s from 21:00 on September 14th to 3:00 on September 15th, 2009, respectively.

3.3. Temporal variations in the SSW, SST, Shannon Weiner index and FSN

The three-day average SSW was variable from March 2nd, 2009, to December 22nd, 2010. From August 2nd to September 15th, 2009, there were two peaks with high wind speeds due to typhoons GONI and Koppu on August 3rd and September 14th (Fig. 2(a)).

The three-day average SST increased in the beginning of the summer and then decreased to a low value by the end of the year in both 2009 and 2010. Many small serrations can be seen on the curve, including two valleys on August 6th and September 15th, 2009, just a few days after the two typhoons (Fig. 2(b)).

The three-day average Shannon Weiner index exhibit two peaks with value of 2.28 and 2.41 on August 14th and September 19th, 2009((Fig. 2(c)).)

The three-day average FSN from March 2nd, 2009 to December 22nd, 2010, displayed an irregular distribution. Two peaks, with values of 30 and 29, appeared on August 14th and September 19th, 2009, respectively (Fig. 2(d)).

3.4. Spatial variations in the marine ecological environment before and after the two typhoons

The SSW data for August 1st indicated that there was a weak wind in the FG region (Fig. 3(A1)). On August 4th, an SSW higher than 20 m/s gathered near the water, with 40 to 100 m isobaths outside the PRE (Fig. 3(B1)). Daily data from September 13th to 14th, 2009, indicated changes

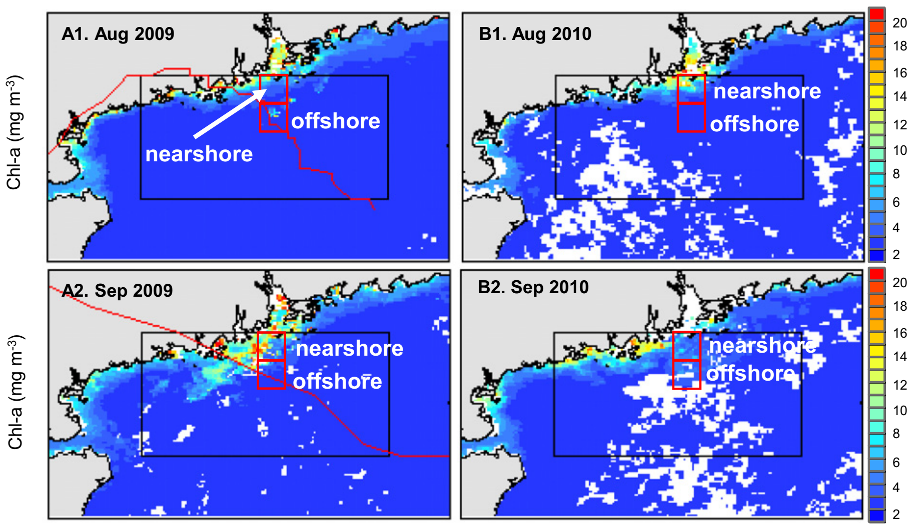

Fig. 5. Spatial distribution of Chl-a (mg m^{-3}) in August 2009 (A1), August 2010 (B1), September 2009 (A2) and September 2010 (B2).

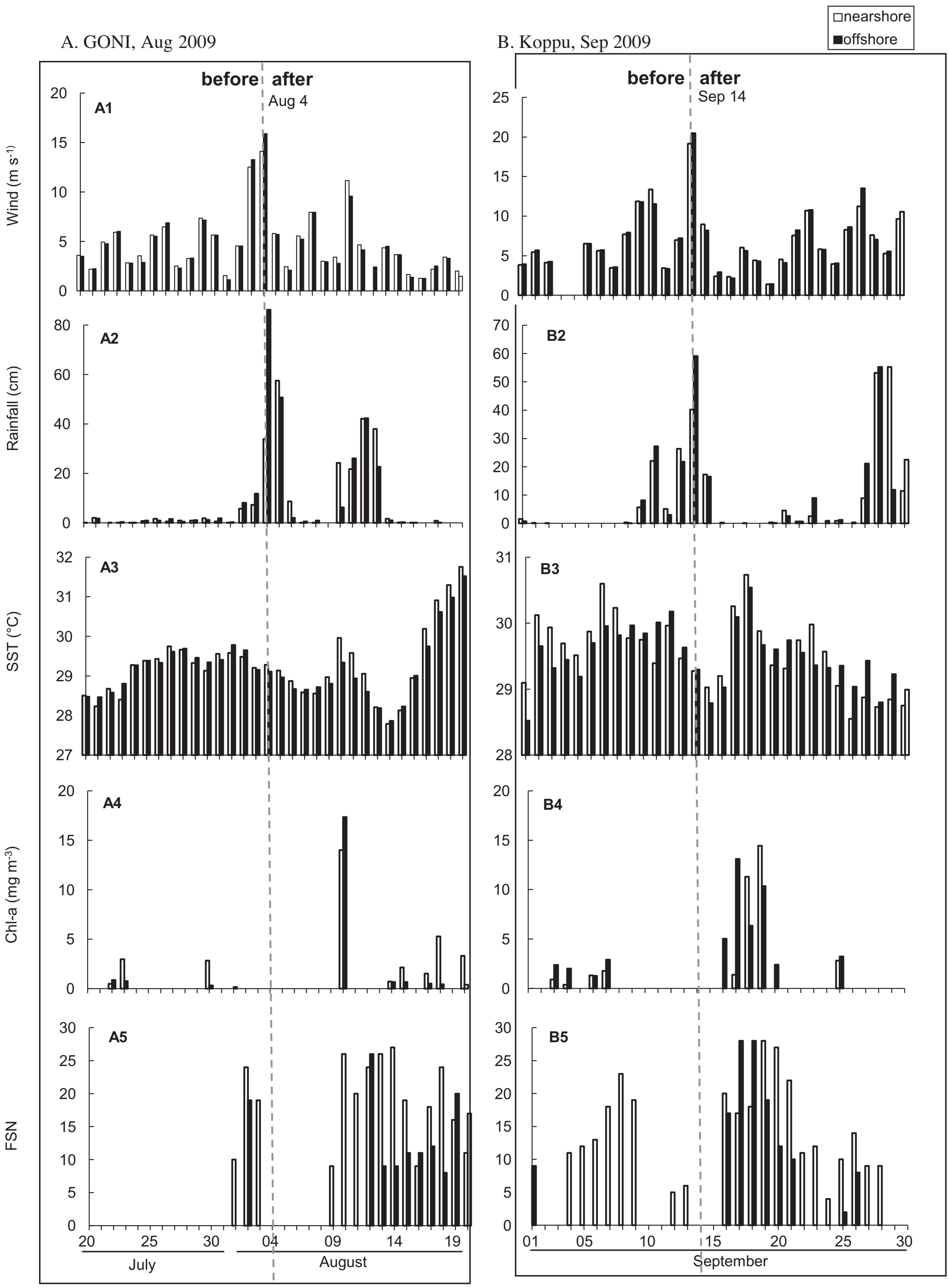

Fig. 6. Time series of wind (m s^{-1}), rainfall (cm), SST (°C), Chl-a (mg m^{-3}) and FSN. A: During typhoon GONI from July 20 to August 20th (A1, A2, A3, A4 and A5); B: During typhoon Koppu from September 1st to 30th (B1, B2, B3, B4 and B5). Blank bar represents the nearshore changes; Black bar denotes the offshore distribution; gray dashed lines indicate the occurrence of typhoons.

in the SSW before and on the day of the typhoon. An extremely high wind occurred on the day of the typhoon that was not observed on September 13th, 2009 (Fig. 4(A1–B1)).

Table 2
Changes in FSN. FR: fishing region; Total: the number of fish species; Increased record: increased records of fish species; Lost records: fish species that are not caught; Shallow sea: fish species mainly living in shallow sea areas; PRE main: fishes that are mainly found in the Pear River Estuary; P (%): percent increase compared to the original FSN.

Typhoon	FR	Before	After								
		Total	Total		Increased records					Lost records	
		Number	Number	P(%)	Total		Shallow sea	PRE main		Total	
					Number	P(%)	Number	Number	P(%)	Number	P(%)
GONI	WGFG	28	32	14.29	5	17.86	2	3	60	1	3.57
	Nearshore	25	31	24.00	7	28.00	4	3	42.86	1	4.00
	Offshore	19	29	52.63	9	47.37	6	3	33.33	1	5.26
Koppu	WGFG	27	31	14.81	5	18.52	2	3	60	1	3.70
	Nearshore	26	30	15.38	5	15.38	2	3	60.00	0	0.00
	Offshore	11	29	163.64	19	163.64	14	5	26.32	0	0.00

Table 3
Fish information. In 'No' column, e: estuarine fish species; s: shallow sea fish species; o: other species; In 'Distribution' column, estuary: main species in the PRE; shallow sea: main species in the northern SCS continental shelf; In 'size' column, S: fishes with an average body length less than 20 cm; MS: fishes with an average body length of 20–30 cm; M: fishes with an average body length greater than 30 cm. The name of shark and ray are defined in order term, the name of cephalopod and crab are defined to family term, the name of other fishes are defined in genus term.

No	Fish	Distribution	Size type	No	Fish	Distribution	Size type
e1	*Harpodon*	estuary	MS	s11	*Tetraodontidae*	shallow sea	MS
e2	*Ilisha*	estuary	MS	s12	*Leiognathus*	shallow sea	S
e3	*Nibea*	estuary	MS	s13	*Thamnaconus*	shallow sea	S
e4	*Collichthys*	estuary	MS	s14	*Nemipterus*	shallow sea	S
e5	*Johnius*	estuary	S	s15	*Parargyrops*	shallow sea	S
e6	*Argyrosomus*	estuary	S	s16	*Priacanthus*	shallow sea	S
e7	*Siganus*	estuary	S	s17	*Psenopsis*	shallow sea	S
s1	*Katsuwonus*	shallow sea	M	s18	*Sardina*	shallow sea	S
s2	*Lophius*	shallow sea	M	s19	*Sillago*	shallow sea	S
s3	*Muraenesox*	shallow sea	M	s20	*Pampus*	shallow sea	S
s4	*Scomberomorus*	shallow sea	M	s21	*Trichiurus*	shallow sea	S
s5	*Decapterus*	shallow sea	MS	s22	*Upeneus*	shallow sea	S
s6	*Epinephelussp*	shallow sea	MS	o1	*Octopodidae*		
s7	*Scomber*	shallow sea	MS	o2	*Portunidae*		
s8	*Saurida*	shallow sea	MS	o3	*Sepiidae*		
s9	*Chondrichthyes*	shallow sea	MS	o4	*Penaeidae*		
s10	*Sphyraena*	shallow sea	MS	o5	*Loliginidae*		

Before GONI, there was little rainfall in the FG (Fig. 3(A2)). On the day of the typhoon, August 4th, rainfall was greater than 130 mm in the FG (Fig. 3(B2)). A significant rainfall event occurred in the FG on September 14th compared to the rainfall on September 13th (Fig. 4(A2–B2)).

The SSC from August 5th to10th (after GONI) indicated a river discharge out of the PRE, while a river discharge was not observed in the SSC from July 25th to 30th (Fig. 3(A3–B3)). The SSC had a stronger discharge from September 15th to 20th (after Koppu) than from September 5th to 10th (Fig. 4(A3–B3)).

Cold water developed near the typhoon's track in the FG after the typhoon (Fig 3(B4), 4(B4)) that was not present before the typhoon (Fig. 3(A4), 4(A4)), indicating that the upwelling emerged on the right side of the typhoon's track.

After GONI, the average Chl-a from August 4th to 20th was higher at the mouth of the PRE and where the 40 m isobath and the typhoon's track intersected (Fig. 3(A5–B5)). After Koppu, a tongue-style increase in Chl-a was observed moving across the typhoon's path from the inner PRE to the coastal area (Fig. 4(A5–B5)).

After GONI, the FSN increased from 25 to 31 nearshore and from 19 to 29 offshore (Fig. 3(A6-B6)). After Koppu, the FSN increased from 26 to 30 nearshore and from 11 to 29 offshore (Fig. 4(A6–B6)).

3.5. Daily variations in the FSN and related environmental elements nearshore and offshore

The SSW obviously strengthened during the typhoons, with maximum values of 14.12 m/s and 15.9 m/s on August 4th, when the typhoon GONI passed nearshore and offshore, respectively (Fig. 6(A1)). During Koppu, the SSW increased to 19.16 and 20.47 m/s nearshore and offshore, respectively (Fig. 6(B1)).

Before GONI, there was less than 10 mm of rainfall within 2 days. Nearshore, rainfall increased to the maximum value (60 mm) on August 5th, one day after the typhoon occurred, while offshore, rainfall increased to

Table 4
Distribution of increased records of fish species according to their body sizes. FR: fishing region; S (small), MS (small and medium) and M (medium), see Table 3.

Typhoon	FR	S		MS		M	
		Number	P(%)	Number	P(%)	Number	P(%)
GONI	Nearshore	2	28.57	3	42.86	1	14.29
	Offshore	5	55.56	3	33.33	0	0
Koppu	Nearshore	2	40	3	50	0	0
	Offshore	9	47.37	5	26.32	3	15.79

90 mm on August 4th, the day the typhoon arrived (Fig. 6(A2)). Before Koppu, there was less than 25 mm of rainfall in 4 days. The rainfall over the two regions reached its maximum value (40 and 60 mm) on September 14th, the day the typhoon occurred (Fig. 6(B2)).

After GONI passed, the SST declined to 0.65 °C (nearshore) and 0.43 °C (offshore) from August 3rd to 8th, as shown in Fig. 6(A3). Fig. 6(B3) displays the maximum reduction in SST of 0.44 °C (nearshore) and 0.84 °C (offshore) from September 13th to 15th.

On the 6th day after GONI, August 10th, Chl-a in nearshore and offshore habitats reached its maximum value of 14.01 and 17.35 mg/m^3, respectively (Fig. 6(A4)). Chl-a nearshore and offshore reached its maximum value on September 19th and 17th, the 5th and 3rd days after Koppu, respectively. The maximum values of Chl-a nearshore and offshore were 14.44 and 1.31 mg/m^3, respectively (Fig. 6(B4)).

Before GONI, the FSN increased to its maximum nearshore value on August 2nd (the day before GONI). After GONI, it increased to its maximum value (27) on August 14th (the 10th day after GONI) and then decreased (Fig. 6(A5)). Before Koppu, the FSN increased to its maximum value (28) on September 8th (4 days before Koppu) and decreased until September 13th. After Koppu, it increased to the maximum value (28) on September 19th (5 days after Koppu) and then decreased (Fig. 6 (B5)). No increase in the FSN could be detected offshore before GONI and Koppu due to the shortage of data. After GONI, the FSN reached its maximum value (26) on August 12th (the 8th day after GONI) and then decreased

Table 5
Fishes caught before and after typhoon GONI in August, nearshore. The gray column indicates the period when the typhoon hit. (e: estuarine fish species; s: shallow sea fish species; o: other species).

No	1	2	3	4 to 8	9	10	11	12	13	14	15	16	17	18	19	20
e2		√	√		√	√		√	√	√				√		
e6		√	√		√	√	√	√	√	√	√	√	√	√	√	√
e7	√	√				√		√	√	√						
s4		√	√		√	√	√	√	√	√	√	√	√	√	√	√
s5	√	√	√			√	√	√	√	√	√	√	√	√	√	√
s6		√							√					√		
s8	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√
s10		√	√		√	√	√	√	√	√	√	√	√	√	√	√
s11	√	√			√	√	√	√	√	√	√	√	√	√	√	√
s12	√			G			√	√	√	√			√			
s13	√	√	√	O			√	√	√	√			√	√	√	
s14	√	√	√	N		√	√	√	√	√	√	√	√	√	√	√
s15		√	√	I		√		√	√	√	√		√	√	√	√
s16		√	√			√	√	√	√	√	√			√		
s17		√	√			√	√		√	√			√	√		
s18		√	√			√			√					√		
s19		√	√			√		√	√	√				√		
s20		√	√		√	√	√	√	√	√	√	√	√	√	√	√
s21	√	√	√			√	√	√	√	√	√		√	√	√	√
s22	√	√	√			√	√	√	√	√	√		√	√	√	
o1		√				√	√		√	√			√	√	√	
o3		√	√			√		√	√	√				√		
o4		√	√		√	√	√	√	√	√	√			√	√	
o5	√	√	√			√	√	√	√	√	√	√	√	√	√	√
s1		√														
e1					√	√	√	√		√	√					
e4										√						
e5								√		√	√					
s3		Increased				√		√	√	√	√					
s7		records				√	√	√	√	√	√		√	√	√	
s9						√					√		√	√		
o2						√	√									

(Fig. 6(A5)). After Koppu, the FSN increased to its maximum value (28) on September 17th (the 3rd day after Koppu) and then decreased (Fig. 6(B5)).

3.6. Changes in the fish species after two typhoons in the FG

In the study area (box FG in Fig. 1(b)), the FSN increased by 14.29% (from 28 to 32) after GONI and 14.81% (from 27 to 31) after Koppu (Table 2). Five increased records for the occurrence of fish species accounted for 17.86% and 18.52% of the total records after the two typhoons. After GONI, increased records of fish species included *Lophius*, *Johnius*, *Harpodon*, *Collichthys* and *Portunidae*, among which two were shallow sea species (*Lophius* and *Portunidae*) and three were estuarine species (*Johnius, Harpodon and Collichthys*). After Koppu, the increased records of fish species included *Lophius*, *Sillago*, *Nibea*, *Ilisha* and *Collichthys*, among which two were shallow sea species (*Lophius* and *Sillago*) and three were estuarine species (*Nibea*, *Ilisha* and *Collichthys*). One species (*Katsuwonus*) was not found after either typhoon (Tables 2 and 3).

Nearshore, the FSN increased by 24% (after GONI) and 15.38% (after Koppu) compared to the FSN before the typhoons (Tables 2 and 3). The increased records consisted of small and medium-sized species (Table 4). During the period with the increased FSN, estuarine species accounted for 42.86% of the species after GONI (*Harpodon*, *Nibea*, *Johnius*, *Muraenesox*) and 60% after Koppu (*Ilisha*, *Nibea*, *Collichthys*), while the other species were shallow sea species (*Scomber*, *Chondrichthyes* and *Portunidae* after GONI; *Priacanthus* and *Sillago* after Koppu) (Tables 2, 5 and 6).

Offshore, the FSN increased by 52.63% after GONI and 163.64% after Koppu, compared to the FSN before the typhoons (Tables 2 and 3). The increased records were generally small species (Table 4). During the period with the increased FSN, estuarine species accounted for 33.33% after GONI (*Harpodon*, *Ilisha* and *Argyrosomus*) and 26.32% after Koppu (*Ilisha*, *Nibea*, *Johniu*, *Argyrosomus* and *Siganus*), while the other species were shallow sea species (*Psenopsis*, *Sardina*, *Sillago* and *Sepiidae* after GONI; *Lophius*, *Muraenesox*, *Scomberomorus*, *Epinephelussp*, *Scomber*, *Sphyraena*, *Leiognathus*, *Parargyrops*, *Sardina*, *Sillago*, *Psenopsis*, *Sepiidae*, and *Penaeidae* after Koppu) (Tables 2, 7 and 8).

3.7. The effect of typhoons on the FSN and related environmental factors

Nearshore, the two typhoons passed with maximum speeds of 14.12 m/s (after GONI) and 19.17 m/s (after

Table 6
Fishes caught before and after typhoon GONI in August, offshore. The gray column indicates the period when the typhoon hit. (e: estuarine fish species; s: shallow sea fish species; o: other species).

No	1	2	3	4 to 8	9	10	11	12	13	14	15	16	17	18	19	20
e7		√									√					
s3		√						√								
s4		√						√							√	√
s5		√						√	√	√	√	√	√	√	√	√
s7		√						√	√	√	√	√	√	√	√	√
s8		√						√	√	√	√	√	√	√	√	√
s10		√						√							√	
s11		√		G				√	√						√	√
s12		√		O				√			√					
s13		√		N				√	√	√	√	√	√	√	√	
s14		√		I				√	√	√	√	√	√		√	√
s15		√						√				√	√		√	√
s16		√						√			√		√		√	√
s21		√						√				√			√	√
s22		√						√		√		√	√	√	√	
o1		√						√	√	√	√	√	√	√	√	
o4		√						√							√	
o5		√						√	√	√	√	√	√	√	√	√
s9		√														
e1								√								
e2								√								
e6								√							√	√
s6		Increased						√	√				√	√		√
s17		records						√		√					√	√
s18								√							√	√
s19								√								√
s20								√			√				√	√
o3								√				√	√		√	√

Koppu) and rainfalls of 57.51 cm (after GONI) and 40.19 cm (after Koppu). The SST decreased by 0.92 °C (from August 2nd to 8th) after GONI and by 0.44 °C (from September 13th to 15th) after Koppu, and the FSN increased by 3 (from August 2nd to 14th) after GONI and 9 (September 9th to 19th) after Koppu (Table 9).

Offshore, the two typhoons passed at maximum speeds of 15.89 m/s (GONI) and 20.47 m/s (Koppu), with rainfalls of 86.19 cm (GONI) and 59.12 cm (Koppu). The SST decreased by 0.93 °C (from August 2nd to 8th) after GONI and 0.84 °C (from September 13th to 15th) after Koppu. The FSN increased by 7 (from August 2nd to 14th) after GONI and 20 (from September 9th to 17th) after Koppu (Table 9).

3.8. Spatial variations in the Chl-a in August 2009, August 2010, September 2009, and September 2010

In August 2009, GONI passed through the northern SCS, and induce an increase in Chl-a in nearshore and offshore compared that in August 2010 (Fig. 5A1, B1). In September 2009, an obviously and highly increase also can be seen after Koppu compared to that in September 2010(Fig. 5A2, B2).

4. Discussion

4.1. Increases in the FSN after the two typhoons

In estuaries, typhoons can affect fish habitats by inducing hypoxia and decreasing salinity through dilution with freshwater discharge. Typhoons may also cause resident fish species to disappear (Collins et al., 1981). However, the increased river discharge also brings nutrients to nourish the mouth of the estuary, where the increased freshwater fishes are found following the increased flow (Greenwood et al., 2006) and marine species accumulate for feeding. The changes in the FSN depend on the difference between the number of additional species and the

Table 7
Fishes caught before and after typhoon Koppu in September, nearshore. The gray column indicates the period when the typhoon hit. (e: estuarine fish species; s: shallow sea fish species; o: other species).

No	4	5	6	7	8	9	12	13	14 to 15	16	17	18	19	20	21	22	23	24	25	26
e1					√								√	√						√
e5					√					√	√	√	√			√	√	√		
e6	√	√	√	√	√	√	√			√	√	√	√	√	√				√	√
e7						√				√	√		√	√	√					
s1					√															
s3					√					√	√		√	√						
s4	√	√	√	√	√	√	√			√	√		√	√	√		√		√	√
s5		√	√	√	√	√		√		√	√	√	√	√	√		√	√		
s7				√	√			√				√	√	√	√		√	√		
s8	√	√	√	√	√	√		√		√	√	√	√	√	√	√	√	√	√	√
s10	√	√	√	√	√	√			K	√		√	√	√	√					√
s11	√	√	√	√	√	√			o	√	√	√	√	√	√	√			√	√
s12				√					p	√		√	√	√	√	√	√			
s13				√	√	√		√	p			√	√	√	√					
s14	√	√	√	√	√	√			u	√	√	√	√	√	√	√	√		√	√
s15				√	√	√				√	√	√	√	√	√	√				
s16					√	√							√	√	√					√
s17	√	√	√	√	√	√				√			√	√	√					
s18			√		√	√								√	√					
s20	√	√	√	√	√	√	√			√	√	√	√	√	√	√	√		√	√
s21	√	√	√	√	√	√				√	√	√	√	√	√	√	√		√	√
s22				√	√	√		√		√	√	√	√	√	√					
o1				√	√	√							√	√						
o3	√				√	√				√	√	√	√	√	√	√	√			
o4		√	√	√			√			√	√	√	√	√	√	√	√		√	√
o5	√	√	√	√	√	√	√	√		√	√	√	√	√	√	√	√		√	√
e2													√	√					√	√
e3							Increased						√							
e4							records													√
s6										√	√	√	√	√						
s19													√	√	√					

number of species lost (Paperno et al., 2006; Switzer et al., 2006).

In our research, the Shannon Weiner index and FSN increased in the northwestern SCS after the two typhoons (Fig. 2(d)). In the increased species records, the large proportion of resident species in the PRE indicated that the PRE's discharge played an important role in the accumulation of the fishes. There were two reasons for the increase in Chl-a after the typhoons. One was that a substantial quantity of nutrients was transported with the river's discharge, and the other was the increase in Chl-a from upwelling (also observed in this study (Fig. 3(B5), 4(B5))) due to the strong wind (Lin et al., 2003; Zheng and Tang, 2007; Sun et al., 2010; Yang and Tang, 2010), which brings nutrients up from the deeper waters (Zhao et al., 2009). The increase in Chl-a may attract increased shallow sea and estuarine fish species after typhoons (Fig. 3(B6), 4(B6)).

4.2. Increase in the FSN nearshore and offshore after two typhoons

The FSN obviously changed in the two regions, nearshore (in the southern PRE, near the PRE) and offshore (in the southern PRE on the typhoon track) (Fig. 3 (B6), 4(B6)). After the two typhoons, Chl-a increased in the two regions (Fig. 3(B5), 4(B5)). This increase in Chl-a indicated that the increase in the FSN in the two regions was associated with the typhoons.

After the two typhoons, the FSN offshore increased to its maximum value two days earlier than nearshore (Fig. 6(A5, A5)). This result indicates that the two typhoons affected the FSN in regions that were close to the typhoon track initially and then extended to the regions near the PRE.

Nearshore, estuarine species were dominant in the increased records of fish species (Table 2), indicating that river discharge may play a more important role than upwelling in changing the FSN. Offshore, shallow sea species were dominant in the increased records of fish species (Table 2), indicating that upwelling may play a more important role than river discharge in the increase in the FSN.

4.3. Increased records of fish species in the two regions

Although typhoons can harm fish habit, increased records of fish species can still be found. Previous research found that increased records of freshwater species in

Table 8
Fishes caught before and after typhoon Koppu in September, offshore. The gray column indicates the period when the typhoon hit. (e: estuarine fish species; s: shallow sea fish species; o: other species).

No	1	2	3	4	5	6	7	8	9	14 to 15	16	17	18	19	20	25	26
s5	√		√						√		√	√	√	√	√	√	√
s8	√								√		√	√	√	√	√		√
s11	√		√						√		√	√	√	√	√		√
s13	√		√						√	Koppu		√	√	√			
s14	√		√						√		√	√	√	√	√		
s16	√		√						√		√	√	√				√
s17	√		√									√	√				
s21	√										√	√	√	√	√		√
o1			√						√		√	√	√				
o5	√		√						√		√	√	√	√	√		√
e2												√					
e3													√				
e5												√	√				√
e6												√	√	√	√		
e7											√	√	√	√	√		√
s2											√						
s3											√	√	√	√			
s4											√	√	√	√		√	
s6												√	√				
s7							Increased records				√	√	√	√			
s10											√	√	√	√			
s12												√	√	√	√		
s15												√	√	√			
s18											√	√	√				
s19												√	√				
s20												√	√	√			
s22											√	√	√	√	√		
o3											√	√	√	√	√		
o4												√	√	√	√		

Table 9
Comparison of the maximum wind, sustained time and maximum rainfall while the two typhoons passed through the FG and the decrease in the SST and increase in the FSN in the FG region.

Cofference	GONI	Koppu	GONI	Koppu
Maximum Wind(m s^{-1})	14.12	19.17	15.89	20.47
Maximum rainfall (cm)	57.51	40.19	86.19	59.12
Sustain time (h)	Unpass	Unpass	7	5
Decrease in SST (°C)	0.92	0.44	0.93	0.84
FSN before typhoon	24 (2 Aug)	19 (9 Sep)	19 (2 Aug)	9 (1 Sep)
Maximum FSN after typhoon	27 (14 Aug)	28 (19 Sep)	26 (12 Aug)	28 (17 Sep)
Increase in FSN	3	9	7	20

estuary areas occurred in high-nutrient areas with increased freshwater inflow due to typhoons (Montane and Austin, 2005; Houde et al., 2005; Pizza and Peyre, 2009). In this research, seven and nine increased records of fish species in the nearshore and offshore regions, respectively, were found after GONI. Five and nineteen increased records of fish species were found in nearshore and offshore regions, respectively, after Koppu. Obviously, these increased records were associated with the typhoons. The high nutrient concentrations and upwelling, caused by river discharge and typhoons, respectively, may be the main reasons for the increase in the FSN.

Nearshore, small and medium-sized fish species were dominant in the increased records. Offshore, however, small fish species were dominant in the increased records (Table 4).

4.4. Difference in the FSN after the GONI and Koppu typhoons

GONI and Koppu caused different changes in the aquatic environment and FSN. Nearshore and offshore, Koppu brought stronger wind, less rainfall, a shorter duration in the FG and a smaller decrease in the SST than GONI. In contrast, the increase in the FSN after Koppu was greater than that after GONI. Above all, a more powerful typhoon, Koppu, caused less rainfall and a decrease in the SST. These factors indicated that fewer nutrients were

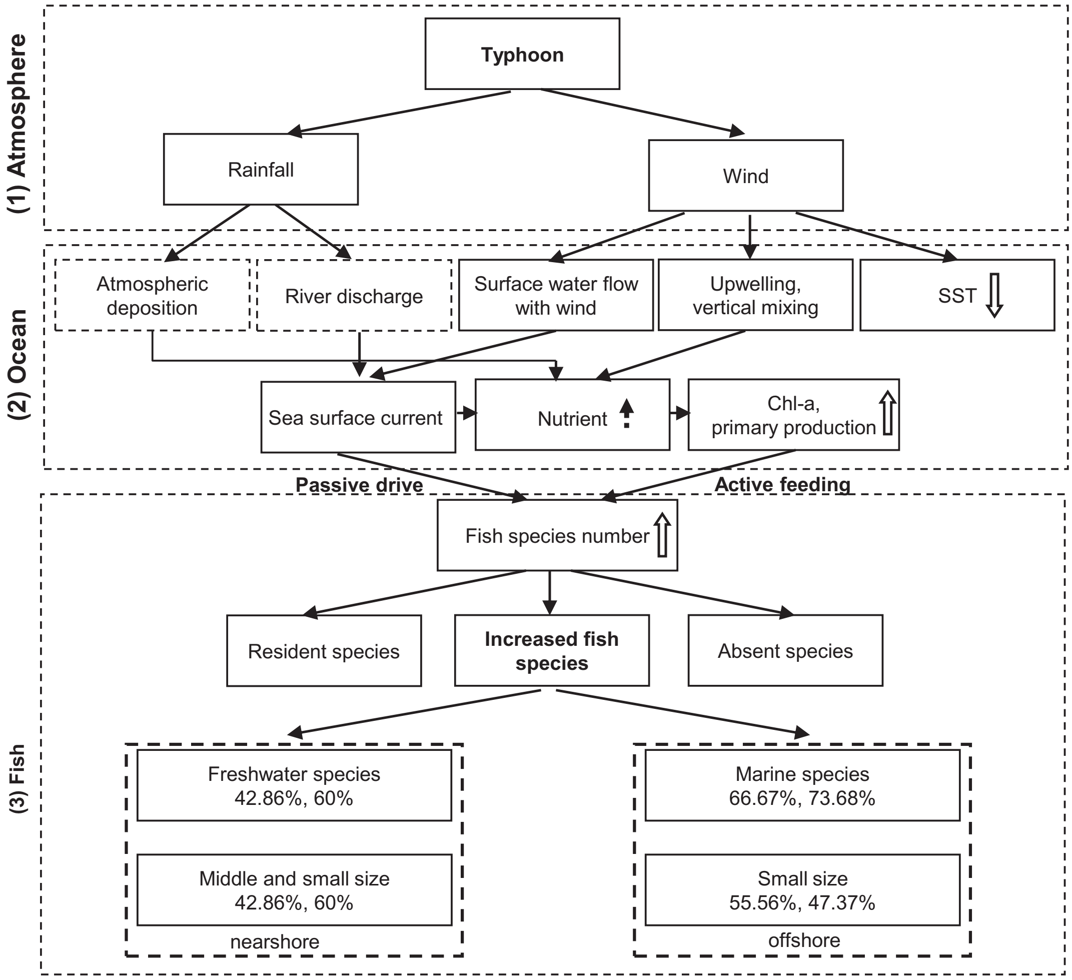

Fig. 7. Mechanism of the increase in the FSN after typhoon in the northern SCS. Blank up and down arrows indicate increases and decreases, respectively, according to the results of this research; Black arrow with tail in dashed line indicates increases according to references; Black arrow indicates correlation between every two boxes; Boxes with dashed borders in (2) Ocean indicate that it is not discussed in this research; Boxes with dashed borders in (3) Fish represent results from nearshore and offshore.

imported through river discharge and upwelling during Koppu than during GONI. A greater increase in the FSN after Koppu indicated that other factors may also affect the movement of fishes.

According to the Chinese fishing moratorium for the SCS, fishing activities were forbidden from May 15th to July 30th in 2009 and 2010. An associated increase in fish resources after the fishing moratorium has been documented (Shi et al., 2008). Because of the fishing moratorium, the FSN before GONI (on August 2nd) was 24 nearshore and 19 offshore, while before Koppu, it was 19 (on September 9th) nearshore and 9 (on September 1st) offshore. After GONI, the FSN was 27 nearshore (on August 14th) and 26 offshore (on August 12th). After Koppu, the FSN was 28 nearshore (on September 19th) and 28 (on September 17th) offshore. Therefore, before GONI, the FSN was larger than before Koppu, but after the two typhoons, the difference in the FSN was small. The increase in the FSN after GONI was smaller than that after Koppu.

4.5. Ecological mechanisms

This research described the variation in the FSN near the PRE and offshore, far from the PRE, during the typhoons GONI and Koppu. The influence of the typhoons on fish in the nearshore and offshore areas is depicted in Fig. 7.

(1) In the atmosphere: When the typhoons hit, rainfall and wind are the two main factors causing environmental changes in the water.

(2) In the ocean: Rainfall can cause nutrient enrichment via two mechanisms: atmospheric deposition and river discharge, which bring nutrients into the water. Wind is the other key factor that increases the nutrient concentrations by bringing the nutrient-rich water to the surface. Chl-a increases during the process of these two nutrient enrichment mechanisms.

(3) Fish: Schools of fish accumulate in two ways. Active feeding behavior encourages fishes to congregate in the nutrient-enriched area that is formed by the typhoons. Due to the typhoons, the strong river discharge and sea surface currents drive some small, sick and old fish with weak swimming abilities into the fishing region. Nearshore, the increase in the FSN is mainly caused by an increase in estuarine species (largely the small and medium-sized species), which follow the increased river discharge from the typhoon's rainfall. Offshore, the increase in the FSN is mainly caused by shallow sea species (predominantly the small species), which gather to feed.

5. Conclusion

5.1. The FSN increases in both nearshore and offshore environments

The FSN increases both nearshore (near the river's estuary) and offshore (near the typhoon's track), exhibiting an enhanced Chl-a that is associated with typhoons. Nearshore, estuarine species dominate the increased records of fish species, while offshore, shallow sea species dominate the increased records of fish species.

5.2. The effect on the FSN was stronger offshore than nearshore

The FSN increases more and faster in offshore (near the typhoon's track) than in nearshore (near the river's estuary). This finding indicates that upwelling plays a more critical role close to the typhoon's track, while river discharge is the major factor in the estuary.

5.3. Increased records of fish species are predominantly small and medium-sized in nearshore environments and small in offshore environments

Nearshore (near the river's estuary), increased records of fish species are mainly small and medium-sized estuarine species that can overcome the strong river discharge. Offshore (near the typhoon's track), increased records of fish species are mainly small, shallow sea fish species.

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