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The positive effects of typhoons on the fish CPUE in the South China Sea

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

[a] Research Center for Remote Sensing of Marine Ecology and Environment, State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology,
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

Due to the logistical difficulties associated with fish data sampling after typhoons, short-term effects of typhoons on fishery in the South China Sea (SCS) have not been well-understood. The present study is to evaluate the impacts on the fish catch per unit effort (CPUE) owing to the three typhoons Chanthu, Vicente, and Kai-tak in the northwestern SCS, using long-term fish catch data and satellite data. The results show that the CPUE of total catch and some sorted catches have been changing because of the typhoons. On total catch, firstly, the CPUE has increased approximately 0.32 kg h^{-1} kw^{-1}, 0.20 kg h^{-1} kw^{-1}, and 0.25 kg h^{-1} kw^{-1} during the three typhoon periods. Then, the CPUEs decreased to the pre-typhoon level in about three weeks. Thirdly, among the three typhoons, the slow-moving Chanthu has caused a larger increase in CPUE. The typhoons impact was two-pronged, depending on fish species. One is the positive effects on meso-demersal fishes, cephalopoda and pelagic fishes. The other is the increase in CPUE of low trophic level carnivorous fishes after the three typhoons. This research provided the first evidence of CPUE increase after typhoons in the open sea.

1. Introduction

Typhoons (tropical cyclones or storms) could change environmental habitats to some extents (Zhao et al., 2008, Tang and Sui, 2014). Certain typhoons have little effect on fishery (Chuang et al., 2008; Kawabata et al., 2010). However, some does, including negative and positive effects on fishery. The strong currents and low oxygen may sweep feeble fish away or kill juveniles (Kawabata et al., 2010; Lassig, 1983). The typhoons increase nutrients concentrations owing to river runoff, and upwelling, which attracts much more fishes to accumulate for food (Houde et al., 2005).

The positive effect is important for fishing (Qiu et al., 2010). Previous studies indicated that typhoons enhance nutrients, increase Chlorophyll a (Chl-a) concentration (Zheng and Tang, 2007; Zhao et al., 2009) and increase primary production (Lin, 2012; Tsuchiya et al., 2013). The increasing concentration of marine phytoplankton after typhoons has been documented (Zheng and Tang, 2007). Distribution of fish is closely associated with the amount of phytoplankton (James et al., 2003).Up to now, there are several studies regarded the changes after typhoons in the fish resources in small streams, bays or coral reef regions (Chuang et al., 2008; Lassig, 1983). The increase in the fish abundance and species richness triggered by hurricane in a bay has been studied (Houde et al., 2005). Our previous study reported an increase in the number of fish species after typhoons in the mouth of the Pearl River Estuary in the northern SCS (Yu et al., 2013). It remains unclear whether fish accumulates in the open sea after typhoons. The ecological mechanisms of fish migration after typhoons are not fully determined; the fish of different ecological types reacts to typhoon differently, and their responses need to be compared.

In this research, we examine the changes in the fish CPUE after 3 class 4 typhoons namely Chanthu, Vicente and Kai-tak with long-term, single-trawl fishery data for the total catch and sorted catch groups, and present the mechanisms of fish movement after typhoons.

* Corresponding author at: State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Xingang Xi Road 164, Guangzhou 510300, China. Tel./fax: +86 20 89023203.
E-mail address: lingzistdl@126.com (D. Tang).

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2. Study area, data, and methods

2.1. Study area

The northwestern SCS is located along the west coast of the northern SCS (18.5°N–23.0°N, 110.0°E–115.2°E) with depths less than 100 m (Fig. 1(a and b)). It is a nearshore fishing ground of traditional importance (Song et al., 2012), it has a higher Chl-a than offshore areas (Pan et al., 2013). This area is affected by the northeast monsoon in winter and the southwest monsoon in summer (Wang et al., 2007). Under the effect of the summer monsoon, upwelling has been documented (Xie et al., 2003). The region is frequently struck by typhoons (Wang et al., 2007).

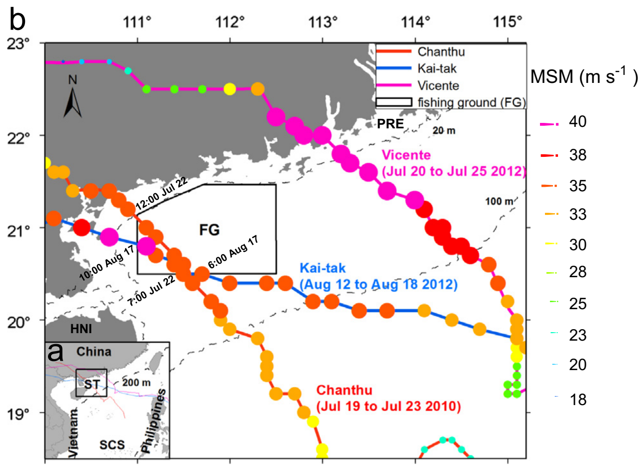

Fig. 1. (a) Study area in the northern SCS and the tracks of Typhoons Chanthu, Vicente and Kai-tak. ST: Study area. SCS: South China Sea. (b) The fishing grounds, paths and wind speeds of Typhoons Chanthu, Vicente and Kai-tak. HNI: Hainan Island. FG: Fishing grounds. PRE: Pearl River Estuary. Black dashed line: 20 m and 100 m isobaths. Red line: typhoon Chanthu path. Pink line: typhoon Vicente path. Blue line: typhoon Kai-tak path. 7:00 and 12:00 July 22: times that Typhoon Chanthu arrived and left the FG. 6:00 and 10:00 Aug 17: times that Typhoon Kai-tak arrived and left the FG. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.2. Fish data

In 2009, a long term fisheries monitoring program in the SCS was conducted by the South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences. One of the sampling trawlers was used to fish in the Western Guangdong Fishing Ground (Box FG in Fig. 1(b)). The time dependent data of the fish CPUE from the boat were obtained and analyzed. Temporal variations in the CPUE of the total catch from May 2009 to March 2013 were plotted. The total catch was classified into pelagic fish, meso-demersal fish, demersal fish, reef fish, cephalopoda, crab and shrimp according to living depth and ecological type (Cheng et al., 1962; Chen and Liu, 1982; Zhu, 1984) (Table 1). Low trophic level

Table 2
Typhoon information.

No	Typhoon	Start and end time	Class	Note	Pass the FG in Fig. 1
1	Soudelor	July 11–12, 2009	2	Tropical storm	No
2	Goni	August 3–9, 2009	2	Tropical storm	No
3	Koppu	September 13–16, 2009	4	Typhoon	No
4	Parma	September 29–October 14, 2009	2	Tropical storm	No
5	Chanthu	July 19–23, 2010	4	Typhoon	Yes
6	Roke	July 25–30, 2011	3	Strong tropical storm	No
7	Vicente	July 20–25, 2012	4	Typhoon	No
8	Kai-tak	August 12–18, 2012	4	Typhoon	Yes

Table 1
Information of 30 main fishes sampled in the area.

No	Common name	Description	Habitat depth	Tropical level
1	Pelagic scad	*Decapterus* spp. dominated by *D. maruadsi*	Pelagic	Low class carnivorous fish
2	Ponyfish	*Leiognathus* spp. dominated by *L. bindus* and *L. elongatus*	Pelagic	Low class carnivorous fish
3	Pomfret	*Pampus* spp. dominated by *P. argenteus* and *P. chinensis*, and *Parastromateus niger*	Pelagic	Low class carnivorous fish
4	Chub mackerel	A single species of *Scomber japonicus*	Pelagic	Low class carnivorous fish
5	Spanish mackerel	*Scomberomorus* spp. dominated by *S.guttatus* and *S.commerson*	Pelagic	High class carnivorous fish
6	Spinyhead croaker	*Collichthys* spp. dominated by a *Collichthys lucidus*	Meso demersal	Low class carnivorous fish
7	Jewfish	*Johnius* spp. dominated by *J. dussumieri* and *J. belangerii*	Meso demersal	Low class carnivorous fish
8	Yellow drum	a single species of *Nibea albiflora*	Meso demersal	Low class carnivorous fish
9	Silver croaker	*Pennahia argentatus*	Meso demersal	Low class carnivorous fish
10	Grouper	*Epinephelus* spp. dominated by *E. akaara* and *E. awoara*	Meso demersal	Middle class carnivorous fish
11	Red barracuda	a single species of *Sphyraena pinguis*	Meso demersal	High class carnivorous fish
12	Hairtail	*Trichiurus* spp. dominated by *T. lepturus*	Meso demersal	High class carnivorous fish
13	Pacific rudderfish	a single species of *Psenopsis anomala*	Demersal	Low class carnivorous fish
14	Threadfin bream	*Nemipterus* spp. dominated by *N. virgatus*	Demersal	Low class carnivorous fish
15	Porgies	a single species of *Parargyrops edita*	Demersal	Low class carnivorous fish
16	Bigeye	*Priacanthus* spp. dominated by *P. tayenus* and *P. macracanthus*	Demersal	Low class carnivorous fish
17	Filefish	Thamnaconus spp. dominated by *T. hypargyreus*	Demersal	Low class carnivorous fish
18	Goatfish	Upeneus spp. dominated by *U. moluccensis* and *U. sulphureus*	Demersal	Low class carnivorous fish
19	Tonguesole	*Cynoglossus* spp.	Demersal	Low class carnivorous fish
20	Sillago	*Sillago sihama* and *S. japonica*	Demersal	Low class carnivorous fish
21	Monkfish	*Lophius* spp. dominated by *Lophius litulon*	Demersal	Middle class carnivorous fish
22	Snakefish	a single species of *Trachinocephalus myops*	Demersal	Middle class carnivorous fish
23	Conger pike	*Muraenesox cinereus*	Demersal	High class carnivorous fish
24	Lizardfish	*Saurida* spp. dominated by *S. tumbil* and *S. undosquamis*	Demersal	High class carnivorous fish
25	White-spotted spinefoot	*Siganus* spp. dominated by *Siganus oramin*	Reef	Omnivorous fish
26	Octopus	*Octopus* spp.	Cephalopoda	Low class carnivorous fish
27	Squid	*Loligo* spp.	Cephalopoda	Low class carnivorous fish
28	Cuttlefish	*Sepia* spp.	Cephalopoda	Low class carnivorous fish
29	Crab	*Portunus* spp. and *Charybdis* spp.	Crab	Low class carnivorous fish
30	Shrimp	*Penaeidae*	Shrimp	Low class carnivorous fish

carnivorous fish, middle trophic level carnivorous fish and high trophic level carnivorous fish were classified according to their trophical level (Huang, 2004; Zhang, 2005; Huang et al., 2008; Chen and Qiu, 2010) (Table 1). The CPUE of the total catch and sorted catch groups from July 17th to September 15th in 2010 (during Typhoon Chanthu) and the average CPUE from July 17th to September 15th in 2009 to 2011 was compared. The CPUE of the total catch and sorted catch groups from July 15th to September 30th in 2012 (during Typhoons Vicente and Kai-tak) and the mean CPUE from July 15th to September 30th in 2009 and 2011 were also compared.

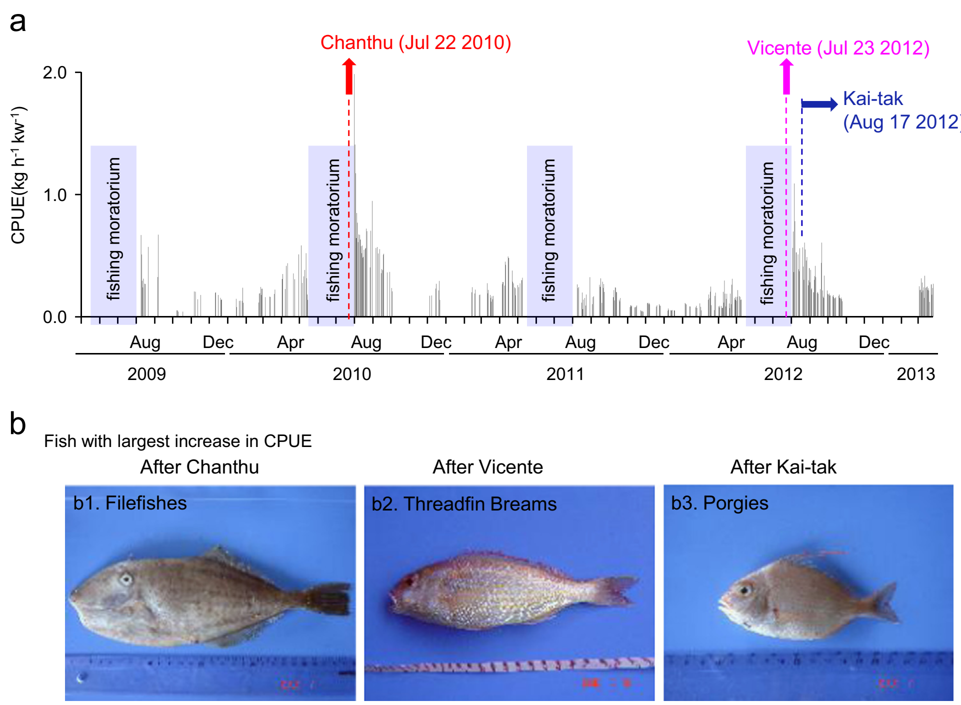

Fig. 2. (a) Time series of the CPUE (kgh1kw1). Pictures of the fishes with the largest increases in the CPUE (b1) Filefishes (after Chanthu), (b2) Threadfin Breams (after Vicente), and (b3) Porgies (after Kai-tak). Red arrow and dashed line: the time of the occurrence of typhoon Chanthu. Pink arrow and dashed line: the time of the occurrence of typhoon Vicente. Blue arrow and dashed line: the time of the occurrence of typhoon Kai-tak. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Comparison of the typhoon, wind, EPS, rainfall, SST, Chl-a and CPUE while the typhoon Chanthu, Vicente and Kai-tak pass through the study area. To Chanthu: typhoon month represents August 10–20th, 2010, non-typhoon month represents August 10–20th, 2009 and 2011; To Vicente: typhoon month represents August 9–15th, 2012, non-typhoon moth represents August 9–15th, 2009 and 2011; To Kai-tak: typhoon month represents August 20–30th, 2012, non-typhoon month represents August 20–30th, 2009 and 2011. The unit of CPUE is kg h^{-1} kw^{-1}.

	Variable	Chanthu	Vicente	Kai-tak
Typhoon	Wind speed (m s^{-1})	35	Unpass	35, 40
	Sustain time (h)	4–5	Unpass	4–5
	Moving speed (m s^{-1})	4.99	Unpass	5.58
Wind (m s^{-1})	Maximum wind	11.32 (Jul 21)	13.31 (Jul 23)	17.31 (Aug 17)
	Sustain days	5	10	4
EPS (10^{-5} m s^{-1})	Increase in EPS	5.58	4.86	12.96
	Recover days	4	3	3
Rainfall (cm)	Maximum rainfall	78.09 (Jul 22)	46.62 (Jul 22)	44.48 (Aug 16)
	Days reach to highest rainfall	0	1	−1
	Sustain days	4	8	2
SST (°C)	Decrease in SST	1.93	3.05	2.57
	Days reach to lowest SST	5	8	4
	Last days	11	11	10
Chl-a (mg m^{-3})	Increase in Chl-a	1.6	0.7	0.29
	Maximum Chl-a	4.76 (Jul 27)	2.08 (Jul 30)	0.90 (Aug 21)
	Days reach to highest Chl-a	6	8	5
CPUE (kg h^{-1} kw^{-1})	CPUE in non-typhoon month	0.24	0.32	0.24
	CPUE in typhoon month	0.56	0.52	0.49
	Increase in CPUE	0.32	0.20	0.25
	Increase rate (%)	133.33	62.50	104.17
	Maximum CPUE after typhoon	1.99 (Aug 1)	1.03 (Aug 7)	0.64 (Aug 23)
	Days reach to highest CPUE	11	16	7

2.3. Typhoon data

2.3.1. Typhoon wind

The paths and maximum wind speeds of Typhoons Chanthu, Vicente and Kai-tak were obtained from the Wenzhou Typhoon Delivery System (http://www.wztf121.com/). The typhoon data were recorded each hour and classified by symbols with different sizes and colors according to wind speed values in ArcGIS.

2.3.1.1. Wind speed and Ekman pumping speed (EPS) equation. Daily wind speed data were retrieved from ASCAT with a resolution of 0.25° and taken from the Center for Satellite Exploitation and Research (CERSAT) (http://cersat.ifremer.fr/Data). The time series of the wind speeds for the study region from July 17th to August 31st, 2010 and July 15th to September 15th, 2012 were compiled through Excel. The EPS were calculated by $W=\nabla(\tau/\rho f)$, where $\rho=1025\ \mathrm{kg\ m^{-3}}$ is the density of seawater, f is the Coriolis parameter, and τ is wind stress derived from ASCAT (Stewart, 2008, Tang et al., 2002).

2.3.2. Rainfall

Daily rainfall data for the study area were taken from the Tropical Rainfall Measuring Mission (TRMM) with a resolution of 0.25° (http://mirador.gsfc.nasa.gov/). The rainfall on July 19th (before

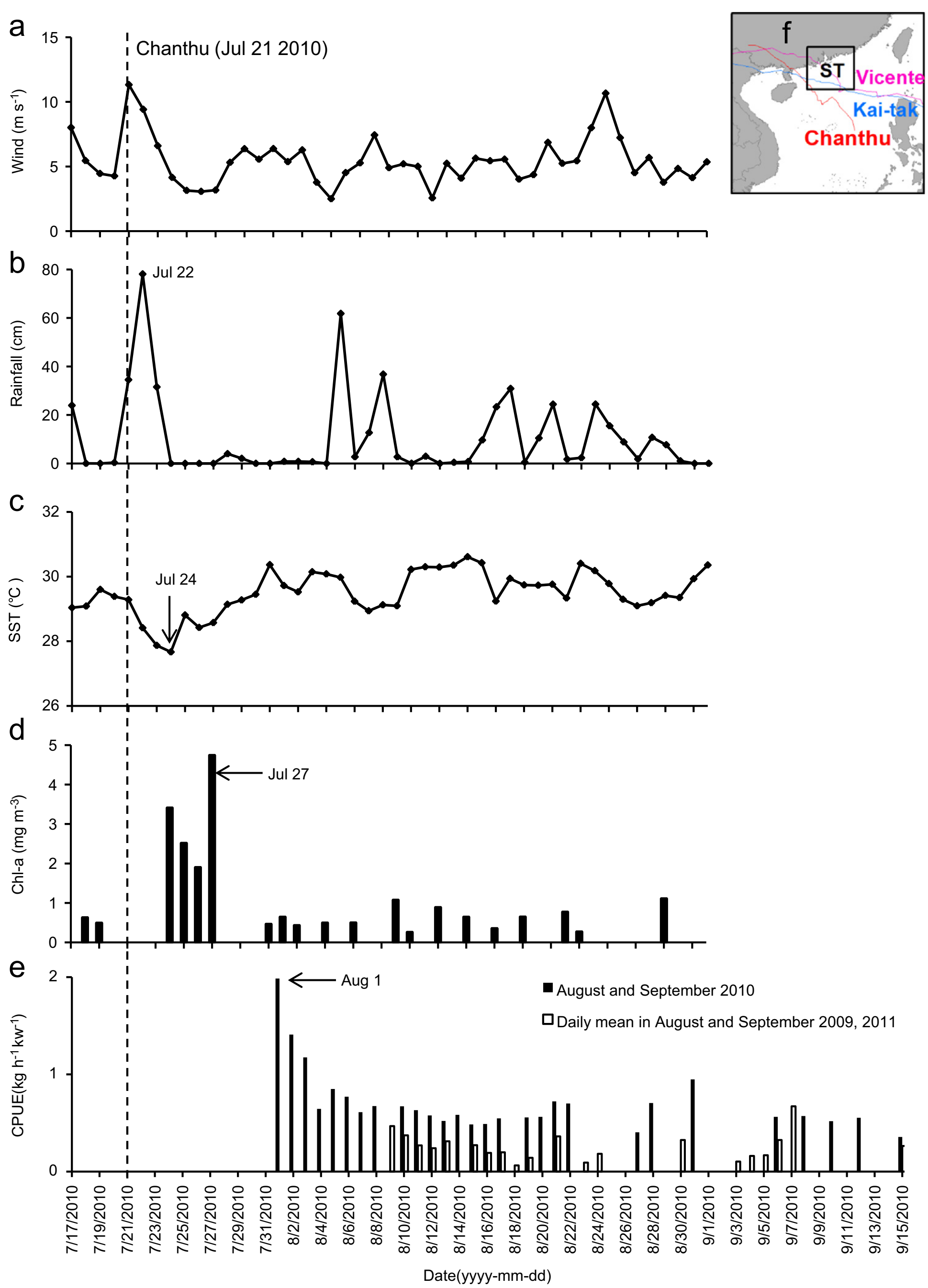

Fig. 3. Time series of mean values of (a) wind ($\mathrm{m\ s^{-1}}$), (b) rainfall (cm), (c) SST (°C), (d) Chl-a ($\mathrm{mg\ m^{-3}}$) and (e) CPUE (102 $\mathrm{kg\ h^{-1}\ kw^{-1}}$) on the FG box in Fig. 1(b) from July 17th to September 15th, 2010. The black dashed line indicates the occurrence of typhoon Chanthu.

Chanthu), 22nd (during Chanthu), 24th, 2010 (after Chanthu), July 16th (before Vicente), 25th (during Vicente), 30th, 2012 (after Vicente), August 15th (before Kai-tak), 18th (during Kai-tak), and 19th, 2012 (after Kai-tak) were imaged with ArcGIS. The distributions in daily rainfall from July 17th to August 31st in 2010 and from July 15th to September 15th in 2012 were processed by using Excel.

2.4. Environmental data

2.4.1. Sea surface current (SSC)

The five-day average SSC data for the study region were obtained from the Ocean Surface Current Analyses (OSCAR) projected by the National Oceanic and Atmospheric Administration (NOAA). The resolution of the SSC is one third degree (http://www.oscar.noaa.gov/). The SSC from July 15th to 20th (before Chanthu), from 20th to 25th (during Chanthu), from 25th to 30th, 2010 (after Chanthu), from July 20th to 25th (before Vicente), from 25th to 30th (during Vicente), from August 1st to 5th 2012 (after Vicente), from August 5th to 10th (before Kai-tak), from 15th to 20th (during Kai-tak), and from 25th to 30th, 2012 (after Kai-tak) were mapped in ArcGIS.

2.4.2. Sea surface temperature (SST)

The blended SST is composed of microwave (MW) and infrared (IR) SST. MW SST was from Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) and Tropical Rainfall Measuring Mission microwave imager (TMI). IR SST was from Moderate Resolution Imaging Spectroradiometer (MODIS).

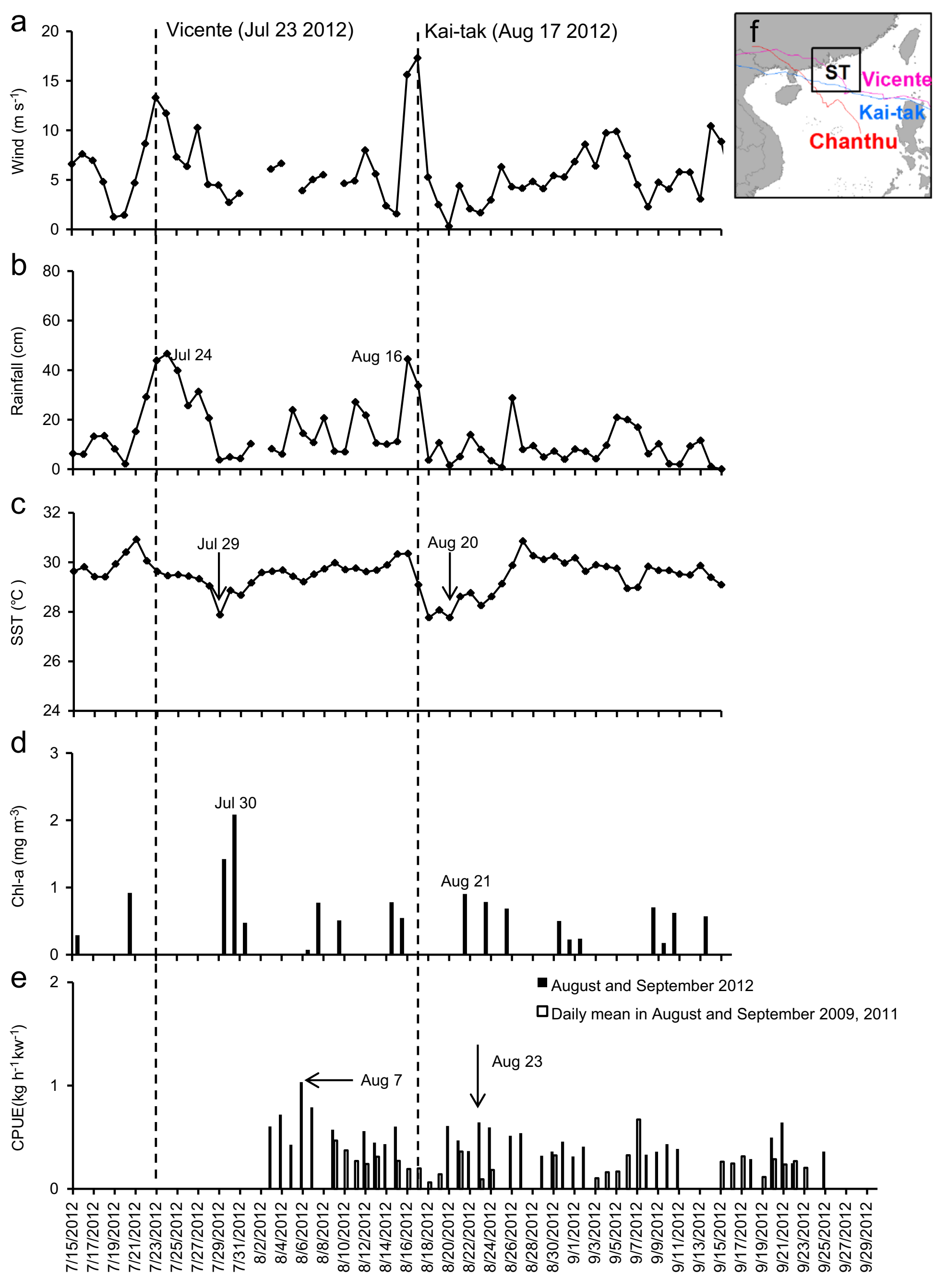

Fig. 4. Time series of mean values of (a) wind ($m\ s^{-1}$), (b) rainfall (cm), (c) SST (°C), (d) Chl-a ($mg\ m^{-3}$) and (e) CPUE ($102\ kg\ h^{-1}\ kw^{-1}$) on the FG box in Fig. 1(b) from July 15th to September 30th, 2012. The black dashed lines indicate the occurrences of typhoons Vicente and Kai-tak.

The blended SST was compiled by NASAs Earth Science Physical Oceanography Program. With the spatial resolution of 9 km, MW-SST is lower than that of IR. Because the microwave can penetrate the cloud, the blended SST could take the advantages from both MW and IR SST. We obtained MW-SST data from the Remote Sensing System (http://www.remss.com). The SST for the study was based on the system. Daily SST images from July 19th (before Chanthu), 24th (during Chanthu), 31st (after Chanthu) in 2010, July 21st (before Vicente), 29th (during Vicente), August 2nd (after Vicente) in 2012, August 16th (before Kai-tak), 20th (during Kai-tak) and 22th (after Kai-tak) in 2012 were processed using ArcGIS. Temporal variations in the SST from July 17th to August 31st in 2010 and July 15th to September 15th in 2012 were plotted using Excel.

2.4.3. Chlorophyll a (Chl-a)

The Chl-a data were obtained from a GlobColour project run by the European Space Agency (ESA). Daily and eight-day average data sets for the study area were downloaded from the website (http://hermes.acri.fr/). The Chl-a concentration is based on the merging of MERIS, SeaWiFS and MODIS level-2 data over the entire globe with a resolution of 4.6 km. Eight-day integrated Chl-a images during the typhoon periods (Chanthu: July 20th–27th, 2010, Vicenct: July 27th–August 3rd, 2010, Kai-tak: August 20th–27th, 2012) were individually compared with Chl-a images from July 12th to 19th, 2010 (before Chanthu), from July 19th to 26th, 2012 (before Vicente), from August 12th to 19th, 2012 (before Kai-tak), from July 28th to August 4th, 2010 (after Chanthu), from August 4th to 11th, 2012 (after Vicente), from September 5th to 12th, 2012 (after Kai-tak). Four selections of eight-day average Chl-a images were combined into a 32-day mean Chl-a image from July 20th to August 20th in 2009, in 2010, in 2011 respectively and from July 27th to September 4th in 2009, in 2011 and in 2012 with ArcGIS. Time series of the daily Chl-a from July 17th to August 31st, 2010 and that from July 15th to September 15th, 2012 were compiled using Excel for temporal analysis.

3. Results

3.1. Three typhoons occurred in the area

From 2009 to 2012, 8 typhoons passed through the study region (Table 2), among which 2 typhoons Chanthu and Kai-tak passed right on the fishing ground (FG in Fig. 1(b)), other 6 typhoons (Soudelor, Goni, Koppu, Parma, Roke, and Vicente) were out of the FG. Among which, 4 storms (Koppu, Chanthu, Kai-tak, and Vicente) were class 4 typhoons, 2 were weak typhoons with class 2–3. Our fish data were collected after the 3 typhoons Chanthu, Kai-tak, and Vicente (Fig. 2(a)).

Typhoon Chanthu originated in the middle of the SCS on July 19th, 2010 with a maximum wind speed (MWS) of 16 m s^{-1} and then strengthened into a typhoon on July 21st before landing on the Chinese mainland. It struck the study area from 11:00 to 12:00 on July 22nd, 2010 with a MWS of 35 m s^{-1}. The translation speed was approximately 4.99 m s^{-1} when passing through the study area (Fig. 1(b), Table 3).

Typhoon Vicente originated in the Philippine Sea on July 20th, 2012 with an initial MWS of 12 m s^{-1}. It strengthened into a typhoon on July 23rd near the Dongsha Islands in the northern SCS. Vicente passed near the study area with a MWS of 40 m s^{-1} from 23:00 July 23rd to 7:00 July 24th (Fig. 1(b) and Table 3).

Typhoon Kai-tak originated in the Philippine Sea on August 12th 2012 with an initial MWS of 16 m s^{-1}. It strengthened into a typhoon on August 16th at a longitude of 118°. Kai-tak passed through the study area from 6:00 to 10:00 on August 17th with a MWS of 35–40 m s^{-1}. The translational speed was approximately 5.58 m s^{-1} while crossing the study area (Fig. 1(b) and Table 3).

3.2. The increase in the fish CPUE

3.2.1. The effect of the fish moratorium

The Chinese Fishery Department created a fishing moratorium for the SCS in 1999 (Shi et al., 2008); it required that all fishing activities with the exception of single layer gill net and fishing tackle are forbidden in the SCS at latitudes north to 12° from May 15th to July 31st. Some studies indicated an increase in the fish production after the fish moratorium (Shi et al., 2008; Duan et al., 2010). During this study (from May 2009 to March 2013), there were four periods of fishing moratoria. We supposed that the effects of the fishing moratoria on the fish production were relatively stable each year. The differences in the CPUE during the periods after the fishing moratoria were caused by other atmospheric and hydrological phenomena.

Table 5
Difference in CPUE of different fish groups classified by tropical level between the typhoon periods and the no-typhoon periods. The typhoon periods and the non-typhoon period are defined as Table 3.

Carnivorous fish groups	Chanthu		Vicente		Kai-tak	
	IR (%)	Increase in CPUE	IR (%)	Increase in CPUE	IR (%)	Increase in CPUE
Low class	195.61	0.294	132.33	0.088	129.71	0.08
Middle class	−59.96	−0.002	−100	−0.004	−100	−0.0003
High class	−21.17	−0.008	−42.10	−0.044	−35.54	−0.031

Table 4
Difference in the increase rate (IR) and increase amount of CPUE of different fish groups classified by living depth and ecological type between the typhoon periods and the non-typhoon periods. The typhoon periods and the non-typhoon period are defined as Table 3.

Fish groups	Chanthu		Vicente		Kai-tak	
	IR (%)	Increase in CPUE	IR (%)	Increase in CPUE	IR (%)	Increase in CPUE
Pelagic	16.56	0.001	102.11	0.023	83.38	0.015
Meso demersal	139.00	0.009	249.19	0.007	168.88	0.017
Demersal	145.50	0.152	−16.96	−0.024	7.25	0.007
Reef	−47.46	−0.003	135.66	0.016	202.87	0.012
Cephalopoda	81.42	0.007	234.63	0.030	99.05	0.018
Crab	203.04	0.015	−100.00	−0.009	155.30	0.008
Shrimp	173.86	0.099	−90.56	−0.060	700.49	0.005
Other	127.00	0.046	278.03	0.170	186.00	0.138

3.2.2. The increase in the CPUE of total catch

Daily variations in the CPUE from May 2009 to March 2013 presented increase in the CPUE after Typhoons Chanthu, Vicente and Kai-tak (Fig. 2(a)). The CPUE of the total catch increased by 133.33%, 62.50% and 104.17% compared with the average CPUE in the non-typhoon periods after Chanthu, Vicente and Kai-tak, respectively. The increased CPUE between the typhoon periods and the non-typhoon periods were approximately 0.32 kg h^{-1} kw^{-1}, 0.20 kg h^{-1} kw^{-1} and 0.25 kg h^{-1} kw^{-1} after Chanthu, Vicente and Kai-tak, respectively (Table 3). The increased amount of the CPUE for Filefishes (Thamnaconus spp.), Threadfin Breams (Nemipterus spp.) and Porgies (Parargyrops edita) (Fig. 2(b1–b3)) had largest values after the three typhoons.

After Chanthu, the CPUE decreased from 1.99 kg h^{-1} kw^{-1} to 0.56 kg h^{-1} kw^{-1} over the period from August 1st to 20th, 2010. While after Vicente and Kai-tak, the CPUE increased over time until the values reached the maxima of 1.03 kg h^{-1} kw^{-1} and 0.64 kg h^{-1} kw^{-1} respectively, and then decreased to normal levels. The CPUE recovered to normal values after approximately 20, 23 and 14 days after Chanthu, Vicente and Kai-tak respectively (Figs. 3(e), 4(e), and Table 3).

3.2.3. The increase in CPUE of pelagic fish, meso-demersal fish and cephalopoda

The changes in the CPUE of the eight sorted fish groups (pelagic fish, meso-demersal fish, demersal fish, reef fish, cephalopoda,

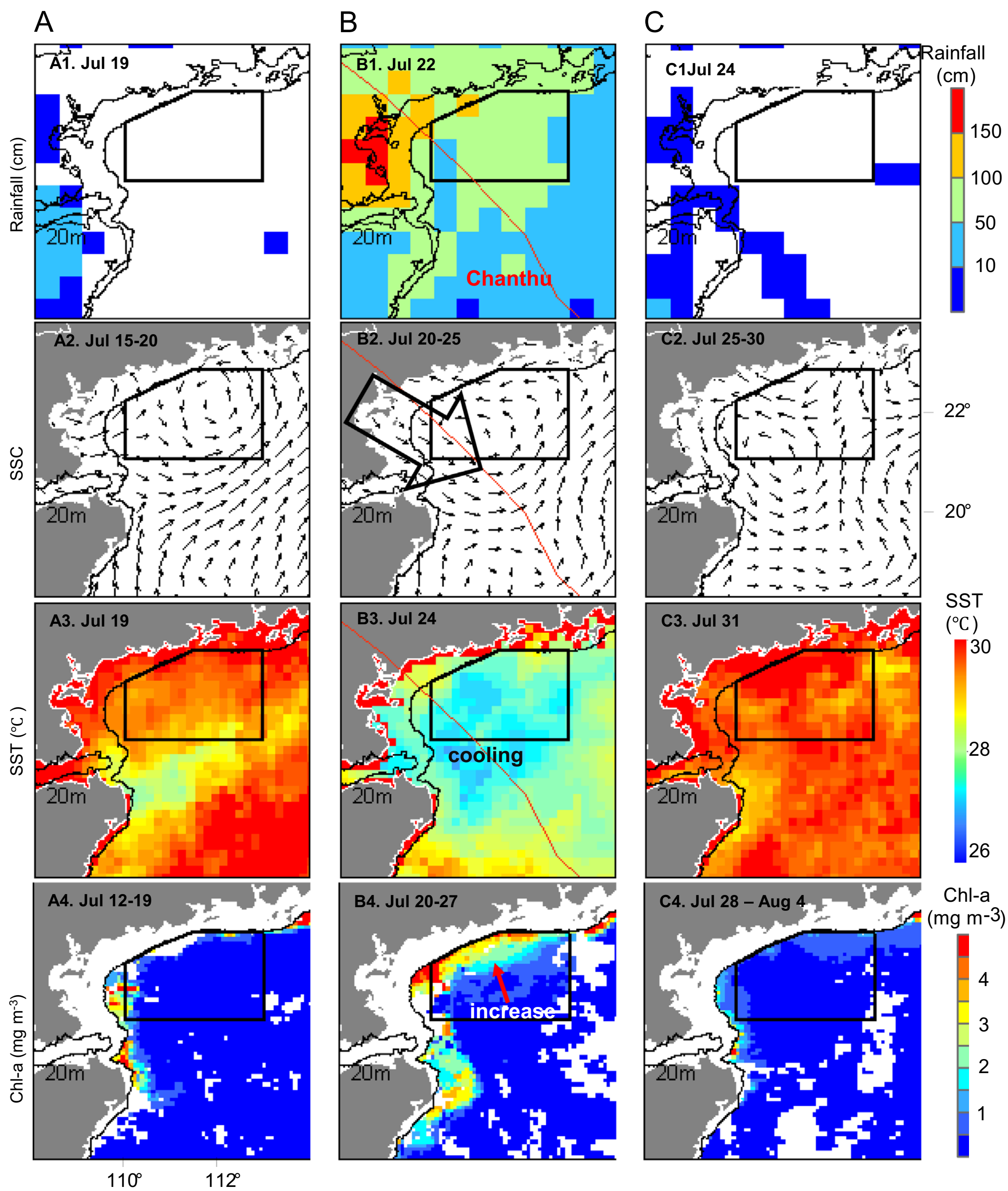

Fig. 5. Spatial distribution of the rainfall (cm), SSC, SST (°C), Chl-a (mg m^{-3}). A: before typhoon Chanthu (A1–A4); B: during typhoon Chanthu (B1–B4); and C: after typhoon Chanthu (C1–C4).

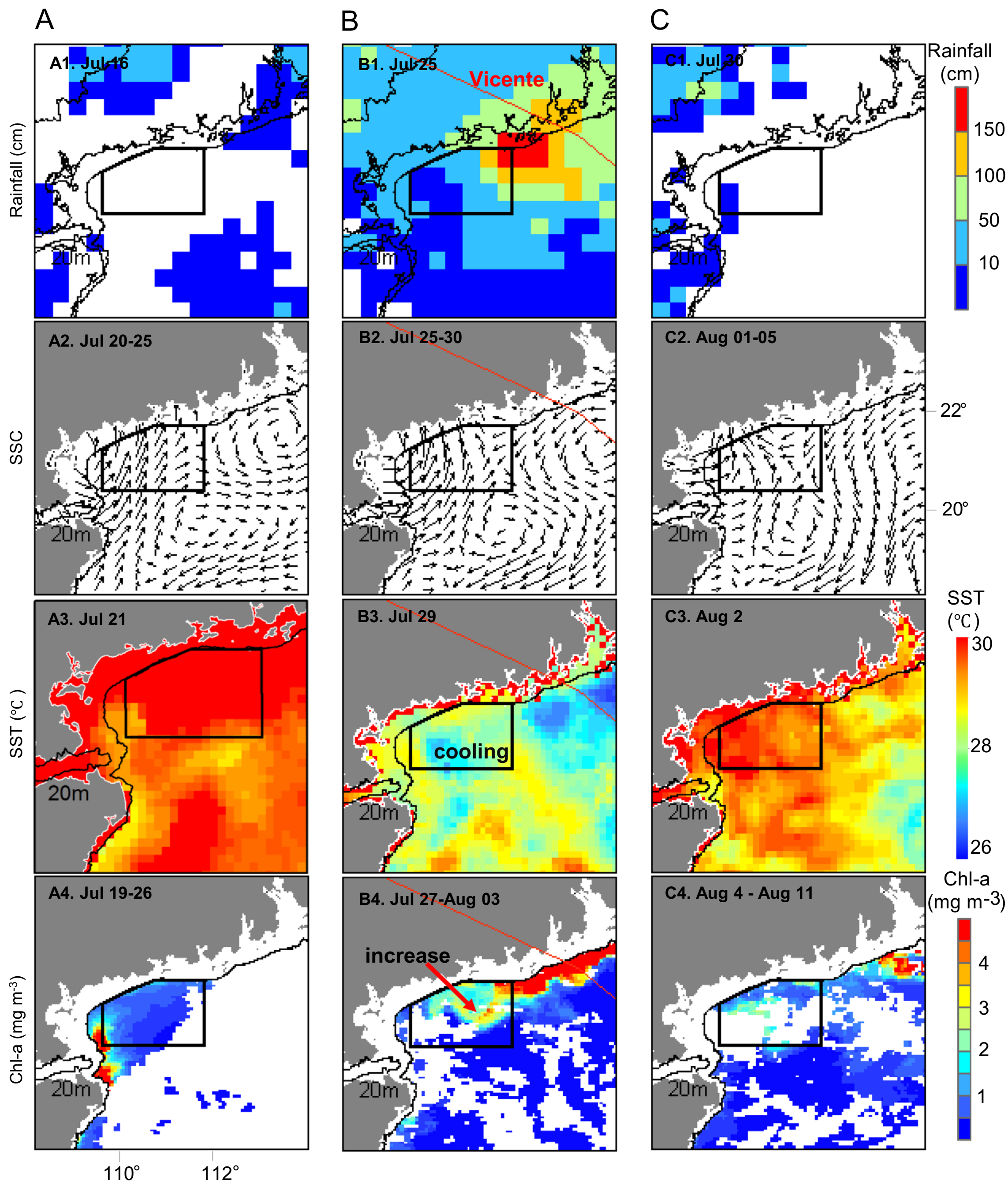

Fig. 6. Spatial distribution of the rainfall (cm), SSC, SST (°C), Chl-a (mg m^{-3}). A: before typhoon Vicente (A1–A4); B: during typhoon Vicente (B1–B4); and C: after typhoon Vicente (C1–C4).

crab, shrimp and other fish) after the three typhoons were complicated. After Chanthu, the CPUE of the pelagic fish, meso-demersal fish, demersal fish, cephalopoda, crab, shrimp and other fishes increased by 16.5%, 139.00%, 145.50%, 81.42%, 203.04%, 173.86%, and 127.00%, respectively, while the CPUE of the reef fishes decreased by 47.46%. After Vicente, the CPUE of the pelagic fish, meso-demersal fish, reef fish, cephalopoda and other fishes increased by 102.11%, 249.19%, 135.66%, 234.63%, and 278.03%, respectively while the CPUE of demersal fish, crab and shrimp decreased by 16.96%, 100%, and 90.56%, respectively. After Kai-tak, the CPUE of pelagic fish, meso-demersal fish, demersal fish, reef fish, cephalopoda, crab, shrimp and other fishes increased by 83.38%, 168.88%, 7.25%, 202.87%, 99.05%, 155.30%, 700.49%, and 186.00%, respectively (Table 4).

3.2.4. The increase in CPUE of the low carnivorous fish

Changes in the CPUE of low, middle and high carnivorous fish varied with the same trend after Chanthu, Vicente and Kai-tak. After Chanthu, Vicente and Kai-tak, the CPUE of the low trophic level carnivorous fish increased by 195.62%, 132.33% and 129.71%, respectively, while the CPUE of middle and high trophic level carnivorous fish decreased by 59.96% and 21.17% after Chanthu, 100% and 42.10% after Vicente, and 100% and 35.54% after Kai-tak (Table 5).

3.3. Variations in the wind, rainfall and runoff after the 3 typhoons

Typhoon Chanthu, Vicente, and Kai-tak caused increase in average wind speed (Figs. 3(a) and 4(a)). The maximum wind speeds (MSW) were 11.32 m s^{-1}, 13.31 m, and 17.31 m s^{-1} on July

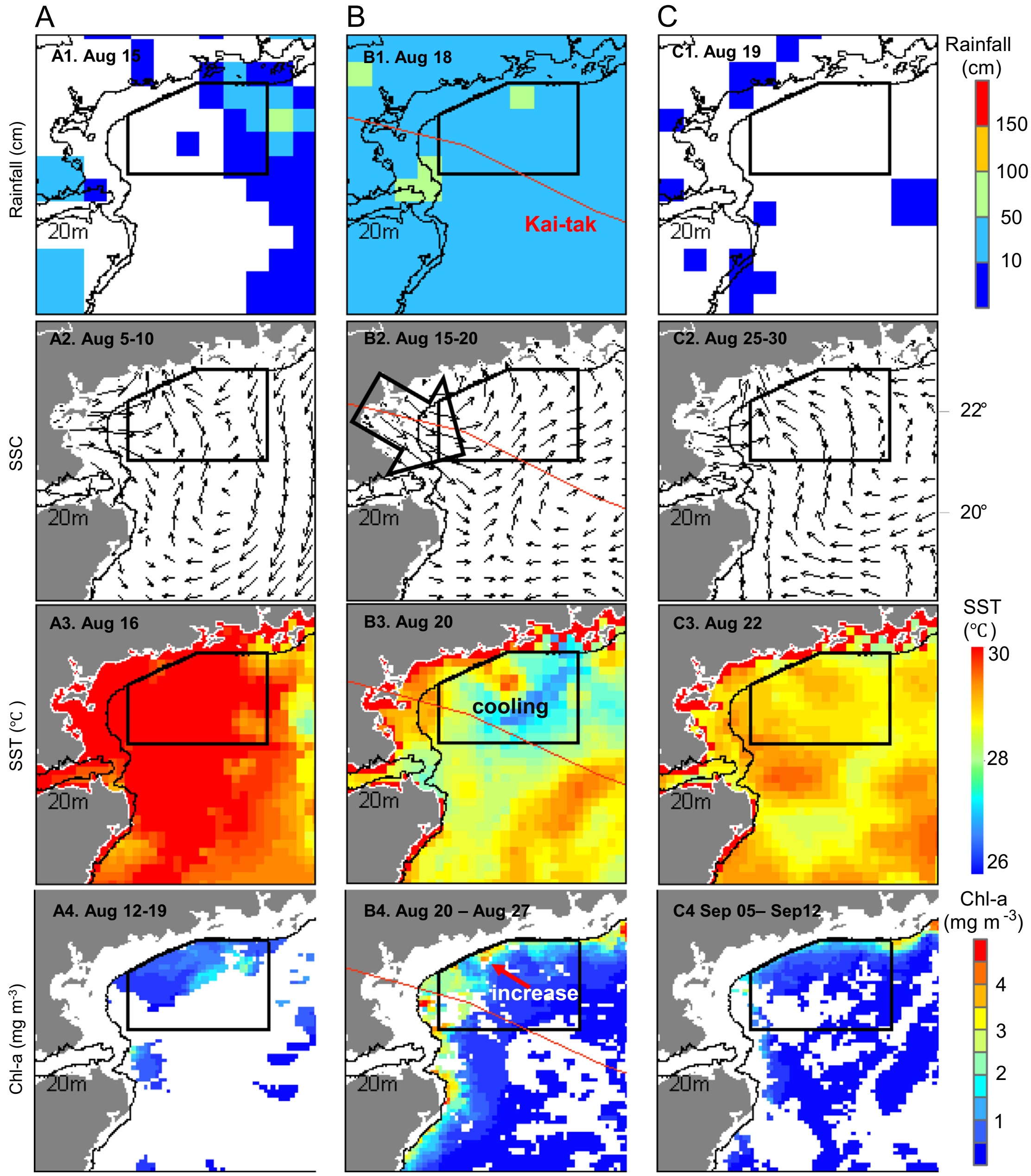

Fig. 7. Spatial distribution of the rainfall (cm), SSC, SST (°C), Chl-a (mg m^{-3}). A: before typhoon Kai-tak (A1–A4); B: during typhoon Kai-tak (B1–B4); and C: after typhoon Kai-tak (C1–C4).

21st 2010, July 23th and August 16th, 2012. The MSW decreased to minimum value after 5, 10, and 4 days (Table 3). The increase in Ekman pumping speed between pre-typhoon and after-typhoon were 5.58 m s^{-1}, 4.86 m s^{-1}, and 12.96 m s^{-1} (Table 3).

After 3 typhoons, rainfall of 78.09 cm on July 22nd, 2010, 43.91 cm on July 24th, 2012, and 44.48 cm on August 16th, 2012 are represented in the study area (Figs. 3(b), 4(b), and Table 3). The position of maximum rainfall greater than 150 cm is located at northwest and northeast of the fishing ground (FG in Fig. 1). The amount of rainfall after Kai-tak was less than 50 cm at most of the study area (Figs. 5(A1–C1), 6(A1–C1), and 7(A1–C1)). The rainfall lasted for 4, 8, and 2 days during 3 typhoons (Table 3).

During Chanthu and Kai-tak, the runoff from the land to the northwest of the study area increased compared with the amount before the typhoon (Figs. 5(A2–C2) and 7(A2–C2)). During Vicente, there was no change in the direction of SSC. But the SSC strengthened (Fig. 6(A2–C2)).

3.4. Variations in the physical environment after the three typhoons

After Chanthu, Vicente, and Kai-tak, upwellings were observed in the FG in Fig. 1 (Figs. 5(A3–C3), 6(A3–C3), and 7(A3, B3, C3)). The maximum decrease in the SST was 1.93 °C, 3.05, and 2.57, which occurred 5, 8, and 4 days after the 3 typhoons (Table 3).

After Chanthu, Vicente, and Kai-tak, there were increases in the Chl-a in FG in Fig. 1 compared to the Chl-a pre-typhoon (Figs. 5 (A4–C4), 6(A4–C4), and 7(A4–C4)) and non-typhoon month (Fig. 8 (A1–A3)). The maximum Chl-a was 4.75 mg m^{-3}, 2.08 mg m^{-3}, and 0.90 mg m^{-3},which occurred on the 6th, 8th, and 5th days after 3 typhoons (Figs. 3(d), 4(d), and Table 3). The increase in Chl-a were 1.6 mg m^{-3}, 0.7 mg m^{-3}, and 0.29 mg m^{-3} (Table 3).

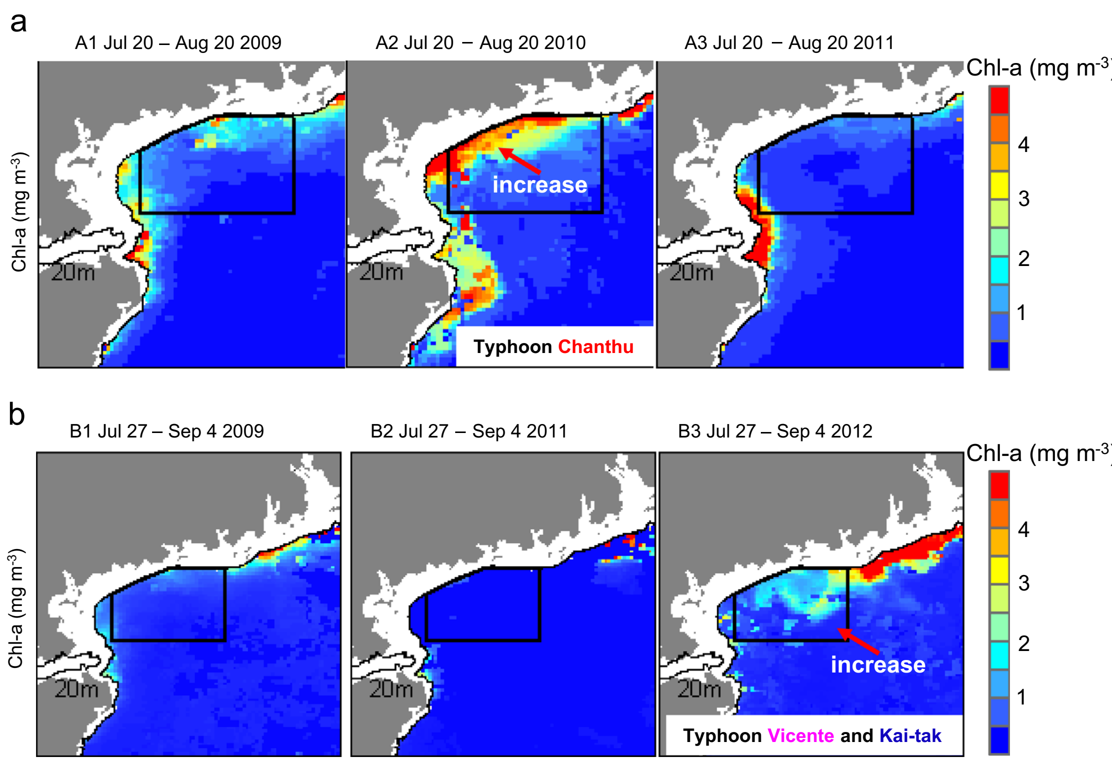

Fig. 8. (a) Spatial distribution of Chl-a from July 20th to August 20th, 2009 (A1), 2010 (A2) and 2011 (A3). (b) Spatial distribution of Chl-a from July 27th to September 4th, 2009 (B1), 2011 (B2) and 2012 (B3).

4. Discussion

4.1. The CPUE increased related to typhoons

Typhoons routinely result in changes in fish behavior because of the strong wind, rainfall, land runoff, river discharge and upwelling (Yu et al., 2013). Massive amounts of nutrients enter the nearshore waters or the waters near the typhoon track due to the flow of the runoff (river discharge) and upwelling (Zhao et al., 2009). Some foraging fishes actively migrate to the nutrient rich waters, and at the same time, some small or feeble fishes enter the waters because of strong currents (Yu et al., 2013; Kawabata et al., 2010; Switzer et al., 2006). A previous study documented that the increase in fish CPUE was more than 30-fold after typhoon compared to the CPUE pre-typhoon in a bay (Houde et al., 2005).

In this study, Typhoons Chanthu, Vicente and Kai-tak delivered rainfall and decrease in SST to different extents. The runoff formed on the continent to the northwest of the study area after Chanthu and Kai-tak, while an enhanced costal current formed after Vicente. The increase in Chl-a in the study area was the result of runoff, rainfall and upwelling after Chanthu and Kai-tak, while the Chl-a's increase after Vicente was owing to rainfall and upwelling. The increase in the CPUE was closely related to the nutrient enhancement.

4.2. Positive impacts on pelagic fish, meso-demersal fish and cephalopoda

Typhoons change the composition of the local fish community (Mukherjee et al. 2012).There were some impacts on fish, cephalopoda, shrimp and crab from the typhoon Chanthu, Vicente and Kai-tak, respectively. An increase in the CPUE of pelagic fish, meso-demersal fish and cephalopoda occurred after all three typhoons. These increases indicated that typhoons led to stable, positive effects on these fishes. The increase in CPUE of meso-demersal fish, cephalopoda and pelagic fish varied from high to low. We can assume that the typhoon first affects species living at meso-demersal depths and then those living at lower depths. This study showed that the three typhoons had positive effects on the low trophic level carnivorous fish.

4.3. The differences in the CPUE after the three typhoons

Typhoons Chanthu, Vicente and Kai-tak passed through or nearby the study area with different intensities and translational speeds. A previous study showed that a weak, slow typhoon can induce phytoplankton blooms with a higher total Chl-a than a fast-moving, strong typhoon (Zhao et al. 2008). In this study, a slow-moving typhoon (Chanthu) caused more rainfall and larger upwelling than the fast-moving typhoons (Vicente and Kai-tak). The increase in the CPUE after the slow-moving typhoon was higher than the one after the fast-moving typhoons. The increases in the CPUE after the typhoons were attributed to the accumulation of fish.

The accumulation of fishes was related to the increase in nutrients after the typhoons. The amount, extent and location of rainfall, runoff and upwelling were the main factors which affected the distribution of the nutrients. Although Typhoon Vicente did not pass over the northwestern SCS, there was still an increase in the Chl-a due to the large volume of rainfall and upwelling after the typhoon.

The different effects of the three typhoons on the nutrient were as follow: (1) Rainfall: after Chanthu, a large amount of rainfall lasted for four days and fell on the land to the northwest of SCS, and the nutrients from the land were introduced to the study area through runoff. After Vicente, there was a little rainfall but no runoff in the northwestern SCS. After Kai-tak, only a relatively small and short-lived (two days) rainfall occurred over the land to the northwestern of the study area, and relatively small amounts of nutrients from the land were introduced to the study area through runoff. The amounts of nutrients transported by rainfall and runoff after Chanthu, Kai-tak and Vicente differed, with Chanthu introducing the largest amounts of nutrients and Vicente the least amounts. (2) Upwelling: the upwelling

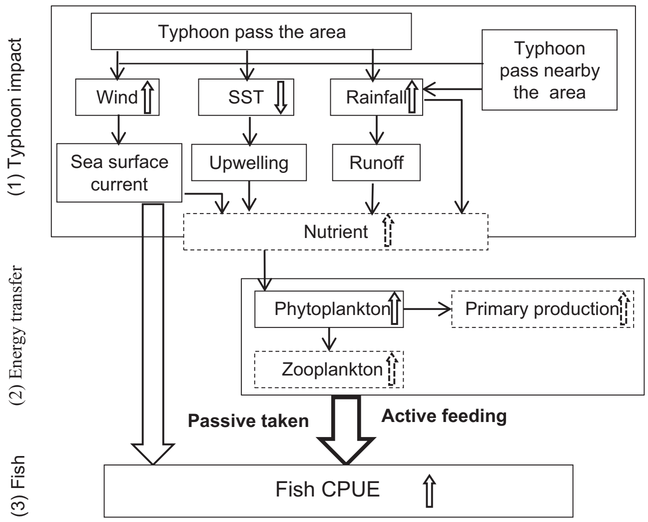

Fig. 9. Mechanism of the increase in the fish CPUE after the typhoons in the northwest SCS. Black up arrows: increase. Thick black down arrows: the two causes of fish congregation. Thin black arrow: the correlation between every two boxes. Boxes with dashed borders indicate that the subject was not discussed in this research.

EPS after Kai-tak, Chanthu and Vicente differed, with Kai-tak and Vicente causing, respectively, the strongest and weakest upwelling, but the center of upwelling after Chanthu was located closer to the northern coast of SCS than the upwelling centers after Kai-tak and Vicente. In the northern SCS, there were more nutrients nearshore than offshore. We can infer that the nutrient uptake from upwelling after Vicente was smaller than the one after Kai-tak and Chanthu. Although there was a strong Ekman pumping after Kai-tak, the spatial extent of the upwelling was smaller, and the location of upwelling center was farther from the coast than it was after Chanthu. The amount of nutrient uptake with the upwelling caused by Chanthu and Kai-tak was difficult to compare. The total amount of nutrients after Chanthu, Vicente and Kai-tak introduced through rainfall, runoff and upwelling differed. The slow-moving, weak Typhoon Chanthu introduced more nutrients into the study area through runoff and upwelling, which resulted in a larger accumulation of fishes.

4.4. Recovery of fish CPUE from both the pressure of fishing and the recovery of the environment

The three typhoons greatly affected fishery in the study area, but the effects did not persist. After a typhoon, decreases in the SST can last for more than 10 days (Zheng and Tang, 2007; Shang et al., 2008), while the increase in Chl-a can last for more than 16 days (Chen and Tang, 2012). In this study, the upwelling lasted for 11 days, 11 days, and 10 days (Figs. 3(c) and 4(c)), while the Chl-a values peaked after six days, eight days, and five days separately. After Chanthu, the upwelling was very large. The strong vertical mixing uptake amounts of nutrients from bottom to upper waters. A previous study showed that the increase in the subsurface Chl-a is stronger and longer than the surface Chl-a bloom (Ye et al. 2013). Under the pressures of fishing activities and the recovery of the environment, fish production will recover to a normal level after several days. When considering the long-term effects of typhoons, previous studies showed that fish resources may spend a few years to recover in some lakes (Alford et al., 2010). In some bays, fish resources returned to natural levels after decades (Greenwood et al., 2006). In the northern SCS, typhoons occur frequently. The post-typhoon changes in these habitats are complex because there may be another typhoon happening shortly after the first; therefore, it is difficult to investigate long-term recovery phase. In this study, fish production returned to the normal levels after approximately three weeks because of the fishing pressure and the recovery of environment (Figs. 3(e) and 4 (e)) Observations evidenced the recovery of fish community in India River Lagoon needs several weeks (Paperno et al. 2006), and the recovery of nekton community in St. Lucie estuary was 4 months (Switzer et al. 2006). The present study showed that the recovery of fish community in open sea was shorter than that in estuary and lagoon.

4.5. The positive effects of the typhoons on some fish groups are (Fig. 9)

(1) Rainfall, runoff, upwelling, and sea surface currents are the four main routes that fertilize the northwestern SCS through the transfer of nutrients, which brings terrestrial nutrients seaward and subsurface water rich in nutrients to the surface.
(2) Energy is transported from organic elements to phytoplankton through the photosynthesis process and then to zooplankton through feeding activities.
(3) Fishes accumulate through two mechanisms: passively, owing to strong currents, and through active migration to nutrient-rich waters. Fig. 9.

5. Conclusions

The CPUE increase in the northern SCS after typhoons.

(1) The study found CPUE increases in the northwestern SCS associated with typhoons. The increased CPUE recovered to the normal level nearly three weeks after typhoons; (2) the effect of the typhoons on the CPUE of meso-demersal fish, cephalopoda and pelagic fish are positive. Fishes with low trophic level carnivorous exhibit increase in CPUE; (3) a typhoon with a slower translational speed can cause a larger increase in CPUE.

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