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Short-term change in fish assemblages after the passage of a typhoon in a temperate, coastal bay

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Abstract

To study the effects of a typhoon on a temperate, coastal bay community, the species composition, catch amount, and diversity of epipelagic fish assemblages were investigated. Fish samples were taken from catches of a purse seine fishery in Tachibana Bay, Japan between May and July 2011, covering before and after the passage of a typhoon in the area. Although major changes in total catch amount were not observed before and after the passage of the typhoon, the abundance of the Japanese anchovy, *Engraulis japonicus* Temminck et Schlegel, 1846, markedly decreased and bycatch of species increased, accompanied by increasing levels of diversity of the fish assemblage. Multivariate analysis showed that community differences before and after the passage were quantitative rather than qualitative. Comparisons in total length frequencies between the two periods indicated that specimens of the species compared were bigger in size for *Trachurus japonicus* (Temminck et Schlegel, 1844) and smaller for *E. japonicus* in the "after" period. These results suggest that the passage of the typhoon triggered not only interspecific faunal change but also intraspecific recruitment shifts in and around the bay.

Keywords

bycatch, diversity, fish assemblage, migration, purse seine fishery, typhoon

Introduction

The effects of hurricanes, typhoons (also termed tropical cyclones), and tropical storms, are major sources of physical disturbance to shallow water communities, affecting geological features (Kahn 1984), hermatypic corals (Woodley et al. 1981; Harmelin-Vivien and Laboute 1986), and other reef organisms (Yoshioka and Yoshioka 1987; Moran and Reaka-Kudla 1991). Although much information on the impact of hurricanes and tropical cyclones on fish assemblages is available in tropical, coral reef areas, the results of these studies are inconsistent (Kaufman 1983; Lassig 1983; Fenner 1991; Letourneur et al. 1993; Cheal et al. 2002; Guillemot et al. 2010; Kawabata et al. 2010; Foster et al. 2011). Breder (1962) noted the loss of the most abundant fish species, the pinfish, *Lagodon rhomboides* (Linnaeus, 1766), and proposed that a faunal shift had occurred. High post-hurricane mortality among metamorphosed damselfishes (Beecher 1973) and juveniles of other fishes (Lassig 1983; Bouchon et al. 1994) suggests that susceptibility to hurricane-induced stress may be related to the life-stage. In some cases, post-hurricane increases in fish abundance have been observed (Woodley et al. 1981; Turpin and Bortone 2002) while in other cases minimal or no effects on fish assemblages were found when compared with pre- and after-passage of the hurricane (Springer and McErlean 1962; Fenner 1991).

It has been suggested that global warming may increase the frequency of strong typhoons (Emanuel 2005; Webster et al. 2005), and consequently temperate, coastal communities would increasingly be exposed to such severe disturbances.

However, only a few studies refer to the effects of typhoons on fishery activities in subtropical and temperate, coastal bays (Kawabata et al. 2010; Yu et al. 2013, 2014; Chang et al. 2014). Additionally, as far as I knew, there is no information about the impact of a typhoon on changes in species composition obtained from purse seine fishing. This type of information is important in order to consider if the change in catch amount and/or composition originates from either human or natural factors for fishery management and to estimate how communities and coastal marine ecosystems are impacted by typhoons. For these objectives, I considered that monitoring the species composition of purse seine catch, including bycatch (i.e., the fraction of the catch that consists of nontarget species that are encircled by the fishing gear and are unable to escape (Romanov 2002) is an effective method to determine the structure and spatial organization of multispecies aggregations of coastal communities (Hall 1996; Erzini et al. 2002).

On 26 June 2011, the typhoon MEARI (international number: 1105) passed approximately 500 km offshore of the west coast of Kyushu, Japan (Fig. 1). Maximum wind velocities near the storm center were 30 m•s^{-1} (Table 1). The presently reported study examined the effect of this typhoon by comparing catch amount, species composition, and diversity obtained from purse seine catches before and after the passage of the typhoon, to test the hypothesis that such meteorological phenomena change the fish assemblage community structure and diversity in a temperate, coastal bay.

Materials and methods

Study area

Tachibana Bay is located in the southern part of Nagasaki Prefecture, Kyushu, Japan. The northern and southern sides of this bay are enclosed by the Nagasaki and the Shimabara peninsulas, and the bay is connected to the Ariake Sound in the east, and exposed to the East China Sea in the west (Fig. 1). In Tachibana Bay, purse seine fishing has been operated since the early 1950s and has become the main fishery for epipelagic fish species. Although the purse seine fishery in Tachibana Bay mainly targets Japanese anchovy *Engraulis japonicus* Temminck et Schlegel, 1846, bycatch occurs. Our sampling of the purse seine fishing catch takes place within an area at a mean depth of 36 m (hatched area, Fig. 1).

Sampling design

Six random sampling operations were carried out opportunistically before and after the passage of the typhoon MEARI from May to July in 2011. Each sample of approximately 3 kg was taken from the purse seine catches prior to the sorting procedure at the Kyodomari Port of Tachibana Bay. The fishing gear was approximately 380 m in length, 30 m in depth, and 6 mm in minimal stretched mesh size. Total catch amount, the number of hauls, and sea surface temperature of the fishing grounds on sampling days were collected from the fishing master of this fishery.

In the laboratory, fishes from each sample were counted and identified to the lowest possible taxonomic level. The total weight of each taxon was also recorded in 0.1 g order and the total length frequency for each species, except for Japanese anchovy, was measured from randomly chosen 100 individuals.

Data analysis

The total catch amount and abundance of the samples were expressed as the weight of fish per haul. To analyze

Table 1. Best track data of MEARI (1105) in 2011 from the Regional Specialized Meteorological Center (RSMC), Tokyo, Japan.

Date (June)	Time	Center position (DDM) Latitude and Longitude	Central pressure [hPa]	Maximum wind speed near the center [m•s^{-1}]	Radius of area of winds [km] 25 m•s^{-1}	15 m•s^{-1}
	09	13°12′N, 129°18′E	998	18	–	NE: 440 SW: 280
	15	14°00′N, 128°54′E	998	18	–	NE: 440 SW: 280
	21	14°48′N, 128°42′E	994	20	–	E: 700 W: 370
23	03	15°36′N, 128°24′E	990	23	–	E: 700 W: 370
	09	16°36′N, 127°54′E	985	25	–	SE: 750 NW: 370
	15	17°24′N, 127°24′E	985	25	–	SE: 750 NW: 370
	21	18°12′N, 126°54′E	985	25	–	SE: 750 NW: 370
24	03	19°18′N, 126°30′E	985	25	–	SE: 750 NW: 370
	09	20°48′N, 126°00′E	980	30	190	SE: 750 NW: 440
	15	22°48′N, 125°18′E	980	30	190	SE: 750 NW: 440
	18	23°36′N, 125°00′E	975	30	E: 220 W: 190	SE: 750 NW: 440
	21	24°24′N, 124°30′E	975	30	E: 220 W: 190	SE: 750 NW: 440
25	00	24°54′N, 124°06′E	975	30	E: 220 W: 190	SE: 750 NW: 440
	03	25°30′N, 123°48′E	975	30	E: 220 W: 190	SE: 750 NW: 440
	06	26°00′N, 123°36′E	975	30	E: 220 W: 190	SE: 750 NW: 440
	09	26°36′N, 123°18′E	975	30	E: 220 W: 190	SE: 750 NW: 440
	15	27°42′N, 123°18′E	975	30	E: 220 W: 190	SE: 750 NW: 370
	21	29°12′N, 124°06′E	980	30	150	SE: 700 NW: 370
26	03	32°06′N, 124°42′E	980	30	150	SE: 700 NW: 370
	09	35°06′N, 124°24′E	980	30	150	SE: 700 NW: 370
	15	36°48′N, 123°00′E	980	30	130	SE: 650 NW: 370
	21	37°06′N, 122°48′E	980	30	130	E: 600 W: 370
27	03	37°30′N, 123°00′E	985	25	–	E: 560 W: 370
	09	38°30′N, 124°18′E	990	23	–	330

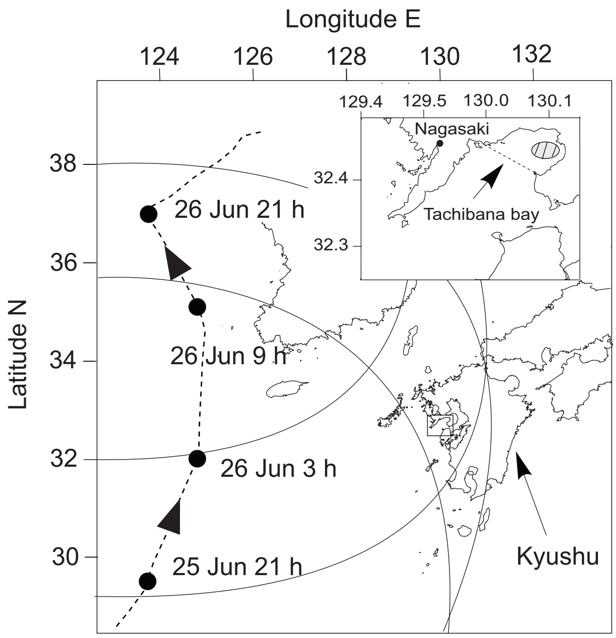

Figure 1. Map showing the trajectory of the tropical cyclone MEARI (dashed line) and the fishing ground (inset, shaded area) of the purse seine fishing in Tachibana Bay in 2011. Radii of circles show the areas affected by winds of 15 m•s–1. Best track data of MEARI is available in Table 1.

the species composition per haul before and after the typhoon, the following indices were calculated: number of species, abundance (i.e., weight of fish) of *E. japonicus* and of bycatch species, Simpson's reciprocal index ($1 \cdot D^{-1}$), Shannon–Wiener species diversity (H'). Simpson's reciprocal index $1 \cdot D^{-1}$ was calculated as:

$$D = \sum_{i=1}^{S} p_i^2$$

where S is the number of species and p_i is the ratio of abundance of occurrences of the ith species to that of total species in the sample. Similarly, H' was derived by:

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i$$

where H' is the Shannon–Wiener function, S is the number of species and p_i is the ratio of abundance of occurrences of the ith species to that of total species in the sample. Both indices $1 \cdot D^{-1}$ and H' reflect not only species richness but also provide an index of the evenness of a community (Krebs 1989). The index $1 \cdot D^{-1}$ is more sensitive to changes in abundant species, whereas H' is more sensitive to changes in rare to intermediate species in a community (Peet 1974; Krebs 1989). K-dominance curves (Clarke and Warwick 1994; Machias et al. 2004) were also plotted for each sampling period. Multivariate analysis of fish community data involved the use of the Bray–Curtis similarity index on double square-root transformed and on presence-absence data.

The mean values of the pooled data from the 3 purse seine fishing samples carried out 'before' and in the 3 samples 'after' the passage of the typhoon of total catch amount, abundance, and diversity for the community were compared by student t-test. Mann–Whitney U test was used to compare the total lengths of three species, *Engraulis japonicus*, *Trachurus japonicus* (Temminck et Schlegel, 1844), and *Sarda orientalis* (Temminck et Schlegel, 1844) (for which the data greater than two individuals were recorded in both 'before' and 'after' the typhoon) between the two sampling periods ($P < 0.05$).

Results

The distribution of sea surface temperature data in Tachibana Bay, Kyushu, Japan is presented in Fig. 2. Changes in surface water temperature and total catch amount per haul during the experimental period are presented in Fig. 3. The sea surface temperature of the purse seine fishing grounds in Tachibana Bay ranged between 18.3 and 25.7°C (Fig. 3A). After the passage of the typhoon, ranges between the maximum and minimum sea surface temperature in the fishing ground became narrower. There is no significant difference in the mean total catch amount per haul between 'before' and 'after' ($t = 1.14$, $P = 0.16$) (Fig. 3B, C).

Ratios of the number of individuals and of the abundance of bycatch species such as *T. japonicus* and *S. orientalis* abruptly increased just after the passage of the typhoon, and *E. japonicus* decreased (Fig. 4). *Engraulis japonicus* accounted for more than 90% of abundance in the period 'before' passage while this ratio decreased to 57% in the 'after' period (Fig. 4). A total of 16 species were caught in total, in 'before' and 'after' the passage of the typhoon. Seven species were found in the samples of 'before' and 16 species in the 'after' typhoon. All species caught 'before' were also found in 'after' with the exception of one species *Stephanolepis cirrhifer* (Temminck et Schlegel, 1850). In the 'after' samples an additional nine species, *Sardinops sagax* (Jenyns, 1842), *Decapterus maruadsi* (Temminck et Schlegel, 1843), *Seriola quinqueradiata* Temminck et Schlegel, 1845, *Nuchequula nuchalis* (Temminck et Schlegel, 1845), *Spratelloides gracilis* (Temminck et Schlegel, 1846), *Trichiurus lepturus* Linnaeus, 1758, *Auxis rochei* (Risso, 1810), *Scomber australasicus* Cuvier, 1832, and *Lagocephalus wheeleri* Abe, Tabeta et Kitahama, 1984, were found that were not caught in the 'before' samples (Fig. 4).

Several descriptors of the fish community are shown in Fig. 5. The mean number of species increased from 1.0 to 4.4, but this is not a significant change ($t = 0.99$, $p = 0.19$) (Fig. 5A). The mean abundance of *E. japonicus* significantly decreased ($t = 3.98$, $p = 0.0082$) (Fig. 5B), thus the abundance of bycatch species increased in the period after the passage of the typhoon. Conventional diversity indices such as those of Shannon and Simpson showed significant increases indicating that the distribution of individuals among species was more even in the period

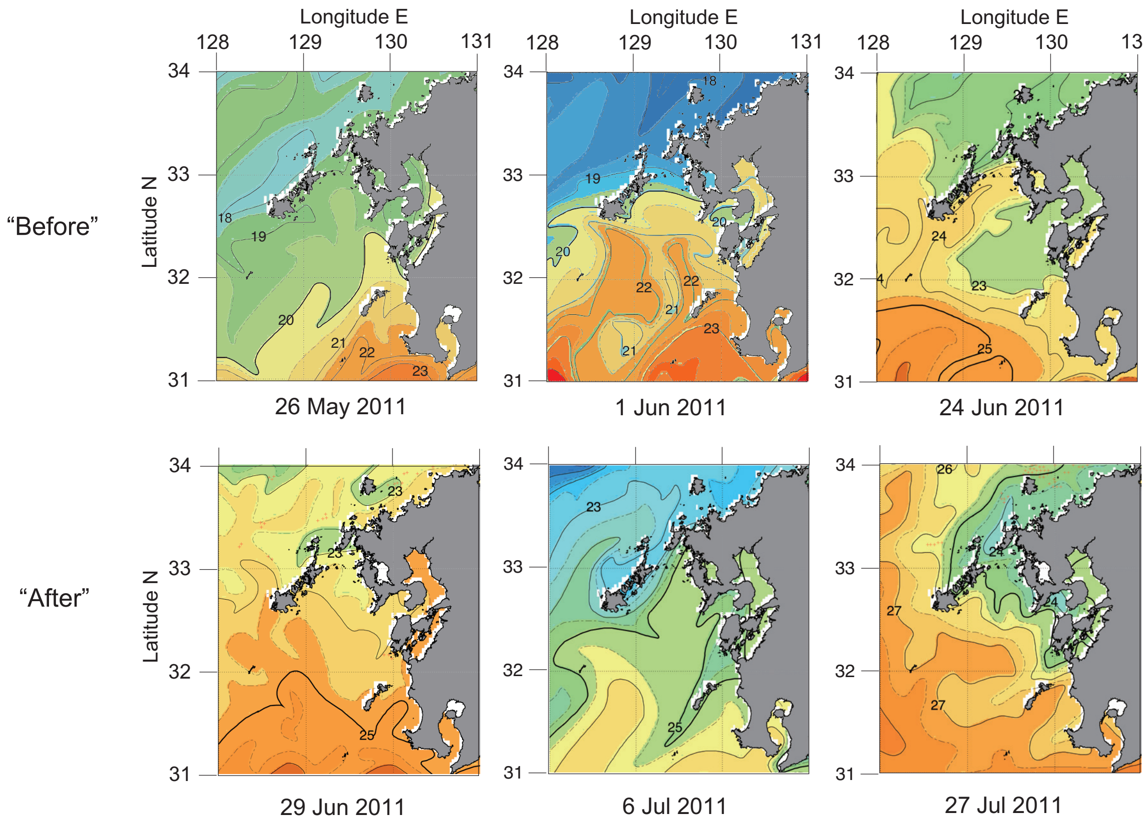

Figure 2. The distribution of sea surface temperature data in the sea around Tachibana Bay, Kyushu, Japan collected by the Japan Fisheries Information Service Center (JAFIC), Tokyo, Japan. The contour intervals are 1.0°C (solid lines) and 0.5°C (dashed lines).

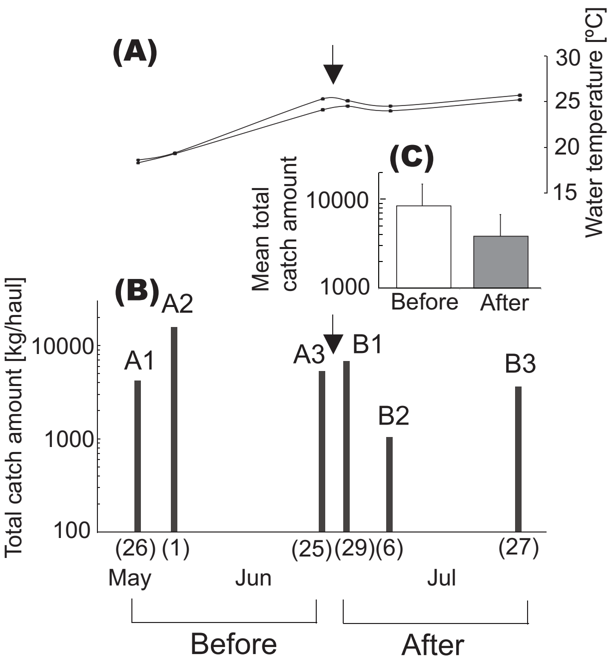

Figure 3. Changes in sea surface temperature and total catch amount during the experimental period in Tachibana Bay, Kyushu, Japan in 2011. **A:** Observed maximum and minimum sea surface temperature in the fishing ground, **B:** Total catch amount per haul, **C:** Mean total catch amount between 'before' and 'after' the passage of the typhoon. Data are means ± S.D. Arrows indicate the passage of the typhoon, A1~B3 indicate sample numbers and numbers in parentheses indicate dates.

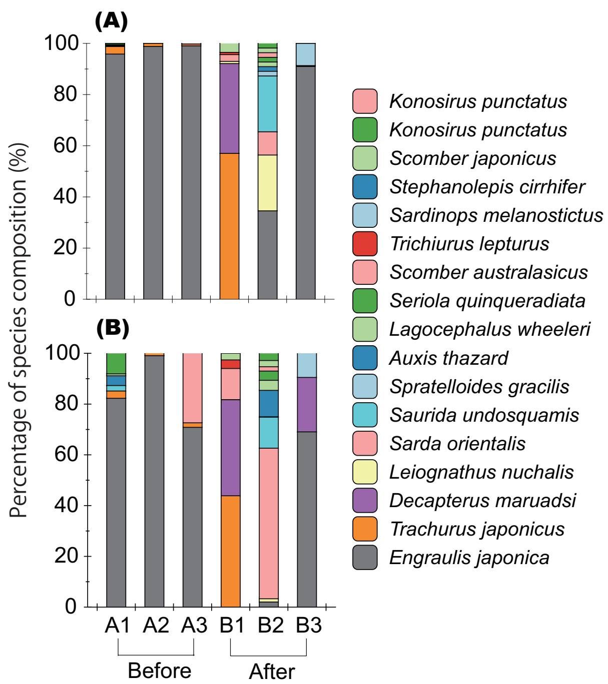

Figure 4. Changes in species composition of the fish community during the period before (A1, A2, and A3) and after (B1, B2, and B3) the passage of the typhoon in Tachibana Bay, Kyushu, Japan. Percentages of the Japanese anchovy *Engraulis japonicus* (grey) and bycatch species, based on **A:** The number of individuals and **B:** Total wet weight of the species sampled (abundance) data.

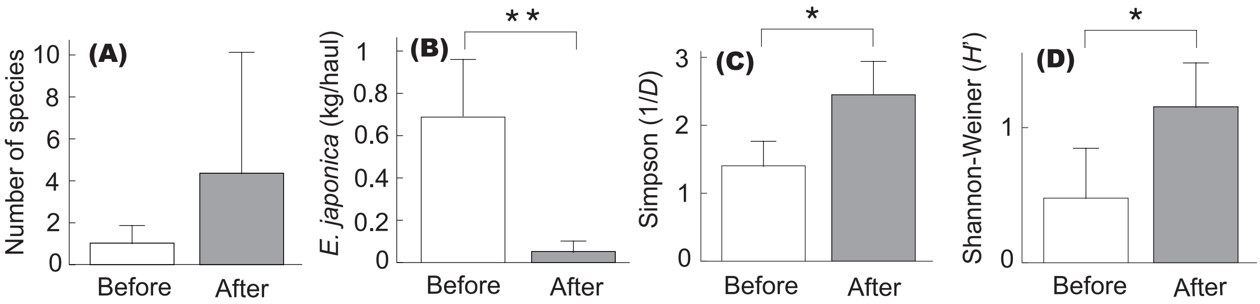

Figure 5. Comparisons of several descriptors of the fish community between the two sampling periods 'before' and 'after' the passage of the tropical cyclone (*$P < 0.05$, **$P < 0.01$, student-*t* test). **A:** Number of species, **B:** Abundance (wet weight) of the Japanese anchovy *Engraulis japonicus*, **C:** Simpson's reciprocal index $1 \cdot D^{-1}$, **D:** Shannon–Weiner species diversity H' (log 2). Data are means ± SD.

than before ($t = 2.98$, $P = 0.020$ for $1 \cdot D^{-1}$ and $t = 2.38$, $P = 0.038$ for H': Fig. 5C, D). The same is also true of the *k*-dominance curves (Fig. 6).

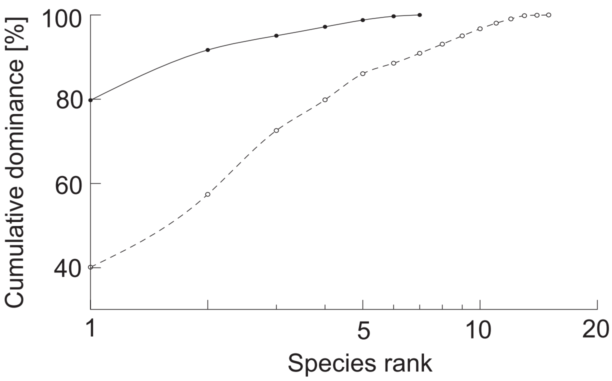

Figure 6. *K*-dominance curves on mean abundance of the period 'before' (solid line) and 'after' (dashed line) the passage of the typhoon.

The classification dendrogram showed two defined clusters corresponding to the 'before' and 'after' periods, except for one sample (B3), at similarity levels of 52% and 74%, respectively (Fig. 7A). By contrast, the classification based on presence–absence data did not reveal any difference between 'before' and 'after' (Fig. 7B), indicating that the overall changes in community structure between the two periods are quantitative rather than qualitative.

Comparisons in total length frequencies between the two periods indicated that specimens of the species compared were not significantly different in size for *S. orientalis* ($P = 0.68$; Fig. 8A) but were bigger for *T. japonicus* ($P = 2.4 \times 10^{-7}$: Fig. 8B) and smaller for *E. japonicus* ($P = 2.5 \times 10^{-75}$: Fig. 8C) in the 'after' period.

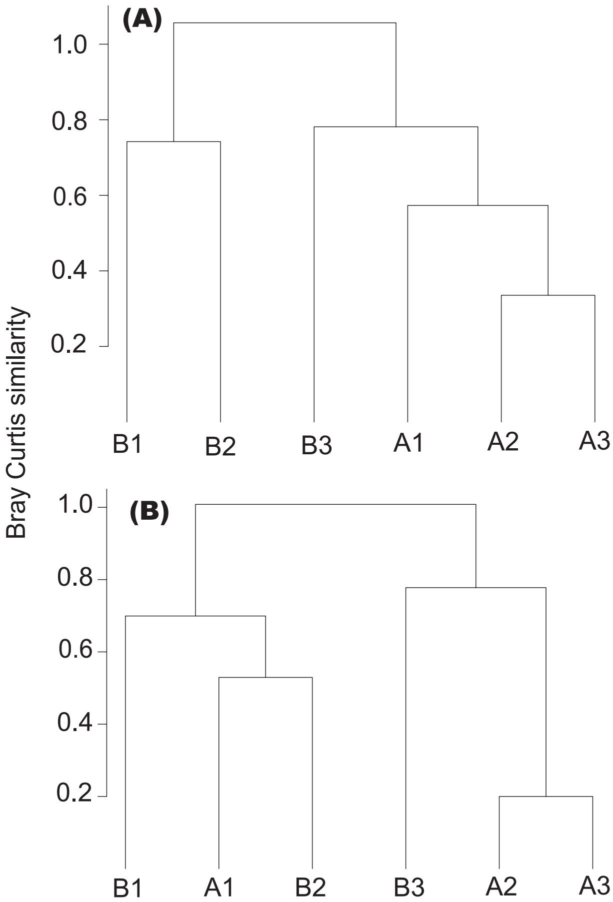

Figure 7. Cluster analysis dendrograms on data obtained during the period before (A1, A2, and A3) and after (B1, B2, and B3) the passage of the typhoon, based on **A:** 4th root-transformed species' total wet weight (abundance) data and **B:** Presence/absence data.

Discussion

In the presently reported study, although major changes in the total catch amount per haul obtained from purse seine catches were not observed before and after the passage of the typhoon, the abundance of *E. japonicus* markedly decreased and that of bycatch species such as *T. japonicus* and *S. orientalis* increased in the 'after' period, accompanied by increasing levels of diversity in the fish assemblage. Furthermore, changes in total length frequencies of two fish species (*T. japonicus* and *E. japonicus*) occurred, respectively. These results support the hypothesis that the typhoon was likely to have changed the structure and

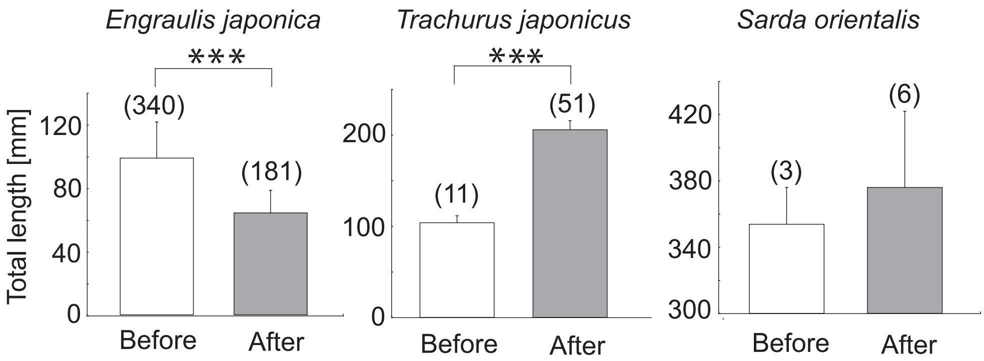

Figure 8. Comparisons of total length of the fish species between the two sampling periods 'before' and 'after' the passage of the tropical cyclone (***P < 0.001, Mann–Whitney U test).

spatial organization of multispecies aggregations of the fish community in the temperate, coastal bay.

An explanation for changes in fish assemblages could be that typhoon-induced forces affected the fish distribution. Typhoons have both direct and indirect effects on the distribution of fish species (Kaufman 1983; Halford et al. 2004; Wantiez et al. 2006; Kawabata et al. 2010; Yu et al. 2013, 2014; Chang et al. 2014). Direct effects are considered as the result of severe oceanic conditions, such as wind-associated strong currents that sweep fishes from their habitats (Lassig 1983). However, in this study, changes in fish distribution might be caused by indirect effects of the typhoon, because changes in oceanic conditions in Tachibana Bay did not notably occur.

Indirect effects could be caused by changes in abiotic factors, such as temperature, salinity, and turbidity of seawater. The main parameter known to affect the spatial organization of coastal communities is the temperature (Peterson and Ross 1991; Jaureguizar et al. 2004). Satellite observations and observational data obtained from moored instruments have shown cooling at the sea surface as well as in the mixed layer after a typhoon has passed (Price 1981; Cornillon et al. 1987; You et al. 2011). I also observed that ranges between the maximum and minimum sea surface temperature in the fishing ground became narrow just after the passage of the typhoon, suggesting that mixing in the bay had occurred (Fig. 3). This mixing of the water column in the fishing ground was thought to distribute heat deeper, where epipelagic fish species are present. Each species has an optimal temperature range within which it can be active, grow, reproduce, and metabolize. For example, the optimal temperature range is 15–17°C for *E. japonicus* (see Mitani 1981), but 20–23°C for *T. japonicus* (Ochiai et al. 1983) and 14–23°C for *S. orientalis* (Collette and Nauen 1983). Considering these differences in optimal temperature, *T. japonicus* and *S. orientalis* rather than *E. japonicus* prefer warmer temperatures. This indeed would comply with (i) the respective temperature ranges of each species given above and (ii) the trend for heat being distributed deeper after the passage of the typhoon as mentioned above. These fish species regulate body temperature by moving between areas or depths of different water temperatures (Pough et al. 2009). Thus, the water temperature could explain the change in their habitat use and consequently would affect species composition and abundance of purse seine catches. In fact, it was reported that temperature has an influence on species composition and abundance determined by trawl sampling (Jaureguizar et al. 2004). Similar observations were also reported using some other fishing methods, such as set net (Yoshida and Akimoto 2000), two-boat seine (Tomiyama and Yanagibashi 2004), beach seine (Abookire et al. 2002), and purse seine (Lehodey et al. 1997). To fully clarify our speculation, detailed studies on the multiple measurements of water monitoring before and after the passage of typhoons and behavioral responses of fish species to such typhoon-induced environmental change are necessary.

Although multivariate analysis showed that the overall changes in community structure between the two periods are quantitative rather than qualitative, changes in total length frequencies between the two periods of two fish species may be thought of as qualitative. In this study, the mean total length for *E. japonicus* decreased from 98 mm (sub-adults) to 64 mm (juveniles) in the period after the passage of the typhoon. *E. japonicus* generally spawn from spring to autumn, resulting in the occurrence of several seasonal cohorts (Funamoto et al. 2004). In Tachibana Bay, *E. japonicus* can be caught almost all seasons except the summer season. From late spring to early summer in Tachibana Bay, *E. japonicus* targeted by purse seine fishery were mainly the juveniles (total length < 70 mm) (spring population), which are considered to have been spawned in open waters of the Amakusa Sea and/or the Goto Sea, in early spring (Shimomura et al. 1970; Tanaka et al. 2010). On the other hand, *E. japonicus* fished from autumn to winter mainly consisted of sub-adults. This autumn population is considered to migrate from the inner bay of Ariake Sound and then moves to Tachibana Bay (Shimomura et al. 1970; Tanaka et al. 2010). Although the mechanism(s) for a delay in spring population's move in 2010 are currently unknown, I considered that replacement from autumn population to spring population occurred after the passage of the typhoon. In addition, the mean total length for *T. japonicus* increased from 100 mm to 200 mm in the 'after' period. In Tachibana Bay, frequencies of total length for *T. japonicus* gradually increased from spring to summer with growth. The observed abrupt increase in total length may be considered as an effect of the migration from open waters into the bay after the passage of the typhoon. These results suggest that passage of the typhoon may trigger intraspecific recruitment shifts in and around the bay area. On average, approximately 11 typhoons per year approach Japan within 300 km. Because typhoons have occurred with such frequency over the evolutionary history of the region's ecosystems, these disturbances may play an important role in shaping the seasonal migration patterns of the indigenous species (Pimm et al. 1994; Turpin and Bortone 2002).

Finally, before–after comparisons have an advantage over those involving impact since it is easier to eliminate the factor of spatial variability. However, this type of comparison might be sensitive to seasonal and inter-annual variability (Underwood 1997; Machias et al. 2004). Previous studies on the effects of typhoons on fish assemblages can be categorized according to temporal effects: short-term versus long-term (Turpin and Bortone 2002). Long-term (more than 1 year) effects of typhoons may be difficult to determine because the effects of other factors such as food supply, competition, and/or predator-prey interaction will become more important as the time elapsed after the event increases. Yu et al. (2013) showed short-term effects of typhoons on fishery catches to provide evidence of CPUE increase after the typhoon. The presently reported study has also tried to eliminate the factor of seasonal and inter-annual variability by carrying out the series of samples in a short period (2 months). However, the purse seine fishery is characterized by a moon-dependent cycle, with high catches during the new moon and low catches around the full moon (Dudley and Tampubolon 1986; Pet et al. 1997). Although I did not sample during a number of days around the full moon, lunar variability may have potential effects on the catches. Thus, further evaluations determined by other fishing methods as well as fish tagging and marking techniques are required to better clarify the impacts of a typhoon on fish communities in a temperate, coastal bay.

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