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Interannual–interdecadal variations of spear squid *Loligo bleekeri* abundance in the southwestern Japan Sea during 1975–2006: Impact of the trawl fishing and recommendations for management under the different climate regimes

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ABSTRACT

A climatic regime shift, characterized by an abrupt change from cool to warm conditions, occurred in the Tsushima Warm Current (TWC) region in the Japan Sea in the late 1980s. The abundance of spear squid *Loligo bleekeri* in the southwestern part of the Japan Sea responded strongly to the changing thermal regime. Spear squid are widely distributed in Japanese coastal waters and form one of the most important target species of pair trawlers in the southwestern Japan Sea. Catch from the southwestern Japan Sea has fluctuated from a minimum of 16 tons in 2003 to a maximum of 13,700 tons in 1977. Catch has decreased to less than 100 tons in recent years, and consequently the stock is at the point of collapse. The abundance index of spear squid shows a decadal pattern of variation with a step change from positive to negative annual anomalies that occurred around 1990; this pattern corresponds closely with the changing regime in water temperature in the TWC, strongly indicating that the decadal variability in spear squid was largely affected by the climatic regime shift in the late 1980s. Significant negative correlations between water temperature and an abundance index of spear squid ($R^2 = 0.39$, $p < 0.01$) indicate that increasing ambient water temperature reduced spear squid abundances during the 1990s. Monthly CPUE (catch per unit effort) decreases sharply during the fishing season from autumn through winter, a patterns that was well described by a DeLury model. DeLury estimates of apparent mortality showed that the fishing mortality coefficient was relatively stable during 1975–1987, but has increased greatly since the late 1980s. The average fishing mortality coefficient averaged during the warmer 1990s was about 2.1 times higher than during the colder late 1970s and 1980s, indicating that the fishing mortality has intensified during the 1990s and has accelerated the collapse of the stock. This suggests that the decadal pattern of variation of spear squid was largely forced by the late 1980s climatic regime shift of the TWC, while high fishing magnified interannual variation of spear squid and attributed to the subsequent collapse of the stock. Reducing fishing pressure on juvenile squid during the early part of the fishing season in autumn is considered to be particularly important for the recovery of this stock under the current unfavorable thermal regime.

1. Introduction

Spear squid, *Loligo bleekeri* Keferstein, are widely distributed in Japanese coastal waters. It is a commercially important species for coastal fisheries and commands a high market price in Japan (Ito, 2007; Tsuda, 2004). Annual landings of spear squid in Japanese coastal waters, between 1990 and 2006, have ranged from 2600 to 7100 tons in the Japan Sea and from 1300 to 4800 tons in the Pacific. Spear squid is a short-lived, cold-water, demersal species with a life span of one year (Kinoshita, 1989). In the southwestern part of the Japan Sea, spear squid spawn in winter and spring, grow quickly to attain about 10 cm in mantle length within six months (Kinoshita, 1989; Murayama and Kitazawa, 2004), then recruit to the fishery in autumn and winter, when they are caught by bottom trawl and set nets in coastal waters of Japan (Kitazawa, 1986). It is known that spear squid move from deep offshore waters to coastal waters for spawning but the species does not undertake large-scale migrations (Sato, 1990).

The west of Cheju Island (Korea, around 127°E) is the southern limit of the distribution for spear squid. The extended continental shelf of the southwestern Japan Sea, from Tsushima Islands to Oki Islands historically has been an important fishing ground for pair trawling (Fig. 1; Tian, 2007). The catch of spear squid by pair trawlers has increased since the mid-1970s. Spear squid comprised about 25% of the total catch, and was the most important target species of pair trawlers from the late 1970s to the early 1980s (Tian,

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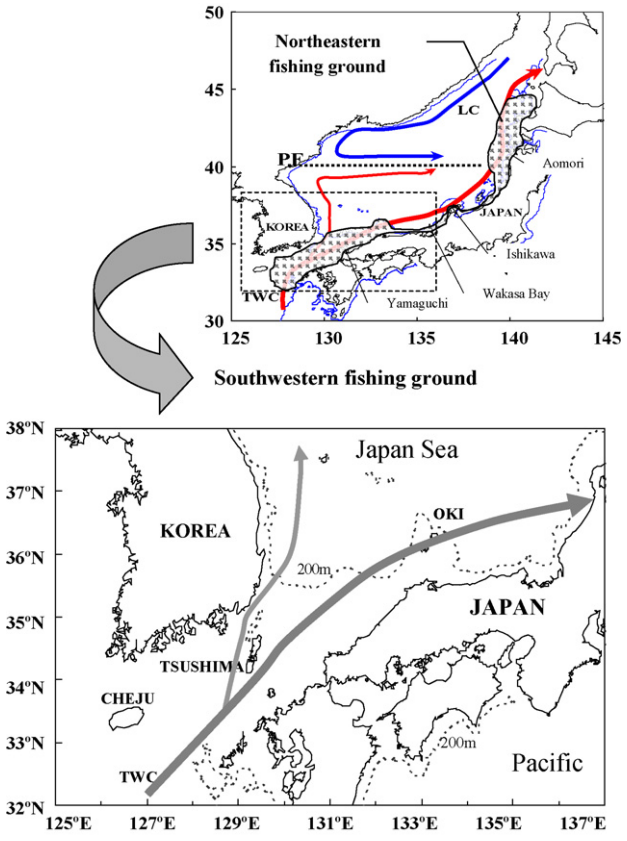

Fig. 1. Schematic diagram showing the oceanographic structures and the distribution of spear squid in the Japan Sea. The shaded area (in the upper panel) indicates the entire distribution of spear squid in the Japan Sea. Solid arrows indicate the Tsushima Warm Current (TWC) and the Liman Cold Current (LC), respectively. Dotted line indicates the location of the Polar Front (PF). CHEJU, TSUSHIMA and OKI are names of islands. The 200 m depth contour is superimposed. Locations of some place names mentioned in the text are shown. Adapted from Tian (2007).

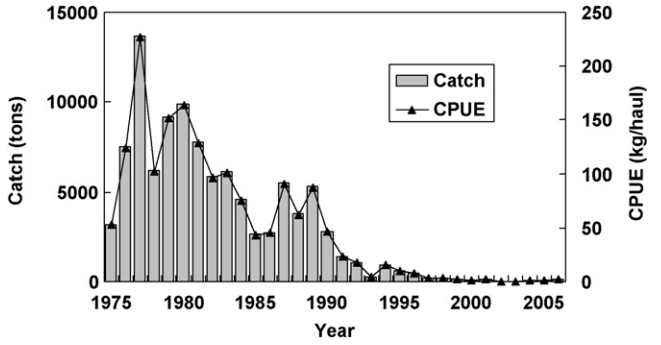

Fig. 2. Annual changes in the catch (vertical bars) and CUPE (solid line with triangles) of spear squid from pair trawlers for the period of 1975–2006.

2007). However, the annual catch of spear squid has fluctuated greatly and reached a maximum of 13,700 tons in 1977, but subsequently decreased sharply to less than 200 tons during the 1990s, and consequently the stock is at the point of collapse in recent years (Tian, 2007). The factors leading to this rise and fall of spear squid abundance in this area have not been determined yet.

Recent studies (e.g. Sakurai et al., 2000; Anderson and Rodhouse, 2001; Chen et al., 2006) have demonstrated that oceanographic conditions often play an important role in determining the variability in both the abundance and distribution of short-lived species such as squids. In the southwestern Japan Sea, the Tsushima Warm Current (TWC) flows from the East China Sea into the Japan Sea across the Tsushima Strait (see Fig. 1), and greatly affects the dynamics of fish populations in the Japan Sea (Naganuma, 2000; Tian et al., 2006, 2008). There is increasing evidence that the oceanographic conditions in the TWC abruptly changed from colder to warmer regime around the late 1980s (e.g. Minami et al., 1999; Minobe et al., 2004; Katoh et al., 2006). This climatic regime shift has had a large impact on fish communities and ecosystem in the area affected by the TWC, and the abundance of both demersal and pelagic species shifted around the late 1980s (Tian et al., 2006, 2008). In a previous study, I examined long-term changes in the distribution of spear squid in relation to sea surface temperatures using a GIS approach (Tian, 2007). This study showed that spear squid disappeared from the area south of Tsushima Island after the 1990s, presumably as a result of increases in water temperature that reduced the extent of suitable habitat for spear squid. However, no studies have been carried out on the impacts of trawl fishing and oceanographic conditions, particularly the late 1980s climatic regime shift, on the southwestern stock of spear squid in the Japan Sea, and factors leading to the collapse of the squid stock are not well understood. The purpose of present study is to examine the impacts of the late 1980s climatic regime shift and trawl fishing on interannual to decadal variability in the abundance of spear squid and to discuss a possible management policy for the recovery of the declining stock under the current unfavorable thermal regime.

2. Data and methods

2.1. Oceanographic and fisheries datasets

A seawater temperature time series at 50 m depth was used to represent the oceanic conditions in the southwestern part of the Japan Sea (Tian et al., 2006, 2008). This dataset was an area-averaged time series for the coastal waters of the southwestern Japan Sea (from Wakasa Bay in Kyoto Pref. to Yamaguchi Pref., see Fig. 1), based on monthly oceanographic monitoring observation data collected by Japanese official organizations (Katoh et al., 2006). This 50 m depth seawater temperature dataset is available for the period 1964–2006, and is generally used as an indicator of the strength of the TWC, which greatly influences the oceanographic conditions and fisheries production in the Japan Sea (Naganuma, 2000; Tian et al., 2006, 2008).

The Japan Sea Pair Trawler Fishery data were provided by the Japan Fisheries Agency (JFA). The pair trawlers are mainly operated on the continental shelf in water depth of less than 200 m; the fishing grounds of the pair trawlers in the southwestern Japan Sea, which target spear squid, are limited to the continental shelf between 127°E and 135°E (see Fig. 1; Tian, 2007). Catch log information of the main target species of the pair trawlers has been reported to the JFA to enable fisheries management since 1965 (Misu, 1974). In this dataset, information on spear squid is available at the species level since 1975, and the database demonstrates a rapid increase in the catch of spear squid during the late 1970s (Fig. 2). Monthly catch and fishing effort (number of hauls) by species are available with a spatial resolution of 10 min (longitude–latitude, the unit of fishing area in the database).

Because the CPUE (catch per unit effort) is highly variable among fishing areas, an index of abundance (*AI*) for spear squid for the total fishing areas in a given year was calculated as the follows instead of using annual CPUE (total catch/total number of hauls):

$$AI = \frac{\sum_{j=1}^{12}\sum_{i=1}^{n_j}(C_{i,j}/X_{i,j})}{\sum_{j=1}^{12} n_j} \quad (1)$$

where C, X, i and j represent the catch (kg), effort (number of hauls), fishing area number and month, respectively. The n_j indicate the total number of fishing areas in a given month in which