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Ecosystem Consequences of an Anomalously High Zooplankton Biomass in the South Sea of Korea

YOUNG SHIL KANG[1,*] AND GINGER A. REBSTOCK[2]
[1]*National Fisheries Research & Development Institute, Marine Harmful Organisms Division #408-1, Shirang-ri, Gijang-up, Gijang-gun, Busan 619-902, Korea*
[2]*Department of Biology, Box 351800, University of Washington, Seattle, WA 98195-1800, U.S.A.*

We used long time series of hydrographic and biological variables to examine the ecosystem consequences of a rare, anomalous event in the south sea of Korea. The highest zooplankton biomass in 36 years of sampling occurred in April 1997. Zooplankton biomass exceeded 2 times than the long-term mean at 35% of the stations. Copepod abundance was low in April and June and also failed to show a seasonal peak in 1997. Mackerel (*Scomber japonicus*) catches were very low in spring 1997 and 1999, in spite of a positive correlation between zooplankton biomass and mackerel catches at lags of 0, 12 and 24 months. It was discussed that a high zooplankton biomass with low copepod abundance in April 1997 resulted from unusual high temperature and salps abundance. Water temperatures were *ca.* 2°C higher than the long-term mean at the surface. Salps and doliolids (thaliaceans), especially the warm-water species *Doliolum nationalis*, dominated the zooplankton. An unusual incursion of the Tsushima Warm Current may have transported the thaliaceans into the area and/or produced favorable conditions for a bloom. This study suggested that taxonomic composition of zooplankton was important to decide mackerel catches.

Key words: Zooplankton, Long-term series, Copepoda; Episodic event, The south sea of Korea

INTRODUCTION

Biological oceanography can be studied on various time scales. Some relevant time scales are periodic (e.g., diel, seasonal) or quasi-periodic (e.g., El Niño). However, many important events occur episodically or rarely. Because of their unpredictable nature, these rare events are difficult to study. In addition, it is difficult to define whether an event is anomalous or not without baseline data. Long time series of zooplankton biomass and sea water temperature *etc.* make it possible to study episodic or rare events, by capturing the data, including the lead-up conditions, and providing the context for the event.

The importance of episodic events, such as rare dispersal or mass mortality events, has long been recognized in evolutionary biology (Boero, 1996). However, the importance of rare events in ecological dynamics is not well understood. Episodic events may affect multiple trophic levels, may have effects that are not detected immediately (Cyrus and McLean, 1994), and may affect the structure of populations for years (Sebens and Lewis, 1985). Density-dependent compensation may lessen the effects of catastrophic events with time scales that depend on life history characteristics of the populations, and the strength of the compensation (O'Connor, 2001).

A rare, anomalous event occurred in the ecosystem of the south sea of Korea in April 1997. Zooplankton biomass was the highest seen in 36 years of sampling. The spatial extent and the causal taxonomic groups of the anomalous biomass are examined here, as well as its effects on other components of the ecosystem, especially copepods and mackerel.

DATA AND METHODS

The National Fisheries Research and Developmental Institute (NFRDI) has conducted bimonthly (February, April, June, August, October and December) oceanographic surveys in Korean waters since 1965 (Fig. 1). Temperature and salinity were measured at eight standard depths, bottom depth permitting in the south sea of Korea: 0, 10, 20, 30, 50, 75, 100 and

*Corresponding author: yskang@nfrdi.re.kr

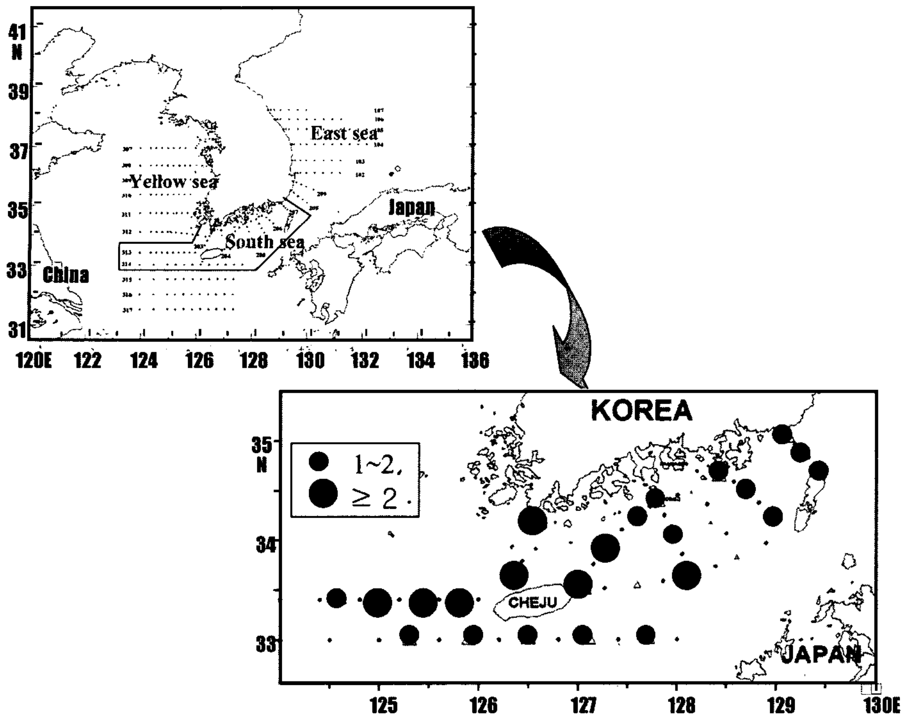

Fig. 1. Map showing sampling stations of the study area in the Korean waters and zooplankton sampling stations in southern Korean waters with showing the magnitude in April 1997 higher than the log-term mean.

125 m. Temperature was measured using a thermometer or Seabird 19 CTD. Salinity was measured using a salinometer or CTD.

Zooplankton was collected with NORPAC nets (0.45 m diameter, 0.33 mm mesh) towed vertically from 100 m or near the bottom at shallower stations. Zooplankton biomass was calculated as the wet weight of zooplankton smaller than 3 cm in body size. In this study, data of zooplankton biomass during 1965~2000 were used. Of these data, data for 1966 and 1974-1976 were excluded because the sampling frequencies were low. Total individual numbers of copepods were counted from 1978 through 2000, and total thaliaceans were counted from February 1997 through August 1999. Annual and monthly catches from 1980 to 2000 for mackerel (*Scomber japonicus*) in the south sea of Korea were obtained from the Statistical Yearbook of Agriculture, Forestry and Fisheries (SYAFF).

All biological variables were log-transformed for statistical analyses. Correlation coefficients between mackerel (*Scomber japonicus*) catches and zooplankton biomass and copepod abundance were calculated. Time lags ranging from 0 to +12 months and +24 months were used on the assumption that zooplankton leads to mackerel.

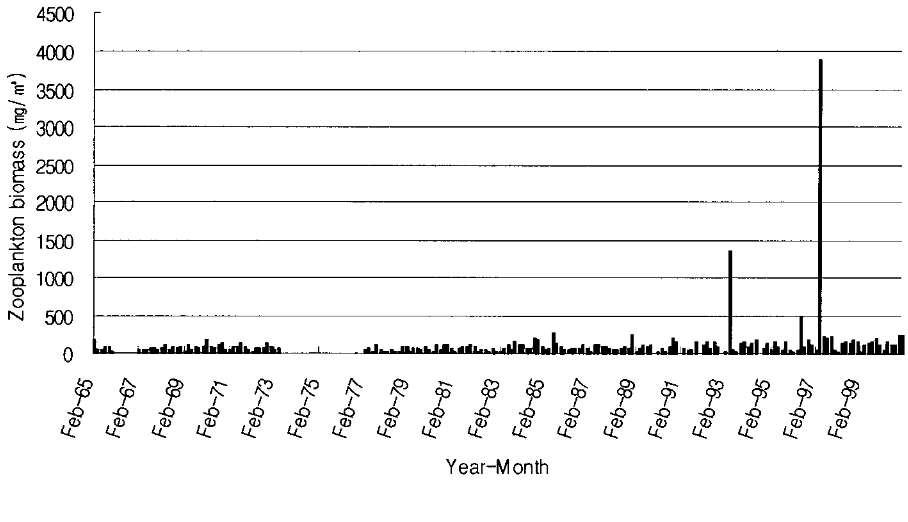

Fig. 2. Long-term changes in zooplankton biomass in the south sea of Korea during 1965~2000.

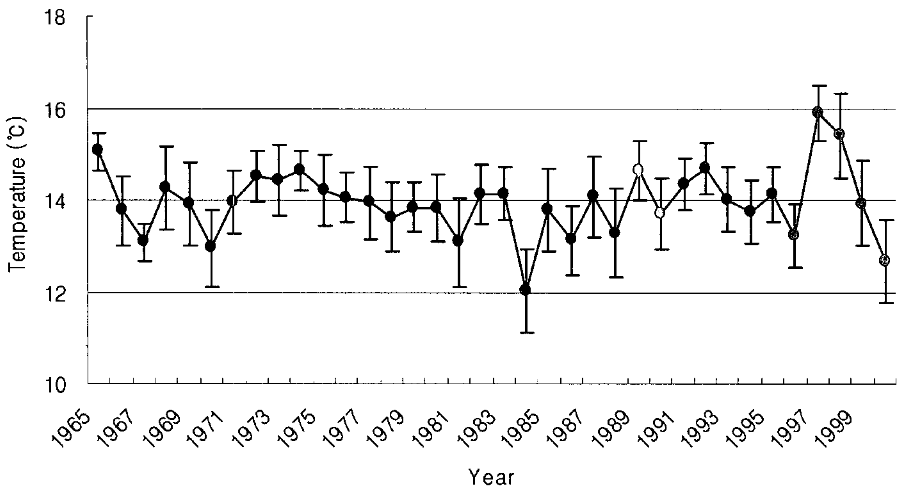

Fig. 3. Long-term changes in mean sea surface temperature in April in the south sea of Korea during 1965~2000.

RESULTS

Zooplankton biomass was unusually high in the south sea of Korea in 1993 and 1997 during 1965~2000 (Fig. 2). In particular April 1997 (Fig. 2), zooplankton biomasses from 9 stations (35%) exceeded 2 times than the long-term (1965-2000) mean for April (Fig. 1). The mean zooplankton biomass in April 1997 was more than one or two order of magnitude higher than the long-term mean in the all stations. In particular, the anomalously high biomass was found in the western and northern areas of Cheju Island.

Sea surface temperatures in the south sea of Korea were anomalously high in April 1997 (Fig. 3). Anomalies from the long-term mean exceeded *ca.* 2°C.

The high zooplankton biomass in April 1997 was composed mainly of salps and doliolids (Thaliacea), especially the warm-water species *Doliolum nationalis* (Fig. 4). Thaliacean abundance was elevated at

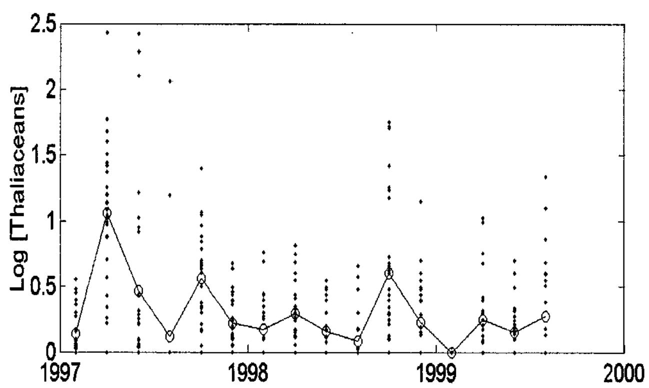

Fig. 4. Thaliacean abundance (ind/m^3) in the south sea of Korea was unusually high in April 1997. Small filled symbols represent individual stations. Open circles represent cruise means. Cruises were conducted in February, April, June, August, October and December.

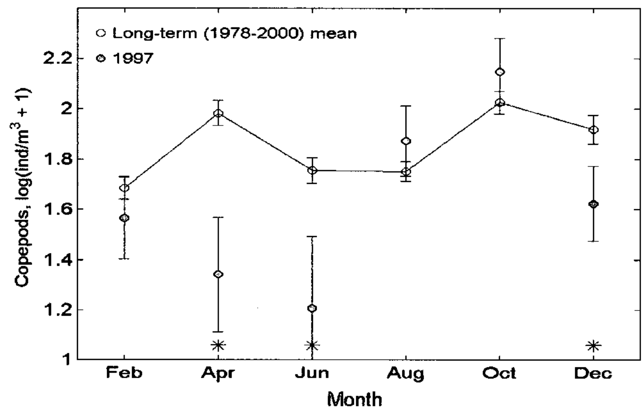

Fig. 5. Copepod abundance was low in April and June 1997 and failed to show a seasonal peak. Error bars represent 95% confidence intervals. Asterisks indicate months in which 1997 differed from the long-term mean (*t-test*, $p<0.05$).

most stations in April 1997, in agreement with the distribution of high zooplankton biomass (Figs. 2 and 4). A few stations in June and August 1997 also showed high thaliacean abundance.

Copepods, the dominant component of the net zooplankton (Kang and Lee, 1991; Kang and Kim, 2002), also deviated from the usual seasonal cycle in 1997 (Fig. 5). The long-term (1978-2000) mean showed peaks in April and October, while no peak occurred in April 1997. Abundance was significantly lower than the long-term mean in both April and June 1997 ($p<0.05$), but close to the long-term mean by August.

Mackerel catches were positively correlated with zooplankton biomass at lags of 0, 2, 12 and 24 months ($p<0.05$, Fig. 6a). Correlations with copepod abundance was significant at lags 11, 12 and 24 months ($p<0.05$), but not at short lags (Fig. 6b). Contrast to

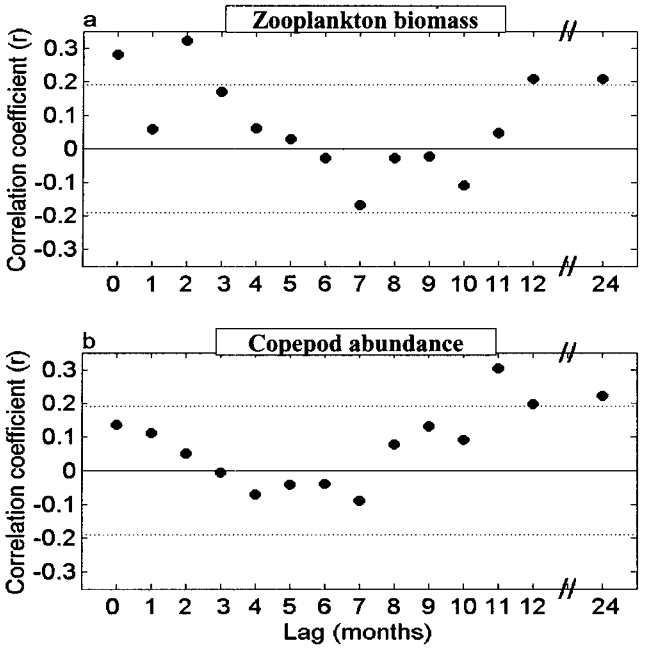

Fig. 6. Monthly mackerel catches were positively correlated with zooplankton biomass at lags of 0, 2, 12 and 24 months (a) and with copepod abundance at 11, 12 and 24 months (b). Horizontal dashed lines indicate approximate 5% significance levels.

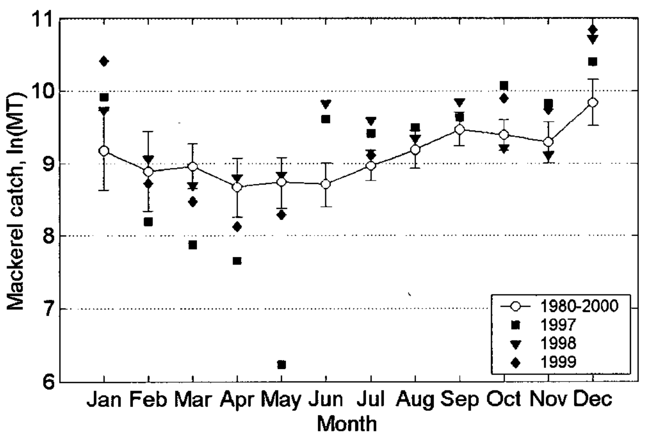

Fig. 7. Mackerel catches in the south sea of Korea were low in spring 1997 and 1999, coincident with the anomalous zooplankton biomass and 2 years later. Error bars represent 95% confidence intervals for the long-term (1980-2000) mean.

the previous results, the high zooplankton biomass in April 1997 did not result in high mackerel catches in spring 1997, or two years later (Fig. 7). Catches in spring 1997 were much lower than the long-term monthly means. Catches in spring 1998 were close to the long-term mean, while catches in spring 1999, two years after the anomalously high zooplankton biomass, were low.

DISCUSSION

The anomalously high zooplankton biomass in April 1997 in the south sea of Korea comprised primarily thaliaceans and negatively affected trophic levels from zooplankton to pelagic fish. The zooplankton bloom was related to high water temperatures, possibly indicating a northward incursion of the Tsushima Warm Current, a branch of the Kuroshio Current. Water temperatures in the south sea of Korea were anomalously high. Sea surface temperatures were *ca.* 2°C high in April 1997 compared to those in the other years. Toba and Murakami (1998) noted unusual positions of the Kuroshio Extension from December 1996 to May 1997. Lots of thaliaceans or their seed stock may have been transported into the area by the Tsushima Warm Current, which also provided suitable conditions for a bloom of warm-water thaliaceans (Kang *et al.*, 2000). Salps and doliolids have very high growth rates; few individuals are required to start a bloom (Paffenhofer and Lee, 1987).

In April 1997, thaliaceans abundance was very high (Kang *et al.*, 2000), while copepod abundance was unusually low. Many field studies have shown copepod production to be food limited at chlorophyll-*a* concentrations <0.5-1 μg/l (Checkley, 1980; Richardson and Verheye, 1999). Food limitation in copepods is sometimes size specific, depending on the relative abundance of appropriately sized prey (Richardson and Verheye, 1999; Campbell *et al.*, 2001). However, thaliaceans are nonselective particle feeders capable of retaining particles over a wide size range, down to less than 1 μm in diameter (Paffenhofer *et al.*, 1995). If the thaliacean bloom reduced picoplankton and microzooplankton as well as chlorophyll-*a* concentrations, all sizes of copepods may have been food limited. In addition, ingestion of copepod eggs by thaliaceans may have a negative effect on copepod populations (Haskell *et al.*, 1999; Paffenhofer *et al.*, 1995).

In April 1997, the high thaliacean abundance and the low copepod abundance appeared to affect higher trophic levels. Mackerel catches were very low in spring of 1997, coincident with the thaliacean bloom. In spring two years later, mackerel catches were also low compared to mean over 1980~2000. Mackerel is an important fisheries resource off southern Korea (Kim and Kang, 2000), and a predator of crustacean zooplankton such as large copepods (Park *et al.*, 1973). Mackerel spawning peaks in May to July around Cheju Island and the juveniles recruit to the fishery in autumn (Kim and Kang, 2000). Although zooplankton biomass was anomalously high, copepod abundance was very low in April and June 1997. Thus, it is assumed that the high thaliacean abundance and low copepod abundance may have led to decreased aggregations of adults in spring 1997 and to decreased survival of the larvae. There is a possibility that the unusual event in spring 1997 contributed to the fishery for the subsequent few years.

That is, the effects of the thaliacean bloom on populations varied with generation time. Copepod abundance remained low for two sampling periods, but was near average four months later. Mackerel catches were low two years after the event. It is suggested that life history traits and generation times may dictate the time scales of recovery of populations (O'Connor, 2001).

This event demonstrates the importance of the taxonomic composition of the zooplankton. In spite of a positive relationship between zooplankton biomass and mackerel catches in the current month and one and two years later, the high zooplankton biomass in April 1997 was associated with low catches of mackerel in spring 1997 and 1999. If we assumed that the zooplankton biomass was dominated by copepods, the usually dominant taxon, the low catches of mackerel would be hard to understand. However, the low composition of copepod in the high zooplankton biomass provides an explanation for the low catches of mackerel in April and June 1997.

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