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Effects of Environmental Changes on Stock of Krill and Salp in the Atlantic and Indian Sectors of the Antarctic

Chung Il Lee*, E.A. Pakhomov, Angus Atkinson[1] and Volker Siegel[2]

Department of Earth and Ocean Sciences, University of British Columbia, British Columbia, V6T 1Z4, Canada

[1]British Antarctic Survey, Natural Environment Research Council, High Cross, Cambridge CB3 OET, UK

[2]Sea Fisheries Institute, Palmaille 9, 22767 Hamburg, Germany

Long-term variation in krill (*Euphausia superba*) and salp (mainly *Salpa thompsoni*) stocks was compared to environmental changes in the Atlantic and Indian sectors of the Antarctic. Environmental conditions examined were air temperature, water temperature, salinity, and sea-ice extent from 1926 to 1938 and from 1982 to 2000. The long-term pattern of krill was opposite to that of salp: krill stock decreased while salp stock increased concurrently. Krill stock was about three-fold higher from 1926 to 1938 than from 1982 to 2000, but salp was about four –fold lower in 1926-1938 than in 1982-2000. A warming trend was observed in the environmental data, and the long-term variation in krill and salp stocks was affected by this trend.

Key words: Antarctic, *Euphausia superba*, *Salpa thompsoni*, Warming trend

Introduction

The Atlantic and Indian sectors of the Antarctic are the main nursery grounds of Antarctic krill (*Euphausia superba*) and salps (mainly *Salpa thompsoni*), and which are major grazers at lower trophic levels (Marr, 1962; Foxton, 1966; Lefevre et al., 1998; Pakhomov et al., 2002) and support commercial fisheries in these areas (Mackintosh, 1991; Quetin, 1991; Kock and Shimadzu, 1994; Marchant and Murphy, 1994; Nicol, 1994; Everson, 2000). In particular, although salps are not a major dietary item for vertebrate predators living in the Southern Ocean, salp bloom affect adult krill reproduction and the survival of krill larvae (Foxton, 1966). Although both krill and salp inhabit the Southern Ocean surrounding the Antarctic plateau, the main habitats of these species are probably associated with different marine environments because they show different long-term abundance patterns; there has been a long-term decline in krill stock and an increase in salp stock in the Southern Ocean. Salps tend to occupy warmer water than do krill (Foxton, 1966; Lefevre et al., 1998, Pakhomov et al., 2002,), and prefer oceanic regions with lower food concentrations (Lefevre et al., 1998, Pakhomov et al., 2002). Thus, a warming trend in the Southern Ocean means that long-term variation in the krill stock might be different from long-term variation in salp stock, and the habitat of krill may be retreating toward the Antarctic continent with the spread of warmer water. Inter-annual variation in the krill stock around the Antarctic Peninsula from 1975 to 2002 was opposite that of the salp stock (Loeb et al., 1997). During this period, the water temperature rose about 0.02-0.03°C/yr (Levitus et al., 2000), and warmer water spread toward the Antarctic Peninsula.

In this paper, we compared long-term trends in krill and salp stock in the Atlantic and Indian sectors of the Antarctic using in situ data on krill and salp population and on environmental changes.

*Corresponding author: leeci@pknu.ac.kr

Materials and Methods

Water temperature and salinity

Hydrographic data for the analysis of water masses in the study area were collected from the World Ocean Database for 2001 and 2005 (WOD01 and WOD05, respectively; http://www.nodc.noaa.gov/OC5/WOD01/pr_ wod01.html and wod05.html; Fig. 1). WOD05 is an update of WOD 01 containing climatological data at standard depths within a World Meteorological Organization (WMO) square. In

WOD01, data from 1995 for the Southern Ocean, especially between 50 and 80°S, are scant; WOD05 has more information for the period after 1995 than WOD01. However, WOD01 contains some data for the 1970s and 1980s that are not included in WOD05. Although WOD05 contains some data for this period, some of the data for this period are missing. Therefore, I used both the WOD01 and WOD05 data sets to compensate for the shortcomings of each. Water temperature and salinity measurements in the study area were extracted from WOD01 and WOD05 from 1982 to 2000. The data for each factor extracted from WOD 01 and WOD05 were averaged through-out the study area for every austral summer (January-March) at the sea surface.

Sea-ice index and air temperature

Sea-ice extent (northernmost latitude of sea-ice) data from 1982 to 2000 in the study area were taken from the Australian Antarctic Data Centre (http://aadc-maps.aad.gov.au/aadc/envi/search_ice extent.cfm); these data mark the average northernmost latitude of the ice pack over the study area. Surface air temperature measurements on South Georgia Island for periods 1926 to 1938 and 1982 to 2002 were taken from Mitchell and Jones (http://www.cru.uea.ac.uk/~timm/grid/table.html; resolution 0.5×0.5°). Air temperature and sea-ice extent were averaged throughout the study area for every austral summer (January-March).

Krill and salp

Data (Fig. 1) from two published sources (Loeb et al., 1997; Atkinson et al., 2004) on krill and salp abundance were used. The first data source is primarily from December-March net-sampling operations by German expeditions and by US Antarctic Living Resources Program surveys around Elephant Island, close to the Antarctic Peninsula. Details on net sampling and sample processing, and considerations of gear selectivity and sampling bias were provided by Loeb et al. (1997). The second data source, for

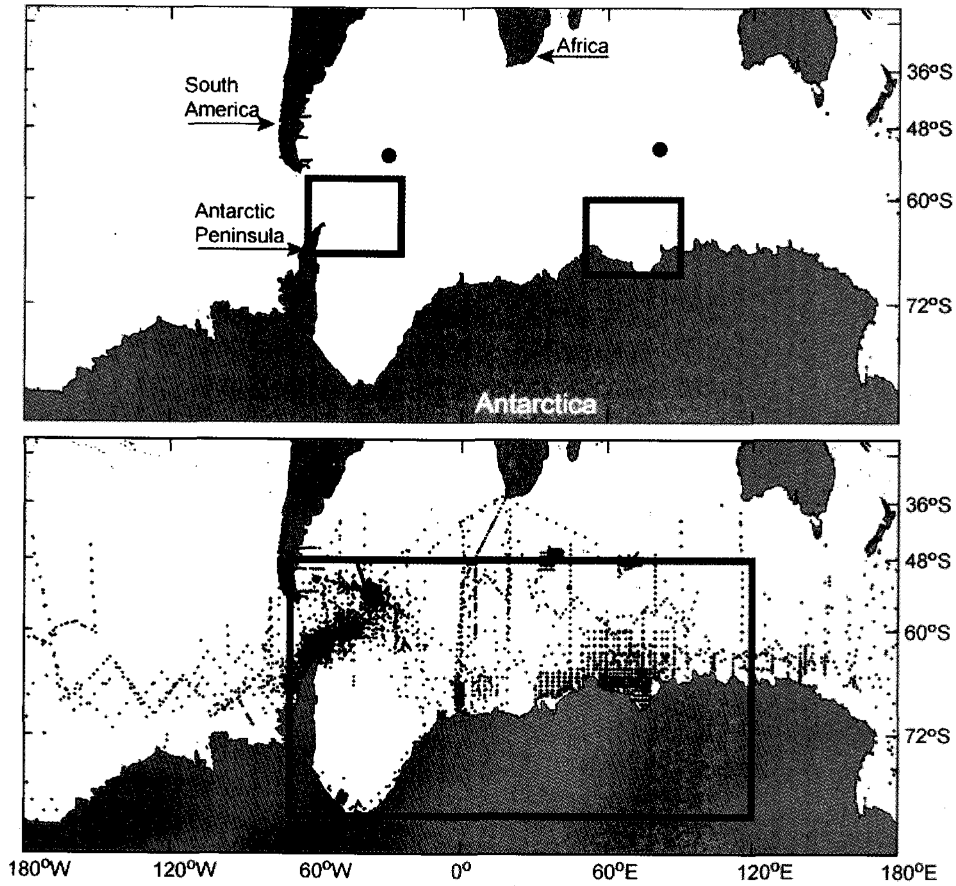

Fig. 1. Study area in the Atlantic and Indian sectors of the Antarctic. Top: Locations measured for air temperature (closed circles), water temperature, salinity, and sea-ice (rectangles). Bottom: Sampling area of krill and salp (rectangles).

January-March, was mainly derived from Atkinson et al. (2004) who used various observation programs. Detailed information about this database accompanies the published paper (Atkinson et al., 2004; see also Fig. 1). Mean abundance of krill and salps in the area during austral summer (January-March) from 1980 to 2002 were calculated.

Results and Discussion

The long-term trend in krill abundance was opposite to that of salp (Fig. 2). The number of krill per 1000 m^3 decreased during 1926-1938 and 1982-2000, while the salp population showed gradual increases during these two periods. Krill abundance decreased suddenly after 1931 and after 1988, and salp abundance increased gradually after those years. Krill stock was about three-fold higher in 1926-1938 than in 1982-2000, whereas salp stock was about four-fold lower in 1926-1938 than in 1982-2000. For krill, there were less than 10 krill per 1000 m^3 for the periods 1932-1938 (except 1935) and 1990-1995, while the salp stock peaked at those times. The krill stock peaked in 1930, and after that the stock was less than 40 individuals per 1000 m^3. As shown in Fig. 2, krill and salp showed different long-term population trends. This difference is probably associated with environmental changes (Figs. 3 and 4). The abundance of krill decreased gradually from 1926 to 1938, but salp abundance increased during this time (Fig. 2).

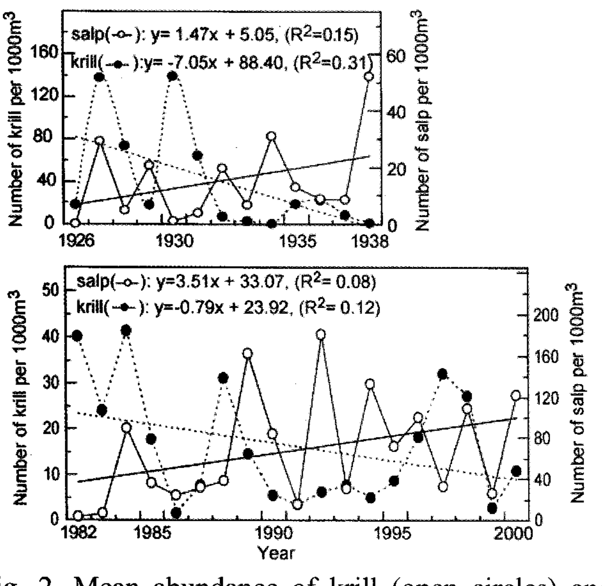

Fig. 2. Mean abundance of krill (open circles) and salp (closed circles) for every austral summer season (January-March) from 1926 to 1938 (upper) and from 1982 to 2000 (lower). Krill and salp data were extracted from the area shown in Fig. 1.

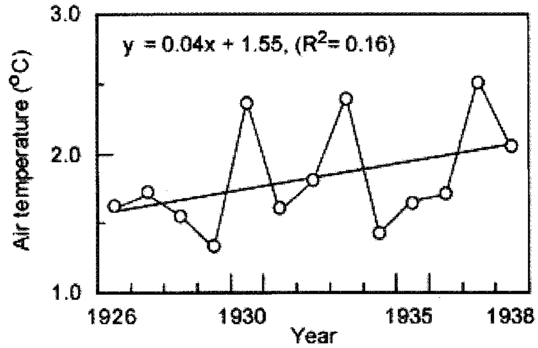

Fig. 3. Time-series of mean air temperature for every austral summer season (Jan.-Mar.) from 1926 to 1938 in the Atlantic sector of the Antarctic. There are no data available for the Indian sector during the period.

Over the same time, air temperature increased (Fig. 3). However, no marine environmental data for the period 1926 to 1938 are available for 1926 to 1938. If we assume that air and sea surface temperatures interact through their boundary with a certain time lag, we can assume that air temperature reflects sea surface temperature (Fig. 4). Therefore, a warming trend in air and sea surface temperatures probably occurred from 1926 to 1938, and this warming trend likely caused the difference in time-series patterns of krill and salp abundance. In Fig. 4, these relationships between krill/salp abundance and environmental conditions are clearly shown. Air and sea surface temperatures increased from 1982 to 2000 (Fig. 3). The retreat of sea-ice towards the Antarctic continent also reflects the warming trend in the Atlantic and Indian sectors of the Antarctic. Changes in sea-ice extent also caused a decrease in salinity. Salinity in this region decreased as sea-ice melted, and this may have caused a shift of the Antarctic plankton community from species that prefer higher salinity environments to species that favor low-salinity. Salps tends to prefer warmer water more than krill do, and salp seem to be better competitors and more adaptable (Foxton, 1966; Lefevre et al., 1998; Nicol, 2000; Pakhomov et al., 2002). Therefore, if this warming trend continues, salps might dominate the ecosystem because krill will likely leave the area due to higher temperatures. The krill population decreased dramatically between 1982 and 2000 compared to 1926-1938, while salp increased greatly during the same period. This result indicates that warming trends affect the abundance of krill and salp even though the species prefer different environmental conditions. What is the driving force for the warming trend around the Southern Ocean? Activity of the Antarctic circumpolar wave (ACW), which propagates eastward with cir-

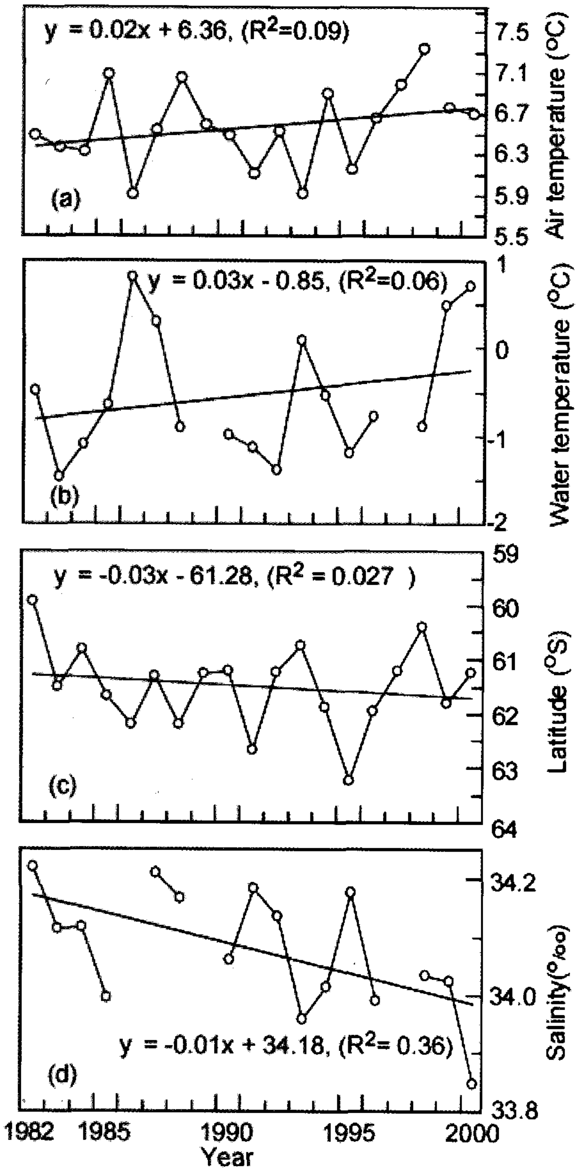

Fig. 4. Time-series of mean air temperature (a), water temperature at sea surface (b), sea-ice extent (c), and salinity (d) for every austral summer season (Jan.-Mar.) from 1982 to 2000 in the Atlantic (left panel) and Indian sectors (right panel) of the Antarctic.

cumpolar flow with a period 4-5 years and takes 8-10 years to encircle the Antarctic continent, is possibly associated with El Niño activity in the equatorial Pacific, perhaps through an atmospheric teleconnection with higher latitudes in the Southern Ocean (Karoly et al., 1989; Rasmusson and MO, 1993; White and Peterson, 1996). El Niño event, sea surface temperatures, and temperature at surface and 100 m in the Atlantic sector of the Southern Ocean showed have a period of 2-6 years, and a period of about 3-5 years from 1960 to 2002. Water temperature at the surface and m are better correlated with a period of 4-5 years with El Niño events (Southern Oscillation Index: SOI); time lags between water temperature at each depth and SOI are about 1.5 yrs. Water temperature with a period of about 4 yrs is possibly associated with the ACW and El Niño events. As shown in Figs. 2-4, annual variation in each parameter had a period shorter than 5 yrs, and long-term trends in krill and salp stock seemed to be closely correlated with long-term trends in marine environmental factors. If krill and salp stocks are affected by variation in the marine environment as seen here, then El Niño activity affecting marine environments in the Southern Ocean influences krill and salp stocks.

Acknowledgements

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References

Atkinson, A., V. Siegel, E. Pakhomov and P. Rothery. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature, 432, 100-103.

Foxton, P. 1966. The distribution and life history of *Salpa thompsoni* Foxton with observations on a related species, *Salpa gerlachei*. Discovery Rep., 34, 1-116.

Fraser, W.R., W.Z. Trivelpiece, D.G. Ainely and S.G. Trivelpiece. 1992. Increase in Antarctic penguin populations: reduced competition with whales or a loss of sea ice due to global warming? Polar Biol., 11, 525-531.

Karoly, D.V., R.A. Plumb and M. Ting. 1989. Examples of the horizontal propagation of quasi-stationary waves. J. Atmos. Sci., 46, 2802-2811.

Kock, K.H. and Y. Shimadzu. 1994. The Biomass perspective. In: Southern Ocean Ecology. Elsayed, S.G. ed. Cambridge University Press, London, 287-312.

Lefevre, J., L. Legendre and R.R. Rivkin. 1998. Fluxes of biogenic carbon in the Southern Ocean: roles of large microphagous zooplankton. J. Mar. Syst., 17, 325-345.

Levitus, S., J.I. Antonov, T.P. Boyer and C. Stephens. 2000. Warming of the world ocean. Science, 287, 2225-2229.

Loeb, V., V. Siegel, O.H Hansen, R. Hewitt, W. Fraser, W. Trivelpiece and S. Trivelpiece. 1997. Effects of sea-ice extent and krill and salp dominance on the Antarctic food web. Nature, 387, 897-900.

Marr, J.W.S. 1962. The natural history and geography of the Antarctic krill, *Euphausia superba* Dana. Discovery Rep., 32, 33-464.

Mackintosh, N.A. 1973. Distribution of post-larval krill in the Antarctic. Discovery Rep., 36, 95-156.

Marchant, H.H. and E.J. Murphy. The Biomass perspective. In: Southern Ocean Ecology. Elsayed, S.G. ed. Cambridge University Press, London, 267-285.

Nicol, S. 1994. Global concerns. In: Antarctic Science. Hempel, G. ed. Springer, Berlin, Germany. 144-166.

Nicol, S. 2000. Ocean circulation off east Antarctica affects ecosystem structure and sea-ice extent. Nature, 406, 504-507.

Pakhomov, E., P.W. Froneman and R. Perissinotto. 2002. Salp/krill interactions in the Southern Ocean: spatial segregation and implications for the carbon flux. Deep-Sea Res., 49, 1881-1907.

Quetin, L.B. and R.M. Ross. 1991. Behavior and physiological characteristics of the Antarctic krill. *Euphausia superba*. Am. Zool., 31, 49-63.

Rasmusson, E.M. and K. MO. 1993. Linkages between 200-mb tropical and extratropical circulation anomalies during the 1986-1989 ENSO cycle. J. Clim., 6, 595-616.

White, W.B. and R.G. Peterson. 1996. An Antarctic Circumpolar Wave in surface pressure, wind, temperature, wind, temperature and sea-ice extent. Nature, 380, 699-702.

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