Preliminary examination of the effect of timing of ice melting on the density of Antarctic minke whales - a new environmental index-

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ABSTRACT

Effect of days after sea ice melting on densities of Antarctic minke whales was examined in the Weddell Sea (0°-60°W; Area II as defined by the IWC) of Antarctic. Area II was surveyed in 1986/87 as second circumpolar survey (CPII) and, in 1996/97 and 1997/98 as third circumpolar survey (CPIII). This paper corresponds to the recommendation raised in 60th IWC/SC. CPII and CPIII were surveyed in same season (austral summer from late December to early February). However, allocations of survey effort in IO mode in reference to timing of sea ice melting were different between CPII and CPIII. Peak of survey effort was after 20 days of sea ice melting in CPII while it was after 50 days in CPIII. Densities of minke whales were high right after the sea ice meting and they declined subsequently. Consideration of effect of days after sea ice melting on abundance estimation of minke whales is critically important to understand reasons of the difference of abundances between CPII and CPIII. Direct comparison of abundance between CPII and CPIII is not valid at this stage because the timing of survey in terms of timing of sea ice melting is different. We only focus on Area II in the present study as preliminary attempt. It is necessary to investigate the relationship in other areas to determine whether it is regional or circumpolar phenomena.

INTROIDUCTION

The International Whaling Commission (IWC) has conducted the Antarctic minke whale (*Balaenoptera bonaerensis*) abundance assessment cruises since 1978/79 in the Antarctic in austral summer. The names of the cruises were firstly the International Decade of Cetacean Research programme (IDCR, from 1978/79 to 1995/96) and then the Southern Ocean Whale and Ecosystem Research programme (SOWER, from 1996/97 to present). Matsuoka *et al.* (2003) presented an extensive review of these cruises. To the present time, these cruises covered three circumpolar surveys for the purpose of comprehensive assessments. Abundance estimates were calculated using each circumpolar data set; 1978/79-1983/84 (first circumpolar, CPI), 1984/85-1990/91 (second circumpolar, CPII) and 1991/92-2003/2004 (third circumpolar, CPIII) (Branch, 2006). A noticeable abundance decline from CPII to the CPIII using the IWC standard abundance estimation method (Branch, 2006) has raised questions whether the decline is true or apparent. Discussion on reasons for differences between minke whale abundance estimates between CPII and CPIII is ongoing in the Scientific Committee of IWC (IWC/SC).

It is well documented that minke whales are aggregated along sea ice edge while they spend their time in Antarctic waters in austral summer (Kasamatsu *et al.*, 2000) where their prey, krill, is abundant (Murase *et al.*, 2002). However, high densities of minke whales have been observed in offshore of sea ice edge in some occasion. It was reported that high densities of minke whales were observed offshore region of the Weddell Sea (0°-60°W; Area II as defined by the IWC) in CPII (Kasamatsu *et al.* 1998). Kasamatsu *et al.* (1998) investigated relationship between the density of minke whales and two environmental factors (sea surface temperature and distance from the ice edge) but they found no clear relationships. Such offshore aggregation of minke whales was not observed in Area II in CPIII.

Position of sea ice edge rapidly changes in austral summer because of process of melting (Calvalieri and Parkinson, 2008). Phytoplankton bloom is associated with sea ice retreat (Lancelot *et al.*, 1993). Density of Antarctic krill (*Euphausia superba*) is generally high around the sea ice edge in the Weddell Sea (e.g. Brierley *et al.*, 2002; Daly and Macaulay, 1988; Donnelly *et al.*, 2006; Godlewska, 1993). Some of these results suggested that density of krill was high just outside of the ice edge (Daly and Macaulay, 1988; Donnelly et al., 2006; Godlewska, 1993). Receding speed of sea ice edge may exceed swimming speed of krill (Brierley and Thomas, 2002). Brierley and Thomas (2002) postulated that distribution of krill in offshore side of sea ice edge could be the results of receding of sea ice above krill to south. If the postulate is true, such dynamic interaction between sea ice melting and krill could affect distribution pattern of minke whales.

The effect of sea ice dynamics on distribution pattern of minke whales was discussed in the Sub-Committee on In-Depth Assessment (IA) in the 60th IWC/SC (IWC, 2009). Such interaction was observed, for example, in the northeastern region of Area II during CPII. The interaction could account for reasons of differences between minke whale abundance estimates from CPII and CPIII. The IA Sub-Committee recommended to the sea-ice intercessional group to investigate the interaction. This paper corresponds to the recommendation. This paper examined the effect of timing of ice melting on the density of minke whales in Area II. Specifically, following points were examined: 1) difference of sighting survey effort allocation between CPII and CPIII in relation to days after sea ice melting, 2) relationship between days after sea ice melting and school density of minke whales.

MATERIALS AND METHODS

Data sets

Sea ice

To calculate timing of days after sea ice melting, satellite derived sea ice data were used. Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I (Comiso, 1999) was used in the analysis. The data were recorded daily basis. The original data was in the polar stereographic projection and it was converted to the Zenithal equal area projection. The sea ice data (sea ice concentration) was recorded at 25 km by 25 km grid resolution.

Whale sighting data

IWC divided southern ocean into six areas for the management of baleen whales (Donovan, 1992). Area II is set between 0° and 60°W (Fig. 1). Sighting survey for the abundance estimation of Antarctic minke whale was conducted in austral summer. CPII survey was conducted from December 28, 1986 to February 4, 1987. Full longitudinal coverage was made in 1986/87 cruise. In CPIII, Area II was divided into two at 30°W. Eastern half (0°-30°W) was surveyed in 1996/97 cruise (January 16-February 14, 1997) whereas western half (30°W-60°W) was surveyed in 1997/98 cruise (January 18-February 14, 1998). Latitudinal coverage was south of 60°S to ice edge except 0-°20°W of CPII where the northern limit was set at 61°S-63°S. Sighting survey effort (surveyed distance), positions of sighted Antarctic minke whale and survey area boundary stored in the IWC Database-Estimation Software System (DESS) version 3.0 (Strindberg and Burt, 2000) were used.

There were two survey modes: the closing mode and the passing mode with independent observer mode (IO mode). In closing mode, two observers were stationed in top barrel while no observer was stationed in independent observation platform (IOP). Once a sighting was made, the ship approaches to the sighting to confirm species and school size. In the IO mode, two observers were stationed in top barrel while an observer was stationed in IOP. No approach is made to sightings in the IO mode.

Analysis methods

Surveyed distance was divided into 5 km segments. For each 5 km segment, days after sea ice melting were calculated. A program search sea ice data until it found the day with more than 15 % sea ice concentrations which corresponded to segmented survey effort data. Sea ice concentrations more than 15% was commonly used as definition of sea ice edge in the sea ice analyses (e.g. Bjøgo et al., 1997; Hanna 2001; Zwally *et al.*, 2002). After the days after sea ice melting were calculated, the data were aggregated into 30 km by 30 km grids by using ArcGIS 9.3. The data were aggregated by survey vessels, survey stratum and survey mode. Total effort, total number of schools of minke whales and mean days of days after sea ice melting were calculated for each 30 km by 30 km grids. Density of school of minke whales was calculated by using effective search half width (*esw*) reported in Branch (2006).

RESULTS AND DISCUSSION

Geographic distribution patterns of the sighting survey effort in Area II in relation with days after sea ice melting are shown in Fig. 1. As indicated in the figure, timing of the survey in CPIII was later than CPII in terms of timing of sea ice melting. Peak of the survey effort in CPIII was around 50 days after sea ice melting while it was around 20 days in CPII (Fig. 2). Mean of density of school of minke whales in each 10 days bin indicated that the density declined as days after sea melting increased (Fig. 3).

In response to last year’s recommendation by the IA sub-committee specifically, effect of timing of sea ice melting on density of school of minke whales in the northeastern region of Area II (Fig. 4) was examined. The general patterns were same as in the case of entire area of Area II. Peak of the survey effort in CPIII was around 50 days after sea ice melting while it was around 20 days in CPII (Fig. 5). In CPIII, no survey was conducted in the area with less than 30 days after sea ice melting where density was high in CPII (Fig. 6).

This qualitative study suggested the negative relationship between the timing of sea ice melting and school density of minke whales. Further consideration of effect of days after sea ice melting on abundance estimation of minke whales is required to understand the reason of the difference of abundances between CPII and CPIII. Direct comparison of abundance between CPII and CPIII is not valid because the timing of survey in terms of timing of sea ice melting is different.

In this study, we only focused on school density in Area II. Same analysis in other Areas must be conducted to detect whether the relationship is global phenomena at the circumpolar scale. In addition, the effect of the timing of sea ice melting on school size must be examined in the future. The *esw* reported in Branch (2006) was used in this study but the timing of sea ice melting could affect the estimation of *esw* itself. Ultimately, the effect of timing of sea ice melting should be considered in newly developed abundance estimation models, if the further qualitative analysis provides promising results.

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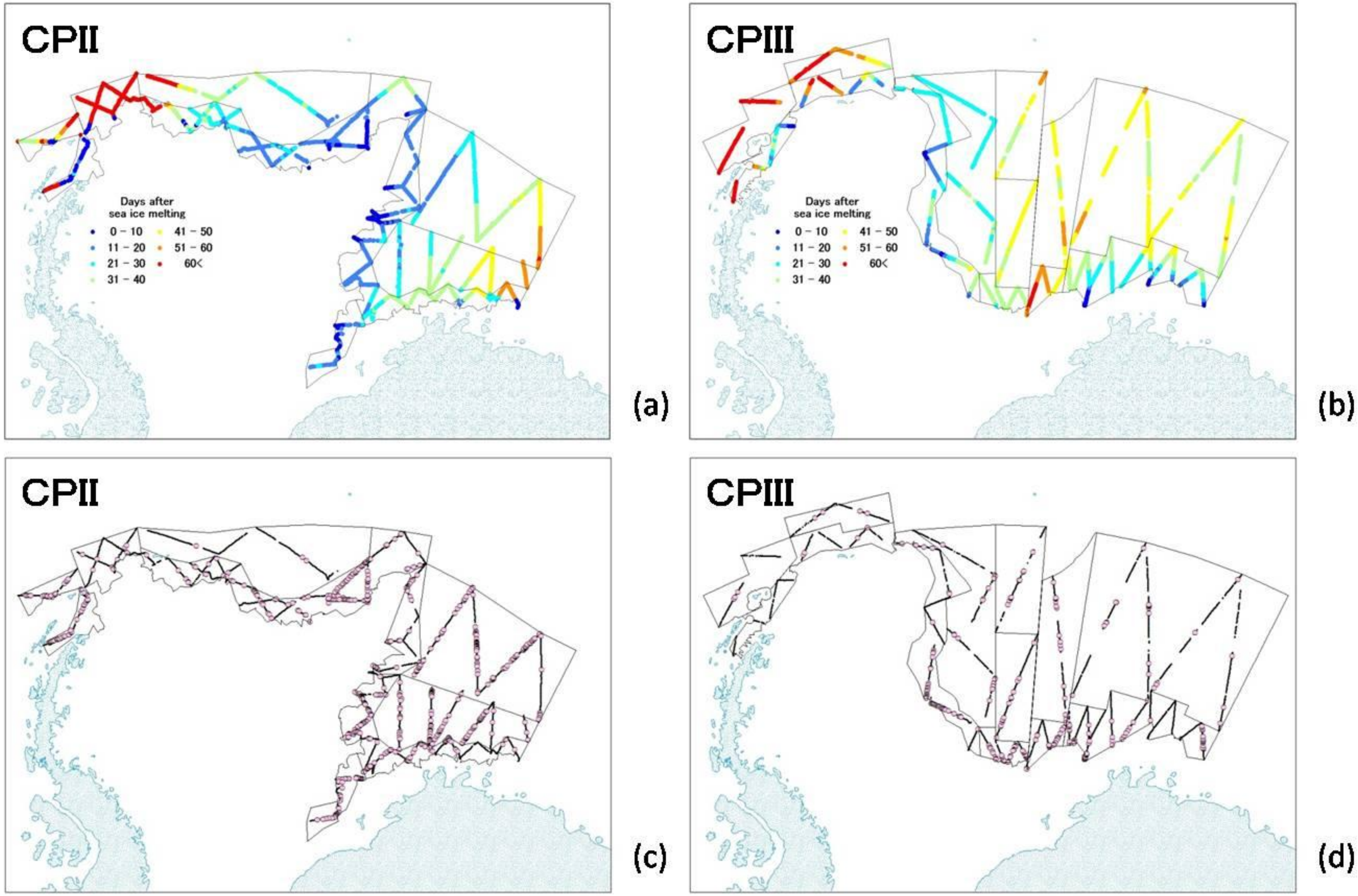

Fig. 1. Spatial distribution patterns of the sighting survey efforts in terms of days after sea ice melting: CPII (a) and CPIII (b). Sighting efforts and sighting positions of minke whales: CPII (c) and CPIII (d). IO and closing mode survey data are shown in the maps simultaneously in these figures.

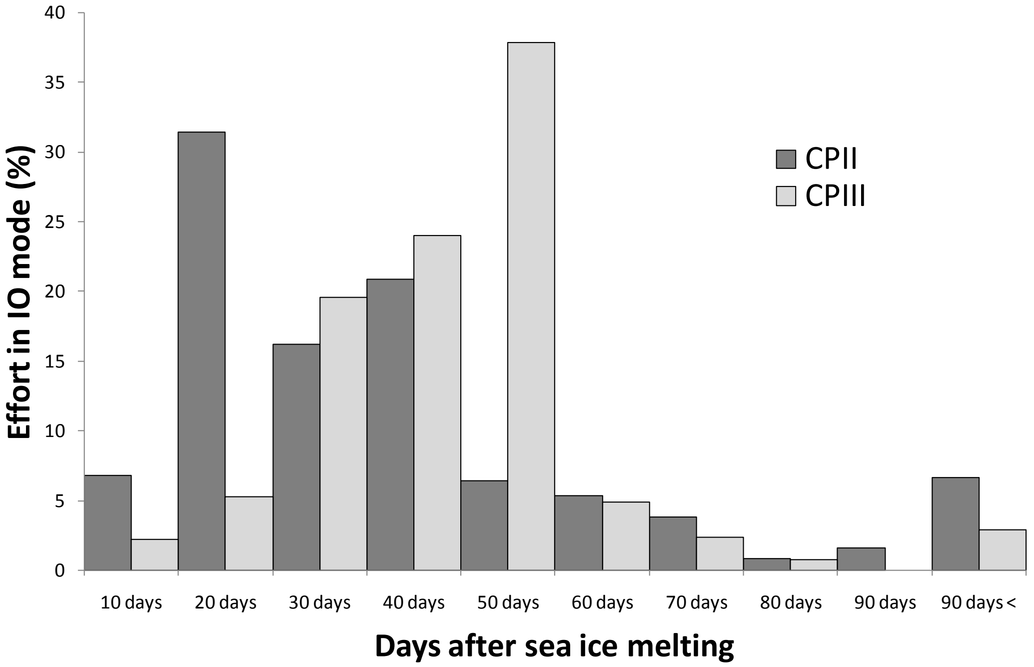

Fig. 2. Frequency of IO mode survey effort distances in the entire area of Area II in relation to days after sea ice melting. Frequency is calculated in each 10 days bin.

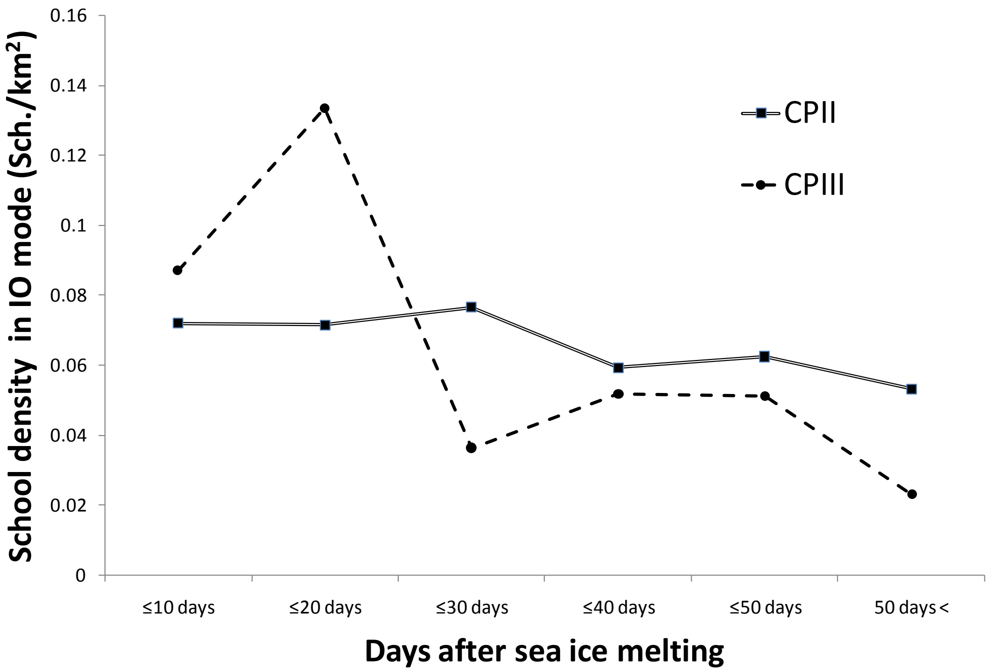

Fig. 3. School density of Antarcitic minke whales in the entire area of Area II in relation to days after sea ice melting. Mean of the density in each 10 days bin is caluculated. School density in IO mode is shown.

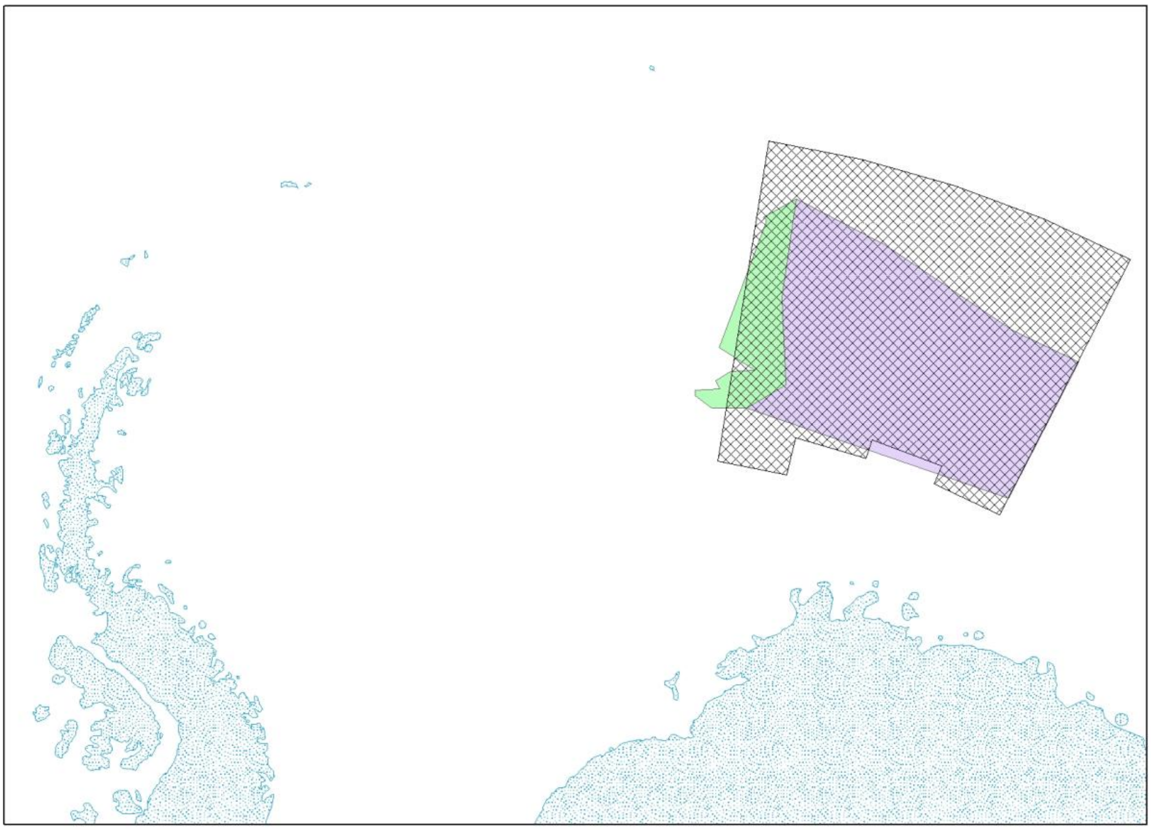

Fig. 4. EN stratum in CPIII (hatched area) is overlaid on EN (purple area) and ES1 (green area) in CPII. These area are defined as the northeastern region of Area II in this study.

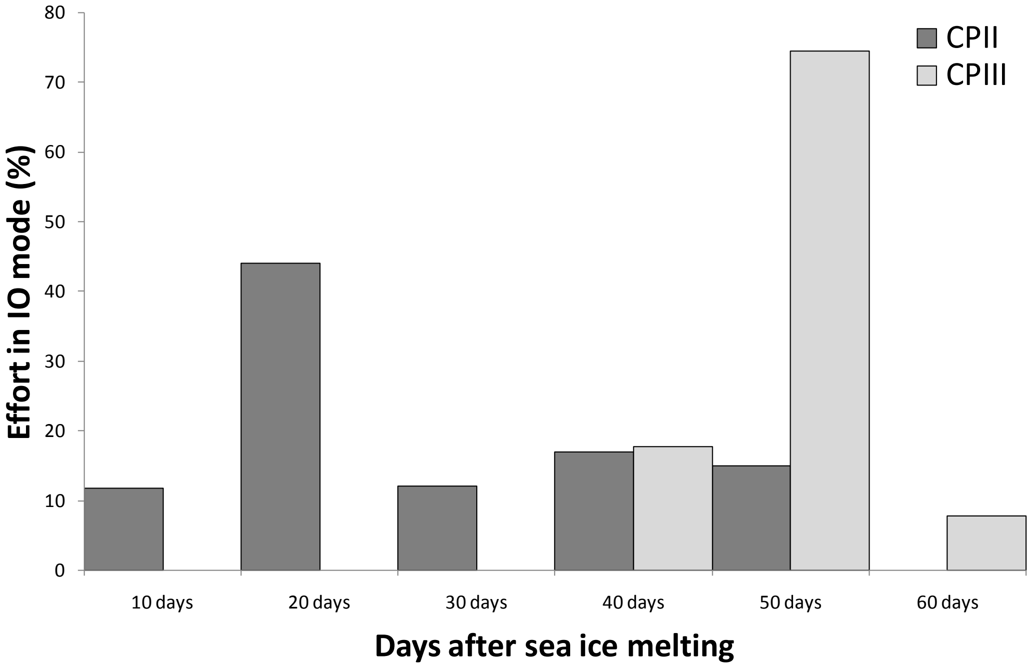

Fig. 5. Frequency of IO mode survey effort distances in the northeastern region of Area II in relation to days after sea ice melting. Frequency is calculated in each 10 days bin.

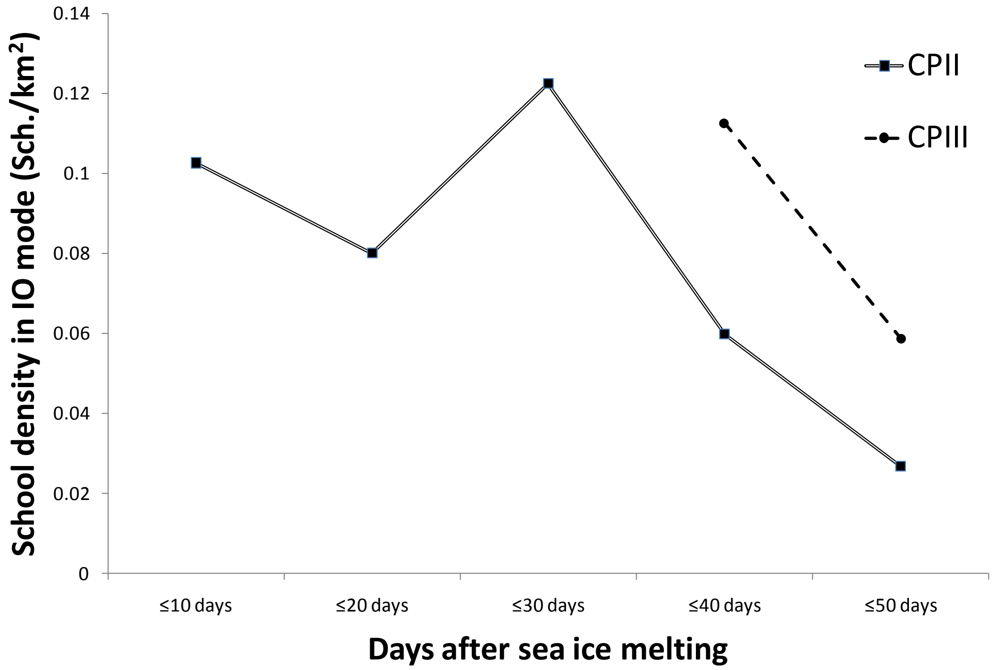

Fig. 6. School density of Antarcitic minke whales in the northeastern region of Area II in relation to days after sea ice melting. Mean of the density in each 10 days bin is caluculated. School density in IO mode is shown.