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Possible impact due to variability of sea ice condition on Antarctic minke whale abundance estimation in the Antarctic from 1978 to 2002

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ABSTRACT

Antarctic sea ice variability in each IWC baleen whale management area from 1978 to 2002 was examined using satellite data. Monthly anomaly trend from 1978 to 2002 suggested that sea ice extents were significantly decreased in Area I while they were significantly increased in Area V and Area VI. Sea ice extent showed large year to year changes. Sea ice extent in January and February was generally larger in CPIII than in CPII except Area II and VI. Greater sea ice extent in CPIII could have negative effect on the abundance estimation of Antarctic minke whale in four ways: 1) high density area of Antarctic minke whale could not be surveyed by the vessels because of sea ice, 2) krill abundance could be reduced because of see ice extent and the reduction could affect the abundance estimation of Antarctic minke whale, 3) narrower longitudinal coverage in CPIII than in CPII in single survey could be susceptive to the effect of the sea ice change and 4) larger sea ice extent could reduce the survey area as a whole. In the case of the large sea ice extent in CPIII, the abundance estimates decreased in Areas I, III and IV. In contrast, the abundance estimate in Area VI increased in CPIII along with decreasing sea ice extent. The results suggested that large sea ice extent could have negative impact on abundance estimate. Though sea ice extent in Area II was decreased in CPIII, this was due to the formation of large polynya. Because the polynya region was not covered by the sighting vessel in CPIII, the abundance must be underestimated. Effect of sea ice configuration on abundance estimates should be investigated further. Because of large sea ice variability between CPII and CPIII, direct comparison of Antarctic minke whale abundance estimates between CPII and CPIII is difficult without removing the effect.

KEYWORD: ANTARCTIC MINKE WHALE; SEA ICE; ABUNDANCE ESTIMATE; ANTARCTIC

INTRODUCTION

The Antarctic minke whale abundance assessment cruises has been conducted in the Antarctic in austral summer by the International Whaling Commission (IWC) since 1978/79 (Matsuoka *et al.,* 2003, for review). The names of the cruises were the International Decade of Cetacean Research programme (IDCR) from 1978/79 to 1995/96 and the Southern Ocean Whale and Ecosystem Research programme (SOWER) from 1996/97 to 2003/04. The cruises covered three circumpolar surveys. Abundance estimation was made using each circumpolar data set; 1978/79-1983/84 (first circumpolar, CPI), 1984/85-1990/91 (second circumpolar, CPII) and 1991/92-2003/04 (third circumpolar, CPIII). Though the abundance estimate of the third circumpolar set has not been completed, noticeable abundance decline from CPII (766,000) to CPIII (268,000) (Branch and Butterworth, 2001) brought question whether the decline is true or apparent. It is hypothesized that change in sea ice could have one of the large impacts on the abundance estimations (IWC, 2003). Tynan (2002) advocated that the linkage between the regional sea ice trends and the change in the abundance estimation of Antarctic minke whales was necessary but no analysis was presented to the IWC Scientific Committee (IWC/SC) hereafter. Shimada *et al.* (2001) tentatively analyzed the impact of the sea ice change on the abundance estimation of Antarctic minke whales within pack ice but how the change in sea ice related to the open water abundance estimation was not discussed fully. This paper presents (1) monthly mean anomaly sea ice extent trend 1978-2002, (2) January and February monthly mean sea ice extent trend 1979-2002, (3) comparison of January and February monthly mean sea ice extent between CPII and CPIII in each baleen whale management area defined by the IWC and (4) relationship among sea ice extent, krill and Antarctic minke whales in Area IV using JARPA data. Possible implication of the linkage between the sea ice and abundance estimation is discussed.

MATERIALS AND METHODS

Satellite derived daily sea ice data, Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I (Comiso, 1999) from October 1978 to September 2002 was used in the analysis. The original data was in the polar stereographic projection and it was converted to the Zenithal equal area projection. Sea ice extent (km^2) was defined as the sum of the image pixels that contained more than 15% sea ice concentrations. Sea ice concentrations more than 15% was commonly used in the sea ice trend analysis (e.g. Bjøgo *et al.,* 1997; Hanna 2001; Zwally *et al.,* 2002). The monthly anomaly (deviation) trend of sea ice extent was estimated using the simple least squares regression in each IWC baleen whale management area. January and February monthly mean sea ice extent trend in each area was also estimated using the simple least squares regression. The IWC baleen whale management area was listed in Table 1. Differences of sea ice extent between CPII and CPIII in each management area were calculated using January and February monthly mean data.

Abundance estimates listed in Table 1 of Branch and Butterworth (2001) was used from 1984/85 to 1997/98. Abundance estimates in the 1998/99, 1999/2000 and 2000/01 cruises were extracted from Burt and Stahl (2001), Burt and Hughes (2002) and Burt (2002), respectively.

Bootstrap sea ice data were not available from 2003 to 2004. Abundance estimates of Antarctic minke whale in Area V in CPIII (2001/02-2003/04) were not completed. For those reasons, comparison between CPII and CPIII in Area V was not considered in this paper.

To see the relationship among the sea ice extent, krill density and Antarctic minke whale abundance, krill densities described in Pauly *et al.* (2000) and Murase *et al.* (2002), and Antarctic minke whale abundance estimates in JARPA described in Hakamada *et al.* (2001) were used. Pauly *et al.* (2000) conducted the krill survey off East Antarctica (80-150°E) from January to March, 1996. Murase *et al.* (2002) conducted the krill survey in Area IV (70-130E°) from January to March, 2000. Because the areal coverage of those two surveys was overlap each other, they were considered as comparative surveys. JARPA was conducted in Area IV in 1995/96 and 1999/2000 and the abundance estimates in corresponding year described in Hakamada *et al.* (2001) were used.

RESULTS

Monthly anomaly sea ice extent trend significantly decreased in Area I while it was significantly increased in Area V and VI (Table 2, Fig. 1). January and February monthly mean sea ice extent significantly decreased in Area I (Table 3 and 4, Fig. 2). Year to year variations were observed in each data set in each area. Images of January monthly mean ice extent in each management area in CPI, CPII and CPIII were shown in Fig. 3-8.

Differences of January and February monthly mean sea ice extent (km^2), survey area (km^2) and abundance estimates between CPII and CPIII were summarized in Table 5. Sea ice extent in January and February was generally greater in CPIII than in CPII except Area II and Area VI. Crude abundance estimates in CPII were larger than in CPIII except Area VI. Sea ice extent in Area II was smaller in CPIII than CPII because unusual large polynya observed in 1997/98.

January and February monthly mean sea ice extent in Area IV in 1996 were 558,484 km^2 and 322,609 km^2, respectively. Those in 2000 were 466,461 km^2 and 278,184 km^2, respectively. Sea ice extents in Area IV were lower in 2000 in both months. Krill density in 1996 and 2000 was 5.5g/m^2 (CV=17%) and 13.6g/m^2 (CV=11%) (recalculated based on Table 7 of Murase *et al.* 2002), respectively. First transects in IV-NW and IV-NE were not included in the 2000 estimate as described in Murase *et al.* (2002). Abundance estimates of Antarctic minke whales in the 1995/96 and 1999/2000 JARPA in Area IV was 25,660 (CV=18.3%) and 46,145 (CV=14.1%) individuals, respectively. Sighting survey area in the 1995/96 and 1999/2000 JARPA were 1,840,902 km^2 1,923,617 km^2, respectively. Those results were summarised in Table 6.

DISCUSSION

The greater sea ice extent in CPIII except Area II and VI could have negative impact on the abundance estimation of Antarctic minke whale in four ways as follows;

1) High density area of minke whale could not be surveyed by the vessels because of sea ice.

2) Krill abundance could be reduced because of see ice extent and the reduction could affect the abundance estimation of Antarctic minke whale.

3) Narrower longitudinal coverage in CPIII than CPII could be susceptive to the effect of the sea ice change.

4) Greater sea ice extent could reduce the survey area as a whole.

1) High density area of minke whale could not be surveyed by the vessels because of sea ice

As pointed out by Shimada and Murase (2003), changes in sea ice extent and configuration affect the distribution and abundance of Antarctic minke whales because the extensive ice covered the continental slope zone. Krill was abundant continental slope zone that coincided with ice edge (Murase *et al.*, 2002). Such area is important feeding ground of Antarctic minke whales (Ichii, 1990). Thus large sea ice extent change could have negative impact on the abundance estimates.

2) Krill abundance could be reduced because of see ice extent and the reduction could affect the abundance estimation of Antarctic minke whale

The krill density in 1999/2000 (low sea ice extent year) was larger than in 1995/96 (large sea ice extent year) though the interpretation of the results needed caution because the areal coverage and survey design was slightly different from each other. The krill density in 1995/96 was lower end while it was in 1999/2000 was larger end of the density in this area based on past survey results in the Prydz Bay region which were summarized in Pauly *et al.* (2000). In response to the change in the density of krill, Antarctic minke whale could be more abundant in 1999/2000 (large krill density) than in 1995/96 (low krill density). It was reported that poor body fat condition of minke whales were observed when the continental slope region was covered by sea ice during the austral summer months (Ichii *et al.*, 1998). The result of Ichii *et al.* (1998) suggested that the krill biomass could be low when the sea ice extent was large. Primary production was low when the sea ice cover was large (Hegseth and Von Quillfeldt, 2001; Arrgo *et al.*, 2002). The low primary production in the large see ice cover season could decrease the abundance of krill though further study is required to understand the mechanism of krill-summer sea ice extent relationship.

3) Narrower longitudinal coverage in CPIII than CPII could be susceptive to the effect of the sea ice change

Each baleen whale management area was surveyed in single year in CPII while the area was longitudinally separated into 10 to 50 degree sectors and they were surveyed in different year in CPIII. It took two to four years to complete survey in a baleen whale management area in CPIII. Narrower longitudinal coverage in CPIII than CPII could be susceptive to the effect of the sea ice change. As shown in Fig 5, western part of Area III in 1994/95 (CPIII) was low sea ice extent as in 1987/88 (CPII) but only eastern part where the sea ice extent was large was surveyed in this year. If wider longitude had been covered in 1994/95, the risk of surveying in large sea ice extent would have been hedged. To test the effect, it could be worth to have Antarctic minke whale abundance estimates in each management area in CPIII (for example, combing 1996/97 and 1997/98 into one to get abundance estimates in Area II) instead of estimating abundance by year.

4) Greater sea ice extent could reduce the survey area as a whole

It should be noted that abundance estimate in Area VI in CPIII was larger than in CPII. The result indicated that reduction of sea ice extent in CPIII could be one of the most important factors of the change in abundance estimates in Area VI because survey design was not substantially changed between CPII and CPIII. Increasing in sea ice extent in Areas I, III, and IV was coincided with decreasing in the Antarctic minke whale abundance estimates in CPIII. The result suggested that the large sea ice extent could affect negatively on the abundance estimate though the simple inference could not be made because survey design was substantially changed in these areas. The effect of greater sea ice extent could be large in Area V where see ice extent is generally large. It was reported that survey area was substantially small in the 2003/04 cruise conducted in Area V (Ensor *et al.*, 2004). Though the abundance estimates in the 2003/04 is not available, this factor should not be ignored. Though sea ice extent in Area II was decreased in CPIII, this was due to the formation of large polynya. The effect of the polynya was discussed in Murase and Shimada (2004).

Conclusions

Direct comparison of abundance estimates between CPII and CPIII is not valid unless abovementioned four effects are taken account. Because Antarctic sea ice has highly variable nature, the effect on the abundance estimates of Antarctic minke whale could be substantial. Careful treatment is necessary to elucidate the relationship between sea ice and Antarctic minke whales.

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Table 1. IWC baleen whale management areas.

Management areas	Longitude range
Area I	120-60W
Area II	60W-0
Area III	0-70E
Area IV	70E-130E
Area V	130E-170W
Area VI	170W-120W

Table 2. Monthly anomaly sea ice extent trend in each baleen whale management area from 1978 to 2002.

Management areas	Extent trend ($10^3 km^2 yr^{-1}$)			P-value
Area I	-9.68	±	3.29	<0.05
Area II	-4.41	±	5.46	0.11
Area III	0.01	±	4.08	1.00
Area IV	-1.72	±	2.64	0.20
Area V	9.88	±	2.86	<0.05
Area VI	10.80	±	4.57	<0.05

Table 3. January monthly mean sea ice extent trend in each baleen whale management area from 1979 to 2002.

Management areas	Extent trend ($10^3 km^2 yr^{-1}$)			P-value
Area I	-14.91	±	7.35	<0.05
Area II	-7.15	±	23.96	0.54
Area III	-0.54	±	7.26	0.88
Area IV	0.08	±	3.63	0.96
Area V	11.50	±	12.01	0.06
Area VI	4.27	±	18.90	0.64

Table 4. February monthly mean sea ice extent trend in each baleen whale management area from 1979 to 2002.

Management areas	Extent trend ($10^3 km^2 yr^{-1}$)			P-value
Area I	-20.42	±	7.15	<0.05
Area II	4.54	±	13.36	0.49
Area III	-0.60	±	5.73	0.83
Area IV	0.05	±	4.28	0.98
Area V	7.19	±	8.13	0.08
Area VI	7.36	±	13.94	0.29

Table 5. January and February monthly mean sea ice extent (km^2), survey area (km^2) and abundance estimates difference between CPII and CPIII of IWC-IDCR/SOWER.

Area	Survey year		Sea ice extent (km^2)						Survey area (km^2)			Abundance estimates (individuals)						Survey desgin change
			January monthly mean			February monthly mean						Closing mode			IO mode			
	CPII	CPIII	CPII	CPIII	Diif CPII & CPIII (%)	CPII	CPIII	Diif CPII & CPIII (%)	CPII	CPIII	Diif CPII & CPIII (%)	CPII	CPIII	Diif CPII & CPIII (%)	CPII	CPIII	Diif CPII & CPIII (%)	
Area I	1989/90	1993/94	669,193	663,905	-1%	486,910	536,271	**10%**	1,473,185	2,828,453	**92%**	**66,529**	35,656	-46%	**61,168**	41,394	-32%	Exntend survey area to 60S
		2000/01[*1]		**798,942**	**19%**		535,214	**10%**										
Area II	1986/87	1996/97	1,892,640	1,510,092	-20%	1,079,947	1,213,222	**12%**	1,698,516	2,581,675	**52%**	**110,984**	50,386	-55%	**128,680**	39,852	-69%	Exntend survey area to 60S
		1997/98		1,648,656	-13%		1,001,675	-7%										
Area III	1987/88	1992/93	237,638	**418,510**	**76%**	115,293	252,093	**119%**	1,645,428	2,924,967	**78%**	**96,043**	42,522	-56%	**145,600**	52,134	-64%	Exntend survey area to 60S
		1994/95[*2]		**403,349**	**70%**		254,914	**121%**										
Area IV	1988/89	1994/95 [*3]	489,026	**507,713**	**4%**	313,442	333,539	**6%**	1,622,080	1,401,723	-14%	**78,660**	9,246	-88%	**54,305**	15,320	-72%	Trackline desgin (ratice to zigzag line)
		1998/99		**552,490**	**13%**		402,292	**28%**										
Area V	1985/86	[*4]	In analysis			In analysis			3,304,603	In analysis		229,175	In analysis		**321,207**	In analysis		Stratifcation in western sector
Area VI	1990/91	1995/96	1,469,193	1,360,952	-7%	866,637	638,872	-26%	1,911,911	2,546,402	**33%**	53,091	**74,704**	**41%**	53,541	**61,558**	**15%**	No significant change
		2000/01[*5]		1,011,899	-31%		846,893	-2%										

[*1] Abundance estimates in eastern sector (110W-120W) was included in CPIII estimates.

[*2] Abundance estimate from 70E-80E (Area IV) secotor north to the Prydz Bay was included in CPIII estimates

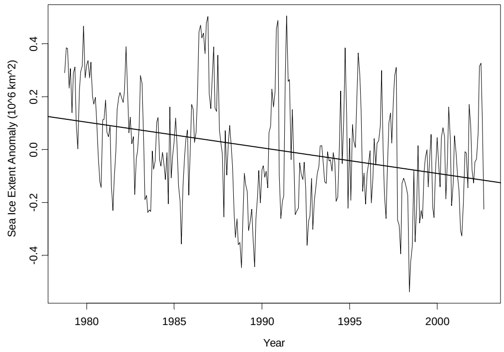
[*3] Abundance estimate from Prydz Bay in 94/95 was included in CPIII estimates

[*4] Abundance estimation in CPIII (2001/02, 2002/03, 2003/04) was not completated.

[*5] Abundance estimates in Weastern sector (120W-140W) was included in CPIII estimates.

Table 6. Sea ice extent, krill density and Antarctic minke whale abundance estimates between the 1995/96 and 1999/2000 JARPA in Area IV.

Category	1995/96	1999/2000	Difference between 95/96 and 99/00 (%)
Sea ice extent (km^2, January)	558,484	466,461	-16%
Sea ice extent (km^2, February)	322,609	278,184	-14%
Krill density(g/m^2)	5.5[*1]	13.6[*2]	147%
Antarctic minke whale abundance (ind.)[*3]	25,660	46,145	80%
Sighting survey area (km^2)[*3]	1,840,902	1,923,617	4%



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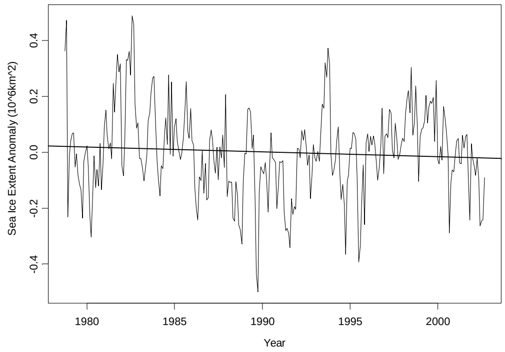

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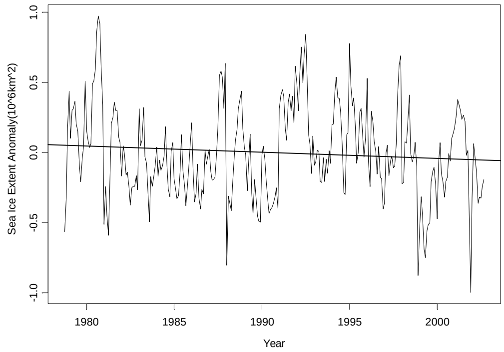

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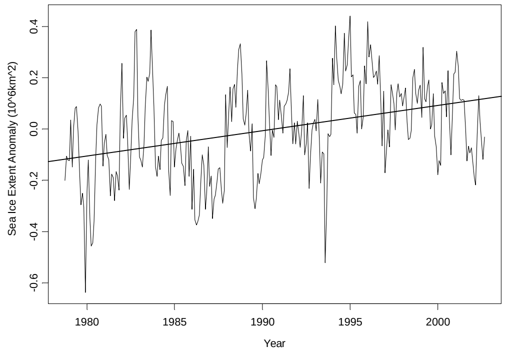

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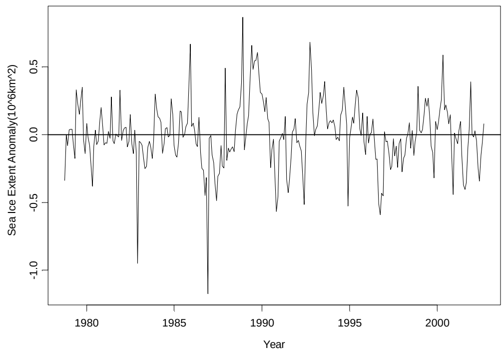

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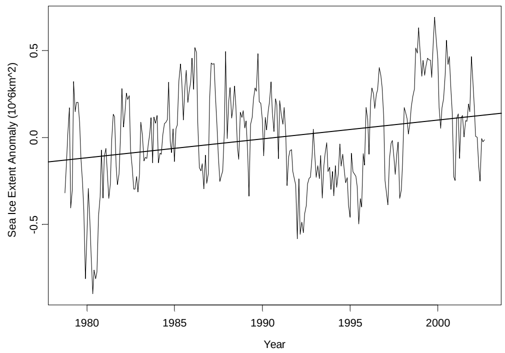
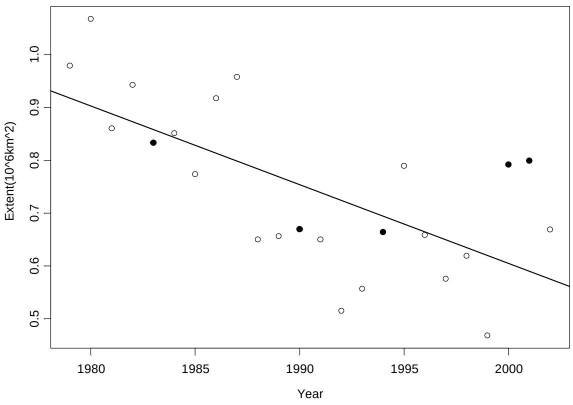


Area VI

Fig. 1. Monthly anomaly sea ice extent trends in each baleen whale management area from 1978 to 2002.



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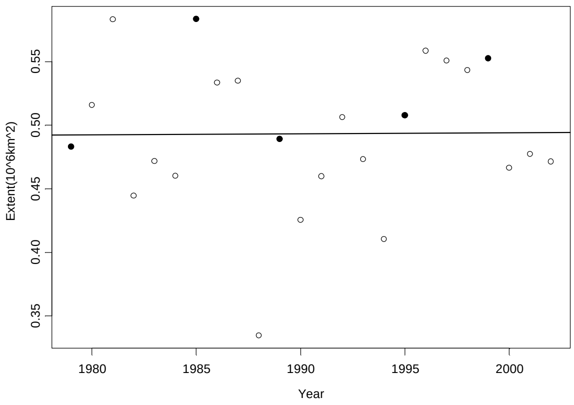

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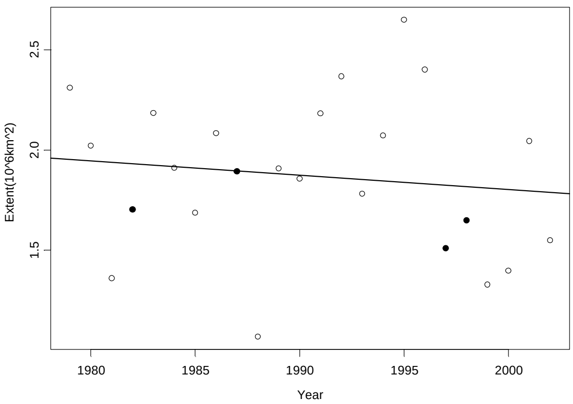

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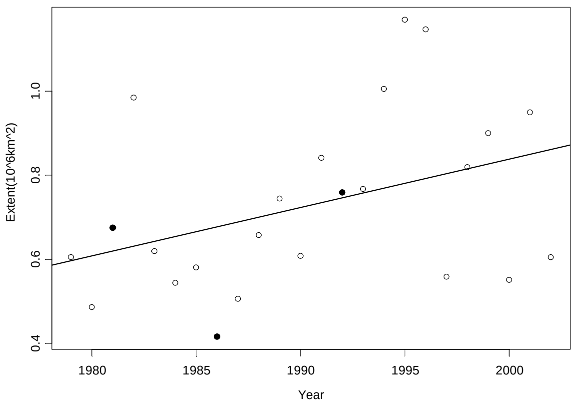

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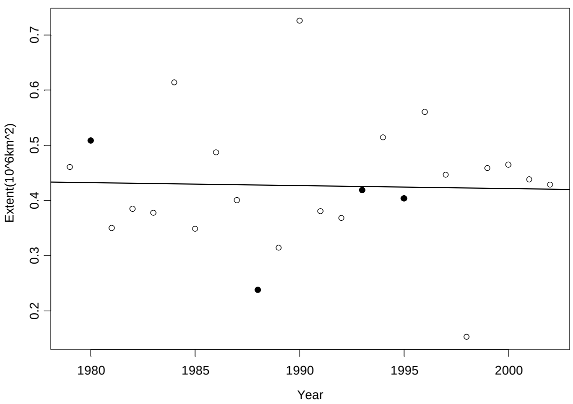

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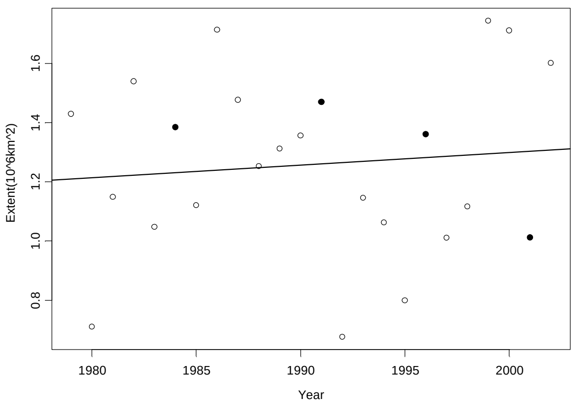

Area VI

Fig. 2. January monthly mean sea ice extent trend in each baleen whale management area from 1979 to 2002. Black filled circles indicate the years when the IDCR-SOWER surveys were conducted.

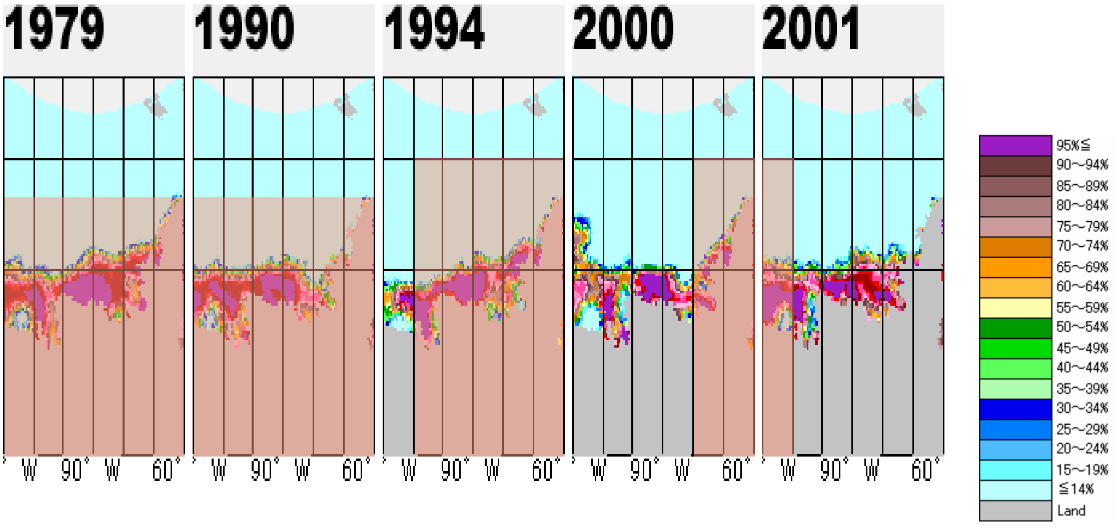

Fig. 3. January monthly mean sea ice extent image in Area I (CPI=1979; CPII=1990, CPIII=1994, 2000 and 2001). Red shadows indicate surveyed area.

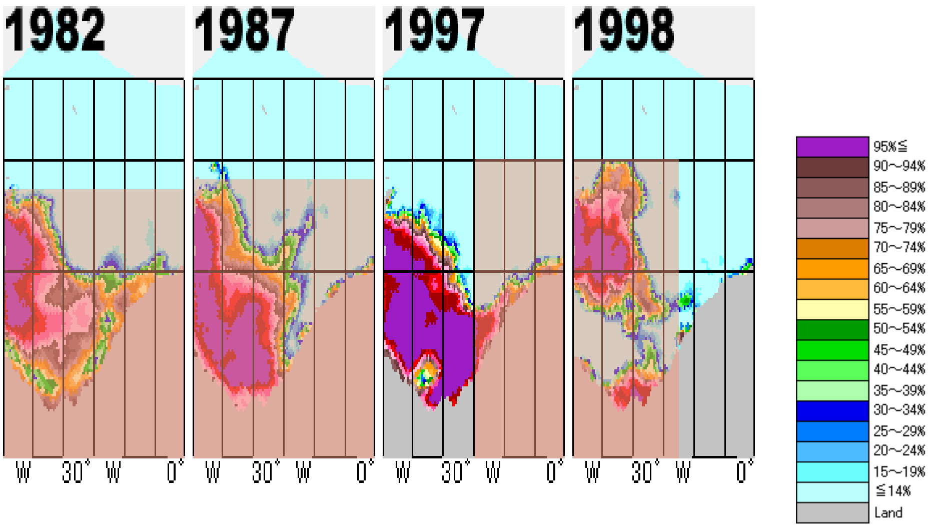

Fig. 4. January monthly mean sea ice extent image in Area II (CPI=1982; CPII=1987, CPIII=1997 and 1998). Red shadows indicate surveyed area.

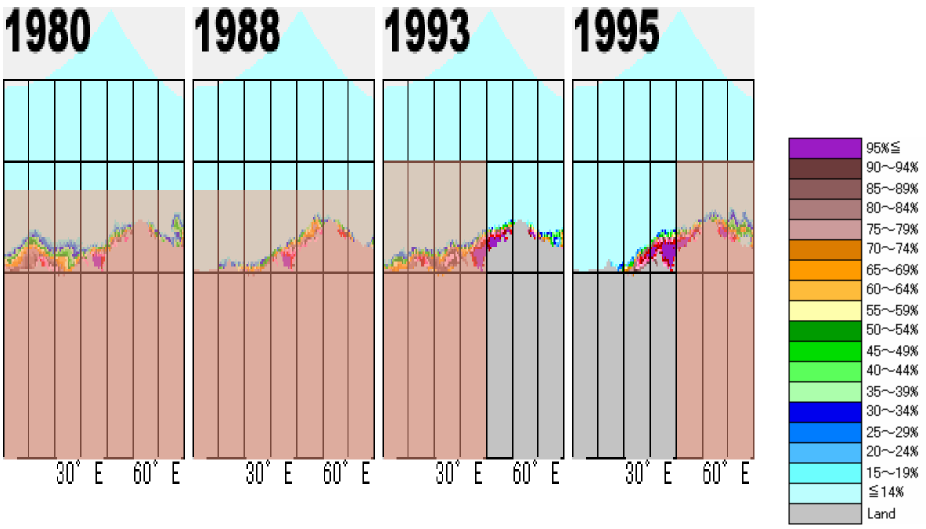

Fig. 5. January monthly mean sea ice extent image in Area III (CPI=1980; CPII=1988, CPIII=1993 and 1995). Red shadows indicate surveyed area.

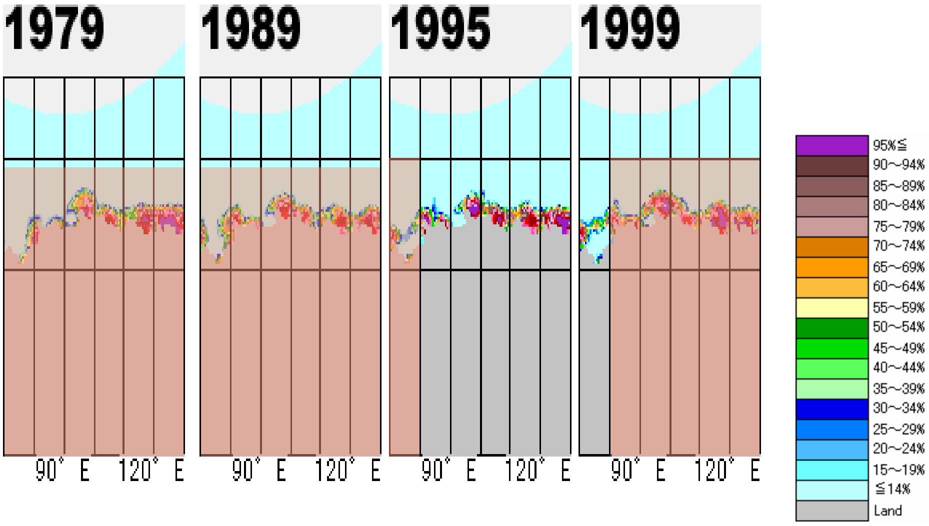

Fig. 6. January monthly mean sea ice extent image in Area IV (CPI=1979; CPII=1989, CPIII=1995 and 1999). Red shadows indicate surveyed area.

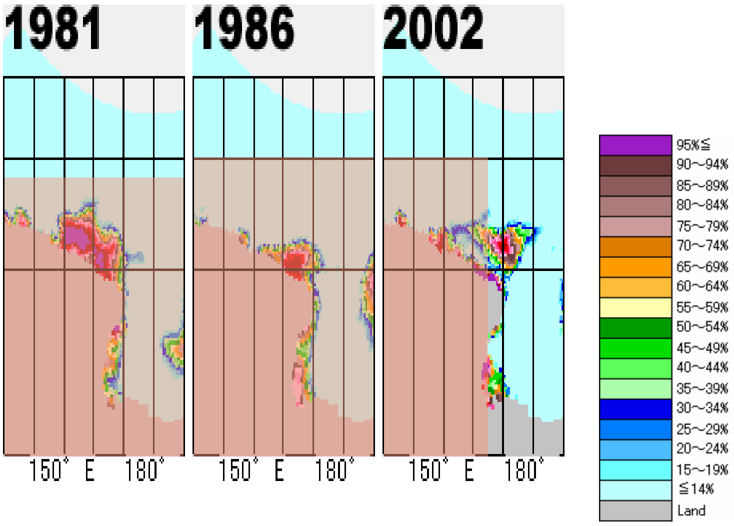

Fig. 7. January monthly mean sea ice extent image in Area V (CPI=1981; CPII=1986, CPIII=2002). Red shadows indicate surveyed area.

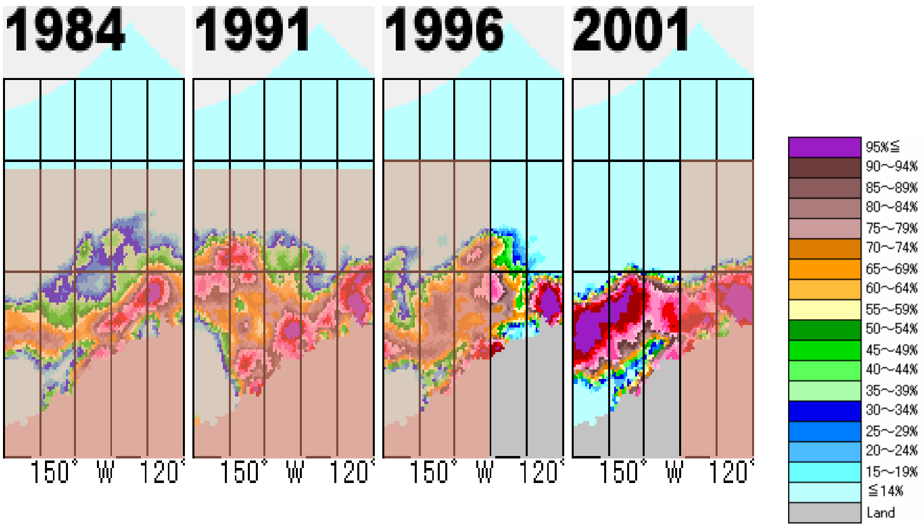

Fig. 8. January monthly mean sea ice extent image in Area VI (CPI=1984; CPII=1991, CPIII=1996 and 2001). Red shadows indicate surveyed area.