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Marine ecosystem monitoring in the sea-ice region of Lützow-Holm Bay, off Syowa Station, during the icebreaker *Shirase* cruise of the 58th Japanese Antarctic Research Expedition

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Abstract: As part of the monitoring program of the Japanese Antarctic Research Expedition (JARE), marine ecological monitoring in the sea-ice region of Lützow-Holm Bay, off Syowa Station, has been routinely carried out since JARE-52 (2010/11 season) to investigate biological production and mechanisms in relation to sea-ice. Water temperature, salinity, chlorophyll-*a* concentration, macro-nutrients (nitrate, nitrite, phosphate, and silicate), and zooplankton data were collected at six stations in various sea-ice environments: fast-ice, pack-ice, and ice-free open ocean. The use of an "ice-fence" protected observation equipment (e.g., plankton nets and CTDs) from damage due to sea-ice. This report provides the data obtained during the icebreaker *Shirase* cruise of the 58th Japanese Antarctic Research Expedition in the 2016/17 season.

1. Background and Summary

The Southern Ocean marine ecosystems have been changing dramatically due to the effects of global climate change. Among the most obvious physical changes are the regionally contrasting variations in the extent and seasonality of sea-ice[1]. The Antarctic sea-ice zone is an ecologically important region of the Southern Ocean. The seasonal fluctuation of sea-ice formation and melting

events has a significant effect on the life cycle of many organisms living in this region. However, since it is difficult to access by existence of sea-ice in these areas, the accumulation of biological knowledge is extremely poor compared to the open ocean region until now. The powerful ice-breaking capability of the current Japanese icebreaker *Shirase* (Japan Maritime Self-Defense Force) raises the possibility of marine observations in the fast-ice and/or permanent ice zone. The ship-based marine ecological monitoring program for the sea-ice region of Lützow-Holm Bay, off Syowa Station, East Antarctica, began with the 52nd Japanese Antarctic Research Expedition (JARE-52) during 2010/11 season[2]. The aim of this program is to investigate biological production and mechanisms in relation to sea-ice.

This report presents the water temperature, salinity, macro-nutrients, phytoplankton chlorophyll-*a* concentrations, and zooplankton monitoring data obtained during a cruise by the icebreaker *Shirase* as part of the JARE-58 (February 2017). Similar datasets collected previously by JARE have been published in JARE Data Reports[2, 3, 4, 5, 6, 7, 8, 9, 10, 11].

2. Sampling Location

Seawater and plankton samples were collected at six monitoring stations (A, B, C, D, E, and BP) in Lützow-Holm Bay in various sea-ice environments: fast-ice, pack-ice, and ice-free open ocean (Fig. 1 and Table 1). At the time of sampling, Station A was in the multi-year fast-ice zone, Station B was in the first-year fast-ice zone, Stations C and D were in the pack-ice zone, and Stations E and BP were in the open-ocean zone.

3. Methods

3.1. Protection of the observation equipment

Oceanographic observations in sea-ice areas have the problem that the existence of sea-ice makes it difficult to use conventional equipment such as plankton net. We devised the “ice-fence” which guards observation equipment from sea-ice (Fig. 2)[12]. Lützow-Holm Bay is a region where fast-ice cover persists during summer and heavy sea-ice states continue. Therefore, we modified the ice-fence several time in order to carry out observation under heavy sea-ice conditions and succeeded in protecting equipment from the damage by sea-ice[13].

3.2. Temperature and salinity

Vertical profiles of temperature and salinity were determined at six stations using a conductivity-temperature-depth (CTD) memory probe (SBE19 plus, Sea-Bird Scientific) attached to a water sampler with six 4-L bottles (SBE 55 ECO, Sea-Bird Scientific). The data were downloaded from the CTD to a laptop computer immediately after each cast. The CTD sensor was calibrated by Sea-Bird Scientific during the last boreal summer. The salinity data in this report were not corrected by the bottle salinity data by the salinometer.

3.3. Chlorophyll *a*

Vertical water samples were collected over the upper 100 m of the water column using six Niskin bottles attached to the water sampler, and surface water was collected using a plastic bucket. Samples for chlorophyll *a* measurement were collected in two dark bottles (ca. 300 mL) for bulk measurements using glass-fiber filter (Whatman, GF/F) and size-fractionated measurements to determine the phytoplankton size composition using Whatman nuclepore membrane filter (pore size: 10 and 2 μm) and a Whatman GF/F. The filters were immediately soaked in N, N-dimethylformamide[14], and the pigments were extracted for more than 24 hours. The samples were stored (–18ºC) until onboard analysis. Concentrations of chlorophyll-*a* were determined fluorometrically[15] with an onboard fluorometer (10-AU; Turner Design, Sunnyvale, CA, USA). The fluorometer was calibrated against a chlorophyll-*a* standard (Fujifilm Wako Pure Chemical Corp., Osaka, Japan) at a laboratory on-land before the cruise, using a spectrophotometer and the specific absorption coefficient of chlorophyll-*a*[16]. For a fluorometer calibration result, see Shimada *et al*. (2020)[17].

3.4. Macro-nutrients

Seawater to determine macro-nutrient contents was collected at the time when seawater was sampled for chlorophyll-*a*. The sampled water was stored (–18ºC) until analysis in a land laboratory. The analytical method after melting the frozen samples was performed according to Makabe *et al*. (2020)[18]. The coefficients of variation calculated from five replicates of nitrate, nitrite, silicate, and phosphate were 0.18%, 0.29%, 0.16%, and 0.13%, respectively.

3.5. Zooplankton sampling

Zooplankton samples are collected using a closing net (mouth diameter 0.75 m, mesh size 100 μm). To prevent sea-ice from entering the net, an “ice-fence” is employed and the net was closed as it reaches the surface[12]. The net was equipped with a flow-meter to estimate the volume of water filtered, and was hauled vertically from a depth of 150 m to the surface at stations where the bottom is deeper than 150 m, or from 5 m above the bottom to the surface at stations where the bottom is shallower than 150 m. All samples are fixed immediately in seawater with 5% buffered formalin.

4. Data Records

4.1. Temperature, salinity, macro-nutrients, and chlorophyll-*a* concentration

All measurements are presented in two data files, named “JARE58_Sea-ice_CTD”, and “JARE58_Chl&Nuts”. The fields in the datasheets in the two files are:

CTDPRS – the pressure (dbar) of the data collected
CTDTMP – the temperature (degree C)
CTDCND – the conductivity (s/m)

CTDSAL – the salinity
THETA – the potential temperature (degree C)
SIGT – the sigma-t (kg m^{-3})
CRUISE – the cruise code of the vessel
SHIP – the name of the ship on which the sampling was conducted
STNNBR – the name of the station on which the sampling was conducted
DATE – the sampling date (DD/MM/YYYY)
TIME – the sampling time (UTC)
LATITUDE – the decimal latitude of the sampling station (negative value for South)
LONGITUDE – the decimal longitude of the sampling station (positive value for East)
DEPTH – the sampling depth (m)
SIG0 – the sigma-θ (kg m^{-3})
CHL BULK – total chlorophyll-*a* concentration (µg l^{-1})
CHL 10UM – composition of chlorophyll-*a* in >10 µm fraction (%)
CHL 2UM – composition of chlorophyll-*a* in 2 – 10 µm fraction (%)
CHL GF/F – composition of chlorophyll-*a* in <2 µm fraction (%)
NITRAT – concentration of nitrate (µmol l^{-1} or µmol kg^{-1})
NITRIT – concentration of nitrite (µmol l^{-1} or µmol kg^{-1})
SILCAT – concentration of silicic acid (µmol l^{-1} or µmol kg^{-1})
PHSPHT – concentration of phosphate (µmol l^{-1} or µmol kg^{-1})

4.2. Zooplankton dataset

Zooplankton monitoring datasets are presented at data file named "JARE58_Sea-ice_Zooplankton" in three data sheets, species/taxa list, abundance data and wet weight data. The fields in the dataset are:

JARE number – the JARE number of this sampling season
Ship name – the name of the ship on which the sampling was conducted
Station number – the name of the station on which the sampling was conducted
Latitude – the decimal latitude of the sampling station (negative value for South)
Longitude – the decimal longitude of the sampling station (positive value for East)
Sampling season – two-year Antarctic season based around the austral summer, e.g. "2016-2017" runs from December 2016 to March 2017
Sampling year – the sampling date year
Sampling month – the sampling date month
Sampling day – the sampling date day
Sampling time – the sampling date time (UTC)
Sampling depth – the depth of sampling tow
Mesh size – the mesh size of plankton net

Estimated volume of water filtered – the estimated volume of water filtered using a flow-meter
Abundance – the abundance of each species/taxa
Total abundance – total abundance of all zooplankton in a sample
Number of species/taxa – the number of species/taxa in a sample
Wet weight – the wet weight of each category
Total wet weight - total wet weight of all zooplankton in a sample

5. Technical Validation

5.1. Zooplankton identification

Zooplankton were identified to lowest practical taxonomic level, generally to species or genus, using a stereo-microscope. Copepodite stages of copepod species, calyptopis stages and furcilia stages of euphausiid species were subdivided from the adults. The nauplius stages of *Rhincalanus gigas* (Copepoda: Calanoida) were distinguished from other calanoid nauplii by their large size and morphology. Zooplankton abundance was converted to individuals per cubic meter.

The species list for this dataset was checked using the Taxon Match of the World Register of Marine Species (WoRMS: http://www.marinespecies.org/index.php) name validation tool. WoRMS is an open-access inventory of all marine species, being >90% complete[19]. The tool performs a cross-check of the spelling and taxonomic status of species against the WoRMS database; it returns standard taxonomic information with valid names.

5.2. Wet weight measurement

Processing of samples was carried out according to the four-step procedure outlined below and shown in Fig. 3.

Step 1: the large-sized zooplankton (more than 10 mm in size) were sorted for the whole sample in the laboratory. Zooplankton were classified into seven categories, and counting number of individuals and measured the wet weight each category using an electronic balance (Sartorius Quintix124-1SJP, readability 0.1 mg).

Step 2: all other species (<10 mm in size) were counted from 1/2 to 1/32 aliquots of the whole sample, and identified to the lowest taxonomic level, generally species or genus, level, using a stereo-microscope. We used a Motoda box-type plankton sample splitter to subdivide a sample. While sorting and counting this size fraction, the wet weight of zooplankton typically reached more than 10 mg per aliquot.

Step 3: given that the wet weight of zooplankton of 1 mm size or less were hard to sort, this fraction was estimated by using conversion factors listed in Table 2.

Step 4: the weights obtained in steps 1–3 were summed to give a total wet weight. Zooplankton abundance was converted to mg m^{-3}. For a detailed description of zooplankton processing for wet-weight measurements, see Ukai *et al*. (2014)[28].

6. Figures

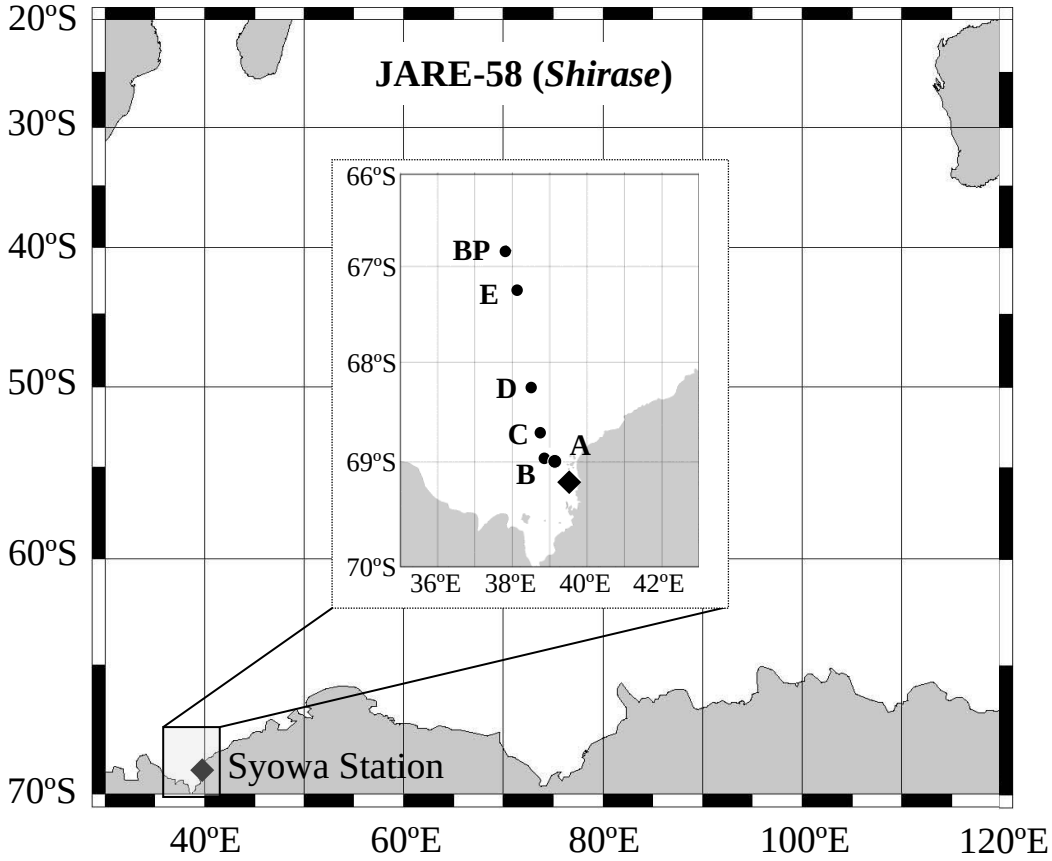

Fig. 1. Location of the sampling sites at Lützow-Holm Bay in February 2017.

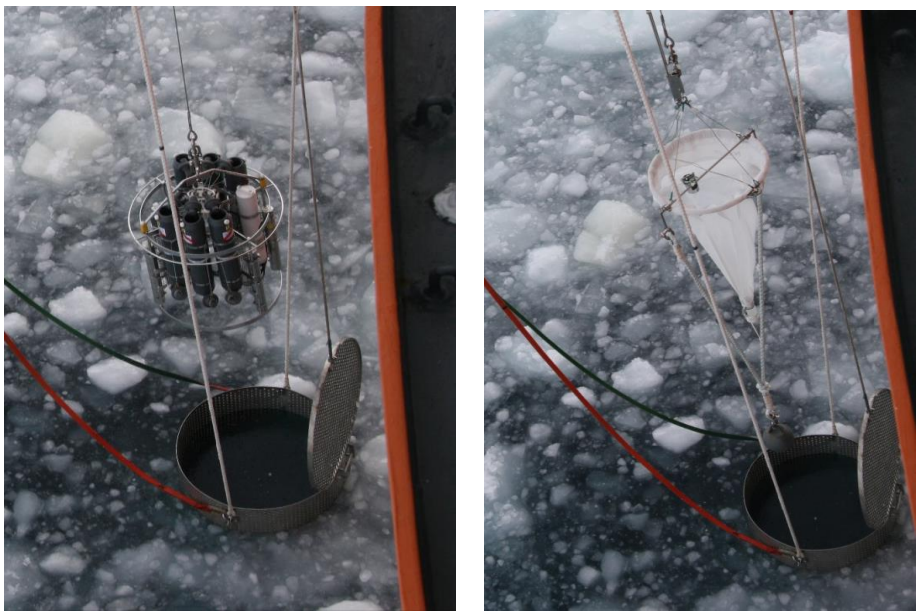

Fig. 2. CTD with a water sampler (left) and closing net (right) used in the monitoring program in the sea-ice region. We used the "ice-fence" which guards observation equipment from sea-ice.

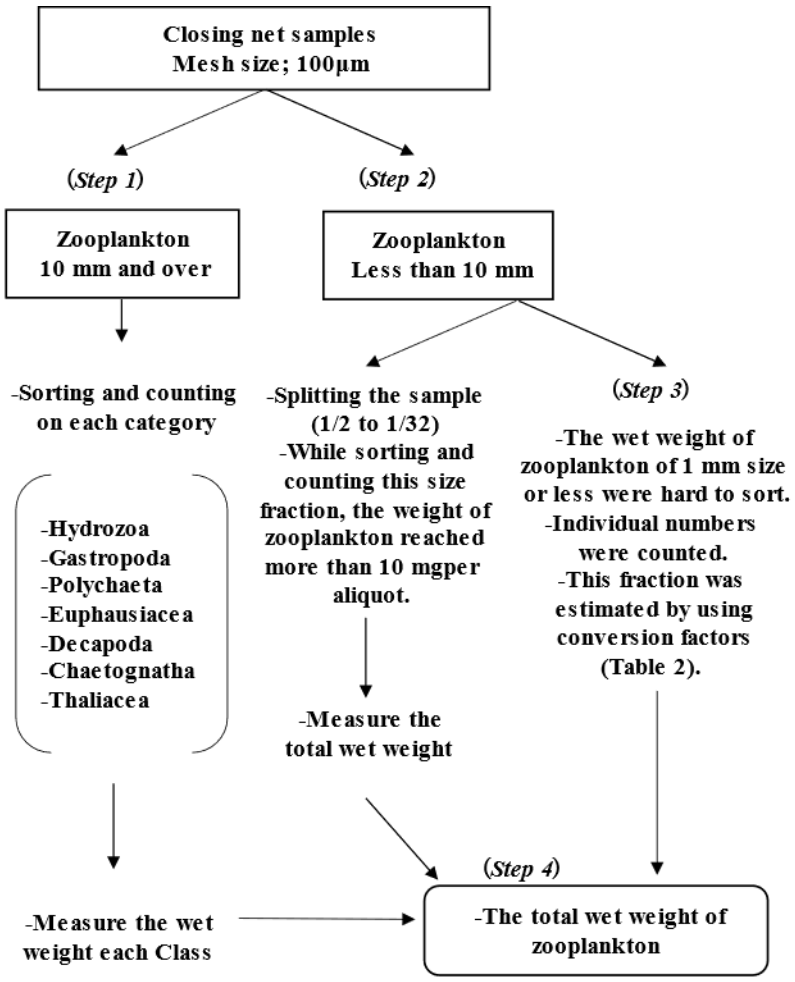

Fig. 3. Four-step procedure used to measure and to estimate the wet weight of closing net samples.

7. Tables

Table 1. Sampling information of CTD cast and closing net at six stations.

Station	Date (UTC)	CTD cast			Closing net sampling		
		Time (UTC)	Latitude (ºS)	Longitude (ºE)	Time (UTC)	Latitude (ºS)	Longitude (ºE)
B	14/02/2017	13:44	-68.94284	38.92443	14:02	-68.94280	38.92432
A	15/02/2017	07:24	-68.99854	39.18048	07:39	-69.00147	39.16450
C	15/02/2017	10:51	-68.59259	38.72969	11:21	-68.59124	38.73656
D	16/02/2017	04:19	-68.26821	38.49425	04:45	-68.26872	38.48760
E	16/02/2017	10:50	-67.28377	38.16855	11:22	-67.29079	38.14853
BP	16/02/2017	13:44	-66.83733	37.84389	14:15	-66.84676	37.82601

Table 2. Conversion factors between Carbon weight (CW), Dry weight (DW), Wet weight (WW), Body length (L), Bell height (BH), Bell diameter (BD), Shell length (SL), Trunk length (TL) and Body width (BW) used in this study.

Category	Species/taxa and/or Form	Developmental stage	Conversion factors of wet weight		Conversion factors of dry weight		Conversion factors of carbon weight	
Cnidaria	BH/BD≧1		WW(μg)=DW(μg)/0.040	[3]	logDW(mg)=-2.333+1.268logBH(mm)+1.125(logBH(mm))^2	[9]		
	BH/BD<1		WW(μg)=DW(μg)/0.043	[3]	logDW(μg)=-7.67+2.75logBD(μm)	[5]		
Mollusca	Thecosomata, Gastropoda larvae		WW(μg)=DW(μg)/0.256	[3]	logDW(μg)=-5.10+2.46logSL(μm)	[5]		
	Cavolinidae(Cone)		WW(μg)=((3.14*BW(μm)^2*L(μm))/12)*10^-6	[2]				
	Bivalve	Larvae	WW(μg)=DW(μg)/0.256	[3]	logDW(μg)=-2.70+1.47logSL(μm)	[5]		
Annelida	Polychaeta	Larvae	WW(μg)=DW(μg)/0.097	[3]	logDW(μg)=-5.68+2.10logL(μm)	[5]		
Arthropoda	Ostracoda		WW(μg)=DW(μg)/0.182	[3]	logDW(μg)=-13.77+4.99logSL(μm)	[5]		
	Copepoda : Calanoida	Adult, Copepodite	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-9.59+3.41logL(μm)	[5]		
	Copepoda : Cyclopoida	Adult, Copepodite	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-6.05+2.10logL(μm)	[5]		
	Copepoda : *Microsetella*	Adult, Copepodite	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-7.59+2.88logL(μm)	[5]		
	Copepoda : *Corycaeus*	Adult, Copepodite	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-6.45+2.43logL(μm)	[5]		
	Copepoda : *Oncaea*	Adult, Copepodite	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-5.59+2.25logL(μm)	[5]		
	Copepoda : Others	Adult, Copepodite	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-9.07+3.26logL(μm)	[5]		
	Copepoda : Eucalanoidae	Nauplius	WW(μg)=DW(μg)/0.135	[3]	logDW(μg)=-9.59+3.41logL(μm)	[5]		
	Copepoda	Other nauplii	WW(μg)=DW(μg)/0.135	[3]	DW(μg)=CW(μg)/0.457	[5]	CW(ng)=1.51*10^-5*L(μm)^2.94	[6]
	Cirripedia	Cypris	WW(μg)=DW(μg)/0.182	[3]	logDW(μg)=-13.77+4.99logSL(μm)	[5]		
		Nauplius	WW(μg)=DW(μg)/0.182	[3]	logDW(μg)=-6.54+2.65logL(μm)	[5]		
	Amphipoda		logWW(mg)=-1.517+2.832logL(mm)	[8]				
	Euphausiacea	Calyptopis, Furcilia, Adult	WW(μg)=DW(μg)/0.159	[3]	DW(mg)=9.954*10^-4*L(mm)^3.156	[10]		
		Nauplius	WW(μg)=DW(μg)/0.159	[3]	DW(μg)=CW(μg)/0.407	[5]	CW(ng)=1.51*10^-5*L(μm)^2.94	[6]
Chaetognatha	-		WW(μg)=DW(μg)/0.068	[3]	logDW(μg)=-0.553+2.79logL(mm)	[5]		
Chordata	Doliolida, Salpida		WW(μg)=DW(μg)/0.050	[4]	logDW(μg)=-6.94+2.54logL(μm)	[5]		
	Appendiculata		WW(μg)=DW(μg)/0.050	[4]	DW(μg)=CW(μg)/0.442	[5]	logCW(μg)=-7.58+2.83logTL(μm)	[7]
Others Larvae		including eggs	WW(μg)=((3.14*BW(μm)^2*L(μm))/6)*10^-6	[1]				

[1]: Wet weight was calculated from the volume of the ellipsoid body (Specific gravity = 1). [2]: Wet weight was calculated from the volume of the cone (Specific gravity = 1). [3]: Beers (1966)[20]. [4]: Ikeda (1970)[21]. [5]: The Oceanographic Society of Japan (1986)[22]. [6]: Uye et al. (1996)[23]. [7]: Sato et al. (2001)[24]. [8]: Ikeda (1990)[25]. [9]: Ikeda and Imamura (1996)[26]. [10]: Iguchi et al. (1999)[27].

Author contributions

K.T. Takahashi performed the processing of zooplankton samples and writing of the manuscript. T. Odate directed the JARE-58 monitoring program. R. Makabe and S. Takao carried out the nutrient analysis in the land laboratory and analyzed the sensor data.

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Data Citations

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