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Zooplankton monitoring using a twin NORPAC net during the 61st Japanese Antarctic Research Expedition in austral summer 2019–2020

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Abstract: As a part of the monitoring programs of the Japanese Antarctic Research Expedition (JARE), zooplankton sampling using a NORPAC (NORth PACific) standard net has been routinely carried out since JARE-14 (1972/73 season) to estimate the long-term trends of abundance, species composition and their temporal/spatial variation in the uppermost 150 m of the Indian Ocean sector of the Southern Ocean. Two separate monitoring surveys were completed during JARE-61 (December 2019 to March 2020). The icebreaker *Shirase* has a fixed schedule and route, traveling down longitude 110ºE each December and returning along 150ºE each March. Data collected on these fixed schedule seems to be ideal for long-term monitoring work in this region. We present data from its 2019/2020 voyage. In additions, separate samplings were carried out on board the T/V *Umitaka-maru* along 110ºE longitude in January 2020. This report provides the latest zooplankton data. These transect data can be used as time series and/or seasonal sets over the last 45 years.

1. Background & Summary

The need to conduct monitoring of zooplankton in the Southern Ocean has long been recognized. Since zooplankton have short life spans and faster population turnover than vertebrate predators, zooplankton communities tend to change rapidly reflecting ambient environmental conditions[1]. They are closer to the base of the marine food web, and they form extremely important links between phytoplankton and higher predators. Therefore, zooplankton community structure is a useful indicator of environmental variability in the Southern Ocean[1, 2]. Moreover, long-term monitoring of zooplankton communities provide a valuable early warning of any changes in the Southern Ocean and Antarctic ecosystem[2, 3, 4]. Numerous intensive surveys have been conducted around Antarctica and its surrounding waters to define zooplankton composition, abundances, and community structures. However, longer-term monitoring is difficult in the remote Southern Ocean, because research opportunities are limited in both time and space.

The Japanese Antarctic Research Expedition (JARE) has been carrying out routine zooplankton monitoring in the Indian Ocean sector of the Southern Ocean every austral summer (December–March) since 1972 (JARE-14). This monitoring program is conducted from an icebreaker, which travels along much the same cruise track at approximately the same time each year. This routine sampling is ideal for long-term monitoring of this region. Although several kinds of plankton nets have been deployed from the icebreakers, vertical hauls using a NORPAC (NORth PACific) standard net have been routinely and frequently carried out to estimate the long-term trends of abundance and species composition of surface zooplankton and its spatiotemporal variability in the upper layers of the Indian Ocean sector of the Southern Ocean. Sampling was conducted from the icebreaker *Fuji* during JARE-14 until JARE-24 (1972–1983)[5, 6], from the icebreaker *Shirase* during JARE-25 until JARE-49 (1983–2008)[7, 8, 9], from RSV *Aurora Australis* during JARE-50 (2009)[10], and from the new icebreaker *Shirase* during JARE-51 to JARE-60 (2009–2019)[10, 11, 12, 13, 14, 15, 16]. The JARE NORPAC monitoring is the longest ongoing zooplankton study within the Antarctic regions; it has been carried for the last 45 years. In addition, zooplankton monitoring has also been carried out by the T/V *Umitaka-maru* of Tokyo University of Marine Science and Technology, since the 2013/2014 season (JARE-55) as a part of the JARE monitoring programs[11, 12, 13, 14, 15, 16]. This report presents the data obtained from the NORPAC standard net during JARE-61 (December 2019 to March 2020).

2. Sampling Location

From JARE-14 to JARE-28 (1986/1987), NORPAC standard net sampling sites were mainly within the western part of the Indian Ocean Sector. Thereafter, sampling stations were shifted to the east where the cruise tracks of the icebreaker *Shirase* remained along the same cruise track each season, beginning with JARE-29 (1987/1988). Regular sampling has been conducted from the icebreaker *Shirase* at five stations along longitude 110°E, ranging from 40°S to 60°S in December. Likewise, sampling is carried out at five stations along 150°E, ranging from 64°S to 45°S in March on its return voyage. The same transect covered by T/V *Umitaka-maru* also comprises nine stations along 110°E, ranging from 40°S to *ca*. 65°S (ice edge). Sampling data from its traverse in January 2020 are also presented herein. Typically, routine sampling stations during the two ships' surveys are located at intervals of 5 degrees of latitude except for KC 7-9 of the T/V *Umitaka-maru*. In JARE-61, sampling station L07 (60°S, 150°E) of the icebreaker *Shirase* and KC3 (50°S, 110°E) of the T/V *Umitaka-maru* were omitted because of rough seas. The locations of sampling stations of the icebreaker *Shirase* and the T/V *Umitaka-maru* during JARE-61 are shown in Figures 1 and 2.

3. Methods

The NORPAC standard net was established as a standard method for collecting zooplankton in international cooperative surveys at an international meeting held in Honolulu in February 1956[17]. A twin NORPAC standard net made of nylon bolting cloth (NGG 54, mesh size 315 µm; NXX 13, mesh size 100 µm) was used at all sampling stations (Fig. 3). The net was hauled vertically at a speed of about 1 m/s from a depth of approximately 150 m. The maximum depth reached was estimated from the wire angle and length of wire paid out. All samples obtained were immediately preserved on board in seawater containing 5%–10% buffered formalin. The volume of water filtered by each net haul was estimated using a flow-meter (Rigo Co., Ltd., Saitama, Japan) mounted at the center of the mouth ring of the net. Sampling was conducted during the daytime at almost stations, reducing the contribution of diel vertically migrating zooplankton to the biomass.

4. Data Records

Zooplankton monitoring datasets are presented 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 cording of 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., “2019-2020” runs from December 2019 to March 2020

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 the 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 morphological characteristics. Zooplankton abundance was converted to individuals per cubic meter of water filtered.

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[18]. 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. 4.

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 nine 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: after removing the larger-sized zooplankton in the step 1, 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. 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 offered to count the individual numbers then the wet weight was estimated by using conversion factors listed in Table 1.

Step 4: the weights obtained in steps 1–3 were summed to give a total wet weight per each sample.

Zooplankton abundance per haul was converted to mg m^{-3}. For a detailed description of zooplankton processing for wet-weight measurements, see Ukai *et al*. (2014)[27].

6. Figures

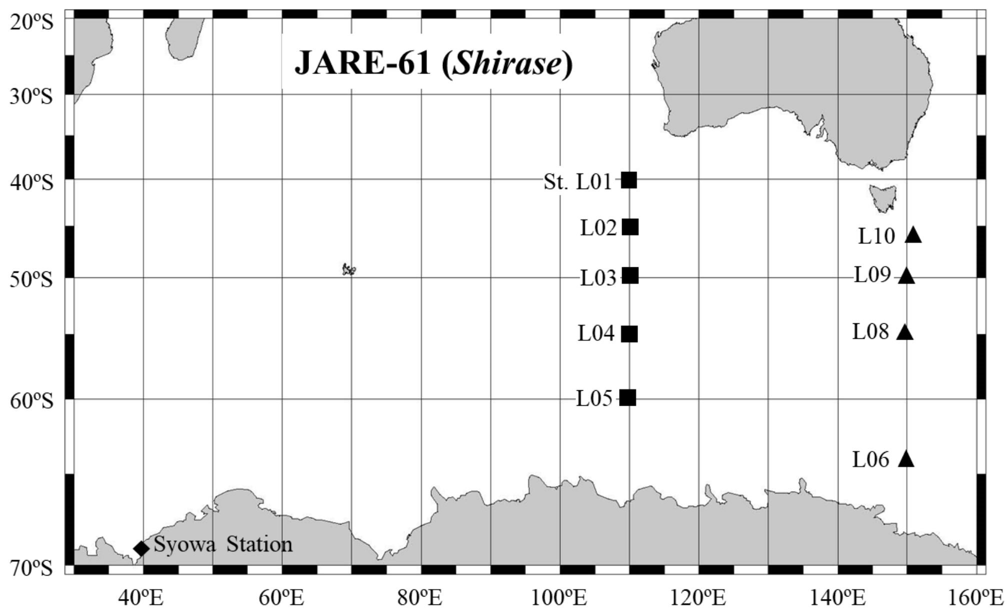

Fig. 1. Locations of the icebreaker *Shirase* sampling stations during JARE-61 in 2019/2020. Station L07 was omitted because of rough sea conditions. ■: December, ▲: March

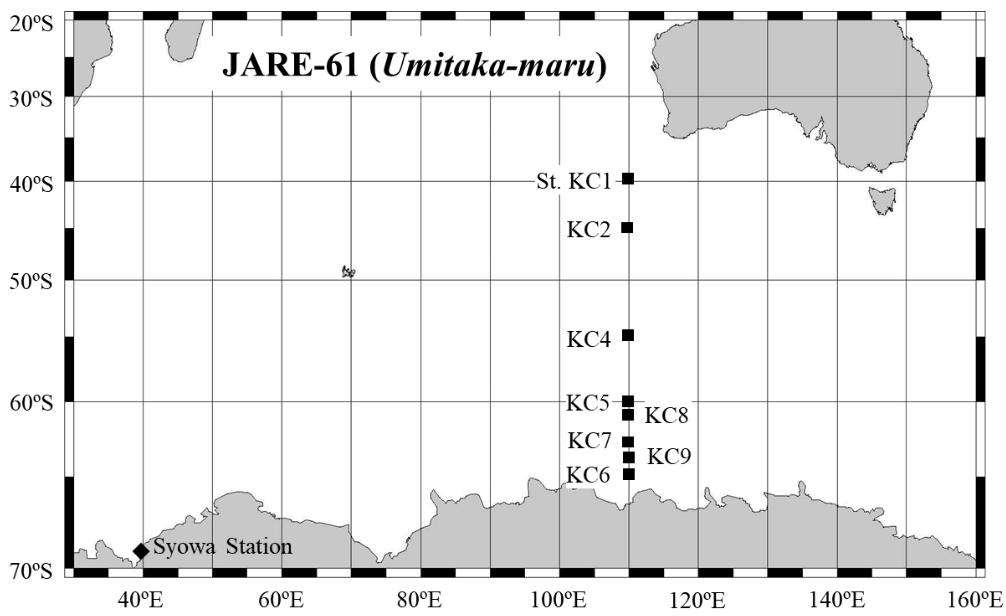

Fig. 2. Locations of T/V *Umitaka-maru* sampling stations during JARE-61 in January 2020. Station KC3 was omitted because of rough sea conditions.

Fig. 3. The twin NORPAC standard net. Flow-meter is attached at each mouth ring of net.

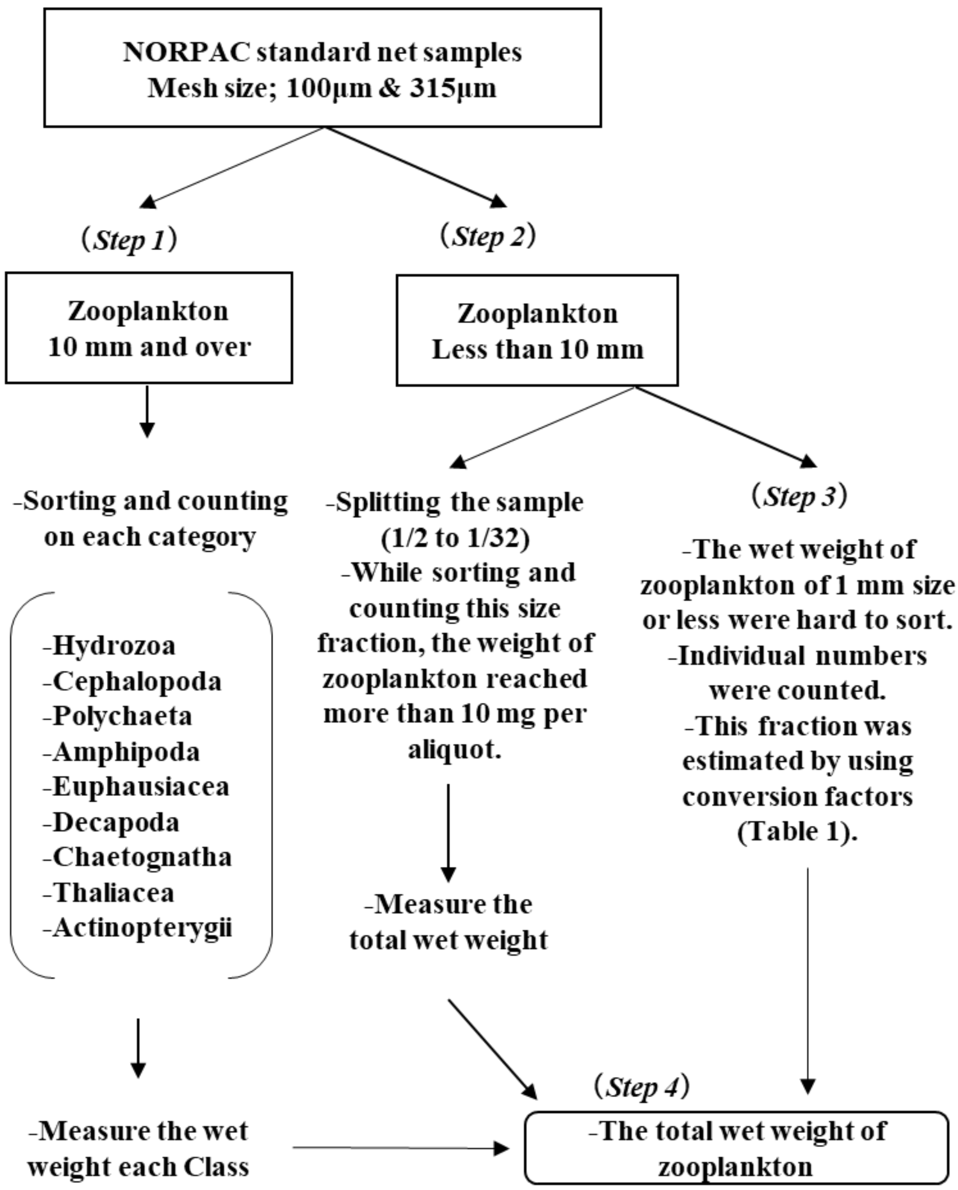

Fig. 4. Four-step procedure used to measure and to estimate the wet weight of NORPAC net samples.

7. Table

Table 1. 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]: [19]Beers (1966). [4]: [20]Ikeda (1970). [5]: [21]The Oceanographic Society of Japan (1986). [6]: [22]Uye et al. (1996). [7]: [23]Sato et al. (2001). [8]: [24]Ikeda (1990). [9]: [25]Ikeda and Imamura (1996). [10]: [26]Iguchi et al. (1999).

Author contributions

K.T. Takahashi carried out the field sampling on board the T/V *Umitaka-maru*, and performed the processing of samples and writing of the manuscript. R. Makabe carried out the field sampling on board the icebreaker *Shirase*. T. Odate directed the JARE-61 monitoring program.

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