Zooplankton community structure and dominant copepod population structure on the southern Kerguelen Plateau during summer 2016

〇Kohei Matsuno, Jake R. Wallis, So Kawaguchi, Sophie Bestley, Kerrie M. Swadling

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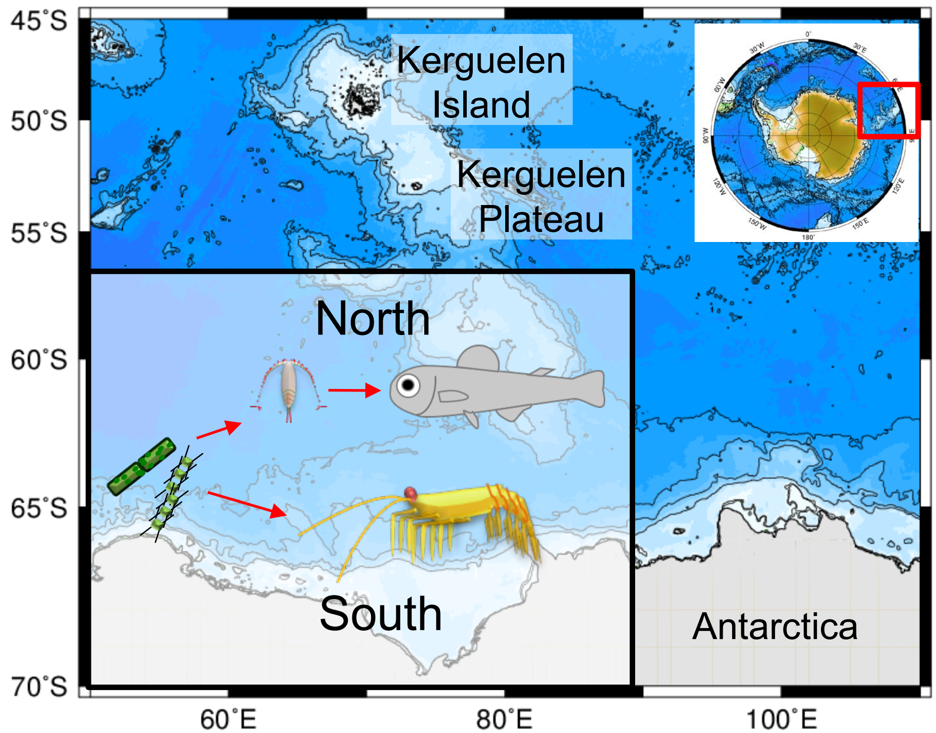
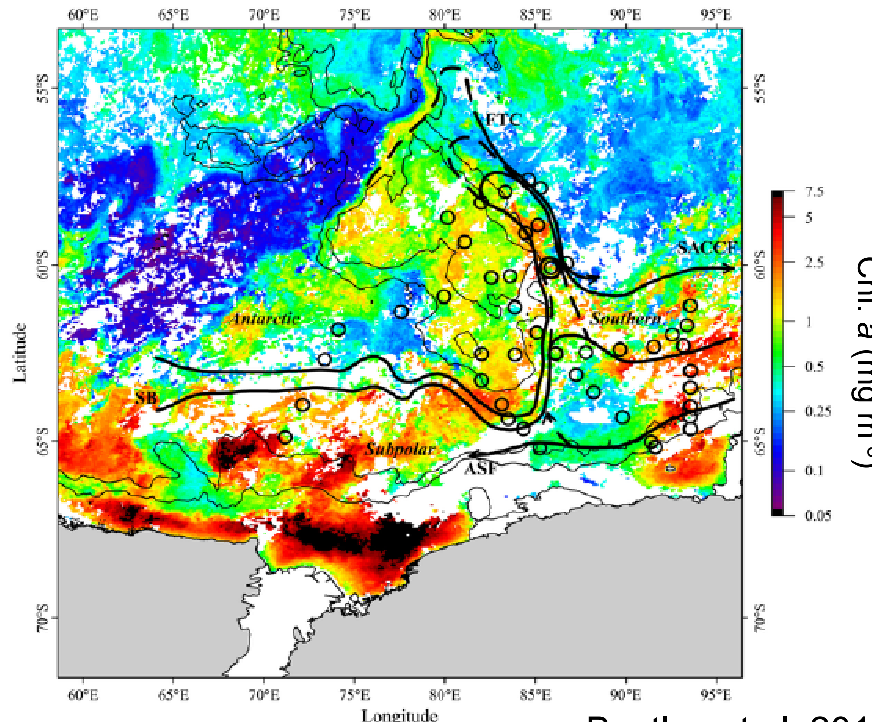


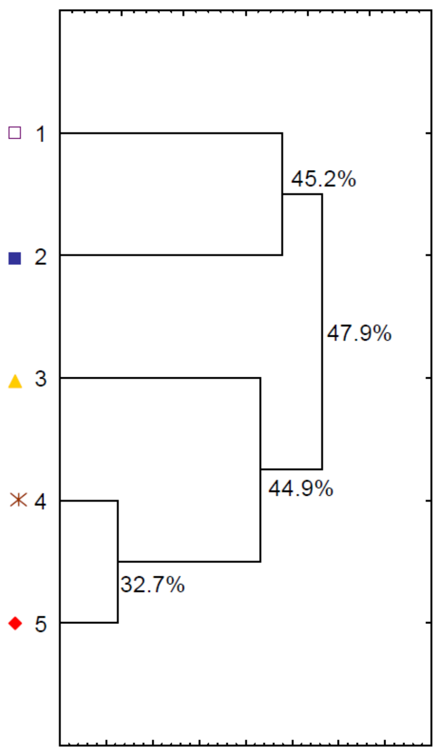


Bestley et al. 2018

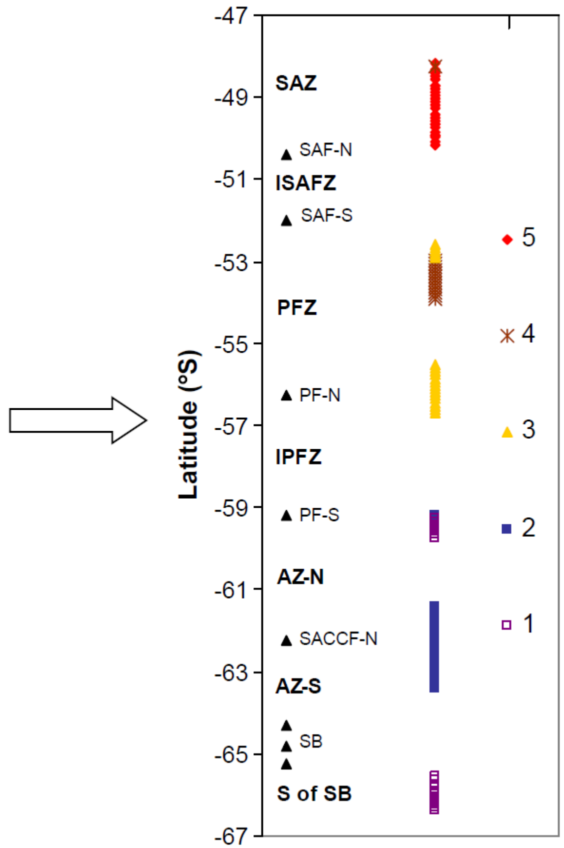
The Kerguelen Plateau, and areas to the south, represents one of the most important regions for primary production in the Indian sector of the Southern Ocean (Arrigo et al., 2008), with high stocks of toothfish and krill found in the north and south, respectively (Nicol, 2006).

Introduction: Zooplankton community

Cluster analysis and spatial distribution of zooplankton community collected by CPR along 140ºE



Hunt and Hosie, 2005



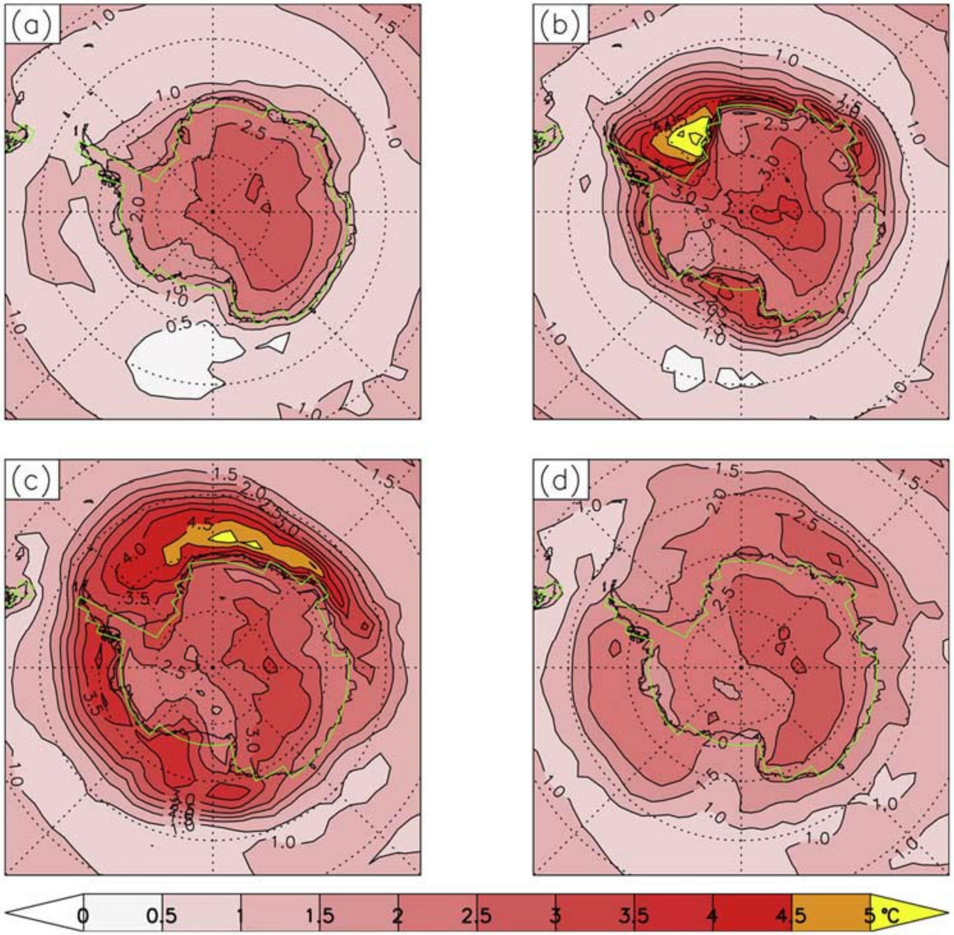
<u>Zooplankton communities:</u>

- Different frontal zones (Hunt and Hosie, 2005; Ward et al., 2012; Tachibana et al., 2017)
- Shifts in the fronts are expected to induce changes in zooplankton distributions (Constable et al., 2014).

For example, a modelled 1 ºC temperature rise produced a pole-ward shift for all zooplankton taxa when based on abundance (Atkinson et al., 2012).

Introduction: Environmental changes

Comparison of surface temperature between 2004-2023
and 2080-2099 predicted by four models



Bracegirdle et al., 2008

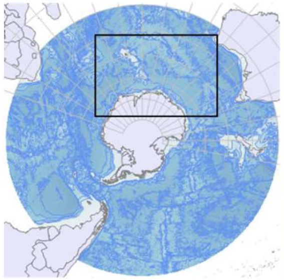
<u>Environmental changes:</u>

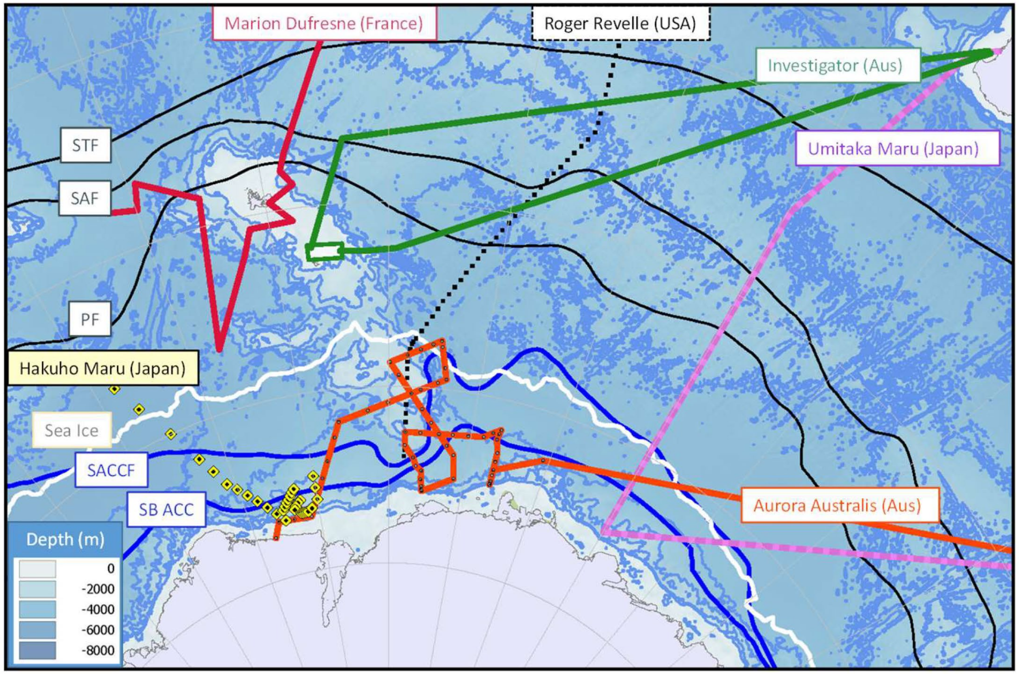
In the Southern Ocean, seawater temperature and variability in sea-ice extent have been observed to be increasing

(Bracegirdle et al., 2008; Turner et al., 2014)

Changing environmental conditions induce changes to marine ecosystems in the Southern Ocean
Zooplankton are one important group that will be affected by these changes.

Introduction: K-Axis project

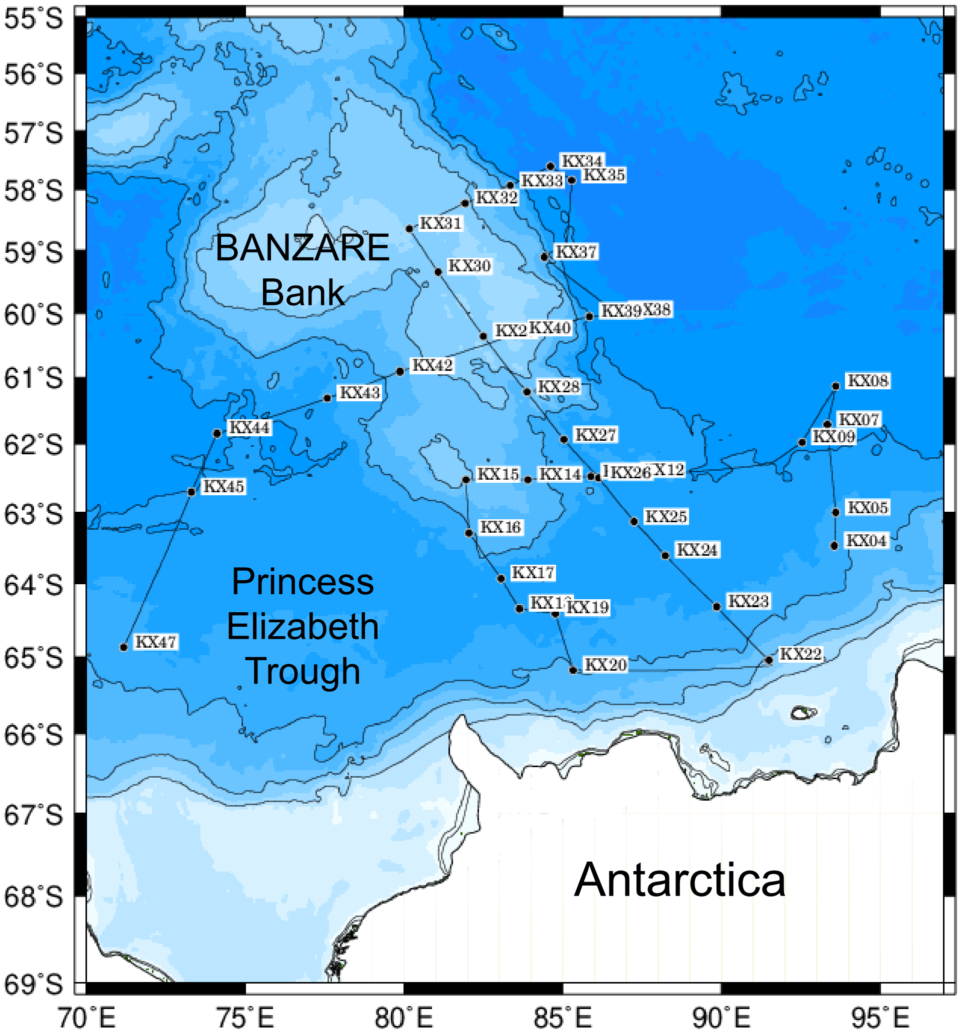




K-Axis was designed to examine details of the marine foodweb from bacteria to mid-trophic levels (fish and squid). This study was conducted under the K-Axis project.

We focusses on the horizontal distribution of zooplankton over the top 200 m, as collected by an RMT1 net.
Population structure of dominant copepods is also presented.
To evaluate the effects of environmental factors on zooplankton distribution, we applied general linear modelling (GLMs).

Materials and Methods: Field observation



Period: 1/23 - 2/26 2016
Ship: *RSV Aurora Australis*
Net: RMT1, mouth area: 1 m^2,
mesh size 0.315 mm
Towing: Oblique from 200 m to surface
Preserve: 4% buffered formaldehyde

Water volume: A water volume on RMT8 calculated with flow meter / 9.42

Hydrography: CTD casts were conducted

Materials and Methods: Sorting

Whole sample

↓

Split with Motoda-splitter
(550-2783 ind. per sample)

↓

Identification as possible as species level

↓

Large copepods were identified to stage

Identification references:
Razouls (1994) for copepods,
Kirkwood (1982) for euphausiids
Boltovskoy (1999) for other species

Species diversity (H')

$$H' = -\sum n/Ni \times \ln n/Ni$$

n: abundance of a species in the i region
Ni: abundance of total zooplankton in the i region

$$\text{Mean copepodid stage} = \frac{\sum_{i=1}^{6} i \times Ai}{\sum_{i=1}^{6} Ai}$$

i: copepodid stage
Ai: abundance of a copepodid stage

Dominant large copepods

Calanus simillimus

Rhincalanus gigas

Calanoides acutus

Calanus propinquus

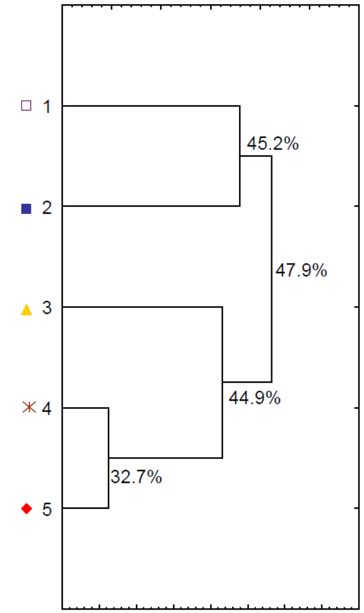
Metridia gerlachei

Metridia lucens

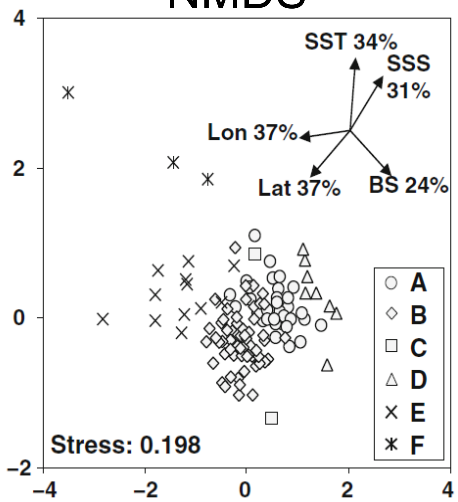
Materials and Methods: Statistical analysis

Examples of analysis

Cluster analysis



NMDS



<u>Data analysis</u>

•Cluster analysis was made on normalized abundance (fourth-root) (Quinn and Keough, 2002)
Bray-Curtis similarity connected by UPGMA with ANOSIM

•Accompanying this analysis, similarity profile analysis (SIMPROF) was added to determine if groupings of the stations were statistically significant.

•Similarity percentages (SIMPER) analysis was applied to determine which species contributed to the top 50% of total abundance for each group.

•Non-metric multi-dimensional scaling (NMDS) with multiple regression analysis was undertaken to explore relationships between the sampling sites and environmental data.

Materials and Methods: GLMs

Variable	Explanation and source
Depth	Bathymetric depth (m) at sampling stations (Weatherall et al., 2015). Values are log10 transformed.
Chl. *a*	Integrated estimate of water column chlorophyll-a (mg m^{-2}; Westwood and Pearce, 2018) obtained using High Performance Liquid Chromatography following Wright et al. (2010), based on six CTD sampling depths within the upper 150 dbar.
Density	Mean potential density (kg m^{-3}) calculated relative to the surface (averaged over the upper 10 dbar). Low values (e.g. <26.8 kg m^{-3}) are indicative of recent ice influence/melt.
$Salinity_{200}$	Mean salinity over the depth between the surface and 200 m (the net sampling depth).
MLD	Mixed layer depth (m) estimates based on a change in density criterion of $\Delta\sigma\theta$= 0.05 kg m^{-3} relative to 10 dbar, following de Boyer Montégut et al. (2004).
$Temp_{200}$	Mean temperature over the depth between the surface and 200 m (the net sampling depth).
Time since melt	The time since ice melted (days) calculated from daily passive microwave estimates of sea ice concentration (%) obtained from the National Snow and Ice Data Center SMMR-SSM/I polar product available for the Southern Hemisphere gridded at 25 km resolution (Cavalieri et al., 1996, updated yearly; Maslanik and Stroeve, 1999, updated daily).
SST	Mean near-surface water temperature (° C, averaged over the upper 20 dbar).
PAR	Ship-based measurement of PAR (photosynthetically active radiation, Watts m^{-2}) averaged from the port and starboard underway data during the RMT sampling periods.

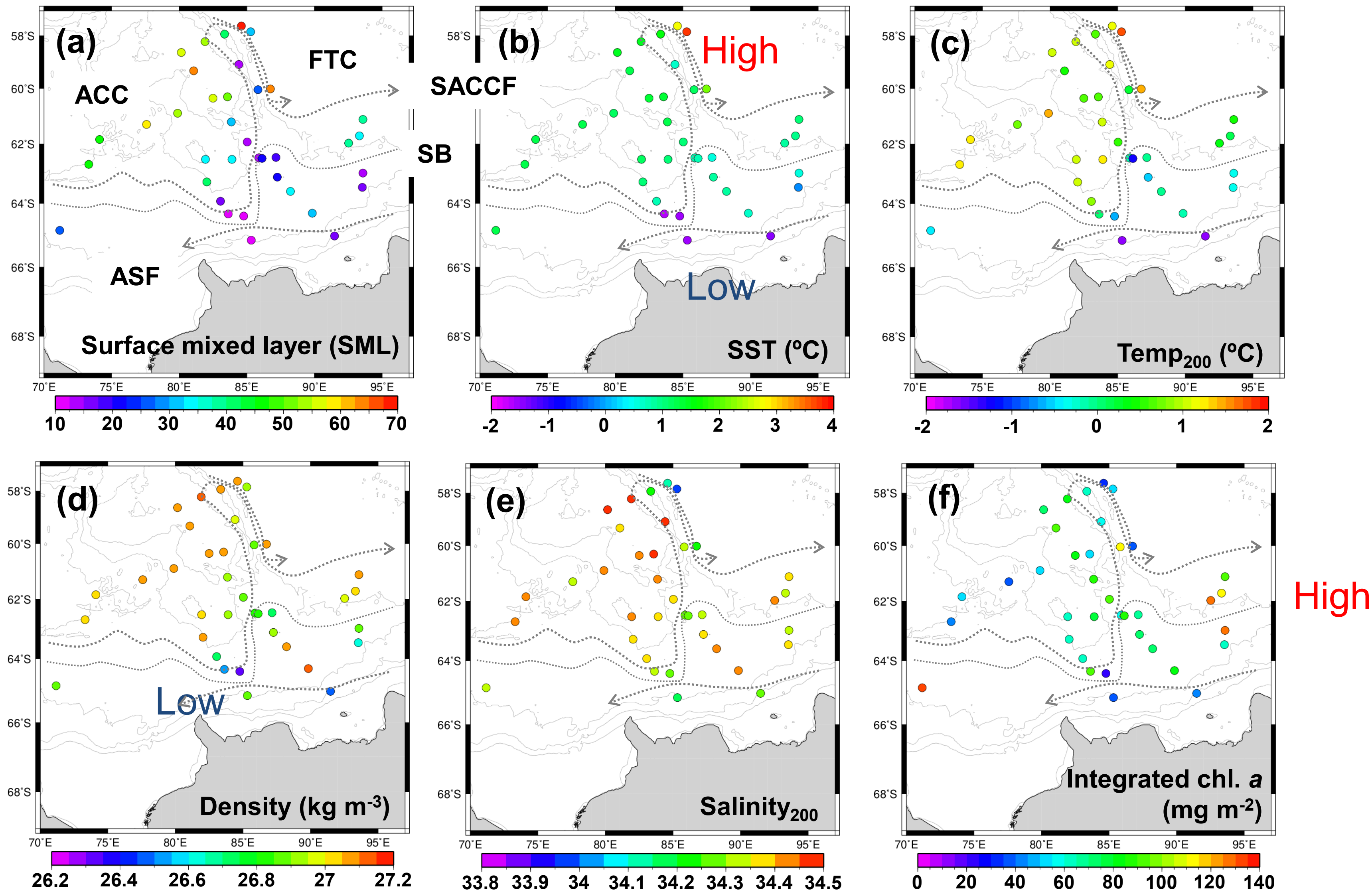
GLMs

To evaluate the effects of environmental drivers on zooplankton abundance,
we applied GLMs with nine parameters.

- To remove multicollinearity among the environmental parameters, we calculated variance inflation factors (VIF) for all the parameters.
- If the VIF was higher than 3, it was removed from the explanatory parameters (O'Brien, 2007).

- To derive the final model, full models with all environmental variables were first constructed.
- Then, model selection was applied by "stepAIC" in the "MASS" package in R to choose the final models.

Results and Discussion: Hydrography



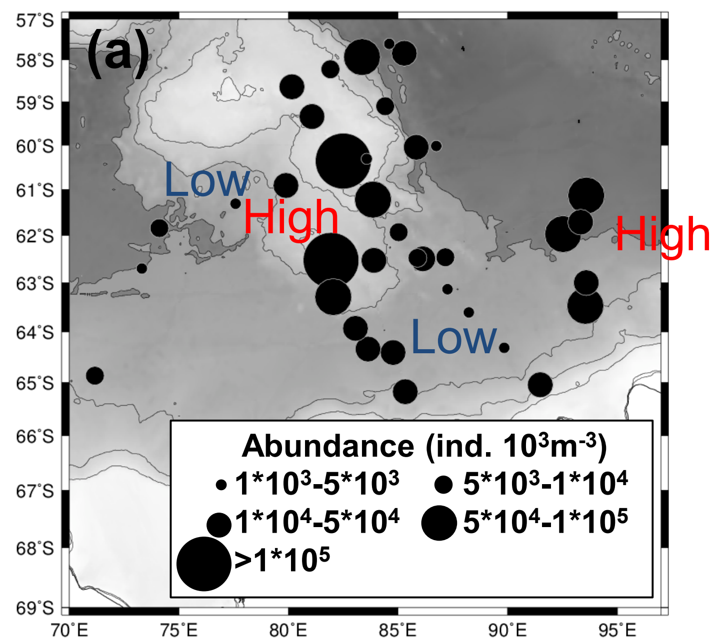
ACC: Antarctic Circumpolar Current; ASF: Antarctic Slope Front;
FTC: Fawn Trough Current; SB: Southern Boundary;
SACCF: Southern Antarctic Circumpolar Current Front.

Bestley et al. 2018

Results and Discussion: Abundance and diversity

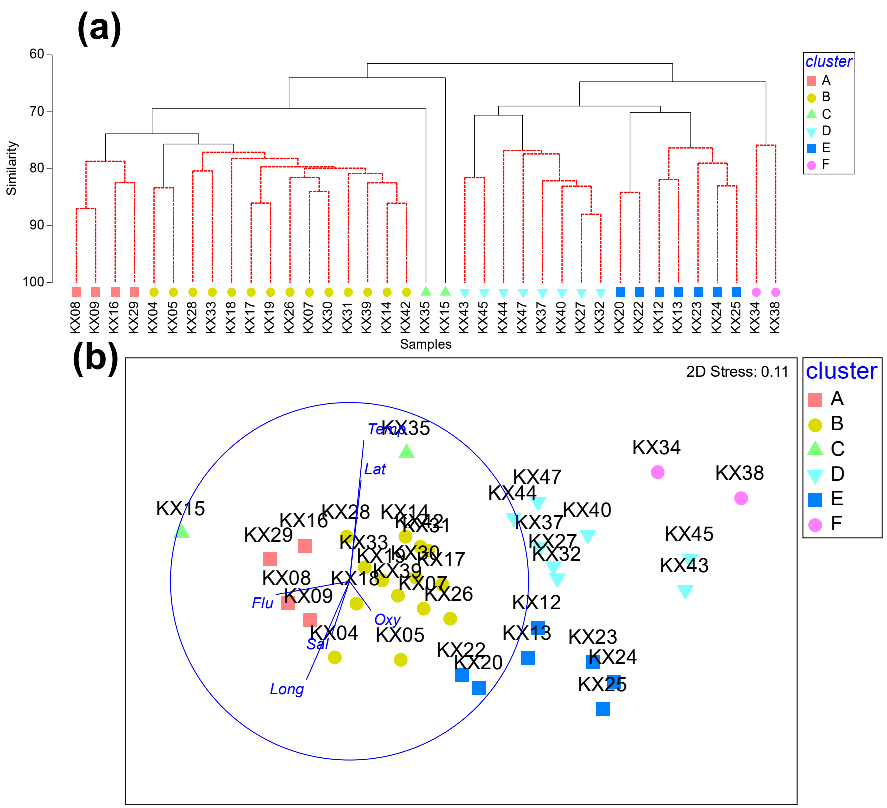
Species list

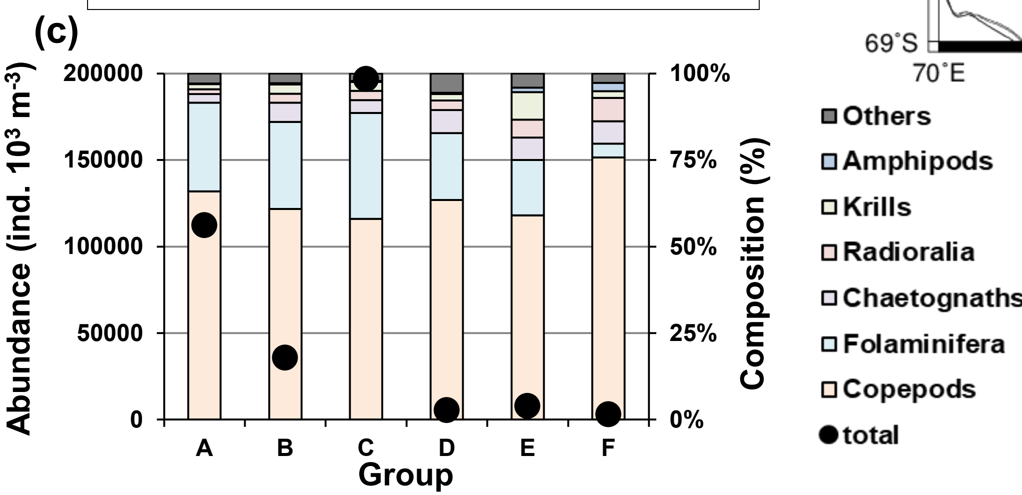
Copepods	**Amphipods**	**Others**
Aetideopsis antarctica	*Cyllopus magellanicus*	Appendicularia
Aetideopsis australia	*Hyperiella macronyx*	*Clione limacina*
Calanoides acutus	*Hyperiella* sp.1(larva)	(Fish)
Calanus nauplii	*Primno macropa*	Folaminifera
Calanus propinquus	*Scina borealis*	Isopoda
Calanus simillimus	*Themist gaudichaudi*	Medusa
Calanoid copepods spp. C1	*Vibilia antarctica*	Ostracoda
Candacia sp.	*Vibilia armata*	Polychaeta
Clausocalanus brevipes		Radioralia
Clausocalanus laticeps	**Chaetognatha**	Salpa
Ctenocalanus spp.	*Eukrohnia bathypelagica*	Urtin larva
Euchirella rostromagna	*Eukrohnia hamata*	
Gaedius tenuispinus	*Sagita gazellae*	
Haloptilus longicirrus	*Sagita marri*	
Heterorhabdus austrinus	*Sagita maxima*	
Metridia gerlachei		
Metridia lucens		
Microcalanus pygmaeus	**Euphausiids**	
Oitona spp.	*Euphausia superba*	
Oncaea spp.	*Euphausia triacantha*	
Paraeuchaeta antarctica	*Thysanoessa macrura*	
Paraeuchaeta barbata		
Pleuromamma robusta	**Pterapods**	
Pseudochirella mawsoni	*Clio pyramidata forma sulcata*	
Racovitzanus antarcticus	*Limacina helicina*	
Rhincalanus gigas	*Limacina retroversa australis*	
Rhincalanus gigas nauplii		
Scaphocalanus farrani		
Scaphocalanus vervoorti		
Scolecithricella minor		
Scolecithricella ovata		
Stephos longipes		
Undinella brevipes		

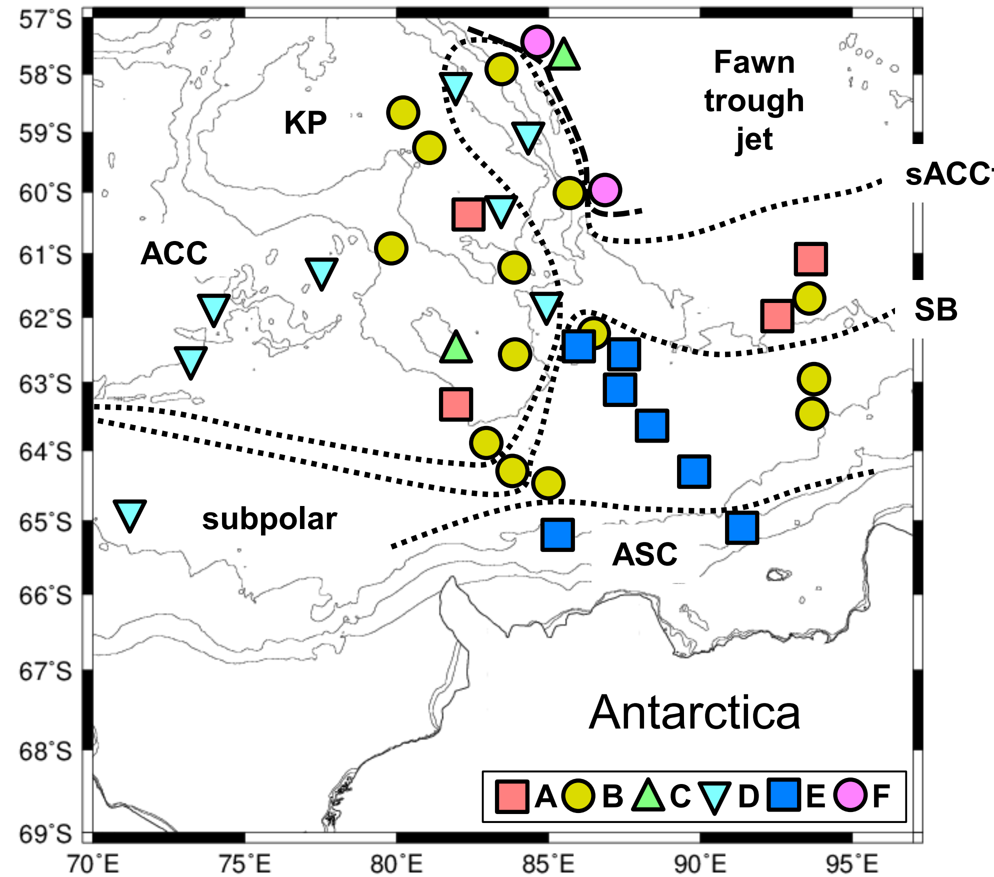


- Total zooplankton abundance ranged from 1490 to 363,484 ind. 1000 m^{-3}, with the lowest abundance at KX43, and the largest at KX15.
- Higher abundances were observed in the eastern and central areas.

Results and Discussion: Cluster analysis

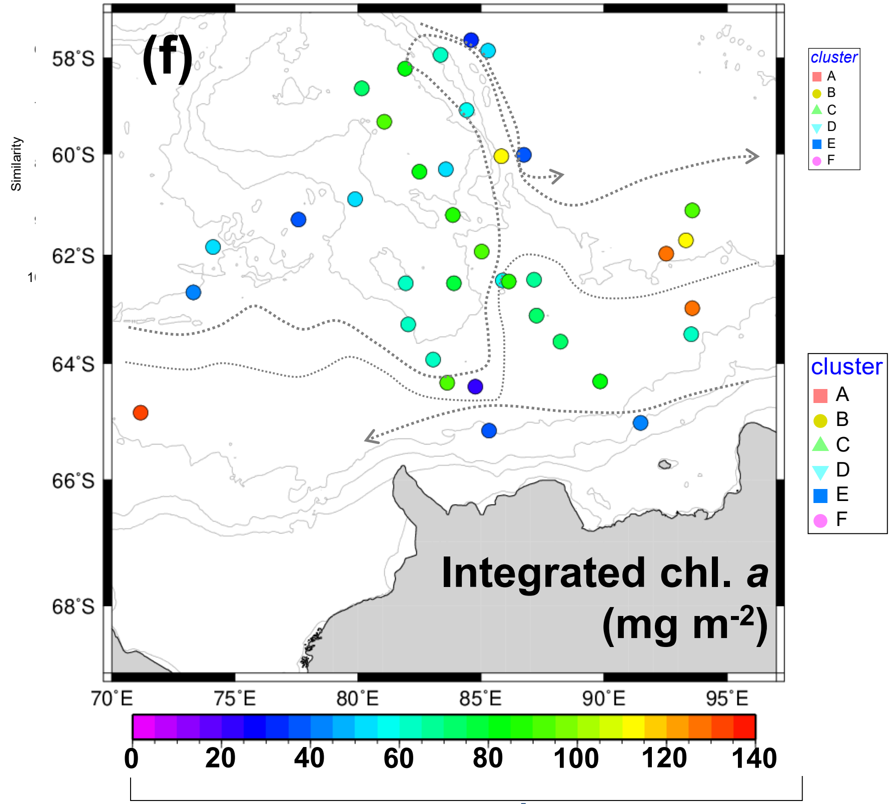


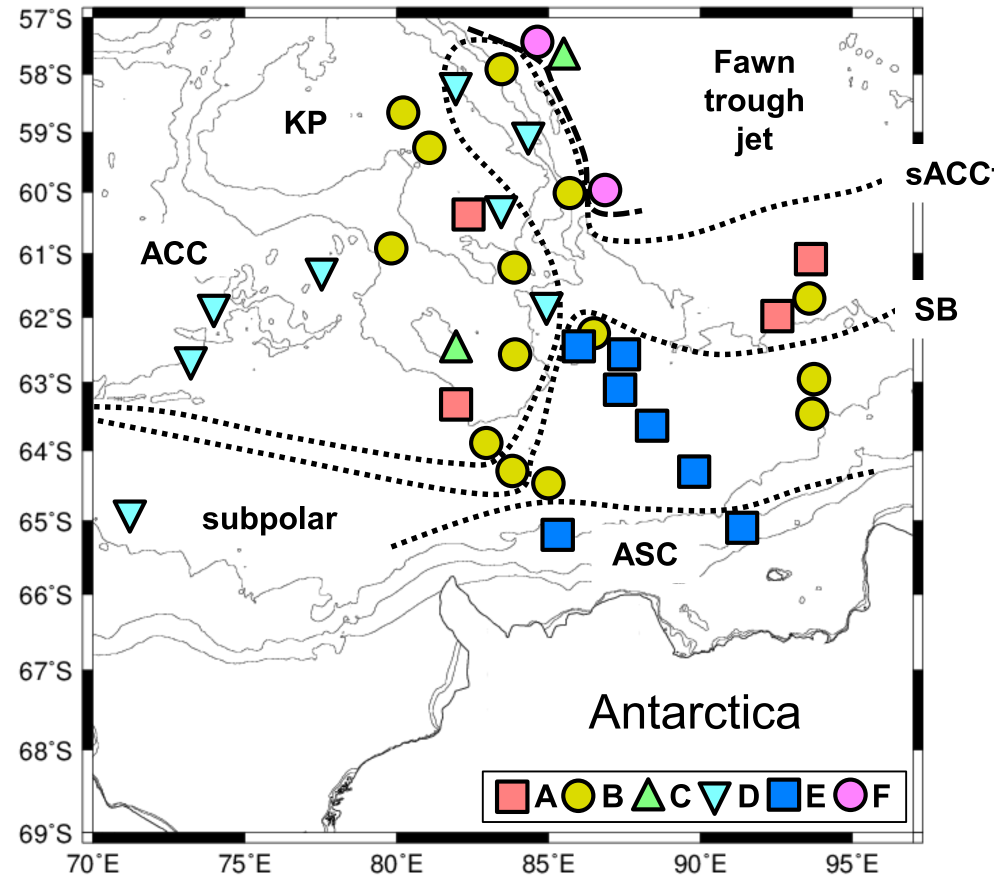


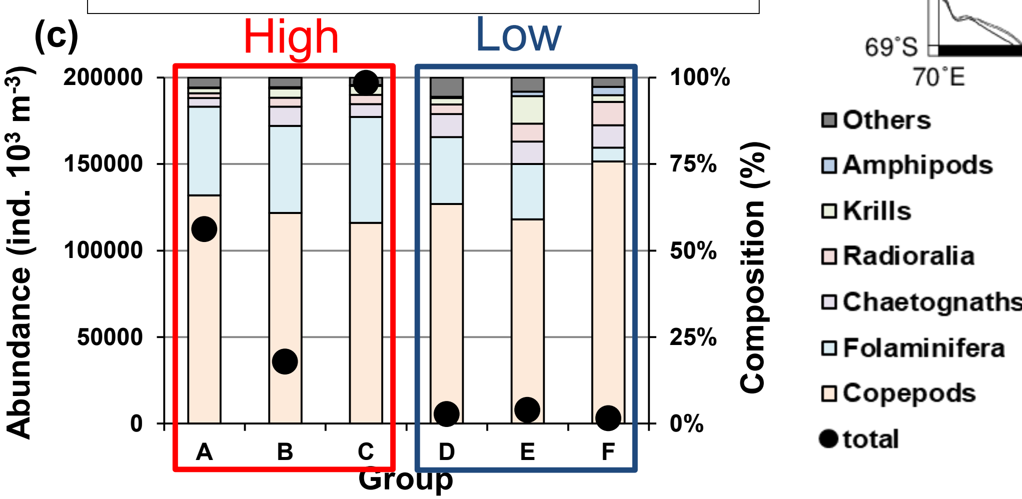


Zooplankton were divided into 6 groups (A−F) that were associated with water masses and frontal systems.

Results and Discussion: Cluster analysis







The zooplankton communities could be split into two groups (groups A−C vs group D−F) based on abundance associated with Chl. *a*.

Results and Discussion: GLMs

	Intercept	Density	Salinity$_{200}$	SST	Temp$_{200}$	MLD	Depth	Chl.a	PAR	Time since melt	p value (ANOVA, null vs final)
Total zooplankton	***↑		***↓	***↓	***↑		***↓	***↑	**↓		***
Amphipoda								*↑			0.0605
Chaetognatha	***↑	***↓			**↑		**↓	***↑	**↓		**
Copepoda	***↑		***↓	***↓	***↑		**↓	***↑	**↓		***
Euphausiacea	*↑					*↓	*↓		-↓		*
Foraminifera	***↑		***↓	***↓	***↑		***↓	***↑	**↓		***
Copepods											
C. acutus	***↑	*↓	**↓		***↑		***↓	***↑	***↓	*↓	***
C. propinquus	***↑		***↓	**↓	***↑		***↓	***↑	***↓		***
M. gerlachei	**↑		**↓		***↓		-↓	***↑	*↓		***
M. lucens	**↑		**↓		***↑		**↓	**↑		*↓	***
R. gigas	**↑	*↓			-↑		*↓	*↑	**↓		*
Mean copepodite stage											
MCS_*C. acutus*	**↓	***↑			**↓	**↓		***↓		*↑	***
MCS_*C. propinquus*	*↑	***↑	***↓	***↓		-↓	-↓				***
MCS_*M. gerlachei*					-↑						0.3302
MCS_*M. lucens*	***↑			**↑			**↓				***
MCS_*R. gigas*	**↑					**↓	-↓		-↑		**

Summary of this results is on next slide.

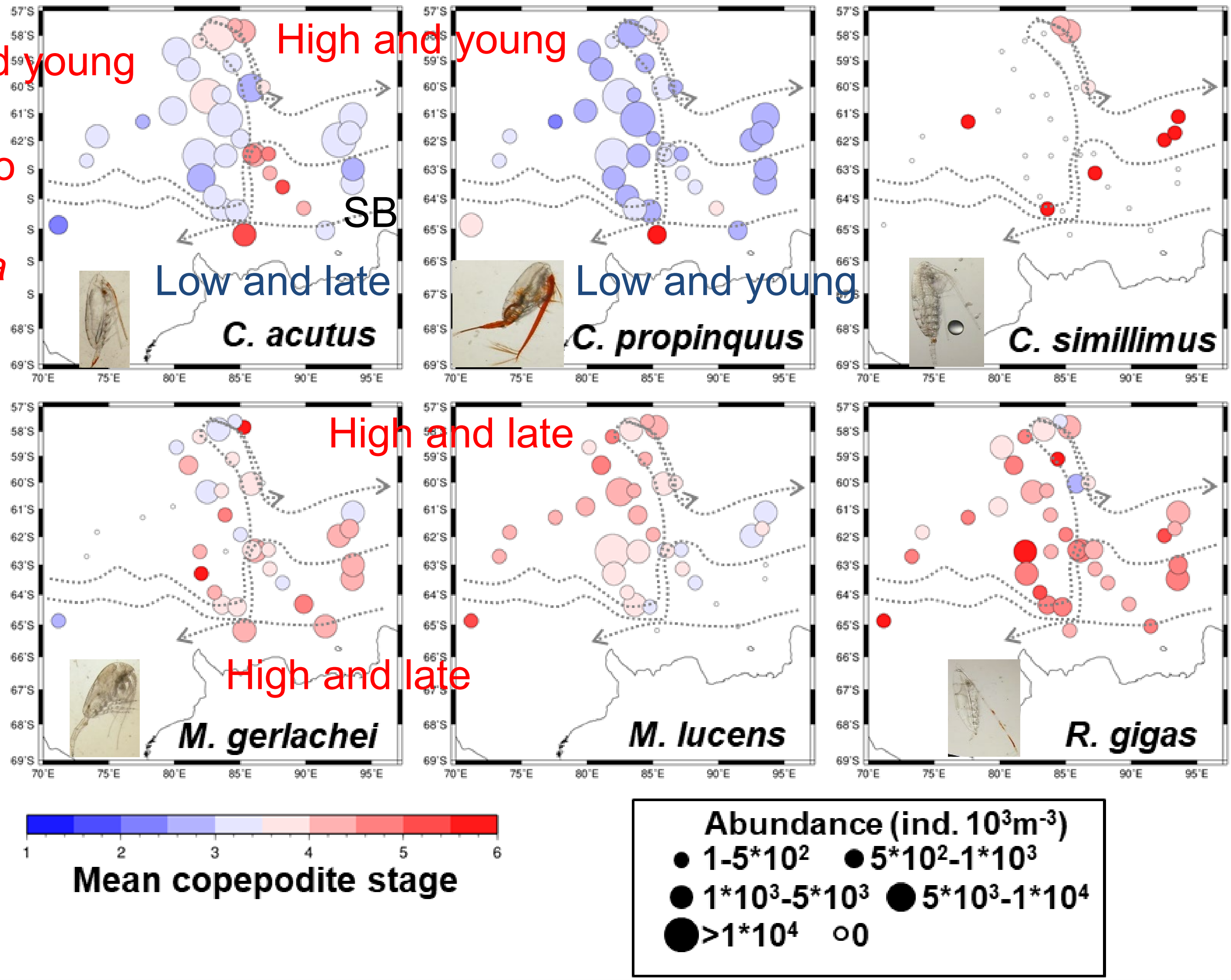
Results and Discussion: Summary of GLMs

Model	Features
Total zooplankton abundance	Generally, higher abundances were associated with warmer temperatures, higher chlorophyll-*a* concentration and shallower depth, which was consistent with high abundances observed over the southern Kerguelen plateau. Lower abundances were associated with increased daylight.
Taxon abundances	Relationships mainly consistent with those reported for total zooplankton abundance. Additionally, chaetognaths were associated with surface low-Density. Higher abundances of euphausiids were associated with shallower mixed layer depths.
Large copepods	Relationships mainly consistent with those reported for total zooplankton abundance. However, M. gerlachei showed an opposite relation with temperature below the MLD. C. acutus and M. lucens were more abundant when there was a shorter time since sea-ice melt.
Copepod stages	The relationships varied with species.

The zooplankton community across the western side of the Indian sector appears to be governed by the interplay of frontal systems, their vertical migration and bottom-up factors affecting productivity around the Kerguelen Plateau during summer.

Results and Discussion: population structures

reproduction using high Chl. *a* before sampling



sub-Antarctic species

lower abundance but older than *C. acutus*

The spatial changes of population structure were different among species. This could be caused by distribution and life cycles of each species.

Summary

<u>Zooplankton community</u>

・Zooplankton were divided into 6 groups were associated with water masses and frontal systems.

・GLMs revealed higher abundances of almost all zooplankton were associated with warmer temperatures, higher chlorophyll-*a* and shallower depth. Also, Lower abundances were associated with increased daylight.

→The zooplankton community was governed by the interplay of frontal systems, their vertical migration and bottom-up factors affecting productivity around the Kerguelen Plateau during summer.

<u>Large-sized copepods</u>

The spatial changes of population structure were different among species.

→This could be caused by distribution and life cycles of each species.

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Thank you for your watching.