

New insights into the Weddell Sea ecosystem applying a network approach

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Abstract. The abstract goes here. It can also be on *multiple lines*.

1 Introduction

Introduction text goes here. You can change the name of the section if necessary using `\introduction[modified heading]`.

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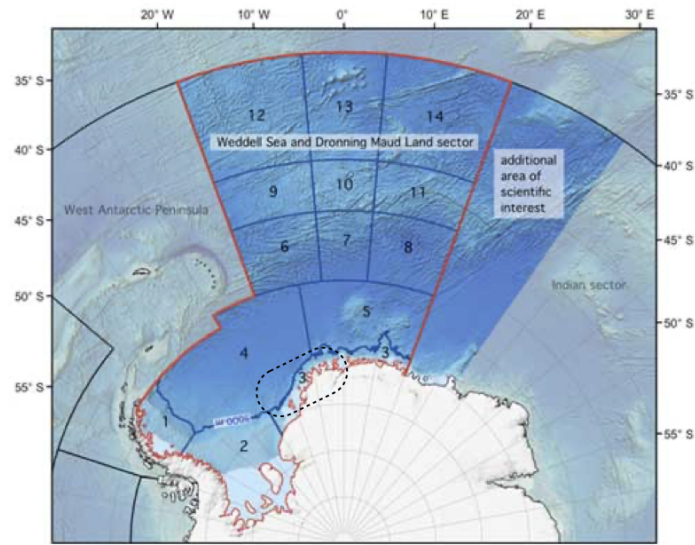


Figure 1. Map of the Weddell Sea and Dronning Maud Land sector highlighting the high Antarctic shelf as a dashed-line contour. Modified from www.soos.aq.

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The objective of this work was twofold: 1) estimate the strength for each interaction in the Weddell Sea food web, and 2) determine key trophic species considering weighted and unweighted properties and the influence on the stability of the network.

2 Methodology

2.1 Study area

The high Antarctic Weddell Sea shelf is situated between 74 and 78°S with a length of approximately 450 km (Figure 1). Water depth varies from 200 to 500 m. Shallower areas are covered by continental ice, which forms the coastline along the eastern and southern part of the Weddell Sea. The shelf area contains a complex three-dimensional habitat with large biomass, intermediate to high diversity in comparison to benthic boreal communities and a spatially patchy distribution of organisms (Dayton, 1990; Teixidó et al., 2002).

2.2 Weddell Sea food web dataset

We obtained the dataset of the Weddell Sea food web from the GlobAL daTabasE of traits and food Web Architecture (GATEWAY, version 1.0) of the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig (Brose, 2018). This open access database is a list of predator-prey interactions that contains several highly-resolved food webs, including biological data about the consumer and resource species involved in each trophic interaction (i.e. mean mass). Furthermore, it incorporates information on the interaction itself, such as the dimensionality.

This marine food web compiles all the food web data available for the high Antarctic Weddell Sea collected since 1983, and is one of the most highly-resolved marine food webs documented to date. It's noteworthy that it is a summary network that ignores seasonal changes (Jacob et al., 2011).

2.3 Dataset analyses

We analysed the food web of the Weddell Sea by: a) estimating the strength of each interaction; b) studying the properties of the species in a network approach; and c) comparing the stability of the food web after performing extinction simulations.

2.3.1 Interaction strength estimation

To estimate the strength of each interaction in the food web, we followed the methodology proposed by Pawar et al. (2012). The minimum data requirements are: body mass of the consumer (predator) and resource (prey), and the interaction dimensionality classified as 2 or 3 dimensions. GATEWAY v.1.0 does provide information on the mean mass for consumers and resources (except for 'detritus' and 'sediment') for every interaction, but lacks the dimensionality for 924 interactions. To solve this issue, we used the information about movement type for consumer and resource. Then, we classified the interaction as 2D when both consumer and resource move in 2D (e.g., both are sessile or walking) or if a consumer moves in 3D and a resource in 2D (e.g., swimming consumer and sessile/walking resource). The interaction was classified as 3D when both consumer and resource move in 3D (e.g., both swimming) or if the consumer moves in 2D and resource in 3D (e.g., sessile/walking consumer, swimming resource) (Pawar et al., 2012).

The main equation we used for estimating the interaction strength IS is:

$$IS = \alpha x_R \frac{m_R}{m_C} \quad (1)$$

where α is the search rate, x_R is the density of the resource, and m_R and m_C are the body mass of the resource and the consumer, respectively (Pawar et al., 2012).

We obtained estimations for the resource density and the search rate from the scaling relationships with the resource and the consumer mass, respectively (Pawar et al. (2012)). The coefficients of such relationships, determined by ordinary least squares regression, vary with the interaction dimensionality. On one hand, resource density scales with resource mass as a power-law with exponents $p = -0.79 \pm 0.09$ in 2D and $p = -0.86 \pm 0.06$ in 3D. Since mean mass for resources 'detritus'

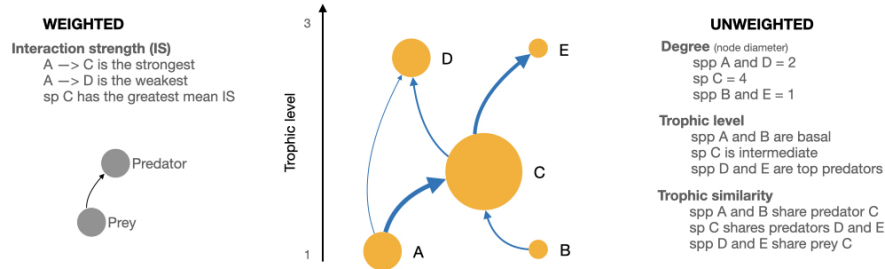


Figure 2. Scheme of a network showing the weighted and unweighted properties we used to characterize the species of the Weddell Sea food web.

and ‘sediment’ were not available in GATEWAY v.1.0, we calculated it considering the scaling relationship with consumer mass, also different in 2D and 3D (for details see equation S9 and figures 2c-d of Supplementary Information in Pawar et al. (2012)). On the other hand, search rate scales with consumer mass as a power-law with exponents $p = 0.68 \pm 0.12$ in 2D and $p = 1.05 \pm 0.08$ in 3D.

2.3.2 Species properties

In order to individually characterize the species of the food web, we considered weighted and unweighted properties (Figure 2). The former is based on the estimation of the interaction strength described in the previous section. The latter is related to properties commonly used in qualitative (presence/absence of interaction) food web studies (Martinez, 1991; Dunne et al., 2002; Borrelli and Ginzburg, 2014). As weighted property we took into account the mean interaction strength, meaning the average strength of all interactions. As unweighted properties we used: a) degree or the total number of trophic interactions, taking into account in- and out-interactions (role as predator and prey, respectively); b) trophic level or the position in the food web relative to primary producers/detritus; and c) trophic similarity or the trophic overlap between species based on shared and unique resources and consumers.

Formulas used to obtain the mentioned species properties are described in Appendix A1.

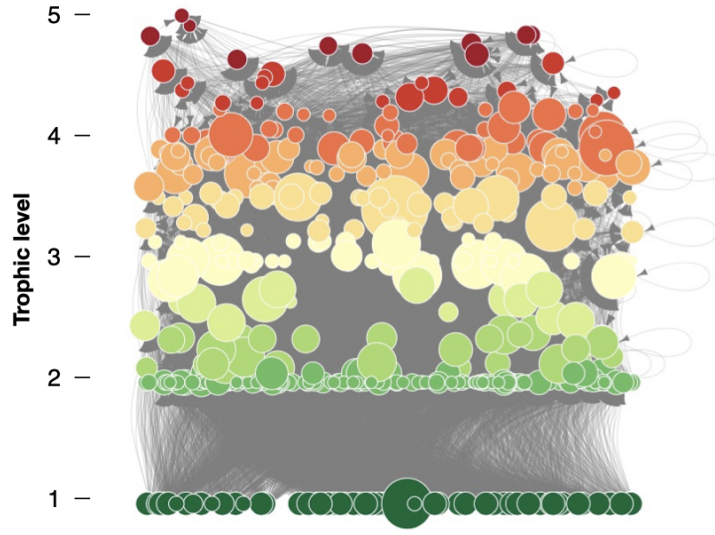


Figure 3. Graphic representation of the Weddell Sea food web. Species (nodes) are arranged vertically and colored by trophic level. The diameter of the node indicates the total number of interactions. Predator-prey interactions are represented by the arrows, from the prey to the predator.

2.3.3 Stability and extinction simulations

Finally, we run extinction simulations and estimated its impact on the stability of the network. For this, we calculated a stability index called Quasi-Sign Stability (QSS), which is the proportion of stable networks using randomized Jacobians and keeping the predator-prey sign structure fixed (Allesina and Pascual, 2008). With the aim of analysing the effect of each species on the food web's stability, we deleted one species at a time, so the network size was reduced by one. After each species extinction, we calculated the QSS for the food web minus one species (size = 489) and compared it with the QSS for the whole network (size = 490); we performed 1000 simulations for each species. Then we statistically analysed such difference with an Anderson-Darling test (Scholz and Stephens, 1987). The formula for the QSS is described in Appendix A2.

All analyses were performed in R software, using packages *igraph* (?), *cheddar* (?), and *multiweb* (?). The source code and data are available at <https://github.com/EcoComplex/WeddellSea>.

3 Results

The Weddell Sea food web comprises 490 species and 16041 predator-prey interactions (Figure 3).

3.1 Interaction strength

Figure of distribution IS Model fit

3.2 Species properties and stability

Clustering in 2 groups: high and low IS Linear regressions btw IS (weighted) and unweighted prop. Biplots btw QSS difference and weighted and unweighted prop.

4 Discussion

5 Examples from the official template

5.1 FIGURES

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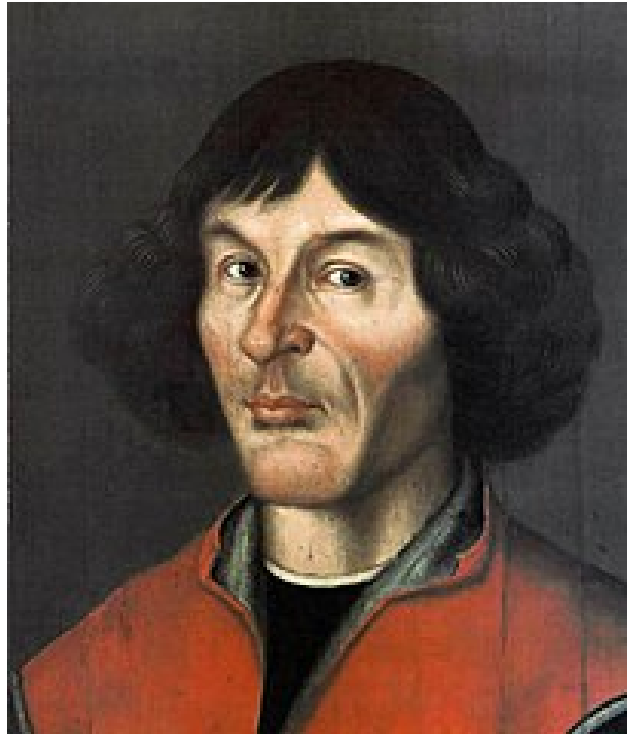


Figure 4. one column figure

Table 1. TEXT

a	b	c
1	2	3

Table Footnotes

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5.1.1 ONE-COLUMN FIGURES

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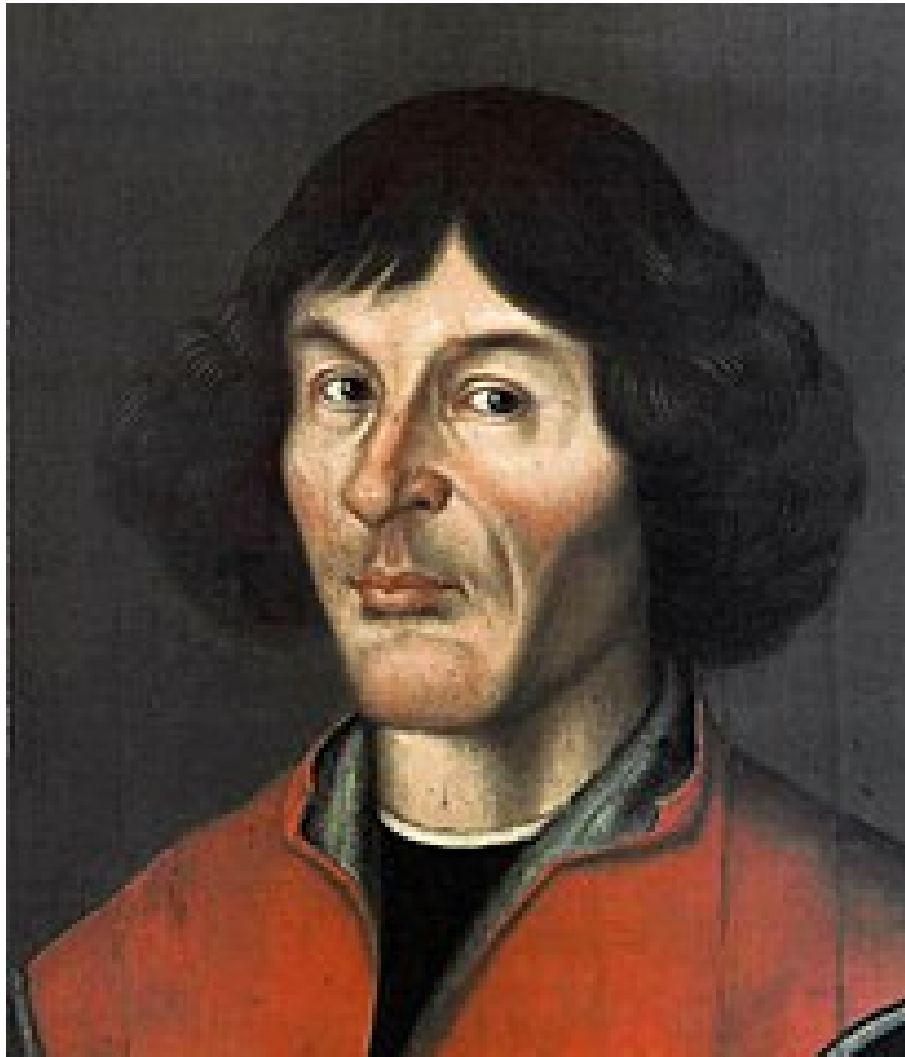


Figure 5. two column figure

Table 2. TEXT

a	b	c
1	2	3

Table footnotes

5.2.1 ONE-COLUMN TABLE

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5.3 MATHEMATICAL EXPRESSIONS

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Physical quantities/variables are typeset in italic font (t for time, T for Temperature)

Indices which are not defined are typeset in italic font (x, y, z, a, b, c)

Items/objects which are defined are typeset in roman font (Car A, Car B)

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5.4 EQUATIONS

5.4.1 Single-row equation

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$1 \times 1 \cdot 1 = 42$

(2)

$A = \pi r^2$

(3)

$$x = \frac{2b \pm \sqrt{b^2 - 4ac}}{2c}. \quad (4)$$

5.4.2 Multiline equation

$$3 + 5 = 8 \quad (5)$$

$$3 + 5 = 8 \quad (6)$$

$$3 + 5 = 8 \quad (7)$$

5.5 MATRICES

x y z

x y z

x y z

5.6 ALGORITHM/PROGRAMMING CODE

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```
## tlmgr update --all --self
```

```
## tlmgr install algorithms algorithmicx
```

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Algorithm 1 Algorithm Caption

$i \leftarrow 10$

if $i \geq 5$ **then**

$i \leftarrow i - 1$

else

if $i \leq 3$ **then**

$i \leftarrow i + 2$

end if

end if

5.7 CHEMICAL FORMULAS AND REACTIONS

For formulas embedded in the text, please use `\chem{ }`, e.g. $A \rightarrow B$.

The reaction environment creates labels including the letter R, i.e. (R1), (R2), etc.

- `\rightarrow` should be used for normal (one-way) chemical reactions
- `\rightleftharpoons` should be used for equilibria
- `\leftrightharpoons` should be used for resonance structures



5.8 PHYSICAL UNITS

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6 Conclusions

The conclusion goes here.

Appendix A: Figures and tables in appendices

A1 Option 1

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A2 Option 2

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. TIM and LAS: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Methodology (lead); Coding (lead); Writing – original draft (lead); Writing – review and editing (lead). SK: Conceptualization (lead); Formal analysis (supporting); Methodology (supporting); Coding (supporting); Writing – original draft (supporting); Writing – review and editing (supporting).

. The authors declare no competing interests.

. Thanks to the rticles contributors!

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