**Review from Anonymous Referee #1**

In this paper, the authors apply a method for estimating interaction strength to a large dataset of the Weddell Sea food web structure. They then conduct network analysis to explore the sensitivity of the Weddell Sea food web stability to loss of species. Within the food web, they identify 13 species whose presence is destabilising and 2 species whose loss would be destabilising. They characterise the species with significant influence on stability according to their average interaction strengths, trophic level, trophic similarity, degree, and habitat association. They have discussed how their findings relate to other theoretical food web analyses to advance understanding of food web stability more generally.

The extreme environments of the Antarctic present major challenges to collecting sufficient data for constructing quantitative trophic networks, and consequently few (if any) studies have assessed stability of Antarctic ecosystems. I was therefore very pleased to read this paper which is an important first step in advancing understanding of ecological networks and stability in this environment. I found the paper interesting and generally well written. The authors have done well to identify methods that cater to the limitations of Antarctic data, although I found it needed additional methodological detail and discussion. Overall, once the minor corrections described below and in the attached document are addressed, I think this will be a valuable contribution to the journal, special issue and literature.

MAIN COMMENTS

My main comment is that the paper is lacking necessary detail about the dataset and methods. As someone familiar with the topic area, but not these precise methods or data, I found myself having to refer the referenced papers for details that should be included here. The choice of methods, and the nature of the dataset, impose a number of assumptions about the underlying food web, and caveats on the findings. This is understandable given the challenges of collecting data in Antarctic ecosystems (the dataset is an impressive one), but readers need these additional details in order to put the findings into context. Here I've documented some questions I had while reading the paper, which should help clarify what additional details are needed and possible implications of these for the conclusions drawn. Addressing these main comments mostly involves adding details to the methods, and extending the discussion to help the reader interpret the findings in the context of the data, methods and realities of the ecosystem in question. Some questions I posed below may not need to be explicitly answered – as long as enough detail is provided, readers would be able to answer some questions for themselves. To support these amendments, I've also included some specific suggestions in the attached document, in addition to some other specific comments.

1. The method for estimating interaction strength does not factor in temporal variability, yet the Weddell Sea is highly seasonal and stochastic, and the topology of

the food web is also variable, depending on the scales and temporal resolution considered. For example, is *Arctocephalus gazella* present in the food web in winter? What are the consequences of assuming that all species are present all year round? E.g. is it valid for the mean IS of a temporary resident be weighted in the same way as year-round resident? What impact would weighting IS according to residence time have on your findings (i.e. what is the sensitivity of your results to the assumption that the food web is constant – would stability still be sensitive to *A. gazella*)? Other studies (e.g. Ushio et al., 2018) have shown that stability varies temporally, and while that can't be assessed with this dataset, it could theoretically be possible to consider e.g. winter and summer versions of the food web separately, or to weight year-round residents interactions differently from migrants within the same network. The authors need to be explicit that the method and data are not temporally resolved, and that the conclusions may be different if the temporally variable nature of the system is taken into account.

**Reply to reviewer:** We agree with the reviewer's comment. In this sense we have added the following in the "Weddell Sea food web dataset" subsection of Methodology (L. 100-103):

*"As the data used to construct the Weddell Sea food web is sampled during the summer season due to the inaccessibility of ecological field sampling in Antarctica during the winter, the Weddell Sea food web is representative of the summer season."*

And L. 105-109:

*"Due to the static nature of the Weddell Sea food web and its low temporal resolution, it is not possible to assess phenological mismatches nor species temporal turnover. Because of these methodological limitations, the nature of the Weddell Sea food web data may likely lead to overestimations of some trophic interactions and network properties (connectance), compared to realised networks at any given point in time and space."*

Also we add the following regarding the structural uncertainty of the network given the seasonality of the Weddell Sea (L. 276-281):

*"One of the primary uncertainties in our analysis stems from structural variability due to, for instance, temporal changes. The Weddell Sea food web, like many high-latitude marine ecosystems, exhibits significant seasonal changes (McMeans et al. 2015, Rossi et al. 2019, Kortsch et al. 2021, Pecuchet et al. 2022). Our study primarily focuses on data from late spring to late summer, potentially overlooking the intricacies of the winter season. Seasonal shifts can lead to variations in species interactions, trophic levels, and overall network structure. Novotny et al. 2023 recently highlighted the importance of considering seasonal variability in food web analyses by showing distinct differences in species diet over seasons."*

2. More detailed description of the dataset is required. For example, what is the temporal resolution and extent of the data? From the cited reference Jacob et al (2011), it looks like all trophic data collected since 1982 is amalgamated (i.e. the food web is assumed to be static) – if so, that should be stated. If there is evidence that the Weddell Sea food web has exhibited trends over that time (ie. is non-stationary), then that discrepancy should be indicated and results should be discussed in that context.

What are the trophic data? According to Jacob et al (2011), it looks like it is mostly stomach content analysis for larger animals, and stable isotope for lower trophic levels – this should be stated because different methods impose different limitations for identifying trophic interactions, which affects the topology of the resultant trophic network.

**Reply to reviewer:** The reviewer made a good point of the temporal nature of our data, and we have now made it explicit in the text which time period and which season the Weddell Sea food web is representative for. We have also added more details about the diet information. The new text in L. 94-100 reads:

*"Complex empirical food webs are compilations of species and their potential feeding interactions within a given area and time period. The species occurrence data to construct the Weddell Sea food web (Antarctica) was sampled between 1983 and 2005, and hence the Weddell Sea food web is representative for this time period. The diet composition for each species was observed between 2001 and 2004 through a combination of field observations and stomach content analyses (further details can be found in Jacob 2005). Some species, such as benthic grazers and suspension feeders had poor taxonomic resolution of their prey, therefore laboratory information about their size, behavior, and stable isotope signatures was used to infer their feeding habits (Jacob et al. 2011)."*

What spatial extent does it represent? (refer to and amend Figure 1 and its legend).

**Reply to reviewer:** We have added the following to clarify the spatial extent of the Weddell Sea food web (L. 109):

*"The spatial extent of the food web is described in the Study area section (Figure 1)."*

We have also modified the legend in Figure 1:

*"Figure 1. Map of the Weddell Sea and Dronning Maud Land sector highlighting with a dashed-line contour the high Antarctic shelf that represents the spatial extent of the food web."*

How are species that have ontogenetic shifts in size and diet treated? (referring to Jacob et al 2011, it looks like all species are assumed to be adult – do you adjust body size estimates to be the mean across all lifestages of a species [e.g. averaging across larval, juvenile and adult lifestages] or are they all adult body size estimates [i.e. averaging across body sizes of the adult population]? If your body size estimates are adult sizes, but you include trophic links that only occur in smaller size classes – how does that affect your findings?)

**Reply to reviewer:** The species of the food web are representative for adult life stages which we have now made explicit in the text, L. 102-105:

*"Moreover, the species in the food web are representative of adult specimens, and were not categorized into ontogenetic life stages (i.e., larvae, juveniles, and adults). As a result, ontogenetic diet shifts cannot be addressed with this food web. The average body masses of species were either directly measured (Jacob 2005) or taken from published accounts for marine mammals and seabirds (Brose et al. 2006)."*

What uncertainties may still underly the dataset and therefore the analysis? (e.g. topological uncertainties due to methodological biases such as trophic interactions that can't be detected by stomach content analysis; uncertainties due to assuming stationarity of the food web – e.g. trophic interactions may have changed strength, been lost through phenological mismatches, or new interactions gained over the time period the dataset represents). Sufficient details about the dataset should be given for readers to understand the caveats they impose on the results.

**Reply to reviewer**: We have added details about the limitations of the data in the Methodology of the manuscript. Since the Weddell Sea food web is a compilation of species and their potential feeding interactions within a given area and time period, it does not describe realised interactions for a given point in time. To clarify this, the following text was added, L. 105-109:

*"Due to the static nature of the Weddell Sea food web and its low temporal resolution, it is not possible to assess phenological mismatches nor species temporal turnover. Because of these methodological limitations, the nature of the Weddell Sea food web data may likely lead to overestimations of some trophic interactions and network properties (connectance), compared to realised networks at any given point in time and space."*

3. There are many different types/dimensions of stability (e.g. Kéfi et al., 2019), and species can also be both stabilizing and destabilizing through their relative impacts on the different dimensions of stability (e.g. White et al., 2020). The type of

stability being assessed here should be defined (some readers will not know what an eigenvalue is), and explained in terms of the ecology – e.g. what does it mean if the foodweb is unstable – what will happen? What is it unstable to? (e.g. press, pulse perturbations?) Then for the discussion – what do the stability results (taking the type of stability and the data and methodological caveats into account) mean for the real Weddell Sea ecosystem and how it will change or be vulnerable into the future?

**Reply to reviewer:** Indeed stability is a multifaceted concept and many definitions of stability exist, and depending on the chosen measure of stability a species may be stabilizing and destabilizing. Due to the high resolution of our data (490 trophic species and 16041 interactions), we decided to apply a stability index that requires less species-level information, for example on species biomass, yet allows evaluating the species' impact on food web stability. The mentioned index is called 'Quasi-Sign Stability' and considers the eigenvalues of the Jacobian matrix to infer the stability of the network. In order to explain this index in ecological terms we added the following in Methodology (L. 177-186):

*"To estimate stability, we utilized the mean of the real part of the maximum eigenvalue of the Jacobian (or community) matrix, employing random values for the elements of the Jacobian while preserving the predator-prey sign structure (Saravia et al. 2022, Allesina 2008,  Pawar 2009). The Jacobian matrix, denoted as $C$, is fundamental to understanding the population dynamics and inter-species interactions within an ecological network. Each element* $c_{ij}$ *of C represents the effect of a change in the* $j^{th}$ *species' density on the* $i^{th}$ *species, at equilibrium. When i equals j,* $c_{ij}$ *reflects the dependence of the* $i^{th}$ *species on its own density, offering insights into intra-species interactions and self-regulation. The maximum eigenvalue describes the rate at which a small disturbance decays or amplifies over time in the vicinity of an equilibrium. Precisely, the real parts of the eigenvalues indicate the rate of exponential growth (if positive) or decay (if negative) of perturbations. Thus, a more negative index is indicative of a more stable food web with reduced probability of perturbation amplification; in other words the network is more resilient to disturbances."*

Furthermore, with the aim of making more robust our comparative analysis when performing extinction simulations, we modified the methodology as follows (L. 187-195):

*"We conducted 1000 simulations for the removal of each species, calculating the maximum eigenvalue for the network in each case. For each simulation, we compared this value against the median maximum eigenvalue obtained from 1000 simulations of the complete network, thus generating a distribution of differences. A positive difference indicates that the food web's stability is greater without the targeted species, suggesting that the species in question contributes to the network's instability. Conversely, a negative difference implies that the network is less stable without the species, indicating a stabilizing effect. Due to the variability in the*

*estimation of the eigenvalues, we decided to consider that a substantial impact on stability was reached when the proportion of either negative or positive differences within this distribution exceeded 0.55, meaning that 55% of the time the difference in stability was positive or negative. A detailed description of the stability calculations can be found in the Supplementary Material (Figure S2).”*

As a general comment, it may help to consider some of the above points in terms of the types of uncertainty they represent – e.g. structural uncertainty, parameter uncertainty or predictive uncertainty (i.e. arising from the way the data are analysed). Conducting additional sensitivity analyses would make the study more robust and enable greater clarification of uncertainties to inform how the results should be interpreted. This could include, as suggested in the comment above, exploring the impact of removing multiple species at once – a situation which is not infeasible. Sensitivity analyses should be standard practice, but I would not strictly require it for this paper so long as all the caveats, assumptions etc highlighted above (and their implication for the results) are made very clear and discussed. It would be interesting to know the authors expectations/thoughts about the likely relative sensitivity of the findings presented to different sources of uncertainty.

**Reply to reviewer:** The reviewer made a good point on the caveats and uncertainties of the study. In this regard, we added the subsection “Caveats and uncertainties” to the Discussion (L. 275-303), with the aim of clarifying the structural, parameter and predictive uncertainties that might arise from the methodology we applied.

The discussion is very brief, and largely focuses on comparison with findings from other theoretical studies. Expanding the discussion to incorporate the above points, as well as considering the findings in the context of observed trends in the Weddell Sea will add value for readers, and better contribute to progressing understanding and management of the Weddell Sea ecosystem.

**Reply to reviewer:** We have incorporated the above points and expanded the Discussion considering the caveats of our study and our findings in the context of the Weddell Sea ecosystem (L. 268-303).