Lipid pump of deep seasonal migrant zooplankton contributes substantially to Southern Ocean carbon sequestration

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□ How the lipid pump in Southern Ocean was estimated

□ The magnitude of this lipid pump

Ecological and biogeochemical implications

Zooplankton play great roles in SO carbon export



Seasonal vertical migration and lipid pump





Jonasdottir et al., 2015, PNAS

Meta-analysis of lipid pump studies in the world ocean



What we want to do

A rough estimation of lipid pump in the Southern Ocean

- **Region:** Southern Ocean
- **Species/group:** mesozooplankton, krill and salps
- 4 parameters: biomass of diapausing population; respiration rate during
- overwintering; mortality rate during overwintering; duration of

overwintering

Biomass_mesozooplankton

Yang et al., 2022; L&O



0-250 m, 1926-2020 ³⁄₄ of the records were from summer (Nov-Mar)



Biomass_mesozooplankton

B_{0-250 m}

Southern Ocean: to the region covering the nine marine protected area planning domains defined by Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) around Antarctica, \sim 36 \times 10⁶ km², 0-250 m, 67 Mt C (Yang et al., 2022)

B_{0-1000 m}

0.51: median of the ratio $B_{0-250 \text{ m}}/B_{0-1000 \text{ m}}$ among Nov, Dec, Jan, Feb and Mar 132.38 Mt C = 67/0.51 in the top 1000 m



Biomass_mesozooplankton



Biomass_krill





Atkinson et al., 2017, ESSD; 30 Mt B = 5.04 Mt Atkinson et al., 2008, MEPS; Schmidt et al., 2011, L&O

Biomass_salps



Foxton 1966

Total biomass: 1.7 Mt

Initial aggregate-to-solitary abundance: 10:1

median oral to atrial opening (OAL) length for aggregates: 16 mm

median OAL length for solitary : 40 mm

 $CM = 0.002 \times OAL^{2.148}$

Aggregate: 0.99 Mt

Solitary: 0.71 Mt

Yang et al., 2022; Foxton 1966; Henschke and Pakhomov, 2019; Dubischar et al., 2012 11

Respiration

I Regin Depth Yar Month Species Regination rate (upC)/upC CMole Reference Anale et al. 2001, Marine Biology: Respiration 2 Workd Samdardized respiration rate (upC)/upC DMI 000885024 Anale et al. 2001, Marine Biology: Respiration Kawal et al. 2001, Marine Biology: Respiration 8 Workdi Saa 0.200 1988 wirter Calamas proprioques 8 37000 µ/Q/mgDMI 000752625 Kawal et al. 2001, Marine Biology: Respiration 6 Indian sector 0.200 1996 Oct-Nov Calamas acutas CV 40 11000 µ/Q/mgDMI 0.0737017 dy weight (uprind) 44 Maryazat et al. 2002, DRH I Feeding, respiration rate (upc) Anay acuta et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Feeding, respiration rate (upc) Anay acut et al. 2002, DRH I Fe	2	A	В	С	D	E	F	G	Н		
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	31	Antarctic Peninsula	0-50	201	9 Αυα	Fuphausia superba Juvenile	11 66400	ulO ₂ /maDM/d	0 014431224		Bernard et al 2022 FiMS: Winter condition

Respiration_standardization

 μ gC/mgDM/d, μ IO₂/ind/d, μ IO₂/mgDM/d \vdots weight-specific respiration rate μ gC/ μ gCM/d

- Step 1: convert O₂ to Carbon
- μ gC d⁻¹ = μ L O₂ d⁻¹ × 12/22.4 × RQ
- 12/22.4: the carbon weight in 1 mol (22.4 L) of CO_2

Respiratory quotient (RQ): 0.97 (Ikeda and Bruce 1986)

Step 2: weight conversion

Carbon weight of each species

species-specific inter-conversion factors between dry mass and carbon mass (Atkinson et al., 2012)

CM = 0.44DM	Copepods	Mean of two large species	Ikeda and Mitchel (1982)
CM = 0.44DM	Copepods	Spring/summer average	Schnack (1985)
CM = 0.27DM	Chaetognaths	Autumn/winter average	Donnelly et al. (1994)
CM = 0.50DM	E. superba	Mixed sexes/stages	Färber-Lorda et al. (2009)
CM = 0.42DM	E. superba	Mixed sexes/stages	Atkinson et al. (2012)
CM = 0.15DM	Salpa thompsoni	Summer/autumn/winter average	Dubischar et al. (2011)
CM = 0.0369DM + 0.0655	Salpa thompsoni	Summer/autumn data	Huntley et al. (1989)
CM =0.074DM	Salps	Autumn/winter average	Donnelly et al. (1994)

Respiration



Mesozooplankton: 0.00585 d⁻¹; krill: 0.00805 d⁻¹; Salps: 0.01907 d⁻¹

Mortality and overwintering period



Mesozooplankton: 0.0056 d⁻¹; krill: 0.00252 d⁻¹;

Lipid pump_mesozooplankton

Assumption: body weight of mezooplankton decreases gradually during overwintering due to mortality and respiration



Day	Biomass (B ₀)
1	$B_1 = B_0 - L_{m, 1} - L_{r, 1}$
2	$B_2 = B_1 - L_{m, 2} - L_{r, 2}$
3	$B_3 = B_2 - L_{m, 3} - L_{r, 3}$

. . .

 $L_{m, d} \text{ (from mortality)}$ $L_{m, 1} = B_0 * m$ $L_{m, 2} = B_1 * m$ $L_{m, 3} = B_2 * m$

 $L_{r, d} \text{ (from respiration)}$ $L_{r, 1} = (B_0 - L_{m, 1}) * r$ $L_{r, 2} = (B_1 - L_{m, 2}) * r$ $L_{r, 3} = (B_2 - L_{m, 3}) * r$

Lipid pump_krill

Assumption: body weight of krill remains unchanged during overwintering

Krill: business as usual, quiescence, flexibility feed, even at low rates

Meyer et al., 2010, MEPS; Schmidt et al., 2014, L&O

Lipid pump by mortality:

 $L_{m, n} = B_0 \times (1 - m)^{n-1} \times m$

Lipid pump by respiration:

$$L_{r, n} = B_0 \times (1 - m)^n \times r$$



Apr, May: 0.0108 d⁻¹; Jun-Sep: 0.0101 d⁻¹; Oct: 0.0129 d⁻¹

Lipid pump from Salps





The lipid pump in relation to POC flux

- 39 Mt, 35% (17% 61%) of the satellite-derived export flux at 100 meters during the productive season (Oct – Mar)
- 65 Mt, 38% of the modeled POC flux 500 m 103% of the modeled POC flux 1000 m
- The mean carbon sequestration depth (defined as the depth where the carbon remains sequestered for more than 100 years) in the Southern Ocean is only 381 meters (ranging from 137 to 758 meters) (Cavan et al., 2024)



Hotspots of lipid pump



Ecological and biogeochemical implications



Shifts in dominance among krill, salps and copepods Krill distribution contracts southward during rapid regional warming

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Ecological and biogeochemical implications



-SAM/El Niño

+SAM/La Niña



Diapausing periods: shorter +SAM More salps but less krill



Reduce the lipid pump strength

Conclusion

- □ A rough estimate of lipid pump by zooplankton in the SO.
- Mesozooplankton (80%), krill (14%) and salps (6%) collectively transport 65 Mt

carbon to depths of at least 500 m.

- The total magnitude of this pump represents a considerable proportion, ranging
 0.36 0.44 and 1.00 1.21 times the annual particulate organic carbon flux at 500 meters and 1000 meters depth in the Southern Ocean, respectively.
- Climate change and its impact on biomass of dominant zooplankton groups and vertical migration behavior, can impact the dynamics of lipid pump.

Thanks !

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Guang Yang



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