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Demersal–pelagic relationships of aquatic animals in the East Siberian Sea based on ($\delta^{15}N$) and ($\delta^{13}C$) ratios and fish diets

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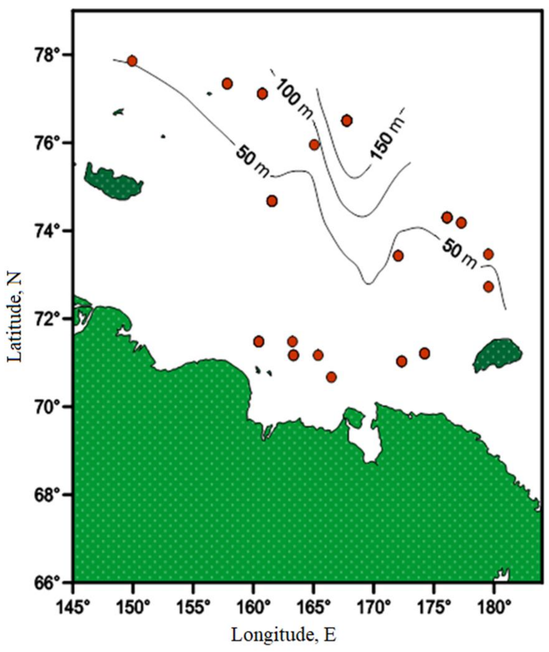
Introduction

Stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope ratios of zooplankton and zoobenthos were analyzed to compare the trophic characteristics of pelagic and benthic communities in the East Siberian Sea (ESS). The carbon isotope ratios of planktonic animals differed from those of benthic invertebrates; their average $\delta^{13}C$ ratios among taxa varied from –23.2 to –20.8 ‰, while those ratios varied from –21.8 to –17.0 ‰ in the zoobenthos. The lowest value of the stable carbon isotope ratio ($\delta^{13}C$) was found in hyperiid *Themisto abyssorum* (–24.2 ‰); snow crab *Chionoecetes opilio* was characterized by the highest one (–17.0 ‰). The relative boundary separating the pelagic and benthic communities corresponded to an average $\delta^{13}C$ value of –20.5 ‰. The $\delta^{15}N$ ratios of the studied species in the pelagic and benthic communities varied from 9.5 ‰ in comb yoldia *Yoldia myalis* to 18.7 ‰ in the sea star *Urasterias lincki*. There were significant differences in the $\delta^{15}N$ ratios at three trophic levels from the filter feeders to predators. Trophic linkages in the ESS manifest a high degree of interdependence between the benthic and pelagic communities since both pelagic and demersal fish consume as benthic-derived (e.g., zoobenthos) as pelagic-derived (e.g., phytoplankton and associated detritus) food to some extent.

Objections

Determining the trophic status of dominant species in the pelagic and bottom communities using the ratios of stable isotopes of carbon and nitrogen in their tissues and to identify the bottom-pelagic connections in the ESS.

Materials and methods



Sampling sites in the ESS in summer (from 15 Aug to 08 Sept) of 2015 and 2019

This study is based on mass spectrometry measurements of nitrogen (15N/14N, expressed as $\delta^{15}N$) and carbon (13C/12C, expressed as $\delta^{13}C$) stable isotope ratios in samples of soft tissues of certain species of aquatic animals collected in the ESS in the summers of 2015 and 2019. Sampling was mainly conducted within the shelf area within the depth range from 25 to 253 m (Fig. 1).

The isotopic analysis was carried out with a Flash 2000 elemental analyzer connected to the ConFlo-IV interface with a MAT-253 isotope mass spectrometer (Thermoquest, Germany).

Carbon to nitrogen ratio ranged from 2.66 to 2.91 in our samples collected throughout the ESS and Chukchi Sea (**Table** below). The chloroform–ethanol (2:1) was used as a solvent.

Diets of collected animals were routinely investigated on board of research vessels. Fish stomach samples (by fish size groups) were processed according to [Chuchukalo & Volkov 1986]. Food components were weighed within an accuracy of 0.1 g. In total, 251 fish stomach in 29 samples were processed in 2015, and 197 stomachs in 50 samples in 2019. Feeding intensity was expressed by stomach fullness index (SFI, %).

Limit values of stable nitrogen and carbon isotope ratios in the ESS aquatic animals

Subject	$\delta^{13}C$		$\delta^{15}N$		C:N		Number of species
	min	max	min	max	min	max	
Zooplankton	-23.2	-20.8	10.1	16.5	2.70	2.76	14
Zoobenthos	-21.8	-17.0	9.5	18.7	2.68	2.91	18
Pelagic nekton	-22.1	-20.9	15.4	18.5	2.67	2.75	3
Demersal nekton	-21.8	-19.9	13.1	18.5	2.66	2.90	6
Total	-23.2	-17.0	9.5	18.7	2.66	2.91	41

Results

Ecological and trophic characteristics and isotope ratios of predominant zooplankton species in the ESS shelf.

Trophic guilds: Ph – phytophages; Pr – predators; PR – predatory raptorial feeders; TLc – actual trophic level of consumer [calculated according to Post 2002], n – sample numbers

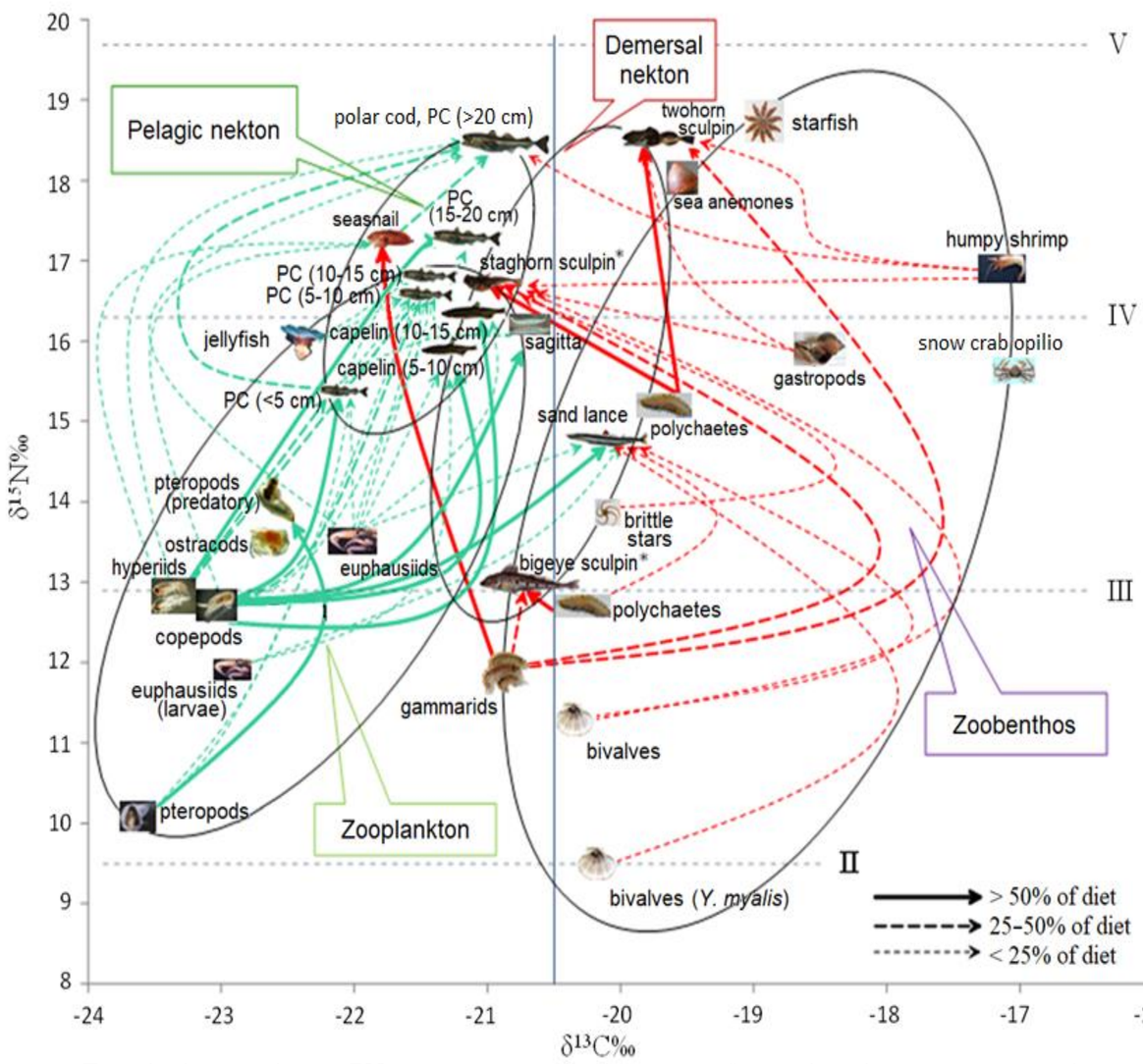
Subject	Tr. Gs.	$\delta^{13}C$	±SE	$\delta^{15}N$	±SE	TLc	n
Copepoda		-23.1	0.01	12.6	0.27	2.9	**5**
Calanus hyperboreus	Ph	-23.1	1.6	12.2	0.02	2.8	2
Calanus glacialis	Ph	-23.1	0.9	13.0	0.1	3.0	3
Euphausiacea		-22.2	0.4	12.9	0.41	3.0	**5**
Thysanoessa sp. juv.	Ph	-22.9		11.9		2.7	1
Thysanoessa longicaudata	Ph	-22.7		13.0		3.0	1
Thysanoessa raschii	Ph – Pr	-22.4	0.2	13.8	0.1	3.3	2
Meganyctiphanes norvegica	Ph – Pr	-20.9		13.9		3.3	1
Hyperiidea		-23.2	0.8	13.1	0.26	3.1	**3**
Themisto abyssorum	PR	-24.2		12.7		2.9	1
Themisto libellula	PR	-22.3	1.9	13.3	0.35	3.1	2
Chaetognatha		-20.8	0.15	16.4	0.09	4.0	**2**
Flaccisagitta maxima	Pr	-20.7		16.3		4.0	1
Sagitta elegans	Pr	-20.9		16.5		4.1	1
Pteropoda		-23.1	0.48	12.1	1.93	2.8	**2**
Limacina helicina	Ph	-23.6		10.1		2.2	1
Clione limacina	Pr	-22.7		14.0		3.3	1
Cnidaria		-22.4		16.0		3.9	**1**
Cyanea capillata	Pr	-22.4		16.0		3.9	1
Ostracoda		-22.7		13.5		3.2	**1**
Conchoecia sp.	Pr	-22.7		13.5		3.2	1

Ecological and trophic characteristics and isotope ratios of predominant macrozoobenthic species in the ESS.

Biotope allocation: NB – near-bottom, B – bottom. Trophic guilds: C – carnivores, SFF – sedentary filter feeders, MFF – mobile filter feeders, CD – surface deposit feeders (collecting detritophages), SDF – subsurface deposit feeders, Pr – predators; TF – tube-dweller filter feeders.

* – Species in biotopes under the influence of the Laptev Sea waters are marked

Subject	B.A.	Tr. Gs.	$\delta^{13}C$	±SE	$\delta^{15}N$	±SE	TLc	n
Actiniaria			-19.6		18.1		4.5	**1**
Hormathia digitata	B	C	-19.6		18.1		4.5	1
Gastropoda			-18.5		15.9		3.9	**1**
Colus sabini	B	C	-18.5		15.9		3.9	1
Gammaroidea			-20.9		11.9		2.7	**1**
Gammarus wilkitzkii	NB	Pr	-20.9		11.9		2.7	1
Bivalvia			-20.4	0.7	10.8	0.9	2.4	**3**
Astarte borealis	B	MFF	-21.7		12.51		2.9	1
Musculus laevigatus	B	SFF	-19.3		10.35		2.3	1
Yoldia myalis	B	CD	-20.2		9.5		2.0	1
Asteroidea			-18.9		18.7		4.7	**1**
Urasterias lincki	B	C	-18.9		18.7		4.7	1
Ophiuroidea			-20.1		13.9		3.3	**1**
Ophioscolex glacialis	B	SDF	-20.1		13.9		3.3	1
Isopoda			-21.8		17.7		4.4	**1**
*Saduria sibirica**	B	C	-21.8		17.7		4.4	1
Polychaeta			-20.1	0.3	14.7	0.5	3.5	**9**
Sabellidae gen. sp. 1	B	TF	-20.4	0.3	12.6	0.9	2.9	2
Sabellidae gen. sp. 2*	B	TF	-22.0		11.3		2.5	1
Maldanidae gen. sp.	B	SDF	-19.4	0.6	15.8	0.6	3.8	2
Nepthyidae gen. sp.	B	C	-18.8		17.2		4.3	1
Pectinariidae gen. sp.	B	SDF	-20.7		14.3		3.4	1
Polynoidae gen. sp.	B	C	-19.8		14.2		3.4	1
Scalibregma inflantum	B	SDF	-20.3		14.0		3.3	1
Brachiura			-17.0		15.6		3.8	**1**
Chionoecetes opilio	B	C	-17.0		15.6		3.8	1
Caridea			-17.2		16.9		4.2	**1**
Pandalus goniurus	NB	C	-17.2		16.9		4.2	1



Trophic linkages in the ESS based on stomach contents of aquatic animals and stable nitrogen and carbon isotope ratios

Conclusions

1. Relative boundary separating the pelagic and benthic communities corresponds to an average $\delta^{13}C$ of -20.5‰.
2. In all samples of aquatic animals from the eastern ESS under the influence of Chukchi Sea waters, an average decrease in $\delta^{13}C$ values of approximately 2–2.5 ‰ was observed. Tissue samples from the western ESS are characterized by minimal $\delta^{13}C$ values, which is due to the influence of oligohaline waters from the Laptev Sea.
3. Due to more severe ice conditions, ice algae are likely to be an even more important source of organic matter in bottom sediments in the ESS than in the Chukchi and Beaufort Seas. The greater enrichment of benthic organisms by ^{13}C could be a consequence of ice algae phytodetritus processing in the benthic food chain.
4. The ^{13}C carbon isotope content in tissues and the fish diet showed that ca. 90% of the demersal nekton species are confined to the bottom food web. Pelagic fish feed mainly on pelagic objects, although the proportion of zoobenthos increases with increasing body size (up to 20%) in polar cod, the predominant species of nekton.
5. The $\delta^{15}N$ values of the studied aquatic animals in the pelagic and benthic communities varied from 9.5 ‰ (in the bivalve mollusk *Yoldia myalis*) to 18.7 ‰ (in the sea star *Urasterias lincki*) and thus occupied three trophic levels in the food web.
6. Trophic relationships in the ESS demonstrate a high degree of interdependence between the benthic and pelagic communities since pelagic and benthic fish consume both benthic and pelagic food to some degree.