Latitudinal and size-based variation in the diet of Arctic cod in the eastern Chukchi Sea

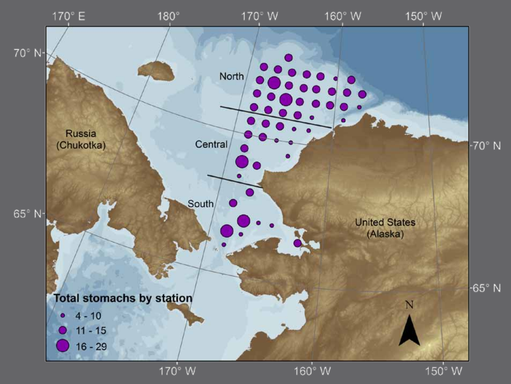

Figure 1. Sampling locations where Arctic cod specimens were collected during the Arctic Eis 2012 summer bottom-trawl survey. The purple dots are scaled to the number of stomachs collected at each station. The 3 subregions are separated by black lines and are labeled North, Central, and South.

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Introduction

Arctic cod (Boreogadus saida) is a nodal species in Arctic marine food webs. It preys on a variety of zooplankton and benthic-oriented organisms, and is itself an important prey of many birds, marine mammals, and fishes. Arctic cod is one of the most abundant Arctic fishes and can be found in both benthic and pelagic environments, and in association with sea ice. We present the diet composition of Arctic cod collected throughout the eastern Chukchi Sea during the summer of 2012, and we test for differences in diet composition with respect to predator size and latitude.

Methods

Arctic cod was frequently caught during a bottom-trawl survey of the eastern Chukchi Sea during the summer of 2012. Stomach samples were collected from 57 different hauls, covering a latitudinal range from 66 to 73°N (Figure 1). We divided the study area into 3 subregions to explore latitudinal variation in diet composition. Arctic cod specimens ranged in size from 5.7 to 19.3 cm fork length (mean 11.2 cm). To examine size based differences in diet we divided predator stomachs into three size classes (Table 1). We use permutational multivariate analysis of variance (perMANOVA) to test for differences in diet composition with respect to predator size and latitude.

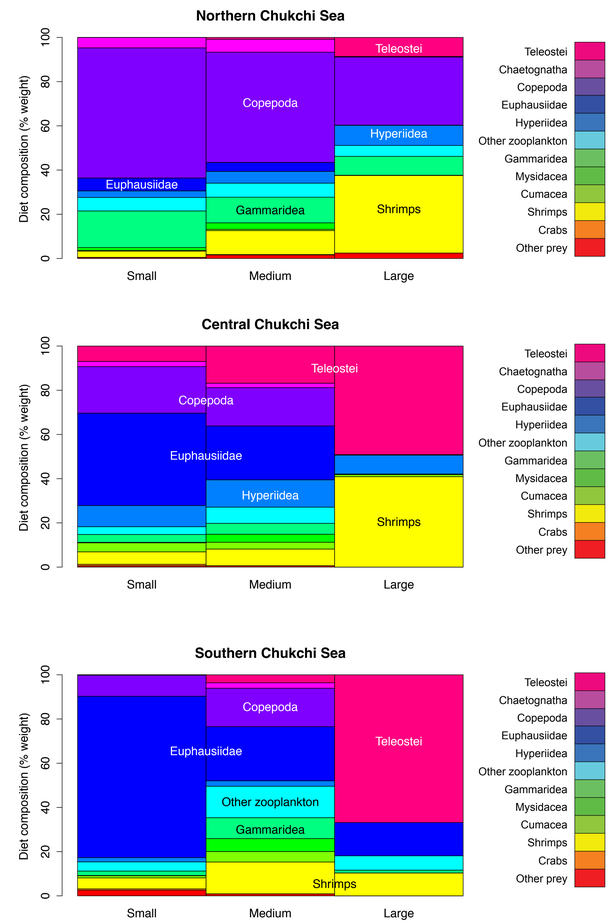
To aid interpretation of diet data and highlight underlying patterns we used Principal Coordinate Analysis (PCoA) to depict the dissimilarity among stomachs in ordination space. The significance of principal components was evaluated with the broken stick criterion. We conducted Constrained Analysis on Principal Coordinates (CAP) to determine how much variation in the diet compositions could be explained by a constraining matrix of environmental variables and predator length.

Table 1. The number of Arctic cod stomachs (non-empty) by size class and by subregion.

		South	Central	North	
		66-68.24° N	68.25-70.74° N	70.75-73° N	Total
Small	5.7-10.2 cm	27	59	137	223
Medium	10.3-14.7 cm	77	101	253	431
Large	14.8-19.3 cm	5	10	23	38
	Total	**109**	**170**	**413**	**692**

Results

- The Arctic cod diet varied with predator size (F=9.54, R^2=0.025, p<0.0001) (Figures 2-4). In the northern Chukchi Sea, the proportion of benthic-oriented prey in the diet, such as gammarid amphipods and shrimps, increased with predator size, while the importance of copepods decreased with predator size.
- The diet composition also varied with latitude (F=27.29, R^2=0.072, p<0.0001) (Figures 2-4). Fish were a more important prey item in the southern Chukchi Sea, while in the northern Chukchi Sea copepods were of greater importance. The proportion of euphausiids in the diet decreased with increasing latitude across the entire study region.
- The first 2 principal components (PC's) of the PCoA explained 13% and 6% respectively of the observed variation in diet composition (Figure 5). Small and medium Arctic cod were widely distributed across ordination space reflecting their generalist diet, while the large size class had several negative values on both PC's.
- Prey groups with significant loadings on the first two PC's (p<0.001) can be used to interpret the position of individuals in ordination space (Figure 6). Confidence ellipses (0.50) of the small and medium size classes are broadly overlapping and associated with all significant prey vectors, while the large size class is concentrated in the lower left corner and associated with prey vectors other than copepods and euphausiids (Figure 6).
- The CAP analysis explained 10% of total variation in the Arctic cod diet compositions (ANOVA, F=12.155, p=0.005). The first two CAP axes explained 8% of the variation in Arctic cod diet. The distance between the plotted Arctic cod indicates their similarity to each other (Figure 7). The diet composition of an individual is generally dominated by prey located near them in the ordination space. For example, Arctic cod located in the upper left corner of the plot (2nd quadrant) consumed higher proportions of euphausiids.
- The environmental variables are represented by vectors which depict the strength and direction of change in a variable through the ordination space (Figure 7). The strongest vectors are for latitude and predator length, which is consistent with the perMANOVA results. Stomachs that are positive on the first axis (CAP1) are associated with increasing latitude and high proportions of copepods in the diet. The length vector is negatively related with both CAP axes. Predators whose stomachs are located near this vector are larger in size and their diets include high percentages of shrimp and fish (Teleostei).



Figures 2-4. Diet composition of Arctic cod collected in the eastern Chukchi Sea across 3 latitudinal subregions (Figure 2-North, Figure 3-Central, Figure 4-South) and 3 size categories (Small 5.7-10.2 cm, Medium 10.3-14.7 cm, Large 14.8-19.3 cm).

Conclusions

- Arctic cod are opportunistic predators consuming a wide range of benthic and pelagic prey.
- The diet composition of Arctic cod in the eastern Chukchi Sea was significantly different among different size classes. Larger predators consumed more fish and shrimp and smaller predators consumed more copepods and other zooplankton.
- Diet composition also varied significantly with latitude. Fish and euphausiids were of greater importance in the southern Chukchi Sea, while in the northern Chukchi Sea copepods, shrimp, and gammarid amphipods were of greater importance.
- Environmental variables and predator length explained 10% of the variation in Arctic cod diet composition.
- Regular sampling of Arctic cod diets (e.g., every 1 to 3 years) across this region will be necessary to determine if the patterns and trends in diet composition observed here are persistent or due to interannual variation.

Acknowledgements

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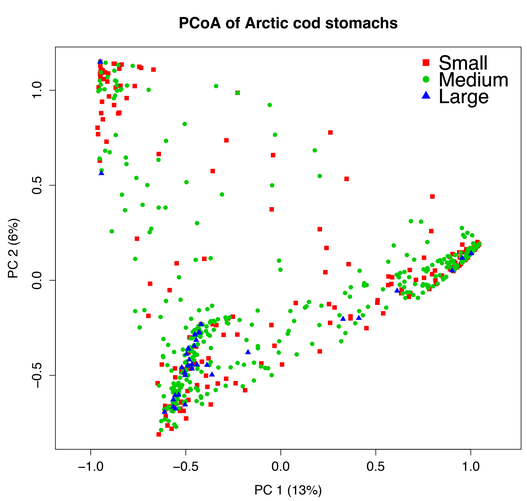

Figure 5. Principal Coordinate Analysis (PCoA) of Arctic cod diet composition with the 3 different predator size classes highlighted (Small 5.7-10.2 cm, Medium 10.3-14.7 cm, Large 14.8-19.3 cm).

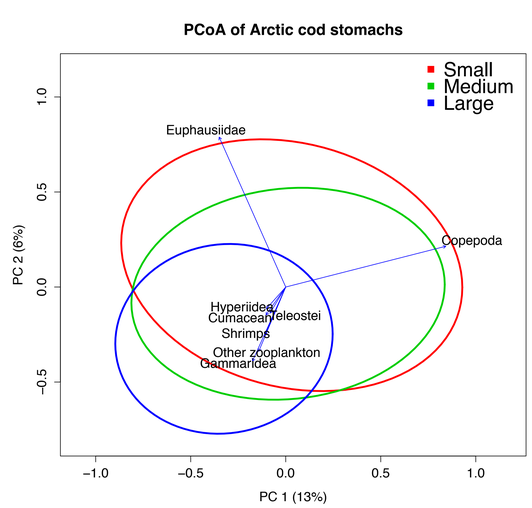

Figure 6. Prey vector arrows with significant loadings (p<0.001) on the first two PC's from the PCoA. The location of the 3 size classes of Arctic cod stomachs in ordination space is shown with confidence ellipses (0.50). The blue prey vector arrows show the direction of variable gradient in the ordination space. The longer the arrow, the more important the prey is in describing the PC's.

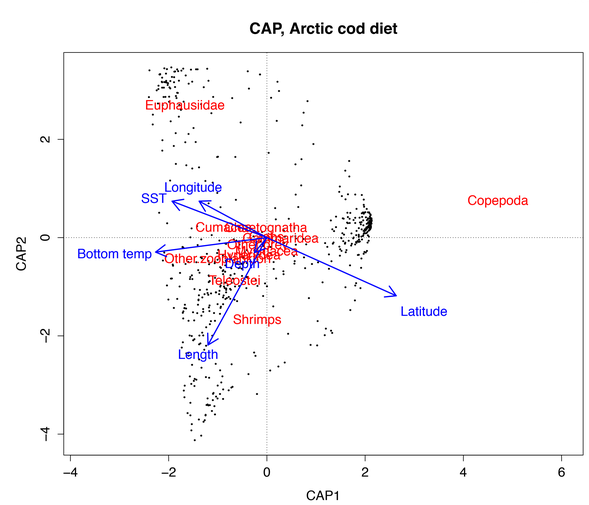

Figure 7. CAP analysis of Arctic cod diet compositions and an environmental dataset (including predator length). The black dots represent the individual stomachs, the red lettering is for prey groups, and the blue vector arrows are the non-diet variables. The vector length indicates its importance to the ordination and direction indicates its correlation with the axes and the other vectors.

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