

1 Developing an observational design for epibenthos and fish assemblages in the 2 Chukchi Sea

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11 12 13 **Abstract**

14 In light of ongoing, and accelerating, environmental changes in the Pacific sector of the Arctic Ocean, the
15 ability to track subsequent changes over time in various marine ecosystem components has become a
16 major research goal. The high logistical efforts and costs associated with arctic work demand the
17 prudent use of existing resources for the most comprehensive information gain. Here, we compare the
18 information that can be gained for epibenthic invertebrate and for demersal fish assemblages reflecting
19 coverage on two different spatial scales: a broader spatial coverage from the Arctic Marine Biodiversity
20 Observing Network (AMBON, 67 stations total), and the spatial coverage from a subset of these stations
21 (14 stations) that reflect two standard transect lines of the Distributed Biological Observatory (DBO).
22 Multivariate cluster analysis was used to discern community similarity patterns in epibenthic
23 invertebrate and fish communities. The 14 stations reflecting the two DBO lines captured about 57% of
24 the epibenthic species richness that was observed through the larger-scale AMBON coverage, with a
25 higher percentage on the more southern DBO3 than the northern DBO4 line. For demersal fishes, both
26 DBO lines captured 88 % of the richness from the larger AMBON spatial coverage. The epifaunal
27 assemblage clustered along the south-north and the inshore-offshore axes of the overall study region.
28 Of these, the southern DBO3 line well represented the regional (southern) epifaunal assemblage
29 structure, while the northern DBO4 line only captured a small number of the distinct assemblage
30 clusters. The demersal fish assemblage displayed little spatial structure with only one coastal and one
31 offshore cluster. Again, this structure was well represented by the southern DBO3 line but less by the
32 northern DBO4 line. We propose that extending the coverage of the DBO4 line in the northern Chukchi
33 Sea farther inshore and offshore would result in better representation of the overall northern Chukchi
34 epifaunal and fish assemblages. In addition, the multi-annual stability of epifaunal and, to a lesser extent
35 also fish assemblages, suggests that these components may not need to be sampled on an annual basis
36 and sampling every 2-3 years could still provide sufficient understanding of long-term changes.
37 Sampling these assemblages every few years from a larger region such as covered by the AMBON
38 project would create the larger-scale context that is important in spatial planning of long-term
39 observing.

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41 **Key words:** Arctic, Observing system, Biomass, Diversity,

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43 **1. Introduction**

44 High levels of biodiversity promote ecosystem productivity and stability and secure the multiple
45 functions and services the oceans provide (Palumbi et al., 2009; Duffy et al., 2017). Essential ecosystem
46 services of the Arctic Ocean for humans include climate regulation from regional to global scales
47 (Overland and Wang, 2010), food and traditional lifestyle for indigenous peoples, untapped reservoirs of
48 natural oil and gas resources, new shipping routes, growing tourism (Hall and Saarinen, 2010), and
49 potential new fisheries as subarctic species expand into Arctic waters (Christiansen et al., 2013;
50 Hollowed et al., 2013). More diverse systems are thought to have higher resilience to perturbations and
51 more potential for recovery and reversibility after they are affected, compared to less diverse systems
52 (e.g. Sala and Knowlton, 2006; Worm et al., 2006; Palumbi et al., 2009). Thus, biodiversity can be used as
53 a gauge of ecosystem status and a “common master variable”, linking ocean management, conservation,
54 and development interests (Duffy et al., 2013). Yet, biodiversity as a cornerstone of long-term observing
55 systems in the marine realm is still in its infancy compared with physical observing programs.

56 One of the world’s oceans in need of increased ocean observing is the Arctic. The ongoing and rapidly
57 increasing drastic changes in the Arctic marine physical environment such as the loss of sea-ice cover
58 and changes in heat budget are projected to elicit significant responses in the marine biological system
59 (Wassmann et al., 2011). Both the ecological significance of the Arctic marine ecosystems, the increasing
60 interest in resource use in the Arctic as well as the global biodiversity loss and its negative influence on
61 ecosystem services (Worm et al., 2006; Cobb et al., 2014; Miller and Ruiz, 2014) spur efforts to develop
62 and maintain observation programs of physical and biological changes. It is well understood that long-
63 term observations of the Arctic (and other) marine ecosystems are needed to create an understanding
64 of natural fluctuations on seasonal to interannual time scales so that long-term, unidirectional responses
65 due to climate warming or other causes can be differentiated (Magurran et al., 2010). However, the
66 logistically and financially intense fieldwork in the Arctic demands a prudent approach to the
67 optimization of resources and collaborative approaches in developing marine observing networks.

68 Both national and international efforts are underway in the Arctic to implement long-term
69 observational programs that capture variability or trends not only in the physical environment but also
70 the biological system (e.g. Soltwedel et al., 2005, 2013; Michalsen et al., 2013; Moore and Grebmeier,
71 2018). Most of these observing systems have a focus on seabed fauna as a long-term indicator of
72 changes from climatic processes or anthropogenic influences. For example, the arctic deep-sea
73 HAUSGARTEN observatory in Fram Strait has measured benthic processes since 1999, measuring faster
74 than expected responses to environmental variation (Soldtwedel et al., 2016). On the European Arctic
75 Barents Sea shelf, the assessment of epibenthos as part of annual fish trawl surveys is starting to provide
76 long-term records that allow the assessment of responses to trawling impacts and shifts in dominant
77 water masses (Jørgensen et al., 2014, 2015). Within the Pacific Arctic, two of the currently ongoing
78 observational programs that link variability or trends in the physical environment with the biological

79 system are the Distributed Biological Observatory (DBO) and the Arctic Marine Biodiversity Observing
80 Network (AMBON). The goal of the DBO is to repeatedly (from seasonally to annually) sample regions of
81 persistently high benthic biomass “hotspots” that are representative of the tight pelagic-benthic
82 coupling and short food webs of many arctic shelf systems (Grebmeier et al., 2010; Moore and
83 Grebmeier, 2018). Core measurements of the DBO program include physical and chemical properties of
84 the water column and sediments; the species composition, abundance and biomass of phytoplankton,
85 zooplankton and macrobenthos; and the abundance and distribution of seabirds and marine mammals,
86 with only occasional epibenthic and fish trawling efforts. DBO sampling is currently implemented as an
87 international collaboration of six countries (USA, Canada, Japan, Korea, China, Russia) along cross-shelf
88 transects in the Bering and Chukchi seas, and with new implementations of shelf to upper slope
89 transects also in the Beaufort Sea and the Atlantic sector (Barents Sea and Fram Strait).

90 The AMBON program is part of a US national effort to develop prototypes for marine observing
91 networks that focus on biodiversity (Duffy et al., 2013). Biodiversity measures are at the core of the
92 AMBON program, which engages in a monitoring approach of ecosystem components from microbes to
93 whales. The ecosystem components monitored include temperature, salinity and nutrient
94 concentrations; microbial and phytoplankton composition and microalgal biomass (as chlorophyll *a*);
95 zooplankton, meiobenthos, macrobenthos, epibenthos and demersal fish composition, biodiversity,
96 biomass and abundance; as well as seabird and marine mammal distribution along observational
97 transects. The strategy of the AMBON project is to continue spatial coverage of previous observational
98 programs to take advantage of existing knowledge and to create or extend much-needed time series.
99 Only long-term, decadal-scale datasets provide the basis for distinguishing natural (stochastic) variability
100 and regular cycles from gradual or abrupt directional changes driven by climate change and other
101 human influences, e.g. chronic pollution or oil spills. For example, a 40-year time series on
102 macrobenthos in the Chukchi Sea allowed detection of decadal changes in this system (Grebmeier et al.,
103 2015b). Similarly, a 60-year time series on zooplankton in the Chukchi Sea detected significant changes
104 in copepod biomass, abundance, and biogeographic affinity in recent years (Ershova et al., 2015).
105 Therefore, survey transects of the past decade-long Russian-American Long-term Census of the Arctic
106 (RUSALCA) program (Grebmeier et al., 2015a) and the 7-year long Chukchi Sea Ecosystem Studies
107 Program (CSESP, Day et al., 2013) are included in the AMBON sampling grid. In addition, the AMBON
108 observing region includes two of the DBO lines, DBO3 in the southern Chukchi Sea and DBO4 in the
109 northern Chukchi Sea (Grebmeier et al., 2010). This overlap provides opportunities to add to the
110 temporal (seasonal) sampling of these lines, to add biodiversity as another element to DBO sampling,
111 and to add ecosystem elements that are not regularly sampled during the existing DBO sampling,
112 including epibenthic invertebrates and demersal fishes.

113 Epibenthic invertebrate assemblages in particular are a biomass-rich ecosystem component of the
114 Chukchi Sea shelf (e.g. Bluhm et al., 2009; Blanchard et al., 2013; Ravelo et al., 2014) fueled by high
115 pelagic primary productivity, much of which is exported directly to the sea floor with little grazing in the
116 water column (Grebmeier et al., 2006). Epifaunal taxa contribute to carbon remineralization (Ambrose
117 et al., 2001), enhance habitat complexity (e.g. Wood et al., 2012), add to food web complexity (Iken et
118 al., 2010), and act as a food source for other higher trophic level organisms, such as fishes and marine

119 mammals (Bluhm and Gradinger, 2008; Divine et al., 2015; Gray et al., 2017). Epibenthic assemblage
120 structure and spatial distribution is driven by a suite of environmental variables, including water mass
121 characteristics, flow regimes, and sediment characteristics (Feder et al., 2005; Bluhm et al., 2009; Ravelo
122 et al., 2014; Pisareva et al., 2015), in addition to trophic interactions (Iken et al., 2010). High biological
123 and functional diversity (Rand et al., 2017), together with high longevity of most benthic invertebrates,
124 leads to the resilience of epibenthic assemblages against short-term (seasonal to interannual) climate
125 fluctuations (Bluhm et al., 2009; Grebmeier et al., 2015a), making them good indicators of long-term
126 changes and useful candidates to be included in long-term observations.

127 Demersal fishes also are important components of the Arctic food web as they consume plankton,
128 benthic invertebrates, and smaller fishes while serving as prey for higher trophic level organisms like
129 birds, whales, ice seals, polar bears, and humans (Lowry and Frost, 1981; Bluhm and Gradinger, 2008).
130 Many demersal fishes are mobile and not strictly tied to the benthos as they swim up into the water
131 column to feed on pelagic prey (e.g. Gray et al., 2015). In addition, many demersal species have pelagic
132 larvae and juveniles, providing important links between the pelagic and benthic environment. Current
133 abundances of fish on the Chukchi Sea shelf are at least an order of magnitude lower than in the eastern
134 Bering Sea (Stevenson and Lauth, 2012), but subarctic species may expand northward into the Chukchi
135 Sea or local populations may increase in a warming climate (Hollowed et al., 2013). The implementation
136 of the Arctic Fisheries Management Plan (NPFMC, 2009), which provides a framework for managing
137 potential future commercial fisheries in the Arctic, has brought attention to the role Arctic fish play or
138 could play in the ecosystem under altered climate scenarios. Similar to epifauna, demersal fish
139 assemblage patterns are related to environmental variables, mostly water mass characteristics for
140 larger-scale distributions (Norcross et al., 2010) or temperature and the erosional or depositional nature
141 of sediment structure for small-scale patterns in fish assemblages (Norcross et al., 2013). The sensitivity
142 of fish species diversity and abundance to temperature changes (Mueter and Litzow, 2008) makes them
143 another good candidate for long-term monitoring.

144 In this study, we made use of the spatial overlap that the AMBON program has with stations of the
145 DBO in the Chukchi Sea to assess how representative the subset of these stations that reflect the DBO
146 lines in the Chukchi Sea are of the larger regional distribution and biodiversity of epibenthic and
147 demersal fish assemblages covered though the AMBON project. Decisions as to which ecosystem
148 components should be included in long-term observations are inherently driven by ecological, practical,
149 and fiscal considerations. Hence, optimization of field efforts, particularly in remote and cost-intensive
150 study areas in the Arctic, is prudent. Our primary research question was to assess whether the DBO
151 stations that were selected based on biomass hotspots for macrofauna and water column productivity
152 are also suitable to provide a sampling framework for assessing the biomass and species diversity of
153 epibenthos and demersal fish.

154

155 **2. Material and methods**

156 Sampling was conducted at 67 stations during the AMBON cruise in the Chukchi Sea on the R/V
157 Norseman II from 8 August – 5 September 2015 (Fig. 1). The AMBON station coverage includes stations
158 along the DBO3 line in the southern Chukchi Sea and along the DBO4 line in the northern Chukchi Sea
159 (Fig. 1). Epibenthic invertebrates and demersal fishes were collected with a plumb-staff beam trawl with
160 a 2.26 m opening and a 7-mm mesh net and a 4-mm cod end liner. Trawls were conducted during the
161 night for 2-5 min duration at ~1.5 knots. Trawl distances ranged from 160 – 840 m, with an average of
162 373 m. Trawl hauls were rinsed, if necessary, and then sorted on board to the lowest taxonomic level
163 possible. For invertebrate taxa that could not be identified on board, voucher specimens were preserved
164 in 4% formaldehyde or 99% molecular-grade ethanol for later consultation with taxonomic experts.
165 Most invertebrate identifications were made to species or genus level, although taxonomic resolution
166 for several phyla was low because of lack of taxonomic expertise, especially Bryozoa, Hydrozoa and
167 Porifera. In cases where morphologically distinct taxa within these phyla could be distinguished, we kept
168 these as separated taxa for analysis. Fish were sorted to species or genus level. Juvenile fishes (mostly
169 gadids) were excluded from the analysis because they are typically pelagic and were likely collected in
170 the water column while the trawl was retrieved. All fish and invertebrate individuals, except for colonial
171 taxa, were enumerated; bulk wet weight was determined at the lowest taxonomic level using spring and
172 digital hanging scales. Trawl distance was estimated by multiplying average trawling speed by the time
173 the trawl was in contact with the bottom. Bottom contact was assessed based on depth recordings by a
174 time-depth recorder (TDR, Star Oddi, Gardabaer, Iceland) attached to the net opening. Abundance and
175 biomass for all taxa were then quantified for each haul as catch per unit effort (CPUE), where effort was
176 computed as trawl distance multiplied by the width of the net opening.

177 Environmental conditions were assessed from water column and sediment samples. Station depth,
178 surface and bottom temperature (°C) and salinity measurements were taken from CTD profiles (Seabird
179 Model SBE911). Water samples from Niskin bottles attached to the CTD were used to analyze
180 chlorophyll *a* (chl *a*) and inorganic nutrients (ammonia, phosphate, nitrite + nitrate, silicate). In addition,
181 maximum chl *a* values at each station were used in the environmental matrix. Samples were processed
182 as follows: Subsamples for inorganic nutrients were filtered shipboard (Whatman GFF), and frozen for
183 post cruise analyses. Nutrient samples were analyzed at the Nutrient Analytical Services Laboratory
184 (NASL) at the Chesapeake Biological Laboratory (see <http://nasl.cbl.umces.edu/> for standard methods
185 used) at the University of Maryland Center for Environmental Science (UMCES). Filtered samples for chl
186 *a* measurements were analyzed shipboard using a Turner Designs AU-20 fluorometer after 24-h dark
187 extraction in 90% acetone at 4°C (non-acidification or Welschmeyer method; see Cooper et al., 2012,
188 2013 for details). The inventory of active chl *a* in surface sediments (upper 1 cm) was measured by
189 collecting undisturbed surface sediments from a van Veen grab with a cut-off 10 cc syringe. Sediments
190 were incubated in the dark with 90% acetone for 12 hours at 4°C and measurements made as with
191 water samples, using a Turner Designs AU-20 fluorometer without acidification (Welschmeyer method).
192 Another subsample of surface sediment was collected and sediment grain size determined according to
193 the Wentworth convention (<0 phi – 4 phi, as well as modal size of phi; for methods see Gee and
194 Bauder, 1986; Grebmeier et al., 1989).

195 Epifauna and demersal fish catch data were considered separately. While both are benthic
196 ecosystem components, they differ considerably in their association with the bottom, especially in their
197 ability to move. In the Chukchi Sea, demersal fishes have a strong association with water mass
198 characteristics (Norcross et al., 2010), while epifaunal invertebrates are more closely related to
199 substrate characteristics (Bluhm et al., 2009). In addition, the order of magnitude higher taxon number
200 and larger biomass of epifauna over demersal fish obscures any fish-specific patterns. We confirmed
201 that there was no correlation between epifaunal and fish biomass or taxon richness across stations
202 (Pearson product-moment correlation coefficient $r = -0.039$ and 0.012 , respectively). While the epifauna
203 and fish dissimilarity matrices showed some coherence (RELATE analysis in Primer-e v7, $\rho = 0.508$), we
204 decided that the ecological differences warranted separate analyses.

205 Analyses of the epifaunal and fish assemblages were performed based on biomass rather than
206 numerical abundances because these data contained all taxa, including epifauna colonial taxa, and
207 because biomass is a more meaningful ecological indicator based on trophic and energetic
208 considerations. All assemblage-level analyses were performed using the multivariate software package
209 Primer-e (v7; Clarke and Gorley, 2015). A Bray-Curtis similarity matrix was created using fourth-root
210 transformed biomass data for epifauna and fish to reduce the influence of biomass-dominant taxa on
211 the analyses. A hierarchical cluster analysis was then used to group stations by similarity (group
212 averaged on the similarity matrix) for both epibenthic invertebrates and fishes. All dendrograms were
213 inspected for significantly different clusters (SIMPROF test, $\alpha=0.05$); in the case of epibenthic
214 invertebrates, SIMPROF resulted in an exceedingly large number of significant clusters. Here, we
215 combined station groups at a lower level of similarity aiming to result at more interpretable station
216 groupings. The resulting clusters were then plotted spatially according to sampling location (Matlab M-
217 Map) to visualize the spatial distribution of assemblage types. A similarity percentages (SIMPER) routine
218 was used to identify the taxa contributing most to similarities within and dissimilarities among station
219 clusters. Epifaunal invertebrate species contributing cumulatively $\geq 30\%$ to within-cluster similarity are
220 presented; for fishes, we present species contributing cumulatively $\geq 50\%$ to within-cluster similarity for
221 higher resolution of species driving cluster similarity of because of the generally much lower fish species
222 richness. Coverage of assemblages by the two DBO lines versus the larger AMBON station coverage was
223 then compared.

224 We tested whether biological assemblages were significantly related to observed environmental
225 variability and, if so, identified subsets of environmental variables that were most strongly related to
226 each assemblage. These analyses were conducted separately for the epifauna and fish assemblages; for
227 both components, separate analyses were conducted for the full set of stations and for the DBO-stations
228 only. Pairwise dissimilarities among stations for each biological dataset were related to pairwise
229 Euclidean distances among environmental variables for the corresponding set of stations using the trend
230 correlation routine called BEST in Primer-e. This is a Mantel-type test that selects the subset of
231 environmental variables whose dissimilarities are most strongly related to the biological dissimilarities
232 (Clarke and Ainsworth, 1993). Environmental variables were normalized to a common measurement
233 scale in Primer and then tested for collinearity using Spearman rank correlations and pairwise
234 scatterplots. For variables that were correlated at $>90\%$, one of the variables was removed. This applied

235 to the nutrients phosphate and nitrite+nitrate, of which we retained the nitrite+nitrate measurement
236 for the analyses.

237

238 3. Results

239 Across the 67 AMBON stations, we collected 317 nominal epibenthic invertebrate taxa (including
240 morphologically distinct taxa within phyla where species identifications could not be made); of these 57
241 taxa were colonial. Taxon richness was dominated by the phyla Mollusca (91 taxa) and Arthropoda (83
242 taxa), followed by Annelida (32 taxa) and Echinodermata (29 taxa). Total wet weight biomass of
243 epibenthic invertebrates across all stations was dominated on the class or order level by echinoids with
244 36% (nearly entirely driven by the sand dollar *Echinarachnius parma* abundant at some stations along
245 line ML6), ophiuroids with 25% (mostly dominated by *Ophiura sarsii*), decapods with 11% (mostly snow
246 crab *Chionocetes opilio*), holothurians with 8% (especially *Psolus peronii*), and ascidians (5%, mostly
247 solitary *Boltenia ovifera*). At the species level, *Echinarachnius parma* and *Ophiura sarsii* were the two
248 single most dominant species in terms of biomass (Fig. 2a), although they were not the species with the
249 highest frequency of occurrence (FO, Fig. 2b). The crab *Chionocetes opilio* and the shrimp *Eualus*
250 *gaimardii gaimardii* had the highest FO and occurred at 94% of all stations (Fig. 2b). Fish taxon richness
251 was mostly represented in the Cottidae (6 taxa), followed by Agonidae (poachers), Liparidae (snail
252 fishes), Pleuronectidae (flounders), Stichaeidae (pricklebacks) and Zoarcidae (eelpouts) (3 taxa each). In
253 general, total fish biomass was mostly comprised (84% of total biomass) by four families: Cottidae
254 (sculpins), Stichaeidae, Gadidae (cods), and Liparidae. Among the 24 collected fish taxa, total biomass
255 was overwhelmingly dominated by just two species, the slender eelblenny *Lumpenus fabricii* (20%) and
256 the Arctic staghorn sculpin *Gymnocanthus tricuspis* (19%). Fish taxa with high biomass contributions
257 were not necessarily those with the highest FO; for example, *Liparis* sp. occurred in 88% of the samples
258 but only contributed about 4% to overall fish biomass (Fig. 3). Arctic cod (*Boreogadus saida*), often the
259 dominant species on Arctic shelves, was the fifth most abundant species by weight in our collections
260 (~6% of total biomass) and occurred at 68% of the stations.

261 Taxon richness for epifaunal invertebrates ranged from 13 – 66 per station (at ML1-2 and ML5-7,
262 respectively), and between 0 – 14 for fish taxa (at ML6-3 and ML3-6, respectively) (Fig. 4a and b). Overall
263 epifaunal species richness was higher in the northern than southern study region (Fig. 4a). For the total
264 study region, the DBO stations harbored 180 of the 317 total epifaunal taxa (57%). Along the DBO3
265 stations we encountered 97 taxa, compared with 127 taxa for the entire southern study region (DBO3
266 and CL lines; 76% along DBO3). A total of 133 epifaunal taxa (45%) were encountered along the DBO4
267 line of the 294 taxa that were found in the entire northern study region. For demersal fishes, of the 24
268 total fish taxa across the total study region we found 21 taxa along both DBO lines (88%). The DBO3 line
269 was represented by 18 taxa, representing 90% of the 20 taxa total found within the entire southern
270 study region (DBO3 and CL lines combined). Along the DBO4 line, 18 fish taxa were found compared
271 with the 24 taxa found in the overall northern study region (75% along DBO4). Among the fish species
272 not encountered along the DBO lines were some generally rare species (e.g. alligatorfish

273 *Aspidophoroides monopterygius*) but also some taxa that were otherwise relatively common (e.g.
274 sturgeon poacher *Podothecus accipenserinus*).

275 Biomass per station for epifauna ranged from a low of 790 g wet weight 1000 m⁻² (stn ML3-13) to a
276 high of 153274 g wet weight 1000 m⁻² (stn ML6-1) (Fig. 5a). Epifaunal biomass along DBO3 was within
277 the lower range of overall biomass while biomass along the DBO4 line was in the intermediate range
278 (Fig. 5a). Fish biomass ranged from 0 – 2362 g wet weight 1000 m⁻² (ML6-3 and ML1-2, respectively; fish
279 biomass at the DBO3 stations was in the higher range while biomass at DBO4 stations was low (Fig. 5b).

280 Epibenthic invertebrate assemblages separated into eleven clusters and two single stations (ML3-2
281 and ML5-1) (Fig. 6). Station clusters were distributed along the south-north axis as well as the inshore-
282 offshore axis of the study area (Fig. 7). The DBO3 stations separated evenly in an inshore (A) and
283 offshore (B) cluster. The inshore cluster was characterized mostly the ascidian *Halocynthia aurantium*,
284 while the main character species for the offshore cluster was the snow crab *Chionoecetes opilio* (Table
285 1). Two of the DBO4 stations were part of a more coastal cluster (H), mostly characterized by the sea
286 cucumber *Psolus peronii*, and the remaining four DBO4 stations were part of a mid-shelf cluster (I),
287 mostly characterized by the brittle star *Ophiura sarsii* (Fig. 7). Between 1 and 5 species accounted for
288 within-cluster similarity of ≥30% (Table 1).

289 The demersal fish assemblage only grouped into two clusters and one single station (ML6-3), where
290 no fish were caught (Fig. 8). One cluster (a) mostly encompassed coastal stations, including all DBO3
291 stations, and the other cluster (b) comprised offshore stations, including all DBO4 stations (Fig. 9). The
292 coastal cluster was characterized by the Arctic staghorn sculpin *Gymnocanthus tricuspis*, the slender
293 eelblenny *Lumpenus fabricii*, and snail fishes (*Liparis* sp.) (57% cumulative similarity) while the offshore
294 cluster was characterized by snail fish (*Liparis* sp.), eelpouts (*Lycodes* sp.), and Arctic cod *Boreogadus*
295 *saida* (51% cumulative similarity).

296 The suite of environmental variables that best explained epifaunal assemblage structure across the
297 entire sampling region included depth, bottom and surface temperatures, and the proportion of
298 sediment grain size phi ≥5, with a correlation coefficient of rho = 0.618. Of these, sediment grain size phi
299 ≥5 was the single variable with the highest correlation coefficient (rho = 0.481) with epifaunal
300 assemblage structure. When only DBO stations were considered, correlation of epibenthic assemblage
301 structure with environmental variables was stronger at rho = 0.859, with bottom temperature, surface
302 temperature and salinity, grain size phi 2, modal grain size, and sediment chlorophyll *a* content
303 contributing most to the correlation. Modal grain size was the single variable with the highest
304 explanatory power (rho = 0.702). For the fish assemblage, the environmental variables bottom
305 temperature, bottom and surface salinity, and grain size phi ≥5 explained most of the fish assemblage
306 structure (rho = 0.422) in the whole data set, with bottom temperature being the most influential
307 variable (rho = 0.330). When only the DBO stations were considered, the combination of surface
308 temperature and salinity had the strongest correlation to the fish assemblage (rho = 0.525), with again
309 bottom temperature as the most influential single variable (rho = 0.422).

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311

312 4. Discussion

313

314 We analyzed the concurrent results that two existing observing programs in the Arctic Chukchi Sea
315 yielded for epibenthic invertebrate and demersal fish assemblages in terms of biomass and biodiversity.
316 The two observing programs differ in their purpose and their spatial extent. The DBO's incentive is to
317 focus on seasonal and interannual variability in macrobenthic hotspots, regions of persistent and high
318 benthic *biomass* due to high water column productivity and tight pelagic-benthic coupling (Grebmeier et
319 al., 2010, 2015b; Moore and Grebmeier, 2017). AMBON's objective is to describe and observe the
320 *regional biodiversity* of various marine ecosystem components. Given these differences in the two
321 programs, careful consideration is needed to assess how much these two initiatives can contribute to
322 each other's objectives to optimize sampling efforts and maximize scientific gain.

323 In terms of benthic biomass hotspots characterizing the two DBO lines, epibenthic invertebrates and
324 fishes displayed opposite trends. While epibenthic biomass along the DBO3 lines was at the lower range
325 of the epibenthic biomass distribution across the total (AMBON-wide) study region, fish biomass was
326 comparatively high. Conversely, epibenthic biomass was relatively high but fish biomass was relatively
327 low along the DBO4 line. This confirms that neither epibenthic invertebrates nor fishes are as tightly
328 linked to areas of high vertical fluxes associated with high local primary production regimes as is the
329 macrofauna, on which the hotspot definition for the DBO program is based (Link et al., 2013; Grebmeier
330 et al., 2015b). This decoupling is likely related to the much higher mobility of many epibenthic
331 invertebrates and especially fishes, as well as the high diversity of feeding types (particle feeders and
332 also predators/scavengers) among these ecosystem components (e.g. Bluhm et al., 2009; Iken et al.,
333 2010; Norcross et al., 2010; Divine et al., 2015). This decoupling is even more pronounced for the mostly
334 predatory fishes (Whitehouse et al., 2017). Of course, predatory epifauna and fishes are linked to
335 particle flux through their macrofaunal prey, but we show that direct relationships from primary
336 production to fish and epifauna are often comparatively weak. This conclusion was supported by the
337 fact that water column chl *a* was not an environmental variable driving these assemblages. Interestingly,
338 epibenthos and fish biomass patterns were not similar, neither along the DBO lines nor the overall
339 AMBON study region. This is likely related to the closer link of the highly mobile fishes to water mass
340 characteristics (this study; Norcross et al., 2010) than epifauna, which is typically more closely related to
341 sediment characteristics (this study; Bluhm et al., 2009; Pisareva et al., 2015).

342 Species richness captured within the AMBON spatial coverage for demersal fishes and epibenthic
343 invertebrates was largely representative of known patterns in the region, while acknowledging that
344 direct comparisons to other studies are challenging because of variable sampling and – in case of
345 epifauna - identification effort. Other studies across the Chukchi Sea shelf reported very similar fish
346 species identities and species richness as the 24 taxa we found during the AMBON sampling (33 species,
347 Mecklenburg et al., 2007; 30 species, Norcross et al., 2010; 29 species, Norcross et al., 2013). Also, our
348 epifaunal invertebrate species number of 127 found for the southern study region was relatively similar
349 to the 165 species reported from a slightly larger and denser station grid reported by Bluhm et al. (2009)
350 and 165 taxa reported from the southern US Chukchi Sea including the Chukchi Bight (Feder et al.,
351 2005). In the northern study region, the 294 epibenthic taxa we identified are comparable to Blanchard

352 et al.'s (2013) report of 239 taxa in a slightly smaller study region. However, both these numbers are
353 much higher than the 44 epifaunal taxa reported from the larger Hana Shoal region (Ravelo et al., 2014),
354 likely because of the much coarser level of identification than in the present study and the exclusion of
355 some species-rich groups like amphipods in that study.

356 From the biodiversity perspective that is at the core of the AMBON project, about half of the
357 epibenthic species that occurred in the entire AMBON study area were also observed on the DBO
358 transects, with a much higher percentage along the DBO3 transect in the south versus the DBO4
359 transect in the north. The DBO3 transect represented epibenthic species richness and assemblage
360 patterns of the southern study area quite well. Invertebrate taxa characteristic for the epifaunal
361 assemblages in the southern study region also were similar to some of those reported previously (Bluhm
362 et al., 2009; cluster CN in that study), namely the snow crab *Chionoecetes opilio*, the sea star
363 *Leptasterias polaris*, and the shrimp *Argis* sp. These assemblage patterns, albeit not absolute biomass,
364 have been fairly stable over at least decadal time scales (Grebmeier et al., 2015a). This suggests that
365 despite the generally relatively low station coverage in the southern region, epibenthic communities are
366 representatively sampled by both the AMBON and the DBO3 grid strategies. The groupings into coastal
367 and offshore assemblage clusters align with the major water masses in that region, corresponding to
368 inshore Alaska Coastal Current and the offshore Bering Anadyr Water (Danielson et al., 2017a), as well
369 as sediment characteristics that drive assemblage structure (Bluhm et al., 2009). The correspondence
370 between our results and the study by Bluhm et al. (2009), which was based on a much denser sample
371 coverage than either AMBON or DBO station coverage, supports our results likely being a reasonable
372 representation of the general epifaunal community patterns of the southern Chukchi region, despite
373 limited spatial coverage. This may be in part due to the less complex hydrographic and bathymetric
374 features in the southern compared with the northern study region, driving more simply structured
375 biological communities in the south (Danielson et al., 2017a; Stabeno et al., 2018).

376 In contrast to the southern study region, regional assemblage patterns apparent from the AMBON
377 sampling grid were not well captured by sampling the DBO4 transect alone. The northern Chukchi Sea is
378 hydrographically and topographically complex (Weingartner et al., 2005), so it may not be surprising
379 that epibenthic assemblages are spatially heterogeneous, too (e.g. Blanchard et al., 2013; Ravelo et al.,
380 2014; Tu et al., 2014). While the DBO4 line captured the northern central shelf assemblage clusters H
381 and I very well, several of the other major northern clusters were not represented. If the DBO4 transect
382 were extended farther in- and offshore as along AMBON's ML3 line, a much greater representation of
383 the northern Chukchi Sea epibenthic assemblage clusters and diversity would be achieved. This would
384 especially include the coastal cluster F and the offshore cluster M. Yet, the other abundant clusters (e.g.
385 clusters K and L) would still not be sampled.

386 At least some of these epifaunal invertebrate assemblage clusters have been stable over time, as is
387 reflective of a generally proposed feature of Arctic benthos (Piepenburg, 2005; Renaud et al., 2007). An
388 example for the persistent assemblages in this study is the northern coastal assemblage (cluster F)
389 dominated by the sand dollar, *Echinarachnius parma* (also described by Grebmeier et al., 2006 and
390 Ravelo et al., 2014). Also, the distribution of *O. sarsii* in the center of the northern study region (cluster I,
391 which includes most of the DBO4 stations, and is also typical for the adjacent cluster K to the north) is a

392 persistent feature, as is the high abundance of *C. opilio* in the surrounding regions to the south and
393 offshore (clusters L and M, respectively), as previously documented (Ravelo et al., 2014; Groß et al.,
394 2017). This stability in epibenthic community composition is likely a result of the typically high longevity
395 of many arctic invertebrates (e.g. Bluhm et al., 1998; Ravelo et al., 2017) and the strong association with
396 stationary environmental variables such as sediment characteristics (this study; Bluhm et al., 2009). This
397 suggests that sampling of these epifaunal communities could occur on less than annual scales and
398 changes could still be detected over longer time frames.

399 Spatial distribution of fish diversity showed a trend of higher diversity in the south and decreasing
400 diversity to the north (lowest along line ML4). This reflects the stronger influence of the Pacific waters
401 entering from the Bering Sea in the south and of the northern waters that were modified during their
402 transport across the shelf, including local cold winter water formation in the northeastern Chukchi Sea
403 (Weingartner et al., 2013). Higher fish species richness in the south is consistent with the higher number
404 of boreal-arctic or boreal fishes that have access to the southern Chukchi Sea versus the number of
405 species that could be expected to occur in the more northern study region (Mecklenburg et al., 2011;
406 Norcross et al., 2013). Fish biodiversity identified by sampling solely on the DBO transects was nearly
407 90% of that observed over the whole AMBON grid. This much higher diversity compared with epifaunal
408 diversity represented along DBO transects was likely related to the much lower total species number of
409 fishes in general and the wide distribution of most fish species across the entire shelf (also see
410 Mecklenburg et al., 2011).

411 The wide distribution of fish species across the study region is the likely reason that we found little
412 spatial fish assemblage structure. The species most characteristic for the more coastal fish assemblage
413 (cluster a), *Gymnocanthus tricuspis* and *Lumpenus fabricii*, are known to utilize the more physically
414 structured coastal waters (Norcross et al., 2013; Logerwell et al., 2015). The eelpouts (*Lycodes* sp.) and
415 snail fishes (*Liparis* sp.) characteristic of the more offshore, northern cluster (b) are among the most
416 abundant demersal fish families in the Chukchi Sea (Logerwell et al., 2015). This assemblage cluster was
417 also characterized by Arctic cod, a key link in Arctic food webs (Hop and Gjørseter, 2013) and of more
418 arctic biogeographic affinity (Mecklenburg et al., 2011). A similar fish assemblage was also observed in
419 2009/2010 in a slightly smaller study area in the northern study region (Norcross et al., 2013). From an
420 observing perspective of fish diversity, extension of the DBO4 line towards off- and inshore regions as
421 suggested above for epifauna would be useful to include the coastal fish assemblage in the northern
422 Chukchi Sea in the overall sampling scheme.

423

424 5. Conclusions

425 The results presented here indicate that the purpose and the scale of existing observing systems
426 have to be carefully evaluated when considering which ecosystem metrics shall be monitored. For
427 example, the DBO program was initially focused on well-defined regions where persistent benthic
428 biomass hotspots occurred while the AMBON program has a larger scale, regional biodiversity focus.
429 DBO locations where benthic macrofaunal hotspots occur are not as consistently high in epibenthic or

430 fish biomass. We further documented that while the DBO3 line represents epibenthic and fish diversity
431 and assemblage patterns well for the larger AMBON study area, sampling along the DBO4 transect alone
432 did not represent the larger regional patterns well, at least for the epibenthic invertebrate assemblage.
433 In assemblages with relatively high taxon mobility such as for many epibenthic invertebrates and fishes,
434 sampling on a larger spatial scale is likely necessary to reliably capture regional community patterns
435 (Armonies, 2000). Depending on the specific community and region, the biologically relevant area
436 (neighborhood) for benthic invertebrates and demersal fish that is needed for monitoring and/or the
437 development of Marine Protected Areas is projected to be several hundred kilometers (Palumbi, 2004).
438 This is consistent with guiding principles in marine spatial planning approaches to take into account
439 *context*, i.e. the larger-scale assemblage patterns, and *variability*, i.e. the level of spatial fluctuation of
440 these assemblages (Foley et al., 2010). More recently, the development of Ecologically and Biologically
441 Significant Areas (EBSAs) has become an important tool for monitoring arctic areas that have particularly
442 high ecological or biological importance for the overall ecosystem (Cobb et al., 2004). EBSA development
443 is based on seven criteria that include, among others, uniqueness of the system, importance of habitats,
444 and biological diversity (Dunn et al., 2014). Sufficient temporal and spatial resolution data are needed to
445 assess these criteria for arctic systems (Cobb et al., 2014). For temporal resolution, we suggest that the
446 relative stability of arctic benthic shelf systems over time warrants that epibenthic and fish communities
447 might not have to be sampled on a seasonal or annual schedule but that sampling every few (2-3) years
448 could be sufficient to observe and detect long-term changes. This is similar to what has been proposed
449 for coastal, rocky shore arctic systems (e.g. Kortsch et al., 2012) although comparability between shelf
450 and nearshore systems may be constrained. To reduce the discrepancy between the slower response
451 time of epibenthic invertebrates and fishes versus the rates of changes of environmental variables, we
452 also recommend, if possible, linking these biological surveys every few years with continuous
453 environmental measurements from moored instrumentation that can provide important contextual
454 data for environmental changes (Danielson et al., 2017b). In terms of spatial sampling scales, we suggest
455 that sampling of the smaller scale such as represented by the DBO transect lines may need to be
456 extended to better capture more of the regional characteristics of the epibenthic invertebrate and
457 demersal fish assemblages. Larger-scale regional sampling such as through AMBON, however, is needed
458 and useful at the beginning of observation planning as well as on longer time scales (e.g. every 5-10
459 years) to provide larger context for the more regionally focused sampling (Foley et al., 2010; Magurran
460 et al., 2010). All these considerations support that the assemblage information gained from the larger-
461 scale AMBON project are essential to determine useful long-term observing scales for these ecosystem
462 components.

463

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472

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Table 1: Epifaunal assemblage clusters and species contributing to $\geq 30\%$ of cumulative within-cluster similarity

662

Cluster	Taxa contributing to cluster similarity	Cum. Sim. %
A	<i>Halocynthia aurantium</i> , <i>Gorgonocephalus</i> sp., <i>Argis</i> sp., <i>Eualus gaimardii gaimardii</i>	34.10
B	<i>Chionoecetes opilio</i> , <i>Leptasterias polaris</i> , <i>Stomphia</i> sp.	37.24
C	<i>Chionoecetes opilio</i> , <i>Neptunea heros</i>	39.68
D	<i>Echinarachnius parma</i> , <i>Chionoecetes opilio</i>	35.39
E	<i>Strongylocentrotus pallidus</i> , <i>Eualus gaimardii gaimardii</i> , <i>Gersemia rubiformis</i>	35.23
F	<i>Psolus peronii</i> , <i>Hyas coarctatus</i> , <i>Strongylocentrotus pallidus</i> , <i>Argis</i> sp., <i>Chionoecetes opilio</i>	33.85
G	<i>Argis</i> sp.	30.37
H	<i>Psolus peronii</i> , <i>Ophiura sarsii</i> , <i>Chionoecetes opilio</i> , <i>Hyas coarctatus</i>	34.22
I	<i>Ophiura sarsii</i> , <i>Chionoecetes opilio</i> , <i>Buccinum polare</i> , <i>Nemertea</i> , <i>Leptasterias groenlandica</i>	31.42
K	<i>Ophiura sarsii</i> , <i>Chionoecetes opilio</i> , <i>Pagurus capillatus</i> , <i>Myriotrochus rinkii</i>	30.01
L	<i>Chionoecetes opilio</i> , <i>Hyas coarctatus</i> , <i>Stomphia</i> sp., <i>Labidocheirus splendescens</i>	31.30
M	<i>Chionoecetes opilio</i> , <i>Pagurus capillatus</i> , <i>Pagurus trigonocheirus</i>	31.49

663

664 **Figure captions**

665 Fig. 1: Map of the AMBON study area and sampling stations; stations that represent DBO coverage are
666 outlined in red.

667 Fig. 2: Epifaunal taxa proportional biomass (a) and frequency of occurrence (FO) (b). Only taxa
668 contributing more than 1% to total average biomass and 50% FO are shown.

669 Fig. 3: Fish taxa proportional biomass (a) and frequency of occurrence (FO) (b).

670 Fig. 4: Epifaunal species richness (a) and fish species richness (b). Boxes indicate stations that represent
671 DBO coverage (see Fig. 1).

672 Fig. 5: Epifauna (a) and fish (b) biomass per station. Stations that represent DBO coverage are circled in
673 red.

674 Fig. 6: Hierarchical clustering of epifaunal assemblages based on fourth-root transformed biomass data
675 and a Bray-Curtis similarity matrix. Red lines indicate non-significant differences among stations; cluster
676 assignment is guided by SIMPROF results but occasionally grouped at lower similarity level to obtain
677 manageable cluster groupings. Clusters are denominated with upper-case letters A-M, "single" refers to
678 stations that did not group with any cluster. Colors and letters are the same as in Fig. 7 but have no
679 relationship to the fish assemblage clusters.

680 Fig. 7: Spatial distribution of epifaunal assemblage clusters (A-M). "Single" refers to stations that did not
681 group with any cluster. Stations that represent DBO coverage are encircled. Colors and letters are as in
682 Fig. 6 but have no relationship to the fish assemblage clusters (Figs. 8 and 9).

683 Fig. 8: Hierarchical clustering of fish assemblages based on fourth-root transformed biomass data and a
684 Bray-Curtis similarity matrix. Clusters are assigned based SIMPROF results, with red connectors
685 indicating non-significant differences among stations. Clusters are denominated with lower-case letters
686 a and b; "single" refers to stations that did not group with any cluster. Colors and letters are the same as
687 in Fig. 9 but have no relationship to the epifauna assemblage clusters.

688 Fig. 9: Spatial distribution of fish assemblage clusters (a-b). Stations that represent DBO coverage are
689 encircled. Colors and letters are as in Fig. 8 but have no relationship to the epifaunal assemblage clusters
690 (Figs. 6 and 7).

691

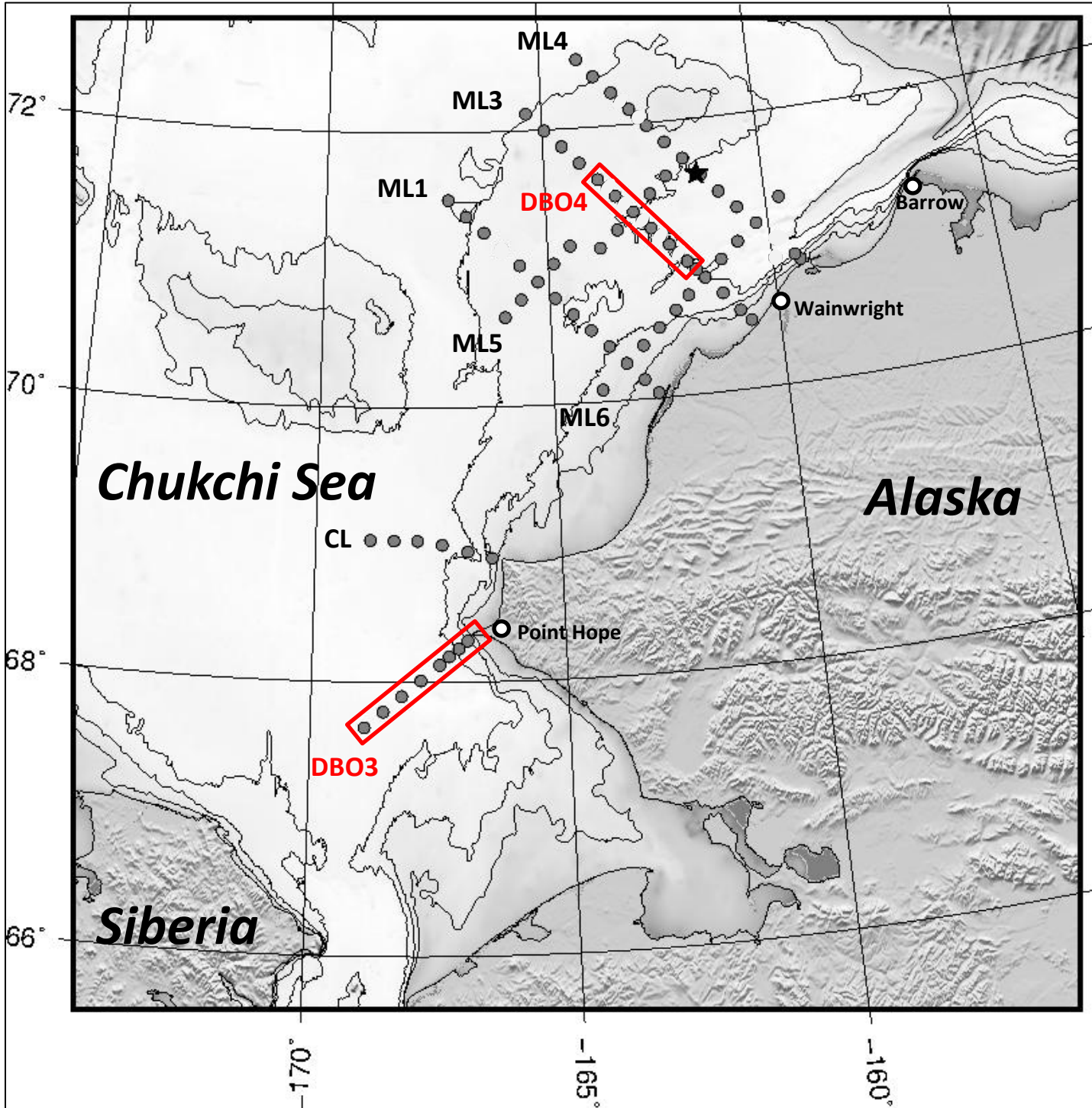


Figure 1

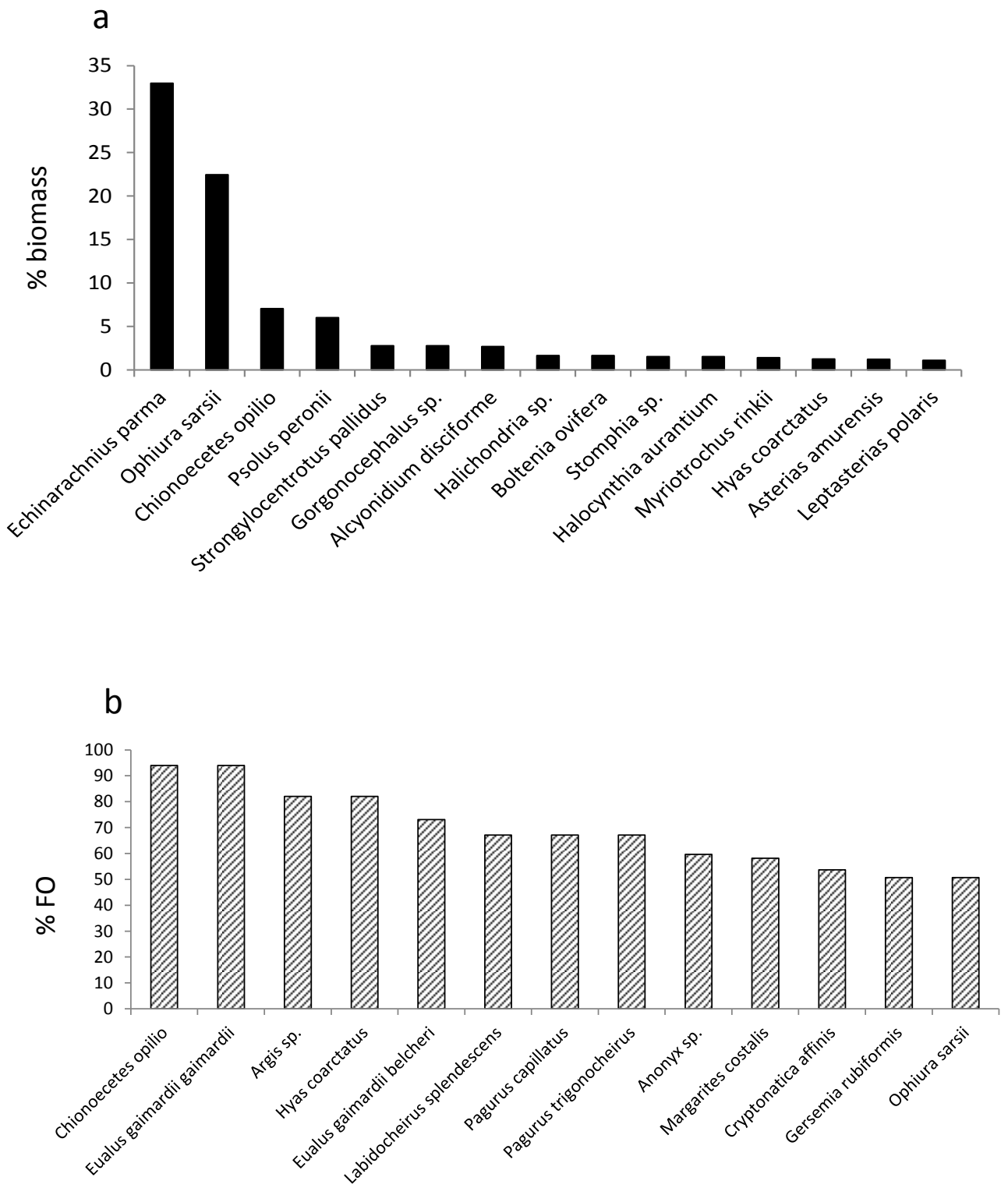


Figure 2

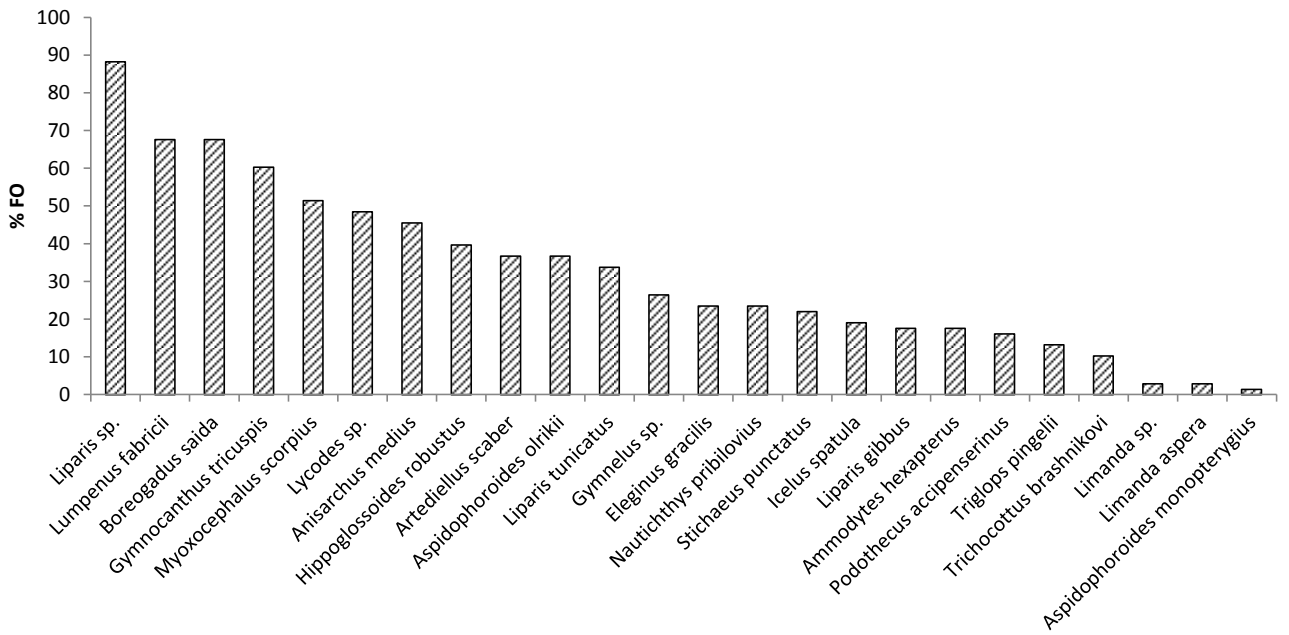
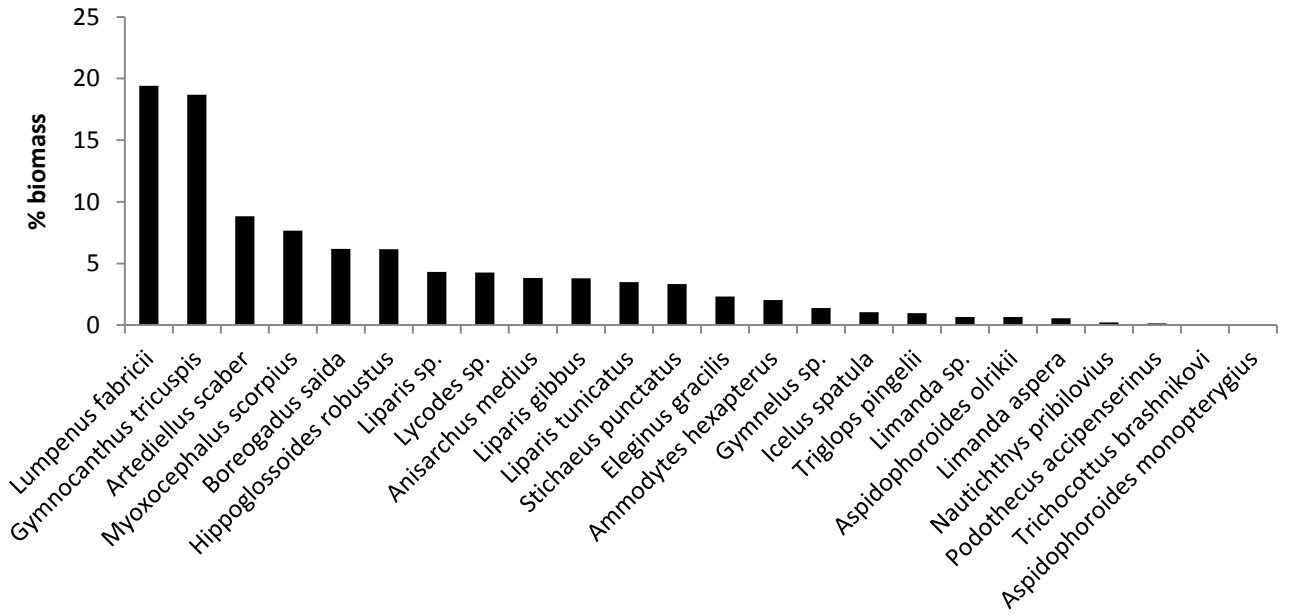


Figure 3

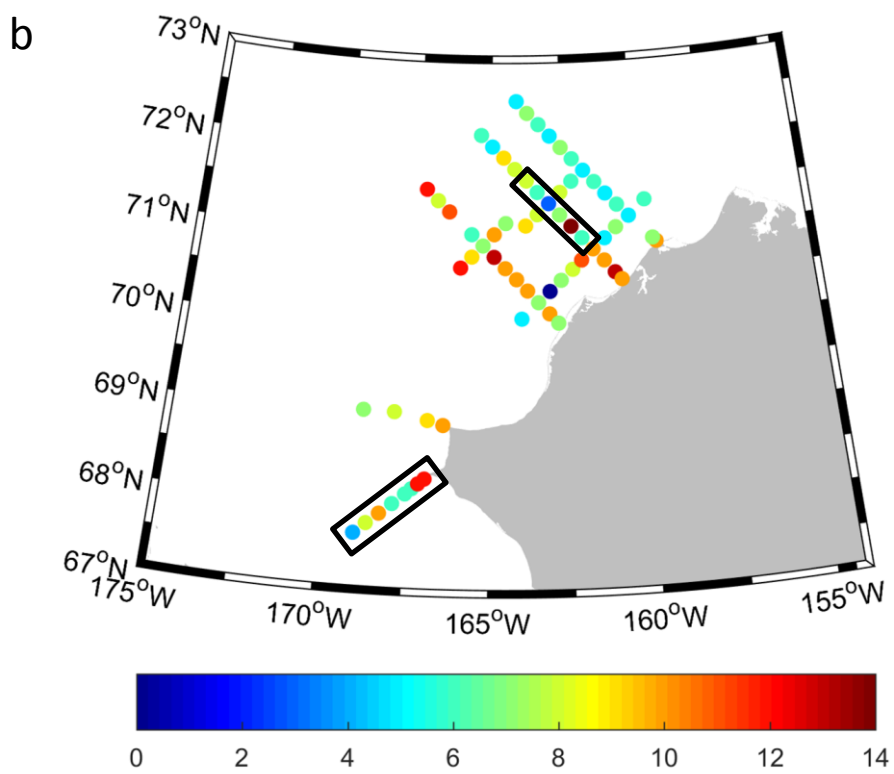
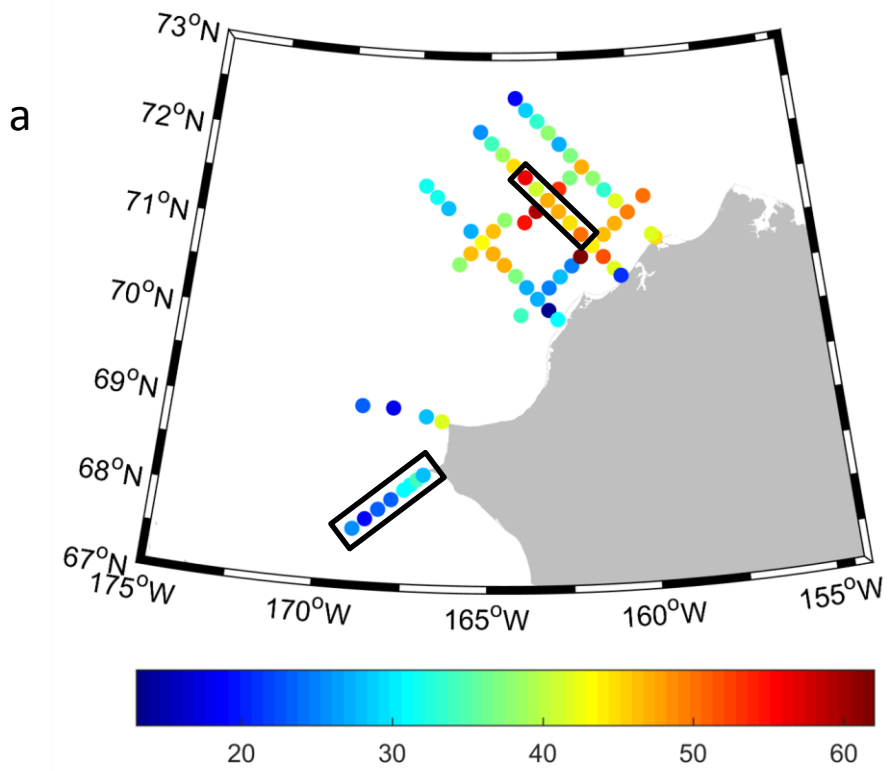


Figure 4



Figure 5

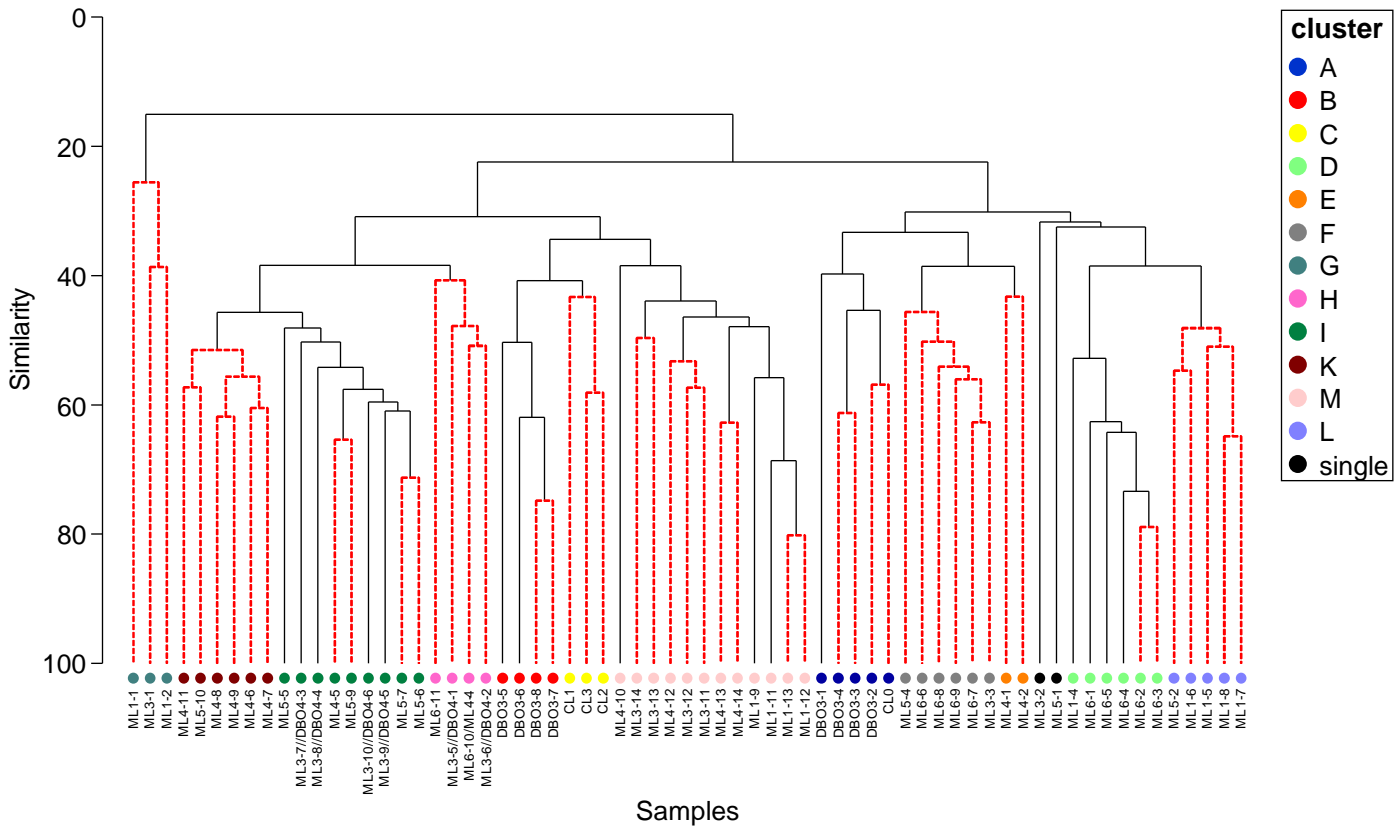


Figure 6

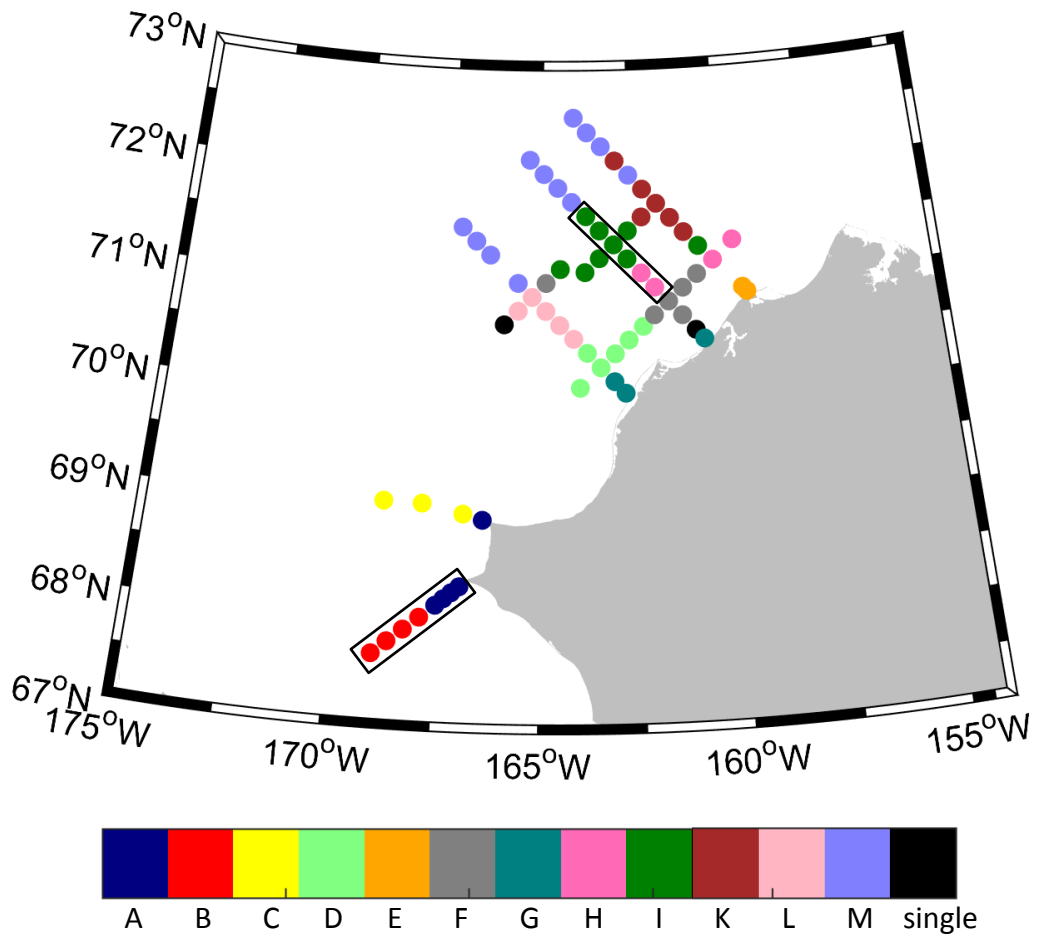


Figure 7

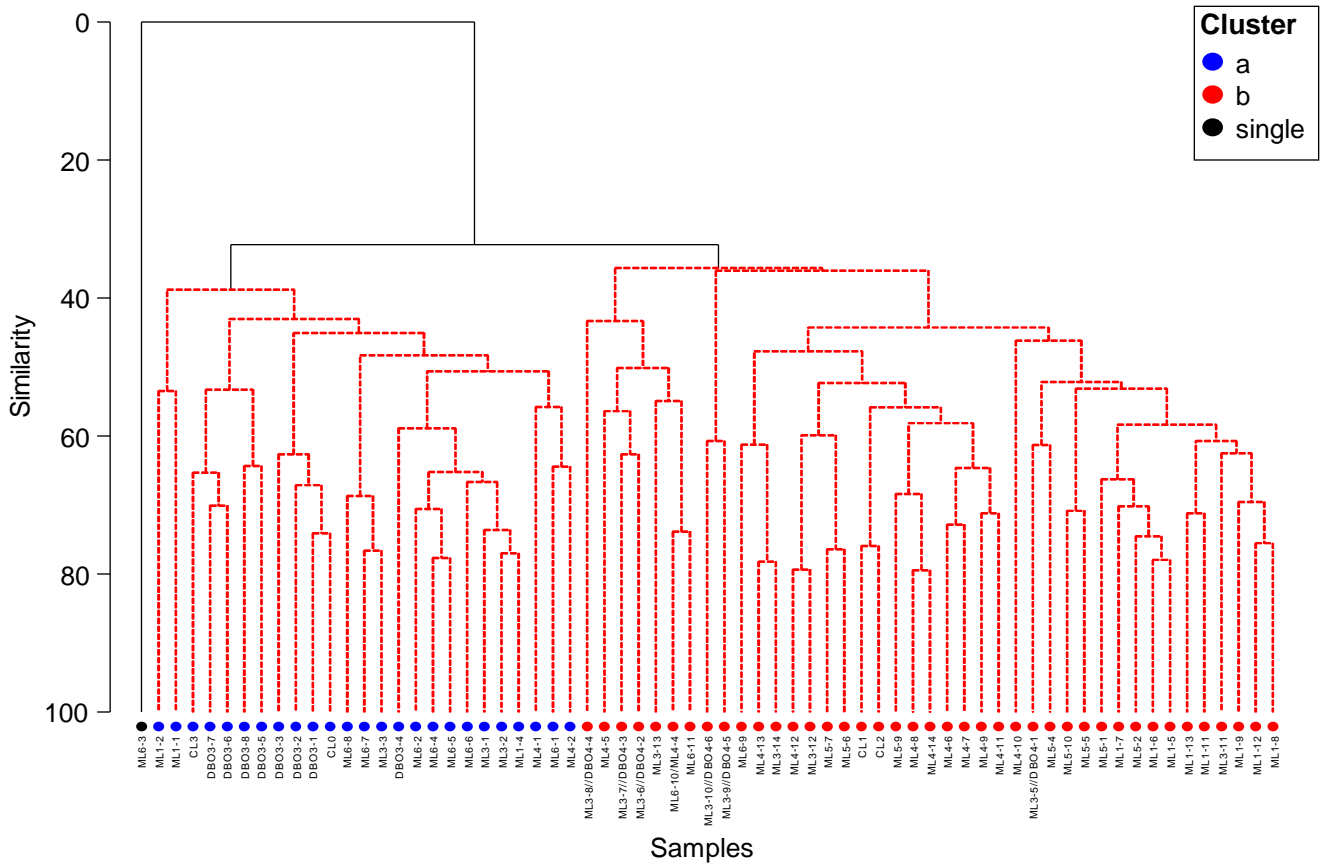


Figure 8

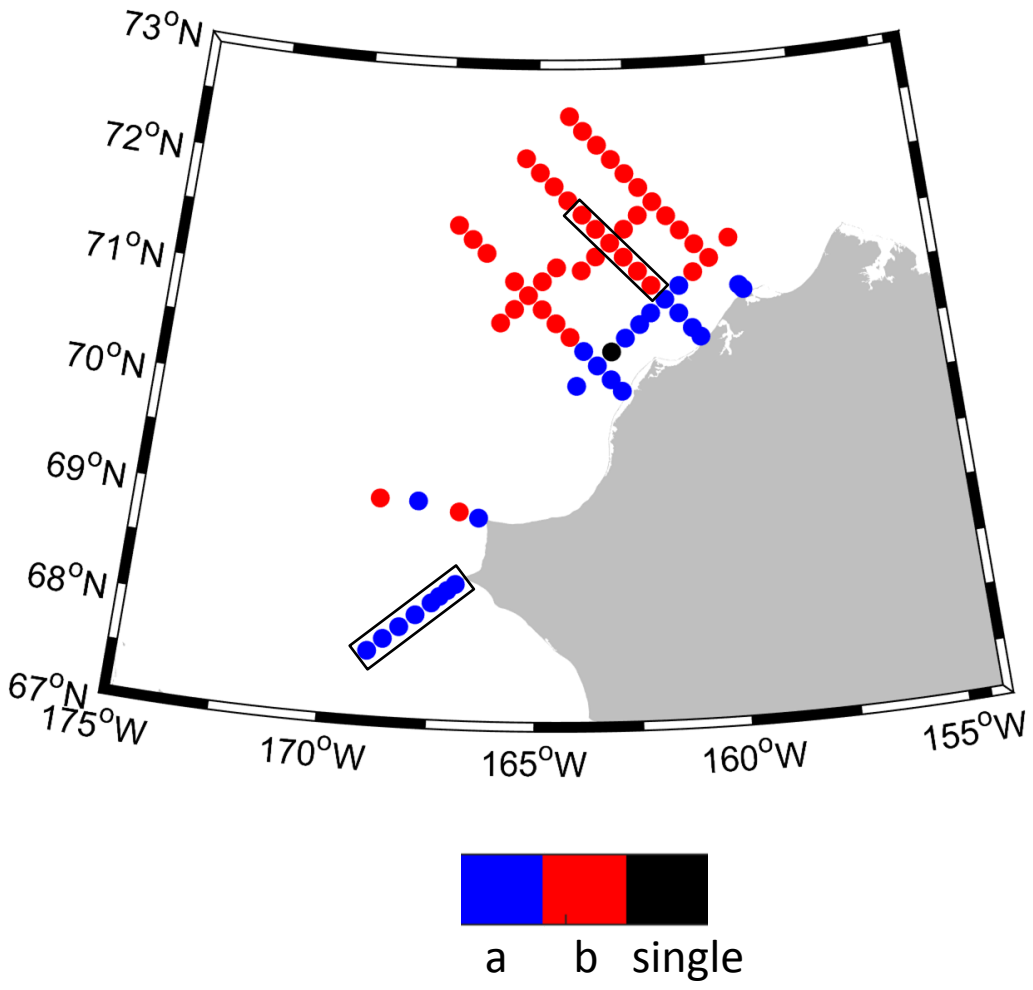


Figure 9